

COMPOUND SEMICONDUCTOR

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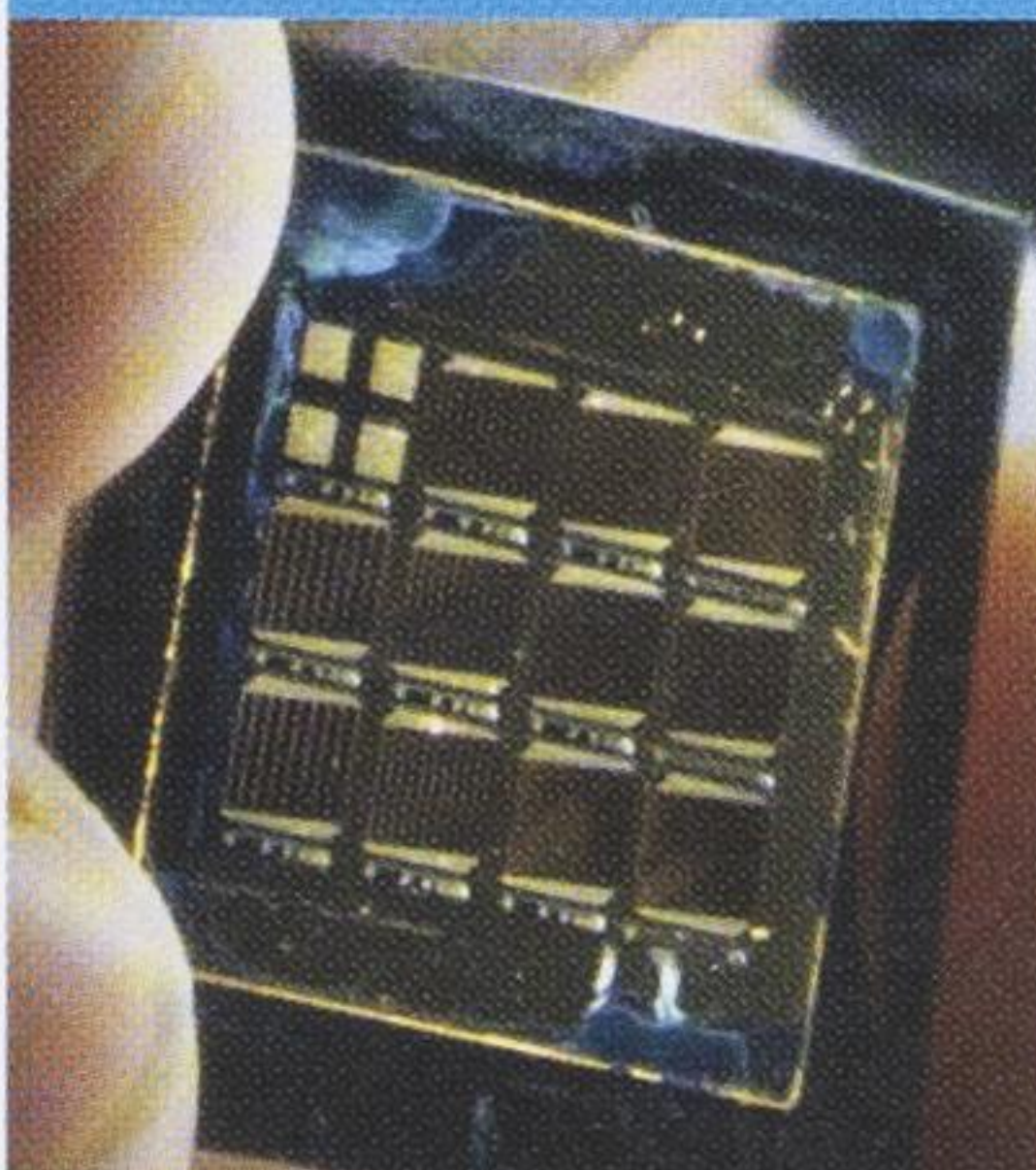
New applications spark industry makeover



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Meet Vikki. Vikki leads a highly experienced team and together they operate one of TriQuint's world-class wafer manufacturing facilities. Under Vikki's leadership, the team monitors, tracks and continuously improves the processes and tools which transform customers' designs into products. Vikki and her management team have more than 120 years of collective GaAs manufacturing experience and are totally dedicated to customer satisfaction. Vikki is one of the people behind the innovation at TriQuint Semiconductor and she's on your team.

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INDUSTRY

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SONY ERICSSON

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CCNY

Shortening wavelengths

City College of New York researchers are developing ZnCdMgSe materials for short-wavelength QCLs. Their MBE reactor features chambers for II-VI and III-V growth. **p25**

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Main cover image: The US is helping to drive up the standard of LED lighting with its Lighting for Tomorrow competition, which is supported by the American Lighting Association, the Department of Energy and the Consortium for Energy Efficiency. The Cylindrium design entered by Californian company Luximo was the winner in the portable desk/task lighting category. Credit: Luximo.

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No down-turn for LEDs



To say that the past month or so has been tumultuous for global commerce might break new ground in stating the obvious. While companies like Lehman Brothers might not at first appear to have much to do with semiconductors, they do have an impact. After all, before its collapse Lehman was set to underwrite Avago Technologies' stock-market flotation.

The unfolding crunch may even peg back the mobile handset business. What it won't do is derail the LED industry, which is maturing nicely.

A sure sign of this is the interest shown in LED manufacturing by some huge companies that are new to the technology. Flat-panel makers Chi Mei Optoelectronics, HannStar and AU Optronics are investing in MOCVD gear, with Chi Mei already pumping out some GaN chips – if rumors are to be believed. TSMC, the giant Taiwanese silicon foundry, seems set to join them, and large Chinese lighting firms are thought to be moving towards vertical integration by investing in epitaxial equipment and hiring MOCVD specialists from LED manufacturing companies.

“Sky-high energy prices have been a key factor in the recent financial ‘meltdown’.”

It isn't just the LED makers who are forcing the pace. Sapphire substrate supplier Rubicon says that it is shifting 6 inch material to Samsung, which is expected to switch to the larger format in 2009 – a year earlier than expected. Monocrystal, the Russian crystal supplier, is even moving ahead with 8 inch sapphire material for LED applications.

However, while Monocrystal's move looks premature, and not all of the new entrants to LED manufacture will be successful, this appears to be the start of an important period in the young industry's maturation. Other suppliers, like metalorganic specialists SAFC Hitech and Rohm and Haas, have responded to the need for larger material delivery systems as part of a wider migration to truly volume LED manufacturing that should be driven by the switch to solid-state lighting.

Sky-high energy prices have been a key factor in the recent financial “meltdown”. But they also play into the hands of this energy-efficient lighting technology and could have sparked a new phase in LED evolution.

Michael Hatcher *Editor*

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LED PRODUCTION

Samsung leads 6 inch LED drive

Korean electronics giant Samsung is on course to make a huge impact on the LED industry, by entering chip manufacture on 6 inch wafers next year.

That's according to sapphire supplier Rubicon Technology, which seems to be enabling a shift to larger wafers in an industry that has clung to 2 inch diameter substrates for a long time.

"In terms of Samsung, I believe that 6 inch production will begin in 2009 – this is very positive news for us," said Raja Parvez, Rubicon's CEO. He explains that the success in LED production on 6 inch sapphire substrates has recently been reported back to him – a year faster than he expected.

Parvez also says that a supplier of epitaxial equipment for LED production has contacted Rubicon to obtain samples of its 8 inch sapphire substrates. Interest from such a customer – which presumably intends to test larger-scale equipment in development – appears to validate the CEO's claim that "there are positive signs regarding the shift to larger substrates".

Such signs are currently welcome at Rubicon, with its sales of 2 inch sapphire wafers wilting as the flow of global consumer spending slows. The Franklin Park, IL, company is predicting that its sales revenues will fall by more than 25% between the third and fourth quarter of 2008. It expects

to bring in up to \$12 million in the three months ended September, but Parvez estimates maximum revenue of just \$8.5 million for the December quarter. Rubicon expects to remain profitable each quarter, in spite of the downturn.

The drop comes because the substrate maker has postponed nearly \$7 million of orders back into 2009 – \$2.5 million relating to 2 inch LED substrates and \$4.3 million for silicon-on-sapphire RF applications. Parvez blames manufacturers targeting hand-held devices and small displays – who he says are struggling in the current economic climate – for the LED shortfall. He says that these companies exclusively use 2 inch substrates, whereas it seems that the users of larger-diameter substrates are aiming for market sectors with greater growth potential.

Demand from RF silicon customer Peregrine Semiconductor, whose use of 6 and 8 inch sapphire wafers makes it particularly important to Rubicon, has been inconsistent as it continues its move to a mainly outsourced production model. Here, the push-out of orders to next year has largely been caused by Peregrine and its foundry partner Oki ordering substrates intended for the same production runs. According to Parvez, Peregrine has two further foundry partners, one of which is developing the 8 inch process.



Bami Bastani, the CEO and president of RF chip maker Anadigics, has resigned after the company's outlook for the three months to September veered sharply from profit to loss. The Warren, NJ, firm parted company with Bastani on August 17 and chairman Gilles Delfassy will now temporarily fill in as CEO until a permanent replacement is found.

Bastani receives a \$3 million severance payment after leaving the role that he has held since October 2, 1998. The GaAs manufacturer had just emerged from a six-year loss-making wilderness, recording an annual profit in 2007. However, the associated production upsurge left Anadigics struggling to meet the demand of handset customers in the crucial December quarter, with adverse consequences on follow-up business.

POWER ELECTRONICS

Rohm steers Nissan and Honda into SiC inverters

Japanese semiconductor manufacturer Rohm has moved ahead of Toyota in automotive applications of SiC by entering into the development of power modules with Honda and Nissan. Each agreement involves testing inverter modules based on Rohm's chips that convert direct current into alternating current for use in an engine.

Takashi Nakamura of Rohm's new material devices research and development center described the two different approaches at the European Conference on Silicon Carbide and Related Materials (ECSCRM) on September 10. In the Honda partnership, which was previously kept a secret, Rohm is providing SiC MOSFETs that are being integrated into 680 V, 200 A inverters.

"We have succeeded in winning the chance to combine the power module technology of Honda and the high-power

devices of Rohm," Nakamura told the crowd in Barcelona. So far the Honda module has cut power losses associated with competing silicon modules by 46%, he says. The inverters will be used in hybrid electric vehicles (HEVs) and other automobiles that are in development.

Similarly, Nakamura says that the heterojunction diode (HJD) used by Nissan has cut inverter losses by 50%. The heterojunction in question – SiC and a polysilicon gate – allows Nissan to make a module using chips that are six times smaller than those needed for a silicon inverter. On September 10, Nissan said that it will now deploy HJD-based inverters in an X-TRAIL fuel-cell vehicle.

It says that the same technology could be exploited in electric vehicles and HEVs, and that it considers inverters as a key technology in electric-powered vehicle develop-

ment. Nissan and Rohm went public with their HJD collaboration in April.

A source close to Toyota told *Compound Semiconductor* that these deals had taken the company – which currently heads the HEV market with its high-profile Prius model – completely by surprise.

Toyota appeared to take the lead in developing SiC for automotive applications in 2004 with a *Nature* paper describing high-quality crystal growth. The source said that the car maker had continued to focus on this area to improve the performance of its devices, but now would have to step up its efforts in module integration.

● Elsewhere at ECSCRM, Honda claimed the highest-ever current gain SiC bipolar junction transistors. At room temperature the devices showed a gain of 134, together with a 950 V blocking voltage.

MANUFACTURING

Skyworks touts sell-out fall quarter

Skyworks Solutions says that it sold out its September quarter order books in the first two months of the period, despite a slower than expected uptake of 3G wireless technology by consumers.

Senior vice-president Liam Griffin told the Kaufman Brothers investor conference on September 3 that the company was also on target to meet its quarterly financial goals. This means that the company is likely to bring in at least \$10 million more than the \$215 million in revenues that it earned in the three months ended June.

Sales of 3G handsets are one important factor in Skyworks' strong performance, but the newer technology has not contributed in exactly the way that Skyworks may have hoped. "The presumption was that 3G – WCDMA – was going to be quite a bit larger in 2008 than it is actually rolling out," Griffin commented.

However, the uptake of mobile phones in countries like China and India is continuing to propel its revenues upwards. Changes



Although Skyworks is reaping the benefits of inclusion in 3G handsets, like this Sony Ericsson W660, uptake has been slower than expected.

to system-on-chip (SOC) manufacturing in low-cost phones are magnifying the effect that this has on Skyworks' sales.

"When you go through SOC integration there's quite a technology burden," Griffin explained. "That is where Skyworks has been able to come in with power amplifiers, switches and filters, and actually deliver solutions that have increased in value as you move to SOC."

In fact, Griffin says that the front-end modules that Skyworks is shipping for low-cost SOC-based handsets bring the company 15% more revenue than the discrete components that it was selling into similar models a year ago. With these effects working in Skyworks' favor, Griffin was able to put forward a confident investment case for his audience – including a sobering reminder not to underestimate the long-term effect of 3G.

"Even though 270 or 280 million WCDMA devices is a bit off the market's view a year ago, it's still driving nearly a billion units of power amplifiers. If you extrapolate to 2010 when you get to 1.5 billion phones, half of those being 3G, you can see the market opportunity for us really accelerates."

EPIWAFERS

IQE says demand for GaAs is insatiable

IQE is backing GaAs sales to support its ongoing expansion, irrespective of large market share shifts among its customers.

The Cardiff, UK, company's operating profit for the first half of 2008 rose to £1.6 million (\$2.9 million) from £11,000 year on year. However, this was wiped out by the costs of relocating its Singapore operation, to help accommodate burgeoning orders, even as it invested another £3.4 million in additional capacity elsewhere.

"I think it's true to say that at the moment demand is outstripping supply across the GaAs sector," said Chris Meadows, IQE's investor relations executive. "Certainly from the forecasts that we're getting from customers it would seem to be the case."

"We're not aware of a huge stash of machines capable of switching on and turning out increased amounts of GaAs HBTs, and PHEMTs and BIFETs," Meadows said, "yet customers are saying that they just need more and more of them."

Wireless revenues grew from £17.3 million in the first half of 2007 to £23.6 million in the same period in 2008. The company

is confident that this figure will continue to increase and support its expansion, in spite of a remarkable drop in orders at Anadigics – an important customer of IQE. "We see downturns from some customers but that's more than made up for by others," Meadows explained.

Robust handset sales in the weak broader economy are also helping IQE's prospects, but even without this the wafer maker still sees GaAs revenues growing. "3G and smartphones are using up to four times the amount of GaAs that the previous generations did," Meadows said. "The sudden, almost insatiable, demand for GaAs is actually dwarfing any increase in handset sales."

Elsewhere in its RF business, IQE has recently announced two new silicon processes, including a silicon-on-sapphire line that has already attracted a significant customer. This is almost certain to be linked to Peregrine Semiconductor, which has recently moved to a 95% outsourced manufacturing model.

In order to diversify, IQE is also hoping to grow business in III-V photovoltaics, which Meadows anticipates will generate revenues in 2009. The epitaxy expert currently has two key partners in this sector, which are likely to be the start-ups Cyrium and Quantasol.



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...International Rectifier showcases GaN

International Rectifier (IR) – the California-headquartered power semiconductor company – introduced its GaN-on-silicon epitaxy-based platform at various conferences in September. IR says that it spent five years developing its "world-class" 150 mm high-throughput process.

...Triple path wins sockets for RFMD

RF Micro Devices' latest amplifier module – which combines three broadband power amplifiers – has scored it a major win in an upcoming 3G handset design. The module supports all 3G band combinations in one package, allowing simpler design and reduced space consumption.

...StratEdge supplies GaAs MMICs

The microwave and millimeter-wave packaging supplier is now selling X-band GaAs amplifiers in surface-mount packages, which boast good thermal properties. The MMICs are made by "a leading US foundry" before assembly at StratEdge's San Diego, CA, headquarters.

STOCK FLOTATION

Lehman blow hits Avago's IPO

Chip maker Avago Technologies is to brave a refloatation on the turbulent post credit crunch stock market, with the hope of raising up to \$400 million.

However, the bankruptcy of Lehman Brothers, one of the initial public offering's (IPO) seven underwriting institutions, on September 15 highlights the risk inherent in this move. When *Compound Semiconductor* asked Avago how this affects its plans, the company said that rules concerning the flotation prevented it from commenting.

Avago filed the papers for its IPO with the US Securities and Exchange Commission on 21 August. The Singapore-registered firm has applied to list on the NASDAQ exchange with the proposed ticker "AVGO". No share price or date for the offering is listed, and the filing doesn't say what proportion of the company is being floated. Part of the IPO proceeds will be used to pay off \$240.5 million of Avago's \$710 million long-term debt that is currently outstanding.

Perhaps best known in the compound semiconductor industry for its LEDs and GaAs wireless chips, Avago largely focuses on III-V manufacturing at its Fort Collins, CO, and Singapore fabs. However, the

majority of its manufacturing is done by silicon foundries such as Chartered Semiconductor and TSMC.

The IPO would take Avago public again, nearly three years after it was carved out of Agilent Technologies, which itself is a spin-off from Hewlett-Packard. While Agilent now concentrates on test and measurement, Avago's focus is on analog semiconductors across several markets, including industrial and automotive, datacoms, wireless communications, and consumer applications.

Private equity firms Kohlberg Kravis Roberts (KKR) and Silver Lake Partners bought the former Agilent semiconductor and optical transceiver business for a whopping \$2.66 billion in 2005. At first Avago struggled, recording a loss of \$227 million in fiscal 2006 and \$159 million in fiscal 2007, but the company has clawed its way back to profitability. It posted a \$21 million profit for the first half of fiscal 2008 on revenues of \$813 million.

Since KKR purchased it, the chip maker has slimmed down by disposing of five businesses. The largest of these was the sale of its storage business to PMC-Sierra for \$420 million in 2007.

APPLICATIONS

Telecom players see 2009 femtocell ramp

US telecom carrier Sprint won't meet its original target of making femtocells available nationwide by the end of the year, according to research from analysts at Heavy Reading.

Instead, the survey suggests that GaAs manufacturers aiming to get their power amplifiers into these home handset signal boosters will have to target ramp-ups in the second half of 2009.

"Launch in the second half of 2008 is unlikely and may reflect internal targets rather than real commercial launches," wrote Gabriel Brown, the report's author.

Of the 111 telecom service provider professionals that were surveyed, 6% expect deployment this year, but 33% said that they would not be launching femtocells until 2011 or later. Brown highlights the second half of 2009 through to 2010 as the critical launch period, when 54% of respondents said that they would begin their femtocell offerings.

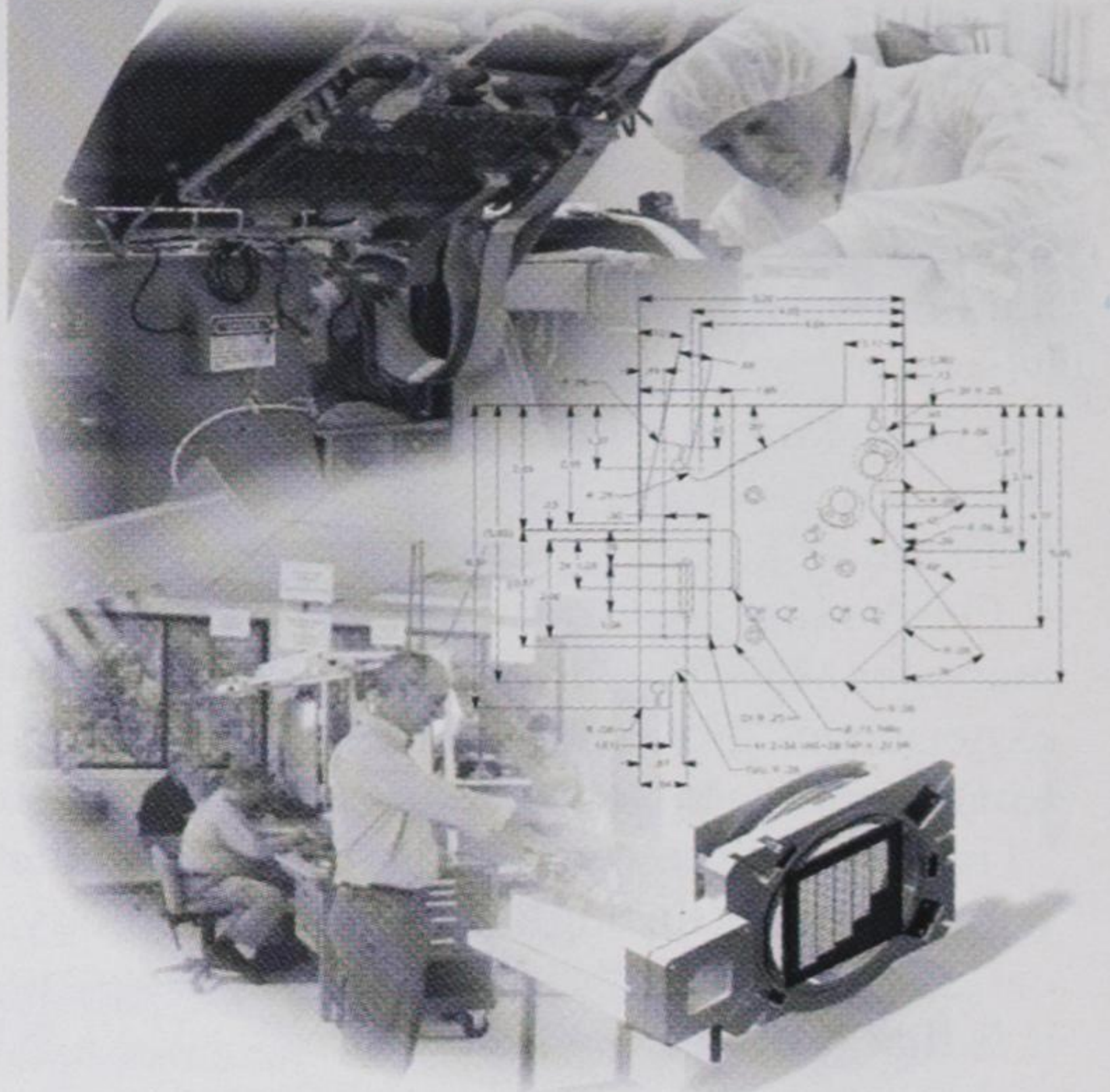
Femtocells offer the dual benefit of improving signal strength for wireless handsets and reducing data flow through the carrier's cellular network, by moving it directly through a wired network instead. Although these factors are intimately related, most respondents saw improved coverage as the most important factor in deploying femtocells.

The telephone companies asked are considering a number of different radio interface technologies for use with femtocells. These range from "surprisingly strong" interest in stalwart 2G standard GSM, through 3G – including HSPA as the most popular single protocol – and on to next-generation technologies such as LTE and mobile WiMAX.

Although the femtocell market is likely to look more like that for wireless modems than handsets, it remains an important opportunity for compound semiconductor firms. Skyworks Solutions is already supplying femtocell maker Samsung, which in turn supplies Airave units for Sprint. With experience as the key supplier for Intel's wireless LAN products, Anadigics is also following femtocells closely.

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OPTICAL MICE

Microsoft launches blue LED mice

Optical mice look set to be the latest consumer application to benefit from GaN LEDs, with Microsoft using this technology to displace red diode lasers. The global computing giant launched its latest mouse on September 9, with the slogan "Say goodbye to laser".

On August 26, research and development manager Mark DePue of Microsoft's desktop experiences group described the technology to Bloomberg's Boot Camp radio program. "This year we're introducing two new mice with our breakthrough tracking technology, called Blue Track," DePue said. "The key to it is that it uses a big blue beam."

A combination of blue LED and wide-angle lens actually produces the beam. The resulting light covers an area four times larger than that produced by a laser, which allows more light to return to the sensor.

Microsoft claims that Blue Track allows excellent performance on problem surfaces, such as wood, granite and carpeting. "It gives you the ability to work on more surfaces than you've ever been able to before," DePue said. "You'll see people taking their



Microsoft's Blue Track mouse uses blue LED light, which is disrupted less easily than coherent red lasers on its way back to the mouse's photosensor.

notebooks to more areas of the house."

Two Blue Track models will be priced at \$79 and \$99 and made widely available in October. As yet there have been no hints as to who might be providing the LEDs enabling the technology.



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...Aviza displaces rival at chip maker

Aviza Technology's renewed focus on the compounds sector has scored it a major order for its Omega i2L etch and Delta i2L plasma-enhanced CVD tools. The multiple orders saw the Californian company displace an incumbent at one of the world's top-five makers of high-brightness LEDs.

...Korean giants pick Luminus

Samsung and LG Electronics are using Luminus Devices' PhlatLight LEDs to power their latest portable LED-based projectors. Thanks in part to the Billerica, MA, firm's PT54 chips, both Samsung's P400 Pocket Imager and LG's HS-102 Ultra-Mobile Projector weigh less than 2 lb and fit in the palm of the hand.

...Monocrystal adds 8 inch sapphire

Russian sapphire supplier Monocrystal began producing 8 inch C-plane epi-ready LED substrates in August. This follows on from the 8 inch R-plane wafers that it has already supplied for RF and LED applications.

CHIP PRODUCTION

Taiwan continues LED manufacturing surge

LED chip manufacturers in Taiwan enjoyed a surge in sales during the first half of 2008, with organizers of the Beijing Olympics ordering tens of thousands of emitters and helping to drive a 16.1% year-on-year increase to \$771.3 million.

That's according to the Taiwan External Trade Development Council (TAITRA), which promotes Taiwanese business. It says that at least 44,000 LED-based lamps featured in Beijing's high-profile Water Cube building, which hosted the Olympics' swimming and diving competitions.

While US and German suppliers Cree and

Osram supplied a large proportion of the chips used to light up the Water Cube, the Taiwanese firm Opto Tech supplied LEDs for some gigantic video screens. Some 44,000 LED lamps are said to have featured in a 147x36 m screen, while the venue also boasted a 200x30 m LED display.

With the Olympics over and increasing worries about the state of the global economy, rumors of slackening demand have begun to circulate. However, according to TAITRA, demand will now be bolstered by the Taiwan government itself, which is aiming to boost the domestic LED industry by replacing all of the incandescent lamps used in the island's traffic lights with solid-state equivalents within three years.

In recent weeks, German MOCVD reactor manufacturer Aixtron announced even

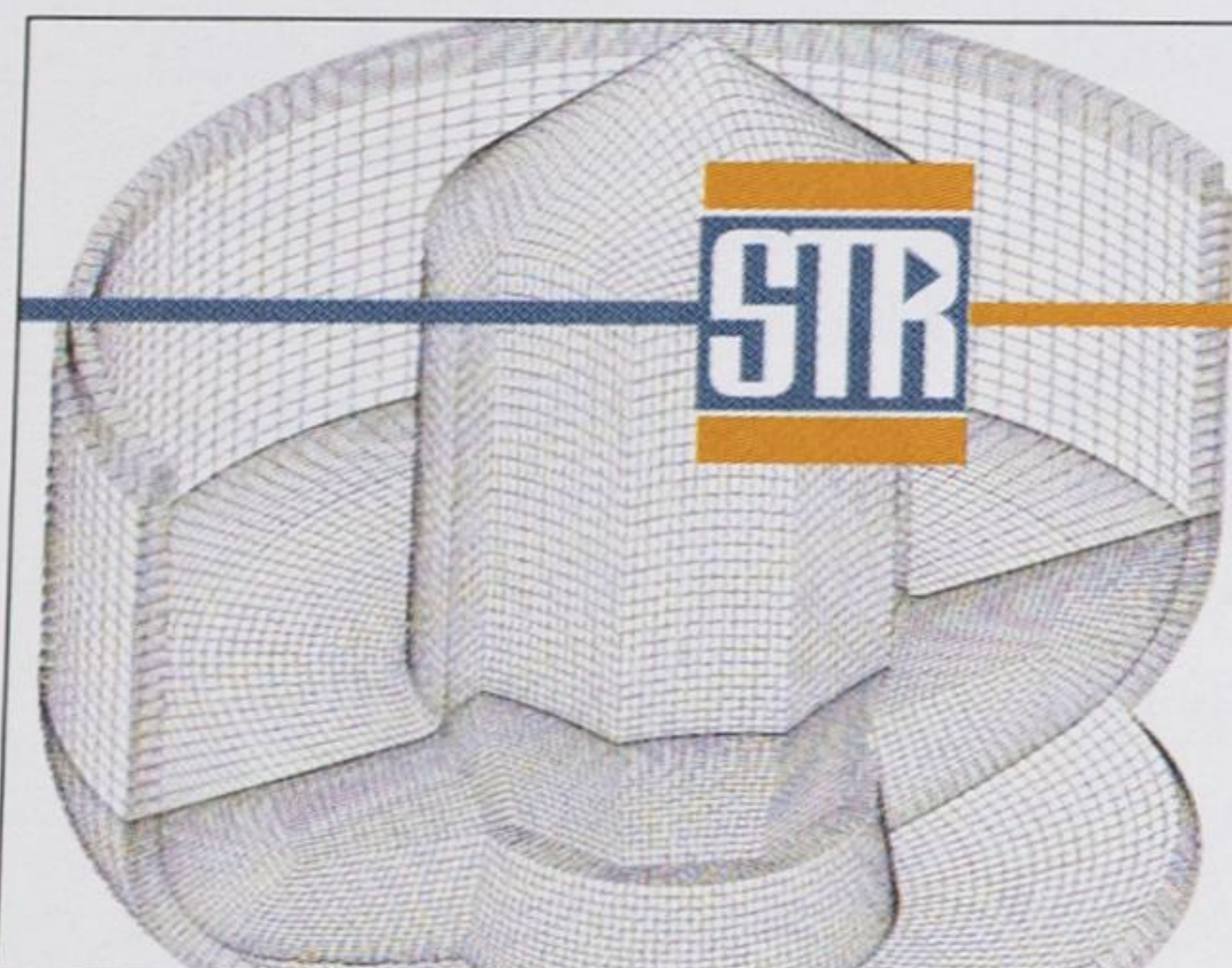
more orders from Taiwanese LED-making companies, in spite of its own admission that new enquiry levels are dropping off. These include Formosa Epitaxy, which is buying another six Crius tools on top of the four that it ordered in July. Walsin Lihwa, the parent company of LCD manufacturer HannStar Display, also plumped for a Crius tool to kick off its GaN LED production. SemiLEDs has bought an AIX2800 GT reactor for its Metal Vertical Photon (MvpLED) high-power technology, which uses a copper-alloy base.

With this level of investment ongoing, plus LCD flat-panel giants AU Optronics and Chi Mei Optoelectronics strongly suggested to be set for volume LED production, it appears that overcapacity may be returning to the Taiwanese supply chain.

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PROCESSING EQUIPMENT

Obducat receives \$12 m nanoimprint tool order

Nanoimprint lithography (NIL) equipment is making more inroads into the LED-manufacturing industry, with Swedish vendor Obducat signing a supply deal worth up to SEK80 million (\$12.6 million). The mass-production order has been placed by Luxtaltek Corporation, a recently formed Taiwanese operation that has major plans to ramp photonic crystal LED fabrication.

Photonic crystal LEDs are similar to regular emitters, except that their structure features arrays of holes. These patterns, if optimized, yield a huge improvement in light extraction. The pattern of holes can be fabricated in various ways, but NIL could now emerge as the standard method, as chip makers target tough applications like LCD TV backlighting units.

Under the agreed purchase order, Obducat will deliver one "Sindre 60" NIL tool in September, allowing Luxtaltek to begin LED wafer production in the final quarter of 2008. This will be followed by a larger Sindre 400 for volume production – the tool can handle a throughput of up to 30 4 inch wafers per hour – in the first quarter of 2009. This initial part of the deal is worth SEK22.5 million.

Citing Obducat's superior imprint performance as the key reason behind his choice of equipment supplier, Luxtaltek CEO Sean Lin says that the company's expansion plan for the next two years would require five more Sindre 400 systems and several more Sindre 60s. Together with a supply of consumables relating to the NIL equipment, it means that the potential value of the deal totals some SEK80 million.

According to Obducat CEO Patrik Lundström, this represents the tip of the iceberg for NIL in LED production. "This is a highly interesting market, with a potential for NIL equipment in the range of €100 million over the next five years," he said. "We are very well positioned to capture a significant part of that."

Although Obducat lists Taiwanese LED giant Epistar among its existing customers, and is widely thought to have supplied US company Luminus Devices with NIL equipment, the Luxtaltek deal is the first major purchase order by an LED maker to have been announced publicly.

Formed earlier this year by Uni-light Touchtek and the Taiwan Oasis Technology Corporation, Luxtaltek recently acquired intellectual property owned by the University of Southampton spin-out company

Mesophotonics. The firm has ambitious plans, and with \$10 million funding in place Luxtaltek is aiming to set up eight production lines by the end of 2010 – equivalent to a processing capacity of 200,000 photonic crystal LED wafers per month, it claims.

Photonic crystal patterns are also abundant in nature. For example, the iridescence of certain species of Morpho butterflies is attributed to a photonic-crystal-like structure of lamellated scales on their wings.



Obducat's NIL allows LEDs to use phenomena seen in Morpho butterflies, to enhance light extraction.

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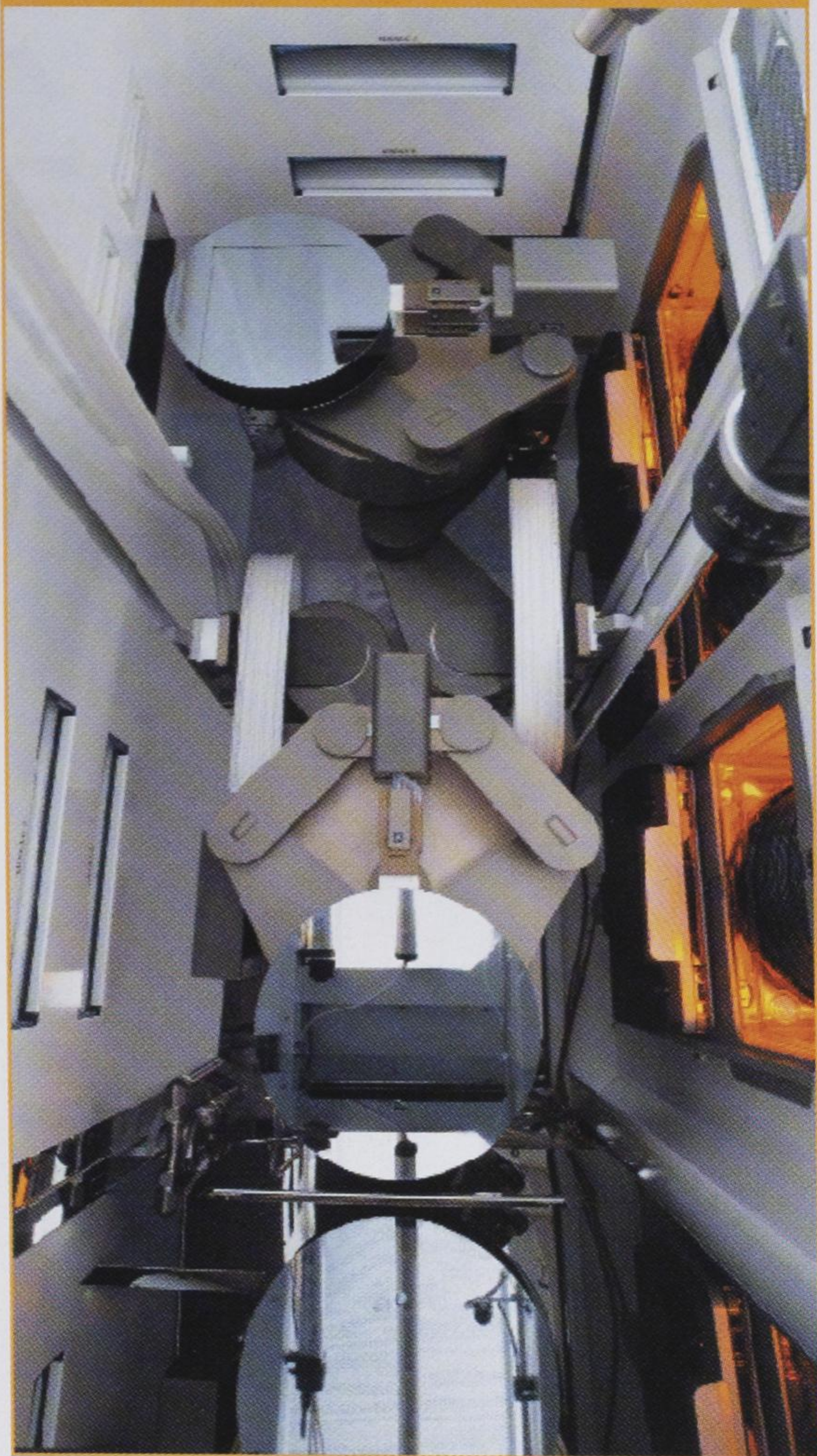
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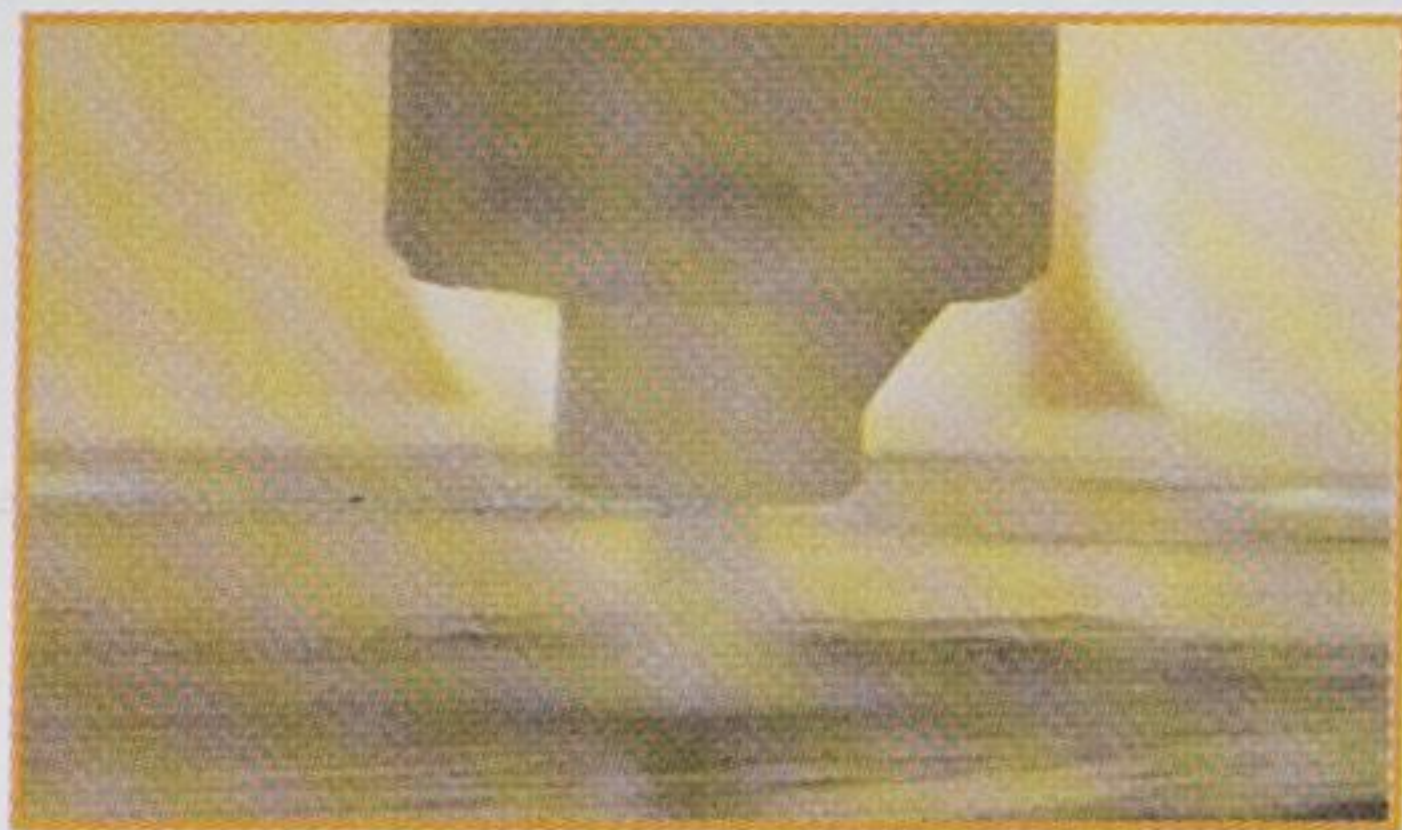
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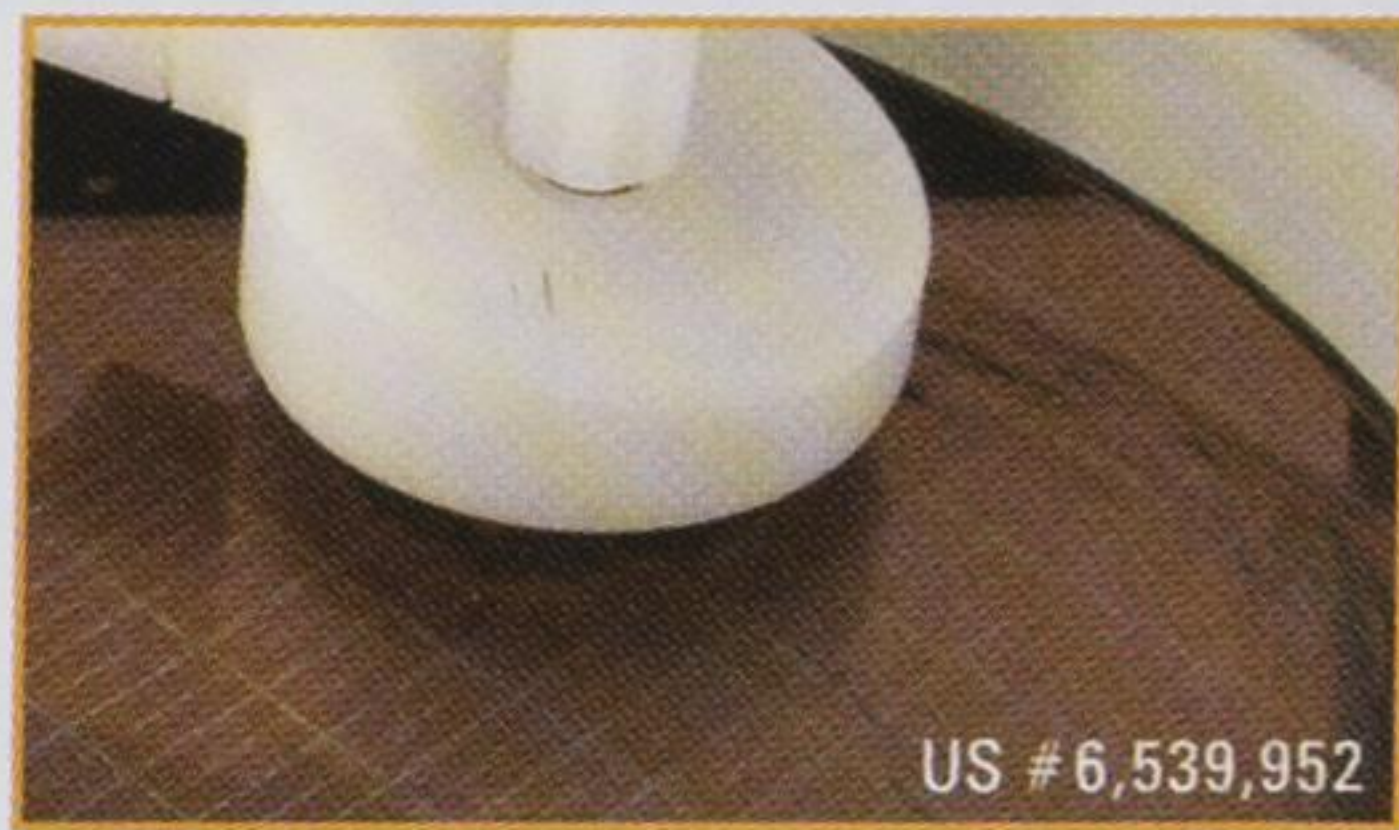
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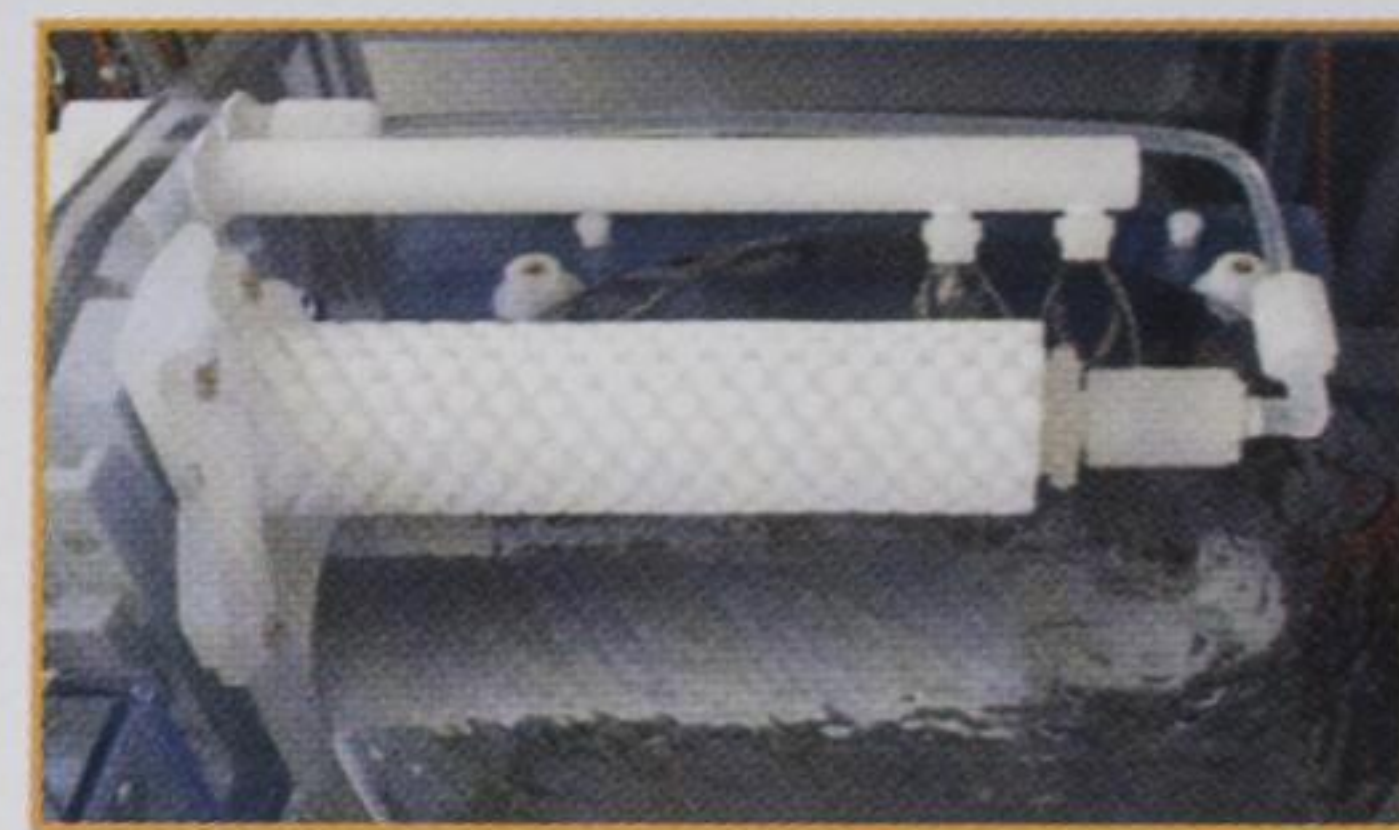
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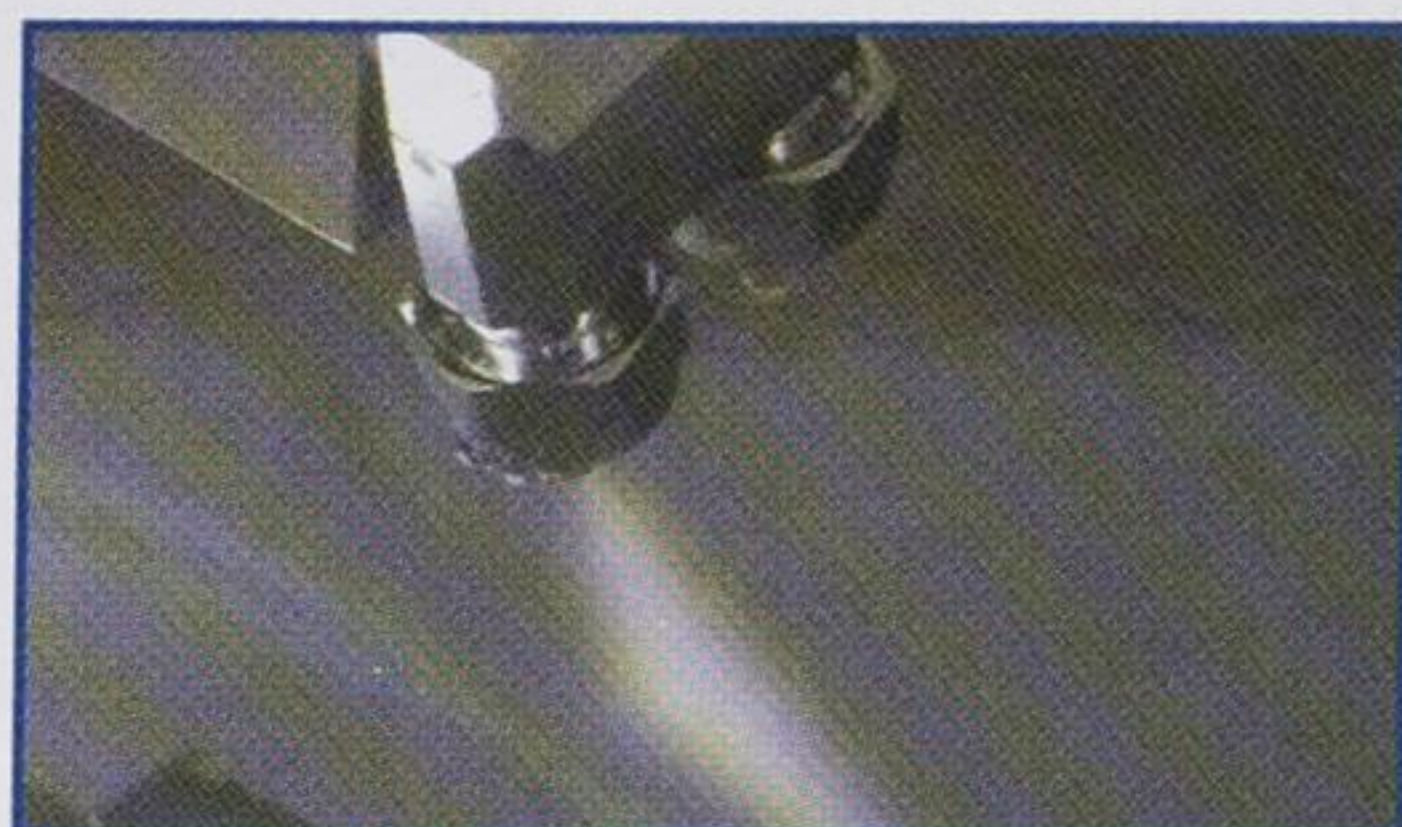


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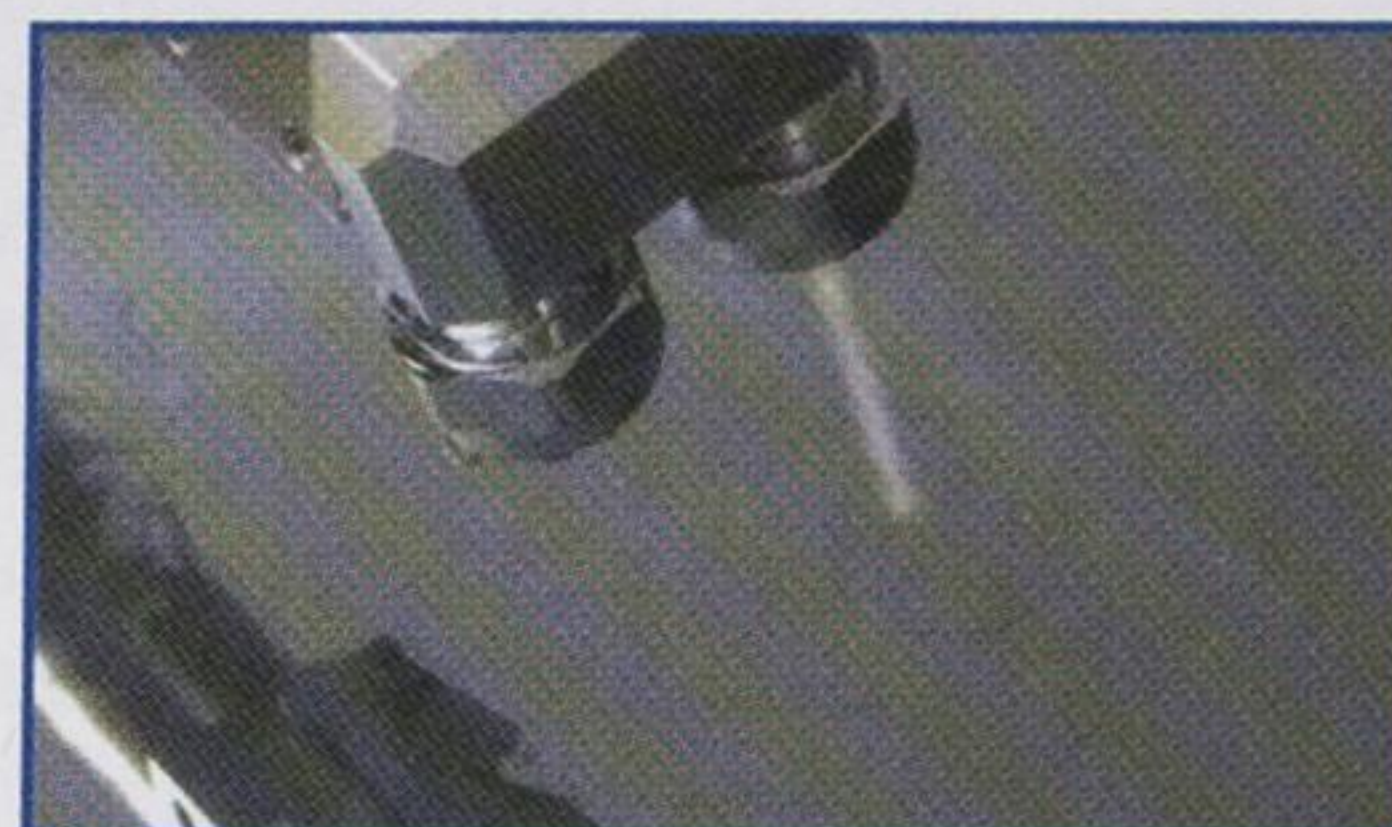
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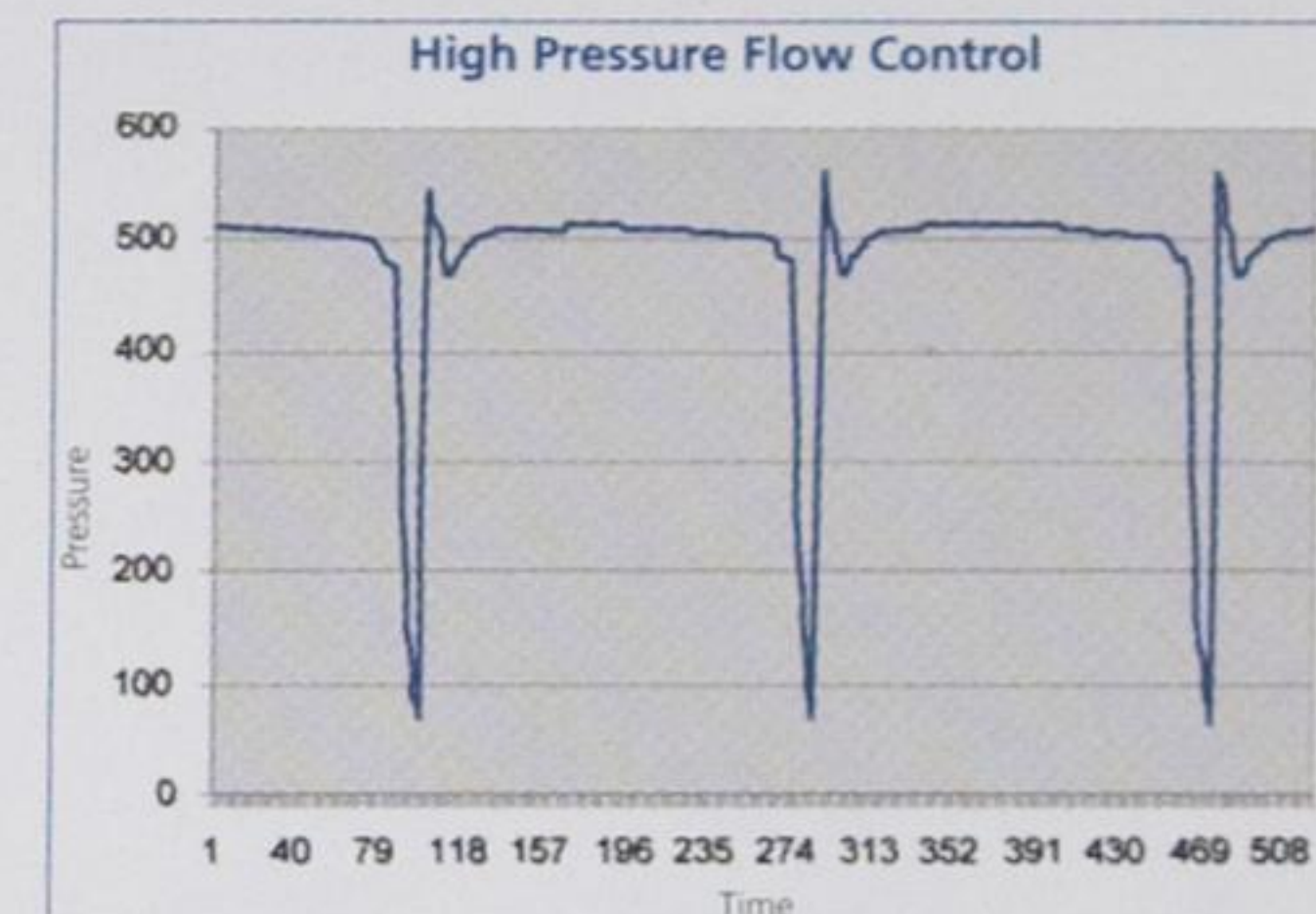
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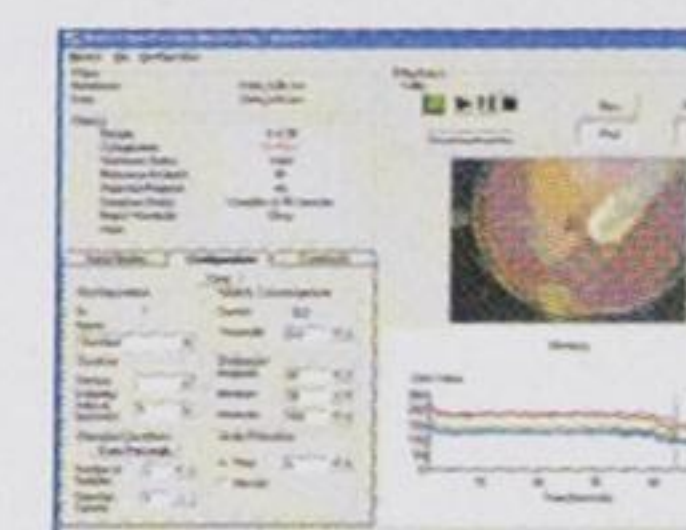
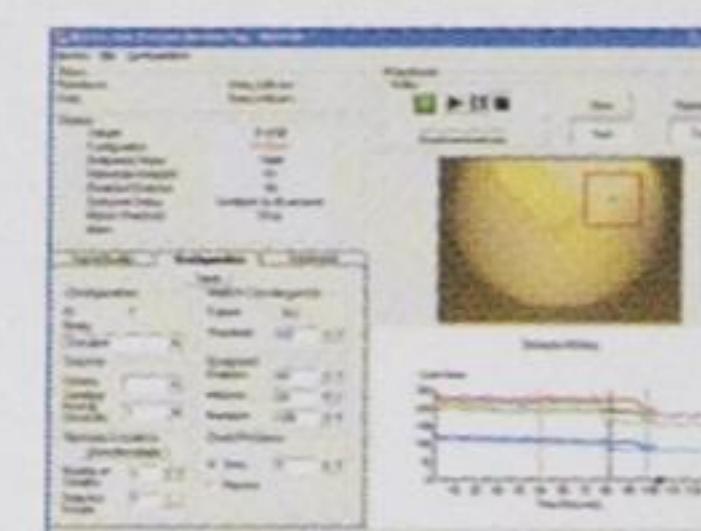
Backside/Bevel Cleaning



Stream Flow Etch



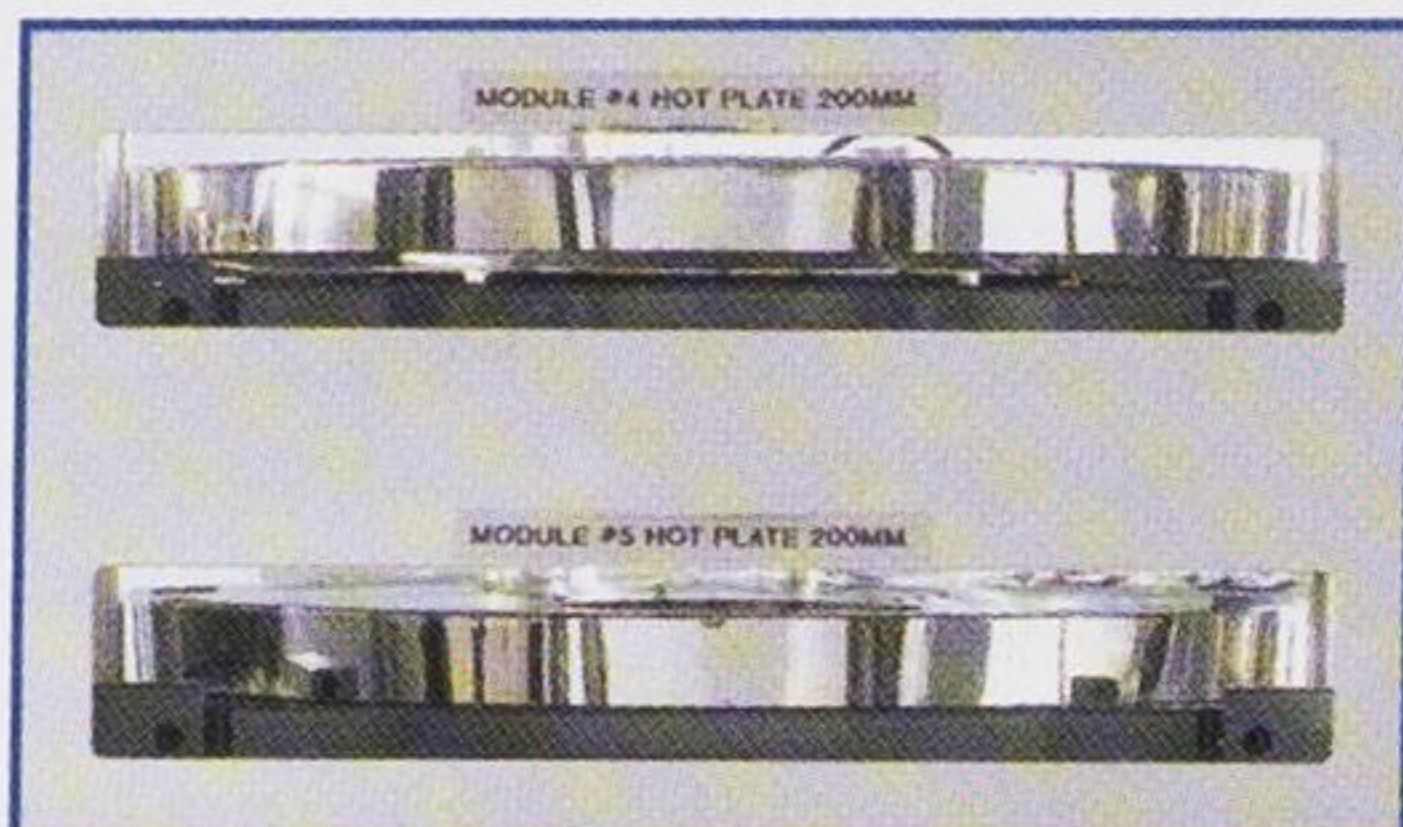
Spray Etch



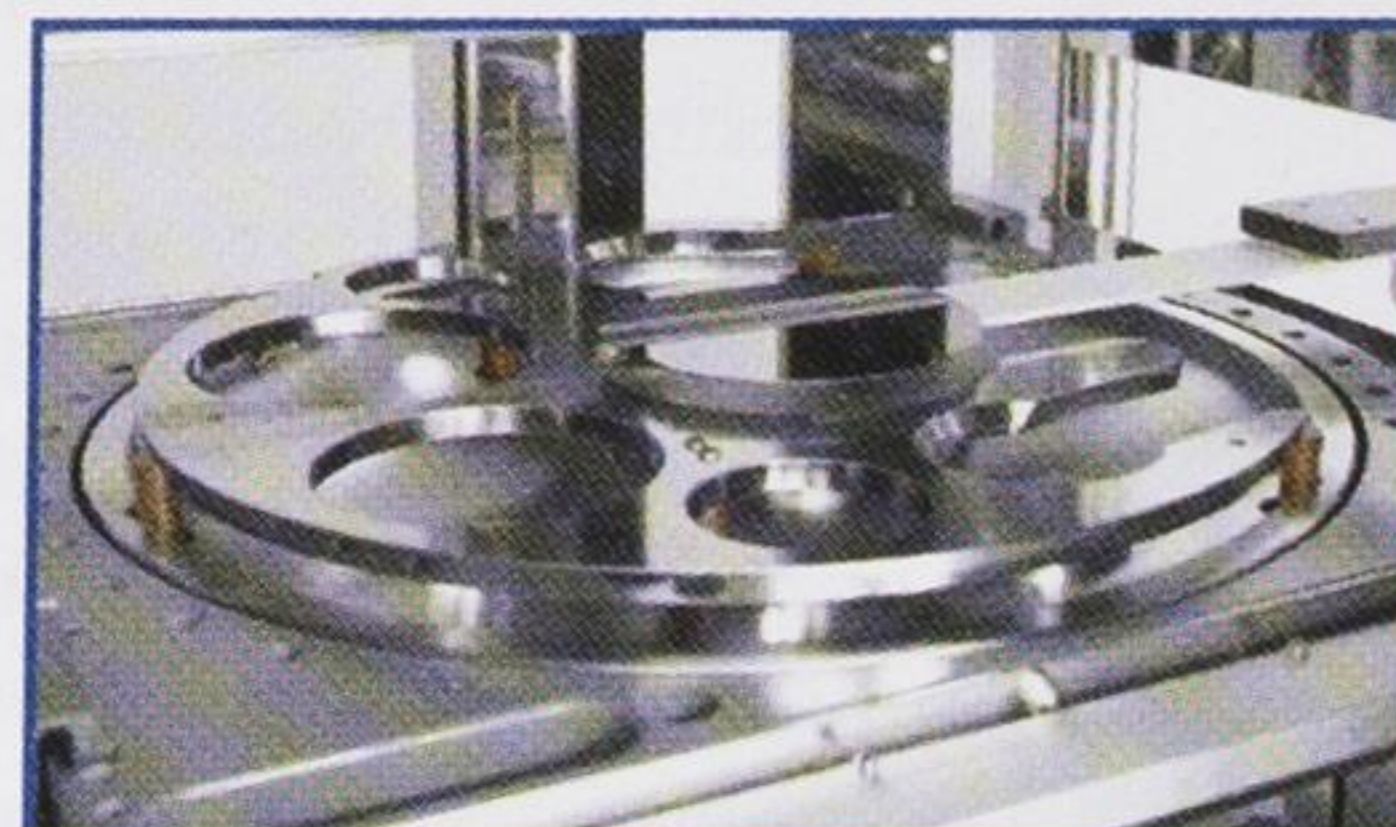
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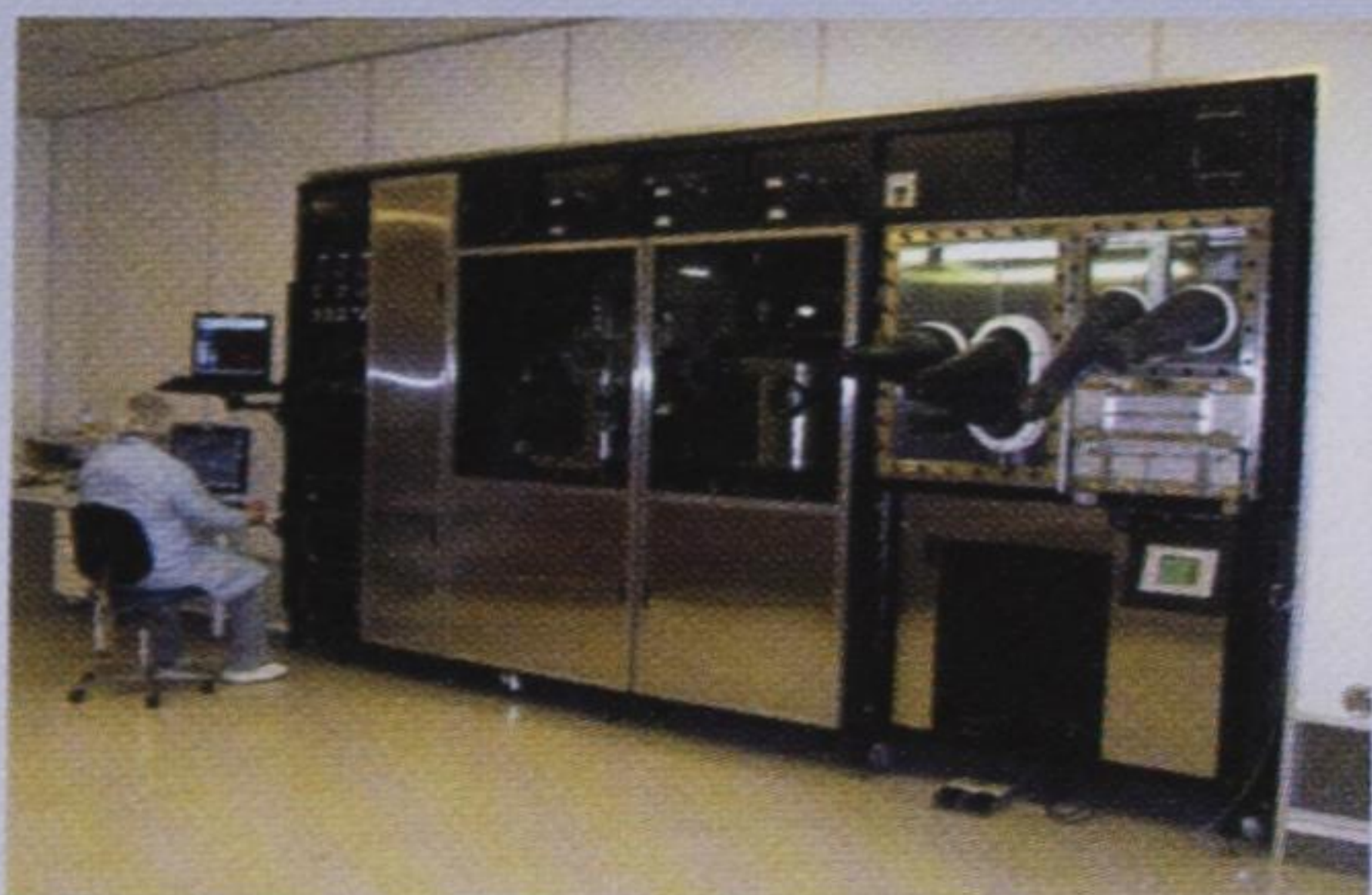
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PHOTOVOLTAIC CELLS

Evolved cell claims solar crown

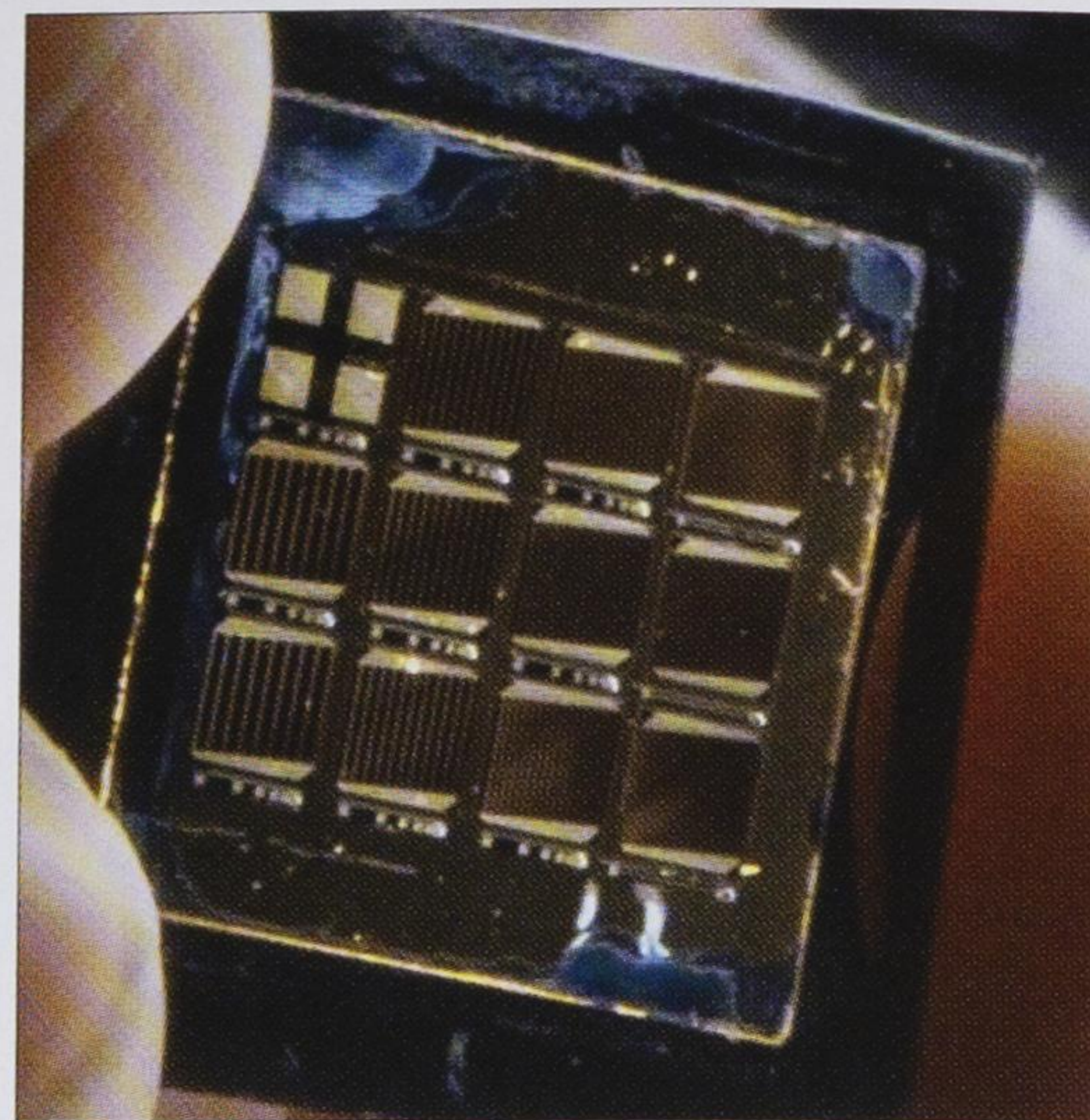
A versatile compound semiconductor solar-cell design has claimed the world efficiency record, doing away with the germanium substrate that Spectrolab's previous record-holder was grown on.

When light is focused on the latest cell from the US National Renewable Energy Laboratory (NREL) at a concentration of 326 suns, it is 40.8% efficient. Although this is only a 0.1% increase from the previous record performance, it's still a significant milestone for the inverted metamorphic (IMM) approach. So says John Geisz, who is optimizing the cells at NREL's Colorado labs.

"The important point is that this new device, which has the potential to increase the efficiency by about 4%, has surpassed the highly mature predecessor technology," Geisz told *Compound Semiconductor*.

NREL has improved on the performance provided by the high-quality epitaxial material in IMM cells by tailoring the semiconductor compounds for their electronic properties. "To optimize the bandgaps of the triple-junction device," Geisz said, "we needed a middle junction at about 1.34 eV, which requires about 4% indium in InGaAs."

The NREL team has calculated that the ideal bandgap combination for a triple-junction cell combines the 1.34 eV middle junction with a 1.85 eV top and 0.93 eV bot-



NREL's inverted metamorphic cell with optimized bandgaps has delivered 40.8% conversion efficiency.

tom junction. Retaining the germanium substrate in the final device would make this impossible, so instead IMM cells are grown on a removable GaAs substrate.

Producing these cells in a manufacturing setting should be straightforward, Geisz says. NREL is now working on a quadruple-junction IMM cell that could achieve concentrated terrestrial efficiencies of 45–50%.

CPV SYSTEMS

Concentrix moves towards CPV expansion

Concentrix Solar, a leading firm involved in solar concentrator systems, began ramping up production at its 25 MW production line in Freiburg, Germany, in September.

The new facility – an expansion from Concentrix's previous 1 MW pilot plant – features 4000 m² of production and service space. It will support as much as 50 MW fabrication in the future – equivalent to approximately 50,000 4 inch wafers at current cell efficiency levels.

The move within Germany's self-proclaimed "eco city" signals the start of a shift for concentrator photovoltaics (CPV) technology from the laboratory and prototyping stage towards true volume production. "It means that we can at last meet the strong demand for our systems," said Concentrix CEO Hansjörg Lerchenmüller.

So far, Concentrix has deployed its "Flat-

con" CPV modules, which are based on Fresnel lens optics, in a record-breaking system in Seville, Spain. A company spokesman told *Compound Semiconductor* that aside from the Seville project, Concentrix has recently installed 100 kW of CPV at a 2 MW total power project led by Abengoa Solar at Casaquemada, also in Spain.

On top of that, the German firm has finished installing its second 100 kW at the ISFOC test-bed in Castilla La Mancha. "We are waiting for the grid connection to feed in," said Concentrix. Starting in September it began to install the final 300 kW of its scheduled allocation at the ISFOC site.

Aside from the existing Spanish installations, Concentrix says that it is receiving requests from companies in Asia and the US. The firm already has long-term cell supply deals in place with the likes of Emcore and Spectrolab in the US, and Azur Space in Germany, but it is now expecting to see some competition in III-V cell manufacturing. "We see that many new players are about to enter the market," said Concentrix.

OPTICAL COMPONENTS

Finisar deal redraws comms map

After completing its merger with Optium on August 29, III-V component and subsystem manufacturer Finisar has posted record sales figures.

The California-based firm delivered total revenue of just under \$129 million, \$115.8 million of which arose from sales of fiber-optic components and subsystems. With Optium also breaking records in the latest quarter, registering a best-ever \$47.2 million in sales, the future looks good for the combined outfit.

From his post as Finisar's CEO, Jerry Rawls has moved to a role as executive chairman following the merger, with Optium's Eitan Gertel appointed as the new CEO.

Rawls expects the firm's VCSEL fab in Richardson, TX, and its longer-wavelength laser chip manufacturing facility in Fremont, CA, to remain busy as robust demand characterizes the resurgent fiber-optics business. "We see strong growth, particularly in the second half of our fiscal year, which starts in November," Rawls said.

He feels that revenues now represent genuine production demand from customers, unlike in the telecom bubble era when components piled up in customers' inventories.

With combined revenues of \$175 million and an overall profit of \$2.6 million Finisar's optical component revenues have pulled ahead of JDSU – the previous leader in the sector. JDSU looks unlikely to

close this gap quickly, as production constraints have forced it to postpone delivery on \$10 million of optical communication orders beyond September.

These orders, which include products containing its InP tunable lasers, have been delayed from the company's current fiscal quarter as demand has risen faster than its own capacity build-up. The Milpitas, CA, headquartered company is also contending with supply delays in the face of what is an otherwise optimistic outlook arising from increasing amounts of internet traffic.

In the June quarter, sales from JDSU's optical communications division were \$136.1 million, up 6% sequentially and 33% year on year. This includes revenues arising from Picolight, the chip maker whose acquisition JDSU completed in May 2007, since when it has added three VCSEL customers.

JDSU predicts that its optical communications unit will grow 5–15% annually in spite of the current obstacles, but says that improving profitability is still a priority. This is because comms was the fastest growing of JDSU's four divisions in the last quarter, but boasts the worst profit margin.

Without boosting its profitability, the health of optical communications will not help to improve on the company's most recent quarterly results, in which its official losses expanded from \$17.9 million to \$29.8 million.

III-V/SILICON INTEGRATION

€8.5 m boosts hybrid photonics

No fewer than 19 partners are working on a new, €8.5 million (\$12.2 million) European project that aims to combine compound semiconductors with silicon in an attempt to merge photonics and CMOS technology.

Led by French technology giant CEA-Leti, the Helios project officially kicked off in May. It also features compound semiconductor expertise provided by the Alcatel-Thales III-V laboratory, fellow French outfit 3S Photonics (formerly Alcatel Optonics and then Avanex) and the Belgian microelectronics research firm IMEC.

Partners with silicon photonics knowledge include the University of Surrey, UK, the University of Trento, Italy, and DAS Photonics – a Spanish spin-out of the Nanophotonics Technology Center in Valencia.

Running over four years, the primary

aim for Helios is to "make CMOS photonics accessible to a broad circle of users in a foundry-like, fabless way".

III-V materials have clearly been identified as crucial to what could be perceived as "silicon photonics", however. For example, one key goal of the project is to develop high-performance WDM sources via heterogeneous integration of compound and silicon semiconductors.

While silicon lasers are listed as one of the more challenging concepts under investigation, III-Vs will clearly have a role to play in the development of a complete production chain for complex functional devices.

Once they are established under the EU's 7th Framework Programme, these design and fabrication chains will transfer to European manufacturers, says the project description.

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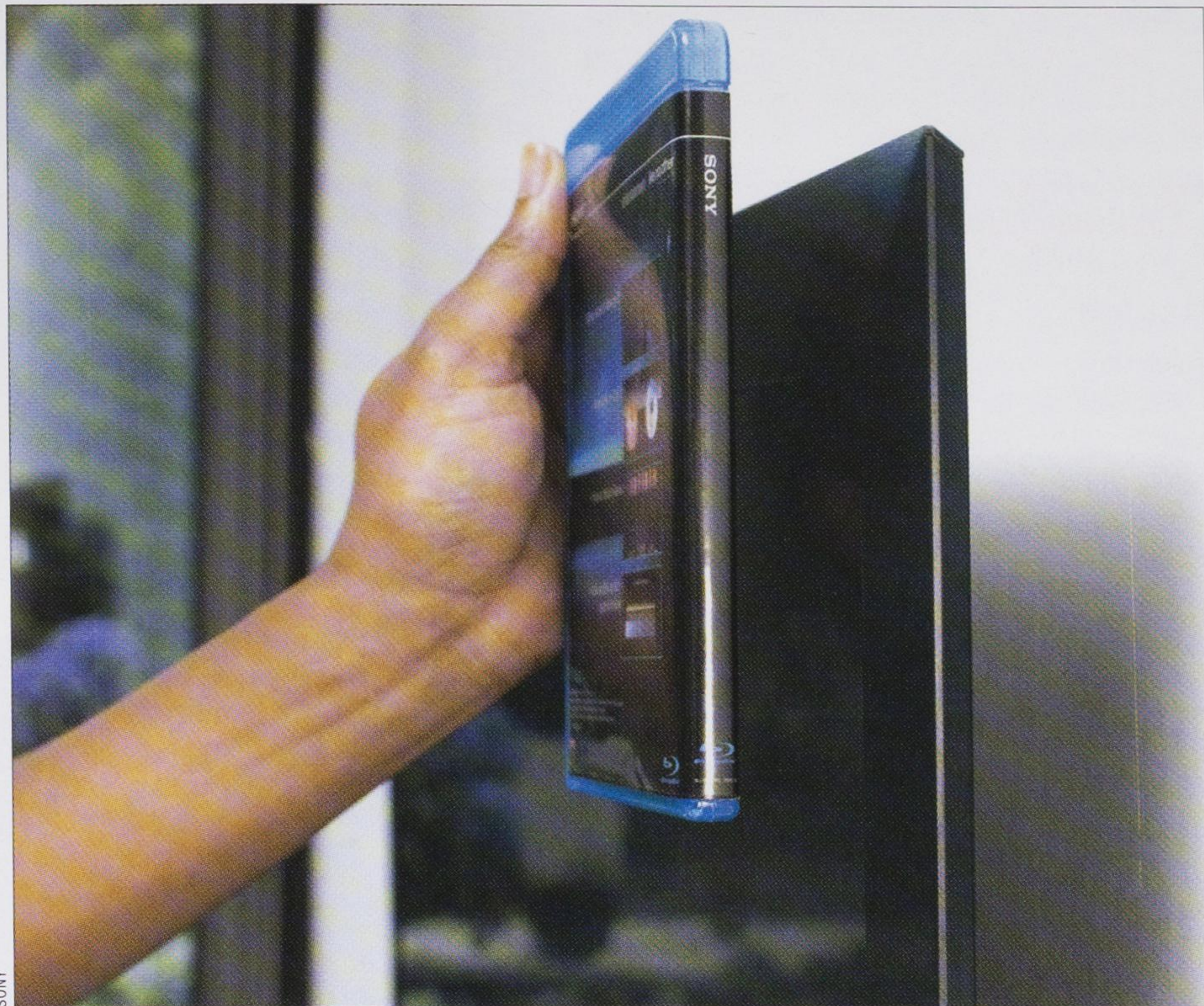
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CHIP MANUFACTURING

Industry giants size up LED potential

A host of powerful companies, among them flat-panel display makers, silicon foundries and consumer electronics giants, look set to enter the LED chip-making industry and have already invested in MOCVD systems. Could they break the long-held grip of the so-called “big six”? **Michael Hatcher** searches for answers with two leading industry analysts.



The latest flat-panel TVs from Sony and Philips now feature backlights that are based on LEDs, rather than on traditional cold-cathode fluorescent lamps. Chi Mei Optoelectronics and AU Optronics are two of the world's biggest makers of these flat panels, and are now thought to be investing in MOCVD equipment with a view to controlling their own LED supply lines in the future.

For an industry that has grown so rapidly over the past few years, the top tier of high-brightness LED (HB-LED) manufacturers has proved remarkably resilient to new entrants.

Nichia still heads a list of the six leading chip manufacturers by some distance, with Epistar, Osram Opto Semiconductors, Cree, Philips and Toyoda Gosei fighting it out at the top of the table.

And so it ever was – save for a few spin-offs and acquisitions. But now a challenge to the status quo appears to be emerging, with major corporations in Japan, Korea, Taiwan and China apparently eyeing the HB-LED sector enviously.

As the leading supplier of the MOCVD equipment that is essential for chip production, Aixtron probably gets to hear about these moves before anybody else. In the German firm's August investor call, Paul Hyland came clean: “Companies that have traditionally operated in the parallel silicon sector have expressed inter-

est in investing in LED equipment,” said the CEO, “as well as liquid-crystal display manufacturers, who are operating further down the food chain.”

It's an open secret that those LCD panel makers include the Taiwanese duo Chi Mei Optoelectronics and AU Optronics (AUO), both of whom rank among the world's leading suppliers to TV and PC monitor producers. A third Taiwanese LCD company, HannStar Display, is a subsidiary of the huge Walsin Lihwa Corporation, which recently purchased a production MOCVD tool. And the company from the silicon business that Hyland alluded to is widely felt to be the giant Taiwan chip foundry TSMC.

Add to these three firms the trio of electronics powerhouses that have existing LED experience – Samsung, Panasonic and Toshiba – plus the recent acquisition of several Aixtron reactors by the government-backed Chinese upstart Century Epitech, and suddenly you have the makings of a very different looking top tier of LED producers.

Changing landscape?

Although all of these companies are keeping their cards very close to their chests, one thing is abundantly clear: if they wanted to, any of them could change the landscape of the LED industry at a stroke by means of an acquisition.

However, that hasn't happened – yet. Instead, it seems that they each want to produce LED die internally. Long-time LED industry commentator Bob Steele, an analyst at Strategies Unlimited, reckons that Chi Mei has been working on LEDs for at least the past couple of years. Rumors would even suggest that the flat-panel specialist is already shipping some low-end die in China.

Chi Mei's rival AUO is only just starting to buy reactors, and is at least a couple of years behind, but it shares this desire to become vertically integrated from the epitaxy stage onwards. The suggestions are that TSMC will do the same and, given the resources at its disposal, this is not altogether surprising: “Compared with the resources required to build a silicon semiconductor fab, or a flat-panel display fab, this is pocket change,” said Steele of the investment in MOCVD reactors so far. But the strategy of AUO and Chi Mei seems more confusing.

“If you look in Taiwan, where there is so much capacity to supply LEDs, you wonder why they would go to the bother of making an investment to build up their own internal supply,” Steele told *Compound Semiconductor*.

The “big six” LED manufacturers

Nichia
Osram Opto Semiconductors
Cree
Epistar
Philips Lumileds
Toyoda Gosei

Table 1. Six new (big) kids on the LED block?

Company	Location	Industry sector	LED status
Taiwan Semiconductor Manufacturing Company (TSMC)	Taiwan	silicon semiconductors	investment in Bridgelux; rumors suggest MOCVD equipment orders
Chi Mei Optoelectronics	Taiwan	flat-panel displays	thought to be producing LEDs for Chinese market
AU Optronics	Taiwan	flat-panel displays	ordered MOCVD equipment in past year
Century Epitech	China	compound semiconductor epiwafer foundry for domestic market	ordered MOCVD reactors in September
Toshiba	Japan	diversified; lighting subsidiary investing in solid-state lighting	AlInGaP expertise; possibly entering InGaN production
Panasonic (Matsushita Electric Works)	Japan	diversified consumer electronics	GaN laser capability already established; claimed new GaN process based on plasma deposition and compatible with 4 inch GaN production

Table 2. Recent investment in MOCVD capacity

Company	Target material	Reactor order	Order/installation date
SemiLEDs (Taiwan)	4 inch GaN	Aixtron single 11 × 4 inch systems	ships before the end of 2008
Century Epitech (China)	2 inch GaN, 2 inch As/P	four production reactors (Aixtron)	ordered early September
Walsin Lihwa (Taiwan), parent of LCD maker HannStar	GaN	single 31 × 2 inch system (Aixtron)	delivery expected Q3 2008
Formosa Epitaxy (Taiwan)	GaN	10 production tools (Aixtron)	ordered in Q1 2008
Changelight (China)	As/P	two production tools (Aixtron)	shipped in Q2 2008
EpiLEDs	2 inch GaN	four production tools (Aixtron)	order announced in July
Genesis Photonics (Taiwan)	2 inch GaN	single production tool (Aixtron); multiple K-series tools (Veeco)	Aixtron order announced in June; Veeco systems received in April
Ubilux (Taiwan)	AlInGaP, GaN	six production tools (Aixtron)	delivery schedule in progress
Bridgelux	2 inch AlInGaP	two 31 × 2 inch systems (Aixtron)	order announced in April

When you consider that neither AUO nor Chi Mei currently makes the cold-cathode fluorescent lamps that are used to backlight their LCD screens, this strategy seems even more curious. Perhaps these two companies anticipate a lucrative side-line as merchant suppliers of LED die?

“The natural thing to do – once the capacity is there – is to sell into the merchant market as well,” added Steele. “But given the capacity that’s out there, especially in Taiwan...well, do we really need another merchant chip supplier?”

For these flat-panel makers, control over the supply of LED die appears to be a key strategic decision. But for a foundry company like TSMC, that argument is irrelevant. So what could be TSMC’s big plan?

Asif Anwar, director of the GaAs service at Strategy Analytics, has also been monitoring developments in the LED industry closely. “When you start talking about a company like TSMC and compare them with even the biggest LED manufacturers in Taiwan, such as Epistar, then they are absolute giants,” he commented. “So, if they put their minds to it, then they will change the landscape.”

However, any market entry for TSMC would only make sense if demand for LEDs with specific wavelengths and emission characteristics becomes huge, reckons Anwar. He believes that this could ultimately be the case in general lighting, where three or four

individual chips might go into every solid-state lighting “bulb” for future domestic applications. “TSMC would want to establish a DRAM-style production regime,” said Anwar. “And even though it has grown quickly, the LED industry is not yet truly ‘volume’ in the same way that silicon is.”

Two major hurdles

With such an elevated level of demand years away, TSMC has time to develop its own processes. If that’s the strategy that it wishes to pursue, a lot of time will be needed. As Steele points out, any new player trying to make a significant impact in the LEDs arena is going to have two major hurdles to overcome – technological development and intellectual property.

“Buying a reactor is one thing, but being able to design and produce high-quality chips is another,” Steele said. Part of the key to that is to acquire experienced technologists, something that Chi Mei is believed to have done successfully when the Taiwanese LED industry went through a protracted period of consolidation a couple of years ago.

However, even with the pool of MOCVD talent that is available in places like Taiwan and Japan, it will take these companies years to catch up with the industry pioneers, and TSMC is likely to be looking at more than five years before it can realize any home-grown LED ambitions. Even with good tech-

“If they put their minds to it, then they will change the landscape”.

Asif Anwar
Strategy Analytics

nology, there is the minefield of intellectual property to negotiate – although the size of the companies seemingly entering the LED business would suggest that they are more than capable of matching the firepower of lawyers working for the likes of Nichia and Seoul Semiconductor.

The business strategy that would appear to make a lot more sense than independently reinventing GaN LED technology is outright acquisition of one of today's major players. Financially, that ought to be no problem for the likes of TSMC, Panasonic and their ilk, but who could be a realistic target?

Nichia, the world's top LED chip maker by far, will no doubt have been subject to these enquiries in the past. However, as a private company with a fiercely independent culture, it has resisted any bids made up until now, and would appear likely to do so in the future. Of the remaining major players, two – Osram Opto Semiconductors and Lumileds – are already subsidiaries of huge multinationals and are critical elements of each of these companies' future generations of lighting technology.

That leaves Cree, Epistar and Toyoda Gosei. As public companies free from parent owners, Cree and Epistar are more likely to be viewed as potential acquisition targets. Rumors about acquisitions of US-based Cree by a major silicon player are pretty common fare in financial circles – although rarely backed up with any hard evidence. For TSMC at least, a bid

for Cree might be less likely than one for its near neighbor Epistar. Aside from the obvious geographical proximity, TSMC also has strong links with California start-up Bridgelux – a company that is in the middle of a patent dispute with Cree over GaN chip technology, and whose foundry partner is Epistar.

Logistically, Epistar and TSMC looks to be the most likely hook-up. But, if the rumors are true, why has TSMC invested in MOCVD reactors rather than build up a share in the LED maker? Perhaps, as Steele muses, the foundry giant is “dabbling” in LEDs, familiarizing itself with the technological processes required and figuring out its next move.

“One thing that you have to look at is the investment that has gone on at all of the major players to reach current performance levels,” commented Steele. “It's enormous.” That said, the LEDs required by Chi Mei or AUO may not necessarily have to be on the leading edge of emitter technology.

Perhaps a steady investment in process development will end up bearing fruit for TSMC and co, or perhaps they will eventually come to the conclusion that the only way to crack the LED business is via a high-profile acquisition. Either way, it will be some time before today's leading players are displaced from their rankings. Steele and Anwar both suspect that the same five or six companies will lead the way for as much as another five years. And beyond that, it's anybody's guess.

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LED chip-manufacturing explodes

At the intersection between the key logic, flat-panel display and LED industries, the former Epichem is proving to be a fantastic investment for Sigma-Aldrich. **Andy Extance** visited the unit's Bromborough, UK, factory to quiz Epichem founder Barry Leese on SAFC Hitech's progress.

Barry Leese, president of SAFC Hitech and founder of the Epichem business that now forms its core, says that current owner Sigma-Aldrich came onboard for chemicals aimed at future silicon technology. However, sales of trimethylgallium (TMG), the crucial LED chemical precursor, have been driven up by industry expansion since the deal went through in February 2007. Consequently, SAFC Hitech's revenues have surged by 26% from 2007, and Leese predicts that they will swell by another 15% into 2009.

SAFC Hitech is something of a bellwether for the III-V industry, a stage along from epitaxy equipment makers like Aixtron and Veeco. It is the next step for new LED makers in making a choice of metal-organic precursors to balance expense and quality of products made with a given system. "Our role has been to advise the customer which chemicals – out of thousands offered by SAFC – are likely to be successful," Leese explained.

SAFC Hitech's sales figures show that TMG demand is rising thanks to recently purchased MOCVD reactors being brought online to manufacture GaN and AlGaInP LEDs. Leese also believes that what his company is seeing corroborates Aixtron CEO Paul Hyland's opinion that the ranks of LED makers are being joined by new entrants from the wider semiconductor community.

Publicly, it seems that the most advanced of these companies are flat-panel display makers like AU Optronics and Chi Mei Optoelectronics. SAFC Hitech is already well known to such LCD companies as a supplier of BCl_3 gas – its largest volume product – which is used as an etchant for aluminum interconnects. Although SAFC Hitech shifts up to 200 tons of BCl_3 annually, TMG brings in greater revenues for a total volume in the region of just three tons.

Silicon semiconductor players may not be far behind the LCD firms, and Leese sees major household electronic brands establishing their own LED manufacturing operations. He feels that these trends are combining to draw more equipment suppliers into competing in the MOCVD equipment market.

The possible downside to this influx is that more powerful customers are likely to demand that SAFC Hitech lowers the prices for starting materials. "The whole semiconductor industry has always been



SAFC Hitech has around 1000 designs of bubblers on file (above), but it is now e systems. Although its trimethylgallium plant (right) has a current output of around t

about driving prices down," Leese said. "We have to explain to them that we buy in gallium metal and indium. We're never going to get the prices that are associated with silicon precursors."

This is where SAFC Hitech's EpiFill liquid and EpiVapor bulk reagent delivery systems come in. The continuous flow of precursors that these tools offer can cut the costly MOCVD system downtime associated with standalone small-scale bubblers. Where bubblers are used – including in conjunction with the bulk systems – the company's capacitance-based EpiSensor also helps by accurately measuring the level of precursor that is remaining. "There's only so far you can go in reducing the price of chemicals, so we're looking at improving the delivery to make it cheaper," Leese explained.

Epichem has long had these systems ready for the kind of market expansion that SAFC Hitech is now seeing. "We developed it around the time of the telecom bubble for the III-V industry, but there wasn't much interest. We've actually sold a few to silicon manufacturers for trimethylaluminum delivery."

Now Leese hopes that companies moving into very-large-scale manufacturing will see the value of its systems for volume LED epiwafer fabrication. However, he concedes that it will take more TMG output to support the transition to high volumes.

"Our biggest challenge over the next year or so



Explosion propels SAFC Hitech



low encouraging large customers to move towards its bulk delivery and three tons per year it can theoretically produce about five tons.



BOTH IMAGES: SAFC HITECH

will be moving LEDs from a cottage industry to larger-scale manufacturing and adding the capacity to serve it," Leese predicted. Given the geographical focus of the market expansion in Asia, SAFC Hitech is planning an expansion of facilities for TMG production in Taiwan. This is likely to demand that its site moves from a single floor at its current Kaohsiung location to a specially built facility.

The difficulty of gaining the finance needed for investments like this played a big part in the decision to sell Epichem to Sigma-Aldrich. When a previous capacity expansion was needed in 2005, Intel Capital took a 15% stake in Epichem. As Intel and Epichem have been working together since 2003 on hafnium precursors for high-k dielectric gates, Leese expected the relationship to be cordial. However, when the next stage of expansion reared its head, the terms on offer put him off asking for more.

"I needed more money and Intel was going to take an arm and a leg in return for further investment," he joked. "Sigma-Aldrich had been knocking on the door for some time prior to that and I told them to go away." This time Leese took the chance to visit the chemical giant's St. Louis, MO, headquarters and was impressed by the comparatively relaxed style of management. Both parties appear to be on the same wavelength, with Sigma-Aldrich understanding the importance of Leese's knowledge of the semicon-

ductor industry to the success of SAFC Hitech.

Intertwined with this knowledge are the existing relationships that Epichem has nurtured, and in that regard Sigma-Aldrich has taken a shortcut on the otherwise long road to becoming a supplier for Intel. There Epichem is supplying precursors for high-k materials used in atomic layer deposition to produce dielectrics for the latest 45 nm scale production processes. Although Intel's HfO₂-gated Penryn technology is in production – with Intel Core 2 Extreme processors even being described in marketing literature as hafnium-infused – SAFC Hitech says that its materials are only just entering the development stage. This is despite the two companies being engaged in conference calls every Friday for the past five years, and the discussions now turning to zirconium as a successor to hafnium.

The link between silicon and compounds, and beyond to other manufacturing, has served Epichem and SAFC Hitech well down the years. Epichem started in 1983 as a silane maker and then led the development of TMG. Having survived the tech bubble, Leese is now wondering which industry will be the next one – with solar being at the center of his worries. However, as it rides the wave of LED expansions and looks ahead to increasingly varied material demands from logic, the mood at SAFC Hitech is definitely one of optimism.

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Powerful QCLs eye remote sensing

QCLs are ideal sources for remote chemical sensors that identify gases by infrared spectroscopy. High powers are essential, and new multiwatt designs from Northwestern University are nearing this target.

Our eyes tell us a great deal about our environment. However, they can't spot the numerous invisible threats to our health and safety; threats that also evade detection by conventional imaging systems. They include harmful pollution released from industrial accidents, and some types of terrorist activity, such as the discharging of nerve agents. We have little protection against these kinds of chemical-based threats, and even governments are ill-equipped to constantly monitor their entire homeland.

What's needed is a low-cost remote chemical sensor. This would eliminate arduous, time-consuming surveys with hand-held detectors, and replace them with faster, cheaper surveys by longer-range ground or air-based detection systems.

Optical detection schemes are ideal for this task because they can quickly cover vast areas with high-power lasers that are directed far from the detection system. The low-flying aircraft ITT Angel Service, for example, covers 1000 miles per day searching for natural gas leaks from pipelines.

This search employs differential absorption spectroscopy – one of several techniques for remote optical chemical sensing. The most promising of these operate in the mid-infrared wavelength range (3–12 μm) that overlaps the so-called “molecular fingerprint” region and allows specific chemicals to be identified by characteristic absorption signatures.

The best results are obtained by scanning over a wide wavelength range because this improves the quantitative detection of trace chemicals against a background of strong absorbers. Infrared spectroscopy's specificity gives it an edge over other techniques, such as laser-induced breakdown spectroscopy.

The most promising source for remote mid-infrared spectroscopy is the quantum cascade laser (QCL), an inherently small and robust device suitable for mass production. QCL characteristics are improving all the time, with progress aided by efforts such as the Defense Advanced Research Projects Agency (DARPA) Laser Photoacoustic Spectroscopy program, which started in 2005. The primary goal is to detect trace amounts of hazardous chemicals and explosives, which requires the development of QCLs for photoacoustic spectroscopy.

Our research team at the Center for Quantum Devices, Northwestern University, IL, is involved in this project. It was given the task of developing room-temperature QCLs operating over many wavelengths with a continuous-wave (CW) output power of at



Gas leaks from an underground pipe have been detected by differential absorption, using an instrument mounted in the low-flying aircraft ITT Angel Service. This approach is far quicker than the traditional methods involving hand-held instruments and it can cover 1000 miles per day.

least 100 mW. We have now exceeded these criteria with a portfolio of QCLs spanning 3.8–11.5 μm .

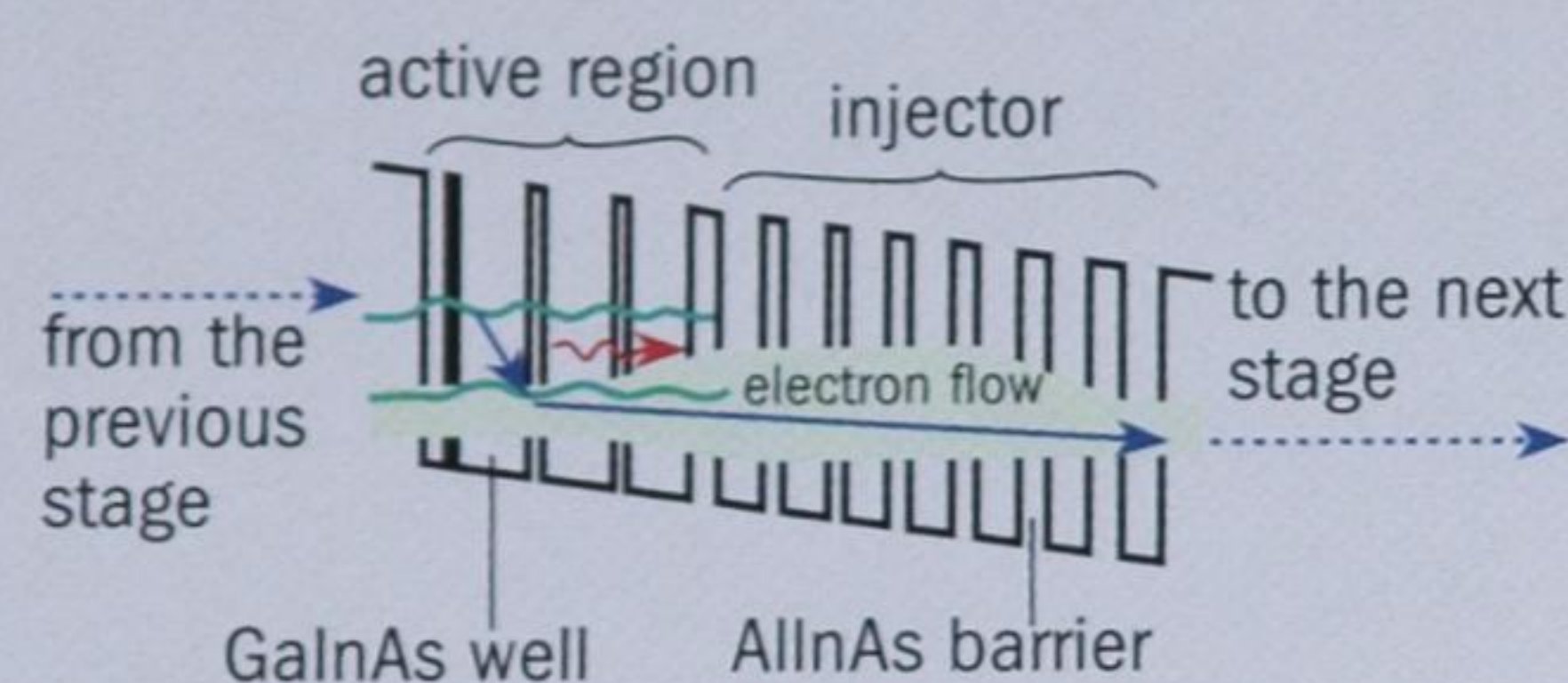
While these lasers' output powers are impressive, they are insufficient for some remote applications that demand 10 W or more. To reach these higher powers requires improvements to the QCL's overall power conversion efficiency, which until recently has languished at less than 5%. DARPA is now trying to address this issue by funding an Efficient Mid-wave Infrared Lasers (EMIL) program that aims to develop more-efficient sources for infrared countermeasures, and for remote chemical and biological threat detection. We have been chasing one of the project's goals – a room-temperature 3.8–4.8 μm QCL with a power efficiency of 50% and an output power of at least 1 W.

QCLs were chosen over competing semiconductor technologies, including nascent interband cascade lasers, which are less-developed devices that need an increase in room-temperature output power of two orders of magnitude to meet DARPA's goal. QCLs also promise to deliver significant energy savings over current sources, such as nonlinear optical parametric oscillators and gas lasers, while employing a tiny active volume comparable to existing diode lasers. What's more, these devices are built on InP, which means that they can draw on mature epitaxial and fabrication technologies that have been honed by the telecommunications industry.

How a QCL works

QCLs are structures with a fully artificial “band gap” that is created within a given band – in our case the conduction band – through the growth of complex III-V heterostructures (see figure). The structure’s emission wavelength can be tuned over a very wide wavelength range by adjustments to the thickness of the quantum well, which alters the electron’s energy states. This is a major benefit because it allows the most mature and robust material technology to be employed. Building mid- and far-infrared lasers operating at room temperature is also more straightforward because the bandstructure in this type of device leads to a far weaker dependence of photon emission on wavelength and temperature.

QCLs also need to feature an efficient method for electron transport. “Injector” regions are designed to do just this,



QCLs emit photons (shown in red) when electrons transfer from a high energy state to a lower one within the conduction band. Typically, 30 or more stages are stacked together to produce many photons from one electron. The shaded area (green) represents a miniband for electron conduction. The electrons are forbidden in other areas.

and enable a single electron to emit multiple photons during its journey across the device. The combination of quantum-based transport and cascaded emitters leads to high-power operation.

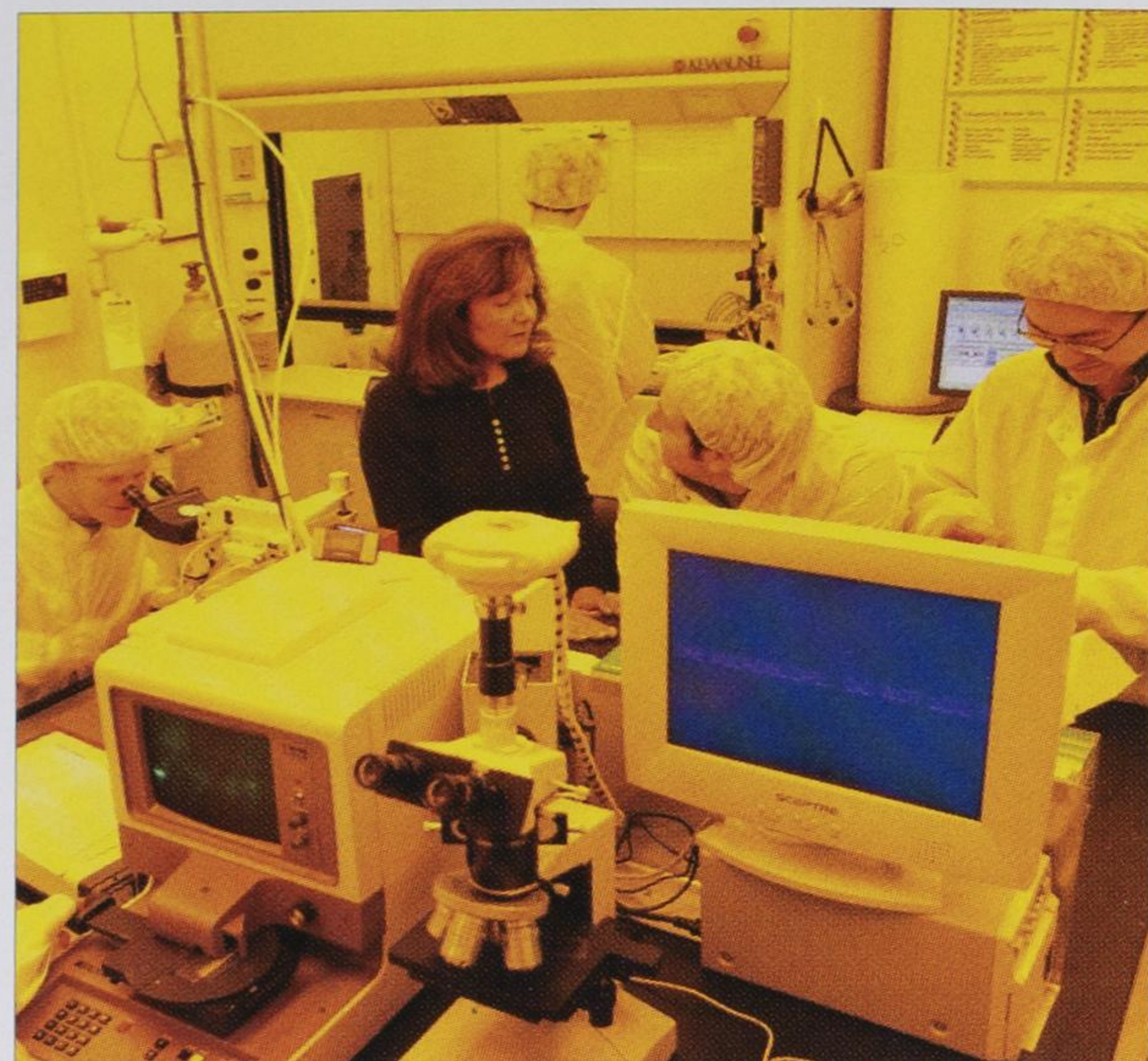
Obstacles to high powers

QCLs produce emission through radiative intersub-band transitions (see box “How a QCL works”), and have output powers limited by electron-phonon scattering. This very fast process, which is weakly dependent on wavelength and temperature, occurs on picosecond timescales. This makes it three orders of magnitude faster than radiative recombination, which accounts for the device’s incredibly low radiative efficiency and differential gain. Only one in a million electrons will recombine radiatively, and differential gain is just 10 cm/kA at most wavelengths. Neither of these key figures of merit is encouraging.

However, the radiative emission rate can draw level with the non-radiative rate when a large photon flux is employed alongside a high optical confinement factor. For modern lasers above threshold, this works so well that the internal quantum efficiency can hit 50% or more, which is a staggering improvement. Getting to these levels is a tall order though, which demands careful engineering of the wave functions within the quantum heterostructure.

The first QCLs were low-temperature devices, and it’s been a massive challenge for our community to transform them to room-temperature sources. Efficiencies are governed by thermal broadening, band filling and electron leakage, and new designs have been needed to combat these effects. Fortunately, improvements have resulted from deeper reservoirs in the injector region and taller barriers that increase electron confinement.

Maintaining strong electron confinement in short-wavelength devices is particularly tricky, because this structure can’t be grown on InP substrates with lattice-matched $\text{Ga}_{0.47}\text{In}_{0.53}\text{As}$ and $\text{Al}_{0.48}\text{In}_{0.52}\text{As}$. But strain-balanced designs – which are still to be



Manijeh Razeghi's team at Northwestern University uses a well equipped facility that features MOCVD and MBE reactors, scanning electron and atomic force microscopes, electron-beam lithography tools, X-ray diffraction and photoluminescence systems, dicing, and life testing systems.

optimized – can address this issue and lead to the growth of dislocation-free $\text{Ga}_x\text{In}_{1-x}\text{As}/\text{Al}_y\text{In}_{1-y}\text{As}$ heterostructures with a band offset of up to 0.9 eV.

Output powers are also held back by laser cavity losses. Free carrier losses from the waveguide cladding and contact layers are far higher in the infrared than the visible, and scale as λ^2 to λ^3 . We minimize this and increase the differential gain by lengthening the cavity to 3–5 mm and employing a 3–4 μm thick, low-doped cladding. This creates a QCL with low threshold gain, good power-conversion efficiency, acceptable parasitic series resistance and an external optical loss to the laser core that can be as low as 0.5 cm^{-1} .

We have taken care to avoid absorption between the other subbands in the active region and injector. This type of loss tends to scale with the doping in the injector, but it can be minimized through wave function engineering and improvements in material quality, which reduce emission linewidths.

Boosting internal efficiencies and cutting optical losses has spurred the fabrication of QCLs with outstanding characteristics. These include 4.6 μm room-temperature multimode lasers with up to 22% wall-plug efficiency and a peak output power of up to 34 W. But QCLs with a high average power are more important for us, and our recent efforts have focused on efficient, high-power CW lasers.

We are working towards DARPA’s 50% efficiency target. As such, all QCLs still generate a tremendous amount of heat. This makes thermal management a key issue. We have investigated several designs, including those featuring a gold heat spreader on the chip’s top surface to increase thermal conductance by 30%. We also used the well known trick of bonding the epitaxial side of the wafer directly to a high

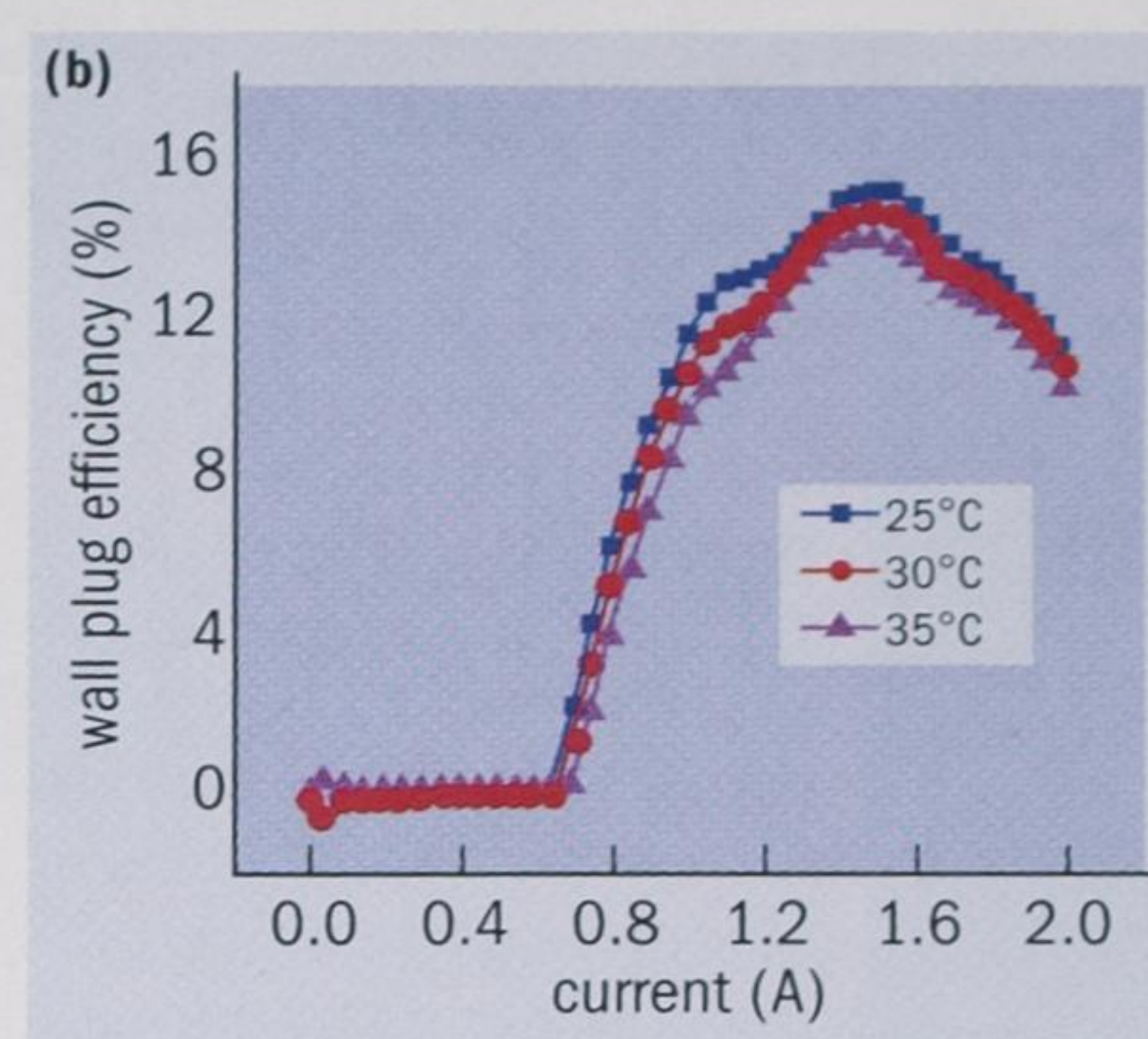
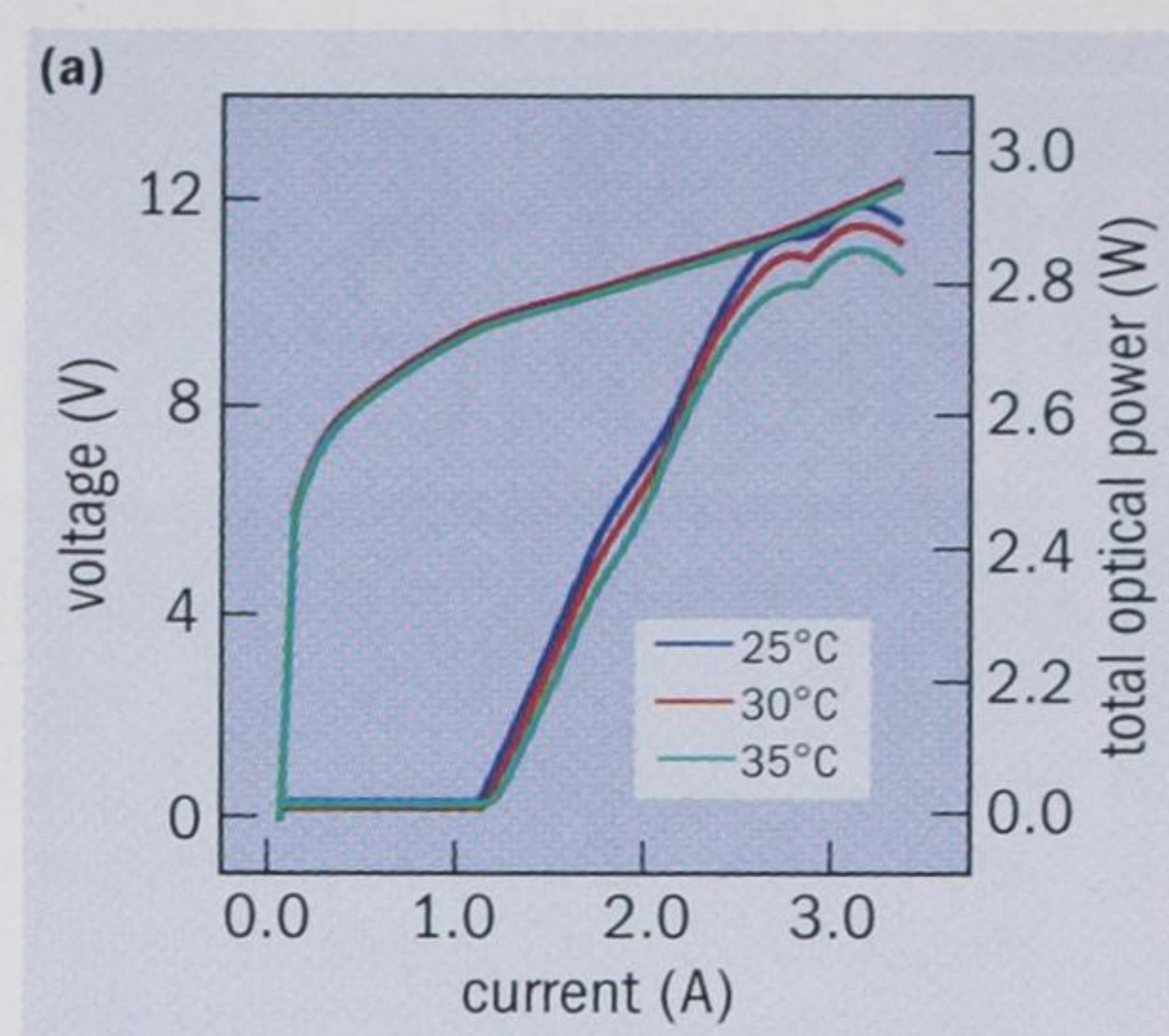
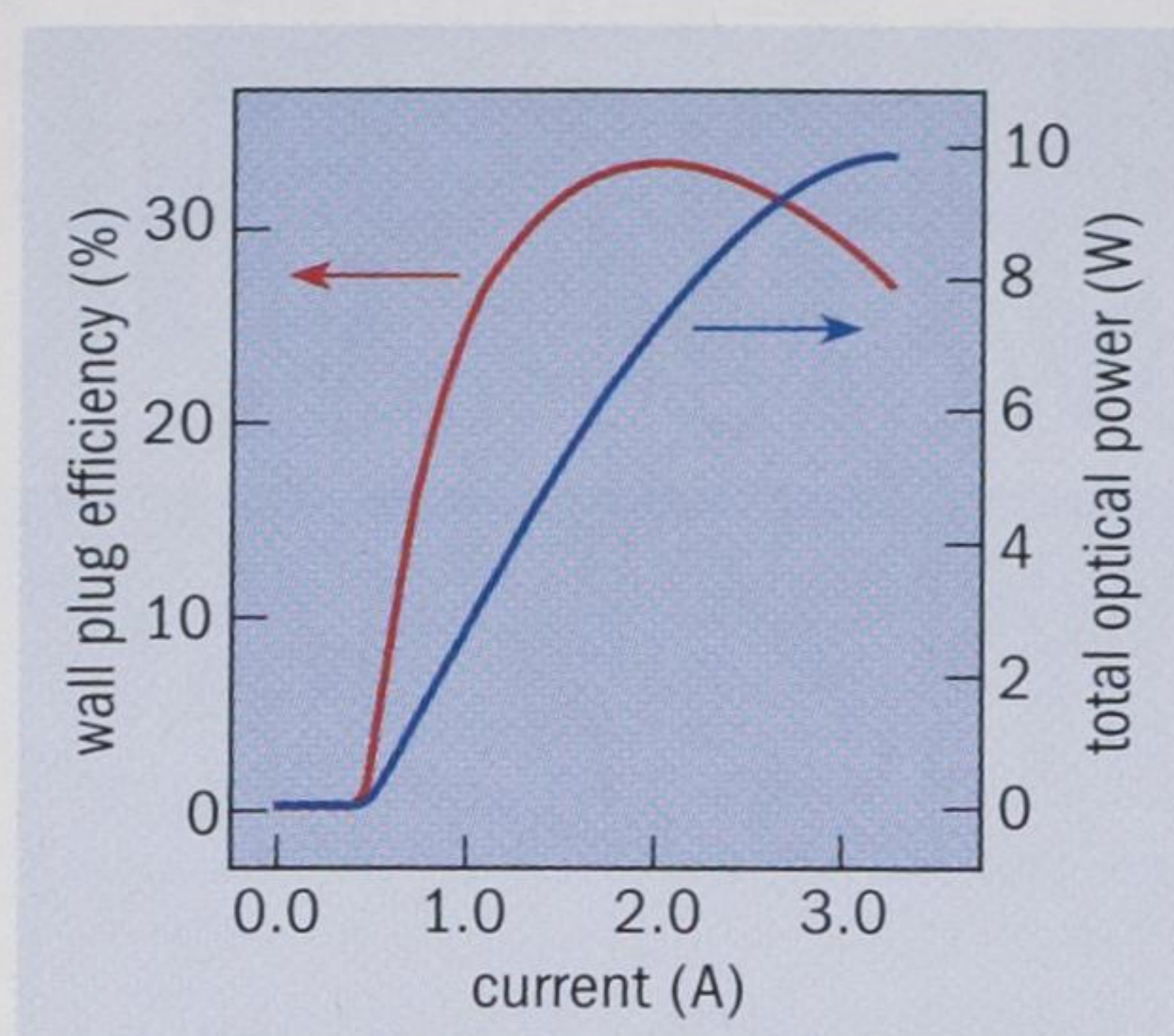


Fig. 1. (top left) Longer cavities, thicker cladding regions and a buried ridge geometry can crank up QCL continuous-wave output powers to almost 10 W at 80 K.

Fig. 2. (top center and right) QCLs operating at close to room temperature can produce an output of several watts (a) at efficiencies of greater than 10% (b).

Fig. 3. (bottom) Photonic crystal distributed-feedback QCLs promise to deliver the spectrally pure emission profile needed for gas sensing. The two-dimensional grating structure (a & b) is tilted with respect to the laser mirrors (c) to improve spatial filtering of the laser's transverse mode. A single-mode output is produced by this design.

thermal conductivity submount.

However, our highest efficiencies have been reached by switching to the more complicated “buried ridge” geometry. The laser is etched into a ridge waveguide before a semi-insulating, lattice-matched InP layer is grown selectively on the side of the ridge. This replaces an amorphous dielectric insulating layer such as SiO₂. The buried-ridge design also cuts optical loss and thermal mismatch, and enables manufacture of laser cores with good structural stability that are less than 10 μm wide.

Combining these advances delivered a dramatic improvement in our 4.6–4.8 μm QCLs. Single emitters at cryogenic temperatures emit a multimode CW output of more than 10 W at 34% wall-plug efficiency (figure 1) and at 25 °C we have produced 2.8 W QCLs with 15% wall-plug efficiency (figure 2).

Power-scaling ambitions

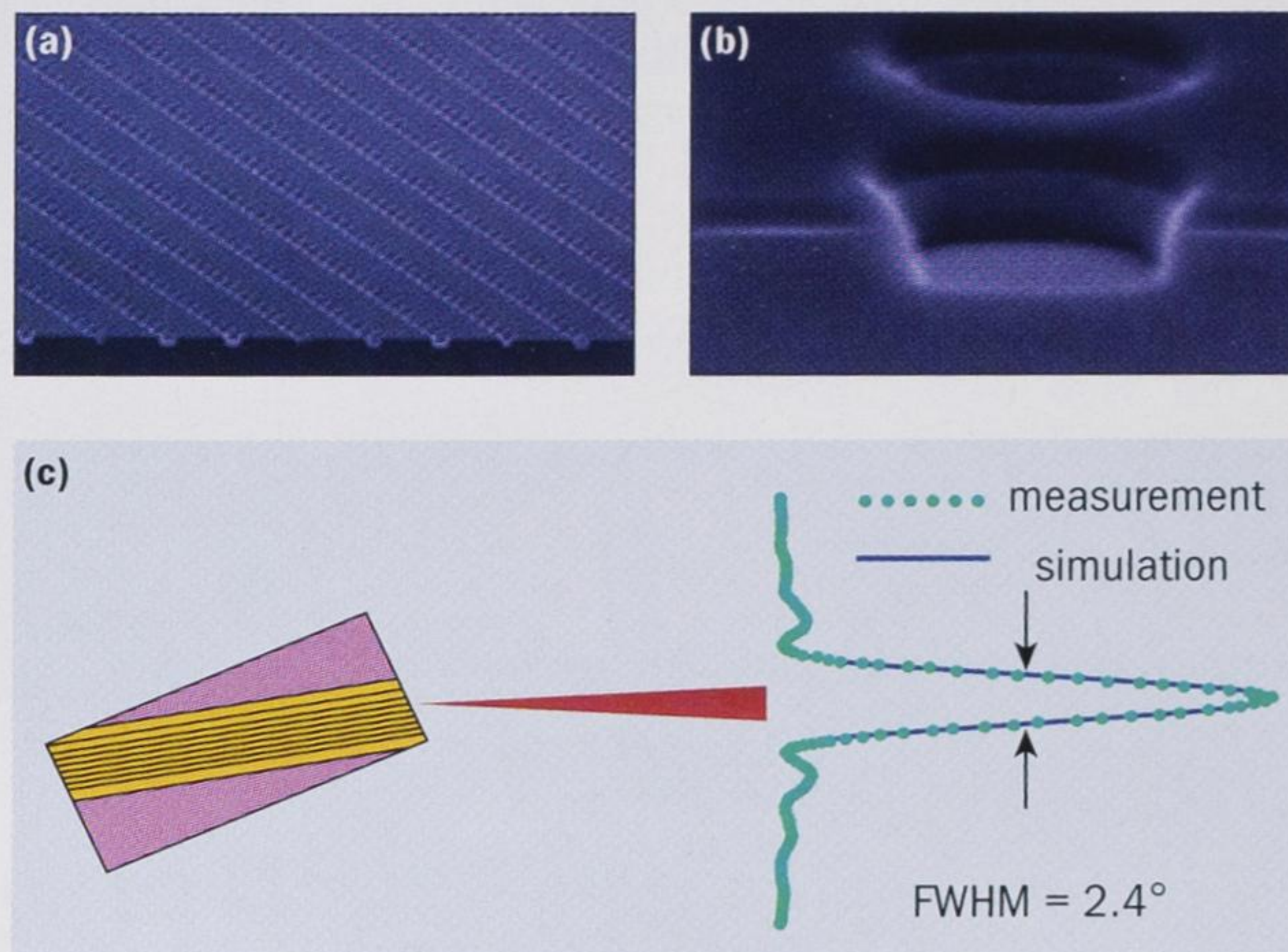
Simple geometrical changes offer us a route to even higher power lasers. One option is to build laser arrays, an approach that is used in near-infrared pump lasers. Alternatively, we could scale our emitter's width from around 10 μm to 100–200 μm.

Both approaches will crank up the output power, but at the expense of beam quality. Emitter width scaling, for example, will probably cause high order, double-lobed emission. However, the beam profile can be controlled to emit within a single spatial mode through additional lateral index modulation. Another way to fabricate a spectrally pure laser source is to incorporate wavelength-specific feedback inside the laser cavity.

One design that features both of these improvements is the photonic crystal distributed feedback (PCDFB) laser. This type of device – which we were inspired to investigate by Jerry Meyer at the Naval Research Laboratory – promises to deliver powerful, high-purity, single-mode emission profiles that are essential for remote infrared spectroscopy.

Our PCDFB laser, like some commercial distributed feedback (DFB) lasers, employs diffractive feedback from a buried grating near the waveguide core (figure 3). However, it differentiates itself with two-dimensional patterning, which is tilted with respect to the laser mirrors to improve the spatial filtering of the device's transverse mode.

Despite its complexity, we have had some success



and reported the results for a spectrally pure, broad-area QCL that emits a diffraction-limited single-lobed far-field pattern. We have only demonstrated low peak power to date, but we are confident that dramatic improvements in output power are possible through design and fabrication refinements.

The US military wouldn't be the only beneficiaries of a successful DARPA program – QCLs are promising sources for free-space communication. They have the capability to create robust links, thanks to emission wavelengths that can penetrate further through dense fog than near-infrared sources.

We believe that QCLs with an output power of up to 10 W will soon be available, providing a major boost to remote sensing. These lasers could also serve a wide variety of other applications, such as multipoint industrial monitoring and standoff detection of hazardous chemicals. Integration with infrared camera systems would even allow differential absorption imaging of chemical spills and clouds. The foundations of this technology are already under development, and several organizations are exploring active imaging with weaker laser sources and passive gas imaging with infrared cameras. ●

Further reading

- A A Kosterev *et al.* 2002 *IEEE J. of Quant. Elect.* **38** 582.
- Y Wang *et al.* 2005 *Optics Express* **13** 6572.
- JS Yu *et al.* 2006 *Appl. Phys. Lett.* **88** 251118.
- Y Bai *et al.* 2007 *Appl. Phys. Lett.* **91** 141123.
- Y Bai *et al.* 2008 *Appl. Phys. Lett.* **92** 101105.



About the authors

Steven Slivken (top left) is the QCL group team leader at the Center for Quantum Devices and is responsible for epitaxial growth of QCLs.

Yanbo Bai (top right) is a PhD student at the Center for Quantum Devices in the EECS department at Northwestern University and is working on QCL simulation, fabrication and testing.

Shaban Ramezani Darvish (bottom left) is a research scientist at the center whose specialty is fabrication, testing and packaging of optoelectronic devices. **Manijeh Razeghi** (bottom right; razeghi@eecs.northwestern.edu) is the director of the center. She oversees all of the group's projects, including QCLs, type-II detectors and focal plane arrays, quantum-dot infrared photodetectors, UV avalanche photodiodes, and blue/green LEDs and lasers.

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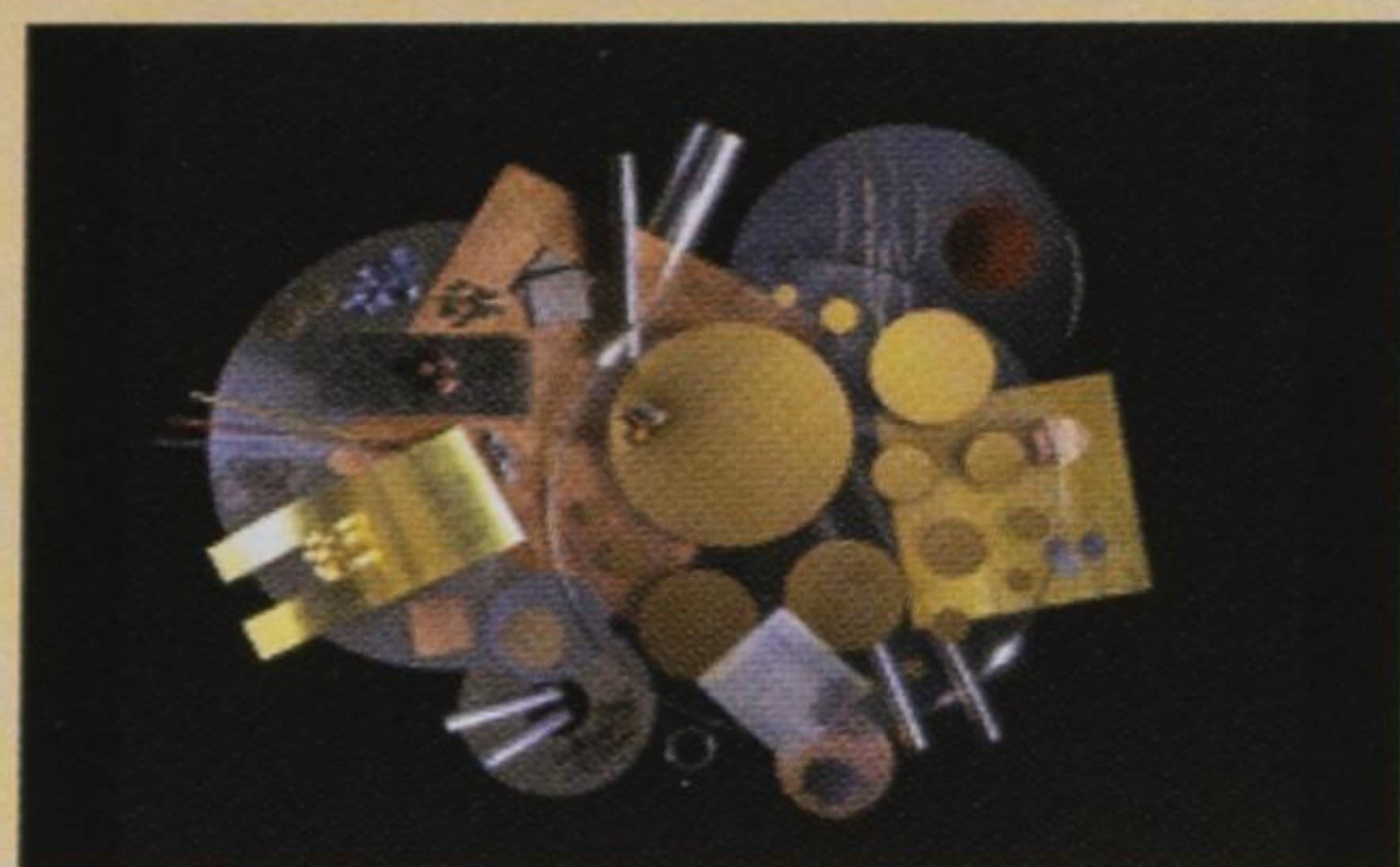
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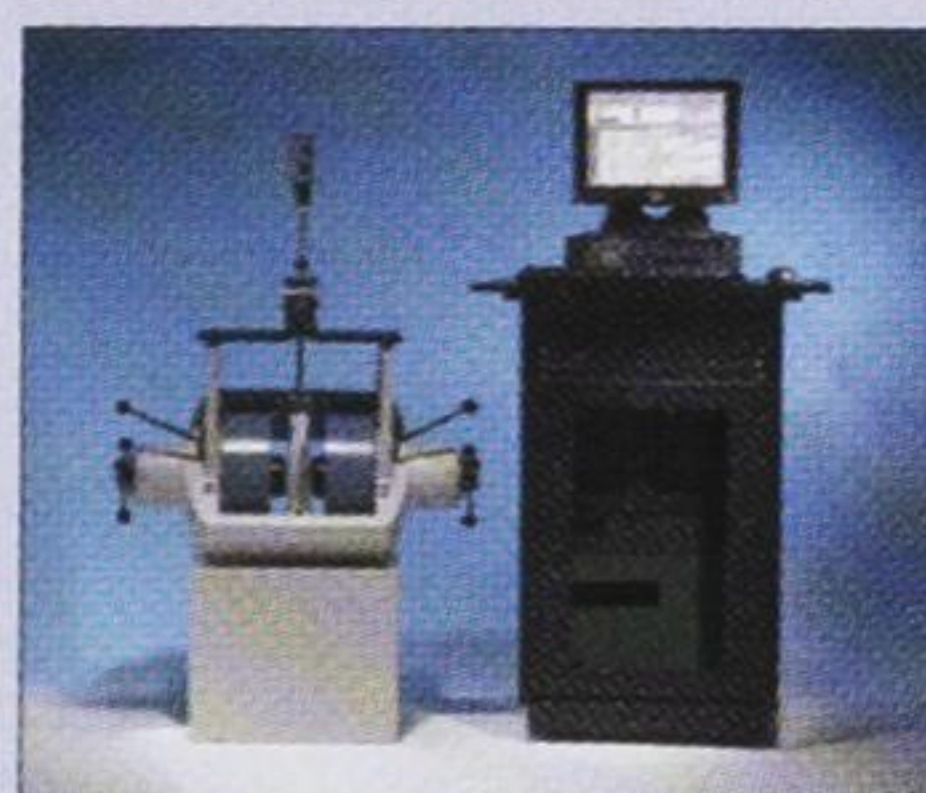
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InP offers a promising base for very-short-wavelength QCLs

Many small organic molecules have strong absorption lines in the 2–4 μm range. Today's III-V quantum cascade lasers cannot extend to probe this domain, but the ZnCdMgSe family of compounds on InP have the potential to get there, says **Maria Tamargo** from the City College of New York.

The quantum cascade laser (QCL) is no longer just a lab curiosity, caged in a cryostat. Room-temperature devices are now commercially available, and they are generating revenue for European firm Alpes Lasers, and for Daylight Solutions and Physical Sciences Inc in the US.

Many of these QCLs are being deployed in gas-sensing tools. These include instruments made by Cascade Technologies of Stirling, Scotland, that reveal traces of methane, ammonia and carbon monoxide at the parts-per-billion level. What's more, this versatile laser can have very different uses, such as high-speed free-space communication.

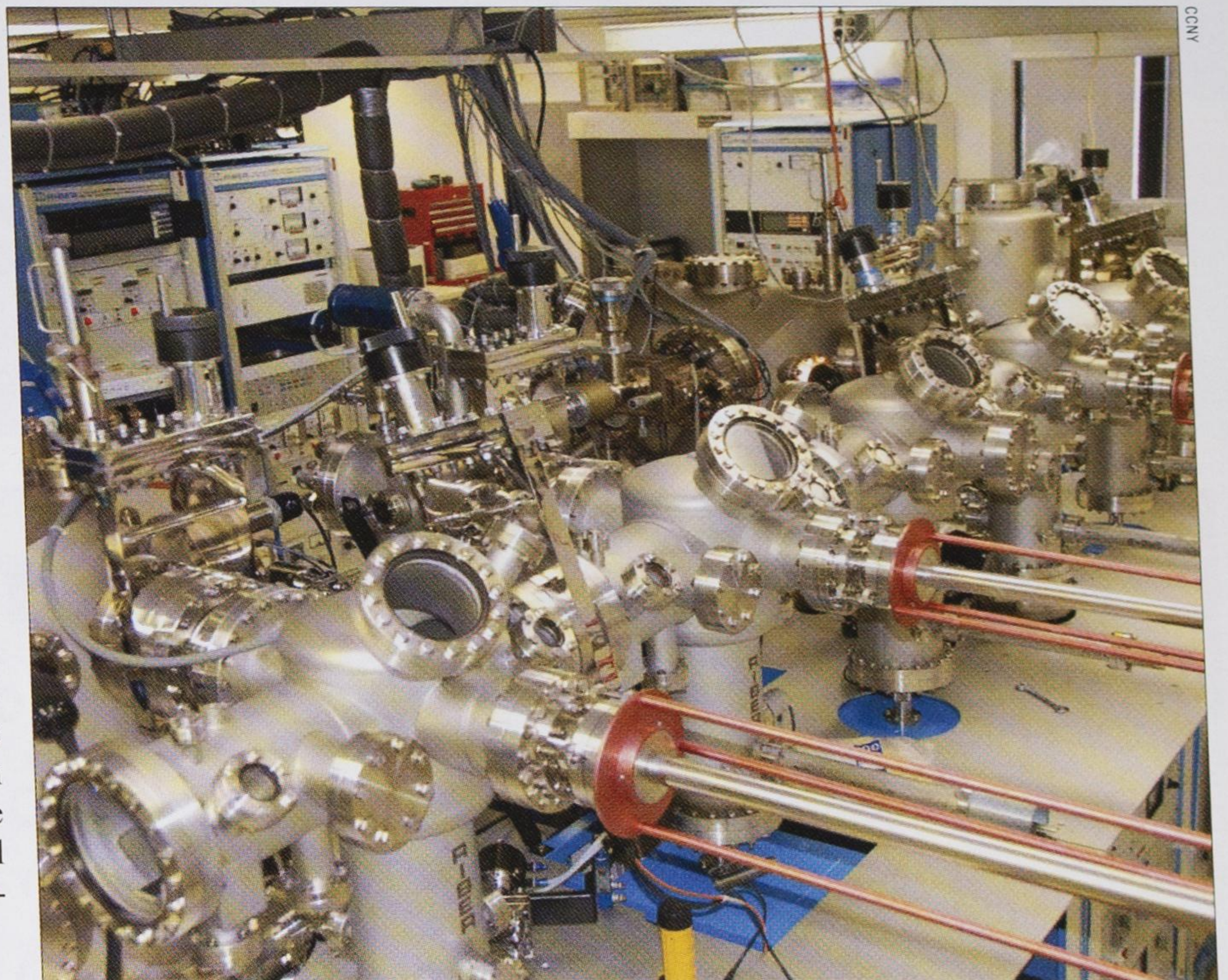
But QCLs would be even more useful if they could be extended to shorter wavelengths and cover the 2–4 μm spectral range, which is difficult to reach with III-V edge-emitters and VCSELs. This region is rich in molecular absorption lines, and spectroscopy within this domain can expose small organic molecule contaminants within the atmosphere. In addition, the same materials that feature in these QCLs could be used to make ultra-fast optical switches for telecommunication networks if inter-subband transitions at 1.55 μm can be realized.

Why turn to II-VIs?

Stretching QCLs to these shorter wavelengths is far from easy, however. Emission is governed by the conduction-band offset between the pair of III-Vs employed in the device, and the commercial two-some of InGaAs and InAlAs, which are grown on InP, is limited to the 7–24 μm range.

This impasse has spurred the exploration of alternative materials, and our group at the City College of New York is going down this road. We've teamed up with Claire Gmachl's group at Princeton University and recently observed the first quantum cascade electroluminescence from a non-III-V semiconductor – a II-VI wide-bandgap material system that is based on ZnCdMgSe.

We are not the first QCL researchers to enjoy success below 4 μm . Antimonide-based lasers have stretched to 2.75 μm thanks to conduction-band



City College of New York researchers **Maria Tamargo**, **Aidong Shen** and **William Charles** are developing ZnCdMgSe materials for short-wavelength QCLs. Their MBE reactor features chambers for II-VI and III-V growth, which are coupled by ultra-high vacuum-transfer modules.

offsets of up to 2.1 eV. However, this material system cannot replicate the performance of longer-wavelength InGaAs/InAlAs QCLs, and it fails to deliver continuous-wave room-temperature emission. Inferiority stems from intervalley electron scattering, which reduces the effective size of the conduction-band offset.

Wide-bandgap II-VIs, and in particular the direct bandgap pair ZnCdSe and ZnCdMgSe, are promising materials for QCLs operating below 4 μm . The materials offer type-I band alignment, a broad band-gap range and a conduction-band offset that can hit 1.1 eV. The only trouble is that well developed, high-quality native bulk substrates do not exist.

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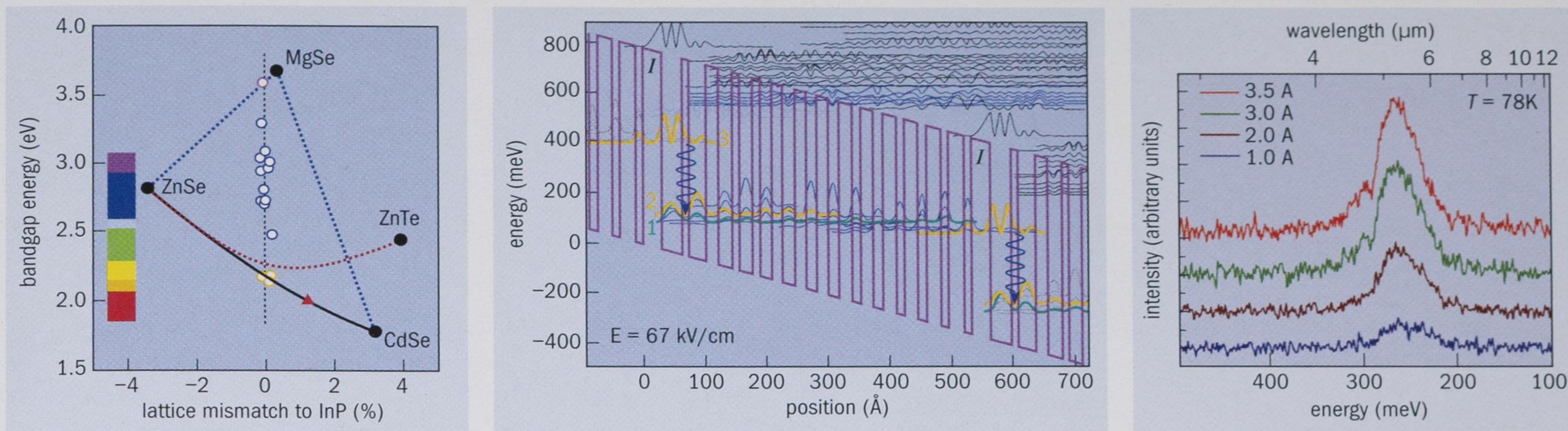


Fig. 1. (left) ZnCdMgSe can be grown lattice-matched to InP. The circles represent layers of different compositions grown in our laboratory. **Fig. 2.** (center) Simulations of the band structure of the quantum cascade emitter were carried out with a program that utilizes the envelope function approximation. The plots show the “modulus square” of the wave function within the active/injector regions (which equates to the probability of finding an electron at that position). This is calculated using electron effective masses for $\text{Zn}_{0.43}\text{Cd}_{0.57}\text{Se}$ and $\text{Zn}_{0.20}\text{Cd}_{0.19}\text{Mg}_{0.61}\text{Se}$ of $0.128m_0$ and $0.181m_0$, where m_0 is the free electron mass. “I” denotes the injection barrier at the start of one active/injector period. One period of the designed structure starting from the injection barrier is made up of the following layers in angstroms: **30/34/10/28/20/24/10/22/12/20/16/20/18/18/18/18/20/16/20/16/20/14/22/14/24/12/26/12**. The $\text{Zn}_{0.20}\text{Cd}_{0.19}\text{Mg}_{0.61}\text{Se}$ barrier is indicated in bold, the chlorine-doped layers are underlined and italics are used to denote the asymmetric coupled quantum-well layers that comprise the active region. **Fig. 3.** (right) The 0.036 mm^2 quantum-cascaded emitter, which has been attached to a heat sink held at 78 K, can produce electroluminescence at 1–3.5 A drive current. Emission was recorded by a Fourier transform infrared spectrometer in step scan mode that featured a cooled mercury cadmium telluride detector.

So we have turned to III-V substrates as a platform for II-VI growth. This is not a new idea, and in the 1990s GaAs was the popular choice for ZnSe-based structures, which were viewed as a promising material system for blue-green laser diodes. Success relied on getting this material combination to work well together, and demanded careful control of lattice mismatch and the chemical imbalance that is inherent in a heterovalent interface between a II-VI and a III-V compound.

But GaAs isn't the only III-V that provides a suitable platform for II-VI materials. In the late 1990s and early years of this decade we demonstrated that InP can be an ideal basis for the ZnCdMgSe family of compounds. Progress wasn't easy, however, and we had to invest a great deal of time in developing a process for a device-quality II-VI/InP interface.

We produce our material by MBE and our approach appears to deliver higher-quality material than that produced by other methods. Growth takes place in a solid-source MBE Riber 2300P system with two growth chambers. One is dedicated to III-Vs, the other to II-VIs, and ultra-high vacuum modules enable sample transfer.

Cleaning the surface

We strip away our substrate's oxide surface layer prior to growth by heating the InP platform in the III-V chamber under arsenic overpressure. This step is monitored by reflection high-energy electron diffraction (RHEED), which can pick up the switch from an arsenic-stabilized surface to one terminated by indium.

Once the surface is ready, we rapidly drop the substrate temperature by 30°C and deposit a lattice-matched $0.25\text{ }\mu\text{m}$ thick $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$ buffer layer. Growth proceeds at $1\text{ }\mu\text{m/h}$ in an arsenic-

rich atmosphere to create an atomically smooth III-V surface with group-V termination. This is ideal for initiation of the II-VI layer.

The wafer is then transferred under vacuum to the II-VI chamber, where its top surface is exposed to a zinc flux for a period of 40 s. This step, which is carried out at 200°C , suppresses In_2Se_3 and Ga_2Se_3 formation at the III-V/II-VI interface. These compounds can degrade material quality by forming defects such as stacking faults.

The wafer's temperature is maintained at 200°C , and a 9 nm thick $\text{Zn}_{0.43}\text{Cd}_{0.57}\text{Se}$ buffer layer is added to promote two-dimensional nucleation. This provides the basis for the growth of epitaxial material with a typical defect density of just 10^4 cm^{-2} , comparable to the best ZnSe-on-GaAs.

A selenium flux is then applied while the wafer is heated to 300°C . Growth of the II-VI structure then resumes, with ZnCdSe and ZnCdMgSe deposited at growth rates of 0.30 and $0.85\text{ }\mu\text{m/h}$, respectively. These layers are grown under selenium-stabilized conditions, which are maintained by ensuring that the selenium to group-II element flux ratio exceeds four. Accurate growth rates are calculated from RHEED intensity oscillation measurements, which can also confirm layer-by-layer growth.

We have refined our process conditions for the deposition of lattice-matched ZnCdSe and ZnCdMgSe layers and quantum wells through the growth of calibration samples (figure 1). Hall-effect measurements have determined the carrier concentrations in n-type layers that were doped with ZnCl_2 .

This work has enabled us to select lattice-matched $\text{Zn}_{0.20}\text{Cd}_{0.19}\text{Mg}_{0.61}\text{Se}$ barriers and $\text{Zn}_{0.43}\text{Cd}_{0.57}\text{Se}$ wells for the quantum cascade emitter structure. They have bandgaps of 2.08 and 3.03 eV , respectively, at 300 K , and produce a conduction-band offset of 0.78 eV .

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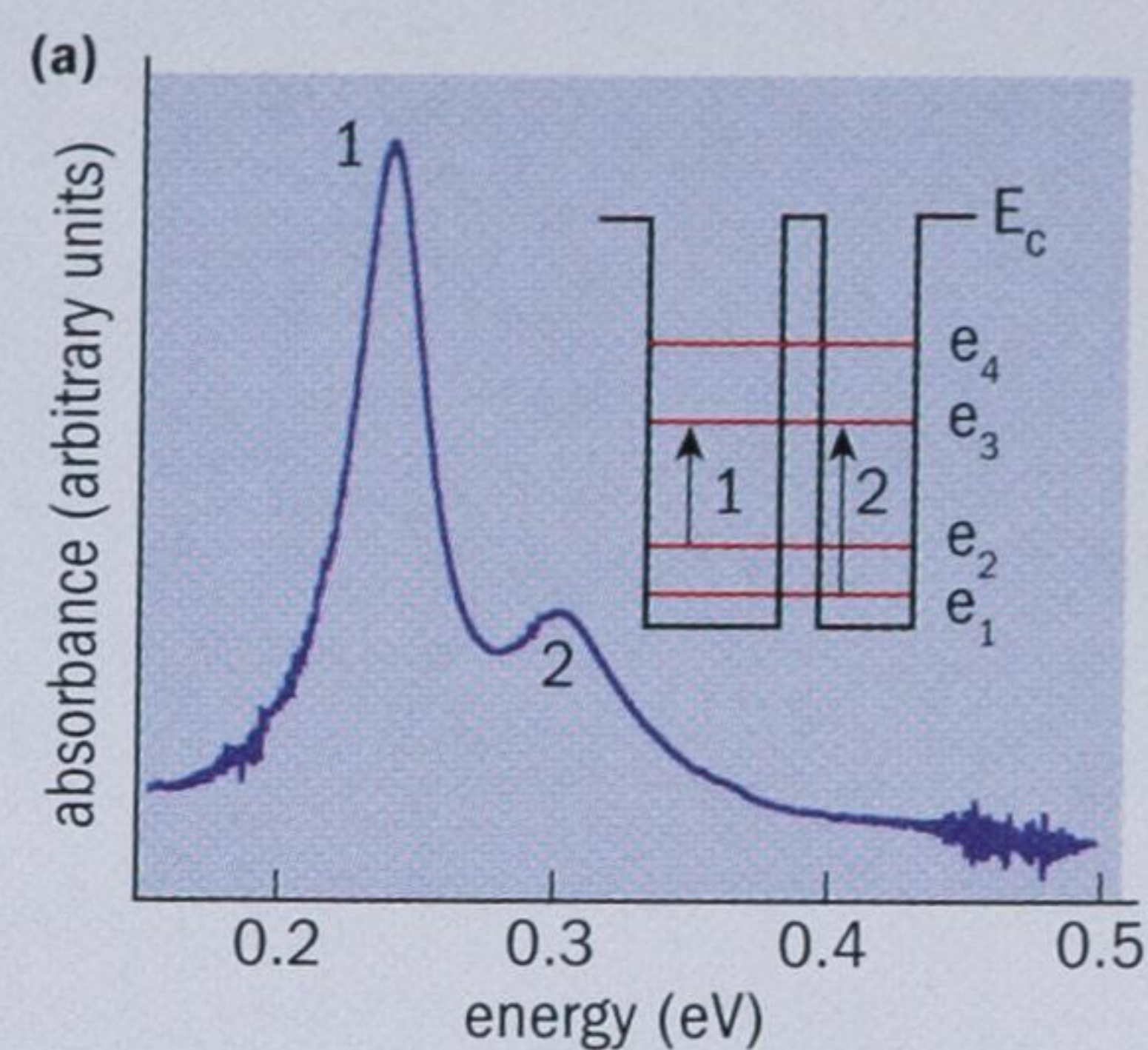
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Calibration structures for fine tuning

Maria Tamargo's group at the City College of New York fine-tuned the 500-layer quantum cascade emitter by first studying a simpler structure. This consisted of several repeats of the asymmetric coupled quantum well (ACQW), rather than the multilayered injector regions. Alternating ACQWs and quaternary barrier layers were repeated 25 times, and the wells doped with chlorine at a concentration of $4 \times 10^{18} \text{ cm}^{-3}$ in order to determine intersubband absorption peaks. These were located by Fourier transform IR (FTIR) spectroscopy measurements employing multipass transmission.

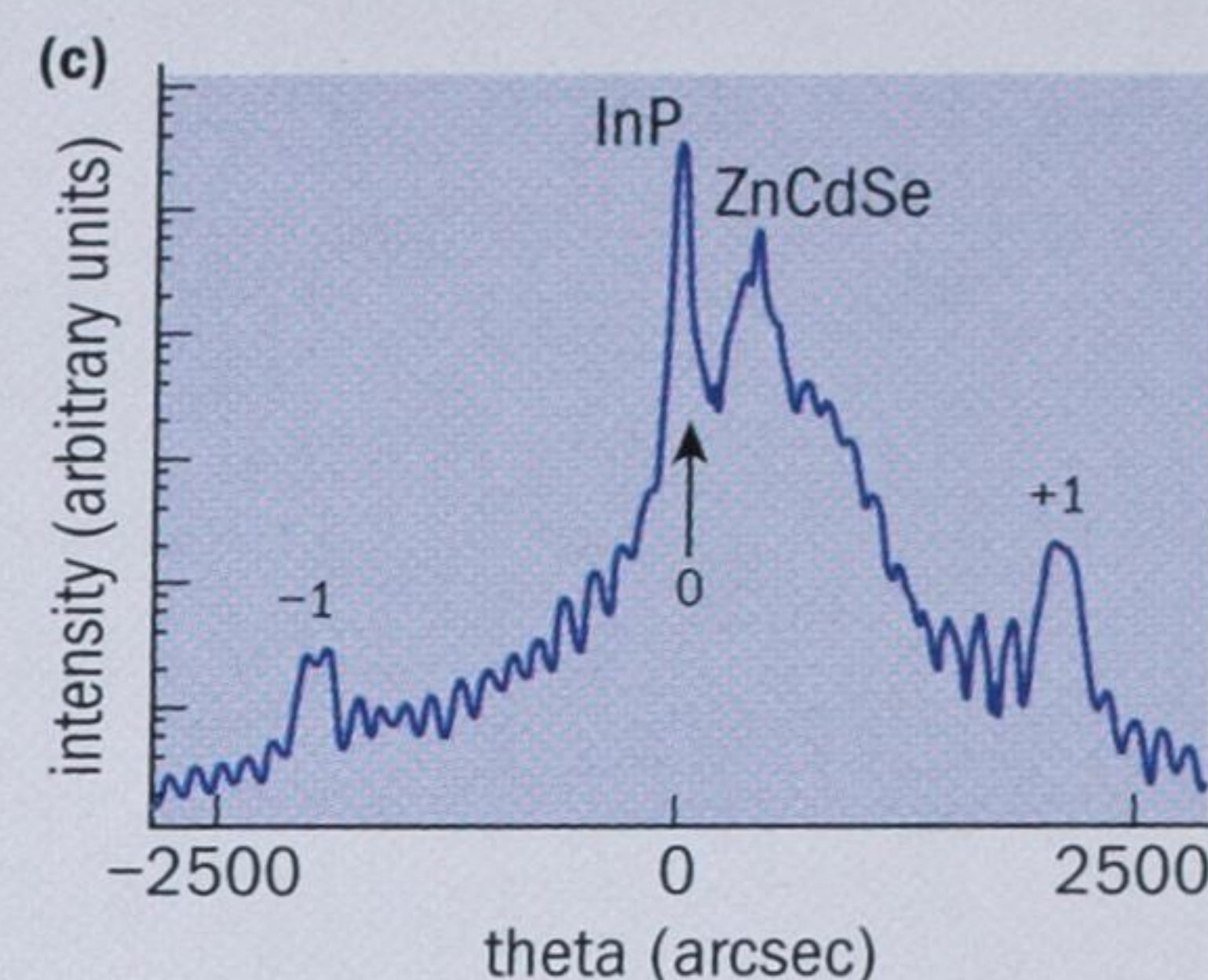
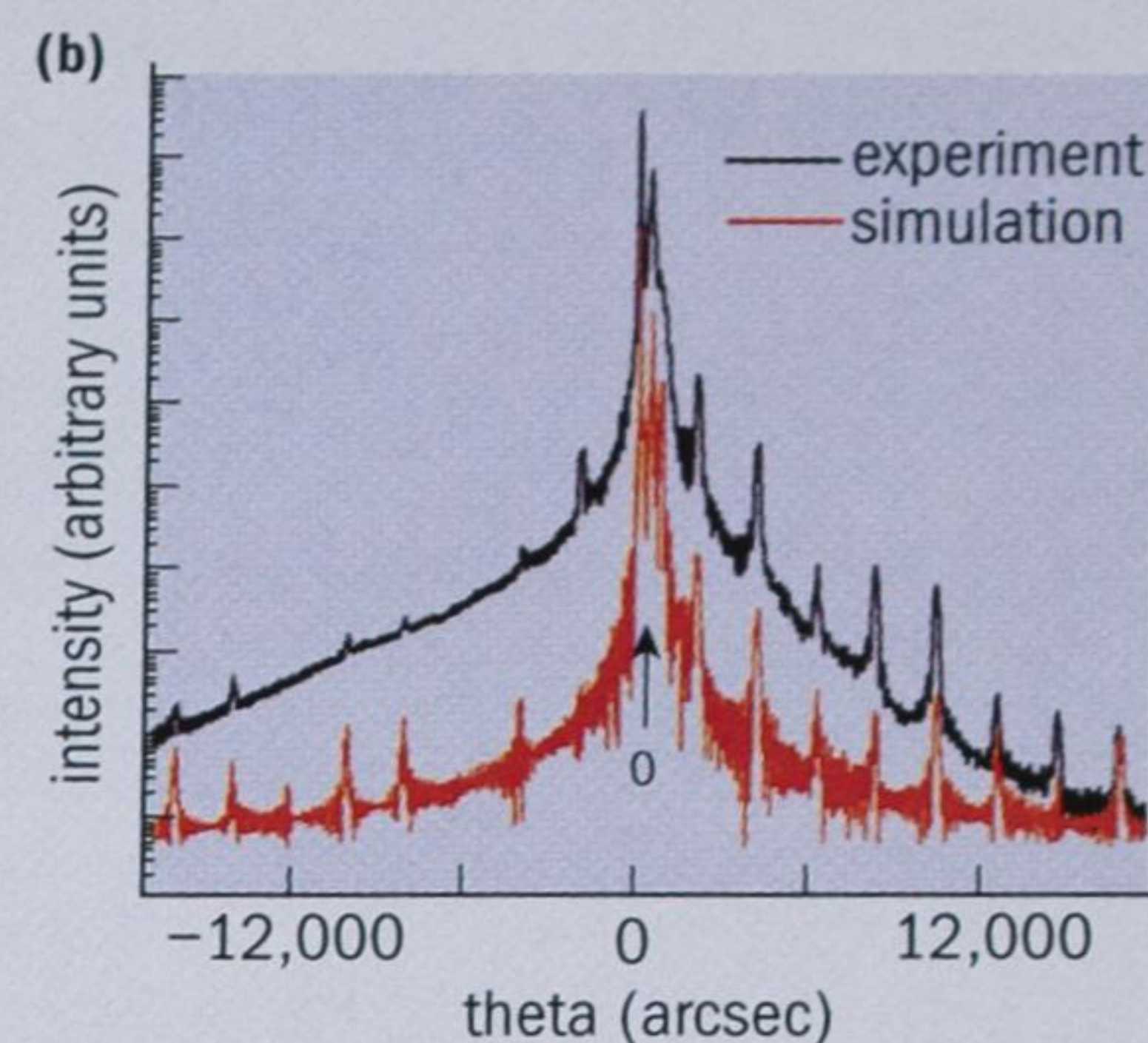
Room-temperature FTIR absorption spectra for the first ACQW structure showed absorption peaks at 0.240 and 0.301 eV, which the researchers assigned as the e_2 - e_3 and e_1 - e_3 transitions (figure a). These positions are close to those predicted by simulations that employ the envelope function approximation and calculate e_2 - e_3 and e_1 - e_3 absorption at 0.266 and 0.313 eV, respectively.

An e_2 - e_1 separation of 0.061 eV can be deduced from the two FTIR



peaks, which is not far off the calculated value of 0.047 eV. The difference probably results from a slightly thinner ACQW barrier than intended.

To make amends, the researchers produced a second ACQW structure with corrected thickness. Each period comprised a 110 Å barrier, a 34 Å chlorine-doped well, and 10 Å barrier and a 28 Å chlorine-doped well. High-resolution X-ray diffraction spectra of this sample indicate that the total thickness of each period is 176 Å, only a few percent off the 182 Å target (figures b and c). Multiple satellite peaks and clear interference fringes demonstrate the quality of the epitaxial layers.



Low-temperature (77 K) photoluminescence measurements were also carried out on this sample. They reveal a 34 meV linewidth and an absence of any deep levels, which confirms the high quality of the material and the well-barrier interfaces.

Mid-infrared emission

Having developed this deposition process, we then designed a quantum cascade emitter structure with 20–30 asymmetric coupled quantum-well active regions, which are sandwiched between multilayer injector regions (figure 2, p27). Each injector contains 14 $\text{Zn}_{0.43}\text{Cd}_{0.57}\text{Se}$ and $\text{Zn}_{0.20}\text{Cd}_{0.19}\text{Mg}_{0.61}\text{Se}$ layers that are several angstroms thick, which means that the device has more than 500 layers. This takes 6–8 hours to grow. To aid the fabrication of such a complex device, we have also produced a simpler structure that just contains several repeats of the asymmetric coupled quantum-well layers separated by simple quaternary barrier layers (see box “Calibration structures for fine tuning”).

These calibration structures have helped us to improve our growth process, and we employed these new conditions in a quantum cascade emitter structure. The devices were processed by photolithography, before contacts were added by electron-beam metal deposition. Electroluminescence at 4.8 μm was produced at 78 K – which isn't far away from the design target of 4.5 μm (figure 3, p27) – and persisted up to room temperature.

With proof-of-principle demonstrations behind

us, we are now focused on optimizing a structure that should ultimately deliver impressive device characteristics. We will be helped by the National Science Foundation-funded Engineering Research Center at Princeton, known as MIRTHER (Mid-Infrared Technologies for Health and the Environment). These collaborators are actively pursuing the optimization of the materials and device design, which should help us to meet our targets of sharper emission lines and lower turn-on voltages.

One of our primary goals is to design quantum cascade structures emitting below 4 μm . We believe that this is possible by increasing the barrier height in the QCL and then taking full advantage of the 1.12 eV conduction-band offset. Another option at our disposal is to turn to symmetrically strained heterostructures. Once we've hit our short-wavelength target of less than 4 μm , we will develop an effective waveguide design and finally build a QCL.

Further reading

KJ Franz *et al.* 2008 *Appl. Phys. Lett.* **92** 121105.
WO Charles *et al.* 2008 *J. Vac. Sci. Technol.* **B26** 1171.
J Devenson *et al.* 2007 *Appl. Phys. Lett.* **91** 251102.



About the author

Maria Tamargo is a professor at the City College of New York, and was previously a research scientist at Bellcore and at AT&T Bell Labs. Her principal focus has been on wide-bandgap II-VI material growth by MBE for photonic device applications. However, she is also interested in III-V nanostructures and II-VI/III-V hybrid materials.

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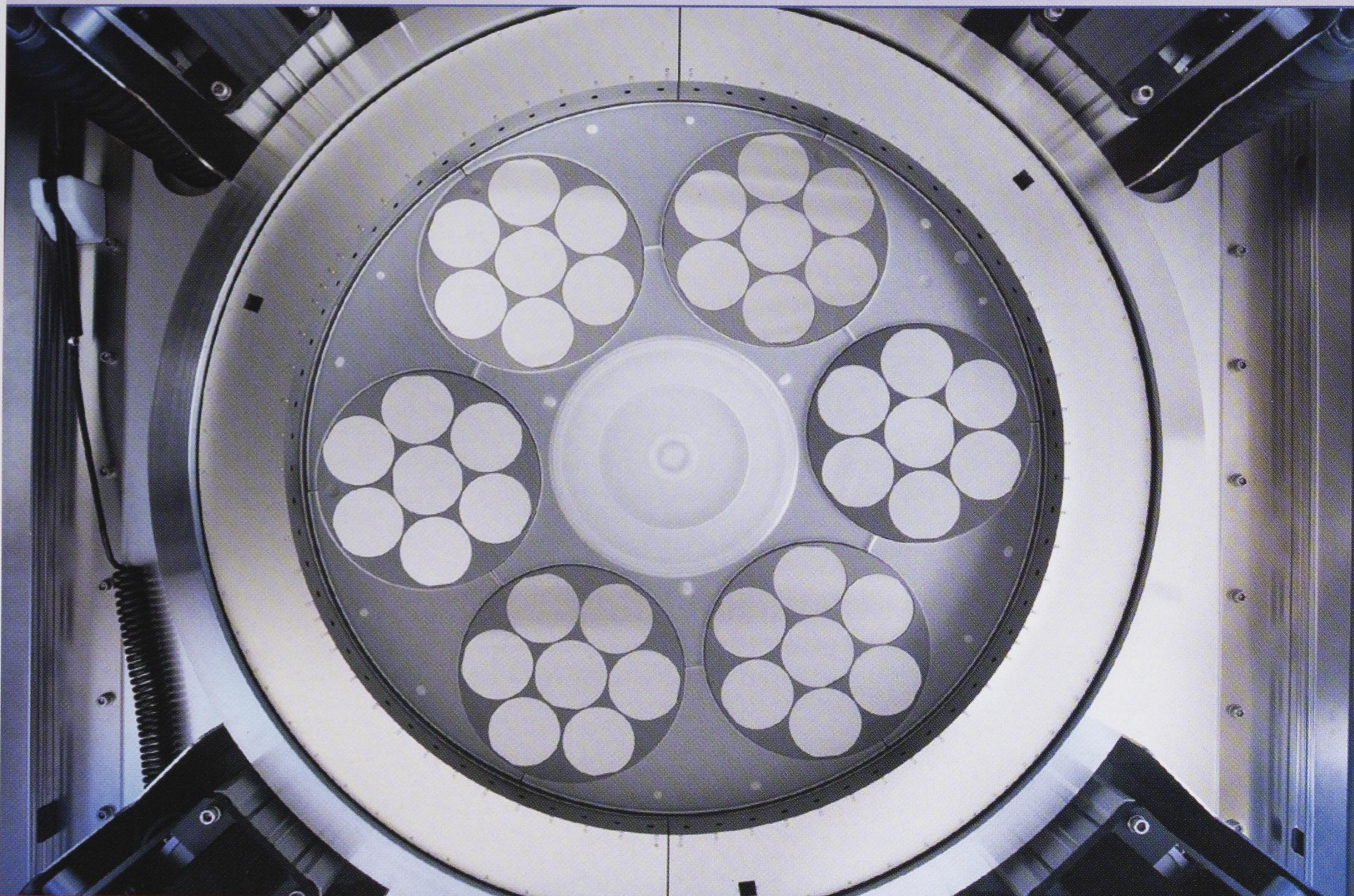
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Comprehensive simulations aim to cut SiC device development costs

Developing SiC devices via tests on a range of prototypes is an expensive business. Simulations can slash the costs, but success demands carefully accounting for the material's anisotropy and very low intrinsic carrier concentrations, say Synopsys' **Sudarshan Krishnamoorthy** and **Vidas Mickevicius**.

It's clear that many firms have recognized SiC's great potential for making power devices. Companies across the globe are now investing heavily in this material, with the goal of producing high-efficiency devices for applications such as DC to AC conversion in hybrid electric vehicles and high-voltage DC power transmission.

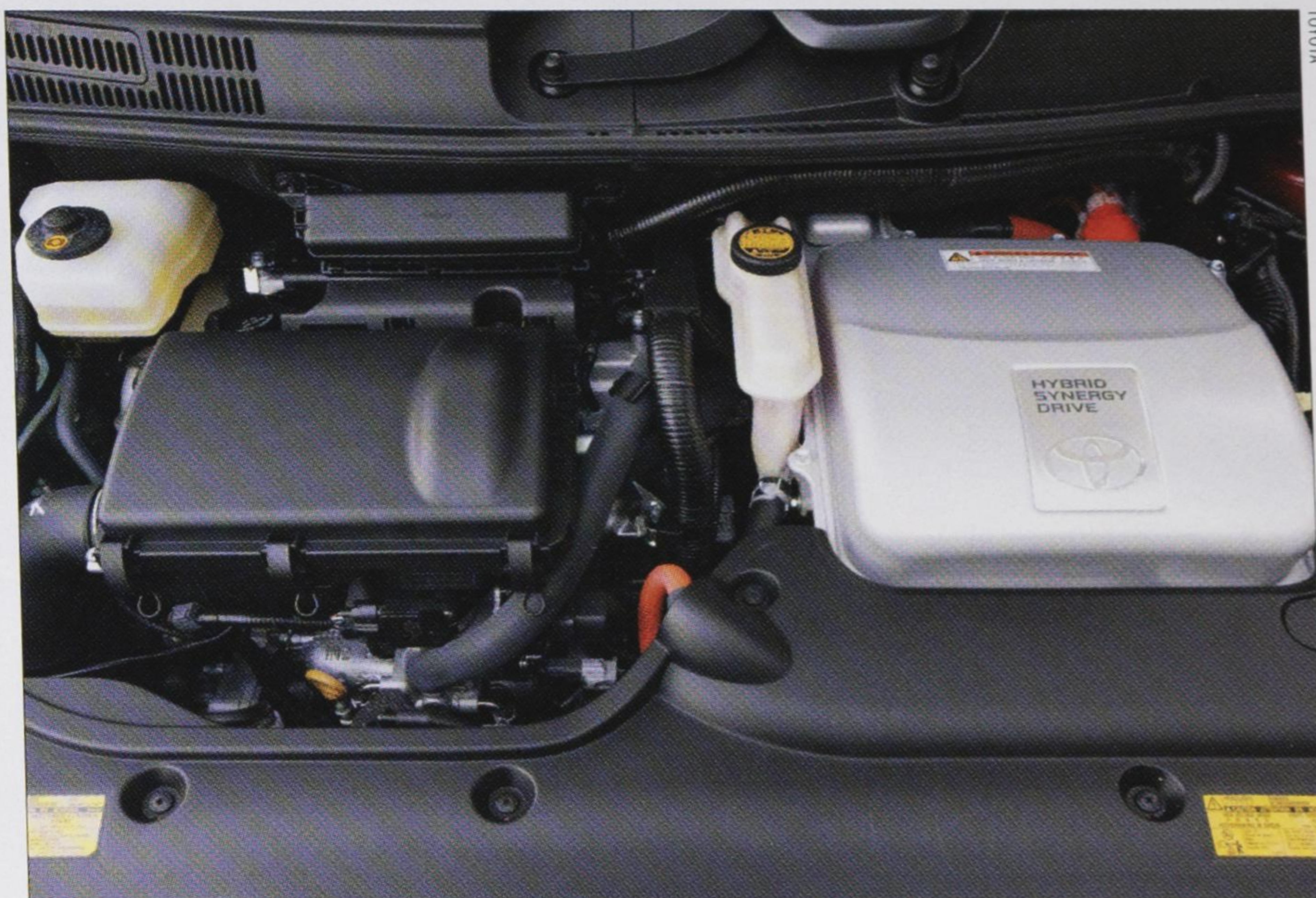
These efforts are expensive, but the rewards come in the form of electrical and thermal properties that significantly reduce costs at the system level. For example, SiC's high thermal conductivity can cut the cost of heat sinks employed for power dissipation.

Bringing many of these fledgling designs to market involves costly device optimization. Building and testing real SiC devices is particularly expensive because substrate costs are high. However, savings can be made by turning to simulations. And although software will never replace the growth and fabrication of real die, simulations can cut the number of experimental wafers needed to design and optimize a developmental device.

One of the most popular types of software tools is technology computer-aided design (TCAD) simulation programs. These employ physical models to provide key insights into device operation. Various technologies have been developed and optimized with this approach, ranging from highly scaled silicon CMOS structures to power devices, non-volatile memory and image sensors.

Device developers perform TCAD simulations by selecting structural details, like a material's layer thickness and doping profile, placing electrical and thermal boundaries, and setting device bias conditions. The program then calculates electrical characteristics, which are usually displayed as a set of graphs. This approach can help to tailor a structure to specific market applications that demand particular performance characteristics.

During the last five years there has been an increase in the application of TCAD to SiC development. This is because this type of simulation can provide key insights into internal device characteristics at different biases and temperatures. The effects of adjusting doping profiles, structural dimensions, the



Hybrid electric vehicles, such as the Toyota Prius, could benefit from SiC devices that can convert the DC source into AC power that drives the wheels. The wide-bandgap chips deliver higher efficiencies than silicon equivalents and have less stringent cooling demands.

contact's work function or the dielectric constant of a passivation layer can be assessed in just a few days. This might sound like a long time, but performing a similar study by experiment can take weeks or even months. TCAD can also help to locate the sweet spot of optimum yield through tools that create "response surface models" by correlating multiple input variables to output electrical characteristics.

Modeling the behavior of SiC devices is not trivial – it demands care. Unique technical issues arise from the material's anisotropy, as well as its incredibly low intrinsic carrier concentrations, which result from SiC's wide bandgap. The anisotropy stems from SiC's hexagonal structure, and calculations must account for directional variations in properties such as carrier mobility, thermal conductivity, electrical permittivity and impact ionization.

At Synopsys – which is headquartered in Mountain View, CA – we have refined our TCAD device

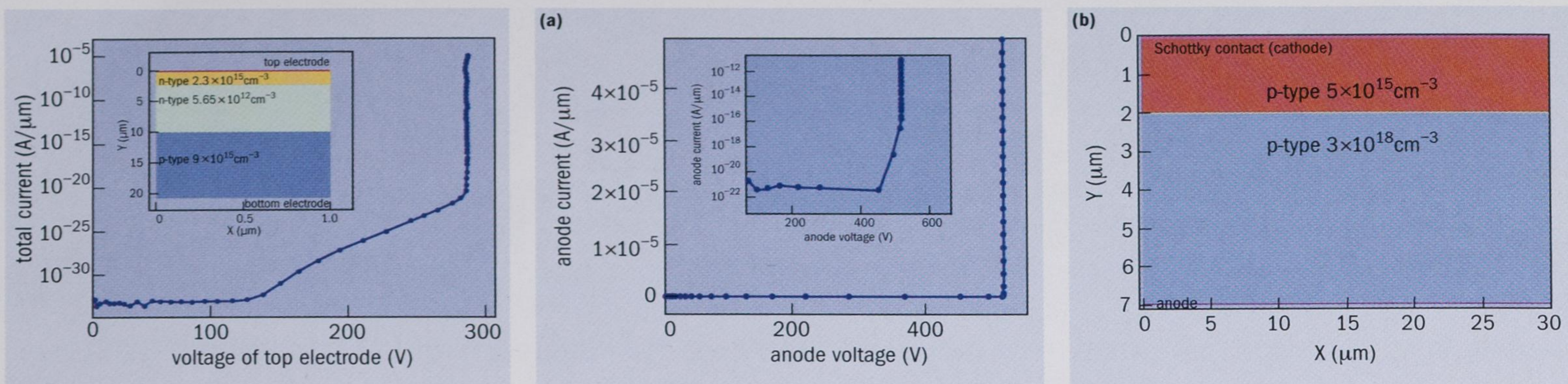


Fig. 1. (left) The extremely low currents that flow in reverse-biased PiN diodes below breakdown are very tricky to model. However, these results with Synopsys' Sentaurus Device show that realistic simulations are possible by taking good care of the very low numbers. **Fig. 2.** (center and right) Modeling of a 4H-SiC Schottky barrier diode, built by Jayant Baliga's group at North Carolina State University, has helped to calibrate the impact ionization coefficients used by Synopsys' software.

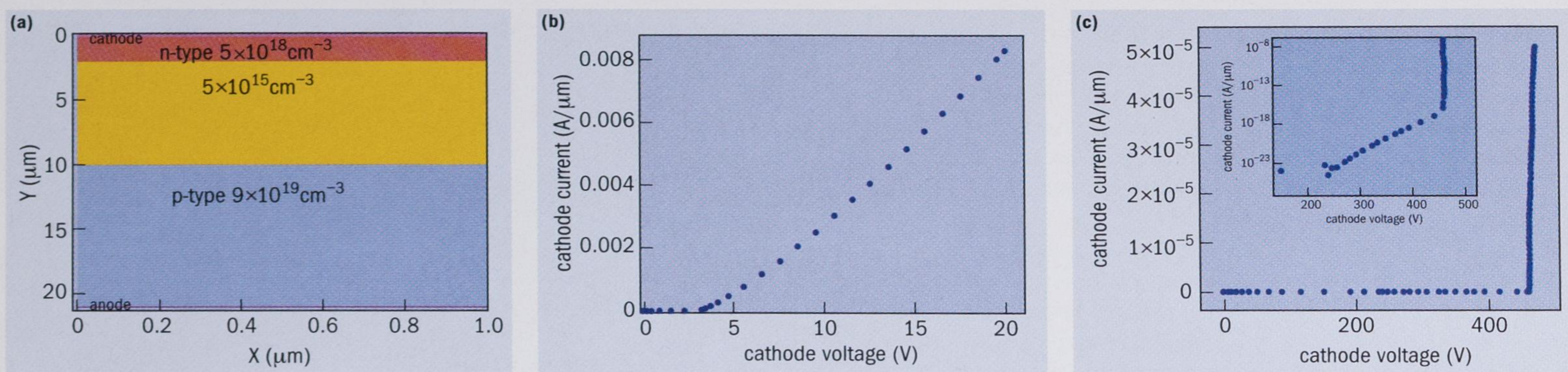


Fig. 3. Anisotropy in 4H-SiC leads to variations in impact ionization coefficient. Coefficients along different directions have been obtained from simulations of a 4H-SiC PiN diode that was experimentally studied at Toshiba's corporate R&D center and the National Institute of Advanced Industrial Science and Technology, Japan.

simulator, Sentaurus Device, so that it is capable of dealing with the complexities of SiC device modeling. This package is suitable for modeling SiC Schottky barrier diodes that have been commercially available for some years. It can also aid research into other devices like vertical-junction FETs and MOSFETs for high-frequency, high-power applications. The latter devices are more complex and offer more options for device optimization. This means that it takes more time and effort to maximize device performance, which allows simulations to play a larger role in reducing development times and costs.

We believe that any SiC device simulator must have three key attributes. It must include a comprehensive set of physical models to describe carrier behavior inside the material; it must employ robust numerical algorithms to solve coupled non-linear differential equations; and a physically reasonable set of model parameters is essential.

Sentaurus Device meets all of these criteria and uses a comprehensive set of physical models to describe carrier transport, generation and recombination in response to variations in electrical bias and thermal conditions. Predictions for direct-current characteristics, time transients and small-signal characteristics can be calculated from these simulations.

Our SiC device simulator can also account for the material's polytype. This has a massive impact on the bandgap, which ranges from 2.39 eV for 3C-SiC, to

3.33 eV for 2H-SiC. For power devices, 4H-SiC is the most popular. This has a bandgap of 3.27 eV.

Crunching numbers with care

The wide bandgap has a profound influence on carrier concentration, which is typically of the order of 10^{-10} carriers per cubic centimeter. Handling these very low carrier concentrations can be numerically challenging. The robustness of current-voltage curve simulations hinges on the level of precision used to store and process these ultra-low numbers, which feature in coupled non-linear equations in a floating-point arithmetic operation.

We have made significant strides in accounting for such low carrier concentrations during the last year. The low carrier concentrations seen in SiC can now be catered for with "extended precision", which enjoys many more bits to store floating point numbers than regular simulations performed on Linux and Sun workstations. This enables us to capture the extremely low currents during a typical breakdown simulation and observe the breakdown characteristics of a 4H-SiC PiN diode (figure 1). Anisotropy of 4H-SiC was accounted for in these calculations.

Our tool's ability to capture very low currents is rarely matched by other simulators. Rivals can't cope with such low currents because excessive noise in the numerical simulation causes them to crash.

The easy way out is to resort to non-physical

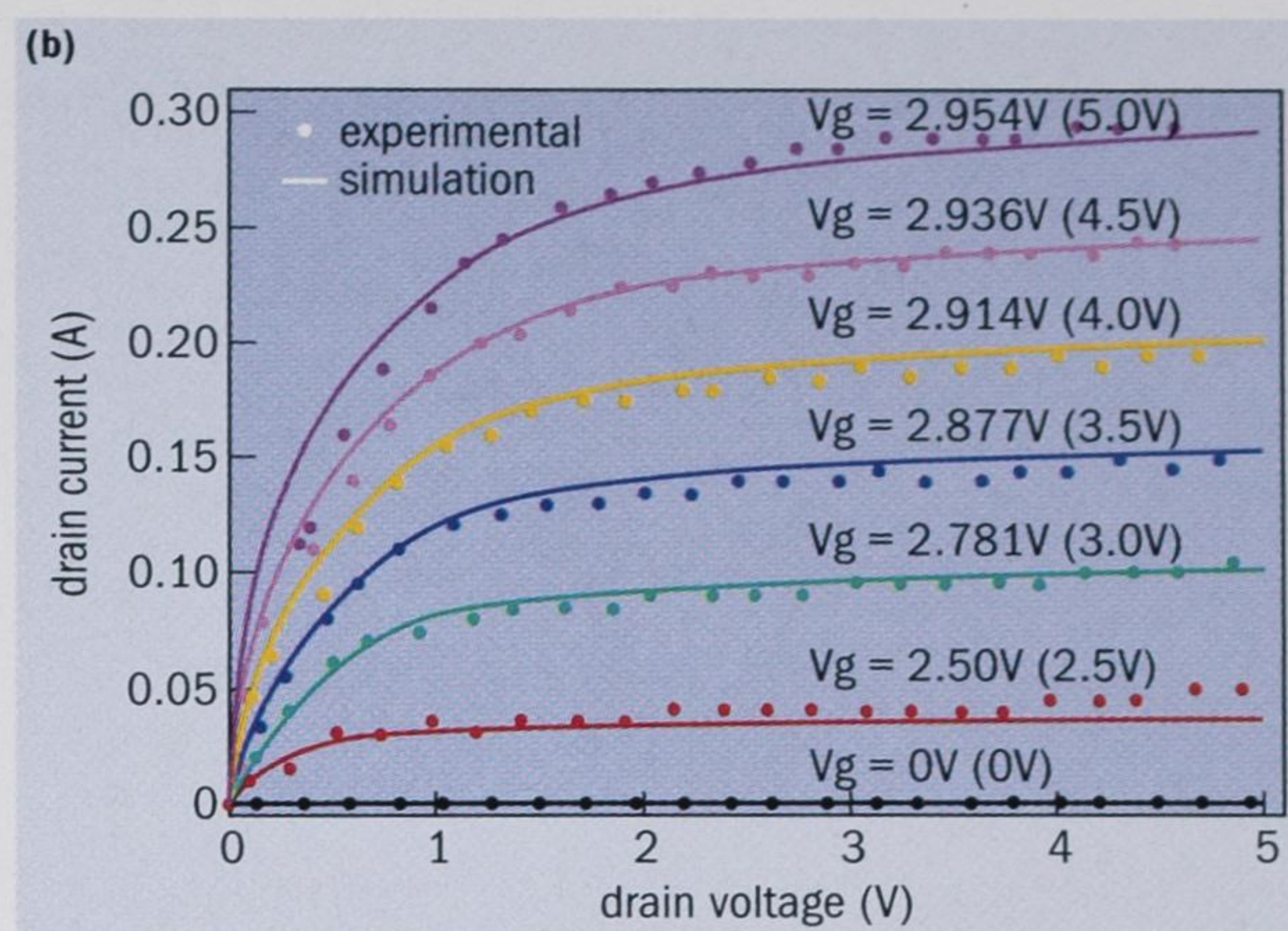
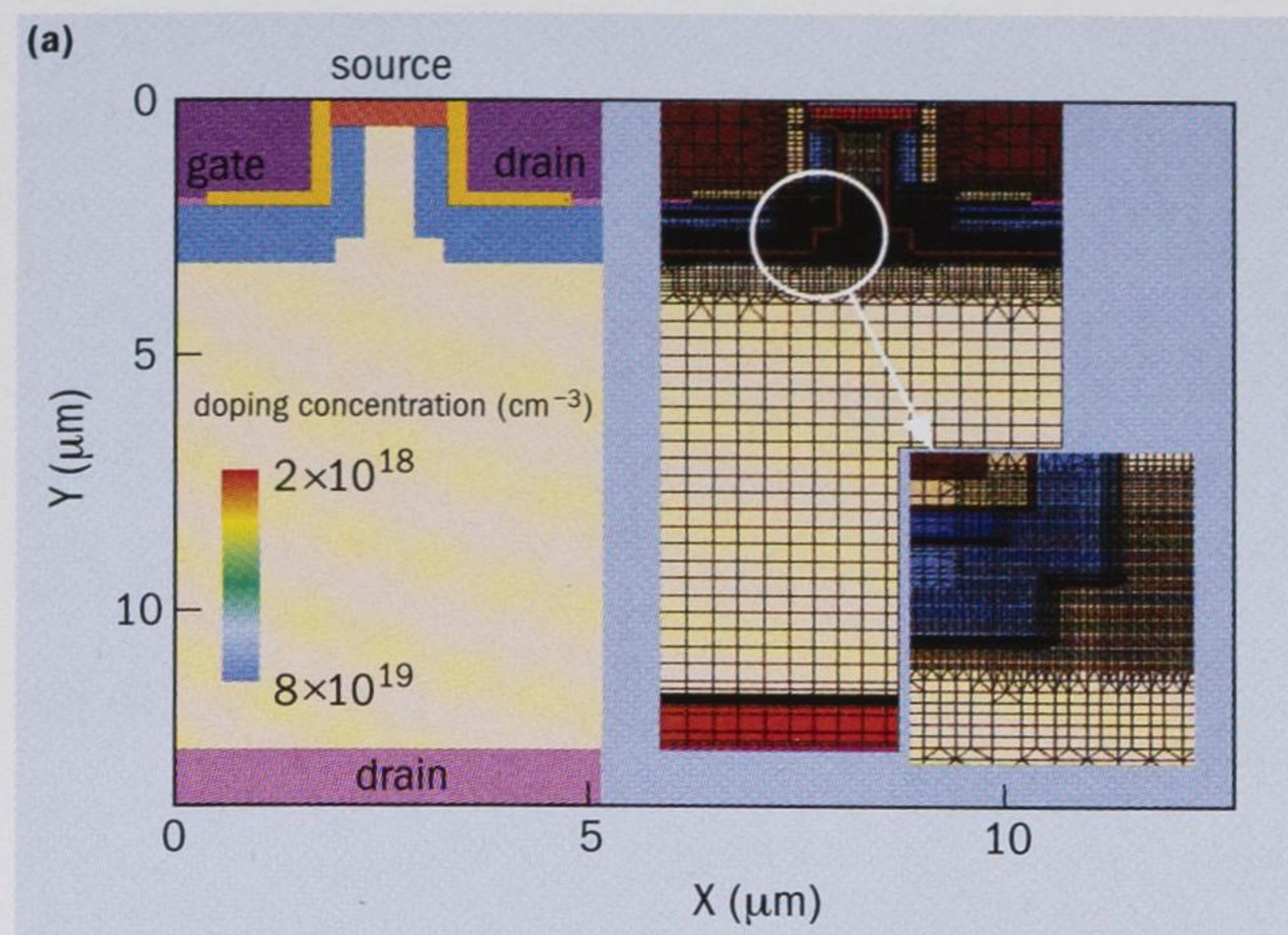
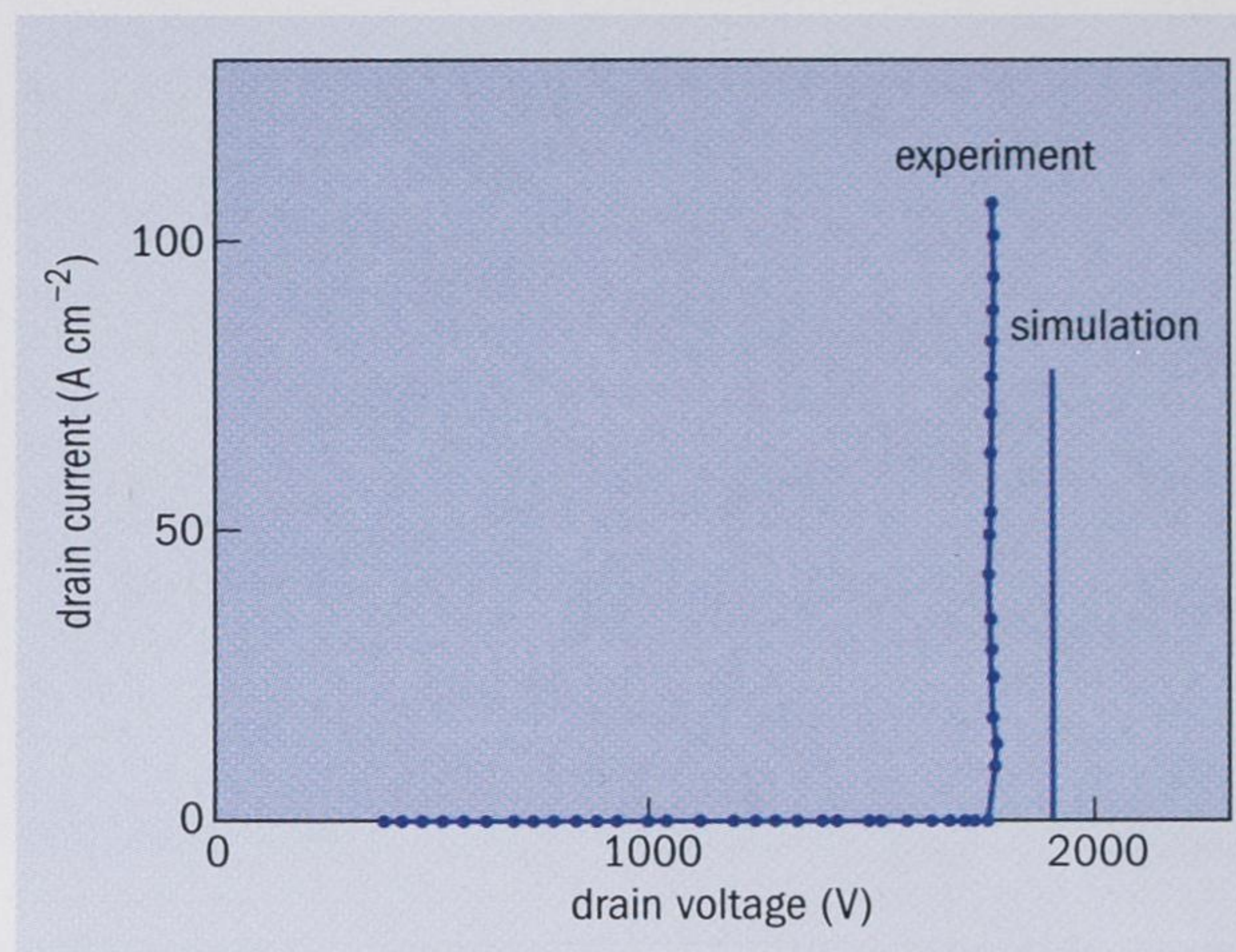


Fig. 4. (top) Simulations of 4H-SiC vertical-junction FETs, which were made at Rutgers University, have helped Synopsys to calibrate carrier mobilities in the $\langle 1\bar{1}20 \rangle$ direction. The plot of drain current against drain voltage contains two values for the gate voltage. The first number is the inner voltage and the bracketed number includes the effects of gate contact resistance. **Fig. 5.** (bottom) The breakdown of Rutgers University's device is 1726 V, which is close to the simulated value of 1900 V. An exact match may require three-dimensional simulations, which were outside the scope of the current study.



methods, like increasing the temperature for device simulation. This increases the currents and allows the simulations to converge, but means that this technique cannot be used for temperature-dependent studies. This is a major problem for high-power SiC devices – they operate at high temperatures and it is important to capture how the material characteristics change with temperature.

Basic material data requirements

Predictions of SiC device performance are reliant on the input of accurate values for the material's characteristics, such as bandgap, mobility, carrier lifetime and impact ionization coefficient. Anisotropy adds to the complexity, but we have addressed all of these concerns with a calibration process that matches simulation results with experimental ones.

Three technical papers have been used as sources of experimental data for these calculations. A variety of device types have been selected – Schottky barrier diodes, PiN diodes and vertical-junction FETs – and the focus has been on obtaining accurate values for the anisotropic carrier mobility and impact ionization coefficients in 4H-SiC. Using more than one device's experimental data is essential, otherwise this would merely be an exercise in curve fitting.

The first paper was a study on the temperature dependence of hole impact ionization coefficients in 4H and 6H-SiC by Jayant Baliga's group at North Carolina State University (figure 2). We calibrated impact ionization coefficients by simulating the Schottky barrier diode that Baliga's team measured. This diode has a Schottky contact for an anode, with a specified work function of 4.5 eV. The breakdown voltage of 520 V from the simulation matched the experimental value for this device.

We also simulated a PiN diode fabricated by Tetsuo Hatakeyama and colleagues from Toshiba's corporate research and development center in Kanagawa, Japan (figure 3). This paper focused on the anisotropic nature of impact ionization coefficients in SiC. Our simulations contain physical models that account for doping and electric field-dependent anisotropic mobility, doping and temperature-dependent Shockley Reed-Hall recombination,

Auger recombination and band-to-band tunneling. We also include an anisotropic Chynoweth model for impact ionization, and models for incomplete ionization and bandgap narrowing.

The third device that we have studied is a vertical-junction FET built by Jian Zhao's team at Rutgers University, NJ (figures 4 and 5). We decided to model this device because its crystallographic orientation is ideal for calibrating mobility values parallel to the crystal axis.

Calibrations with these three types of device have enabled us to determine values for impact ionization and electron and hole mobility along SiC's $\langle 0001 \rangle$ and $\langle 1\bar{1}20 \rangle$ directions. Armed with the right models and these material values, Sentaurus Device can provide valuable support for the development of SiC devices. We can't guarantee 100% accuracy for every device because SiC's characteristics can depend on many factors, including the fabrication process. However, simulations with our software can provide a starting point and can cut project costs by reducing the number of wafers that are grown on substrates during SiC device development.

Further reading

J Baliga *et al.* 1999 *Solid State Electronics* **43-02** 199.
T Hatakeyama *et al.* 2005 *SISPAD* **01-03** 171.
JH Zhao *et al.* 2003 *IEEE* **14-17** 1.



About the authors

Sudarshan Krishnamoorthy (left) is a TCAD technical marketing manager at Synopsys and previously worked as an applications engineer on semiconductor device simulations. **Vidas Mickevicius** (right) is director of corporate applications engineering at Synopsys. He has more than 20 years of semiconductor experience.

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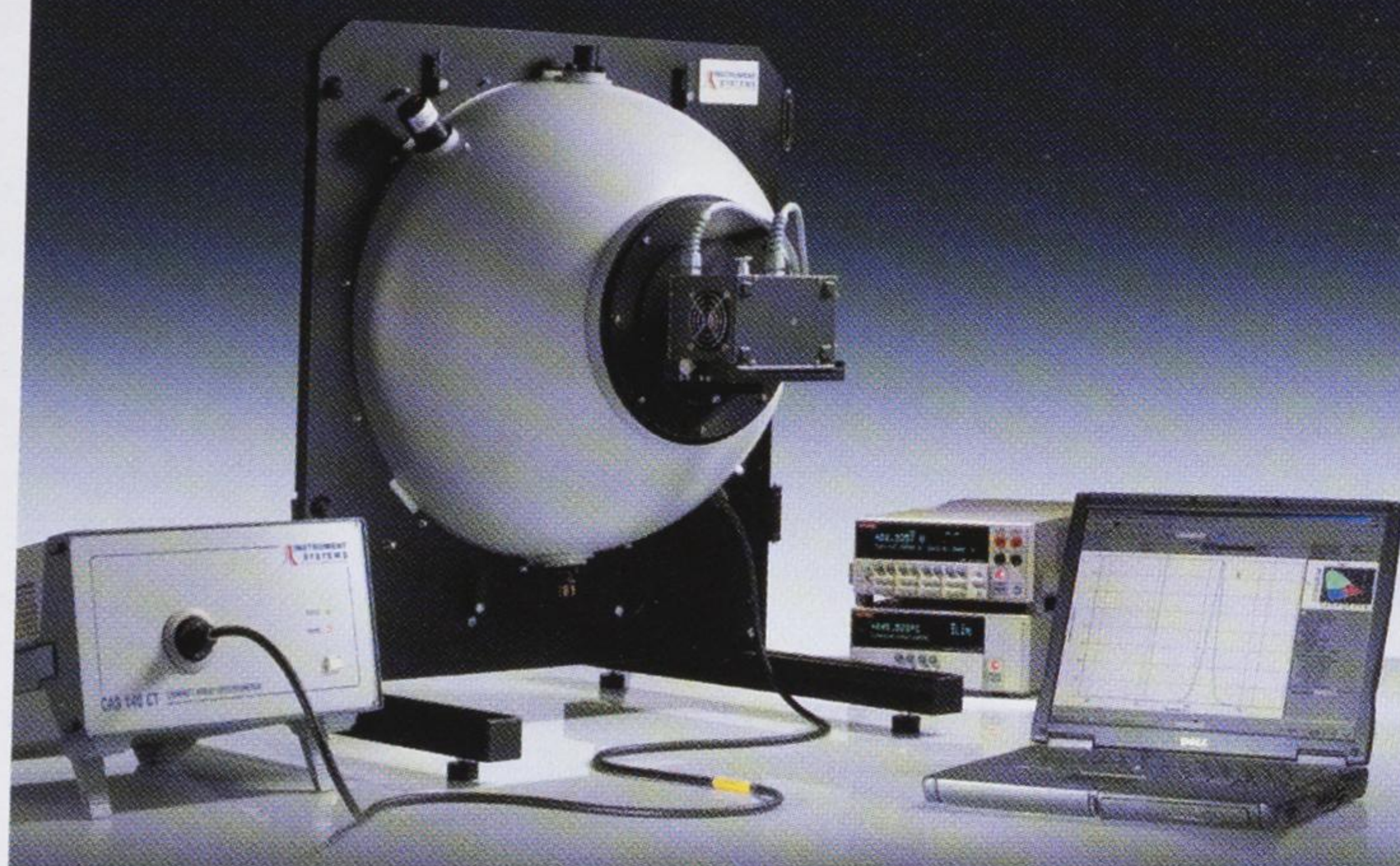
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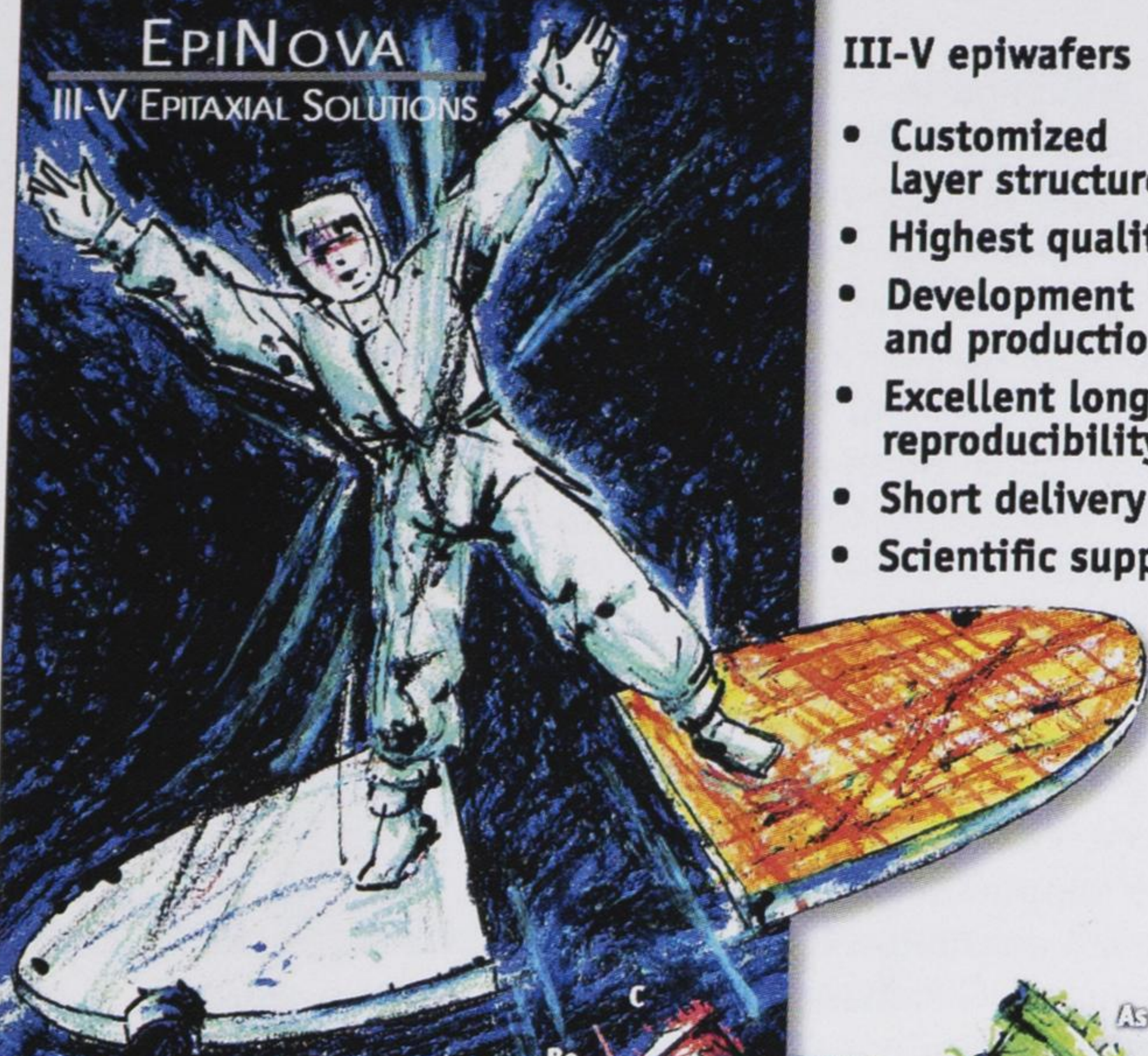
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B10 ☐ Fabless chip supplier/developer
B9 ☐ Other (please specify) _____

4. What semiconductor materials/processes are used/developed at the place where you work? (tick all that apply)

- C1 ☐ III-Vs: arsenides
C2 ☐ III-Vs: phosphides
C3 ☐ III-Vs: nitrides
C4 ☐ III-Vs: antimonides
C5 ☐ II-VIs
C6 ☐ SiC
C7 ☐ SiGe, SOI, epitaxial oxides, other silicon heterostructures
C8 ☐ Other (please specify) _____

5. What types of semiconductor device are manufactured or developed at the place where you work? (tick all that apply)

- D1 ☐ GaAs ICs or discretes
D2 ☐ InP ICs or discretes
D3 ☐ Wide bandgap ICs or discretes
D4 ☐ Devices employing SiGe, SOI or other silicon heterostructures
D5 ☐ Telecom laser diodes
D6 ☐ Non-telecom laser diodes
D7 ☐ VCSELs
D8 ☐ LEDs
D9 ☐ Solar cells
D10 ☐ Detectors
D12 ☐ GaN laser diodes
D14 ☐ Power semiconductor devices
D11 ☐ Other (please specify) _____

6. Please tick other relevant publications you receive/read. (tick all that apply)

- E2 ☐ Semiconductor International
E3 ☐ Solid State Technology
E4 ☐ Laser Focus World
E5 ☐ Photonics Spectra
E7 ☐ EuroAsia Semiconductor
E8 ☐ Semiconductor Today
E6 ☐ Other (please specify) _____

7. How many employees are there at your site? (tick one box only)

- F1 ☐ 0-19
F2 ☐ 20-49
F3 ☐ 50-99
F4 ☐ 100-499
F5 ☐ 500-999
F6 ☐ More than 1000

8. Apart from you, how many people in your place of work are likely to read your copy of Compound Semiconductor? (tick one box only)

- G10 ☐ 0
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MBE

Veeco unites incompatible materials

Veeco's GEN10 features automation and the capability to grow incompatible materials, such as nitrides and oxides.

Richard Stevenson quizzes the company's MBE product manager, **Andy Harkison**, about the merits of the new tool.



The Veeco GEN10 is a flexible system that can feature up to three separate growth modules. This enables simultaneous MBE development by researchers working on different materials.

Why have you launched a tool for growing incompatible materials?

In the R&D environment we're seeing people doing research on oxides and nitrides, as well as the traditional III-Vs. The GEN10 is configurable around a cluster tool. You can add up to three growth modules, each for different material sets. You can transfer between these to grow one layer in one chamber and then move to another chamber to grow another layer.

You can also have two researchers working on different projects that may include different materials. A lot of people already do that manually, by connecting systems with a long transfer tube. We are automating it to remove the variability of transfer.

How does the GEN10 fit with Veeco's products?

This is an R&D-sized system specifically for that purpose, with a process that is scalable to production-type systems. You can do a 1, 2 or 3 inch wafer.

Who is the new reactor aimed at?

It's going to be aimed at university labs and corporate R&D customers. We are seeing interest in migrating to production-worthy processes from universities and corporate researchers.

How does automated wafer transfer work?

You load wafers into the load-lock. The cluster tool takes them and moves them to the growth module. If you are using incompatible materials, or you want to start a recipe in a different growth module, you can move the wafer into a second or third growth module and run those recipes in an automated fashion.

The key benefit is that it gives you time to focus on the science of MBE. So if you're running a calibration wafer, rather than starting it in the morning and being ready in the afternoon, you could have it automated so that you could start up at night and be ready [to go when you get into the lab].

Are the cluster tools reliable?

We've got a good track record with our production environment where cluster tools run all of the time, moving a number of wafer plates. Cluster tools prevent problems. If you're doing manual transfers you could drop a wafer.

How much does the tool cost to run?

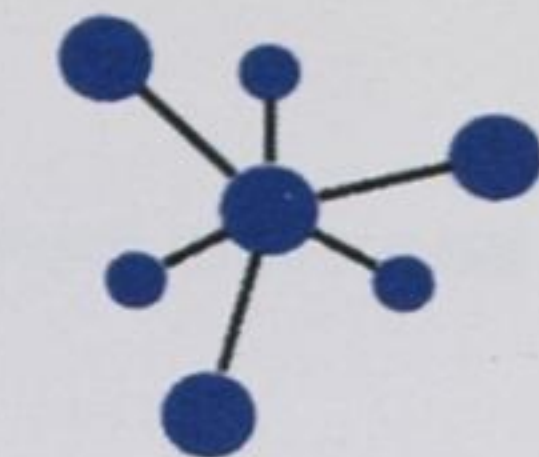
A Veeco automated GEN10 with single growth module is comparable to a 3 inch manual system for research and development. The cost benefits come as you add growth modules. Rather than buying a second MBE system, you buy a new growth module and add it on. So you're capitalizing on some existing infrastructure. That's where the cost savings come in.

What kind of support do customers get?

We have a service person who goes on site to assist in set up and check-out. We work closely with our customers on facility requirements, so that it's all lined up. And we can offer on-site training to help.

You released the GEN10 in August at the International Conference on MBE. Did it attract much interest from delegates?

We met a number of university and corporate customers and they received it very well. Budgets are tight and that's always difficult, but it was well received from the point of view of automation. Researchers need more throughput of research papers, so most appreciated the automated idea and what it meant for being productive with their research.



GaN HEMTs

V-shaped gate boosts X-band power

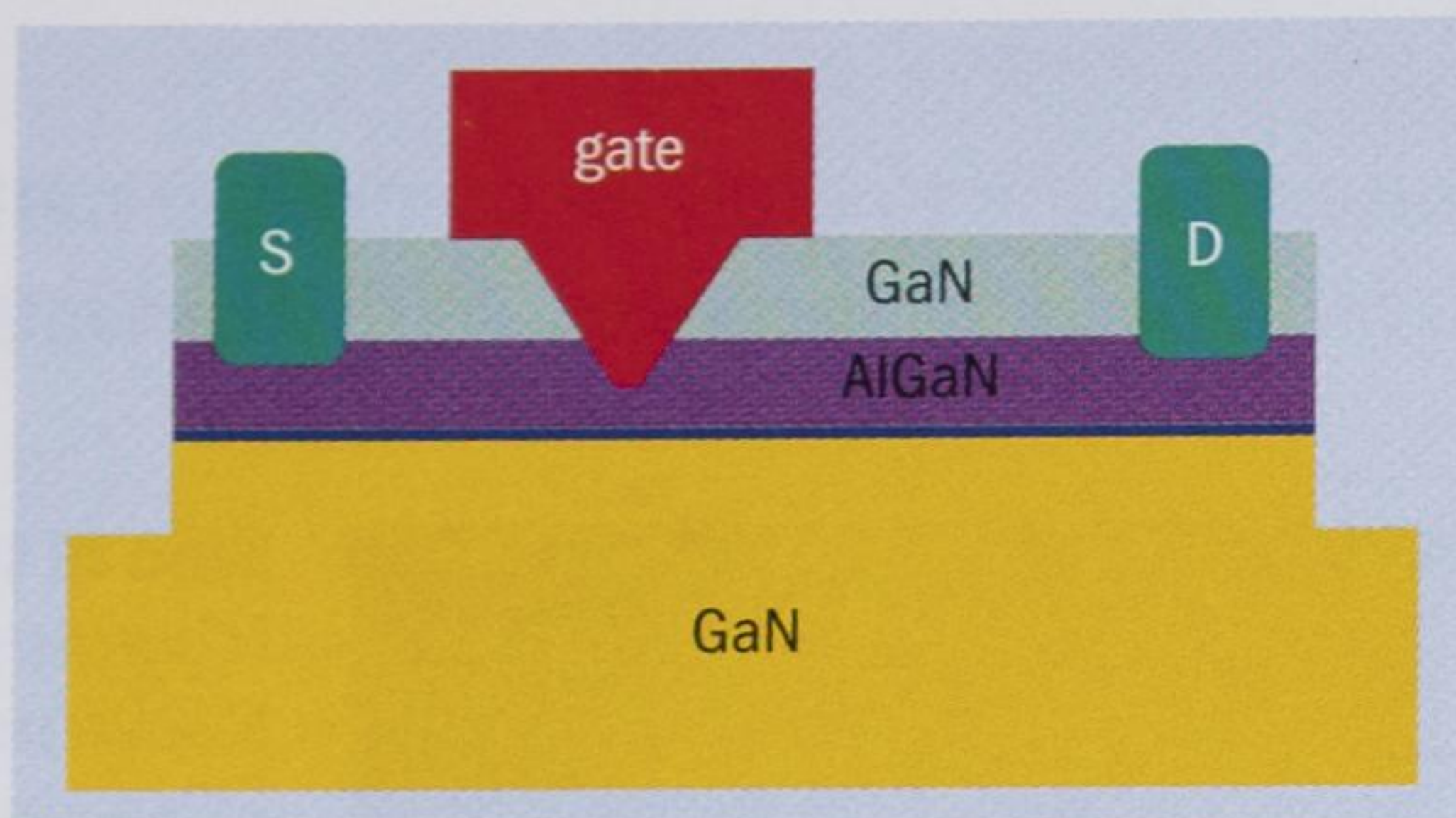
Researchers at the University of California, Santa Barbara (UCSB), have broken the power-added efficiency (PAE) record for an X-band GaN HEMT with a design featuring V-shaped gates.

GaN transistors emitting in this frequency range were previously restricted to a PAE of less than 60% at a drain bias of 48 V or more. But the new V-gate HEMT can hit 65% PAE at 48 V drain bias and deliver 12.2 W/mm.

The V-shaped gate's role is to cut field crowding at the gate edge. This enables sufficient power gain for high-power operation at higher voltages.

Adding field plates – the trick that has paid dividends with L- and W-band transistors operating at lower frequencies – is not an option for X-band HEMTs. This is because it would have increased capacitance and hampered transistor efficiency.

The epitaxial structure of the HEMT was produced by MOCVD on SiC. It comprised a GaN buffer, a 0.6 nm AlN interlayer, a 35 nm



A V-shaped gate holds the key to high power-added efficiency. This is created by removing 80% of the GaN cap layer with a lower-power plasma etch in a mixture of BCl_3 and Cl_2 , which can control the slope of the etched sidewall. Additional etching with BCl_3 and SF_6 ensures that this process stops at the GaN/AlGaIn interface, before further etching with the first gases reduces gate-to-channel separation to 15 nm.

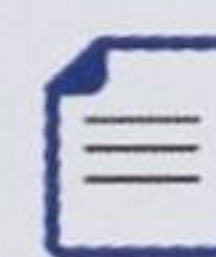
$\text{Al}_{0.22}\text{Ga}_{0.78}\text{N}$ barrier and a 250 nm GaN cap. Subsequent plasma etching created the mesa and the V-shaped gate recess (see figure).

Rongming Chu from UCSB says that it will

be tough to deliver further improvements in HEMT performance. “Our V-gate approach has successfully removed the DC-RF dispersion. The key to an even higher PAE is to further improve the power gain.”

He believes that this could be realized through a reduction in the gate sidewall capacitance on the source side. Turning to an asymmetric gate could reduce this capacitance, while maintaining the existing slope on the drain side that is essential for high-power, dispersion-free operation.

Another option is to shrink the gate length. “Right now the length of the gate footprint cannot be too small, otherwise there will be significant short-channel effects, especially under large drain bias,” explained Chu. However, he says that this could be mitigated with an AlGaIn buffer.



Journal reference

R Chu et al. 2008 *IEEE Electron Dev. Lett.* **29** 974.

MATERIALS

Indium oxide reveals secret surface charge

The widely held belief that In_2O_3 has no carriers close to its surface is wrong, according to efforts from a UK-based partnership.

These revelations result from experiments by Chris McConville's group at Warwick University, which has shown that In_2O_3 can sustain a large electronic charge on the surface of very-high-quality material grown at Oxford University. The samples have a low enough background electron density to expose electron accumulation at the surface.

The generation of terahertz radiation could benefit from electron accumulation in In_2O_3 , according to Warwick University's Tim Veal. Strong fields caused by the surface charges can increase the intensity of terahertz radiation that is emitted from optically excited In_2O_3 .

“InAs and InN, the other semiconductors shown to have electron accumulation as an intrinsic property, are among the best materials for terahertz emission,” said Veal.

In_2O_3 may also be suitable for chemical and biological sensing, thanks to its high surface charge, which encourages “chemisorption” of electronegative molecules, such as ozone and nitrous oxides. These molecules

could be detected through changes in the transparent oxide's conductivity.

The improvements to In_2O_3 quality that allowed the surface's charge to be observed resulted from a switch from sputter deposition to oxygen plasma-assisted MBE.

“MBE is not radical for people from a semiconductor background, but it is relatively radical for metal oxides, such as In_2O_3 and SnO_2 ,” explained Veal, who hopes that this work could spur the development of high-quality, epitaxially grown metal oxides.



Journal reference

P King et al. 2008 *Phys. Rev. Lett.* **101** 116808.

LASERS

Semi-polar nitrides extend to the green

Laser diode developers at the University of California, Santa Barbara (UCSB), are closing in on their quest to produce the world's first GaN-based green laser diode.

The team, which is led by James Speck, Steven DenBaars and Shuji Nakamura, has recently fabricated semi-polar laser diode structures on a (11 $\bar{2}$ 2) GaN plane, which emit spontaneously at 514 nm.

Optical excitation of this multi-quantum-

well structure produced clear threshold behavior with respect to pump fluence, and a spontaneous emission peak with a line width of 13 nm. The measurements also revealed anisotropic in-plane optical properties, and indicated that the preferable orientation for laser diode stripes is $[\bar{1}\bar{1}23]$.

Progress has also been made on electrically pumped (11 $\bar{2}$ 2) lasers, which produced stimulated emission at 427 nm when driven in pulsed mode. This laser has a threshold current density of 12.8 kA cm $^{-2}$.

Although these semi-polar laser diodes are slightly hampered by a reduction in radiative efficiency caused by the quantum confined

Stark effect, they are easier to fabricate than non-polar lasers.

“It is easier to grow high indium-concentration InGaN quantum wells on the semi-polar (11 $\bar{2}$ 2) plane than the non-polar m -plane,” explained UCSB's Hirokuni Asamizu. “In the case of m -plane, we will need a breakthrough to obtain InGaN quantum wells for green wavelength emission.”



Journal references

A Tyagi et al. 2008 *Appl. Phys. Express* **1** 091103.

H Asamizu et al. 2008 *Appl. Phys. Express* **1** 091102.

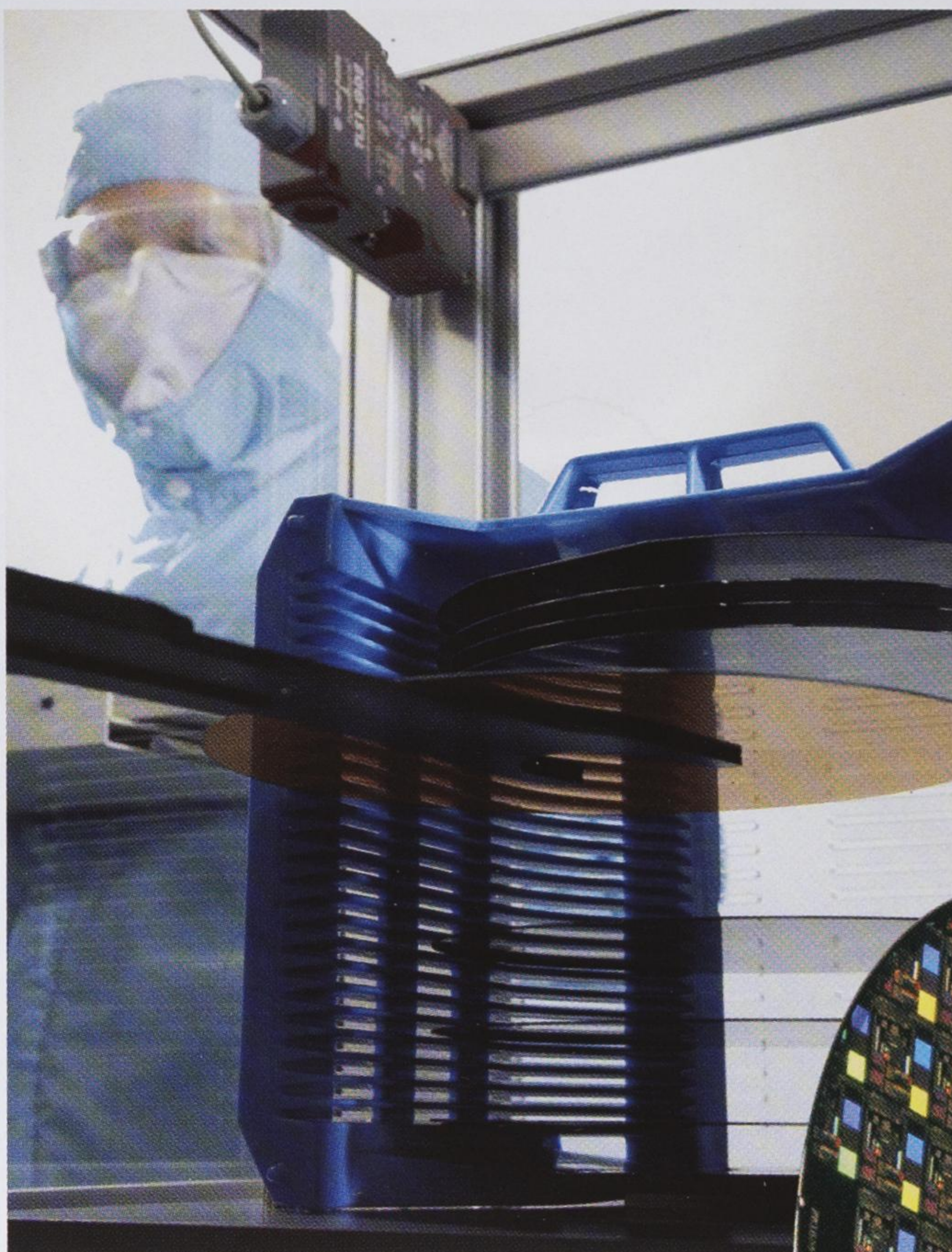
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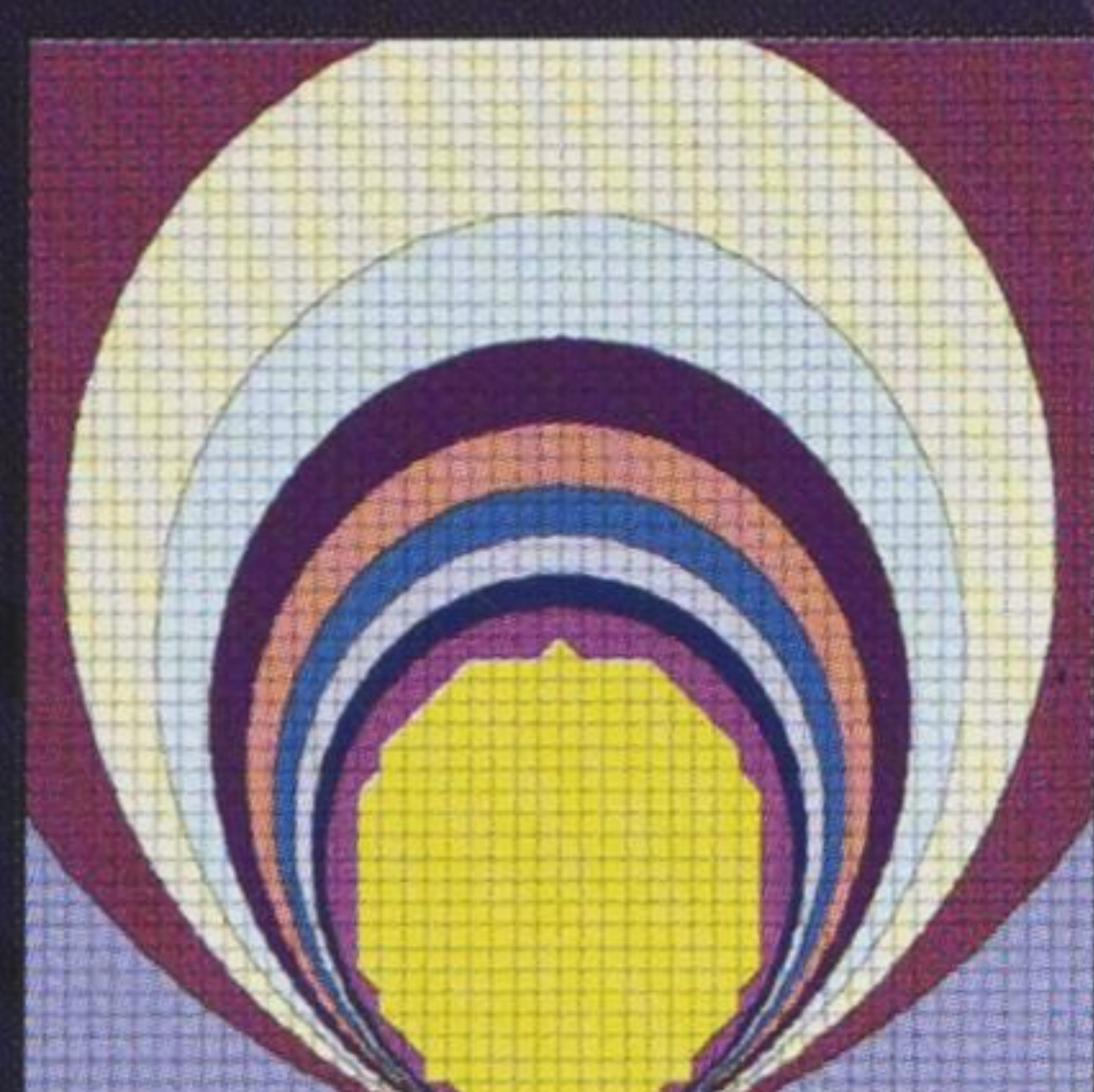
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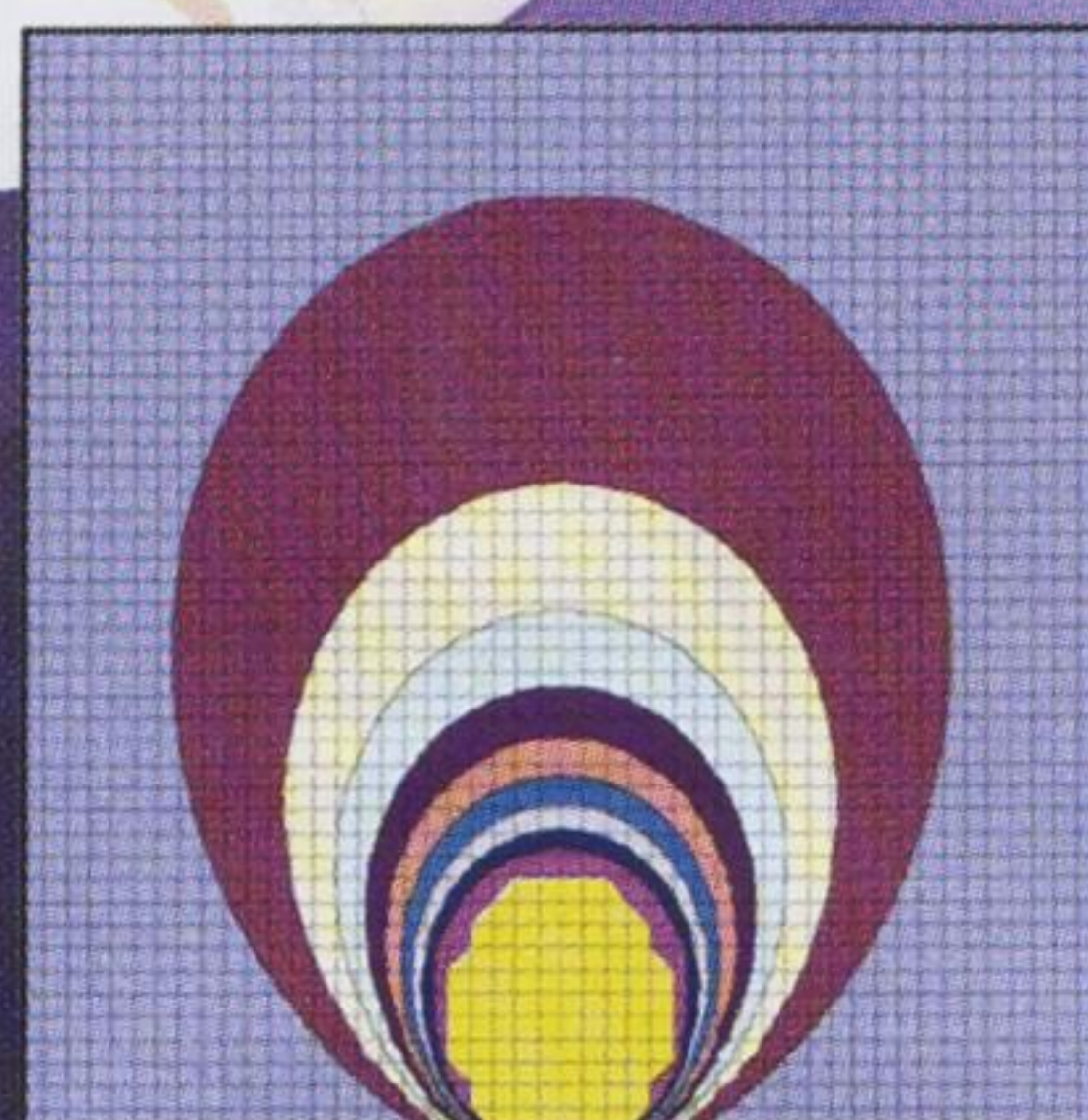


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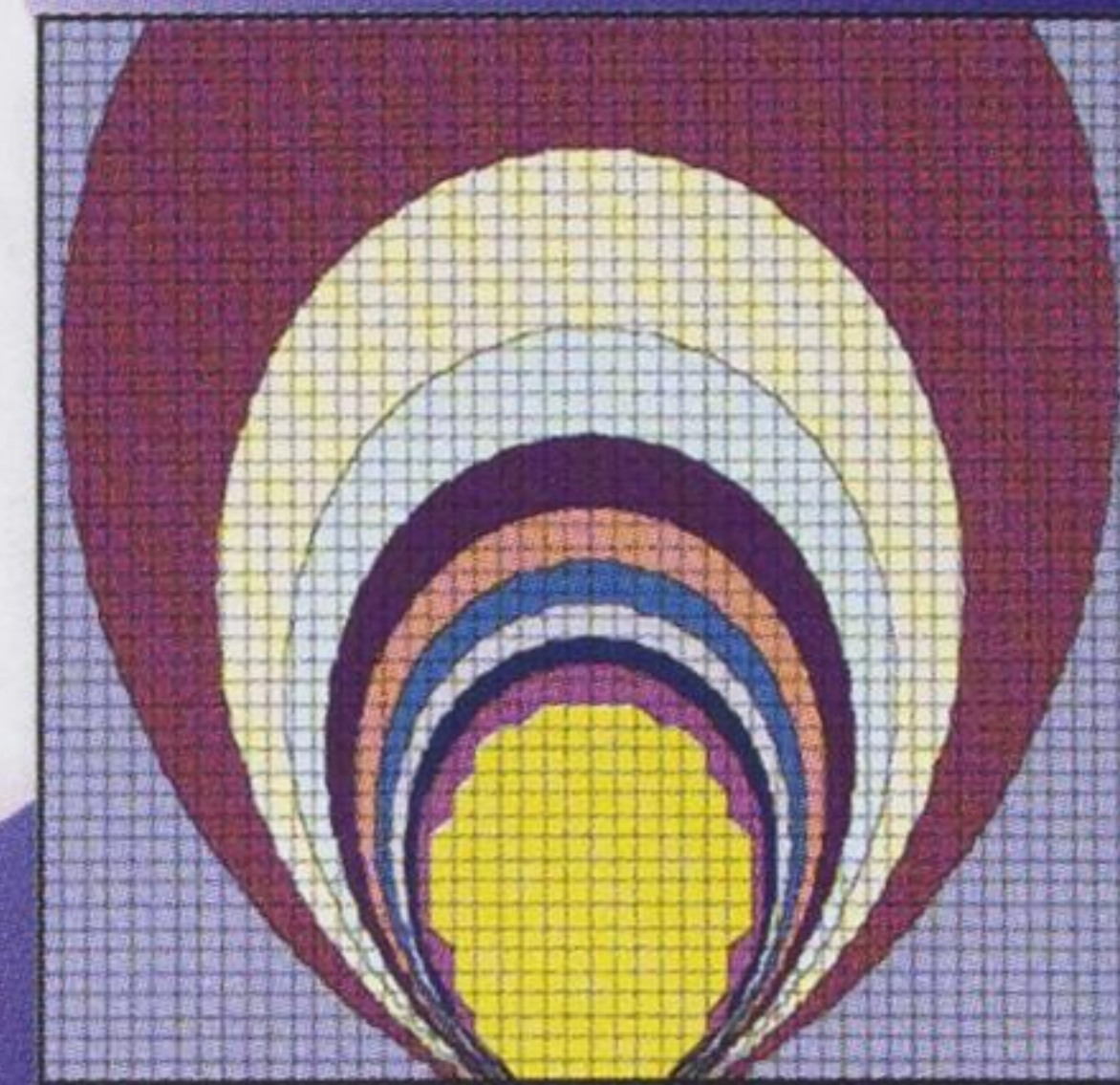
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