

COMPOUND SEMICONDUCTOR

Three-Fives and Silicon Heterostructures

November 2002 Volume 8 Number 10



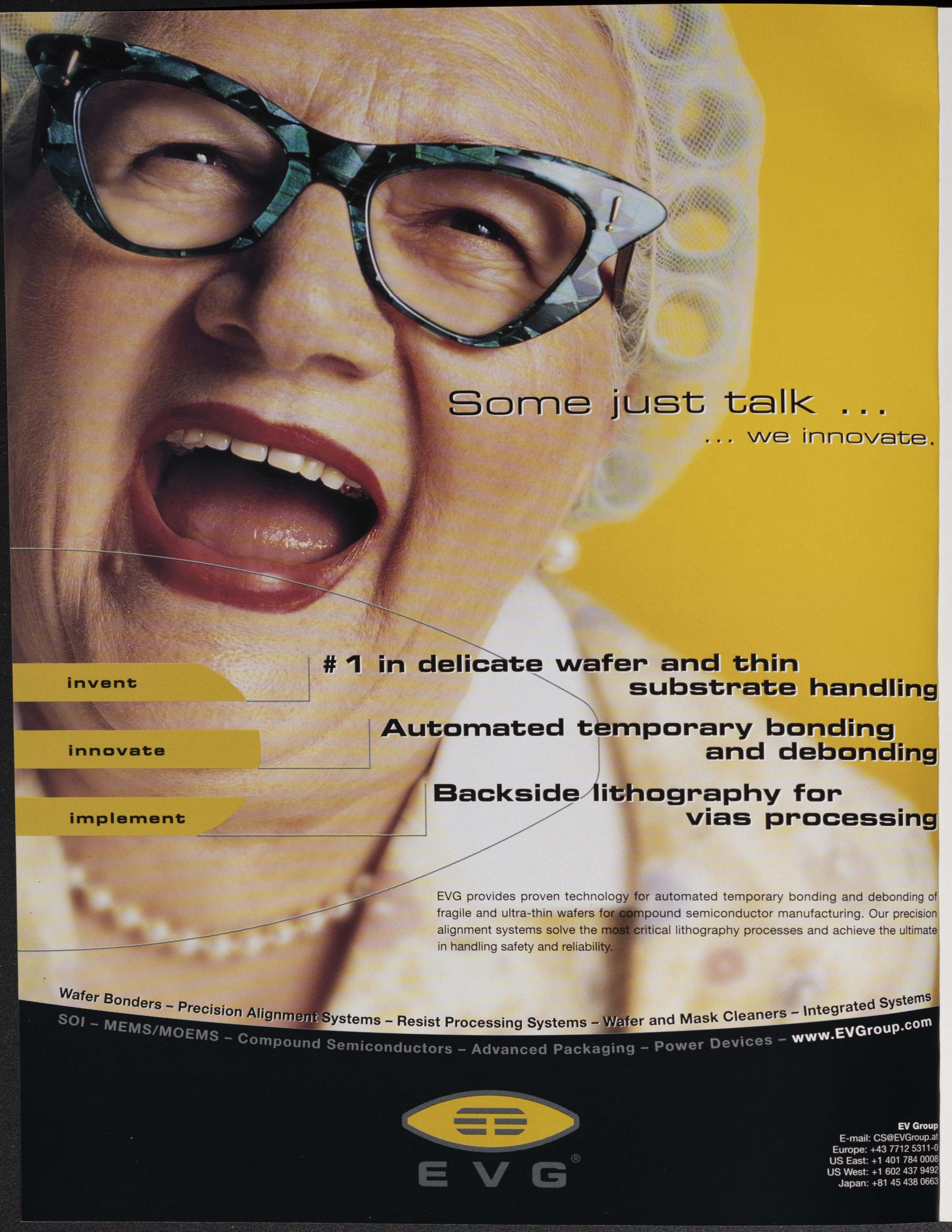
HIGH-VOLUME PRODUCTION
Fab management tools, epitaxy
control and VCSEL testing

ALSO INSIDE

**Bookham buys
Nortel businesses**

**Intel announces
SiGe process**

**Nakamura loses
patent claim**



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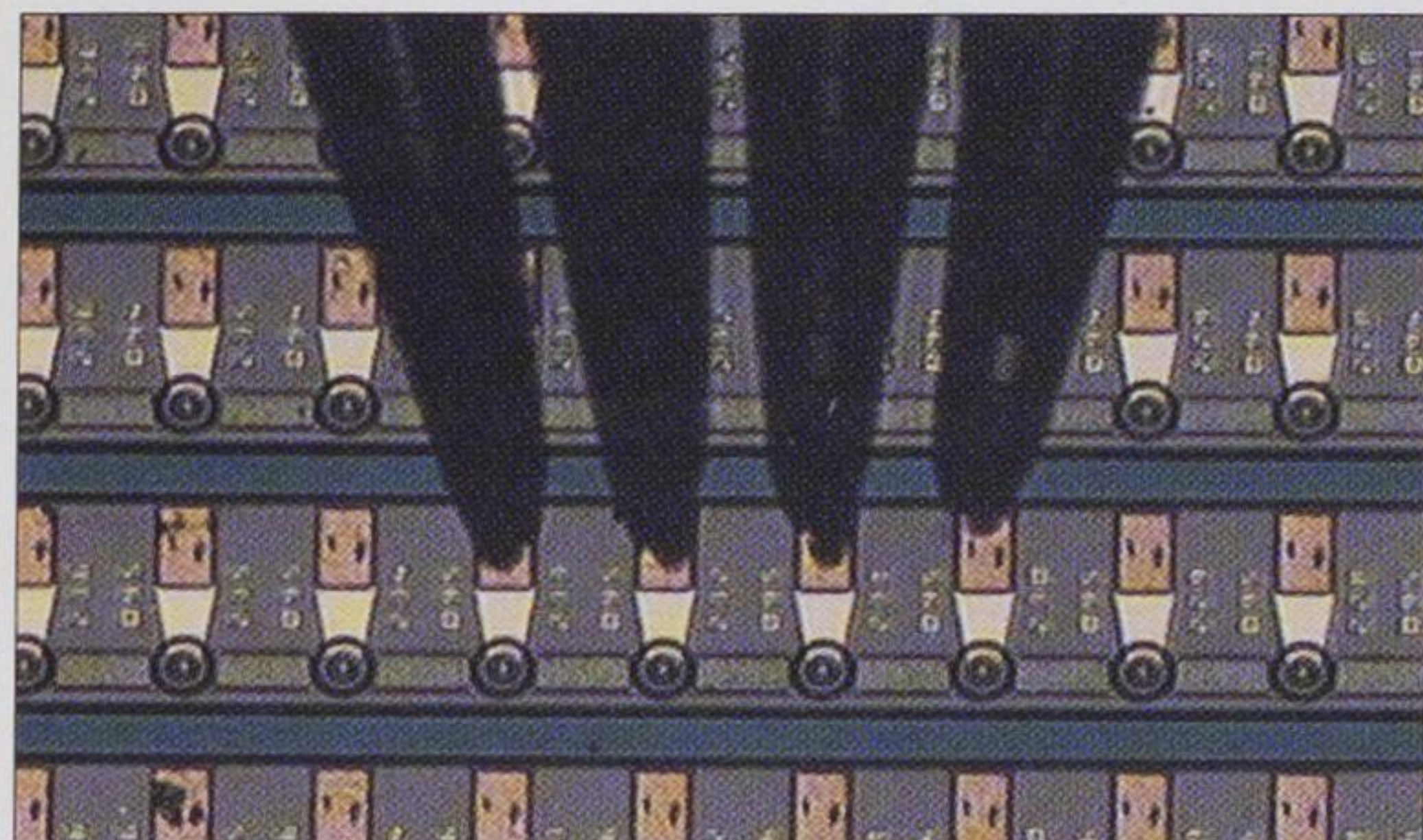


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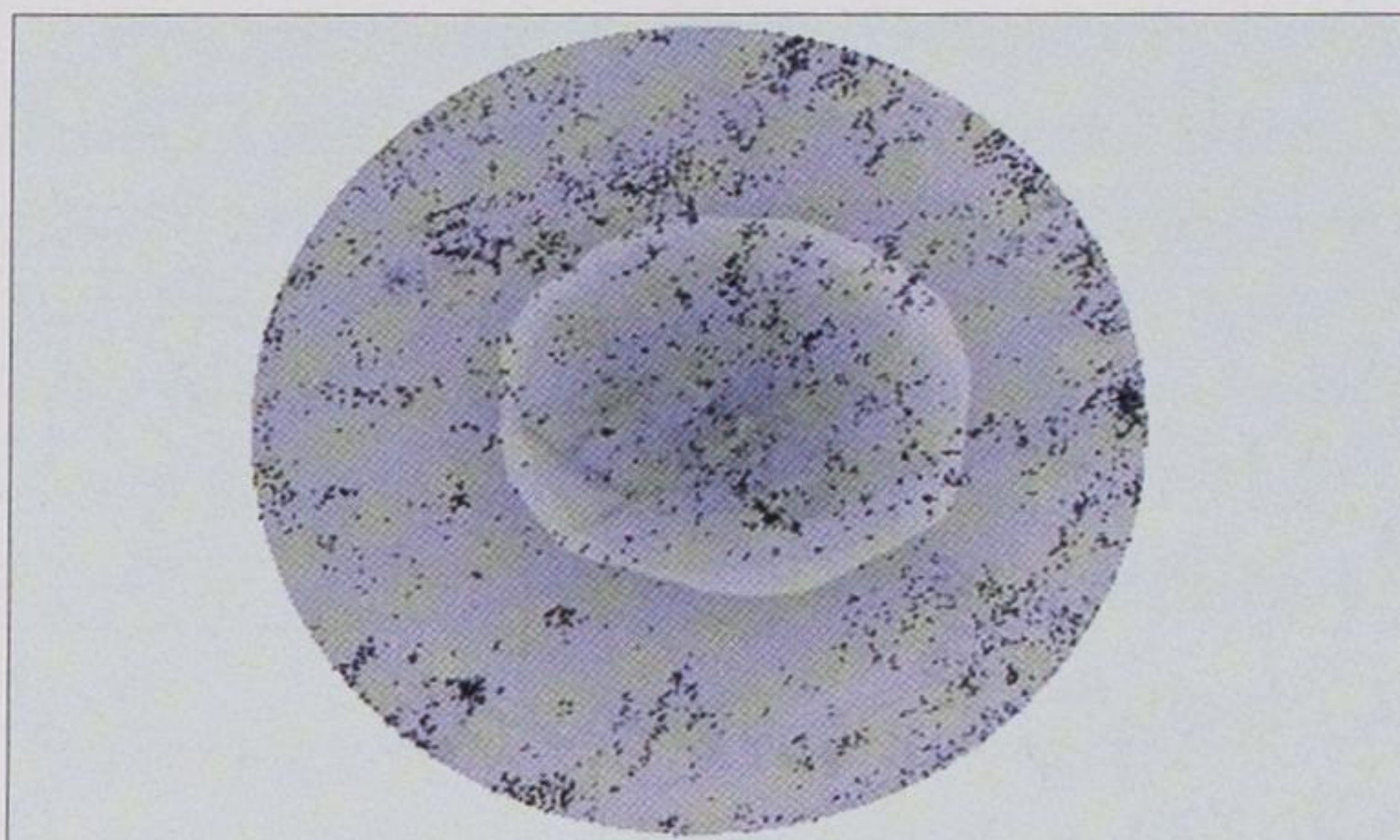
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COMPOUND SEMICONDUCTOR

Three-Fives and Silicon Heterostructures

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Nortel sells optical assets to Bookham

By Jon Newey

The rumors and speculation over who might buy Nortel's optical components business have come to an end with the announcement that Bookham Technology is to purchase most of the unit's assets. Furthermore, Nortel's CoreTek tunable laser business, unwanted by Bookham, will close down.

In a stock-based deal, Bookham will issue Nortel with 61 million new shares, worth approximately \$112 million in mid-October, effectively leaving Nortel with just under 30% of outstanding Bookham shares. Bookham will also assume around \$50 million of debt and pay Nortel \$10 million in cash to cover the restructuring costs that will result from the implementation of the deal.

The deal includes the sale of Nortel's transmitter and receiver business based in Paignton and Harlow in the UK and Ottawa in Canada, as well as the pump laser and optical amplifier business based in Paignton, Zurich in Switzerland and Poughkeepsie, NY. The transferred assets include patents, trademarks and other intellectual property. When the acquisition is complete, Bookham's headcount will rise from 800 to 2100. However, the combined workforce will be reduced by 20% by the end of 2002.

In a repeat of the deal that Bookham made when it took over Marconi's optical components business earlier this year, the transaction with Nortel also includes a three-year supply

agreement and a minimum purchase by Nortel of Bookham products worth approximately \$120 million during the first 18 months.

In a conference call on October 7, Bookham's CEO, Giorgio Anania, went to some lengths to dispel any thoughts that Bookham was rashly taking on manufacturing capacity for optical components at a time when there is significant over-capacity in the industry. Immediately after the takeover is

Most observers rank Bookham-Nortel third in optical components, behind JDS Uniphase and Agere.

approved, a rationalization plan will be implemented that will remove areas of duplication between the acquired business and Bookham's current activities. According to Anania, the end result will be to further reduce global over-capacity, and to leave Bookham with an optical components business that enjoys significant market share. Most observers rank Bookham-Nortel third in optical components, behind JDS Uniphase and Agere. Anania claims that Nortel currently has a market share of about 20%.

Growing its market share and revenue is now essential to Bookham's future survival.

The combined and restructured entity will have a break-even revenue target of \$75 million per quarter. Currently, the combined quarterly revenue is estimated to be \$41 million. The management seem unfazed by this, however, describing the opportunities for revenue growth as being very good.

Nortel shuts down CoreTek

Two weeks before the deal with Bookham was announced, Nortel revealed that it would close its CoreTek optical components unit with immediate effect. Nortel bought CoreTek for \$1.43 billion in March 2000, at the height of the spending spree that gripped the optical networking industry. The shutdown will affect 160 employees at the company, which is based in Burlington, MA.

CoreTek developed a tunable laser employing a VCSEL with a movable MEMS mirror to provide both high power and tunability for bandwidth provisioning in all-optical networks (*Compound Semiconductor* June 2001 p44). Nortel cited its reasons for closing CoreTek as being that its tunable laser technology was far ahead of the current market demands, and that the market for tunable sources was taking too long to emerge. Clearly, CoreTek's tunable laser technology did not fit in with Bookham's plans; Bookham has its own tunable DBR laser technology that it acquired when it bought Marconi Optical Components (*Compound Semiconductor* March 2002 p21).

Nichia and Toyoda Gosei agree to settle their differences

By Tim Whitaker

On September 17, rival Japanese GaN LED makers Nichia and Toyoda Gosei announced details of an agreement to settle their long-running patent dispute (see *Compound Semiconductor* September 2002 p3 for background information). In a joint statement, the companies declared that they would respect each other's patent rights, end all lawsuits that are still pending, and take steps to prevent and resolve any future disputes. The agreement contained several specific terms, as follows:

Damages Both companies agreed that they would not demand injunctive relief or claims for damages in respect of manufacturing or sales based on any patents belonging to

the other. The companies also agreed that neither would be liable for payment of damage compensation with respect to any patents owned by the other, and they would not be required to stop manufacturing or selling any of their current products.

Litigation The companies agreed to cease all patent litigation. This includes pending infringement actions and invalidation proceedings in the Japanese Patent Office (JPO), and any action before the Tokyo High Court for the reversal of any trial decision made by the JPO.

Future royalties If either company utilizes the other's future patents in respect of any future product, a "reasonable" royalty payment will be made.

White LEDs Nichia holds a number of patents relating to the use of YAG phosphors in white LEDs. Toyoda Gosei has agreed to pay Nichia a royalty in respect of future products using YAG for which the said patents will be utilized.

The new agreement appears to signal a conclusive end to the six-year-old patent dispute. Believing it had an unassailable position in the nitride patent field, Nichia filed a large number of lawsuits, not only against Toyoda Gosei but also against Cree, Rohm and Osram Opto Semiconductors, among others. Prior to this year, Nichia also maintained a strict policy of not licensing its patents. However, a series of legal setbacks weakened its position, and in June this year it entered into a cross-licensing agreement with Osram relating to patents covering white LED manufacturing (*Compound Semiconductor* August p9).

Further setbacks against Toyoda Gosei apparently made Nichia realize it could not >>

force its rival out of the nitride LED market. In terms of patents, the only area where Nichia has a significant advantage over Toyoda Gosei is in white LEDs, hence the specific royalty agreement. Otherwise the companies have a great deal to offer one another, and much to gain from keeping GaN-on-sapphire technology ahead of the pack. For example, many competitors are now developing or manufacturing devices on SiC, silicon or GaN substrates.

At first sight, it may appear that the end of the Nichia-Toyoda Gosei patent war will open up the nitride LED market, allowing other manufacturers to flourish, pushing down prices and opening up new applications. However, this is not necessarily the case. At the moment this is a bilateral agreement, although Nichia has said it will "share technology with companies that possess the expertise to complement our technology". One example of this

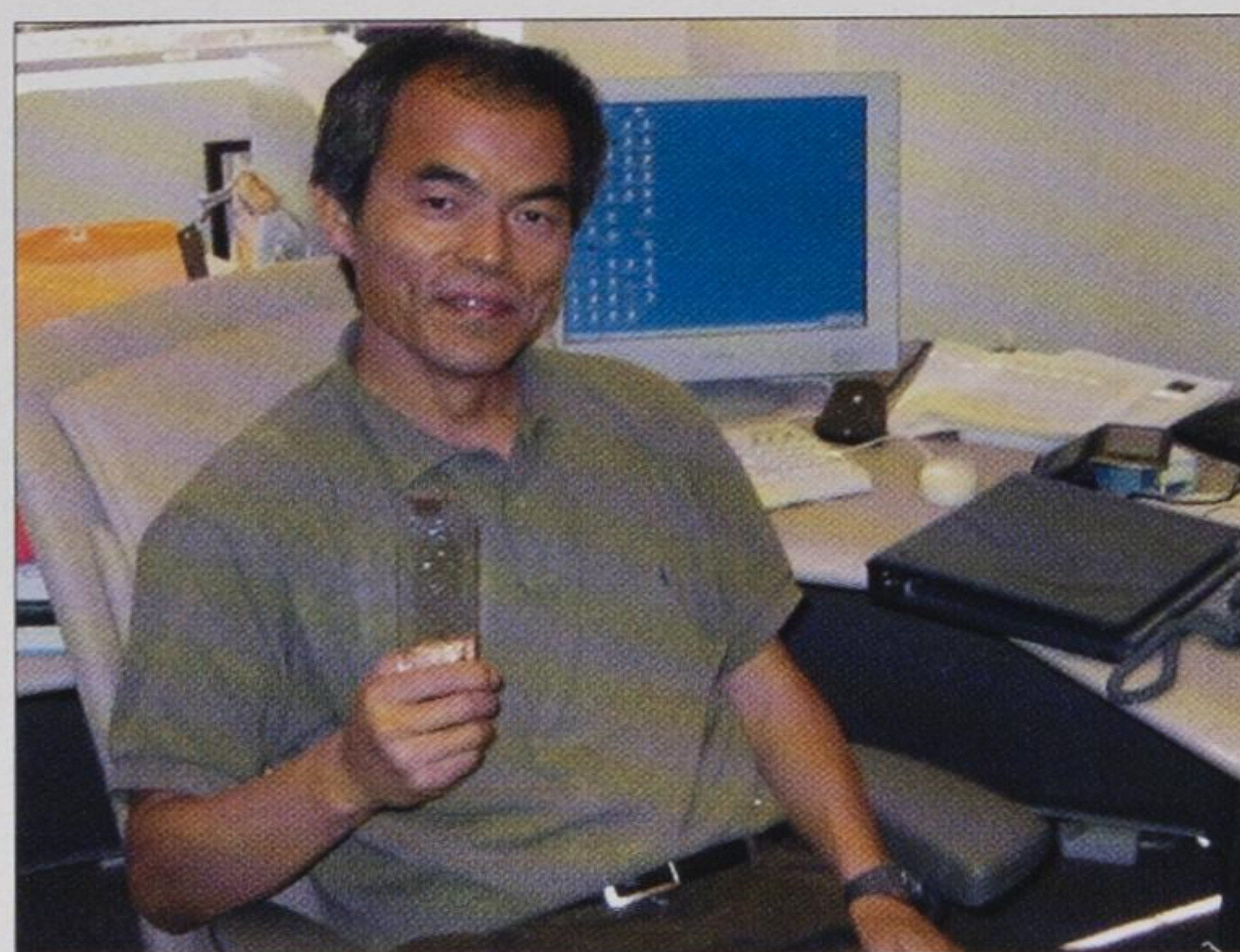
is Nichia's agreement to license its white LED manufacturing technology to Citizen Electronics (*Compound Semiconductor* March 2002 p4); in this case Citizen brought high-volume packaging expertise to the table. Companies that have nothing to offer Nichia are unlikely to receive licenses to its patents, and could start receiving unwelcome attention from patent attorneys now that Toyoda Gosei is no longer Nichia's enemy.

Nakamura loses patent claim against Nichia

Shuji Nakamura has lost his court battle with his former employer, Nichia Corporation, over the ownership of a patent covering GaN-based LED production that resulted from Nakamura's work while employed by Nichia. However, the court recognized that Nakamura is entitled to a reward for the patent, and is now deciding how much he should receive.

Nakamura, now with the University of California at Santa Barbara, filed his lawsuit in the Tokyo District Court on August 23, 2001, claiming ownership of Japanese patent number 2,628,404 and requesting ¥2 billion (\$16 million) in compensation. The 404 patent dates back to 1991 and relates to two-flow MOCVD technology, which was a key factor in allowing Nichia to develop high-brightness, long-lifetime InGaN/GaN LEDs and lasers.

Under Japan's patent law, an employee owns a patent filed while working for a com-



Shuji Nakamura does not own Japanese patent number 2,628,404 – but he is liable for a reward for the invention.

pany, although the company also has rights to use the invention. Employers can also claim the patent after paying "deserving bonuses" to the inventors, based on profits and the com-

pany's involvement. After commercializing the technology, Nichia's annual sales grew from just over ¥20 billion to ¥80 billion in 2001, around 60% of which was generated by its nitride LED products. The court accepted Nichia's claim that it owned the patent because Nakamura received ¥20,000 (\$160) in reward and filed no objection for more than 10 years after the patent application.

On the issue of deserving bonuses, the court ruled that Nakamura is eligible for a "proper amount of rewards", and he is now considering that aspect of the lawsuit. A decision should be made on whether he can claim any portion of the profits from the invention on November 19. Nichia has not commented on the ruling, but Nakamura's attorney said the decision upholding Nichia's ownership of the patent was totally unexpected, and that an appeal would be filed.

Intel to use SiGe for communications

By Tim Whitaker

Intel, the world's largest semiconductor chip maker, has unveiled details of its new 90 nm process for communication ICs, which includes the company's first deployment of SiGe technology. Intel intends to be the first company to offer communication ICs at the 90 nm technology node, and will make the chips at its own 300 mm fabs for introduction in 2003. The new process should enable a new class of highly integrated ICs for broadband, optical and wireless applications.

In March, Intel announced its 90 nm process for logic ICs, a seven-layer-metal, copper-based technology that will enable chips with 50 nm gate lengths. Then, in August, Intel announced it also planned to introduce strained silicon in the process (*Compound Semiconductor* September 2002 p32). The new process for

communication ICs uses the same baseline technology as the logic process, and in addition includes high-voltage RF analog CMOS transistors, precision capacitors and resistors, and high-Q inductors, as well as SiGe HBTs.

The process was unveiled at the mid-September Intel Developers Forum (IDF), at which senior executives outlined Intel's plans to use integrated silicon technologies to drive the convergence of computing and communications over the next decade.

"We believe that integrated silicon will deliver innovative, ubiquitous and low-cost technologies to enable a world in which all computers will communicate and all communication devices will compute," said Intel CTO Pat Gelsinger.

Over the past few years, Intel has made noticeable strides into the communications market, having acquired several fabless IC design houses as well as optical transceiver manufacturer LightLogic. (For more on Intel's progress in photonics, see page 25.) While its

communications ICs have until now been produced using outside foundries, the new process signals Intel's intention to bring more of its manufacturing in-house.

Intel says that the addition of SiGe significantly increases the speed and reduces the noise of transistors for high-speed communications equipment, such as optical switches and wireless basestations. The process is sufficient for optical systems operating at 50 Gbit/s. SiGe and CMOS transistor circuitry fabricated on Intel's 90 nm process could cut the number of chips and processes used to create an optical subsystem in half, claims Intel, or enable connection of wireless components directly to antennae without the intervening circuitry that consumes space and power.

According to Eric Mentzer, CTO of Intel's Communications Group, today's 10 Gbit/s optical modules typically have more than 10 chips built on four process technologies. "Our new SiGe process will reduce this to three chips built on two technologies," >>

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said Mentzer. "In addition to SiGe, InP is also required for the laser drivers."

Mentzer also says that the performance and integration provided by its 90 nm process allows 50–60% of the signal conditioning previously performed by the physical layer analog components to be accomplished digitally. Although there will always need to be an analog input to the optical components (or

an antenna in the case of wireless applications), Intel aims to bring as much as possible of the signal processing and conditioning into the digital domain, since the digital functions can scale with Moore's Law. Also at the IDF, Gelsinger described some of the technologies Intel is pursuing, including the development of a "silicon radio" based on the company's low-power CMOS manufacturing process.

Over the next few years, these radios will be integrated into future Intel chips, so any device powered by one of these chips would have wireless radio communication capabilities.

Although Intel is using SiGe in its 90 nm platform, the ultimate aim is to build the entire radio using CMOS. "SiGe is an important stepping stone," said Gelsinger. "We want to carry on our research and bring it all into CMOS."

Picogiga faces collapse, Umicore may step in

By Marie Meyer

Revenues at French epiwafer supplier Picogiga have been declining precipitously, necessitating a bail-out from Belgian materials company Umicore. Picogiga management says that turnover in the September 2002 quarter is unlikely to exceed €1 million (\$0.99 million). Revenues for the first six months of 2002 were €4.62 million, a decline of 46.2% from the year-ago period, and in stark contrast to the 84% rise in revenues seen by the company in 2000.

As a result, Picogiga is in negotiations with Umicore for a rescue package that would result in Umicore acquiring 40–47% of Picogiga's

stock in return for a cash injection of around €5.5 million. Umicore's investment is subject to approval by the French market regulators and the successful restructuring of Picogiga's outstanding debt, which as of June 30 stood at more than €43 million. Trading in shares of Picogiga on the Paris exchange has been suspended.

According to a statement from Umicore, Picogiga offers a sound fit with Umicore Advanced Materials' strategy to grow its business further and to seek opportunities in areas such as semiconductor wafers. Umicore is a leading supplier of germanium substrates. In addition to extending the use of germanium

to applications other than space solar cells, Umicore's strategy is to broaden its expertise in substrate technology by entering the market for the most advanced generation of wafers, as well as to develop downstream opportunities such as epitaxy.

Umicore recently abandoned its proposed takeover of SiC substrate manufacturer Sterling Semiconductor (*Compound Semiconductor* July 2002 p3). The company says it is pursuing several initiatives to build a strong position in anticipation of a future market recovery, including the development of SiC and InP substrates (see p21).

ATMI to exit GaAs epiwafer business

Equipment manufacturer and epiwafer supplier ATMI is to take restructuring measures in light of a 10% sequential drop in revenue during the September 2002 quarter. One major change is that ATMI will withdraw from the GaAs epiwafer supply business, although the company has no plans to alter its silicon epiwafer business or its nitride activities.

In its financial results for the September 2002 quarter, ATMI wrote off \$34.6 million to reflect the impaired value of its GaAs epi-

wafer business, which has received about \$40 million of investment from the company.

ATMI hopes to transfer its GaAs business to a joint venture company. "We have signed a letter of intent to contribute the assets of our GaAs business to a venture that will be positioned as a global, low-cost producer, with leading-edge technology," said Gene Banucci, ATMI's CEO. "We expect to announce details of the venture soon, but with or without this transaction, it is appropriate to reflect the impaired value of the assets now."

Towards the end of 2000, ATMI relocated its III-V division to a new 50,000 sq. ft facility in Phoenix, AZ, and acquired MOCVD sys-

tems capable of producing epiwafers for InGaP HBTs, PHEMTs, lasers and *pin* detectors.

ATMI's silicon epiwafer division in Mesa, AZ, remains unaffected by the changes, as are the nitride activities at the company's headquarters in Danbury, CT. As well as producing GaN-based epiwafers for optoelectronic and high-power microwave applications, ATMI is also developing free-standing GaN substrates grown by HVPE. The company recently purchased an Aixtron production reactor to expand its GaN epitaxial capacity (see p34), and won a contract from the Office of Naval Research to develop GaN substrates and GaN/AlGaIn epitaxy for high-power HEMTs (see p21).

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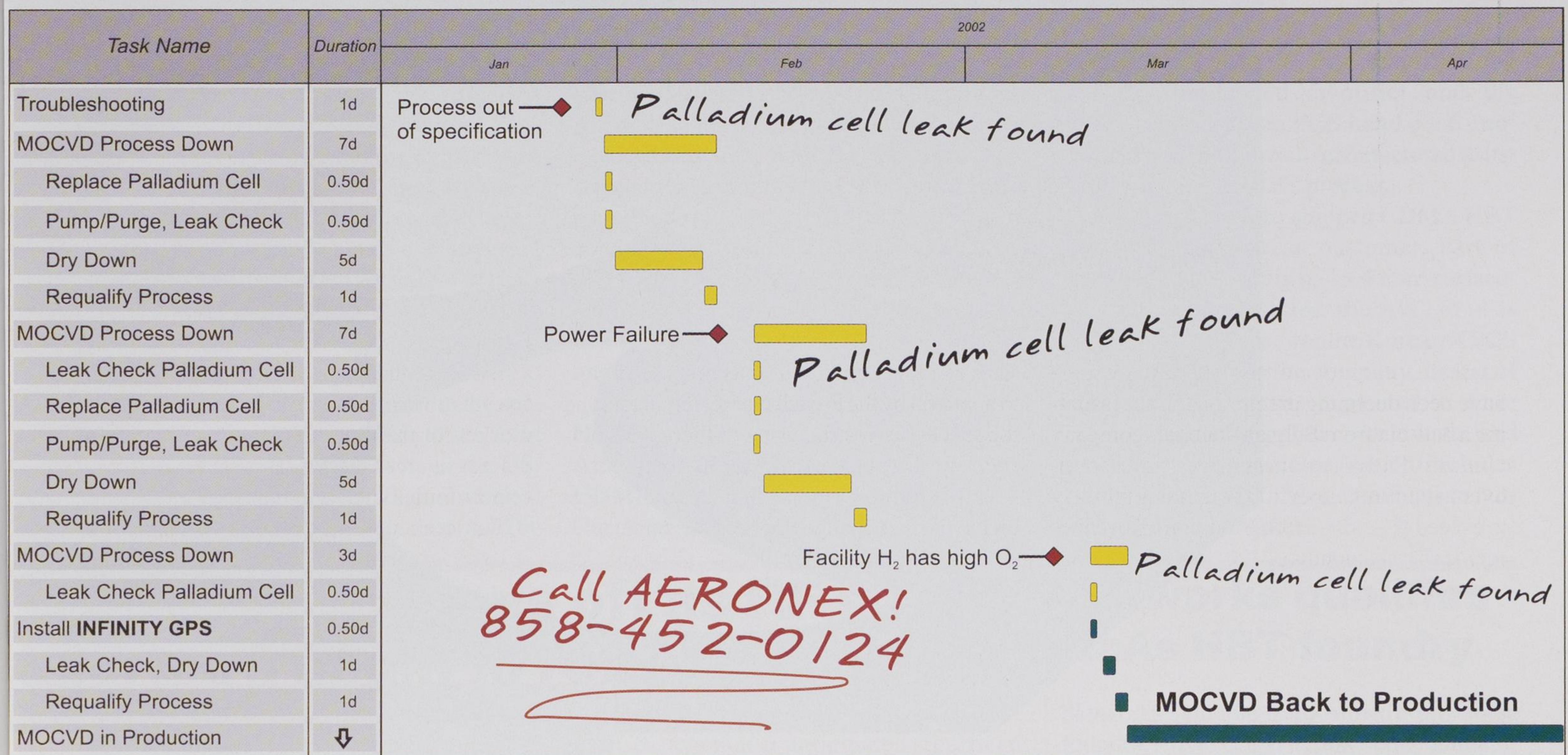
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Power failures, high oxygen levels in hydrogen, and common user errors cause damage to palladium cells. R&D and production schedules are constantly interrupted to leak check palladium cells to make sure that purified hydrogen is available for the process. If the palladium cell is found leaky, the replacement procedure can take days to finish because of pump-purge cycles, heating up and PID tuning, long dry down, etc. Hundreds of thousands of dollars are lost due to the palladium cell related downtime of multi-million dollar process equipment.

The INFINITY GPS is simple to set-up, start, and operate. Unlike palladium cells, the INFINITY is ready to purify gas as soon as its process gas lines are connected and power is applied. There is no need for pump-purge cycles or long waits for the cell to dry down before purified

hydrogen can be provided to the process equipment. Hydrogen with less than 1 ppb moisture is available within a couple of hours, not several days. And, when you want to shut the system down, simply turn it off.

Ambient temperature purification technology makes the INFINITY extremely robust and reliable. The hydrogen purification technology developed by AERONEX works without power or heat. Contaminants are removed by chemisorption, oxidative addition, simple oxidation, and simple adsorption. SIMS data obtained from both GaAs and GaN thin film samples fabricated with hydrogen purified by AERONEX purification technology repeatedly show oxygen levels in the low 10¹⁶ cm⁻³ range (the detection limit of SIMS). The reactions are reversible at high temperature, which makes the purification media regenerable. Heat is only required during this regeneration process. The dual vessel, automatic self-regenerative design gives the INFINITY unlimited capacity for contaminant removal.

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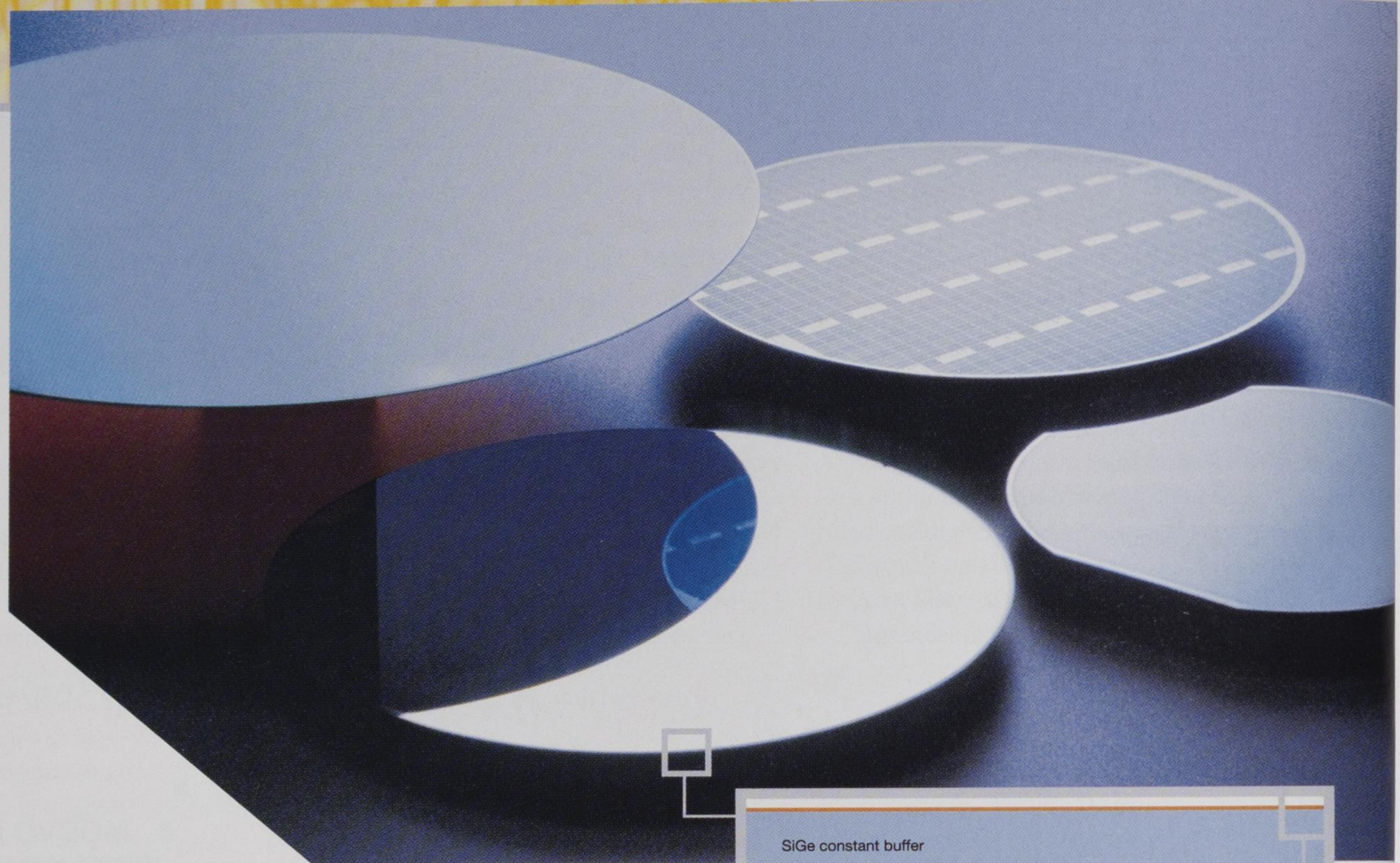
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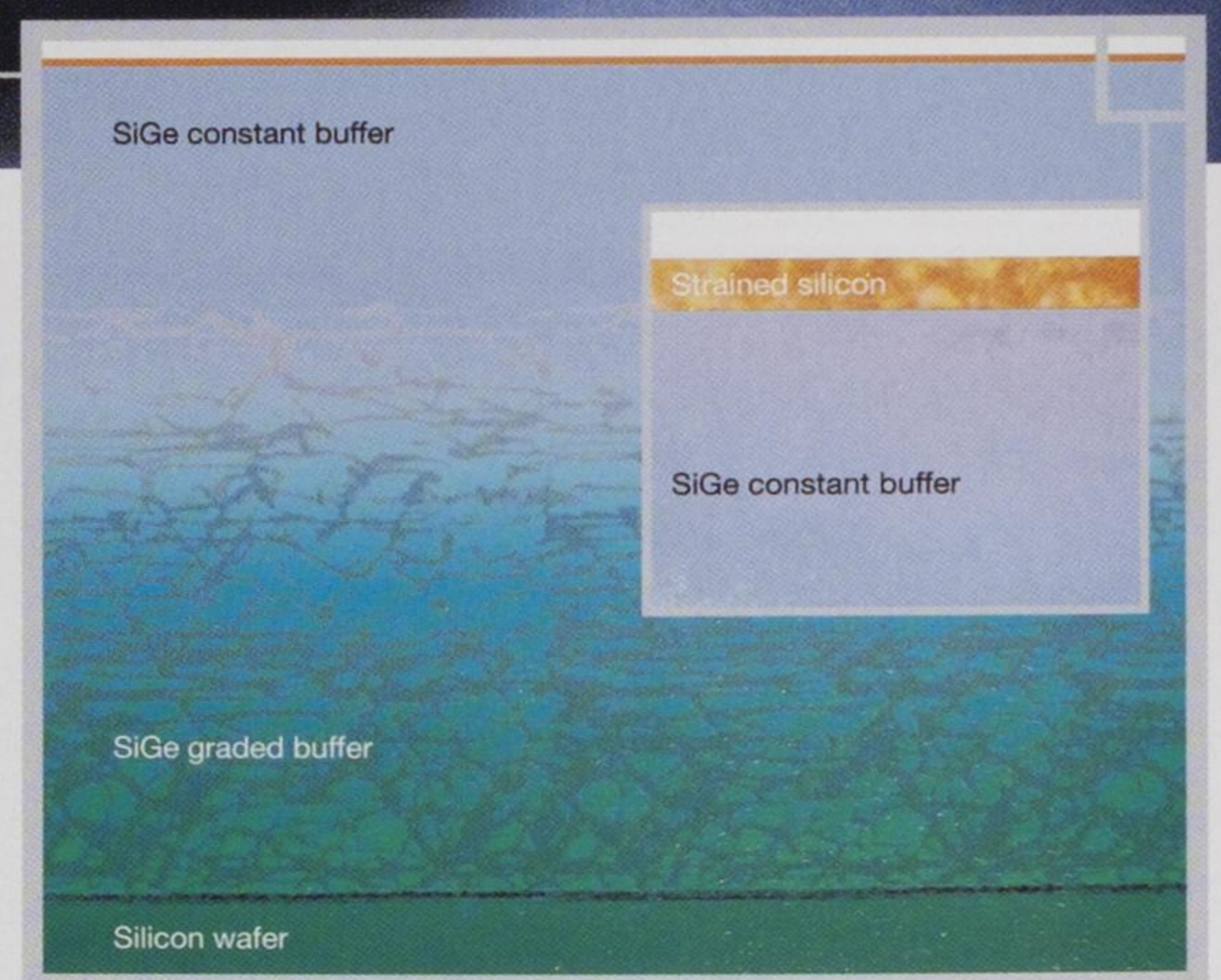


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Anadigics on track, but sheds jobs

While reaffirming its financial guidance for the third quarter ending September 30, Anadigics said it would be required to reduce its workforce of 450 employees by around 10%. The savings resulting from the reduction in Anadigics' labor force, combined with several other cost-reduction initiatives undertaken by the company, will lower its cost structure by \$2.5 million per quarter. Anadigics says the actions will lower its quarterly break-even earnings requirement to around \$25 million.

According to analysts with CIBC World Markets, Anadigics' top customer in the second quarter, Kyocera, continues to see solid demand for its CDMA handsets in the US. However, the majority of Anadigics' wireless components go into CDMA handsets sold by

Verizon and SprintPCS. Given the weakness in sales cited by SprintPCS recently, CIBC World Markets believes CDMA sales for Anadigics may be weak in the fourth quarter.

Anadigics' CEO Bami Bastani says that the company will continue to invest in R&D and manufacturing operations to expand its technology base. "Customer feedback and design-win activity remain strong at all levels, and we are optimistic that our latest CDMA and GSM products will be the major drivers for our future growth," said Bastani.

New customers for CDMA PA modules

Anadigics has recently started shipping CDMA power amplifiers to AirPrime of Carlsbad, CA, for use in several new PDA

wireless modem platforms. AirPrime has ordered the AWT6106 PCS amplifier, the AWT6111 cell-band amplifier and the AWT6109, a Korean PCS band $6 \times 6 \text{ mm}^2$ PA module. These are all manufactured using Anadigics' InGaP HBT process.

Anadigics has also shipped CDMA HBT PAs to a new Korean customer. Part of Anadigics' new family of $4 \times 4 \text{ mm}^2$ surface-mount CDMA modules, the AWT6114 is specifically designed for the Korean KPCS band. According to the company, its list of CDMA customers has expanded to more than 12 handset suppliers worldwide, and the Asian CDMA sector, which includes Korea, China, and Taiwan, continues to outpace the overall market.

Agreement pays off as RF switch orders begin to roll in at Filtronic

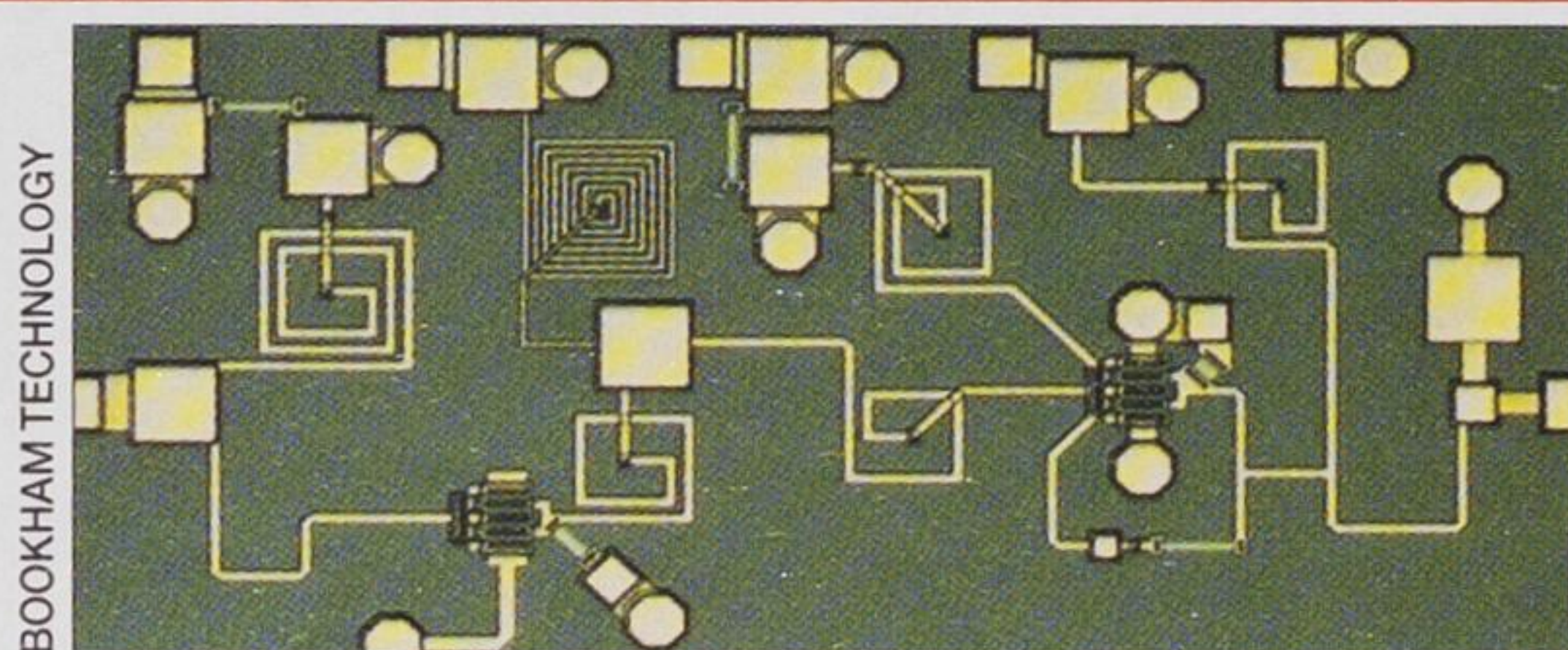
The agreement signed with M/A-COM in November 2001 is finally bearing fruit for Filtronic. The company has received initial production orders from M/A-COM for RF switches to be used in cellular handsets manufactured by one of its customers. The GaAs PHEMT switches will be manufactured by Filtronic Compound Semiconductor (FCS) at its fab in Newton Aycliffe, UK.

FCS says that it anticipates significant follow-on orders, since M/A-COM is expecting business with its OEM customers to grow substantially in the next 12 months. FCS has also said that it is expecting volume orders from M/A-COM for switch products for use in wireless LAN equipment. Production at FCS for the WLAN products is expected to begin in early 2003.

Bookham launches new MMIC portfolio

Bookham Technology has unveiled a new portfolio of GaAs MMICs developed at the former Marconi design center and fab in Caswell, UK. The company's first new product is a 5 W GaAs X-band MMIC power amplifier due to sample later this year. This device complements the company's existing X-band LNA and driver products.

"GaAs foundry services are very much at the forefront of our initial business expansion," said Ray Taylor, Bookham's business manager for RF MMICs and foundry products. "This is a good time for Bookham Technology to raise its profile in RF MMICs, as both the military and space markets are fairly buoyant at the moment. There are many satellites in the pipeline for both military and commercial applications."



Bookham's P35-5112 is a GaAs MMIC LNA intended for applications in the X-band.

Bookham's MESFET technology uses a $0.5 \mu\text{m}$ gate-length process to manufacture devices operating up to 20 GHz. The European Space Agency has qualified both the MESFET gain and switch IC processes. The company's low-noise PHEMT process employs a $0.2 \mu\text{m}$ gate technology for devices operating in excess of 40 GHz. The H40P is a high-power PHEMT process yielding devices with a breakdown voltage of more than 15 V. A new $0.17 \mu\text{m}$ metamorphic HEMT process is also being developed for applications up to 100 GHz.

Skyworks qualifies GaAs HBT foundry

Skyworks Solutions has qualified a Taiwanese foundry, Advanced Wireless Semiconductor Company (AWSC), as a second source to provide GaAs HBT processing services. The announcement comes almost two-and-a-half years after Conexant, whose wireless business joined with Alpha to form Skyworks, first selected AWSC as a foundry partner.

"After meticulous testing, we're pleased to announce that AWSC has met our rigorous process, quality and reliability requirements and is now qualified for production," said Kevin Barber, senior VP of operations for Skyworks. "The qualification of AWSC for HBT foundry services improves Skyworks' ability to meet customer volume and second-source demands."

Celeritek rejects Anaren takeover bid

The ongoing activity surrounding Anaren Microwave's desire to takeover Celeritek has taken some new turns (*Compound Semiconductor* September 2002 p9). On September 19 Anaren made a formal takeover offer to Celeritek's board, of \$8.75 per share. Celeritek's shares closed up nearly 16% at \$7.95 the day following the offer. Within days, however, Celeritek announced that it was rejecting the offer as the board did not consider it to be in the best interests of Celeritek's shareholders.

Companies look to Asian market to develop business opportunities

Reflecting the current buoyancy of the Asian market, more companies have opened support offices in the region. Fabless RFIC designer Sirenza Microdevices has established a new customer support office in Shenzhen, China, while Celeritek has opened a new sales and technical support office in Seoul, Korea. Celeritek's president and CEO Tamer Husseini believes Korea will present significant growth opportunities for the company in handsets, WLAN and other wireless technology areas.

Meanwhile, Skyworks will increase its base of 75 sales and engineering staff deployed throughout Taiwan, China, Japan, Korea and Singapore to around 100 over the next few months. The move allows Skyworks to support regional original design manufacturers (ODMs) and contract manufacturers

through easier access to its switches, PA modules, direct conversion transceivers and complete cellular system chipsets.

RFMD begins production in China

RF Micro Devices has begun production shipments from its new test and tape and reel facility in Beijing, China. The facility supports local handset manufacturers, ODMs and international handset manufacturers with operations in the region.

RFMD has also begun shipping products to Sanyo for its new dual-band, dual-mode SCP-4900 CDMA 2000 1X handset. The handset contains RFMD's RF2496 tri-band, quad-mode SiGe LNA/mixer and two GaAs HBT linear PAs, the RF2192 for the 900 MHz band and the RF5154 for the 1900 MHz band.

WJ Communications receives share acquisition proposal

WJ Communications of San Jose, CA, has received a proposal from investment fund managers Fox Paine & Company to acquire all of the shares held by unaffiliated stockholders. WJ designs and manufactures GaAs-based RFICs and multi-chip modules.

Fox Paine and its affiliates currently own approximately 66% of WJ shares. The company has offered to pay cash for all outstanding WJ shares at \$1.10 per share. The offer price represents a 22% premium on the average price over the 30 day trading period ending September 18. Fox Paine made its original investment in WJ Communications in 2000, paying \$335 million. The acquisition of the remaining stock will cost approximately \$21.5 million.

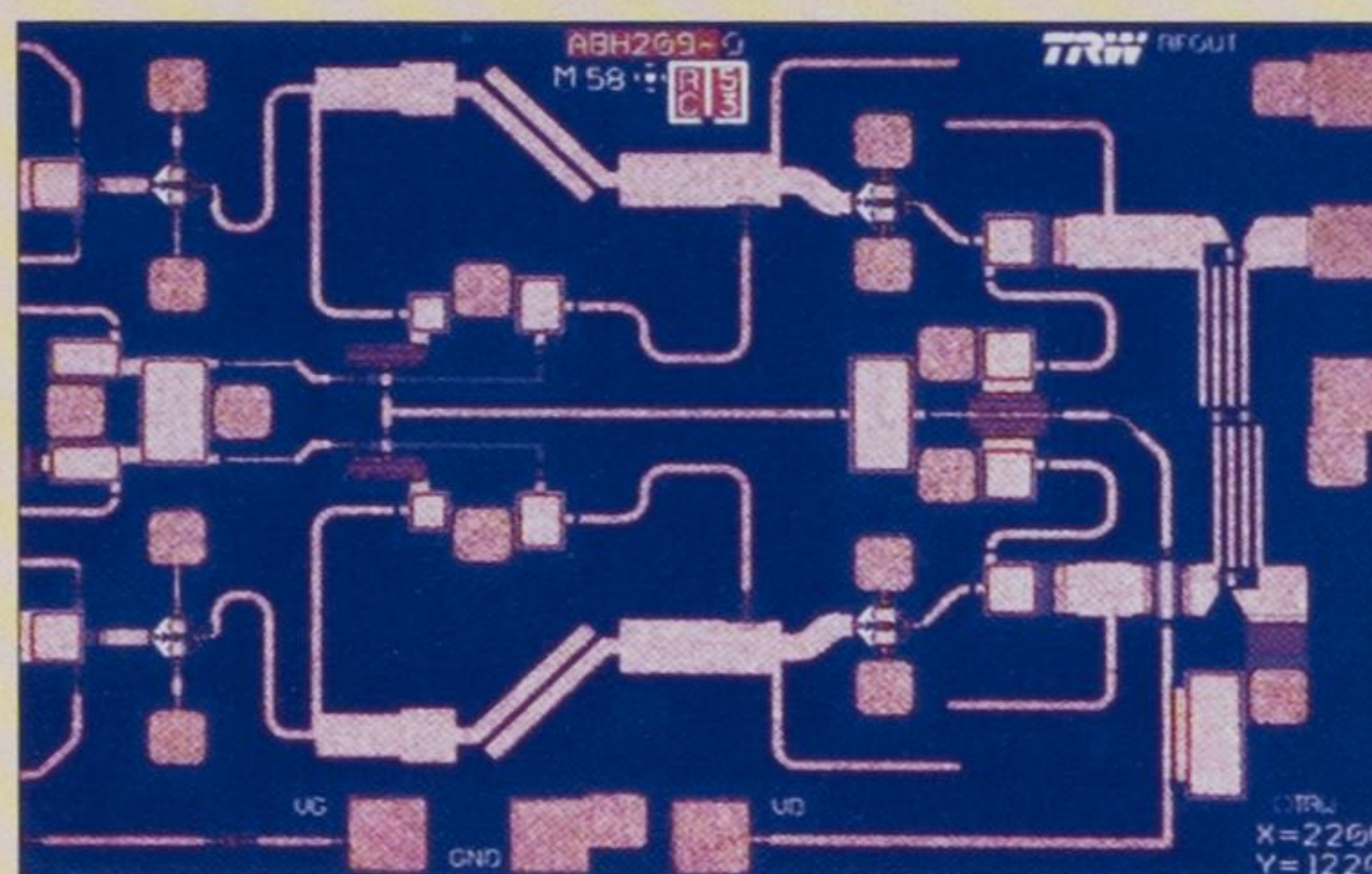
New devices from Mitsubishi, Kyocera, Velocium, Microsemi, Skyworks and Celeritek

Mitsubishi, Kyocera unveil triple-band transmitter

Mitsubishi Electric and Kyocera have introduced an enhanced triple-band GSM/DCS/PCS transmitter module for wireless handsets. The BA01303 module integrates an antenna switch module, RF power amplifier, and RF output power monitor coupler in the same unit. The module occupies 0.1 cm³ and features Mitsubishi's new high-efficiency InGaP HBT MMIC and Kyocera's high Q-factor LTCC substrate and low-loss antenna switch. The power efficiency at the antenna is 43% and 36% for E-GSM and DCS/PCS, respectively. At the PA, this is equivalent to 60% and 56% for E-GSM and DCS/PCS, respectively.

Velocium unveils 60 GHz transceiver chipset

Velocium has unveiled a new chipset operating in the 55–64 GHz frequency range, which is designed for high-capacity, short-haul wireless communications. The new compact chipset employs TRW's GaAs PHEMT technology and consists of a 4x multiplier, LNA and image reject mixer with an IF range of



Part of a 55–65 GHz chipset, Velocium's 60 GHz PA (ABH209) features a linear gain of 11 dB and 18 dBm RF output saturated power.

DC–3 GHz. Two RF switches and an RF power amplifier that is capable of 18 dBm complete the chipset.

Microsemi launches WLAN amplifier for laptops

Microsemi has introduced a two-stage InGaP HBT amplifier targeting WLAN access for laptop computers. In addition to supporting the 5.15–5.85 GHz unlicensed frequency bands, the LX5503E amplifier extends its range to 4.8 GHz in order to accommodate the recently proposed band allocation in Japan. The device consumes 150 mA and provides 21 dB power gain at 5.25 GHz.

Skyworks integrates power control in PA modules

Skyworks Solutions has introduced a new GSM/GPRS 4-band PA module, which is manufactured using its 50 GHz InGaP HBT process. The CX77315 is the first device to employ a current sensing technique for power control, and incorporates the power-control loop into the module to eliminate power-control ASICs. This approach enables the module to be driven directly from the digital-to-analog converter output of the baseband IC.

Celeritek qualifies power amplifier package

Celeritek has qualified its InGaP HBT power amplifier modules in a new laminate-based system-in-package plastic land grid array (PLGA). The PLGA offers improved electrical performance due to the proximity of the surface-mount technology components to the die.

The ICs are mounted on specially designed die flags that employ a PCB thermal via fabrication technology, which is intended to draw heat from the die to the PCB.

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GaAs epiwafer revenues on track for recovery in 2003

A new report by Strategy Analytics says that the market for semi-insulating epitaxial GaAs substrates will begin to recover this year, with sales volumes comparable to those achieved in 2000 being reported by the end of 2003. According to the report "Markets for SI GaAs Epitaxial Substrates: 2001–2006", the market contracted by 27% in 2001 due to a general downturn in the economy and high inventory levels in GaAs fabs.

For the 2001–2006 period, Strategy Analytics expects the market to show a compound annual average growth rate of 28%. However, pricing pressure from end-users will remain intense. Although volumes will increase, the epitaxial wafer market will not return to the \$430 million revenue levels generated in 2000 until 2005 or 2006.

"2001 saw the prices for 6 inch epiwafers drop below \$1000," said Asif Anwar, senior

analyst at Strategy Analytics. "As long as there are no nasty hikes in bulk substrate and raw-material costs, users will expect prices for 6 inch epiwafers to drop below \$700 in three to four years."

The report also includes an analysis of the penetration of InGaP HBTs versus AlGaAs HBTs. InGaP HBTs now account for approximately one-third of HBT epiwafer sales, with MOCVD being the dominant production method. Strategy Analytics expects that the penetration of InGaP HBTs will grow as 2.5G and 3G technologies for mobile phones gain acceptance. These technologies require the improved performance from power amplifiers that the InGaP HBTs are expected to offer. However, the slow rollout of 3G services means that AlGaAs devices are likely to remain dominant until at least 2006.

WLAN technology boosts GaAs IC manufacturers

There's some good news from the research group Gartner Dataquest for GaAs IC manufacturers that are producing devices for WLANs. Gartner Dataquest is forecasting that global unit sales of WLAN systems will increase by 73%, from 15.5 million units in 2002 to 36.5 million units in 2003. However, the manufacturers of ICs can expect pricing pressure from WLAN producers as unit prices will fall rapidly, resulting in revenue growth of only 26%, to \$2.8 billion, in 2003.

WLAN technology is popular with users of portable PCs as they can connect to networks in offices and hotels equipped with WLAN facilities. In 2002 approximately 10% of portable PCs will be shipped with a WLAN card. Gartner estimates that this figure will rise to 31% in 2004.



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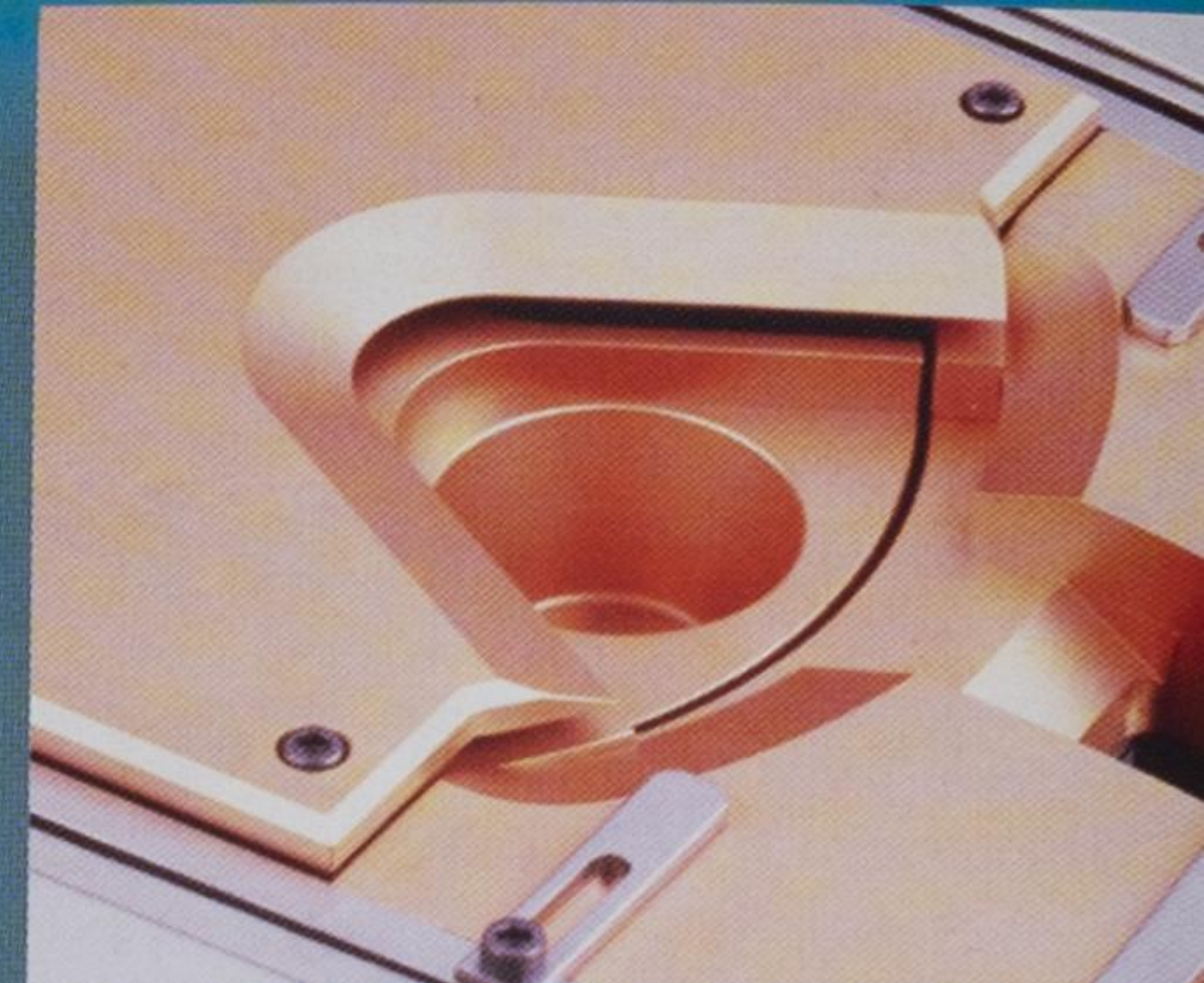
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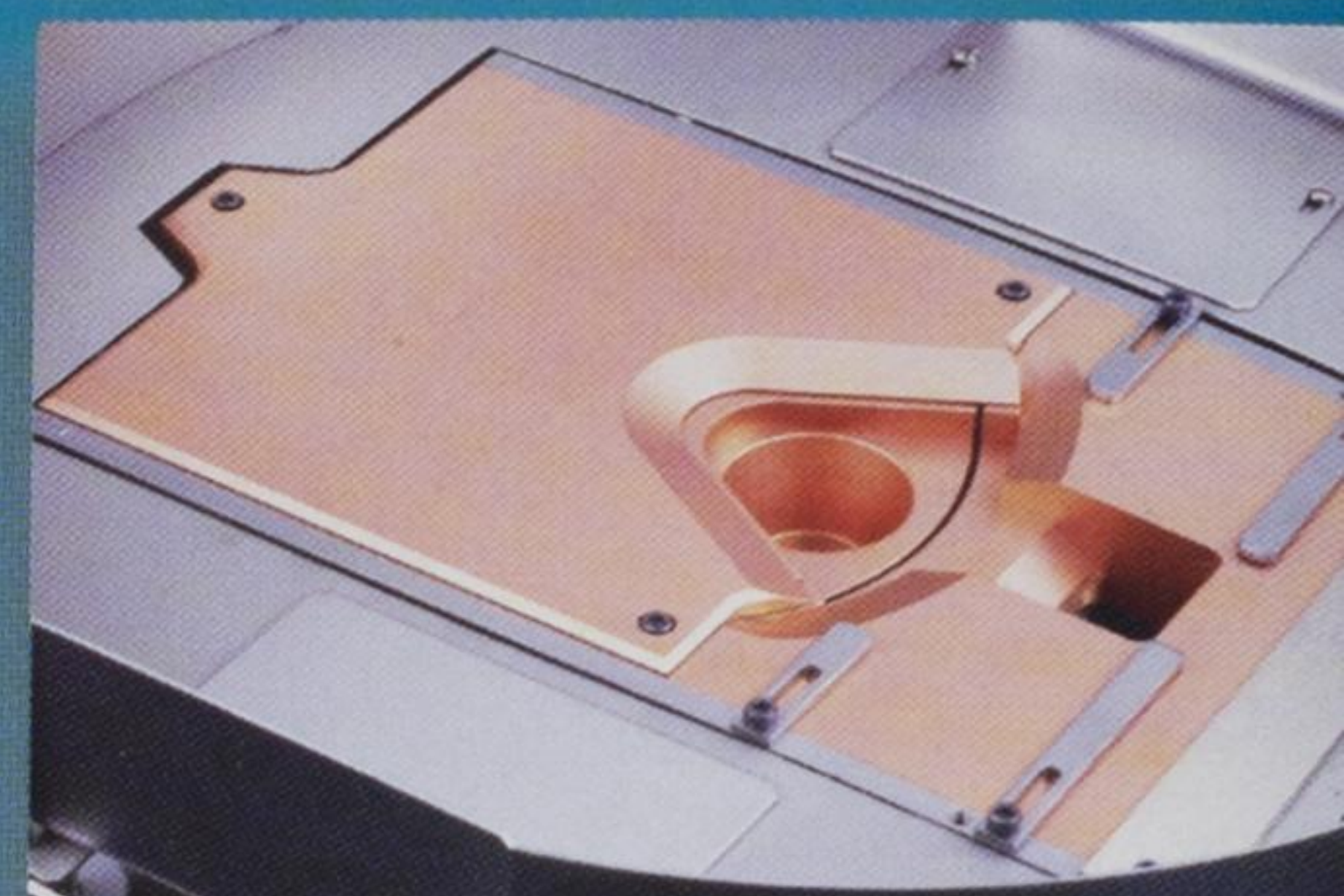
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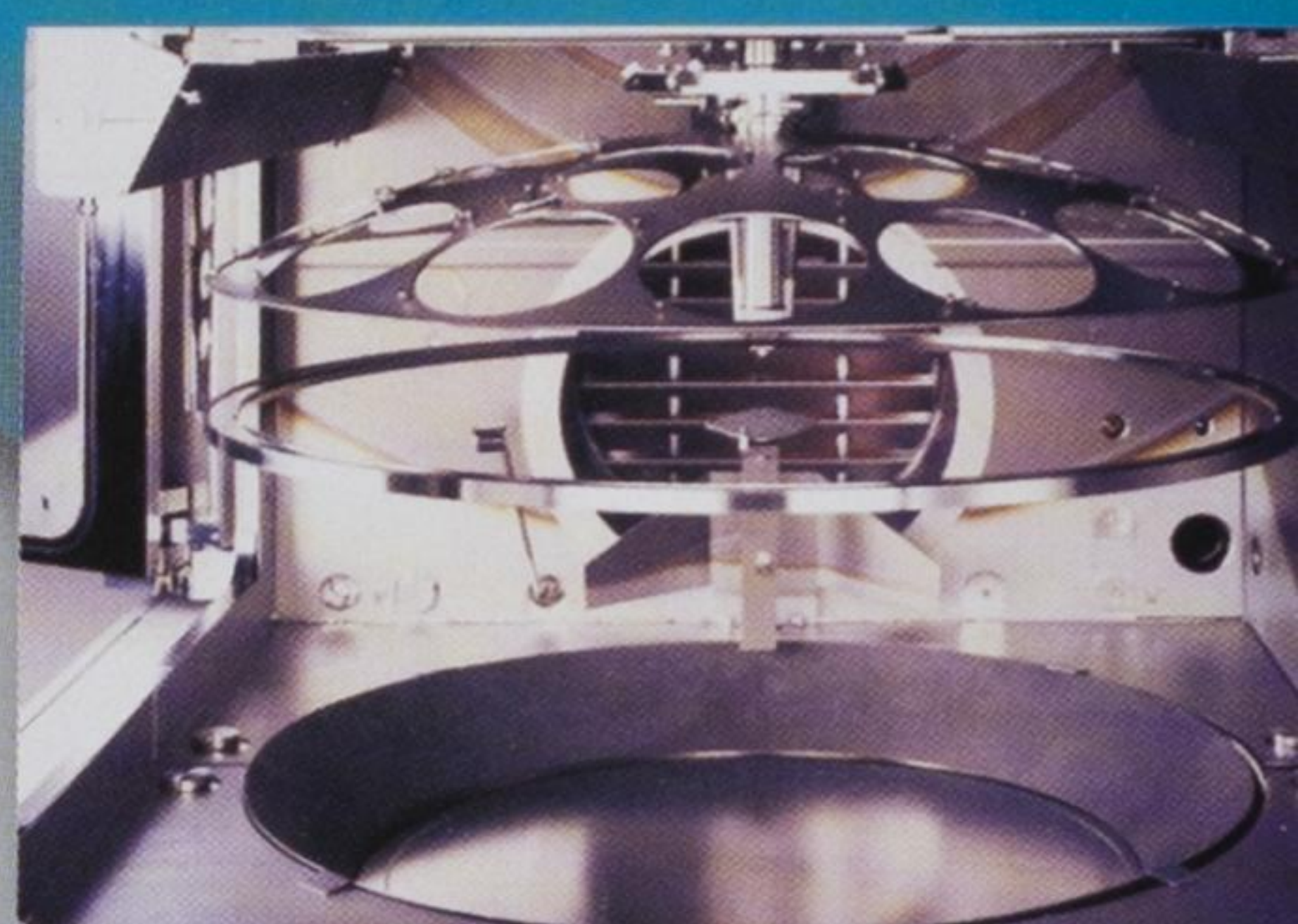
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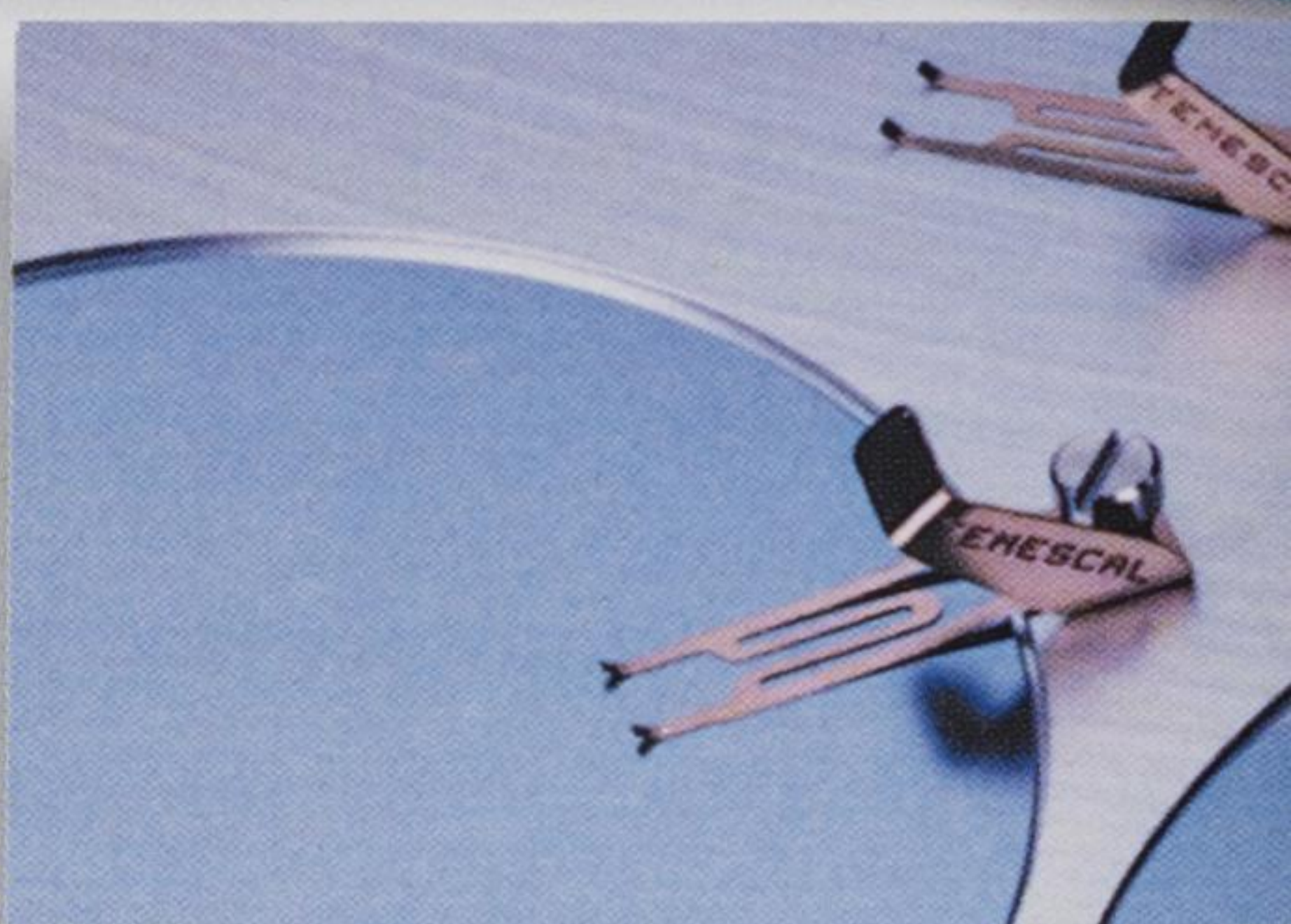
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Consortium boosts white LED performance levels

A group of organizations that are working on the 21st Century Lighting Project in Japan (see *Compound Semiconductor* July 2002 p49) have developed a white LED with an efficiency of 30 lm/W. The new device was fabricated using a 382 nm UV LED and a tri-color (red, green and blue) phosphor, and produced white light with co-ordinates of $x = 0.297$ and $y = 0.362$ on the CIE chromaticity diagram. Mitsubishi Cable developed the UV LED, while Stanley Electric handled the packaging technology and Kasei Optronix provided the phosphors.

The performance of the white LED has been significantly increased by doubling

the efficiency of the red phosphor. Previously, the red phosphor was so inefficient that it accounted for 80% of the phosphor mixture. In the new device, the proportion of red phosphor has been reduced to 40%, meaning that more of the green phosphor can be used. Since the human eye is more sensitive to green, the overall brightness of the white LED is enhanced.

● Toyoda Gosei has also developed a more efficient tri-color phosphor to improve the brightness of its white LED products. The company will begin sample shipments in November, and plans to start mass production in February 2003.

Sony invests in new plant to expand DVD laser production

Sony has recently announced plans to boost its production of red semiconductor lasers for DVD players. The firm will invest around ¥3 billion (\$24 million) to build a new factory at Sony Shiroishi Semiconductor in Migayi prefecture. Construction will begin in October, and the new plant should be in service by summer 2003. Sony is aiming to double its output of 655 nm lasers to 10 million units per month. Sony Shiroishi has operated a laser diode packaging line since 1986, and in 1997 acquired MOCVD capabilities in order to provide a vertically integrated pro-

duction line. The company's accumulated production of laser diodes exceeded 1 billion units in May 2001.

140 mW DVD laser from Mitsubishi

In related news, Mitsubishi Electric has developed a red 658 nm DVD laser with an output of 140 mW, which is suitable for writing speeds of 8× and above. The operating temperature of the device is 75 °C. The company plans to release samples in December, and start mass production of 100,000 units per month in June 2003.

White LEDs replace camera flash tubes in mobile phones

Citizen Electronics has developed two super-bright white LED lamps for use as illumination sources in camera-equipped mobile phones. The products are designed to provide sufficient illumination to record video clips of several seconds in length under dim lighting conditions, something that can not be achieved with conventional flash sources. The small size and low power consumption of the LED sources also make them highly suited for use in mobile phones.

Citizen's CL-460S model contains four white LED chips in a $7 \times 7 \times 1 \text{ mm}^3$ package, while the CL-470S contains between one and three chips in a $3.5 \times 3.5 \times 1 \text{ mm}^3$ package. Samples are currently being shipped at a price of ¥500 (\$4) per unit, and Citizen hopes to eventually sell two million units per month.

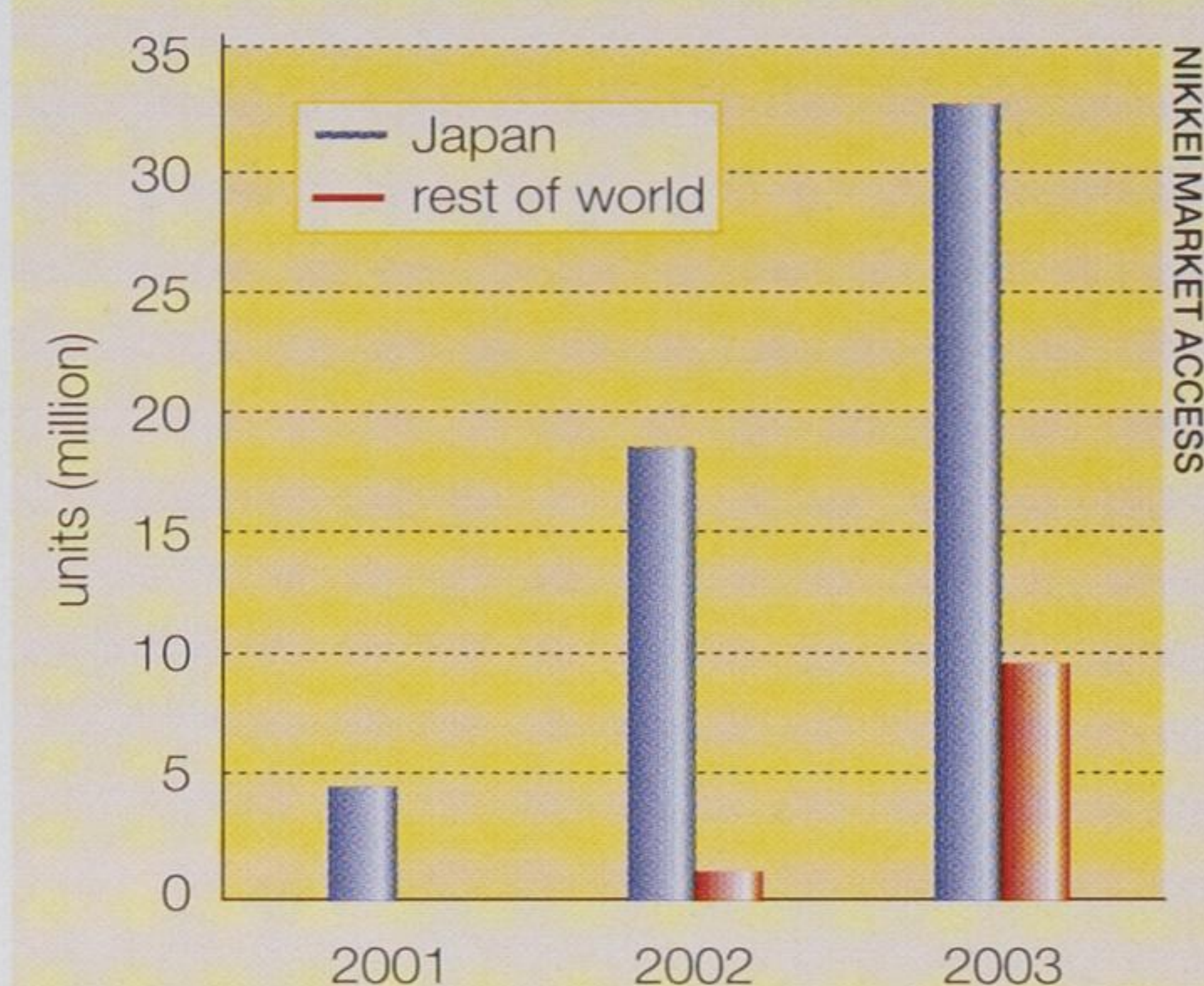
The ultra-thin surface-mount packages (1 mm in thickness) provide a typical light output of 24 lux during pulsed operation (for still image capture) and 8 lux during continuous lighting (for video clips) at a distance of 50 cm.

The products are Citizen's first to be developed since the company announced a packaging alliance with blue LED chip maker Nichia in January of this year.

Alliance to develop white LED products

Taiwan's Ministry for Economic Affairs (MOEA), in co-operation with 11 LED chip and package manufacturers including Ledtech and Everlight, has launched the Next Generation Lighting Source R&D Alliance. The program aims to promote collaboration between the government and the LED industry, in order to develop next-generation white LED lighting technology products.

Cameras and printers in phones



Sales of camera-equipped phones.

● Nikkei Market Access estimates that the production of camera-equipped mobile phones in Japan will increase four-fold in 2002, rising to almost 18.9 million units (see graph). This represents 46% of all phones manufactured in Japan, a figure that will rise to 81% next year. Production of camera phones outside Japan is predicted to rise to 9.45 million units in 2003.

● Sharp Corporation has obtained an order from Vodafone to supply 1 million cellular phones with built-in cameras. Vodafone will offer the phones to subscribers in seven major European countries, including the UK, France and Germany, where it will start a service to send both photos and messages via cell phones this fall.

● Mitsubishi Electric has developed a small photograph printer that could be incorporated into a digital camera or cellular phone. The company intends to begin marketing the printer in two to three years. The printer contains three LEDs (red, green and blue) and color develops on the paper depending on the intensity of the light.

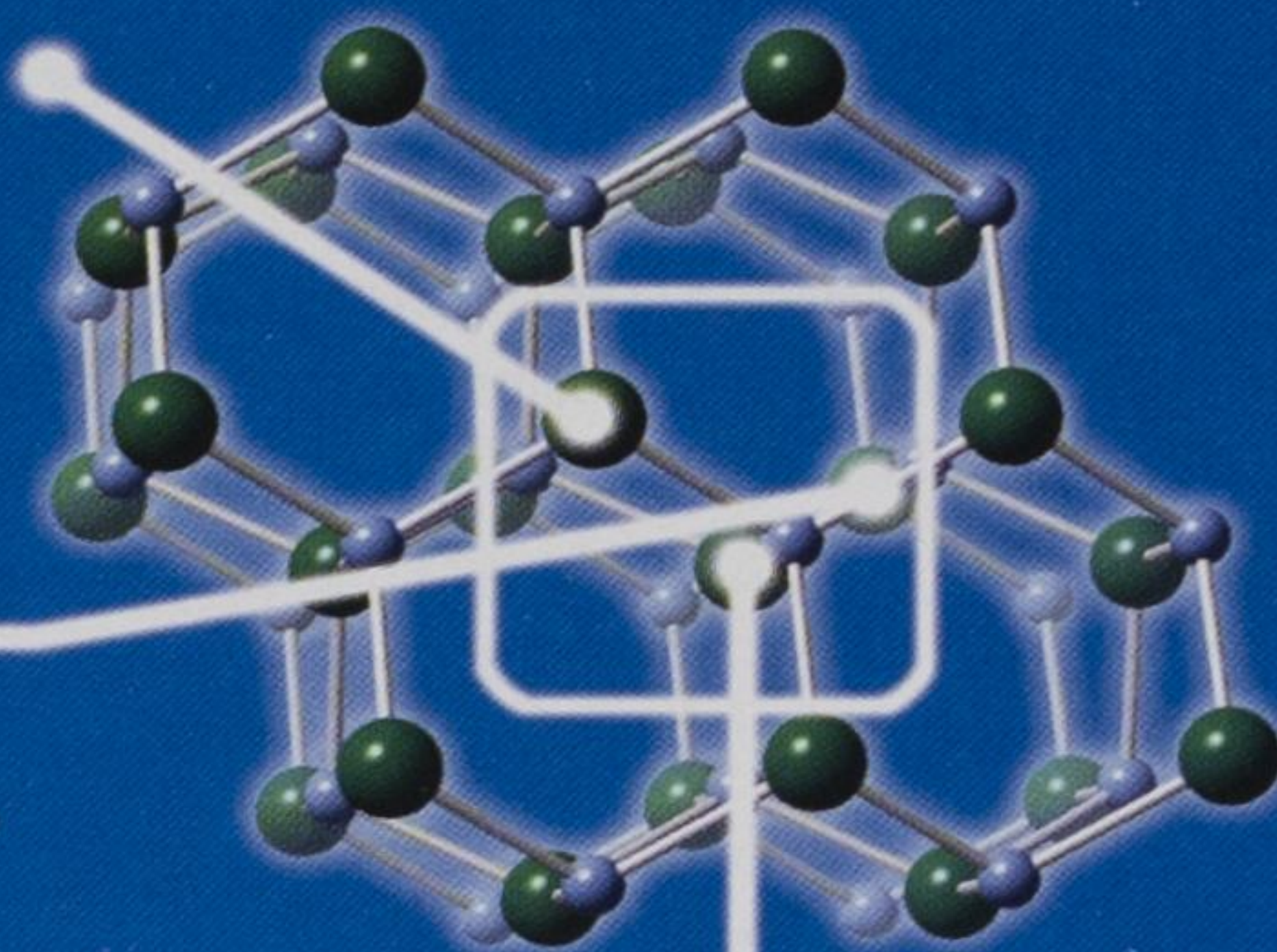
Procomp forms two business divisions

Taiwanese company Procomp is to split into two business operations; a mobile solution division and a GaAs compound semiconductor division. The latter group will comprise Procomp Informatics, a manufac-

turer of epiwafers for microwave applications, and Suntek Compound Semiconductor Corporation, a microelectronic and optoelectronic device foundry.

In more news, Procomp has formed a strategic alliance with Sumitomo Electric Industries. The companies intend to focus on LEDs through their joint venture company, Procomp-Sumitomo Opto Corporation.

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White LED prices set to fall even more

As demand for white LEDs in mobile phones continues to grow, LED makers are facing pressure to lower their prices. The standard price for a white LED lamp, used in Japanese mobile phones as a backlight for the color liquid-crystal display (LCD), is ¥70 (around 56 cents). This price has fallen by about ¥10 (14%) since the start of the year. Phone makers are apparently asking white LED suppliers such as Nichia and Toyoda Gosei to lower their prices by a further 10% for the final quarter of this year. In comparison, Samsung has negotiated a price of NT\$3.1 (around 9 cents) per unit for blue LEDs supplied in high volume by Taiwanese manufacturers.

Although prices are falling, the number of LEDs used in mobile phones is growing. For example, the NTT DoCoMo 504i series uses 10 blue LEDs to illuminate the keyboard, while the number of white LEDs used to light the LCD screen has increased from two or three to at least four, in order to realize a brighter appearance.

Nitride devices

NIMS to grow LEDs on ZnO

The National Institute of Materials Science (NIMS) in Japan has begun a three-year program to develop a new low-cost blue LED. The plan is to grow GaN-based devices on single-crystal ZnO using a buffer layer to be developed by NIMS. The ZnO substrates will be supplied by Tokyo Denpa, which plans to establish a production capability of 300 2-inch substrates per month.

Sharp plans LED launch

Sharp has elaborated on its plans to introduce GaN-based lasers and LEDs. The company expects to start mass production of blue-violet lasers in late 2003 (see *Compound Semiconductor* September 2002 p25), and will also start the trial production of blue LEDs next year, with mass production slated for 2004. Two MOCVD machines are currently being installed to grow lasers on both sapphire and GaN substrates, and the company plans to install at least five more machines in the next few years.

RF Micro Devices invests in Jazz

GaAs HBT manufacturer RF Micro Devices has formed a strategic relationship for silicon manufacturing and development with Jazz Semiconductor, an RF and mixed-signal silicon wafer foundry. Furthermore, RFMD will invest \$60 million in Jazz to acquire a minority equity position in the company. Jazz was spun off from Conexant in February 2002, and is majority owned by the Carlyle Group.

As part of the deal, RFMD will obtain a guaranteed, lower cost supply of wafers fabricated using Jazz's processes, including SiGe, BiCMOS and RF CMOS. RFMD will also collaborate with Jazz on the development of wireless technology roadmaps, including joint process development and optimization for the fabrication of next-generation silicon RFICs. The arrangement should help RFMD develop proprietary mixed-mode silicon technologies for its system-on-chip integration roadmap.

"Jazz is a leader in advanced SiGe BiCMOS and RF CMOS manufacturing processes, with substantial state-of-the-art silicon foundry

resources," said Jerry Neal, executive VP of strategic development and RFMD co-founder, who will join the Jazz board. "We believe this strategic relationship strengthens our competitive position as an integral part of our customers' supply chains, by providing us with a guaranteed source of supply for high-performance silicon products."

RFMD expects that its lower cost structure will enable cost reductions across its silicon product portfolio, while facilitating expansion in new markets and generating incremental growth opportunities in current markets, such as IEEE 802.11. The company has an in-house manufacturing capability for GaAs HBT products and uses external foundries for CMOS, SiGe and GaAs MESFET products.

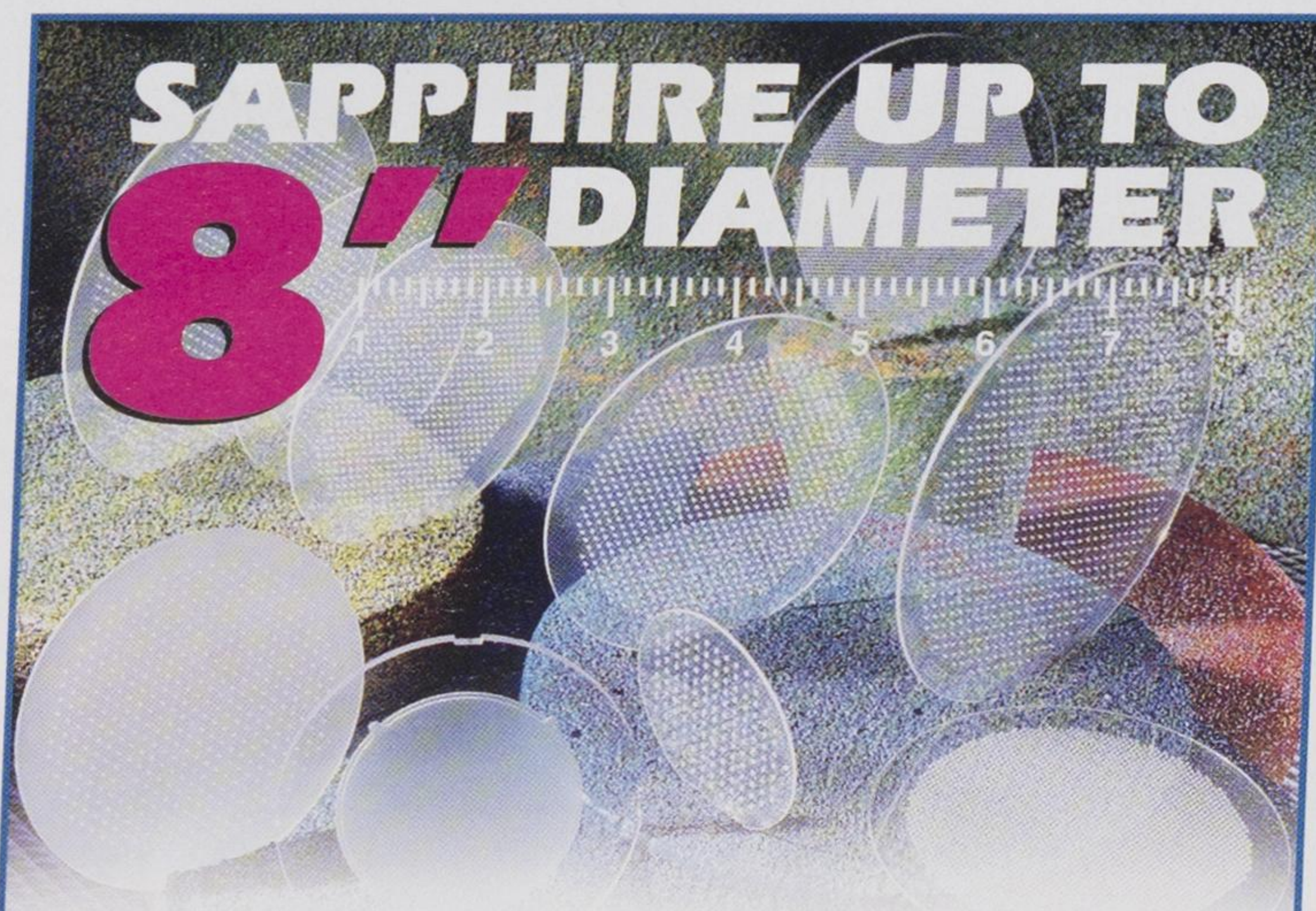
"Many of the millions of PA modules we ship each month contain the industry's most advanced power control circuitry, manufactured using high-voltage CMOS processes currently sourced through traditional foundry relationships," said Neal.

Motorola improves its SiGe:C process

Motorola's Semiconductor Products Sector has improved its 0.18 and 0.35 μm SiGe:C HBT technology. The improved process is expected to provide longer battery life and longer talk times for portable products including cellular phones.

Motorola's process integrates a high-performance HBT with CMOS analog and digital functions on a single chip. Cutoff frequencies have been improved from 50 to 80 GHz for the 0.35 μm BiCMOS process, and to 120 GHz for the 0.18 μm BiCMOS process, with a reduction in minimum noise figure from 0.9 to 0.3 dB. This performance was realized through vertical and lateral scaling of the transistors.

"Our full suite of passives, along with RF/analog MOS and optimized SiGe:C, are designed to enable new products while allowing current reduction in existing products," said Vida Ilderem, director of RF/IF silicon technologies for Motorola.



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Soitec strengthens R&D partnership with LETI

Soitec, a French manufacturer of silicon-on-insulator (SOI) wafers, has augmented its R&D partnership with French research laboratory LETI, in order to develop new applications for Smart Cut layer-transfer technology beyond silicon and SOI.

Smart Cut is a process used to transfer ultra-thin silicon layers from a handle wafer to another surface. During SOI wafer manufacturing using the Smart Cut process, a silicon wafer is oxidized, implanted with hydrogen ions and bonded to a second silicon wafer. The wafers are then separated along the cleavage plane formed by the implanted ions, leaving

an SOI substrate and a reusable silicon wafer.

As part of the Smart Cut-Enabling Application Laboratory (SCEALAB) partnership, Soitec and LETI will enhance their existing collaborative R&D efforts. Soitec will also gain exclusive rights to LETI's intellectual property relating to Smart Cut technology, to target materials such as SiC, SiGe, sapphire and III-V materials.

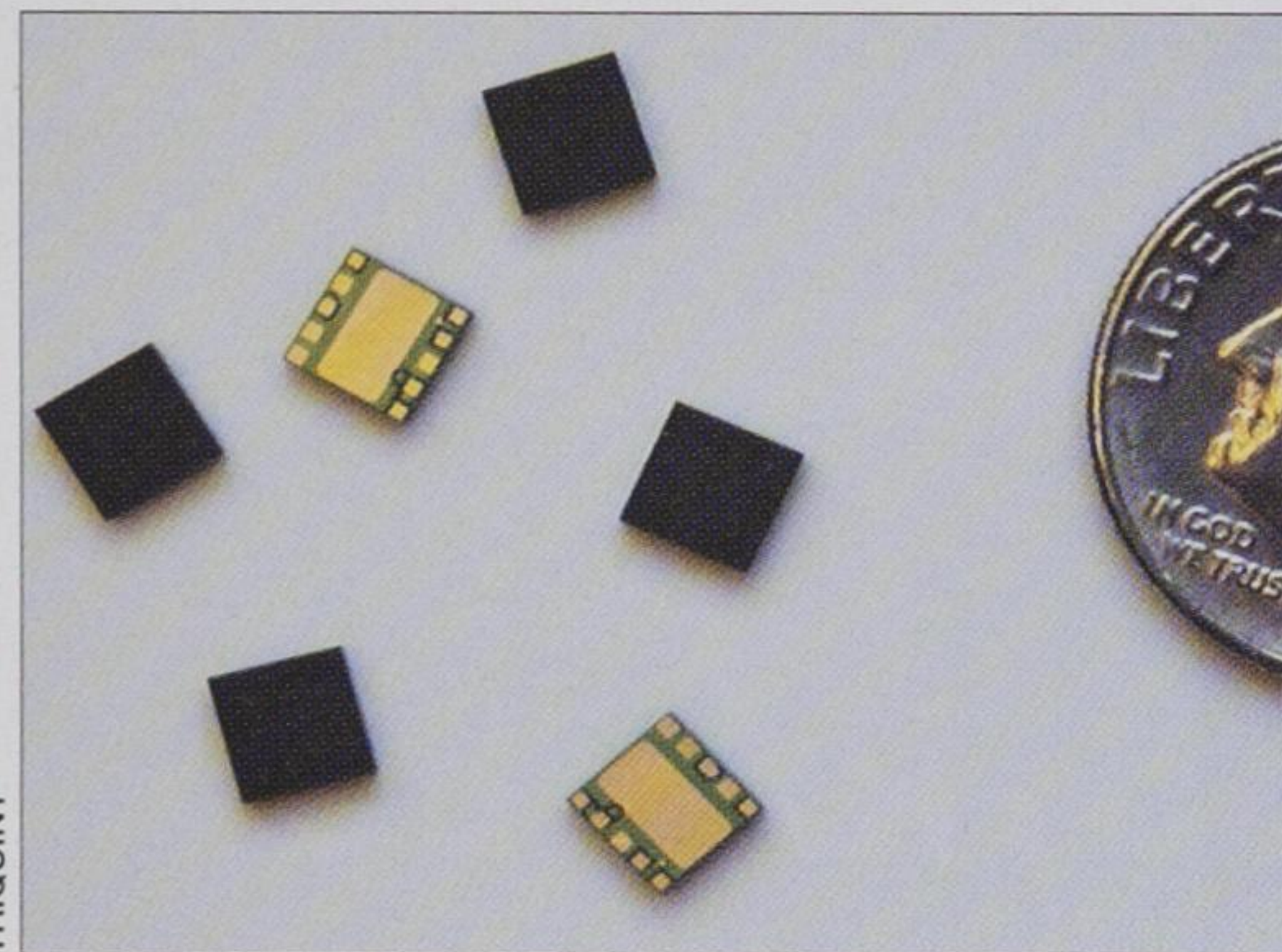
The extension of the Smart Cut technology to new composite-material substrates is now well under way. According to Carlos Mazure, Soitec's CTO, the technology enables more efficient and optimized use of ex-

pensive compound material wafers.

"Innovation has always been the driving force behind Soitec's development efforts, which have included the testing and evaluating of new materials for tomorrow's markets," said Mazure. "This extended partnership with LETI gives us access to an already established state-of-the-art infrastructure and proven analytical tools, providing us with significant time-to-market advantages."

The SCEALAB R&D activity will be conducted in LETI's facilities in Grenoble, as well as in Soitec's new state-of-the-art R&D facility in Bernin, France.

TriQuint and Atmel unveil SiGe modules



New SiGe CDMA PA modules, which are manufactured by Atmel for TriQuint.

TriQuint has introduced a pair of CDMA PA modules manufactured using SiGe. The devices were developed under the CDMA345 program with Atmel, and aim to minimize the average current consumption for power-intensive data-enabled phones. The TQM7138 (cellular band) and TQM 7638 (PCS band) modules deliver efficiencies of 35% and 31%, respectively, and draw less than 100 μ A current. The nominal output power is 28 dBm for both devices.

Atmel has also unveiled two SiGe PA modules developed under the CDMA345 program with TriQuint. The T0372 (cellular band) and T0377 (PCS band) modules have efficiencies of 36% and 31%, respectively, and output powers of 28 dBm. In common with TriQuint's PA modules, the Atmel parts can be interfaced directly with low-voltage CMOS microprocessors without the need for additional circuitry.

IBM, RPI form broadband center

IBM is partnering with Rensselaer Polytechnic Institute (RPI) to form an R&D center to develop broadband data transport technology. IBM will contribute \$33 million to the Center for Broadband Data Transport Science and Technology, to develop infrastructure for optical and electrical data transport, switching, and processing for future information technology systems. As well as RPI, faculty members from SUNY Albany, CCNY and Cornell University will also be involved.

According to the new center's director, Michael Shur, computers will control many processes and appliances in future homes, and this will require seamless interface technology such as voice operation, together with bandwidths many orders of magnitude higher than current capabilities.

"The computing power to operate such functions is already here, but the data transport is not yet well developed," said Shur. "We need to look at optical and electrical data transport, switching and processing to enable the massive scaling that will be required by these new information technology systems. Achieving these goals will not be possible without SiGe technology and compound semiconductors."

The new center will be based at RPI in Troy, NY. Basic and applied research will target broadband circuits and links, including high-speed analog ICs for broadband transmission, coding, compression and error correction algorithms. In addition, the group will examine digital circuits, and develop photonic device modeling, simulation and CAD tools. Fundamental studies will include device-

circuit interactions and interconnect issues, device and system characterization, and testing. Other key areas include layered optical waveguides and vias, and chip-to-chip optical communications on multi-chip modules. Automation methods will provide low-cost packaging for these modules.

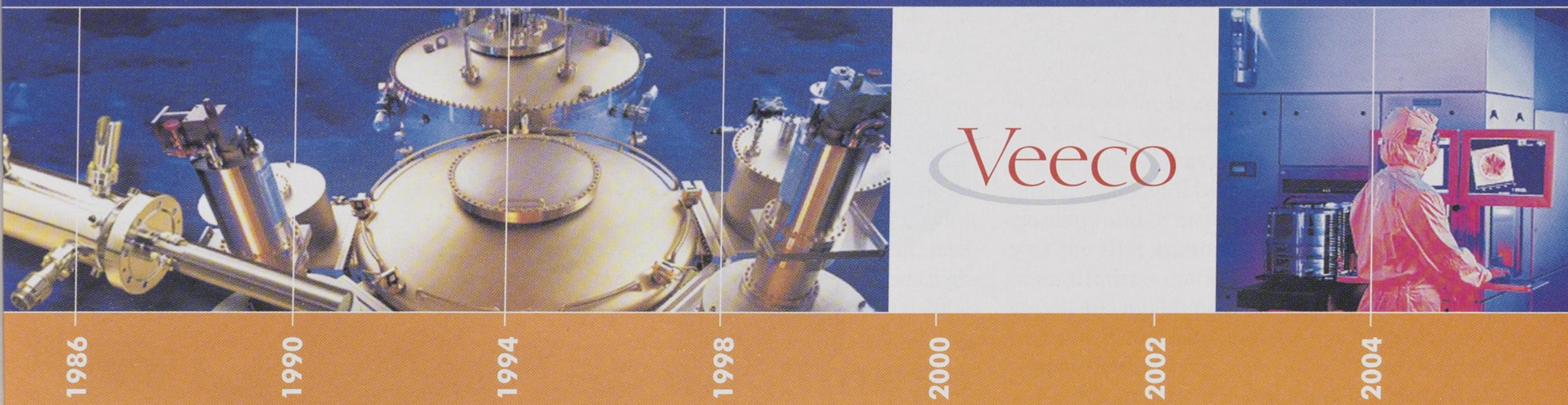
RPI carries out IC research at an 8500 sq. ft micro-fabrication facility with a class 100 cleanroom. As part of the deal, RPI will also gain access to IBM's foundry, including the company's Si CMOS and SiGe BiCMOS processes designed for RF applications. An upgrade of RPI's facilities is planned during the first phase of the venture, including the installation of approximately \$3.7 million worth of 8 inch processing equipment.

Future role for III-Vs

While the main emphasis will be on the development of silicon and SiGe ICs, Shur says that materials, processes and integration schemes will also be developed for compound semiconductors on silicon, in addition to wide-bandgap devices such as those based on GaN for communications and interconnects. Nitride research will be led by the School for Nanotechnology at SUNY Albany. The center will also address a number of limitations with short-range parallel optical systems, including efficient thermal management, internal laser modulation in excess of 10 Gbit/s instead of using external modulators, and improved laser efficiency and reliability at elevated temperatures. Shur says that this work could lead to a research-scale compound semiconductor line at the center.

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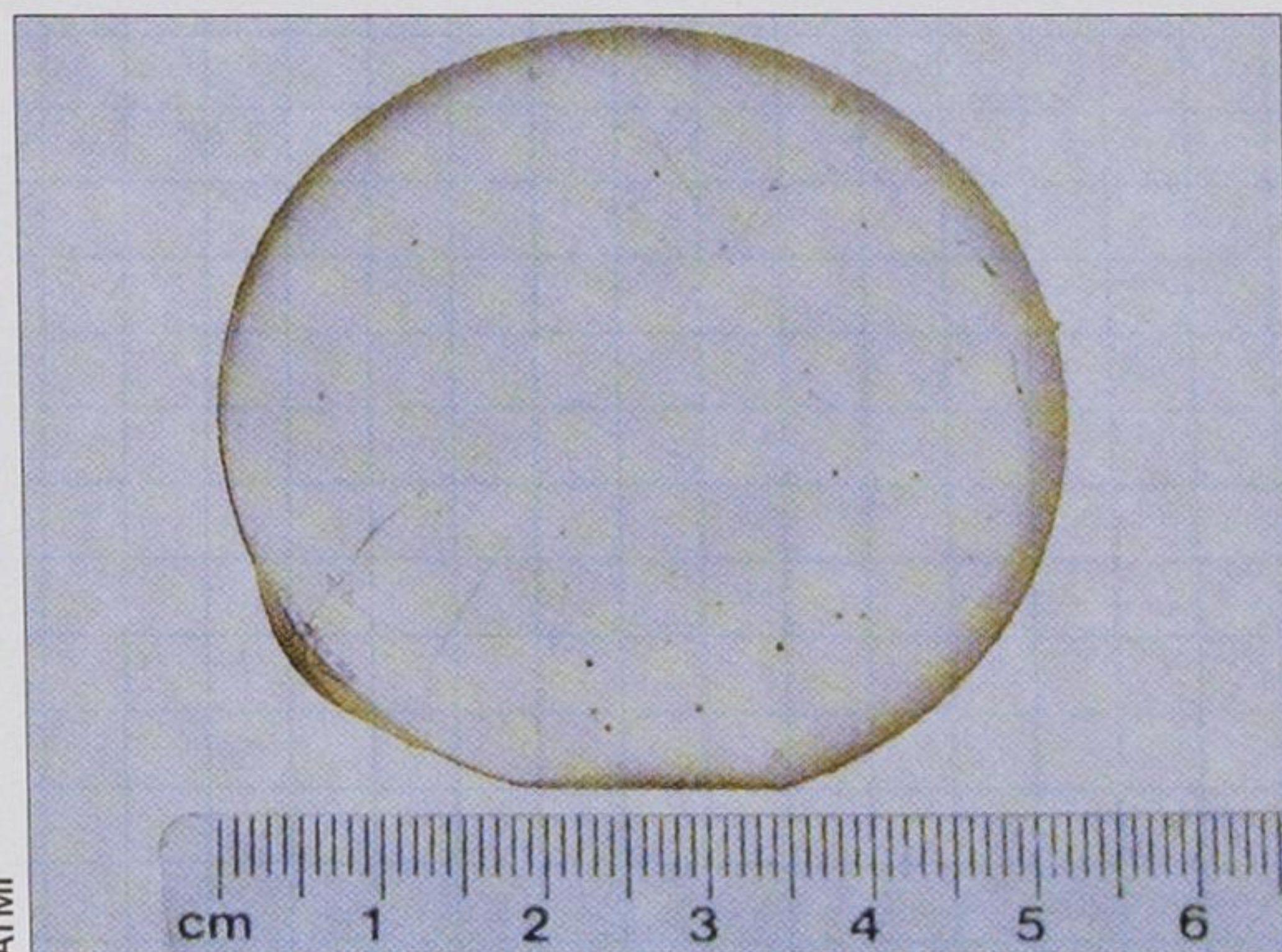


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ATMI wins nitride research contract

ATMI has received a boost to its nitride substrate and epitaxy development activity by winning an R&D contract from the Office of Naval Research. The contract, worth \$9.5 million, is for the development of highly uniform, robust, AlGaIn/GaN HEMTs on 4 inch GaN and SiC substrates. The award is part of DARPA's Wide Bandgap Semiconductor Technology Initiative (WBSTI) – see p43.

The work at ATMI will involve the development of bulk growth techniques for large-area semi-insulating GaN substrates and for highly uniform GaN and AlGaIn epitaxial processes. The contract will run for 18 months, with an option to extend the



A state-of-the-art 50 mm GaN substrate produced by ATMI. DARPA wants the substrates to be bigger, better and cheaper.

work for a further six months.

ATMI will not work alone on the project. DARPA requires its WBSTI contractors to work closely with others in the development of materials and processes (see p43). ATMI's subcontractors in the new project will include NIST, the State University of New York at Stony Brook, and TRW for materials characterization. TRW will assess ATMI's material through device fabrication and testing. Others working closely with ATMI on the contract include TriQuint and Raytheon, which will also provide device fabrication and testing services, and Sterling Semiconductor, which will supply SiC substrates.

ESA awards SiC project to Umicore

Belgian materials company Umicore has signed a co-funded research contract with ESTEC, the research and technology center of the European Space Agency (ESA), for €3.7 million (\$3.66 million). The contract creates a framework for the joint development of SiC substrates to be used in high-power electronic devices.

The project broadens the collaboration between Umicore and ESA, which already includes the development of Ge substrates for space solar cells. According to Umicore, satellite communications is a fast-developing appli-

cation that is demanding smaller devices operating at higher powers than current Si LDMOS or GaAs devices. GaN-based devices grown on SiC substrates could meet this demand.

The program will concentrate on developing SiC substrates with high crystalline perfection and minimum surface defects. The work will also prepare the technological platform for Umicore's future presence in the SiC market. In June, Umicore's proposal to buy SiC substrate and epiwafer supplier Sterling Semiconductor from Uniroyal fell through. At present Umicore is developing both crystal growth and manufacturing technology for mono-crystalline SiC substrates. The SiC facility is currently a pilot-scale operation and high-quality substrates are expected by mid 2003.

AXT boosts blue LED brightness

AXT has announced significant brightness improvements to its production blue LEDs. The new M9 series is designed for surface-mount packages, which are typically used for LEDs in display backlighting for cellular phones, PDAs and other electronic devices.

According to AXT product manager Dan Geckman, the output of the surface-mount devices is given in candela, a measure of luminous intensity in a given direction, instead of radiant power (in mW). For display backlighting, the candela is a more useful gauge than radiant power.

"The output of these new LEDs is measured using the light emitted near the on-axis direction, as light emitted from the edges is not used in backlighting applications," said Geckman. "Our customers tell us that for

these applications, the new devices are approximately 50% higher in output than our previous products. In terms of radiant power, they are around 20% brighter compared with our previous generation LEDs."

The M9 series of InGaIn/GaN-on-sapphire chips has the same $325 \times 375 \mu\text{m}^2$ chip dimensions as AXT's previous C2 generation of LEDs. The devices feature a modified bond pad arrangement and improved epitaxial structure. Luminous intensity is 50 mcd for 460 nm devices, increasing to 85 mcd at 480 nm.

The forward voltage of the M9 series is 3.3 V. The M9 LEDs are currently sampling with customers and will be available in production volumes from late 2002. AXT will extend the brightness improvements to its green and cyan LEDs in the near future.

Nichia introduces new UV laser diode

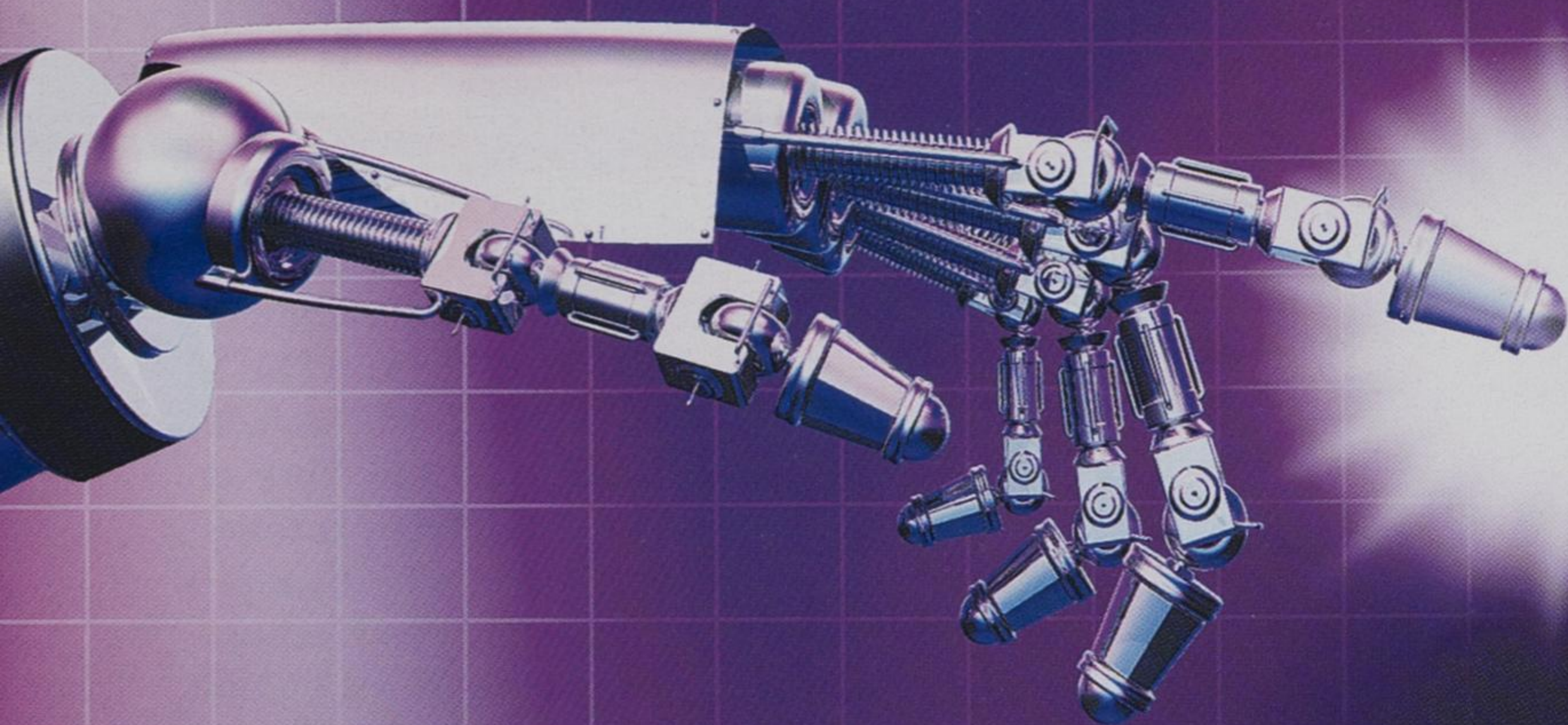
Nichia has announced that it is to begin sampling its first UV laser diode product. The new laser is specified as having a typical peak wavelength of 375 nm with an output power of 2 mW. The typical threshold current is 45 mA and the operating voltage is 4.5 V.

Nichia is the first company to announce the commercial availability of a UV laser diode, which will have applications in spectroscopy and in material processing. Nichia was the first company to pass the 10,000 hour lifetime mark for the longer wavelength 405 nm blue/violet lasers, which will be used in the new generation of optical storage devices.

Further into the UV spectrum, Nichia has also recently announced that it is to begin sampling a 365 nm LED sometime in early 2003. The UV-LED has an output power of 100 mW at a drive current of 500 mA at 4.6 V. The device is expected to find applications in medical equipment, analyzers and in photocatalysis.

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BOOK REVIEWS

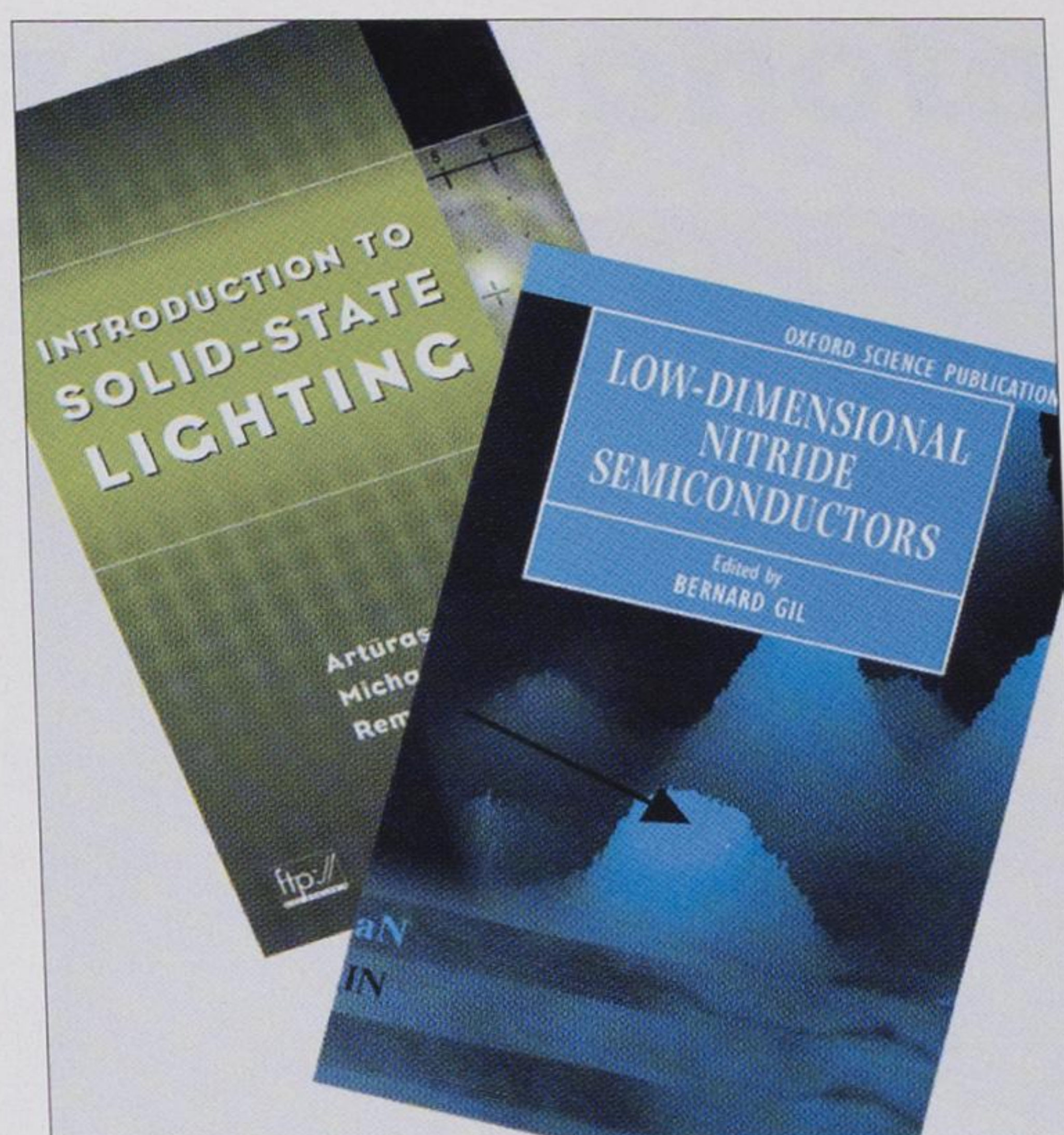
Introduction to Solid-State Lighting

As has been discussed extensively in *Compound Semiconductor* magazine, solid-state light sources based on high-brightness LEDs have the potential to revolutionize the lighting industry. In *Introduction to Solid-State Lighting* the authors treat the emerging LED lighting market as an integral part of the overall lighting industry.

After a historical overview, the book discusses some of the fundamentals of lighting, including human vision, photometry, colorimetry and color rendering. To place LED-based lighting in the context of the lighting industry as a whole, the book describes existing light sources, such as incandescent filament bulbs, fluorescent lamps, high-pressure discharge lamps etc, and compares the "cost of light" from such sources. This is estimated from the cost of the lamp and the power consumed, divided by the number of lumens produced over the life of the lamp.

The book then switches to solid-state lighting, discussing emission and light extraction from LEDs in the various materials systems (AlGaAs, AlGaInP and AlGaInN), and describing "tricks" such as shaped chips, resonant cavities and even photonic crystals.

The ultimate goal of solid-state lighting is to create white light sources that can challenge



(and eventually replace) existing sources. One of the issues in fabricating phosphor conversion or multichip LEDs that emit white light is the trade-off between luminous efficacy and color rendering. The book finishes with a detailed description of solid-state lighting applications, including traffic lights, signage and displays, medical and biological applications, and, of course, illumination.

A Žukauskas (Vilnius University, Lithuania),
M Shur (Rensselaer Polytechnic Institute) and
R Gaska (Sensor Electronic Technology Inc).
2002 John Wiley & Sons, ISBN 0-471-21574-0.

Low-Dimensional Nitride Semiconductors

In the four years since the same editor completed a book on group-III nitride semiconductors, a huge amount has happened in the nitride field. Nichia achieved a lifetime of 10,000 h for a violet laser and subsequently commercialized the device; blue, green and even white LEDs are now widely used in a variety of applications such as mobile handsets; and considerable progress has been made in solar-blind UV detectors and high-power transistors.

Much of the recent progress is due to an extensive utilization of low-dimensional micro- and nano-structures in nitride devices, hence the title of the new book. In fifteen chapters, written by experts in the nitride field, the book explores many of the issues surrounding the nitride material system. A review of the markets for nitride devices and a chapter on how solid-state properties can be predicted from first-principles calculations are followed

by several chapters on growth. These cover homoepitaxial growth on bulk GaN, HVPE-grown quasi-substrates, and growth by both MOCVD and MBE.

Topological defects, excitons, the optical properties of quantum dots and quantum wells, and electron-phonon interactions are all covered in detail. Particular attention is paid to the optical properties of InGaN layers, found in the active regions of blue, green and white LEDs and violet lasers. Several chapters cover devices including GaN-based modulation-doped FETs and optoelectronic devices, and the final section deals with III-V-N alloys such as GaInNAs.

There still remains a great deal to learn about nitrides, not least a clear and unified understanding of the origin of optical effects in InGaN. This book goes a long way to describing the current state of understanding.

Bernard Gil (ed), CNRS Université de Montpellier II. 2002 Oxford University Press, ISBN 0-19-850974 X.

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Intel capitalizes on photonics market

By Michael Hatcher

It has spelt big trouble for many firms in the photonics industry, but one beneficiary of the great telecom crash could be Intel, the world's largest chipmaker. Intel has been steadily moving into photonics territory over the last few years. Intel Capital, the company's venture arm, has invested in a large number of companies throughout the telecom supply chain, including component makers such as Avalon Photonics, CyOptics, Nova Crystals, Novalux and VSK Photonics. Even in 2001 Intel Capital plowed over \$40 million into more than 15 start-ups working in optical communications.

In April 2001 the parent company acquired LightLogic, a fiber-optic transceiver manufacturer. Then, in May this year, Intel made a key move when it bought the tunable laser business of New Focus for \$50 million. And in September, Intel acquired key assets and intellectual property from Sparkolor, a fledgling tunable-laser manufacturer (see box).

Tunable technology is central to Intel's photonics strategy. Mark Christensen, director of communications sectors at Intel Capital, believes that tunability will be a key part of any recovery in the optical telecom sector. "We think that the next big wave of optical modules will be based on tunable lasers, and that's the direction we're heading in," he said.

In fact Intel has already launched an 8-channel tunable optical transceiver. Introduced at the beginning of September, the 10 Gbit/s TXN13500 transceiver is designed for DWDM transmission over up to 80 km, and contains a temperature-tunable DFB laser.

Bigger than JDSU

The recession is likely to be beneficial for the parent company. "The industry is still burning off inventory, still consolidating and a lot of companies are going out of business," said Christensen. "Companies like Lucent or Alcatel don't want to buy modules from a company that may go out of business in a year – most start-ups have less than a year's funding left, and that plays into the hands of bigger companies like Intel and JDSU."

Does Intel intend to become as big a photonics player as JDSU? "Sure, we'd like to be that big, although we probably wouldn't want that many product lines," said Christensen.

However, Intel has no plans to open a fabrication plant of its own to churn out active

devices. "We would only move into device production if it was to make a very specific set of components that are used only in our transponders and higher level components," Christensen explained. "The nature of the optical industry is of many device types

"We think that the next big wave of optical modules will be based on tunable lasers, and that's the direction we're heading in."

produced in low volume for specialized applications – that's not something that Intel is good at. We want to work with the people who are making innovative, active devices based on III-V materials." Intel has already strengthened its co-operation with component manufacturers in Taiwan (see *Compound Semiconductor* August 2002 p24).

While the parent company may be picking up useful acquisitions on the cheap, Intel Capital-funded start-ups have suffered like any others. For the time being, the primary need is simply to keep these start-ups alive. "There's not a lot of revenue, so we've been working with the companies to get their cash-burn down, to keep them alive as long as possible," said Christensen.

From an investment point of view, Intel Capital now appears somewhat cautious. Tim Keating, managing director of Intel Capital Europe, said: "We will be very, very selective. We are looking for complementary and breakthrough technologies – things that will get us closer to this ideal of integration."

In the short-term, further acquisitions seem more likely. With plenty of companies available at bargain-basement prices in the depressed telecom components business, Intel is set for rich pickings.

Michael Hatcher is technology editor of Opto & Laser Europe magazine. Web optics.org.

Intel buys Sparkolor laser technology

Sparkolor, a start-up that developed tunable optical networking components and modules, sold its Planar Hybrid Integration (PHI) technology to Intel in a deal finalized on September 4. As part of the deal, Intel acquired almost all of Sparkolor's assets and intellectual property, along with certain key personnel, who are being transferred from Sparkolor's facility in Santa Clara to Intel's Photonic Technology operation in San Jose, CA.

Sparkolor's PHI technology allows various materials such as silica, InP and polymers to be combined onto a single silicon chip. Last year, Sparkolor demonstrated a tunable laser operating across 26 channels with 25 GHz channel spacing

(*Compound Semiconductor* January/February 2002 p16). The device was a hybrid DBR laser, in which the various components of the device were built from different materials, allowing each part to be optimized separately without requiring performance tradeoffs.

However, it is not clear whether Intel is interested in Sparkolor's tunable laser; some reports suggest that thermally tuned, polymer-enhanced gratings were the real target. Intel already owns tunable external-cavity laser (ECL) technology acquired from New Focus, in which the output from a standard Fabry–Perot gain chip is tuned using a movable mirror. However, Intel's first tunable transceiver, which

was introduced in September, is based around a temperature-tuned DFB laser.

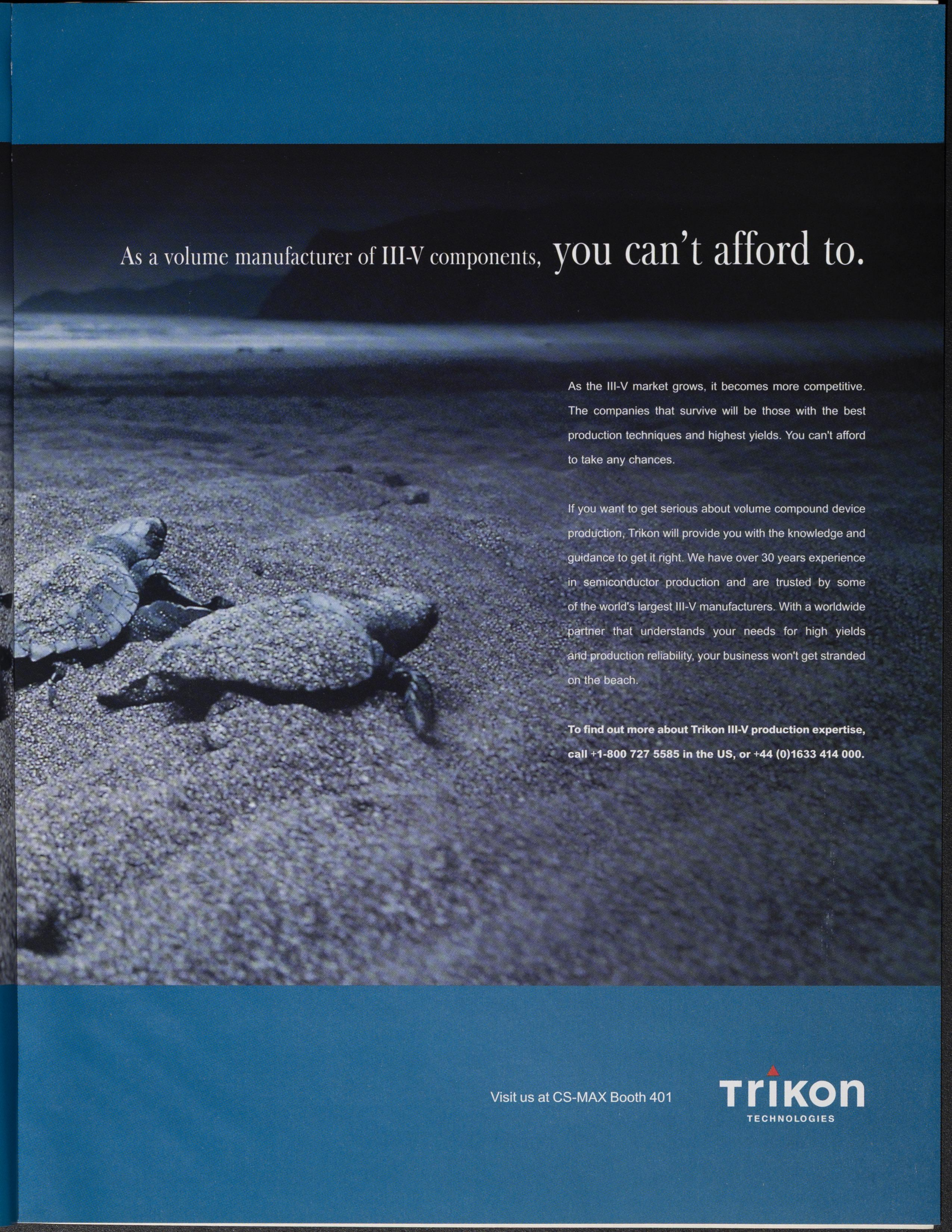
At the recent Intel Developers Forum, Intel's CTO Pat Gelsinger described the company's progress in developing a "silicon-based" tunable laser, combining an InP Fabry–Perot laser with a silicon-based grating. The company's R&D unit has also developed a series of silicon-based photonic building blocks, such as waveguides, filters, modulators, switches and SiGe-based photodetectors. Intel's ultimate aim in the photonic arena is to integrate as many functions as possible at the chip level and to build them all using silicon.

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Bookham integrates its new GaAs-based optical modulator

Bookham Technology has released details of its new GaAs-based optical modulator, which has monolithically integrated signal power monitors for accurate clock and data phase alignment. The device is a two-stage Mach-Zehnder modulator that generates return-to-zero (RTZ) data signals at 40 Gbit/s (*Compound Semiconductor* March 2002 p50).

Accurate phase alignment between the clock pulses applied to one stage of the modulator, and the data modulating signal applied to the other stage is essential to the performance of such devices in high data rate, long-distance applications. In order to achieve accurate phase alignment, Bookham has monolithically integrated GaAs optical power monitors on the output of each modulator stage. These monitors detect any variation in signal output as a result of misalignment, and adjust the phase alignment via a feedback circuit.

The monitors exploit the two-photon absorp-

tion (TPA) effect in GaAs to provide a photocurrent of 1–10 μ A for a 2 mm long in-line detector at typical optical transmission powers. Little of the optical signal is absorbed by the TPA monitors, resulting in lower losses than for conventional monitoring techniques that require interruption to the optical path.

The TPA monitors provide a photocurrent proportional to the square of the time-averaged optical intensity. This means the detector gives a large response for a short pulse with a large peak (typical of an RTZ output pulse), and a low response for a broad low-intensity pulse. The response characteristics enable the monitors to easily detect when output optical power is decaying as a result of poor clock and data alignment. The transmitters work at 10 and 40 Gbit/s and are co-packaged with Bookham's narrow- and wide-band tunable laser modules. The 10 Gbit/s transmitter is now sampling to customers, with the 40 Gbit/s to follow in 2003.

Revenue warnings force Alcatel to begin refocusing

Alcatel Optronics has accelerated its restructuring plans based on warnings that its September quarter revenues could fall by as much as 50% sequentially. In a statement, the company blamed the continuing recession in the fiber-optic sector and persistent inventories held by its customers. A strategic refocusing plan will be launched that includes rationalizing the company's manufacturing facilities, with the loss of two-thirds of its workforce.

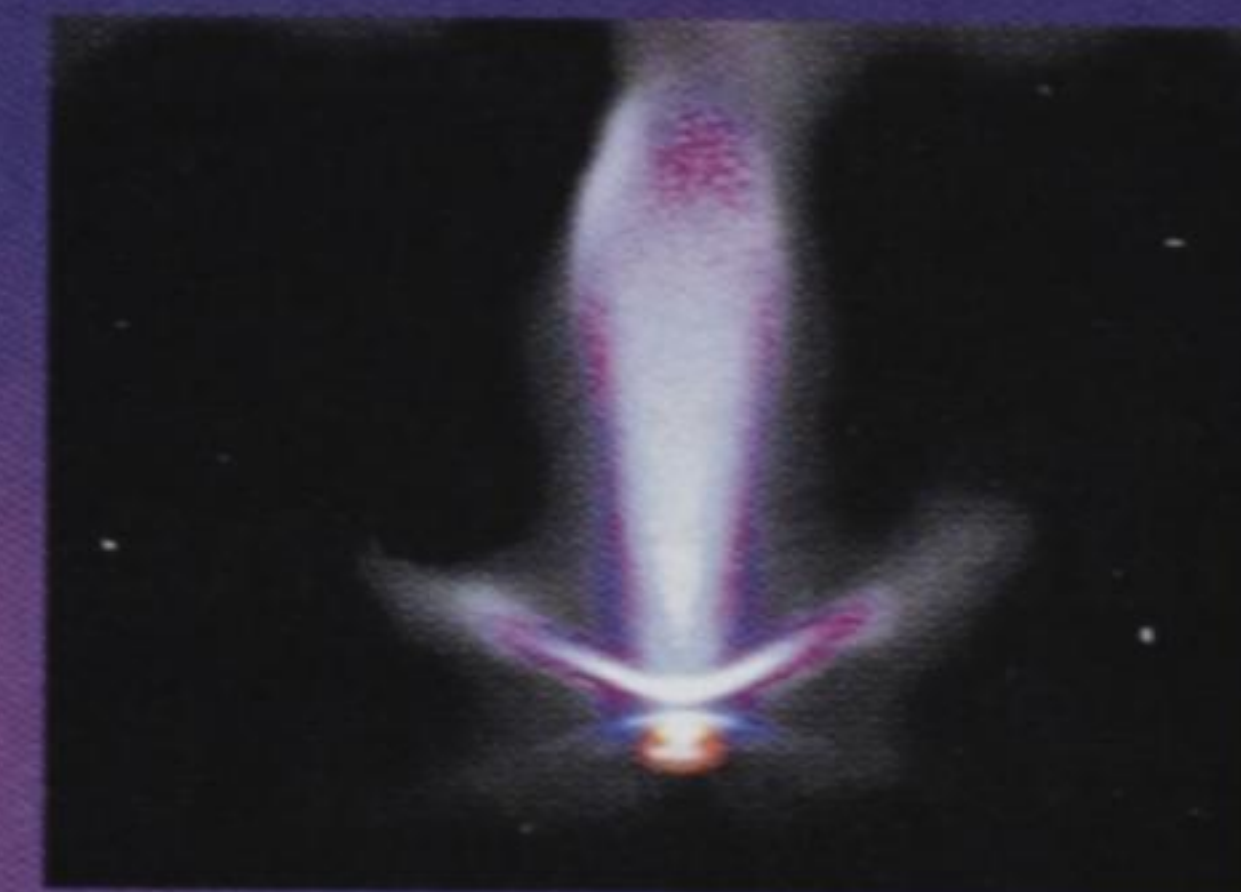
"We want to reach a streamlined business model as soon as possible, with our Nozay [France] manufacturing facility focusing on active components, our Livingston [Scotland] plant on passives, and both units combining forces in a joint effort towards hybrids," said Jean-Christophe Giroux, CEO of Alcatel Optronics. "From 1550 staff today, we expect to have around 1000 before year end, and ultimately less than 500 by the end of 2003."

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ASIP uses ATG to build uncooled EML

ASIP, a start-up optoelectronics company located in Somerset, NJ, has announced its first commercial product – an uncooled 10 Gbit/s 1310 nm electroabsorption modulated laser (EML). ASIP, whose financial backers include Redpoint Ventures and Multilink, fabricates monolithic photonic ICs using what it calls asymmetric twin-guide (ATG) technology. ATG integrates optical functions such as lasers, optical amplifiers, waveguides, modulators and detectors on InP-based epitaxial wafers.

Each of the device types for a particular function is grown and optimized in a single epitaxial growth sequence. The final structure is etched into the epiwafer. During the etch process, tapered waveguides, or optical vias, are formed to transfer the optical signal between the laser and modulator structures (in the case of the EML) in different layers of the epiwafer. The process uses standard etching techniques and removes the need for epitaxial regrowth steps, often used for integrated optical device production, which adversely impact yield.

ASIP has been commercializing the technology, developed at Princeton University, since July 2000 and has full licenses on the ATG process. ASIP says the key feature of the technology is its ability to scale, which significantly lowers overall manufacturing costs.

ASIP's 20,000 sq. ft building in Somerset houses its R&D, epitaxial growth and reliability test labs for InP photonic chip manufacturing, and high-end optical and microwave packaging design and manufacturing. According to marketing manager Yassi Mohaddam, ASIP is also working with external epiwafer suppliers, and may move to a fabless approach in future depending on product volumes.

ASIP's first product, the 10T101 EML, supports data rates up to 10.75 Gbit/s and link distances up to 10 km. Future versions will extend this to 80 km. Sample quantities of the first devices are available in chip-on-submount form, with volume production expected in Q1 2003. The submount accommodates an integrated monitor photodiode, thermistor and bias tee.

CTO and co-founder Milind Gokhale says the EML has two advantages: simplicity and unparalleled eye quality at high operating temperatures. "Eye quality translates directly to design margins," said Gokhale. "ASIP's eye margins are typically in the range of 25% or more, compared with directly modulated lasers that struggle to achieve single-digit margins."

IPAG closes second round of funding

Innovative Processing AG (IPAG), a German manufacturer of InP-based electronic and optoelectronic components, has successfully closed on a second round of financing. IPAG was established by former employees of the University of Duisburg at the end of 2000.

IPAG's new funding was led by High Tech

Private Equity and included first-round backers Agite. The undisclosed funds will develop highly integrated electronic and optoelectronic components for high-speed communication networks. "Our technological expertise is in developing high-speed components for telecom systems based on InP," said CEO and founder Ralf Bertenburg. "One of our initial products is a receiver module, consisting of a *pin* diode integrated with a traveling-wave amplifier, with a transfer speed of up to 43 Gbit/s."



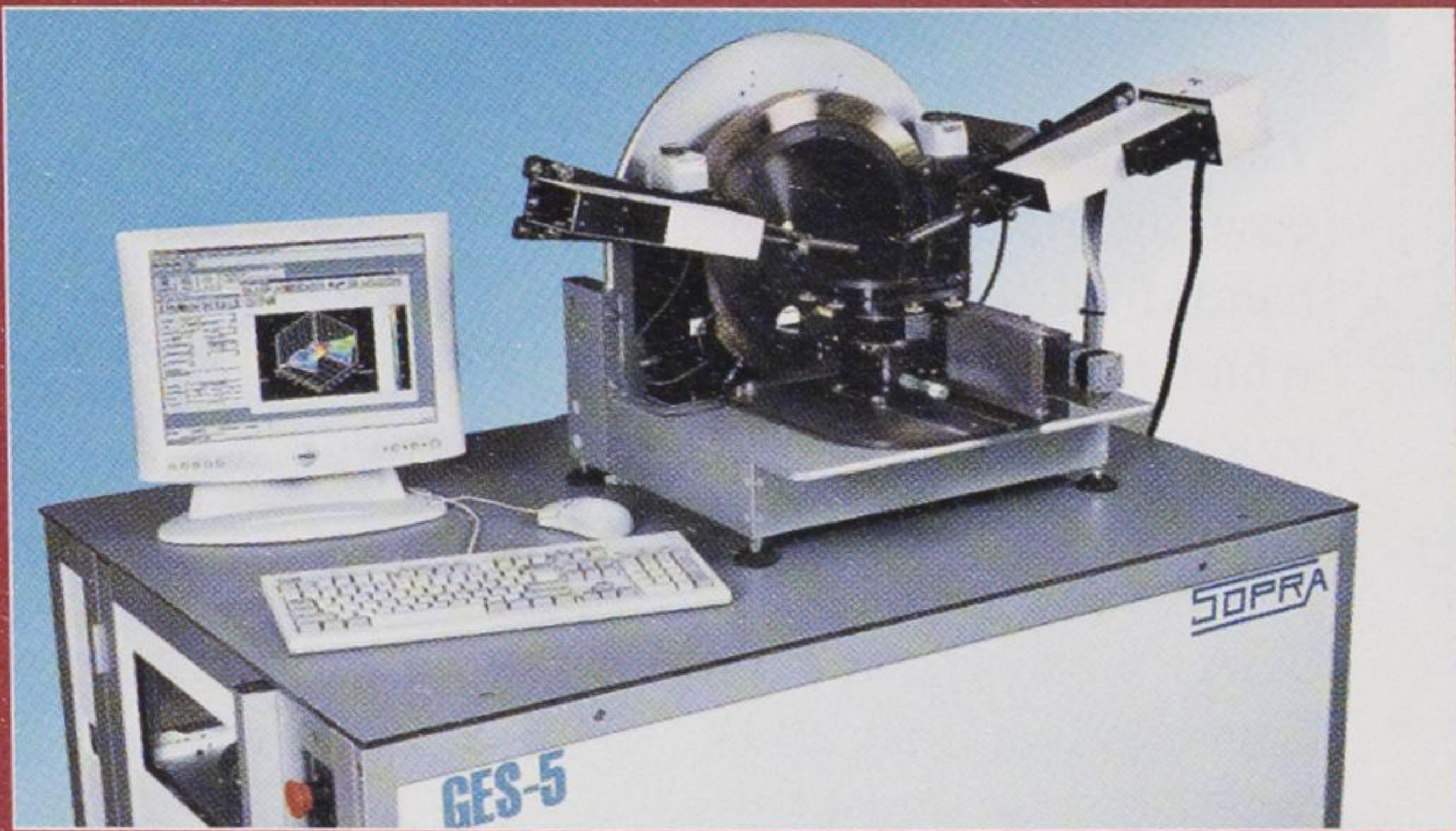
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Sensors Unlimited buys itself out of Finisar for \$6.1 million

Just two years after it was bought by Finisar for \$700 million, Sensors Unlimited is to become a privately held entity focusing on applications for InGaAs photodiode arrays and cameras. Finisar will receive a total of \$6.1 million in cash for its subsidiary based in Princeton, NJ. The new company will retain the Sensors Unlimited name, along with the existing management team and employees.

Sensors Unlimited was acquired by Finisar, a supplier of optical subsystem components and test systems based in Sunnyvale, CA, in

fall 2000 (*Compound Semiconductor* Sept/Oct 2000 p41), on the strength of its linear photodiode arrays that can be used to monitor the performance of DWDM systems. Finisar also acquired Demeter Technologies, a laser-diode manufacturer. While Finisar will retain its high-speed avalanche and *pin* photodetector product lines and technology, Sensors Unlimited will gain a royalty-free license to use this technology in areas such as military and free-space communications.

According to Sensors Unlimited president

Greg Olsen, the buy-out will allow the company to focus on its core markets. "We're going back to our small business roots," said Olsen. "Sensors Unlimited built its business on InGaAs photodiode arrays and cameras, primarily for the industrial spectroscopy and military markets. Our focus shifted when telecom companies found that our photodiode arrays could be used to monitor optical networks. However, in the current economic climate, we must diversify our market focus to achieve profitability and long-term revenue growth."

Olsen adds that Sensors Unlimited has recently installed an Emcore R&D reactor for crystal growth, and among other applications is interested in developing lasers for mid-infrared sensor applications at 2.5 μm .

Products from Oki, Quantum Photonics, Princeton Optronics, Genoa and Multiplex

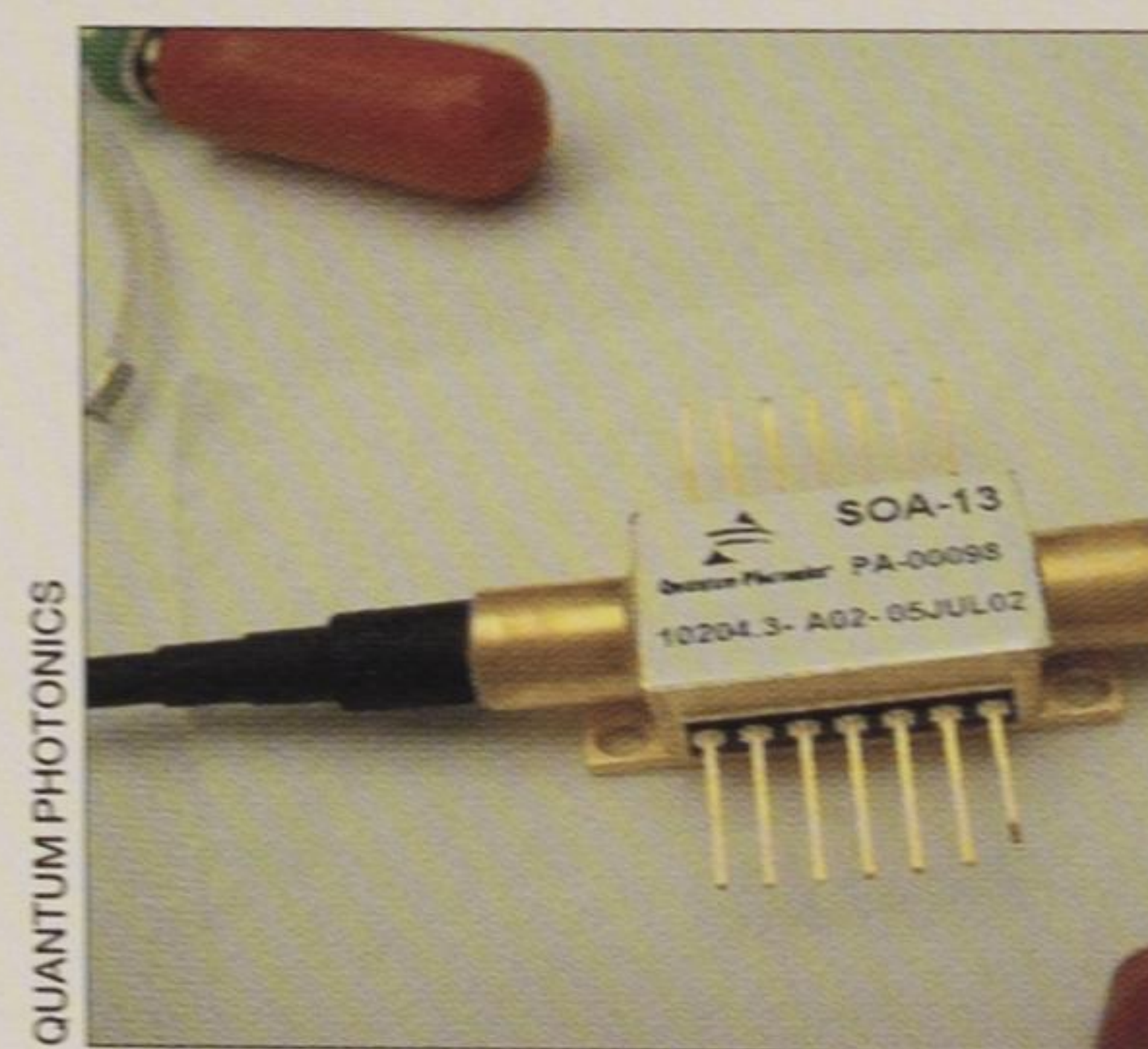
● **Oki Electric** has developed a 10 Gbit/s surface-mount receiver module that is designed to meet the MSA requirements announced in March by Agere and Nortel. The OD9241N contains a side-illuminated mirror *pin* photodiode and has a typical bandwidth of 9.5 GHz and sensitivity of -19 dBm.

Meanwhile, **Oki Optical Components** has released a 45 GHz GaAs-based broadband amplifier. The KGM8010 module has an adjustable output DC bias level, power consumption of 0.76 W and 18 dB gain. The die version can be used as a pre-amplifier, baseband amplifier, EA-modulator driver or LNA, and delivers a gain of 11.5 dB, a noise figure of 3.5 dB and an output power of 12 dBm.

● **Quantum Photonics** has demonstrated its first SOA. The ChAMP (channel amplifier) enables up to 40 channels at 10 Gbit/s, and is available at a lower cost than current EDFAs, says CTO Mario Dagenais. The InGaAsP/InP amplifier has an angled facet and an AR coating, which provides a very low facet reflectivity of 10^{-5} (*Compound Semiconductor* May 2002 p30).



The 45 GHz GaAs-based broadband amplifier from Oki.



The new ChAMP SOA from Quantum Photonics.

The wide bandwidth enables coverage of the S-, C- and L-bands from a single device, which is also claimed to offer as much as a four-fold improvement in saturated output power, compared with other SOAs. General availability is scheduled for early 2003.

● **Princeton Optronics** has demonstrated a continuously tunable external cavity laser with an output power of 30 mW. The PowerSweep covers the entire C-band with a wavelength stability of ± 1 GHz for channels spaced at 25 GHz. The device provides high output and alleviates the need for an SOA to compensate for low signal power, resulting in high-quality spectral output that can be used for long- and ultra-long-haul network applications.

● **Genoa**, which manufactures an InP-based linear optical amplifier (LOA), has teamed with optical transceiver manufacturer Finisar to demonstrate a coarse WDM link with a reach of 160 km. The

LOA provides a gain of greater than 10 dB across the 1500–1610 nm range, which is sufficient to support four CWDM channels with a spacing of 20 nm. EDFAs typically operate over the 1530–1610 nm range, and cover one or two channels at a time. The wide spacing of CWDM channels allows lower engineering tolerances and the use of less expensive, uncooled lasers, but the adoption of such systems is being held up in part by concerns over capacity and link distance. The Genoa/Finisar demo addresses some of these concerns.

● **Multiplex** has unveiled an InGaAs/InP avalanche photodiode (APD) receiver, which operates at data rates of 10 and 12.5 Gbit/s. The RP192 features a sensitivity of -26 dBm (BER of 10^{-12}) and bandwidth of more than 8 GHz. The APD targets long-reach (80 km) transponders, meeting Telcordia GR-253 specifications, and devices are currently sampling in a small-form-factor butterfly package, with volume production anticipated by the end of the year.

ACROTEC

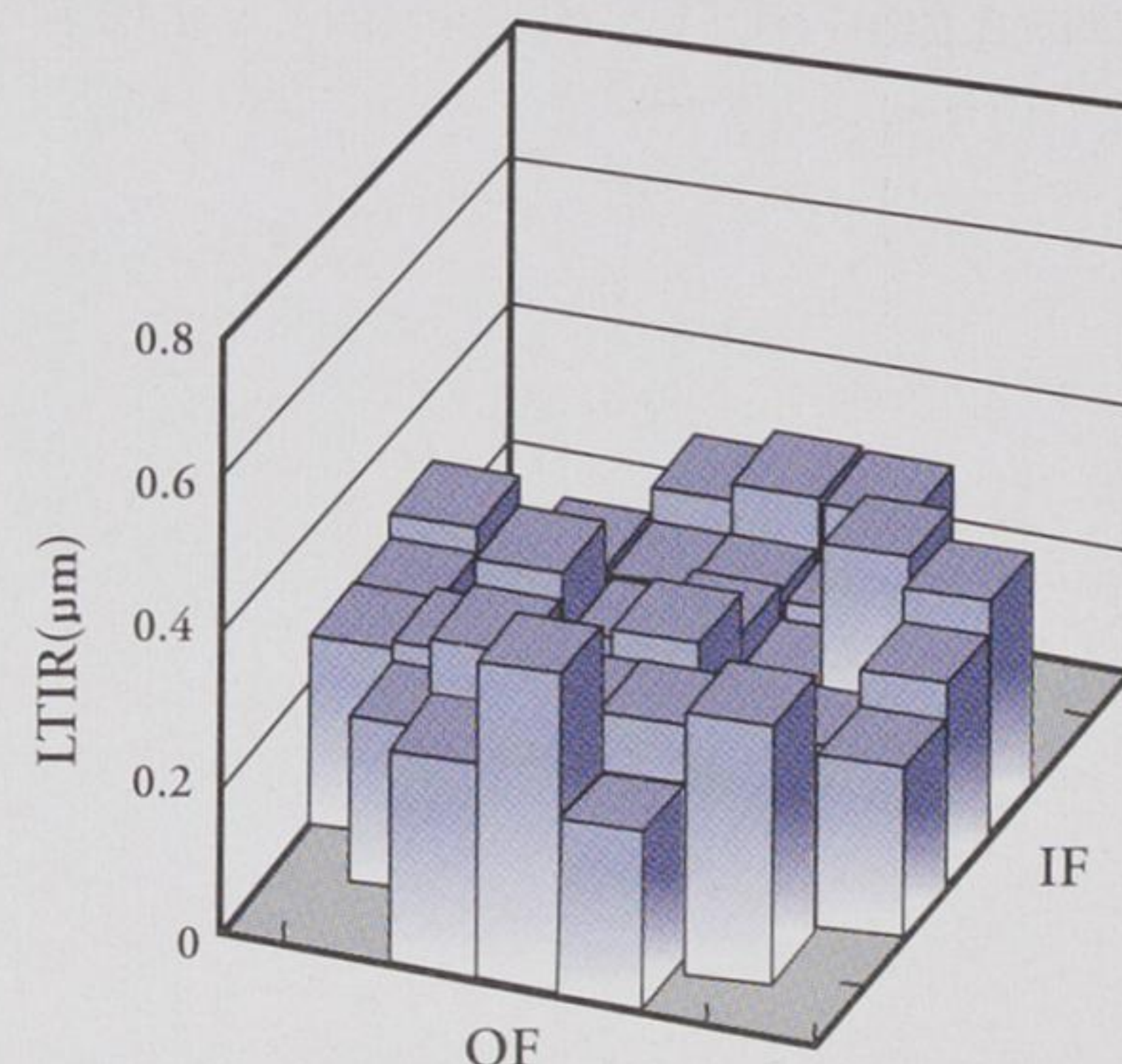
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IQE and Rockwell reach agreement

IQE and Rockwell Automation have settled their dispute relating to the MOCVD process patents held by Rockwell. These patents were part of a licensing agreement between the two companies lasting from October 1991 to January 2000. The settlement includes a cash payment by IQE, and the issue of 300,000 ordinary IQE shares to Rockwell. In return, Rockwell has agreed to release IQE and all its customers, past, present and future, from any obligations under Rockwell MOCVD process patents. Around £750,000 (\$1.2 million) had been assigned by IQE for legal costs for this matter, which was due to go to court in January 2003.

Rockwell has pursued a number of com-

panies in the past, including SDL and Spectra-Physics, for allegedly infringing its MOCVD patents. In 2000, the courts ruled that the patents in question were unenforceable and since then the patents have expired. However, IQE and Rockwell continued to disagree over whether retrospective payment was due to Rockwell under the terms of the licensing agreement that predated the 2000 ruling.

IQE's board considered it more appropriate to settle the case now, removing the uncertainty over legal costs and payments to Rockwell. The board is hoping that this course of action will provide IQE with stability as it addresses the current difficult market conditions.

Joint venture with QinetiQ suspended

The plans for a joint venture between IQE and QinetiQ have been put on hold. The two companies had been negotiating for more than a year on the formation of a joint venture company, that was to provide materials characterization and epitaxial process development for IQE and its customers (see *Compound Semiconductor* October 2001 p29). "Given the current business climate, it has been decided not to proceed with the proposed joint venture," explained Chris Meadows from IQE. "However, we are still intent on maintaining a business relationship with QinetiQ."

Newport and EM4 to join forces

Newport Corporation and EM4 Photonics have agreed to jointly develop and refine photonics device manufacturing equipment and processing, as well as establish an equipment-supplier relationship. The move is targeted at lowering fiber-optic component assembly costs – the subject of a workshop recently attended by both companies (see *Compound Semiconductor* August 2002 p38).

EM4 of Burlington, MA, provides active optoelectronic component package design and manufacturing services, including the design, development, production and reliability testing of active fiber-optic components. As part of the transaction, EM4 will provide Newport with an exclusive license

to use portions of its proprietary optoelectronic packaging technology.

Newport supplies automated assembly and test systems, precision robotics tools, sub-micron positioning systems, vibration isolation and optical subsystems. The company will become a preferred supplier to EM4 of all test and assembly equipment, in support of EM4's optical manufacturing services business.

"The combination of Newport's automation expertise and our manufacturing processes and services allows for tremendous advancements in the evolution of bringing lower cost active optoelectronic devices to market," said Basil Garabet, EM4's CEO.

Tokyo Electron to sell Bede's products

Tokyo Electron has been appointed as the sole distributor for Bede Scientific Instruments' products in Japan. Tokyo Electron will begin marketing, selling, installing and maintaining the entire range of Bede's products for the semiconductor and other markets from October this year. The agreement between the companies is expected to lead to sales of around \$20 million within the next three years.

"The completion of this agreement is a major breakthrough for Bede, representing the best possible route to market for our products in Japan," said Neil Loxley, Bede's chief executive.

Equipment sales

● **ATMI** (Danbury, CT) has expanded its GaN epitaxial capacity with the purchase of an **Aixtron 2600G3 HT MOCVD** reactor. The company says the new 8 × 4 inch tool is needed to meet increasing demand for GaN microelectronic and optoelectronic devices.

● **Epistar** (Hsinchu, Taiwan) has ordered an **Aixtron AIX 2600G3 HT** production reactor to increase production levels of AlInGaN LEDs. The system has a capacity for 24 × 2 inch

wafers, and adds to a number of Aixtron reactors already in use at the company.

● **Highlink Technology Corporation** (Hsinchu, Taiwan) has ordered an E300 GaNzilla GaN production reactor from **Emcore** for the manufacturing and development of GaN-based LEDs. The new system adds to the eight MOCVD systems, including several Emcore reactors, already in use by Highlink. Highlink has also

ordered a NE 860 IL inductively coupled plasma etching system from **Unaxis**. This will be used for etching features in GaN.

● **EpiPlus** (Gyeonggi-Do, Korea) has ordered an E300 GaNzilla GaN production reactor from **Emcore** for GaN-based blue and green LED epiwafer production.

● **ETH** (Zurich, Switzerland) has taken delivery of an **Aixtron AIX 200/4 MOCVD** system.

The reactor will be used by ETH for the growth of InP-based electronic and optoelectronic devices.

● The **Fraunhofer Institute for Applied Solid State Physics (IAF)** in Freiburg, Germany, has ordered a GEN200 MBE system from **Veeco-Applied Epi**. Fraunhofer IAF will use the reactor as part of a government-sponsored program to develop InP-based microelectronic devices.

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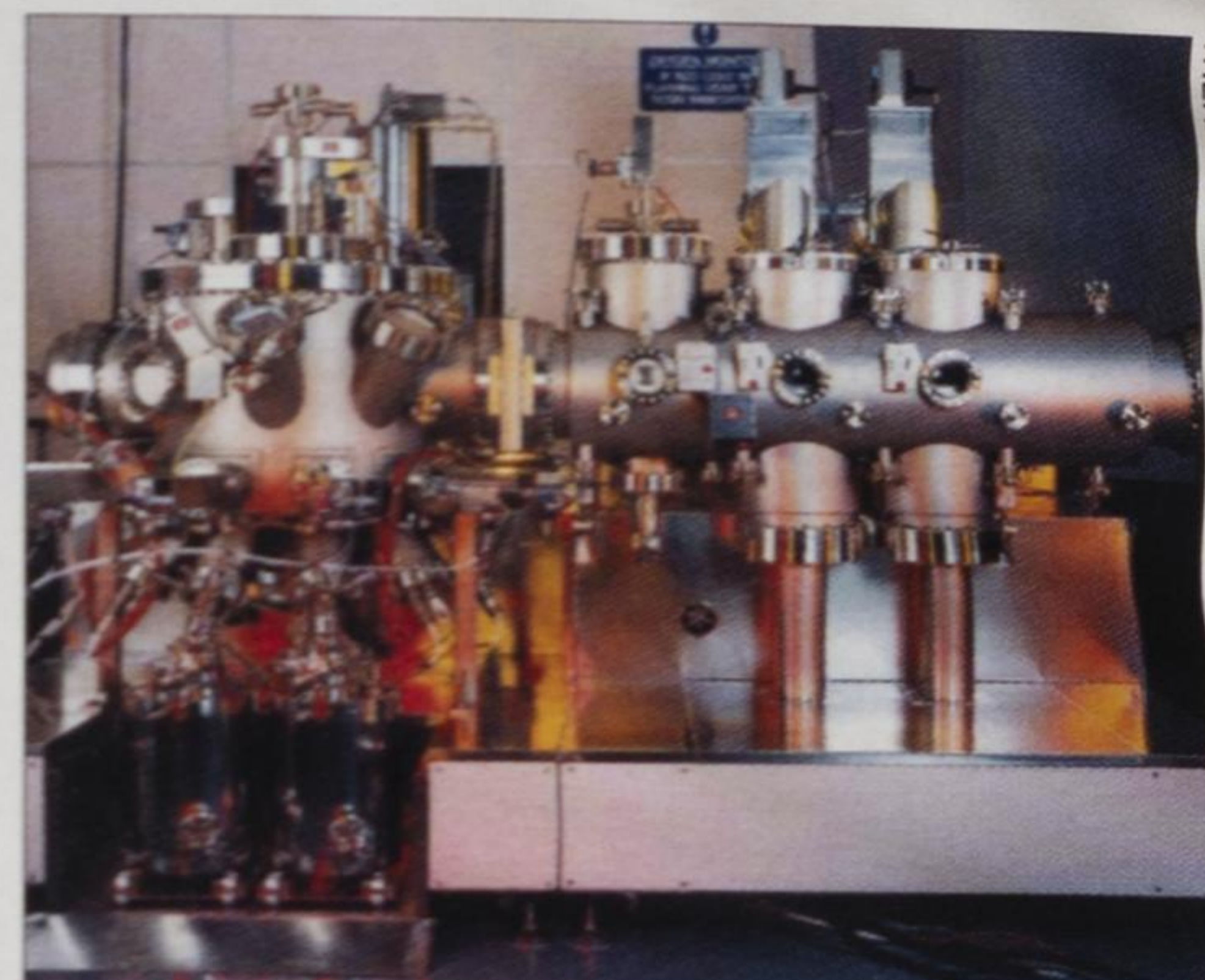
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Thermo VG Semicon and UMIST launch MBE development center

Thermo VG Semicon and the University of Manchester Institute of Science and Technology (UMIST) have jointly established a new facility for MBE process development. Located at UMIST in Manchester, UK, the new facility will be opened in late 2002.

The laboratory features a V100 multiwafer MBE reactor and a V90H research MBE system, in addition to metrology and device fabrication equipment and lecture rooms. Using UMIST's academic setting, the new facility will provide a range of services for Thermo VG Semicon customers, including equipment demonstrations and training, collaborative growth process development, and summer-school courses in MBE technology.

"UMIST's experience in semiconductor materials and devices, together with Thermo VG Semicon's MBE equipment expertise provides a unique capability," said Larry Leung, Thermo VG Semicon's process development



The new MBE process development facility to be located at UMIST in the UK will feature a multiwafer V100 system, as shown here, and a V90H research reactor.

manager. "This innovative collaboration allows us to offer a broader range of support solutions to the semiconductor market."

Riber reports results for first half of 2002

French MBE equipment manufacturer Riber has reported its financial results for the first half of 2002 ended June 30. Riber is suffering from the sales decline that is impacting many semiconductor processing equipment suppliers. The company's sales were €13.6 million (\$13.46 million) for the

first half of 2002, down 38% on the year-ago period. Sales were €4.0 million in the first quarter of 2002 and €9.6 million in the second quarter of the year. Riber also reported a net loss of €0.5 million for the first half of the year, compared with a profit of €3.3 million in the year-ago period. Production machines accounted for 73% of Riber's sales; the company delivered three MBE 49 machines and one MBE 7000 machine during the period.

People news

● **Global Communication Semiconductors** has selected **Sam Lee** as its new CEO. Lee replaces Owen Wu, who has taken up the position of chief strategy officer. The new CEO has prior experience with Fairchild, Motorola, Raytheon, AMCC and TRW.

● **Aixtron** has appointed **Derek Houghton** as director of sales and marketing for equipment

and technology related to SiGe, strained silicon and other materials deposited onto silicon wafers. Houghton joins Aixtron from SiGe Semiconductor, a company he founded and led as president and CEO.

● **Shuji Nakamura** is one of three recipients of this year's Takeda Foundation Techno-Entrepreneurial Award for Social/Economic Well-Being. The award is in recognition of the

recipients' work on the development of blue LEDs and lasers. Nakamura shares the \$833,000 award with **Isamu Akasaki** and **Hiroshi Amano**, both at Meijo University.

● **Graham Riley** has joined **Accent Optical Technologies** as the head of product marketing for Accent's DIVA product line. Riley was formerly with Agilent.

Researchers choose MBE for dielectrics

DCA Instruments of Turku, Finland, has sold an MBE system to the University of Hanover, Germany, for silicon and oxide deposition on 8 inch wafers.

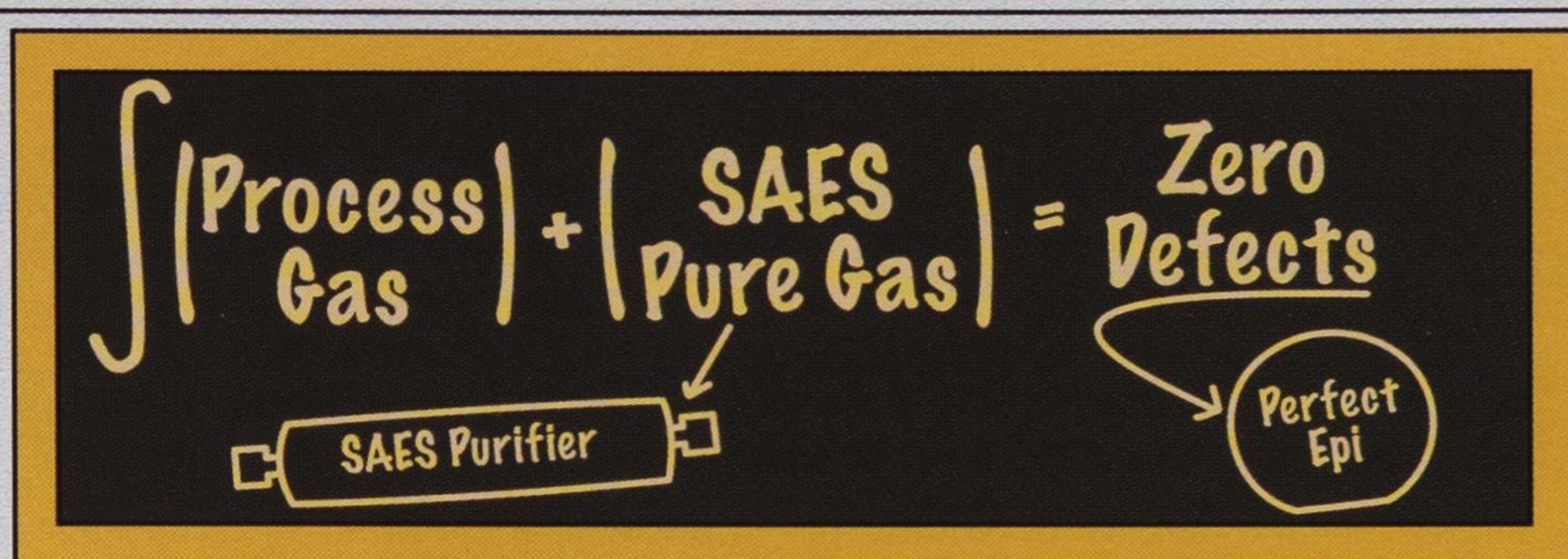
Joerg Osten, who until joining the university in February 2002 worked with IHP in Frankfurt, is leading a research effort at the university into thin-film, high-k dielectrics as an alternative to SiO₂ for the silicon microelectronics industry (see *Compound Semiconductor* September 2001 p35). CMOS devices with channel lengths of 70 nm will require gate oxide thicknesses below 1.5 nm. Since direct tunneling increases exponentially with decreasing oxide thickness, an alternative insulator with a dielectric constant greater than that of SiO₂ is needed if CMOS devices are to continue scaling down. In particular, Osten's research group is looking at the MBE of single-crystal oxides of rare earth metals such as Pr₂O₃. Other researchers around the world are working on perovskite oxides such as BaTiO₃ and SrTiO₃.

The new materials that are being investigated and commercialized by the silicon industry are becoming an important focus for the manufacturers of MBE and MOCVD systems that were originally developed for the compound semiconductor industry. While at IHP, Osten worked on the development of SiGe:C HBTs. The early work on SiGe:C deposition at IHP was done using solid-source MBE before being transferred to a low-pressure CVD process, which is now in commercial use. "I believe that MBE is still the supreme method for developing new materials," Osten told *Compound Semiconductor*. "With MBE you have the flexibility to control growth temperature, rate and growth ambient, independently."

However, Osten does have some doubts as to whether the metal-oxide gate dielectric deposition will transfer from MBE to MOCVD as well as SiGe:C did to CVD. "To achieve good device performance, you need a lot of interface engineering on a monolayer level," Osten said.

DCA moves to bigger facilities

DCA has recently moved into a new 54,000 sq. ft production plant in Turku. The new facility features an extended cleanroom assembly area, and is designed especially for the manufacture of UHV components and systems.



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MKS consolidates to reduce costs

MKS Instruments of Andover, MA, a manufacturer of instruments including mass-flow controllers, gas analyzers and RF plasma generators, is rationalizing its manufacturing operations to reduce costs. The move will result in a loss of 173 employees, or 7% of the workforce.

As part of its reorganization, the company's ENI and ASTeX RF power and plasma generation product groups will operate as the Power and Reactive Gas Product Group, with continued design and manufacturing in New York, Massachusetts and China.

MKS will consolidate all RF power products into the ENI manufacturing plants. The Colorado Springs RF facility will become the design center for high-power RF products. The company's Spectra Products group will maintain a design center for process monitoring products in California, while consolidating the manufacturing of those products in the UK.

GE acquires Advanced Ceramics

GE Specialty Materials, a unit of General Electric Company, has signed an agreement to acquire Advanced Ceramics Corporation and Advanced Ceramics International Corporation. Advanced Ceramics is a specialty high-temperature ceramics firm, and a leading producer of boron nitride powders, shapes, coatings and other specialty ceramics. The company's Boralloy pyrolytic boron nitride components are widely used in MBE cells and in the bulk crystal growth of semiconductor materials.

The deal is subject to regulatory approval and should close before the end of the year.

Advanced Ceramics will become part of the GE Quartz business within GE Specialty Materials. The terms of the deal were not disclosed.

"Advanced Ceramics makes sense for our growing, specialty materials business," said William Woodburn, president and CEO of GE Specialty Materials. "Advanced Ceramics is a high-technology company serving the global materials industry. We are excited about the synergies with GE Quartz, GE Superabrasives and GE Silicones, in both improving our growth through new products and in reducing our manufacturing materials costs."

Luxtron focuses on fiber thermometry

Luxtron Corporation (Santa Clara, CA) is tightening its focus on its *in situ* fiber-optic temperature measurement business. The company's thermometry systems employ fiber optics to enable remote temperature sensing

in applications such as semiconductor manufacturing and biomedical research.

Luxtron will concentrate R&D, applications engineering and product development on developing fiber-optic measurement systems and integrating them into OEM tools. Probes include the TR-1000, which provides MBE and MOCVD tools with *in situ* substrate temperature measurements covering 400–1600 °C.



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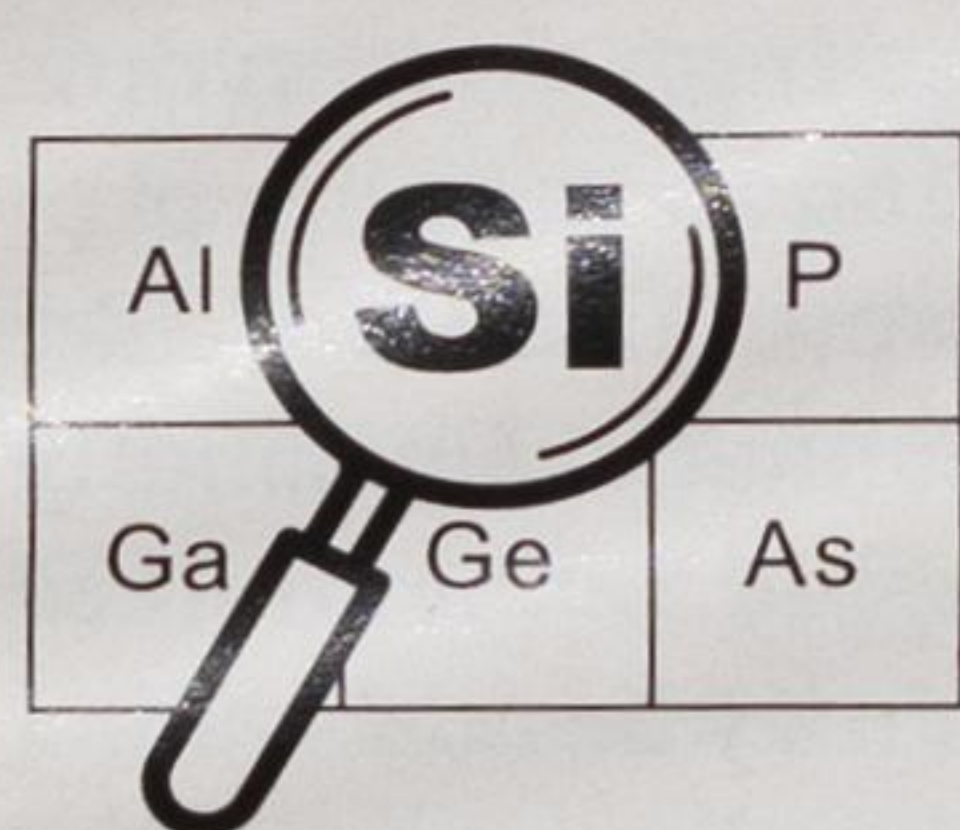
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Wafer bonding brings SOI to strained silicon devices

Established silicon-on-insulator processes have helped CMOS to reach higher speeds. With new strained silicon processes on the silicon industry's roadmap, it was only a matter of time before somebody combined the new technology with a buried oxide, but at what cost?



SOI wafers are typically made in one of two ways, either by separation by implanted oxygen or by wafer bonding.

Silicon-on-insulator (SOI) substrates and strained silicon are two significant developments that have enhanced CMOS performance. In the case of SOI, the use of a buried oxide greatly reduces parasitic RF coupling to the lossy Si substrate. The thin Si layer (typically 50–200 nm) above the buried oxide significantly reduces the junction area, and so decreases both leakage and operational currents, which in turn lower the noise figure and overall power dissipation. For strained Si, the strain induced in a thin Si layer by growth onto a SiGe buffer layer modifies the Si band-structure in such a manner as to improve both electron and hole mobilities, resulting in improved drain currents (*Compound Semiconductor* September 2002 p39).

It was inevitable that these two significant enhancements would be brought together in a single process, and it should come as little surprise that researchers at IBM's Watson Research Center, who have performed extensive work in both these areas, have merged them into a single process (Huang *et al.*).

Bonding beats implantation

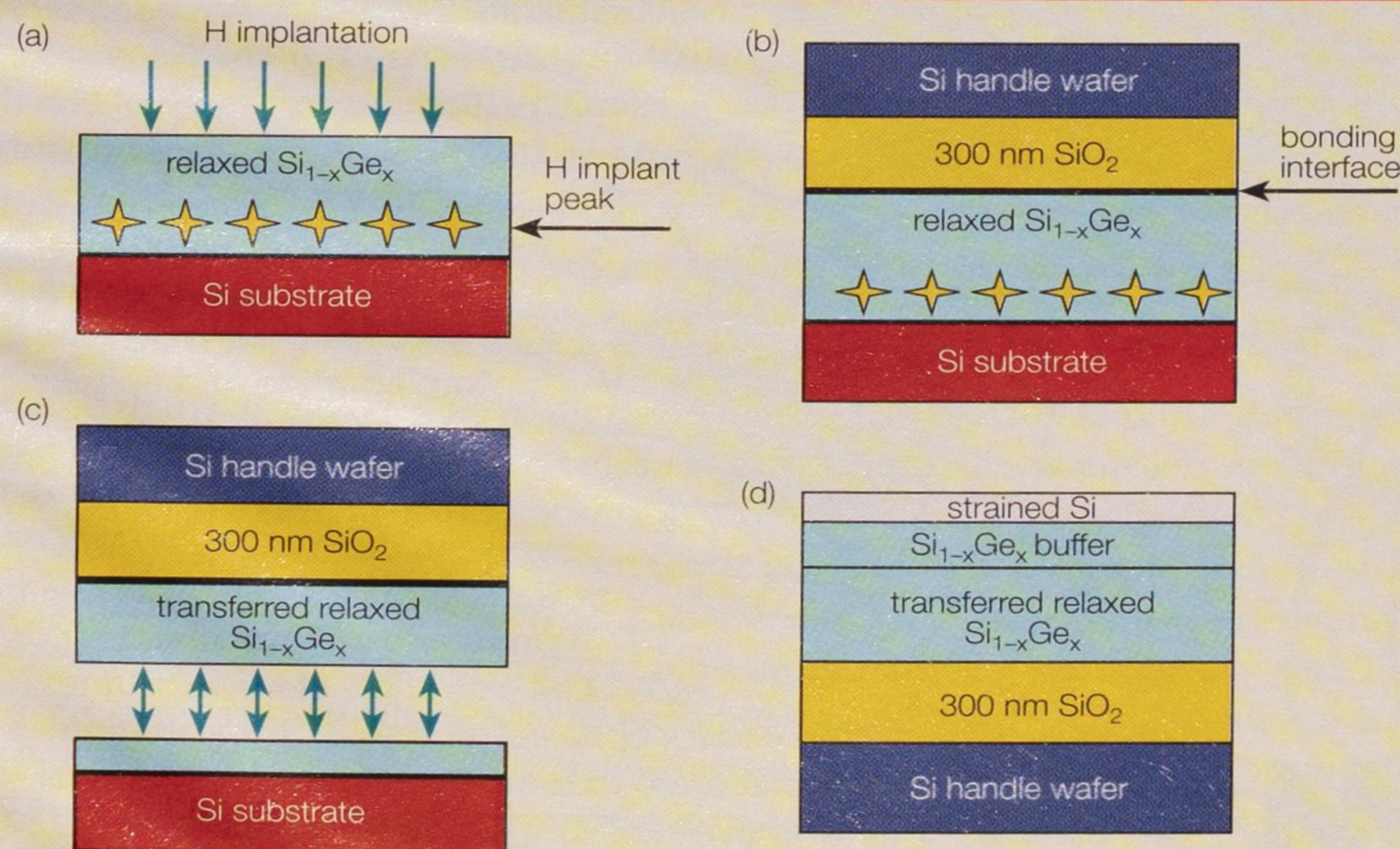
SOI wafers are typically made in one of two ways, either through separation by implanted oxygen (SIMOX) or wafer bonding. During the SIMOX process a high-dose oxygen implant is performed, and through subsequent high-temperature annealing (in excess of 1000 °C) a buried oxide layer is formed beneath the surface Si layer. While this process has served standard SOI applications well, it has proved very difficult to incorporate in the presence of a SiGe buffer layer above the implanted oxygen. Problems arise during the high-temperature annealing step required to form the buried SiO₂, in which it is difficult to maintain the integrity of the SiGe/Si layers. As a result, the IBM researchers have combined the SOI and strained Si processes by using wafer bonding.

The process flow is illustrated in the figure. A strain-relaxed SiGe buffer layer with uniform Ge content in the range of 15–25% above a step-graded SiGe layer is first grown by UHVCVD. Surface smoothness is critical to successful wafer bonding. Due to the relaxation of the SiGe layer during the step grade, the resulting surface is cross-hatched. To provide the required low roughness for wafer bonding, a chemical-mechanical polishing (CMP) process is used to reduce the roughness from an as grown 6–8 nm RMS to about 0.5 nm RMS. A high-dose hydrogen implant is performed with the ion energy selected to place the implant peak within the lower portion of the SiGe buffer.

The polished SiGe wafer is then bonded to a Si handle wafer, which has a 300 nm thermal oxide layer on its surface. The bond between the two wafers is formed by a 20–30 h anneal at a temperature of 250–350 °C. Once the bond has been formed, a second higher temperature anneal (400–500 °C) induces a splitting process that separates the bonded wafer pair along the hydrogen implant peak. This results in an approximately 500 nm thick relaxed SiGe layer along with the 300 nm buried oxide atop the Si handle wafer.

A second CMP process is then performed to smooth the SiGe surface, which is left roughened by the hydrogen splitting process. This is followed by UHVCVD growth of a second thin layer of SiGe with the same Ge mole fraction as the transferred SiGe buffer, followed

The process flow



The process flow for the fabrication of a strained SOI wafer. The relaxed SiGe is implanted with hydrogen (a) and then bonded to a Si wafer with an SiO₂ surface (b). The bonded wafers are then annealed to separate them along the H implant peak (c). After a CMP step, a SiGe buffer layer is deposited followed by a strained Si layer (d).

As the III-V community has learned, no-one is willing to pay extra for performance that they do not need.

by the deposition of 18 nm of strained Si.

Both NMOS and PMOS devices were fabricated in the strained Si layer using gate oxides of 4 nm and channel lengths of 25–250 μm . Similar devices were fabricated on Si-only control substrates in order to make performance comparisons. The NMOS devices were fabricated on SiGe buffers with a Ge content of 15%. Drain current comparisons with the Si-only control devices extrapolated to give a 50% higher effective electron mobility in the strained SOI devices. The Si universal mobility curves taken at an effective field of 1.0 MV/cm also showed 50% greater mobility in the strained SOI devices.

In the case of the PMOS devices, a larger Ge content (20–25%) is needed as the mobility enhancements are not as strong as in the NMOS devices. Mobility improvements in the range of 15–20% were observed over the Si-only devices for effective fields of 0.2–0.5 MV/cm. A fall off in this enhancement is seen at higher effective fields, as is observed in conventional strained Si PMOS devices.

These results clearly show that the incorporation of a buried oxide into the strained Si process flow results in significant enhancements over the Si-only approach, and minimal degradation of the enhancements normally

provided by the strained Si process. While no RF measurements were reported, it would be expected that the typical RF improvements observed in an SOI CMOS processes would also be obtained here.

Lessons from the III-V experience

This process clearly has the potential to produce the best possible RF performance of any CMOS process, but as has been learned time and time again in the III-V community, no-one is willing to pay extra for performance that they do not need.

So while this process offers obvious performance benefits, they do come at a significant process cost: two starting substrate wafers, two UHVCVD growth sequences, two CMP sequences, a high-dose hydrogen implant, and a long annealing time. This process will undoubtedly be able to produce III-V-like device results, but the low costs that are normally associated with CMOS will not apply to this strained SOI CMOS process. In the end, it may be costs rather than performance that determine the commercial viability of this approach. ●

Further reading

Huang *et al.* 2002 *Trans. Elec. Dev.* **49(9)** 1566.

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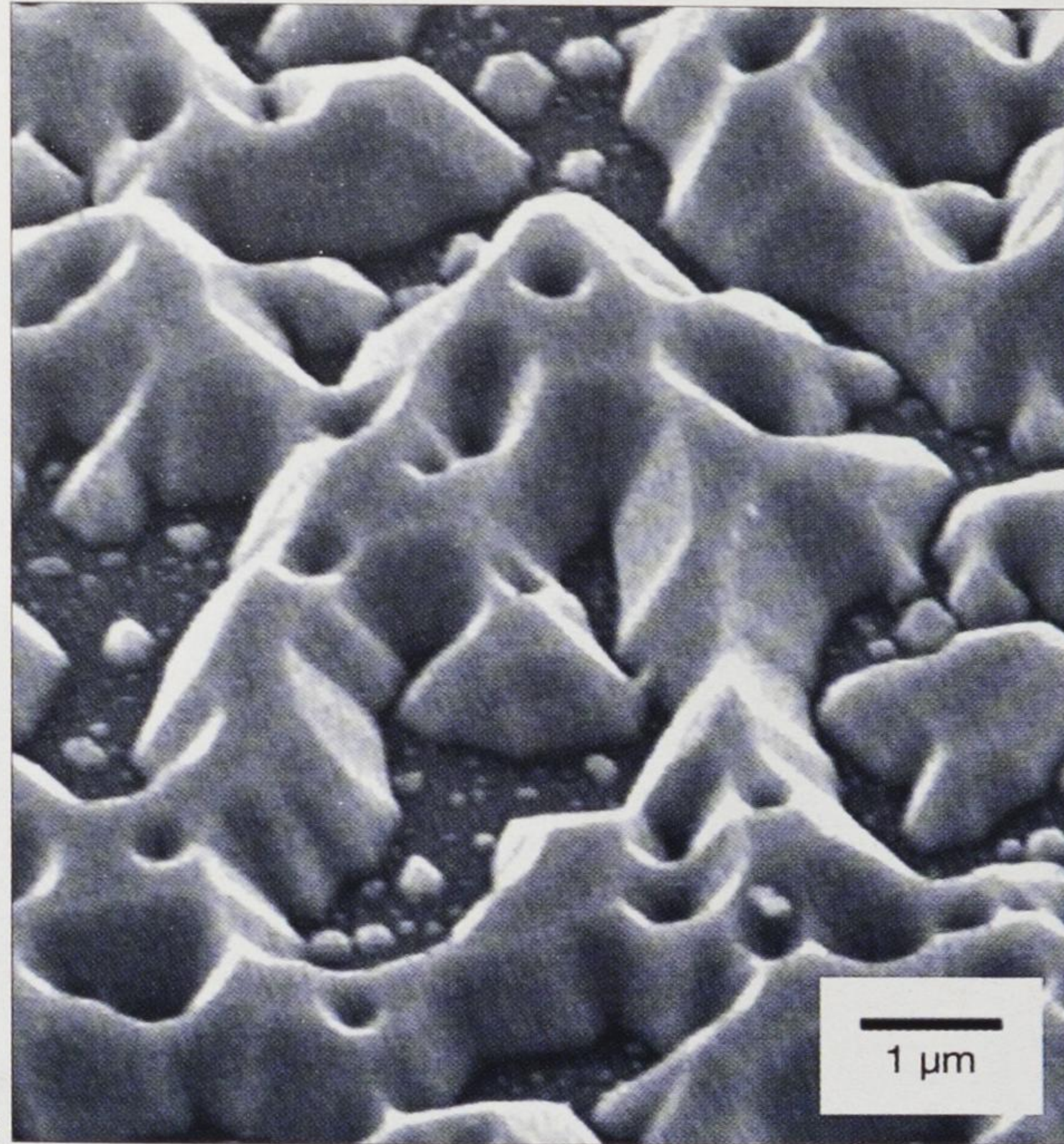


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Less ammonia gives brighter UV LEDs

For solid-state white lighting, GaN-based UV LEDs coupled with tricolor phosphors may provide more uniform light emission and improved color rendering than blue LEDs coupled with a single phosphor. The UV emission in GaN-based LEDs is limited by non-radiative recombination at either dislocations or other non-radiative recombination centers. Reducing the dislocation density in these UV LEDs will therefore be crucial in achieving maximum brightness.

Dan Koleske and colleagues at Sandia National Laboratories (*Appl. Phys. Lett.* 2002 **81**(11) 1940) have recently reported increased light output in 380 nm LEDs using conditions that favor 3D morphology during the early stages of MOCVD growth. The 3D GaN morphology was enhanced by reducing the typical NH_3 flow during the initial growth, resulting in partly coalesced hexagonal GaN grains (see figure). The



A SEM image showing the 3D GaN morphology after 15 minutes of growth with a reduced NH_3 flow.

3D grains were then coalesced by increasing the NH_3 flow to form a smooth 2D morphology.

The transition from 3D to 2D growth was measured using optical reflectance. From the reflectance waveform, the time required to recover 2D morphology was quantified. This recovery time was then correlated to the output power of UV LEDs, with longer recovery times leading to brighter LEDs. The LED structure with the longest recovery time had an output power of 1.3 mW at 20 mA, which is 15 times brighter than previous UV LEDs grown and processed at Sandia. AFM images of films grown with short and long recovery times had dislocation densities of $4 \times 10^9 \text{ cm}^{-2}$ and $1.5 \times 10^8 \text{ cm}^{-2}$, respectively. Reducing the dislocation density improved the LED brightness through the reduction of nonradiative recombination centers in these LEDs.

Growth on GaN improves properties of UV LEDs

Short-wavelength GaN-based UV LEDs require the use of high aluminum mole fraction alloys. This leads to increased strain and cracking, more resistive material, larger piezoelectric fields, and lower overall material quality, when compared with the InGaN-based structures used for longer wavelength LEDs. Free-standing GaN substrates provide a good lattice match for GaN-based LED structures, allowing for the growth of higher quality material. In addition, these substrates provide for significantly better heat dissipation compared with thin GaN films grown on poor thermal conductivity sapphire. In future, the use of GaN and AlN substrates is expected to have a major impact on

III-nitride device technology, if the substrates can be provided cheaply and in large quantities (*Compound Semiconductor* July 2002 p45).

Researchers at Northwestern University have made the first reporting of significant improvements to the electrical and optical properties of 340 nm UV LEDs through growth onto free-standing GaN substrates (*Appl. Phys. Lett.* 2002 **81**(12) 2151). The researchers compared the properties of UV LEDs with AlInGaN/AlInGaN MQWs and peak emission at 340 nm, grown on either a free-standing GaN substrate or on sapphire. For the LED grown on a GaN substrate, a differential resistance as low as 13Ω , and an output power more than one order of magnitude higher than that of the same structure grown on sapphire, was achieved. Due to the higher thermal conductivity of GaN, the output power of the LEDs saturates at higher injection currents compared with the devices grown on sapphire.

High T_0 achieved in QD lasers at room temperature

Because of the discrete nature of their carrier energy states, quantum dots (QDs) have found use in semiconductor lasers, providing sources with high characteristic temperature (T_0), very-low power density, and chirp-free modulation. However, while low power density and low-chirp modulation have been demonstrated, high T_0 has mainly been obtained in QD lasers operating below room temperature, with T_0 decreasing dramatically above room temperature.

Oleg Shchekin and colleagues at the University of Texas at Austin have published data showing excellent high-temperature operation of a five-stack modulation p-doped ridge waveguide QD laser operating at 1290 nm (*Elec. Lett.* 2002 **38**(14) 712). The T_0 for a p-up mounted device with a cavity length of 970 μm was 232K when operating in pulsed mode between 0 and 81 $^\circ\text{C}$. For CW operation, T_0 was 213K. Devices with 650 μm cavity lengths exhibited a low

threshold current of 5.7 mA and a high output power of 27 mW at room temperature. When operating at 101 $^\circ\text{C}$ the threshold current was 9.3 mA with an output power of 13 mW. The CW T_0 was 200 K with p-up mounting. High-quality InP-based lasers typically have T_0 values of approximately 60–70K.

The T_0 of QD lasers depends heavily on the energy separation between the ground and excited states of electrons and holes. Shchekin's group estimated that the electron energy levels in QDs were separated by as much as 80 meV, and hole levels by about 10 meV. The hole energy level spacing is lower than kT so that thermal broadening of the hole's energy levels within the QDs can dominate the gain characteristics at room temperature. P-type modulation doping of the QD active region compensates this, increasing the ground state gain to avoid high-temperature gain saturation.



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Multi-wavelength optical modulator made by QWI

The operating bandwidth of a single-material semiconductor-based optical modulator is restricted to about 30 nm. A collaboration between groups at Nanyang Technological University, Singapore, and Sherbrook University, Canada, has resulted in the demonstration of an electroabsorption modulator that can operate across multiple wavelengths simultaneously (*Appl. Phys. Lett.* 2002 **81**(11) 1958).

The researchers used gray-mask quantum-well intermixing (QWI) to make the multiple sections with different bandgaps that absorb at different wavelengths. Gray-mask lithography enables the fabrication of an SiO₂ implantation mask of varying thickness in a single lithography step. The intermixing implantation depth and hence the degree of QWI varies with the thickness of the mask. The process uses three consecutive steps – SiO₂ deposition, photolithography and dry etching – in a single cycle. Other QWI techniques require these steps to be repeated in multiple cycles.

The group fabricated a 10-channel modulator operating between 1500 and 1560 nm. A modulation depth of –15 dB was measured from the modulator array, with a voltage swing of –4.5 V. Such a multiple-wavelength modulator could be important in WDM applications, where multiple-wavelength sources such as tunable lasers are used.

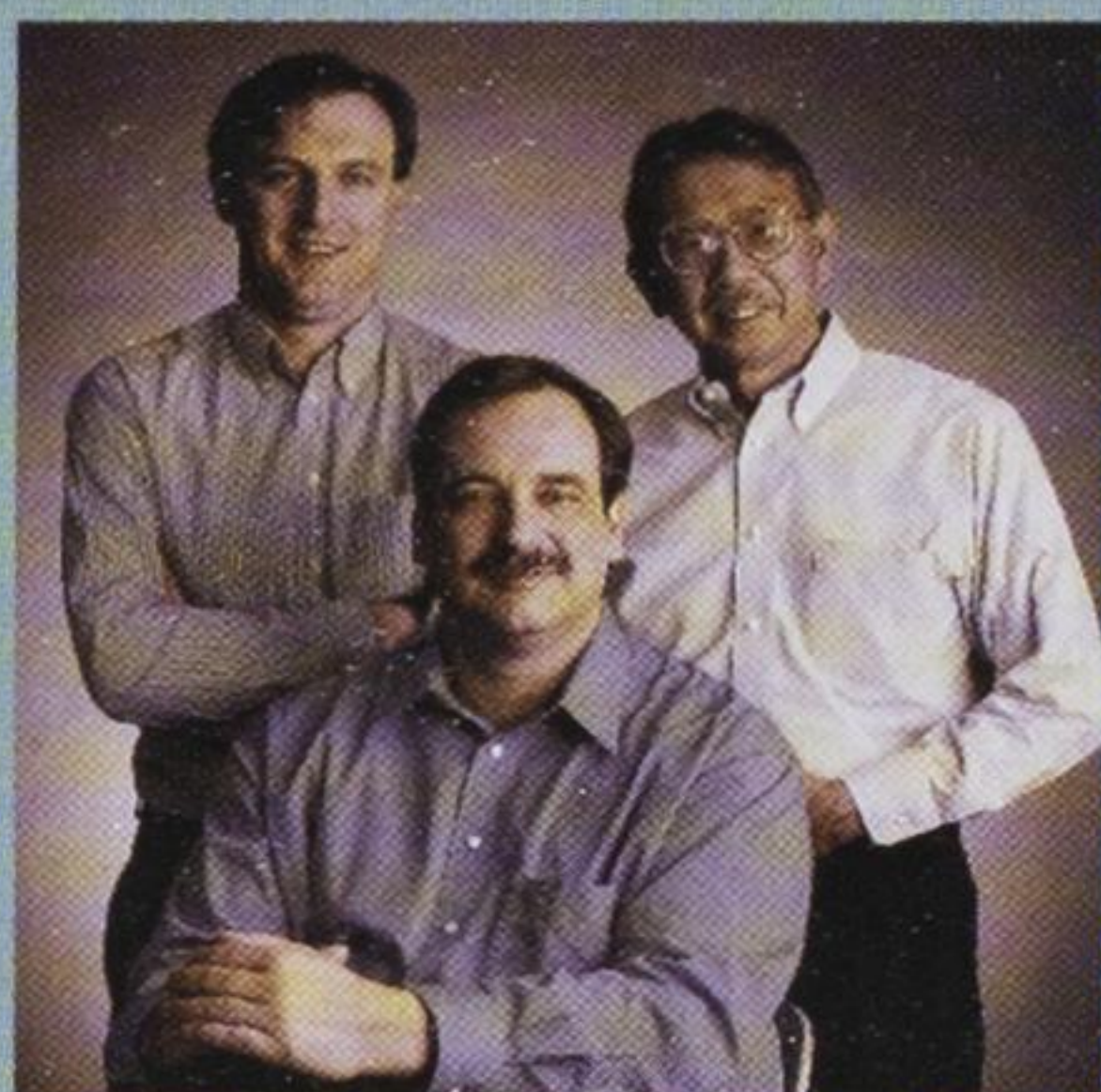
Nanoplus reveals multi-section tunable lasers

There is an increasing demand for widely tunable single-mode lasers with different wavelength ranges for applications in optical communication, gas sensing and spectroscopy. A method for fabricating tunable devices that is independent of a particular material system is therefore very desirable.

Martin Mueller and colleagues at Nanoplus in Gerbrunn, Germany, and the University of Wurzburg have reported the development of a multi-segment quantum dot (QD) DFB laser with lateral coupling (*Phot. Tech. Lett.* 2002 **14**(9) 1246). The laser consisted of a ridge waveguide with two or more segments that could be pumped independently. Due to the lateral coupling, the devices did not require an epitaxial regrowth step and therefore the approach is not limited to material systems for which epitaxial overgrowth is well established. The tunability was realized by changing the effective refractive index of each segment by variation of the injection current to each section. Tunable lasers based on this concept have been realized in a number of material systems, among them 1.55 μm InP lasers, 1.3 μm GaInNAs lasers and 1 μm QD lasers.

The QD devices fabricated by Mueller's group were based on an InGaAs/GaAs/AlGaAs structure, with layers containing self-assembled InGaAs QDs as the active regions. A characteristic property of QD lasers is the broad gain spectrum that makes the fabrication of tunable devices possible.

The reported lasers had a discrete tunability over a range of 30 nm, with side-mode suppression ratios (SMSRs) of at least 35 dB. Continuous tunability was demonstrated over a range of 12 nm, with SMSRs of at least 30 dB. Ongoing improvements to the team's approach are currently focusing on increasing the tuning range and the SMSR.



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DARPA sets tough goals for the wide-bandgap community

Hoping to emulate its past successes with GaAs, DARPA has launched a new initiative this year in an effort to make wide-bandgap semiconductors a cost-effective, high-performance electronic technology to fulfill the military's need for compact high-power devices, writes **Jon Newey**.

The US Department of Defense (DoD) has a proud history of financing the research and development of semiconductor technologies. The compound semiconductor industry certainly owes a great deal of its early development to the backing it received from the DoD through organizations such as the Defense Advanced Research Projects Agency (DARPA). In the last 20 years DARPA has been heavily involved in the R&D of GaAs and InP materials and devices through projects such as MIMIC and MAFET. These projects have brought compound semiconductor technologies from the laboratory into the realm of reproducibly manufacturable devices. Such a transition has provided the military with access to affordable components, and has laid the foundations for the exploitation of compound semiconductor microelectronics for high-volume commercial applications such as mobile phone handsets.

Military needs are continually evolving and, where electronics is concerned, one of the prime needs is for compact devices that are capable of handling high power densities. Wide-bandgap semiconductors including SiC and the III-nitrides are material systems with the potential to meet this need. Although III-nitride optoelectronic devices and some high-power SiC devices are commercially available, there are pressing materials issues that need to be over-

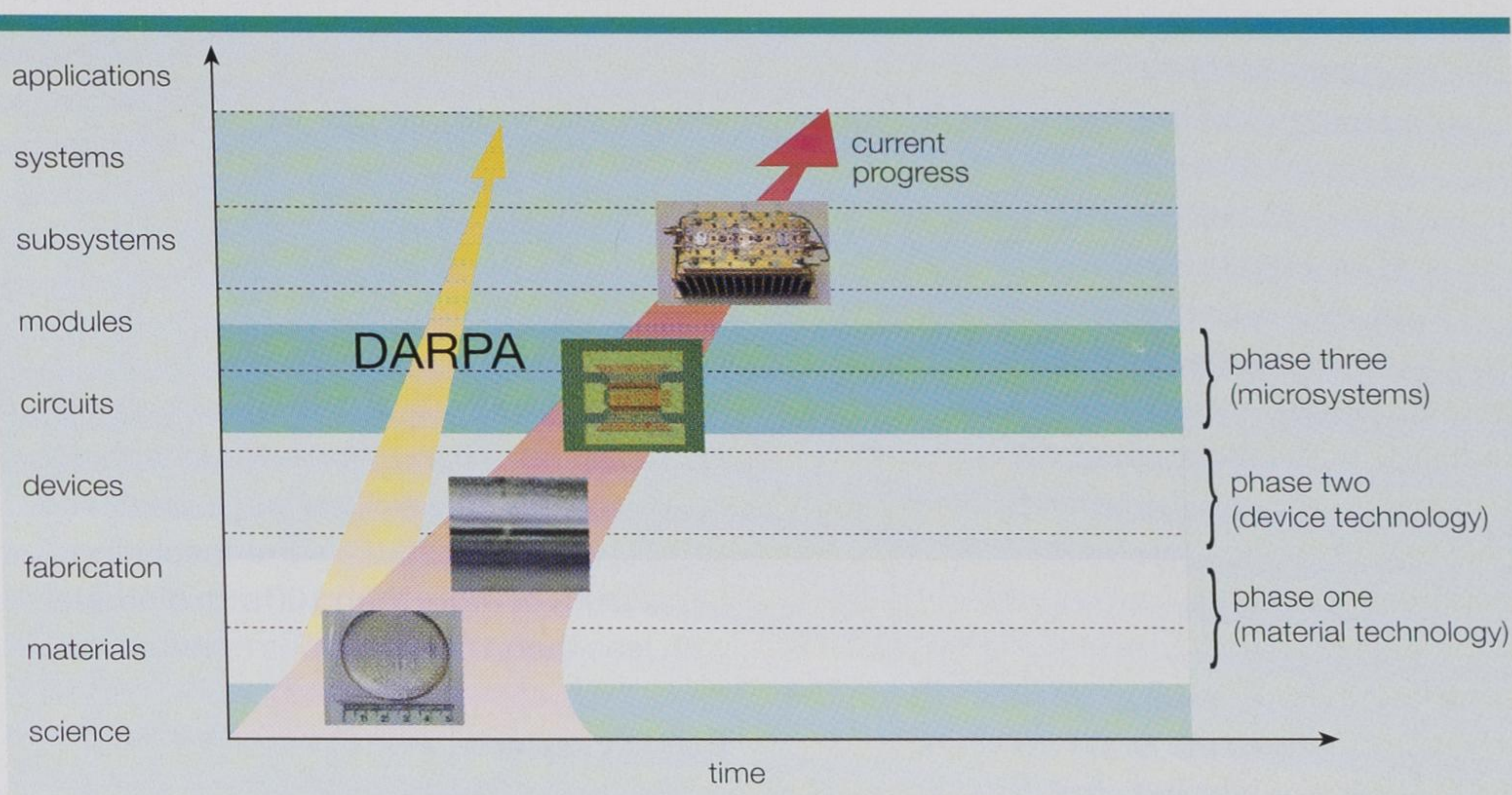


Fig. 1. The WBSTI aims to accelerate the timeline for the progression from material development to the deployment of wide-bandgap semiconductors in military electronics.

come in order to allow SiC and III-nitride electronic devices to perform at the levels required by military users.

The WBSTI is born

Over the years, DARPA has funded a number of programs to develop wide-bandgap semiconductors for military needs. Past programs have focused on areas such as GaN LED technology, solar-blind detectors, AlGaIn-based focal-plane arrays, SiC technology for power control and distribution, and also megawatt-class power control devices. In addition, there has been much activity at the Office of Naval Research (ONR) and other areas of the DoD.

"For the last couple of years we have been looking at how to consolidate all of these activities and establish a new initiative that will really push forward this technology into the DoD," said Edgar Martinez, a program manager at DARPA's Microsystems Technology Office (MTO). "As a result of discussions and planning within the DoD, the Wide Bandgap Semiconductor Technology Initiative (WBSTI) was created."

The birth of the WBSTI did not go unnoticed by the compound semiconductor community. On September 5, 2001, DARPA held an industry briefing at which Martinez and MTO colleague and fellow WBSTI man-

ager John Zolper spelt out the aims and objectives of the WBSTI (figure 1). "We received proposals in the fall, then did a first selection and initiated the contract process over the wintertime," explained Martinez.

Work got underway in earnest earlier this year, with a number of companies familiar to those tracking the compound semiconductor industry being awarded contracts. In July Cree announced that it had been awarded \$14.4 million to develop high-quality 4 inch SiC substrates, epitaxial processes for SiC MESFETs and GaN HEMTs, and also to develop SiC high-power switching devices. Emcore and Crystal IS were other successful bidders to the WBSTI, receiving contracts for the development of GaN epitaxial processes and large-area AlN substrates, respectively (*Compound Semiconductor* July 2002 p11). Zolper and Martinez have also been busy getting their message across at industry events, such as this year's GaAs Mantech and the International Microwave Symposium.

Tough targets for researchers

The WBSTI is divided into two areas called Thrust I and Thrust II. Thrust I concentrates on developments that will enable new analog RF, microwave and millimeter-wave applications. Thrust II will endeavor to make

advances in solid-state devices for high-power conversion and switching applications, and as such is mainly concerned with SiC.

The WBSTI is being run in phases with the first phase, which began this year, intended to provide a foundation for Thrust I and II by achieving advances in bulk and epitaxial material quality, and by tying these to device performance. Activities in phase one include developing crystalline growth techniques leading to large-area epi-ready semi-insulating substrates, including SiC as well as alternatives such as GaN and AlN. Also included are studies of epilayer growth processes.

Phase one is expected to last two years and has a budget of nearly \$40 million. At present about 75% of the funding goes to industry, with the remainder going to universities and federal laboratories. Subsequent phases will concentrate on device and circuit technology and subsystem engineering. These later phases will begin once phase one is completed, and will depend heavily on the advances made in the next two years.

DARPA's wish list for SiC specifies substrates greater than 100 mm in diameter with high resistivity ($>10^7 \Omega\text{cm}$), a thermal conductivity of at least 4 W/cmK, and less than 10 micropipes/cm². For epitaxial material, parties funded through the WBSTI will need to aim for homoepitaxy and heteroepitaxy of SiC and/or III-nitrides with a less than $\pm 1\%$ variation in thickness, composition and doping over the entire area of a 100 mm or larger substrate.

Advances in substrate and epiwafer quality on their own are of limited use if they can not be correlated with improvements in device performance. Such correlation helps to ensure that the materials are meeting the requirements of the device types that the military user needs, and also helps to establish the degree to which material improvements are aiding the development of high-performance, manufacturable devices.

The WBSTI includes tight controls at every step, from bulk crystal growth to device processing. Those submitting work proposals are encouraged to work with others in the material-device food chain. For example, organizations working on epitaxial material need to be able to perform device correlation experiments, if not themselves then through partnerships with others. In turn, those developing substrate technologies are expected to work with organizations performing epitaxial growth. Such close co-operation serves as a feedback loop to

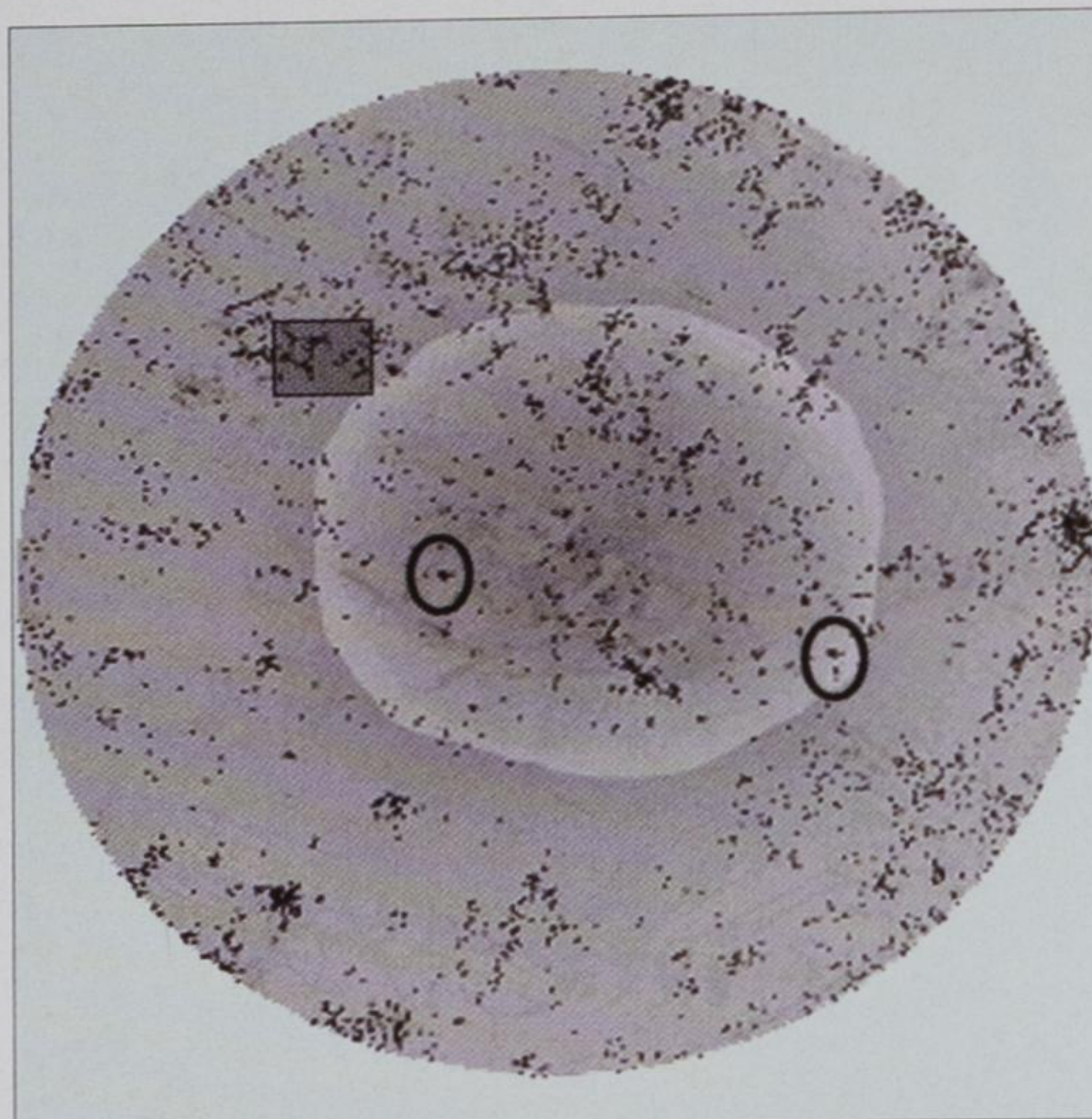


Fig. 2. A 75 mm n-type SiC wafer with micropipe defects (circled). A device switching 100 A would occupy the shaded area. The WBSTI aims to produce semi-insulating SiC wafers of more than 100 mm diameter with less than 10 micropipes per cm².

Military needs are continually evolving and, where electronics is concerned, one of the prime needs is for compact devices that are capable of handling high power densities.

quickly and efficiently establish whether the desired progress is being made, or if efforts need to be redirected.

High-power electronics technology

The military applications envisaged for the high-power devices that are the subject of Thrust II include motor controllers and power distribution in electric vehicles, and high-frequency power controllers and converters for ship propulsion. The WBSTI defines high-power devices as those that can handle megawatt power levels. This translates to blocking voltages in excess of 10,000 V, conduction currents greater than 100 A and a switch rate of more than 150 KHz.

The material improvements required for the Thrust I RF, microwave and millimeter-wave devices are also needed for high-power devices. However, high-power devices have their own set of material-related challenges. The types of applications described above will require devices with areas in excess of 1 cm²

(figure 2). Reducing defects such as micropipes in SiC substrates is therefore crucial in achieving good yields and reliability for large-area devices. High-power devices can also require thick epilayers (approximately 150 μm). Maintaining crystal quality, good surface morphology and doping control through a thick layer across a large-area substrate, while still growing at a reasonable rate, is challenging but essential to the reliability and manufacturing yield of high-power devices.

Looking ahead to the later phases, process technology is another area that will be investigated in Thrust II. A better understanding of how factors such as surface preparation and treatment, dopant activation, and different insulators impact device performance at high powers is needed. The hybrid and monolithic integration of high-power devices with different component types also needs to be addressed. Such considerations are particularly important to the intelligent operation of power devices. This requires the adjustment of power levels to a system's needs using low-voltage controller ICs. Co-packaging such disparate device types is particularly challenging, and the WBSTI is to address device integration strategies and the management of the high thermal loads generated by high-power electronics.

The next success story?

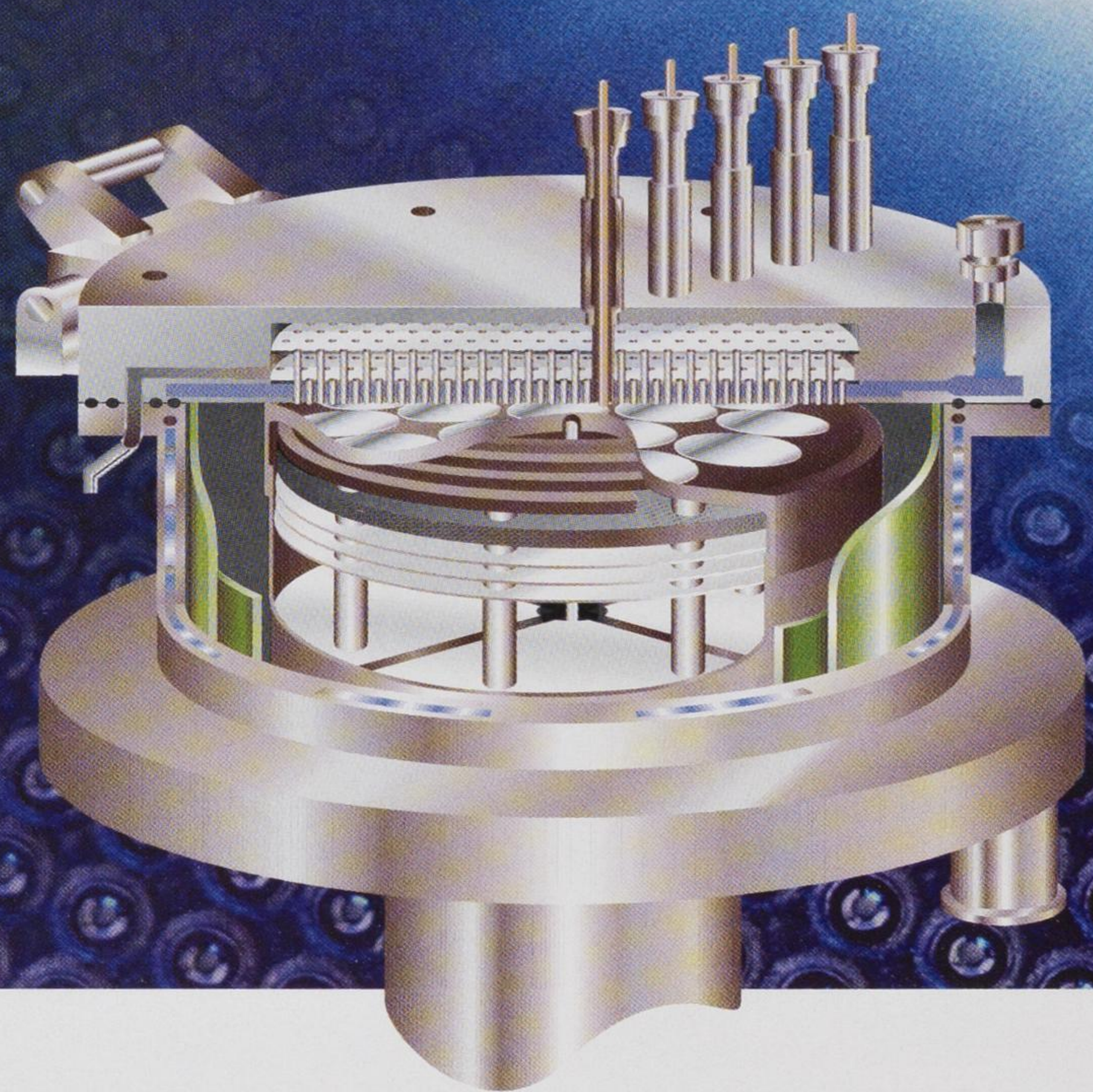
The wide-bandgap device area is one of the good prospects for high growth in the compound semiconductor industry. The market for III-nitride optoelectronics continues to experience excellent rates of growth compared with the industry as a whole, thanks to high-volume applications such as LED displays and the emerging markets for solid-state lighting and lasers for the forthcoming generations of DVD players.

At present the commercial market pull is limited for high-power GaN- and SiC-based devices. The technology is either too immature to fabricate devices with the required performance and reliability, or is too expensive. Cheap technologies such as silicon LDMOS are firmly entrenched in the market for high-power electronics, despite the inefficiency and the large area of such devices when compared with SiC and GaN. If history repeats itself, all this could change in the coming years. SiC and III-nitride power devices will become much cheaper and reproducibly manufacturable, as did GaAs, thanks to a big push from the military. ●

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New on-wafer testing concepts accelerate VCSEL production

Equipment designed for use in high-throughput production environments can lead to a reduction in the overall test time for VCSELs, writes **Jürgen Müller** of Infineon Technologies.

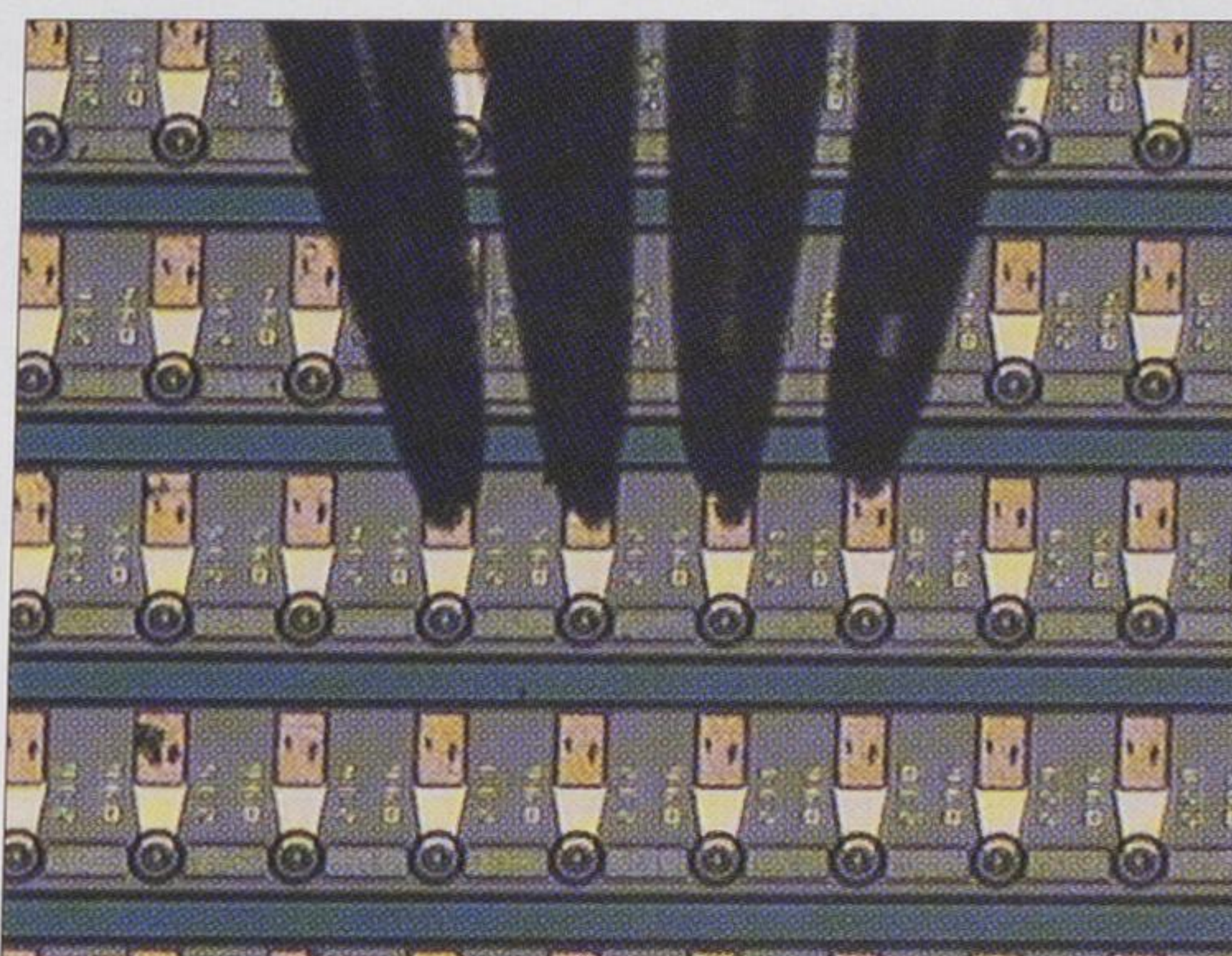
In recent years VCSELs have intruded into the application areas within the fiber-optic communication industry that were previously covered by LEDs or conventional edge-emitting lasers (Wiedenmann *et al.*). More recently, a handful of renowned semiconductor fabricators have started the large-scale production of high-performance and proven high-reliability VCSEL devices for fiber-optic applications.

Infineon Technologies, for instance, is a leading supplier of VCSELs for parallel optical applications. Infineon's PAROLI product at 850 nm is now commercially available in high volume, and 1.3 μm VCSELs for medium-reach applications are to be commercialized soon (Schmale *et al.*).

VCSELs offer particularly strong advantages in both fabrication and test. This is mainly due to the fact that testing can be carried out at the wafer stage. In contrast, competing edge-emitting lasers have to undergo costly "back-end" procedures – including cleaving, coating and bonding – where significant yield reduction occurs before test and qualification steps can be carried out.

The most fundamental and common test that is carried out for semiconductor laser devices is the determination of light-current-voltage (LIV) characteristics over the typical current range of the device. The collected LIV data is analyzed by linear regression to determine laser threshold, slope efficiency, knee voltage and series resistance, as shown in figure 1.

High-volume production and testing of optoelectronic components such as VCSELs and LEDs makes it necessary to migrate from the typical laboratory research equip-



A four-contact probe that is simultaneously testing four VCSELs on a single wafer.

A single 4 inch GaAs wafer contains around 100,000 individual VCSELs, all of which need to be analyzed with high accuracy.

ment used in many industrial fabs towards high-throughput test equipment. As an example of the difficulties faced, a single 4 inch GaAs wafer contains around 100,000 individual VCSELs, all of which need to be analyzed with high accuracy.

Accelerated test procedures

The availability of advanced testing technologies that are compatible with standard PC peripherals provides highly economical ultra-fast testing concepts that were until now only available for the high-budget applications associated with traditional silicon manufacturing.

A new laser diode source measurement module and optical power module has recently been introduced by Irish company PXIT. It has been designed to help photonic component manufacturers minimize their overheads, and is now being utilized by Infineon Technologies for VCSEL testing.

Infineon has evaluated PXIT's test equipment, in combination with a Süss PA-200 automatic wafer test stage, and has investigated the acceleration of test procedures and the concept of test-head duplication.

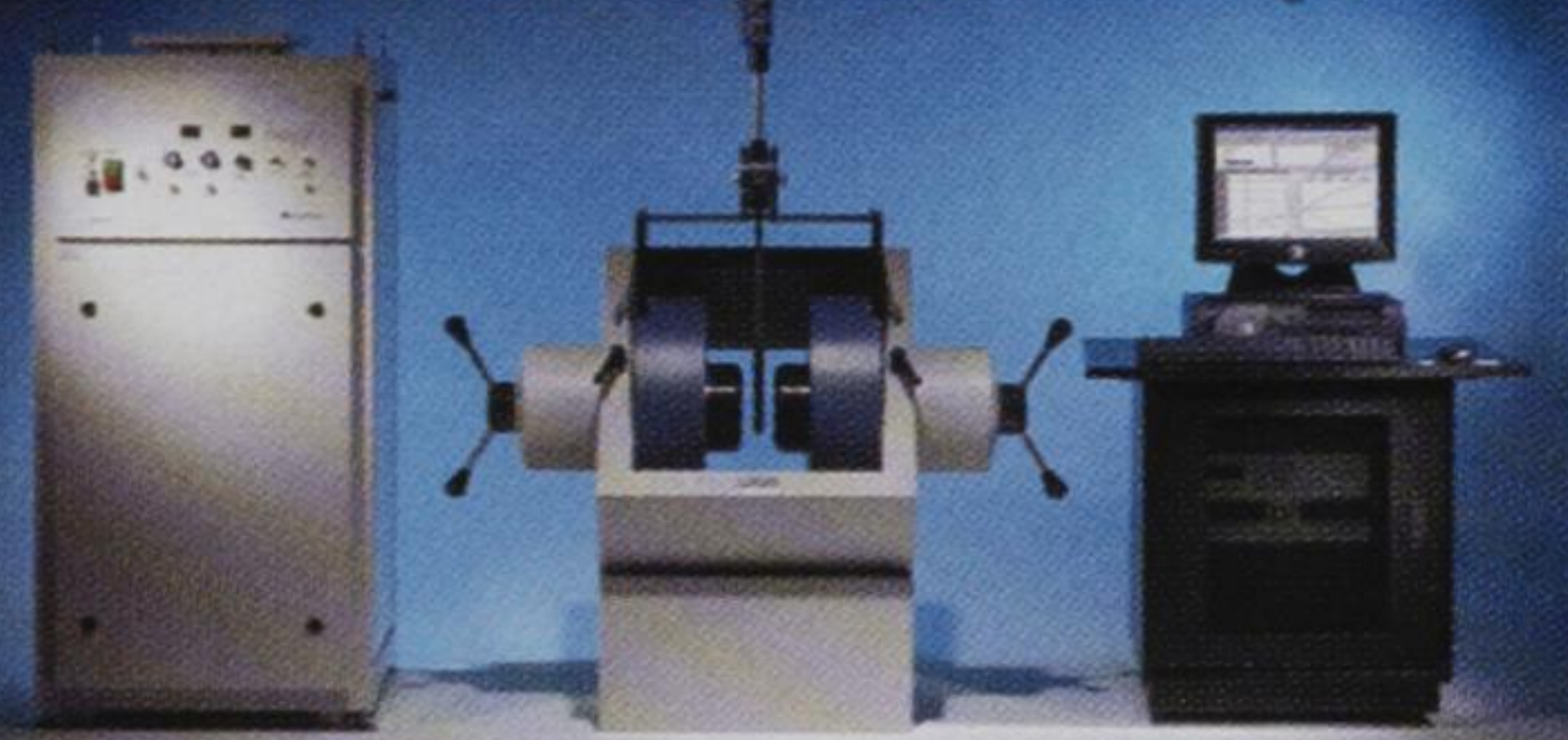
Figure 2 shows how the timing restrictions arise in typical wafer test cycles. Three different test configurations are compared. Figure 2a shows a traditional approach using GPIB instruments (see "GPIB and PCI" box) and single device-under-test (DUT) contacting cycles. The two other timing curves refer to the use of the PXIT test equipment applied in a single DUT contacting cycle (figure 2b), and a parallel multi-DUT contacting cycle (figure 2c).

The most severe timing constant is the contact cycle of the wafer handler (the time to move from one device on the wafer to the next in simple configurations). A typical figure is about 750 ms, due to the fact that the equipment has to incorporate and balance heavy loads such as components for RF and temperature shielding. The testing and sensing equipment also has to be adjusted with high accuracy.

After the contact cycle, typical testing procedures start with a verification of contact integrity. This is usually accomplished by a resistance check across Kelvin contact pairs applied in all testing applications to remove the parasitic resistance caused by system

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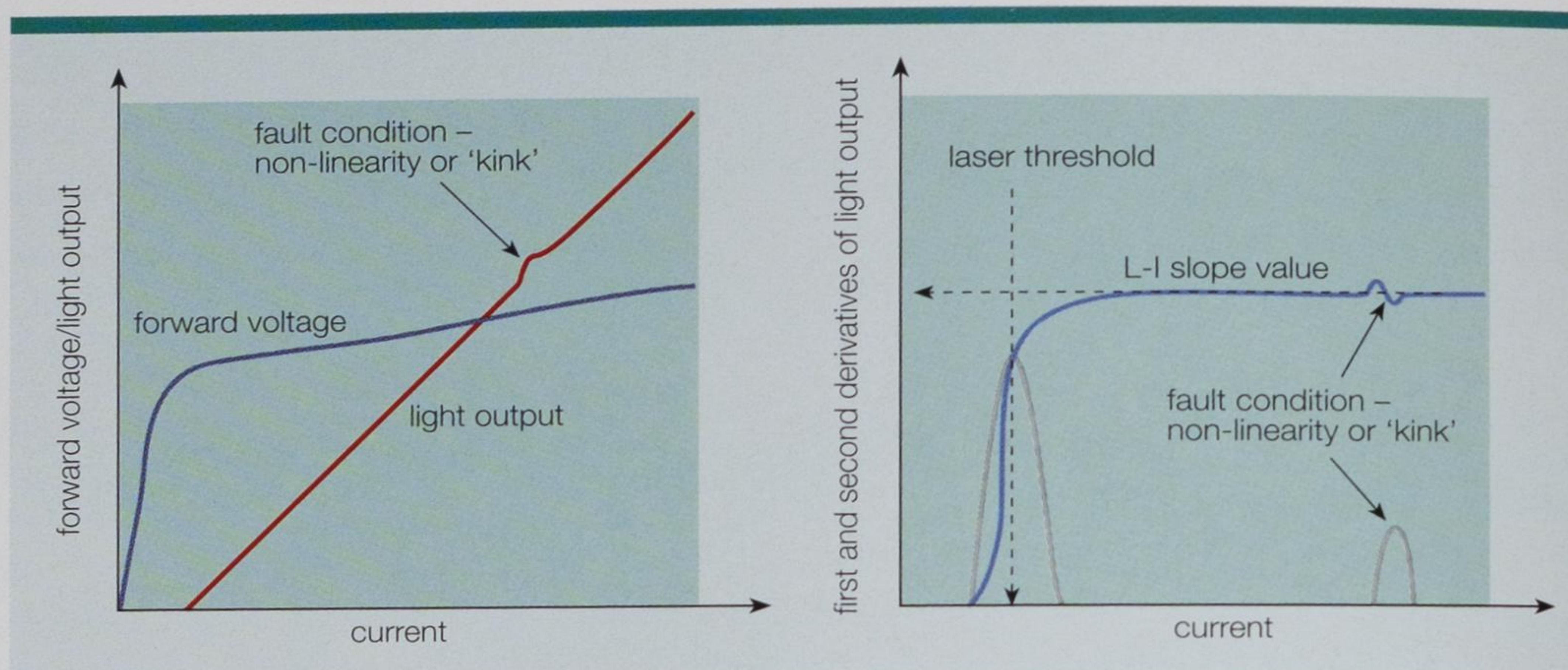


Fig. 1. Graphs showing the typical light-current-voltage characteristics of a laser.

wiring and probe-needle contacting. Once this is verified as being within tolerance, the LIV scan can begin.

For VCSEL devices it is typical to run a scan of 100 points from 0 to 10 mA in 0.1 mA steps. At each drive current step, the voltage drop across the diode is measured and stored locally. The optical power emitted from the VCSEL chip is also collected by a photodiode and stored by the test system.

The overall test time for a typical 2 inch VCSEL wafer containing 20,000 devices adds up to around 11 h (at 2 s per device) for the traditional approach using GPIB and single-DUT contacting. The challenge is to make significant improvements on this time.

Production-designed equipment

The PXIT equipment, which was specifically designed for production-orientated work, provided improvements in three basic areas.

First, the output stage of the current source must have the ability to drive into high inductive or capacitive loads. Usually an instrument such as this would have a very slow output stage to compensate for the former requirement. However, the PXIT design incorporates an analog PID (proportional, integral, derivative) control loop to optimize the output settling time. This allows the output to achieve its programmed state in the shortest possible time without the risk of overshoot. In addition, the output is fully floating with respect to system ground, and so the ground loops that often introduce noise and inaccuracy are eliminated.

Second, each PXIT module incorporates a "Sequence Engine" that takes control of the LIV sweep. It controls the exact timing of each step in real-time and allows the timing to change from step to step. Part of this functionality is achieved by utilizing the PXI local

GPIB and PCI

- GPIB (general-purpose interface bus – IEEE 488) is an early 1980s standard that is used for communication between stand-alone instruments.

- The PXI (PCI extensions for instrumentation) specification defines a rugged PC platform for measurement and automation. PXI modular instrumentation leverages the high-speed PCI (peripheral component interconnect) bus that is the de facto standard driving today's desktop-computer software and hardware designs. As a result, PXI users can enjoy all the benefits of PCI within an architecture that supports mechanical, electrical and software features and that make sense for test and measurement, data acquisition, and industrial computing applications.

trigger bus (the PXI specification allows for slot-to-slot trigger lines that are inherently fast) for board-to-board communication. Measured data is stored in local on-board memory.

Third, as a PXI module the equipment communicates with the controlling PC via the 33 MHz parallel bus, thus allowing large blocks of data to be transferred in just a few milliseconds.

Testing multiple devices

Applying this technology to VCSEL testing allows the 100-point LIV sweep time to be reduced by more than a factor of 10 to about 20 ms. A further reduction of the sweep time should be possible when a low-capacitance detector is used for the test.

In the present set-up, a long settling time was used to obtain a stabilized optical power readout securely, however, the settling time

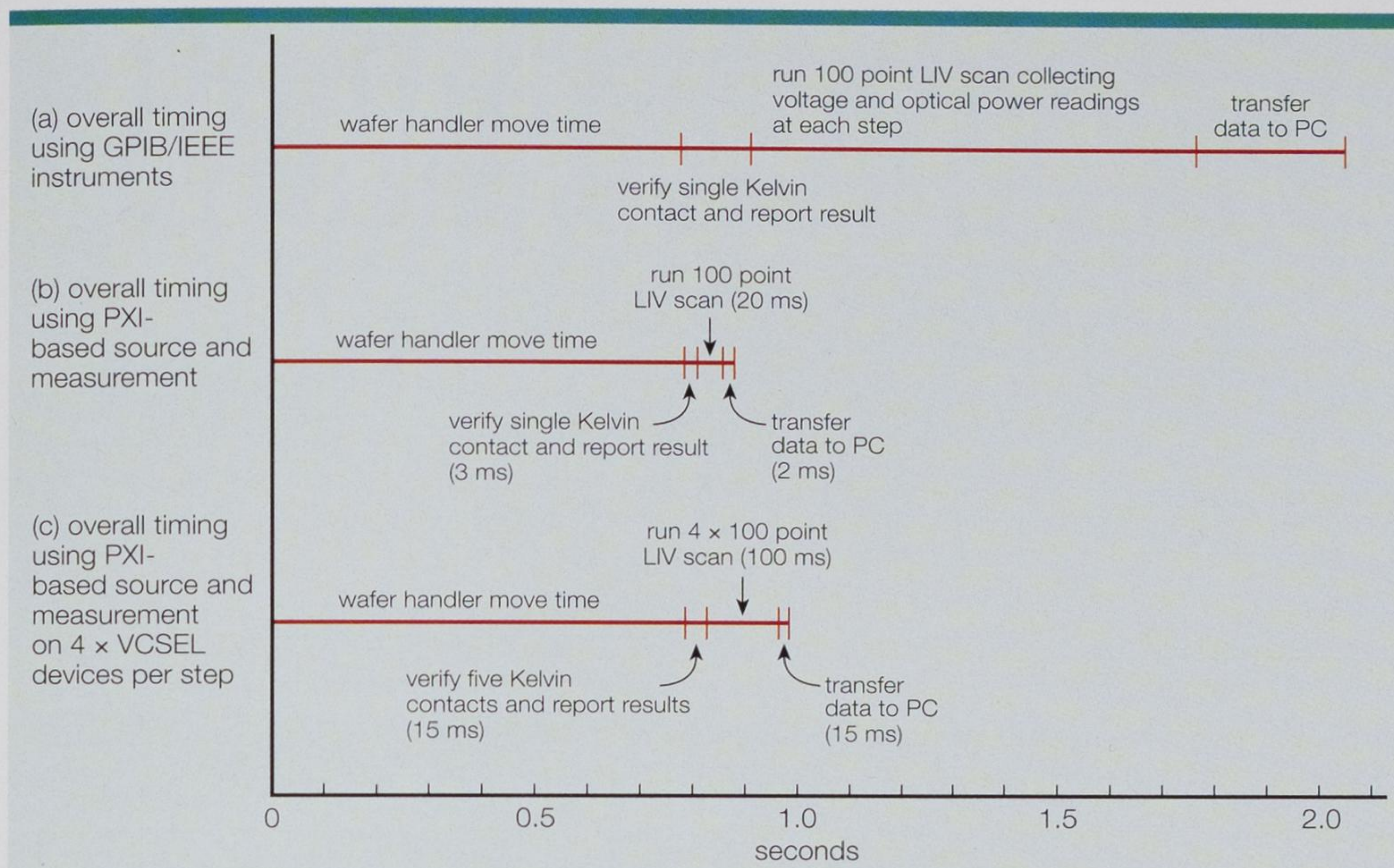


Fig. 2. The timing sequence in a wafer test cycle for three different testing scenarios.

of the PXIT equipment can be set to a minimum delay of 100 ms (assuming sufficiently fast external components are available). Contact integrity and, more importantly, data transfer time can also be reduced significantly.

Taking the previous example where each wafer has 20,000 devices, the overall test time can be reduced to approximately 5 h (0.9 s per device). This represents a 120% increase in productivity.

With the wafer handler now contributing 90% of the overhead, it makes sense to examine the possibility of testing multiple devices in a single scan. Although probe-card complexity is increased, the act of probing four devices at one time does not present a significant technological challenge.

In this scenario the PXI bus advantage is brought to the fore. By using a high-speed multiplex switch card, it is possible to switch between the Kelvin connection test and multiple LIV sweeps on each block of four lasers.

In this case the results for the typical test wafer show the test time to be 1.4 h (1.0 s for each of 5000 blocks of four lasers); this equates to an increase in productivity of approximately 700% compared with what is obtained using traditional test equipment (see image, p47).

Furthermore, the configuration is not limited to four diodes, since the matrix card can accommodate up to 20 diodes in a single probe sequence (see PXIT corporate white paper). This offers a wealth of further possibilities, including the programming of simultaneous LIV sweeps of different VCSEL diodes. It also allows the use of spatially sep-

arated multiple DUT block contacting, and the use of multiple spatially separated *pin* diodes to circumvent optical crosstalk. When measurement configurations with more complicated contacting patterns are used, additional efforts must be made to guide the wafer test stage during its work. We believe that the application of such configurations will lead to further significant increases in productivity beyond the factors proven to date. ●

Acknowledgments

Thanks to PXIT (www.pxit.com) and Suss Microtech (www.suss.de), who helped us get the best from their equipment; Voigt-Automatisierungstechnik (www.atvoigt.de), for their wafer test software; and Marc Ilzhoefer and Christian Degen of Infineon.

Further reading

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I Schmale *et al.* 2000 High-speed 12 × 2.5 Gbit/s parallel optical links (PAROLI) for increased transmission lengths. *Proc. ECOC*.

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Web: www.pxit.com/white-paper.asp.

Jürgen Müller is head of VCSEL Test and Analysis at Infineon Technologies in Munich, Germany. Email Jrg.Mueller@infineon.com.

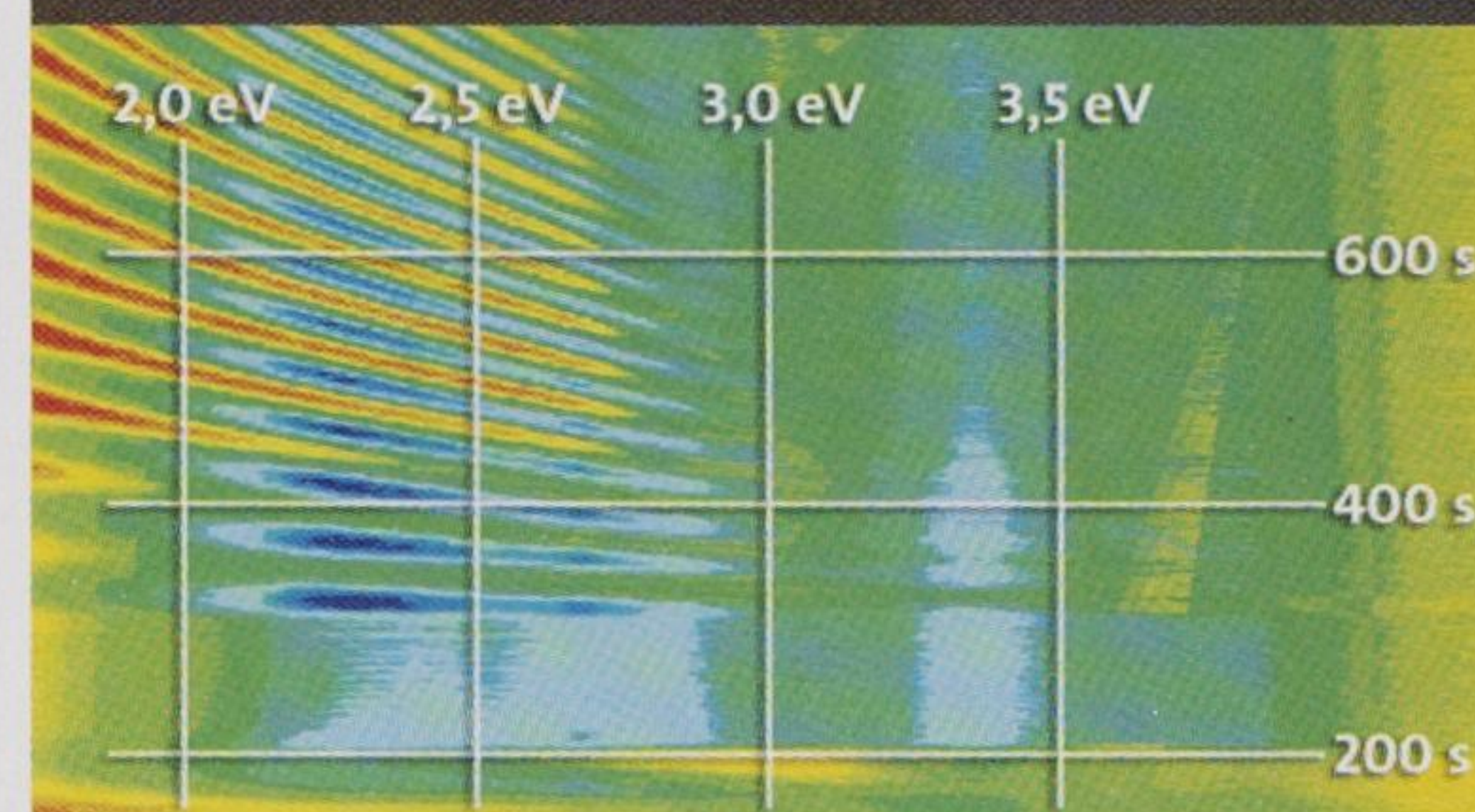
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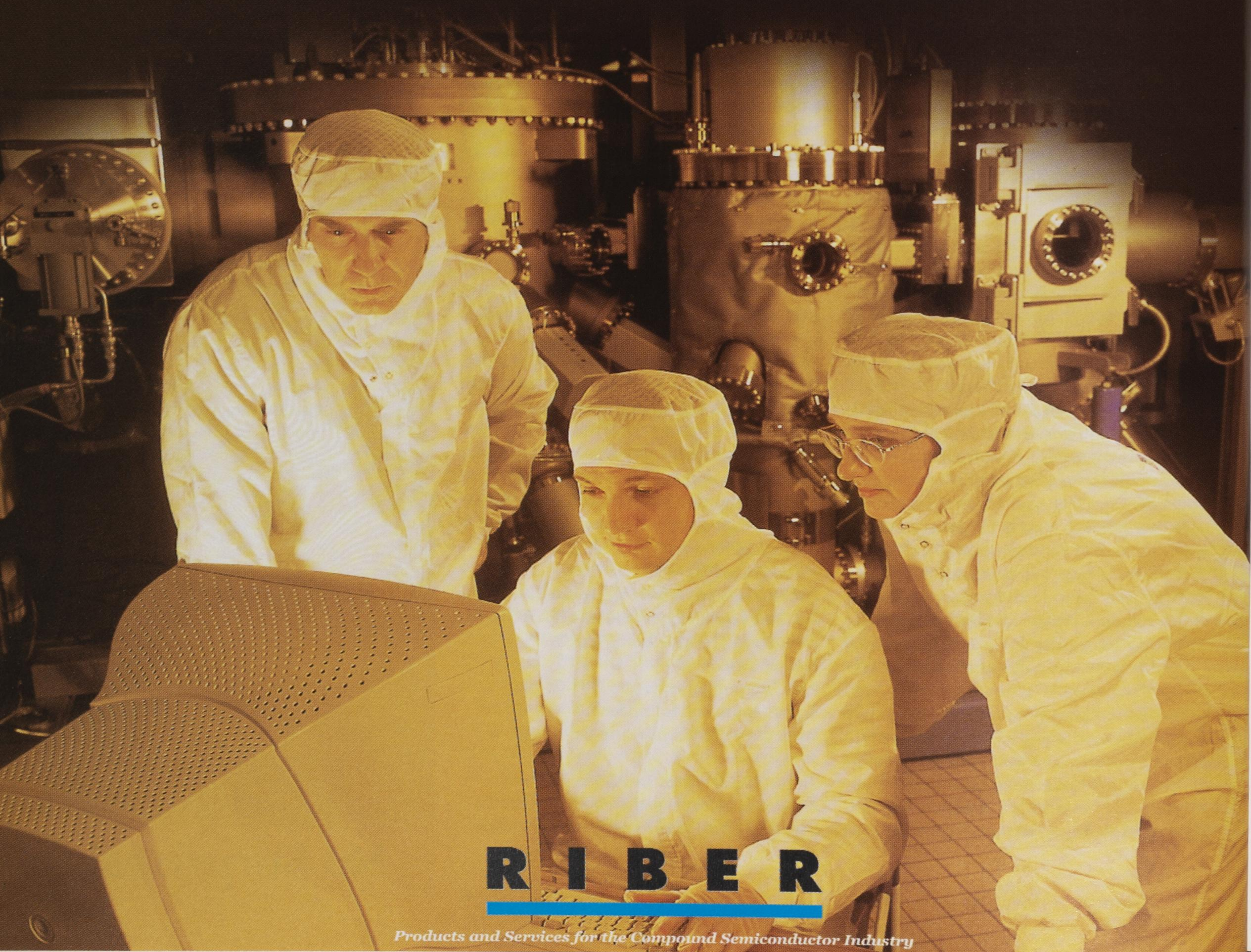
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New integrated manufacturing system boosts fab productivity

At Modulight, all the manufacturing steps and their supporting processes in product development and production have been integrated into a single relational database. The new system has led to an increase in productivity through better manufacturability and support for rapid decision making, write **Seppo Orsila and colleagues.**

Modulight, an optoelectronic component maker based in Tampere, Finland, has integrated all of its manufacturing facility's functions into a database-centered manufacturing system. The database stores all data related to production and product development, and helps Modulight to manage and monitor operations in real time. This can also be performed remotely. The system has improved the level of operations in almost every sector, including maintenance, sales, management and customer service. This article discusses the practical benefits of introducing rigorously defined database-centered manufacturing to a production environment.

The Web interface

Modulight's system has been built around a single relational database, which operates on a standard multiprocessor IBM server running Microsoft SQL Server. The production equipment is directly connected to the database (figure 1), and primary access to the system is realized via an integrated Web-based user interface. Some of the specific elements of the access part have been realized by developing stand-alone programs with a graphical user interface using industry-standard software development tools such as Labview and Visual Studio. All of these systems communicate with the database and store all data



Fig. 1. The new database-centered manufacturing system from Modulight consists of a database server, desktop and hand-held PCs, and production equipment.

and parameters in the database itself.

The use of a Web interface makes the system independent of operation systems and it can therefore be used from any PC or hand-held device that has a standard Web browser and a network connection. Most of the system's functions are also designed to work well with the small screen of a Compaq IPAQ portable hand-held device. This has allowed paper-based process notepads to be completely replaced, resulting in lower costs, improved efficiency and increased process monitoring accuracy.

Web access also makes it significantly easier to allow wider access to employees (and eventually to other interested parties) via properly designed extranets. Engineers with secure connections can also access the system from home, allowing fab engineers to work remotely for perhaps the first time in the industry's history.

The Web interface does not need any special client-side software, so updating it can happen solely at the server side, without disturbance to the users. Also, version control of the user interface is simple and the introduction of upgrades that do not interfere with production to the production system is uncom-

plicated. Upgrades simply appear to users the next time they access the upgraded functionality or resource.

The platform and development tools have allowed Modulight to focus on the system itself rather than the practical implementation. We have found it very easy and cost effective to rapidly improve the system based on the requirements specified by technical personnel.

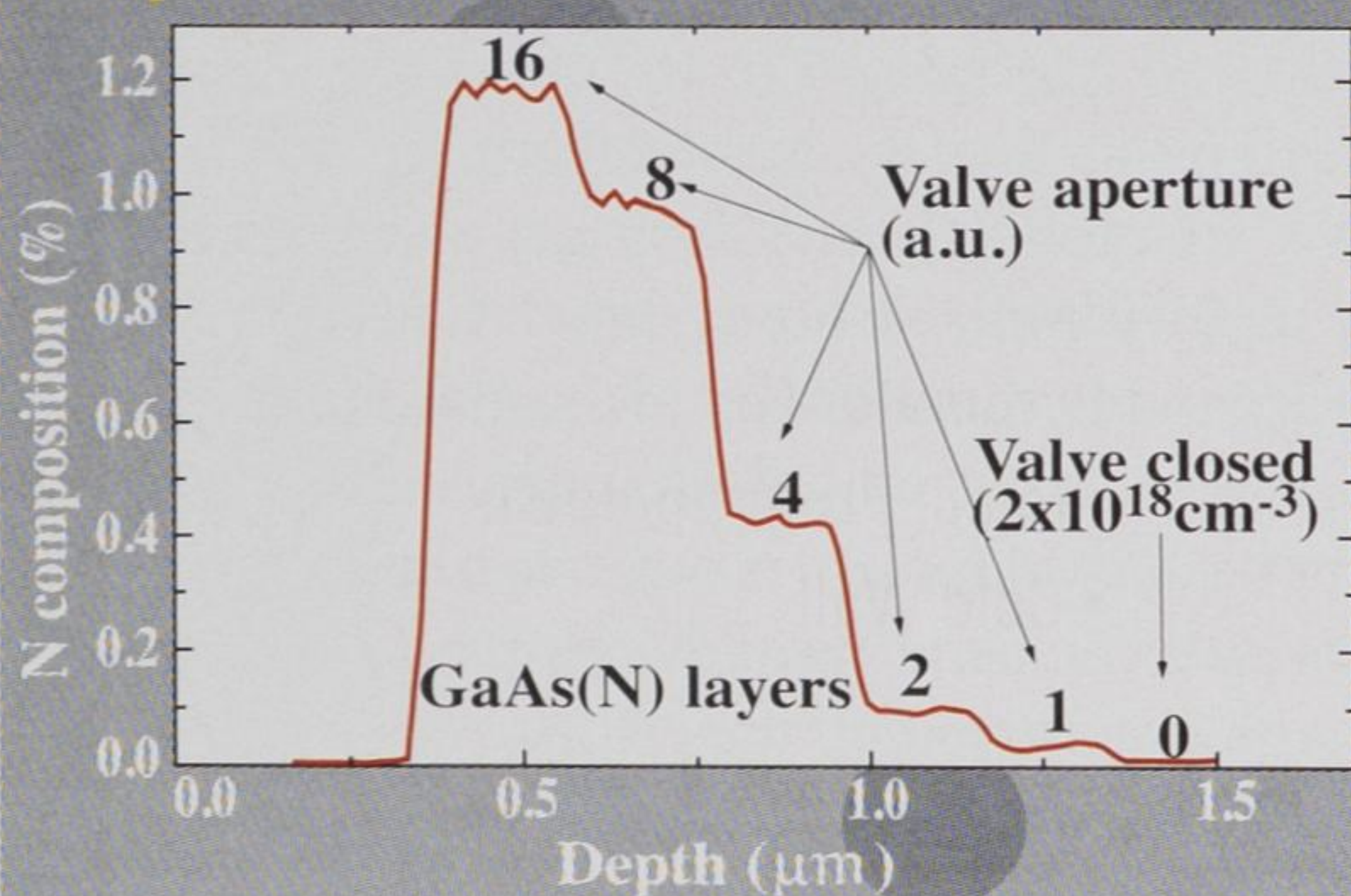
These days, when outsourcing is in and internal development is out, one might wonder whether the benefits of developing a custom-made system match the efforts required. But when the project is periodically analyzed, combining customer feedback, resources spent and the improvement in operations, the conclusion reached is that the development of the system is an essential part of improving operations when compared with a normal software development program.

A system for every business sector

When a process technician starts working and connects to the database, the system suggests a suitable process step to be performed. This suggestion is based on the competence of the technician, the availability of equipment and the priority level of the various processes in

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Production personnel interact continuously with the database as the product is being manufactured and as it passes through various quality control steps.

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Equipment periodic maintenances to come				
Equipment	Equipment periodic maintenance type	Due date	Do maintenance	Omit
Ultra-1	Change water	2-Oct-2002 09:00	Do maintenance	Omit
Ultra-2	Change water	2-Oct-2002 09:00	Do maintenance	Omit
Surface profiler	Vertical calibration	2-Oct-2002 10:00	Do maintenance	Omit
Vacuum packer	Check the oil level	3-Oct-2002 08:00	Do maintenance	Omit
PL mapper	Clean the unit surface	3-Oct-2002 09:00	Do maintenance	Omit
Epitaxy-2	Daily maintenance for Epitaxy-2	3-Oct-2002 17:00	Do maintenance	Omit
LN2 separator	Check the oil level	4-Oct-2002 09:00	Do maintenance	Omit
LD-production tester	Cleaning	4-Oct-2002 09:00	Do maintenance	Omit
DI water system	Change purification pack	7-Oct-2002 10:00	Do maintenance	Omit
Scriber&Cleaver	Cleaning	7-Oct-2002 09:00	Do maintenance	Omit
RIE	Visual inspection	7-Oct-2002 09:00	Do maintenance	Omit
Mask aligner-1	Visual check	7-Oct-2002 09:00	Do maintenance	Omit
PECVD	Visual inspection	7-Oct-2002 09:00	Do maintenance	Omit
Expander	Cleaning	7-Oct-2002 09:00	Do maintenance	Omit

Fig. 2. Automated maintenance and calibration can be scheduled by the database-centered manufacturing system.

progress. Once the technician has accepted the process step, the database gives instructions for performing that step, i.e. what equipment and input parameters should be used and any process-specific instructions given by the engineers. While running the process step, the processing/quality control equipment and/or the technician feed data to the database. When one process step is complete, the database suggests which step to perform next.

The automatic production-control feature significantly reduces the resources needed for production management, and ensures that

production capacity is used in the most effective way. The automatic allocation of process steps not only allows a reduction in the time spent by production engineers in guiding process technicians, but also enables much more complex and efficient logic to be used in workflow management. As listed above, a number of different production parameters can be taken into account when deciding the process order.

One example is maintaining worker competency. The system can be defined to ensure that each operator repeats all the process steps for which they are qualified at least once every two months, ensuring that process technicians remain cross-trained. However, if at the same time we want to choose those individuals with the best track records for high-priority processes, we must apply rather complex logic. This example shows how the completeness of the manufacturing database system can effectively support the company's human-resources process by ensuring the continuous development of personnel. This increases productivity and the ability for rapid change management down to the production floor.

Some advantages, such as assigning each process step individually, might only improve efficiency in a small-company environment, but we believe that significant economies of scale also exist. Indeed, some of the benefits will only appear in larger fabs. Due to the holistic approach required to achieve such benefits as rigorous traceability, interactivity in decision making and future support for all

activities, the basic data structure needs to be very robust and complete. This means that all data must be parameterized if possible, even if the present business model or operations do not necessarily require it. In developing the system we adopted this philosophy, and are now receiving some payback. For example, developing the new functionality requested by users is usually just a matter of adding some logic, parameters or making a new database query. We have found the system easy to integrate with conventional MS Office applications and have produced complex reports in a matter of hours or days.

Challenges of the holistic approach

The completeness is, however, also a drawback. The holistic approach that is required certainly makes implementation time consuming, and the benefits only start to appear after a certain maturity. We have found that this is for three reasons:

- early development of the system requires a lot of basic specification and implementation work, which by itself does not produce anything tangible;
- gaining user confidence and acceptance takes time;
- the system needs to be run for some time to produce enough data to support advanced decision making.

However, we also believe that gradual implementation is the best choice because this allows us to tackle the biggest challenge: obtaining user acceptance via constant dialogue and the integration of the development team with the production team.

Practical benefits

The database-centered manufacturing system also provides support for decision making at the daily production level. The system recognizes failed components, thus preventing unnecessary further processing. It can also be taught to evaluate the need for additional process steps, if the targets were not achieved with the pre-defined processing parameters in the previous steps. All this reduces the possibility of human error and frees human resources for more productive tasks.

For engineers, the database-centered manufacturing system provides a great source of production and product development data. All the data that would otherwise be scattered around the factory in various formats and media is now available from any user's PC in a single format, enabling easy access to product and yield improvement through

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statistical process control tools.

For maintenance personnel, the system not only provides a complete record of maintenance, service and calibration, but can also be used to schedule future maintenance and calibration (figure 2). This helps the maintenance personnel to keep track of all the required activities. When equipment is designated out of use by a technician who observes a sudden equipment failure, it will automatically be removed from available resources. Process technicians are then automatically forwarded to other tasks (process steps) while the repair task is assigned to fab maintenance personnel.

To emphasize the robustness of the approach, it is worth noting that the general rules and logic which companies need to implement anyway, can in many situations be even more effective when automated and set to run in real time. Compare a situation in which a system automatically monitors a process parameter such as yield or tolerances of lasers. When control values are exceeded, the appropriate activities are

halted or corrective action is taken.

For the sales department, in addition to basic information like real-time storage access, the database-centered manufacturing system provides great tools to improve customer service. As the sales team enter customer orders to the enterprise resource planning system, the manufacturing database system can change production priorities for different products automatically, if such a feature is desired. The sales team can also easily extract product verification data from the database for each shipped component, and detailed process information for each particular component can be delivered. The database could also be used as a basis for an extranet that can provide customer access to real-time information regarding their orders.

For the management team, the database-centered manufacturing system provides almost unlimited analytical capabilities to support factual decision making. Up to date production figures or statistics regarding the use of personnel and equipment resources can

be displayed with just a few mouse clicks, providing an efficient way to rapidly reassign part or all of the company's resources.

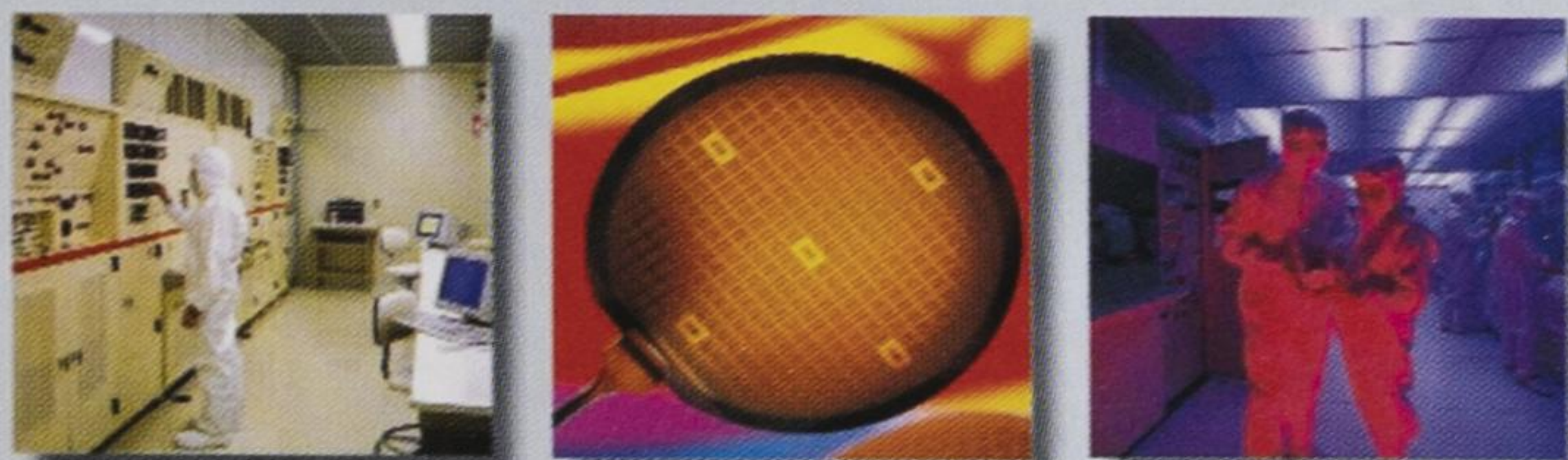
Conclusions

We have demonstrated that database-centered manufacturing can provide access to simple analysis, lead to an improvement in production efficiency and customer service, and support nearly all of the operational processes found in an ISO9001:2000 company. We believe that this is due to the ease of use, as well as the completeness of the implementation. However, it is important to note that some basic time is needed to achieve the first tangible results that will benefit users. Before reaching this point, users will often consider this type of project as unproductive work, and so user confidence must be won if database-centered manufacturing is to be introduced. ●

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Efficiency engineering leads to operational cost reduction

Within the entire life-cycle fab approach, efficiency engineering based on mass, energy and cost analysis identifies inefficiencies and other associated opportunities to reduce media consumption and disposal rates, according to **P Giannoules and colleagues**.

The major challenges to the electronics industry today are short product life cycles and the continuous development of new products with ever-smaller feature sizes. Also of concern are the large initial investments and operational costs that are required for new wafer fabs or upgrading existing ones, specifically during market downturns.

Approximately 40% of the operational costs of a new wafer fab are due to capital investment, and another 30% can be attributed to the supply and disposal of materials and energy. Consequently, activities that support the continuous reduction of material and energy consumption and disposal will improve cost of ownership and therefore the financial performance of a fab (Gälli *et al.*).

Managing costs

During the processing of GaAs wafers, wet cleaning and wet etching are used. These processes require large amounts of ultra-pure water and expensive chemicals, and produce wastewater containing arsenic compounds that must be treated at high cost.

In dry etching some of the process gases used are perfluorinated carbons (PFCs) or related compounds, which results in exhausts containing these gases, their reaction products and arsenic compounds. In GaAs device fabrication the epitaxy process alone often contributes to more than 50% of the wafer cost. This includes the costs for energy as well as chemicals and gases such as trimethyl gallium, arsine and hydrogen. Many of these and their related compounds are toxic, pyrophoric or explosive, and therefore require specific investments for their safe delivery and handling, as well as for the emission control of exhaust, wastewater and solid waste. As a result, efficiency improvements include both the consumption of material and energy as well as the resulting emissions, making the management of reduction programs crucial.

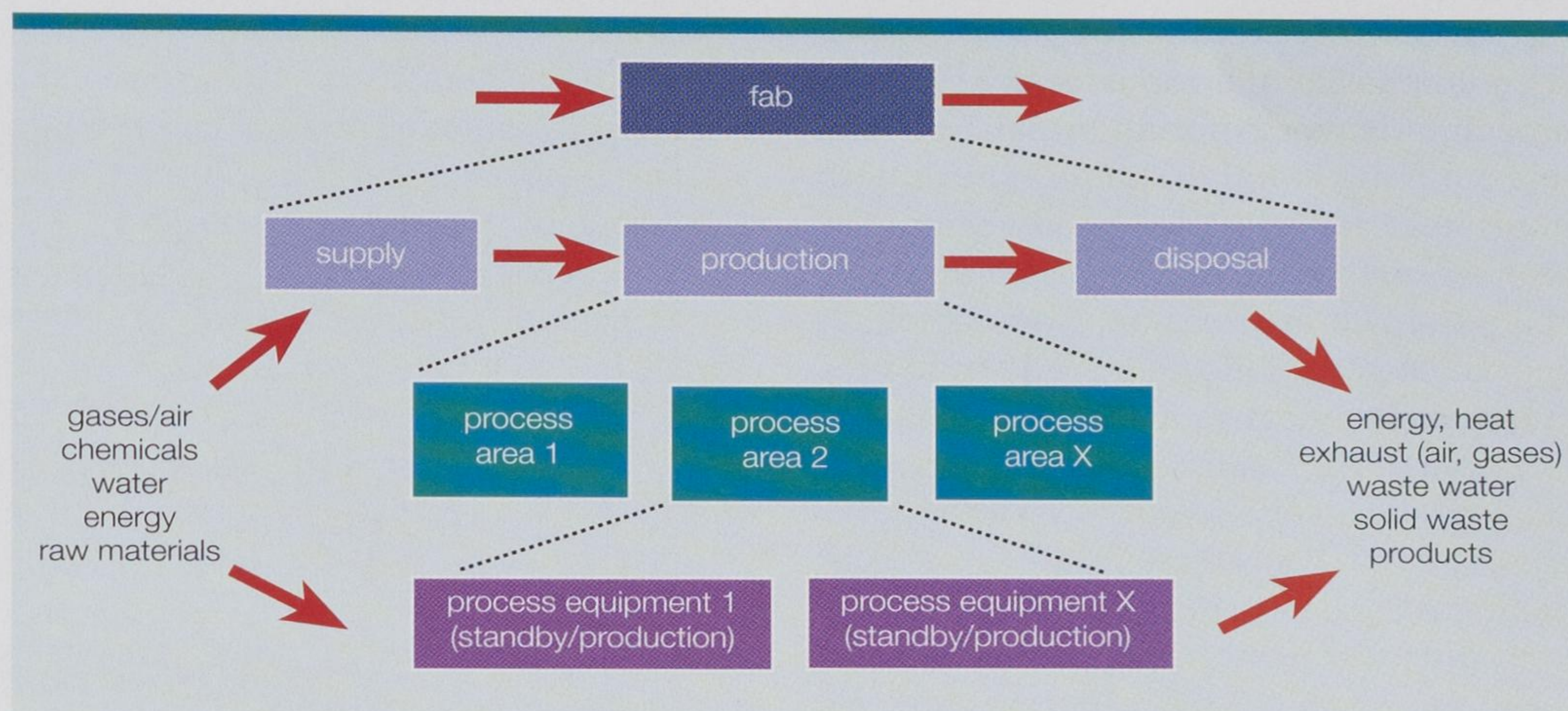


Fig. 1. A fab model for efficiency engineering, fab planning and facility management.

The methodologies for efficiency engineering are mass- and energy-flow analyses, which are based on the principles of mass and energy conservation.

The continual introduction of new processes and materials also creates new costs in supply, disposal, safety and health. To foresee and understand these costs in the context of the entire fab is also therefore an ongoing and critical management task.

The efficiency engineering approach

In a compound semiconductor fab the supply and disposal demands of production determine the capacity of the facility. Within the fab, individual facility systems influence each other. If production needs more ultra-pure water, the consumption of raw water, nitrogen, electricity, chemicals, and heating and cooling energy, will also increase to a certain

extent, since these materials are used in the ultra-pure water plant.

This simple example illustrates the importance of thinking in terms of systems rather than considering plants or media individually. The financial consequences of any planned changes can only be assessed if cost transparency is achieved.

Cost transparency is a key factor in achieving the optimal financial performance of a wafer fab. This is where efficiency engineering comes in. The following five elements are the basis for efficiency enhancement of a compound semiconductor fab:

- transparency of mass, energy and cost flows;
- monitoring of equipment performance;
- benchmarking of production and facility efficiency;
- cost-reduction programs to optimize efficiency;
- planning of future developments.

Combining these elements with the overall efficiency goals set by the fab management will result in a continuous improvement process that is fully compatible with the ISO 14001 strategy of establishing an environmental management system.

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Flow analyses

The methodologies for efficiency engineering are mass- and energy-flow analyses, which are based on the principles of mass and energy conservation. By assigning costs to the media, a cost-flow analysis can be achieved.

Mass-, energy- and cost-flow analyses are used to optimize the entire fab based on input and output considerations. The bottom-up approach starts with the individual equipment and may end at the level of the entire fab (figure 1). In the efficiency engineering approach the fab is viewed as the sum of the processes which have a potential for improvement.

Cost-saving potentials can be classified according to their potential for implementation. Short-term optimization may be implemented immediately without interference to the manufacturing processes. Examples include reducing excessive consumption, changing the segregation of waste streams, and reusing/recycling material and energy.

Long-term optimization includes improvements that often require minor adaptations of processes and equipment. These improvements need to be evaluated and will only be implemented if they are financially attractive. Some improvements might become relevant when assessing cost of ownership for new process equipment. Improvements affecting process equipment and process design require the integration of the tool manufacturer.

M+W Zander's approach is the application of efficiency engineering throughout the entire life cycle of a fab, including design, construction and facility management. This leads to an increase in productivity and a reduction in the total cost of ownership.

Example 1: water management

The total water costs of a fab depend on factors such as the raw water price, the cost of purification and wastewater disposal, the efficiency of the process tools and the extent to which water is reused or recycled. Understanding these processes and their interactions in the fab is a prerequisite to achieving cost reduction.

In figure 2a, the results of a water and wastewater reduction program conducted in a fab are illustrated. All the measurements were non-invasive, using ultrasound measurement technology, and took place in a fully operating fab without affecting the processes or their productivity. The bars in the figure show the water consumption and wastewater generation for different streams before and after optimization.

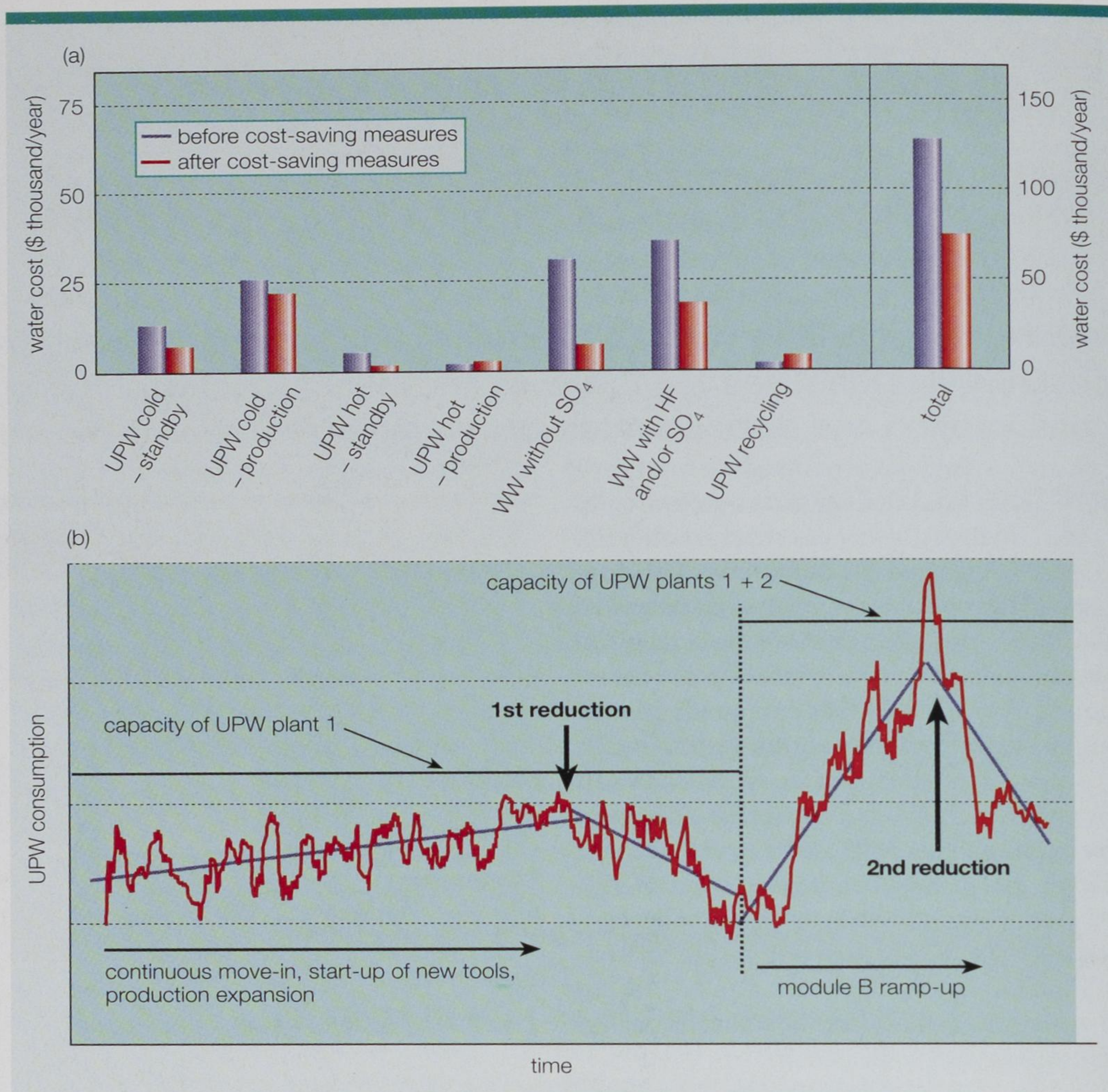


Fig. 2. (a) Consumption of ultra-pure water (UPW) and wastewater (WW) before and after the implementation of cost-saving measures, from a systematic fab analysis. (b) Water savings at the fab level showing the effect of two water usage reduction programs. The second reduction program takes place after the introduction of a second UPW production plant.

In order to demonstrate the effectiveness of the water savings at the fab level, the water consumption of the entire fab was monitored, as shown in figure 2b. During the initial period a continuous increase in water consumption occurred due to the product ramp. After implementing the first reduction program a significant drop in water consumption was observed. In the second stage a new production module, including a new ultra-pure water plant, became operational. After major increases in water consumption during ramp-up, a second reduction program was implemented, and a positive effect on the overall fab water consumption was again observed.

Example 2: clean gas consumption

Various expensive specialty gases are used in cleaning processes for plasma-enhanced deposition and during dry etching. The exhaust from these processes requires abatement

prior to release into the environment, since many of the gases used are toxic or sources of environmental hazards. For example, PFCs or related compounds like NF₃ are strong greenhouse gases.

Figure 3 shows the results of a program to optimize the consumption of NF₃ during the cleaning steps of a deposition process. NF₃ was monitored online using quadrupole mass spectrometry and Fourier transform infrared spectroscopy, in accordance with the new Sematech guideline (International Sematech 2001).

In figure 3, the level of NF₃ consumed by the cleaning process is plotted versus the NF₃ flow rate into the reaction chamber. The data demonstrate that at a flow rate above approximately X sccm the amount of NF₃ consumed does not increase any further. In the original recipe for this cleaning process, the flow rate was A sccm, and the

HIGH-VOLUME PRODUCTION

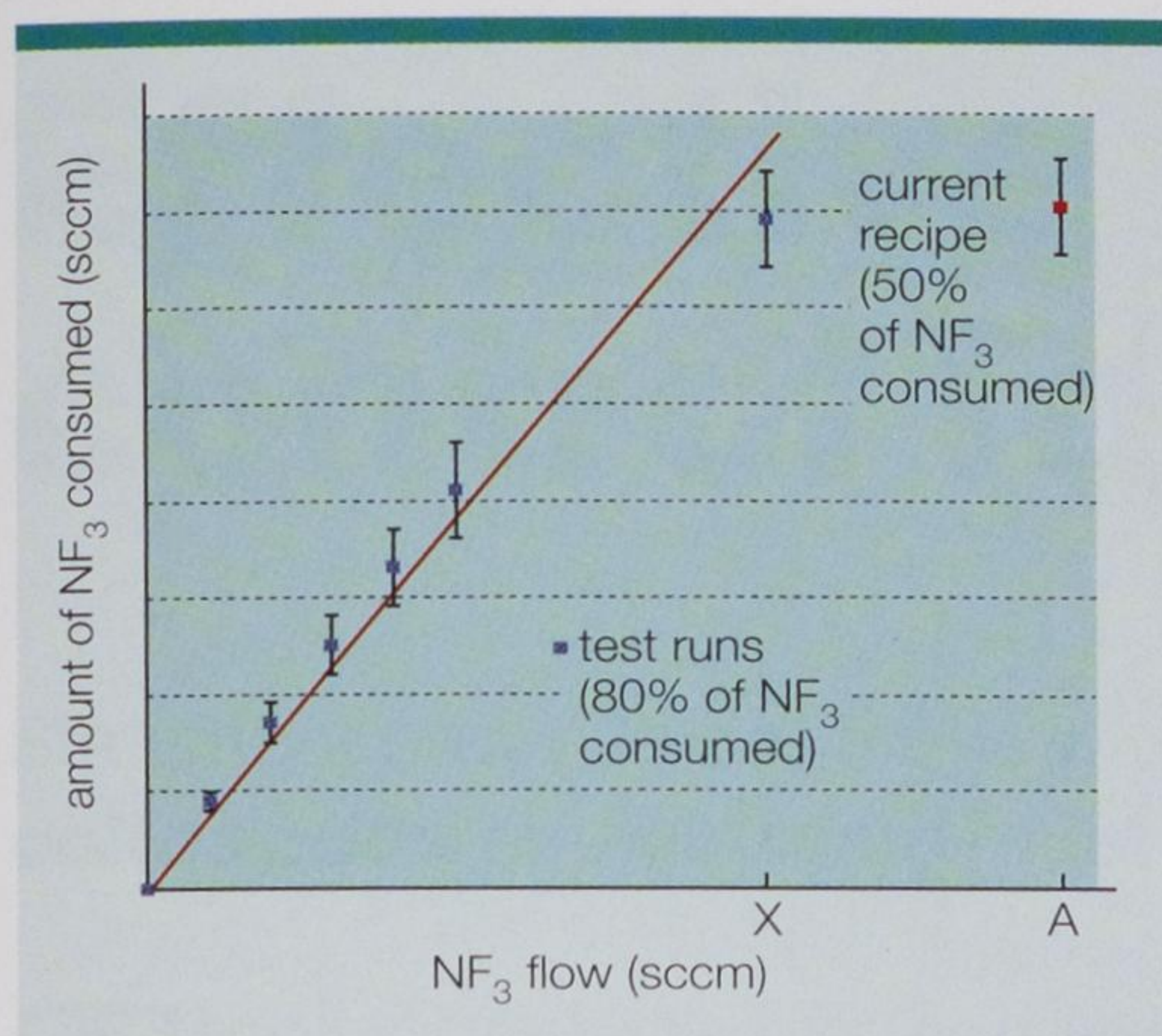


Fig. 3. The optimization of NF_3 consumption during a chamber cleaning process. The NF_3 flow rate was reduced from A sccm in the original recipe to X sccm, without changing the level of NF_3 consumed or affecting the cleaning time.

overall reaction efficiency for NF_3 was less than 50%. Below X sccm, the efficiency is about 80%. The flow rate of NF_3 can be reduced to X sccm without impacting the process cleaning time, while at the same time reducing the amount of NF_3 emitted from the process, which improves the eco-performance of the fab.

Example 3: process cooling water

The cost of process cooling water (PCW) is a function of the energy produced by the process tool and the rate of PCW flow through the tool. Savings are usually achieved by reducing the PCW flow through the process equipment rather than by reducing the heat load received.

If the capacity of the PCW plants becomes limiting, efficient use of the available capacity may postpone the need for plant extensions, which results in significant savings on investment. In a fab, the PCW consumption (including heat load) was quantified for 25 tools. The analysis revealed that more than 80% of the heat released was removed when the PCW volume was reduced to only 40% of its original value (figure 4).

Besides using this data for optimizing an operational fab, the information proved to be very valuable for planning a new fab, where design reductions for PCW consumption of more than 25% were achieved.

Outlook and conclusions

The future extrinsic and intrinsic challenges to the compound semiconductor industry are enormous. From an environmental per-

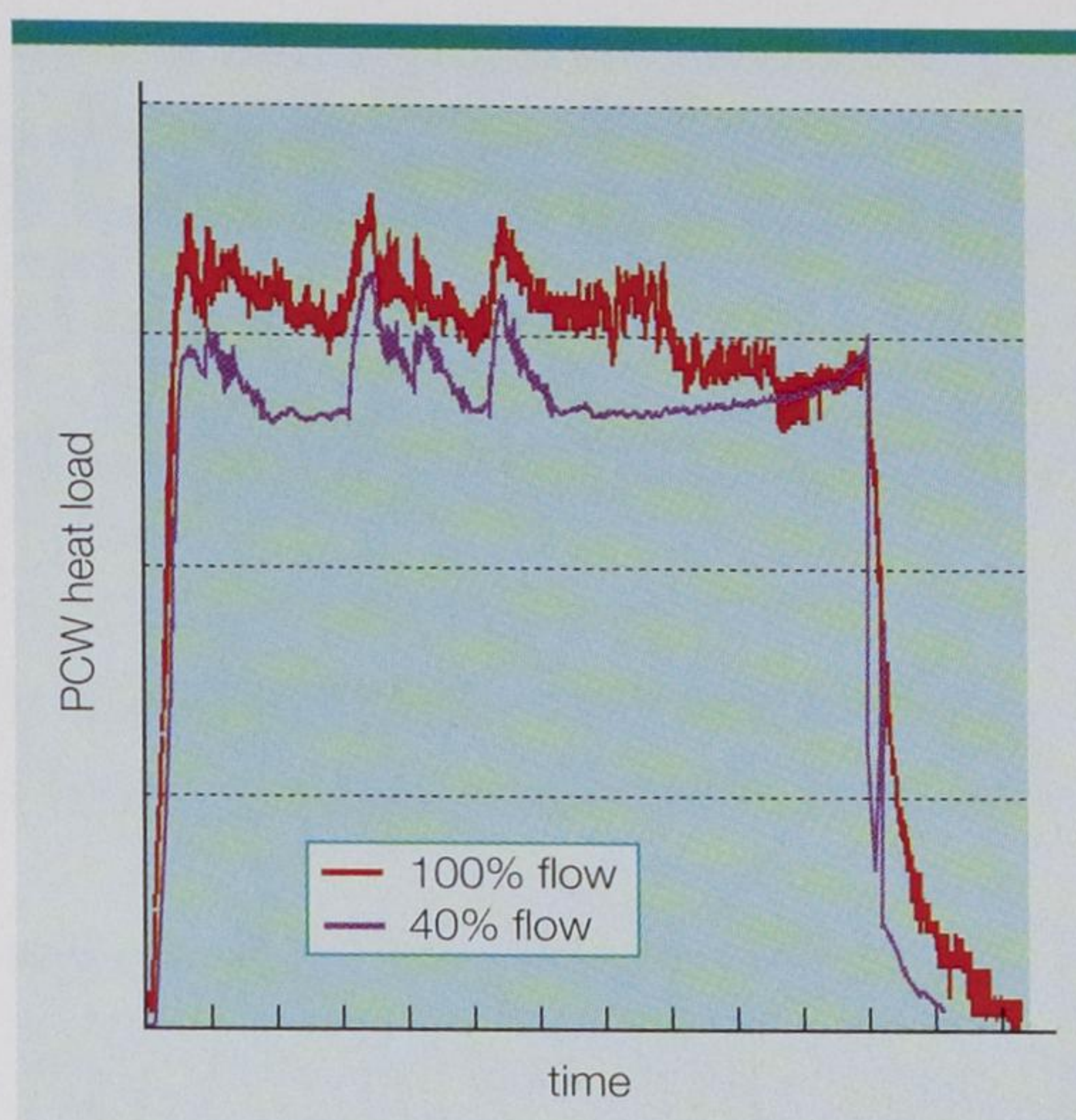


Fig. 4. Heat load of the process cooling water (PCW) used for 25 production tools prior to optimization (100%), and heat load removed by only 40% of the PCW volume.

spective, sustainability is the main driver that will influence the eco-efficiency of the entire industry. The driving forces include more stringent environmental standards, environmental taxes and increasing prices for raw materials and energy. Cost transparency supports the assessment of the consequences for future developments. From a business perspective, with short product life cycles in a competitive environment, efficiency engineering provides a proven and valuable approach to meeting cost reduction while simultaneously lessening the environmental impact. The improvements that the compound semiconductor industry will achieve can be accelerated by the comprehensive life cycle fab concepts, as proposed by M+W Zander in co-operation with device manufacturers, equipment suppliers and materials suppliers.

Further reading

R Gälli, A Bachmann and H Binder 1998 Reduction of production cost through E4 efficiency engineering *Semiconductor Fabtech* 8 85.

International Sematech 2001 Guidelines for Environmental Characterization of Semiconductor Equipment. Document #01104197AXFR (www.semtech.org).

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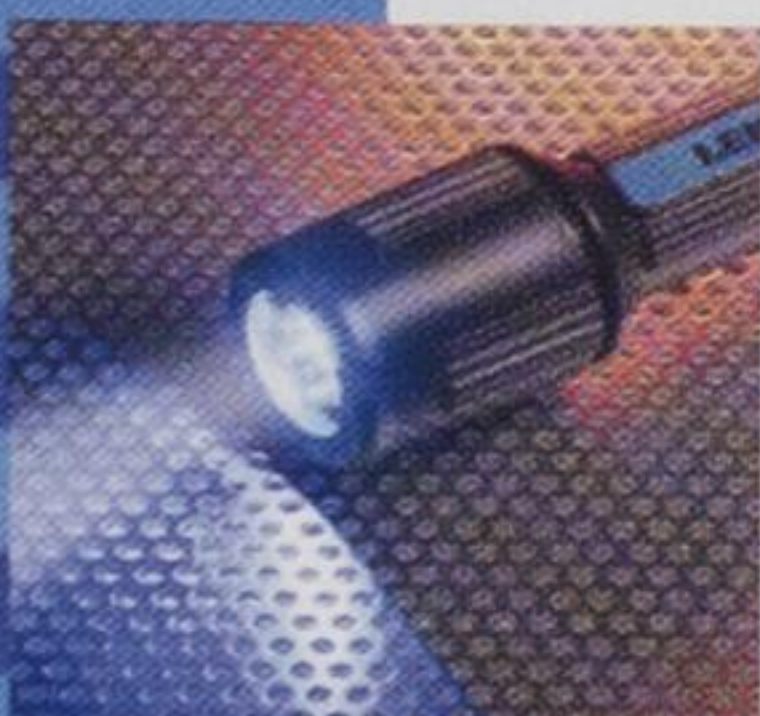
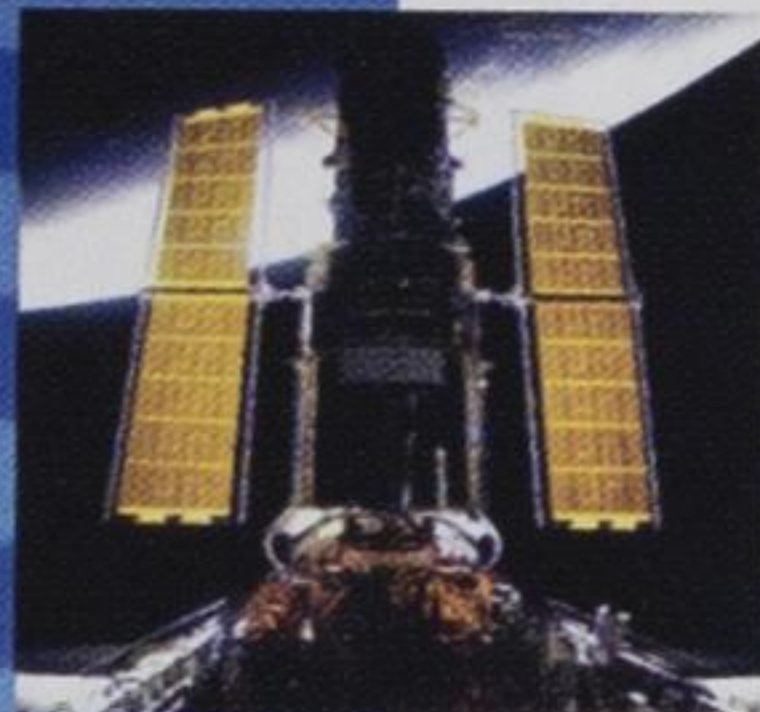
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HIGH-VOLUME PRODUCTION

Effective statistical process control for HBTs and PHEMTs

Statistical process control is widely used for high-volume epitaxy, but as **Paul Cooke and colleagues** explain, care must be taken in the selection and measurement of the parameters.

The current marketplace for compound semiconductor RFIC epiwafers is increasingly shaped by end-user cost limitations. Epitaxial manufacturing processes need to be optimized, well controlled and efficient. Statistical process control (SPC) is almost universally employed to track production epitaxy. However, for SPC to be effective, the process and material parameters to be tracked need to be carefully selected. Ideally, for each chosen parameter, a gauge (measurement system) capability study or measurement system analysis (MSA) is required to validate any collected SPC data. In principle, the incorporation of SPC information into a control or quality plan under QS9000/ISO9000 formalism ensures that realistic control limits are set, process capability is demonstrated and effective out-of-control response plans are established.

Deciding what to measure

At an early, low-volume production stage in a product's life cycle, engineering input may lead to the definition of key parameters or control points. As the product matures and experience is gained, these can either be enhanced or removed depending on the identified sources of variation. For the epitaxial growth of HBTs and PHEMTs, there is the added complication that not all of the key device parameters can be readily assessed at the final epiwafer level. Calibration growths such as capless PHEMTs are required when the desired characteristic to be controlled is either masked or unreliably measured on the final product wafers. Many measurement techniques are destructive in nature, making MSA a difficult and costly process. Ideally, *in situ* control can be used to correct and adapt for thickness or alloy drifts. However, at present few optical or electrical properties can be directly assessed *in situ*.

MOCVD production of PHEMTs makes extensive use of the (004) reflection from

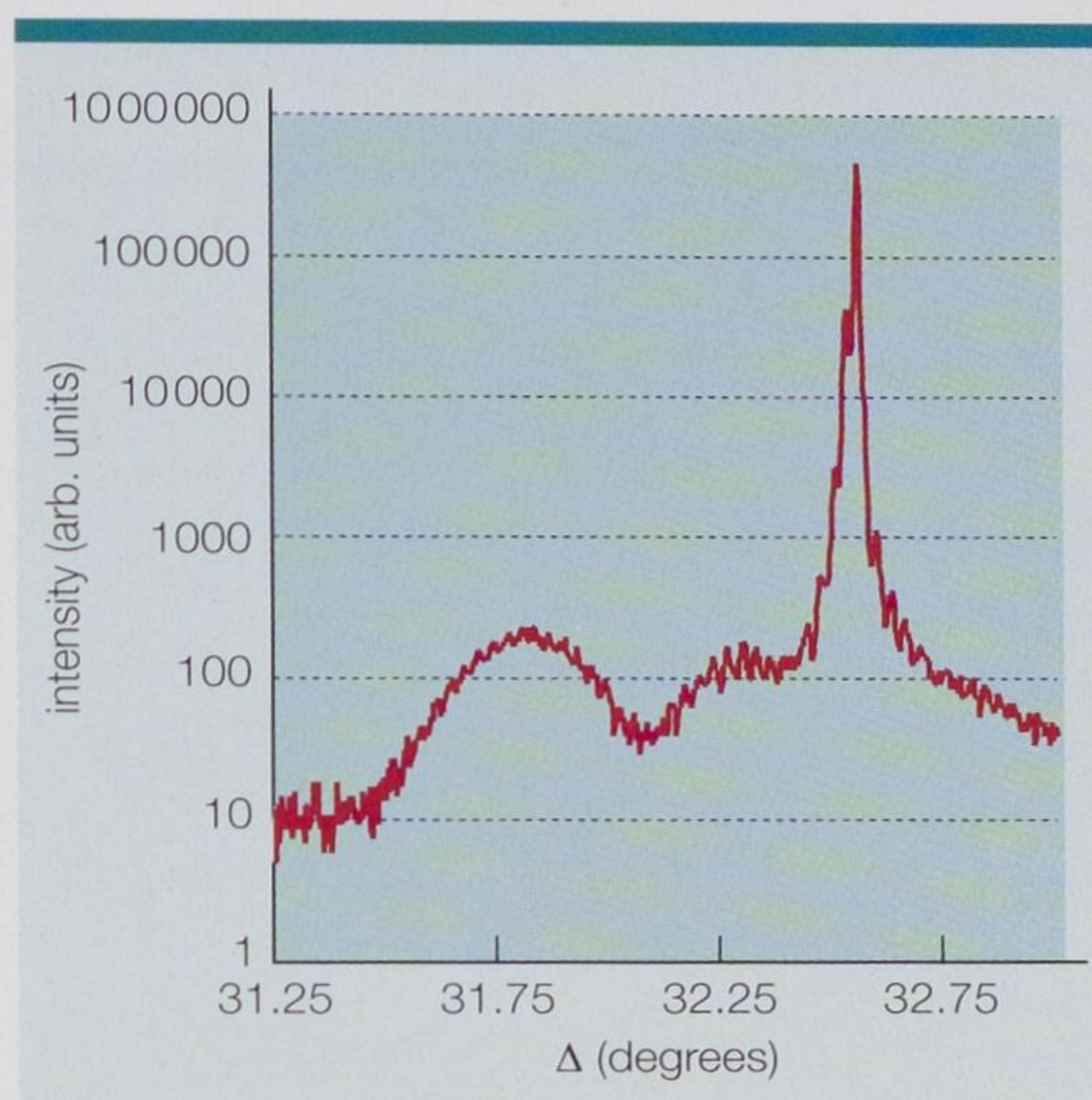


Fig. 1. Graph showing a typical (004) X-ray diffraction spectrum for an MOCVD-grown InGaAs/AlGaAs PHEMT.

InGaAs channel R&R results		
	In mole fraction (%) contribution	InGaAs thickness (%) contribution
total R&R	4.6	1.6
repeatability	4.6	1.6
reproducibility	0	0
part to part variation	95.4	98.4
total variation	100	100

Table 1. The gauge R&R results from XRD for an InGaAs PHEMT channel.

X-ray diffraction (XRD) for epitaxial layer assessment. The recent availability of comprehensive fitting software has led to a trend of extracting and reporting all layer thicknesses and alloy mole fractions. However, care must be taken to separate the parameters that can be extracted reliably and thus employed for SPC. The graph in figure 1 shows a representative diffraction spectrum for an MOCVD-grown InGaAs/AlGaAs PHEMT. The lattice distortion in

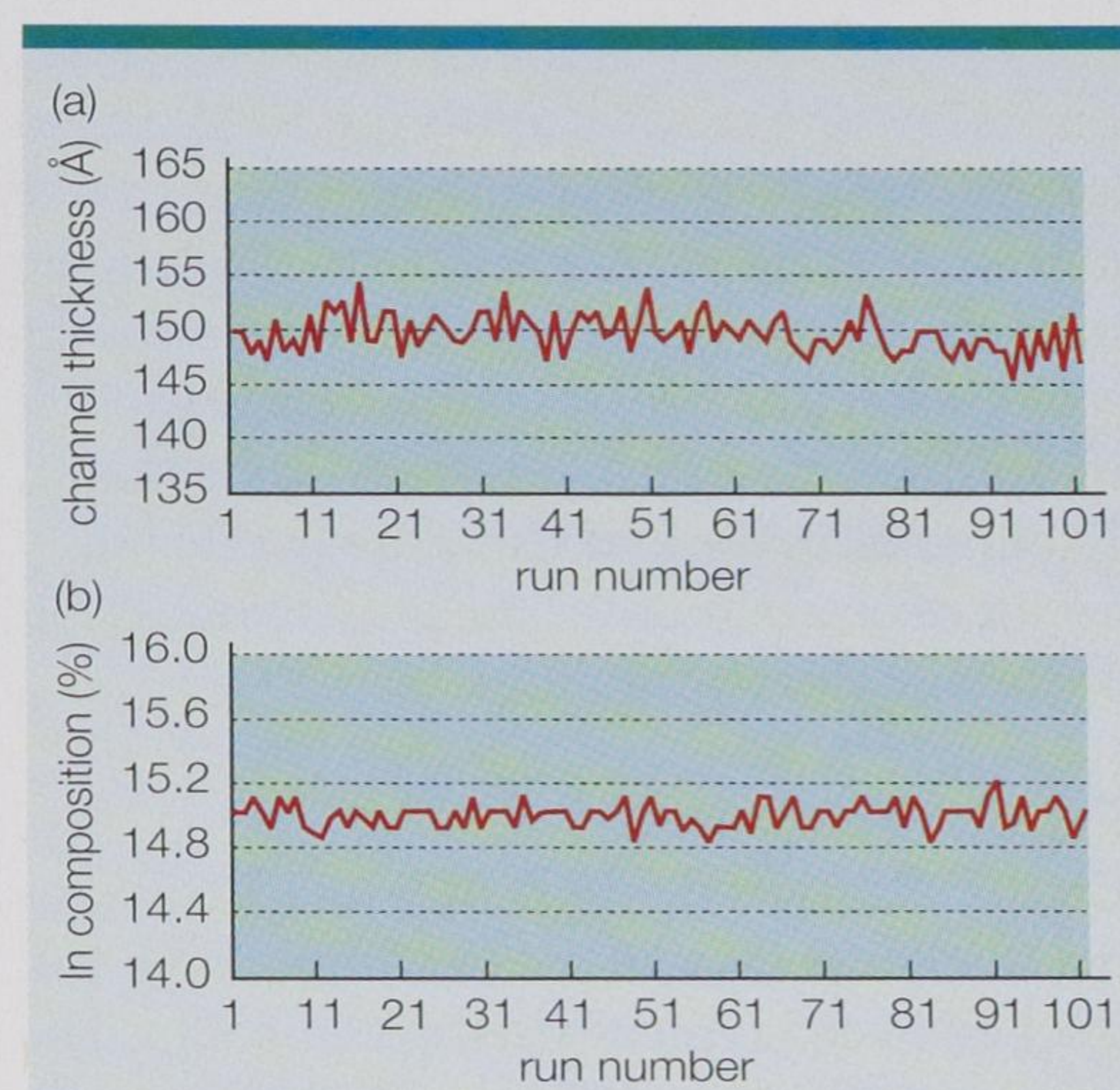


Fig. 2. InGaAs channel thickness (a), and In composition (b), from 150 mm PHEMT wafers tracked over a growth campaign.

the strained InGaAs layer generates a clear signature that is sensitive to both alloy mole fraction and thickness.

Reproducibility and repeatability

To assess the effectiveness of a measurement system and thus how appropriate its use is for an SPC system, gauge reproducibility and repeatability (R&R) data is required. Reproducibility is a measure of the variability between operators measuring the same parameter. The repeatability is the variability of a single operator measuring a particular parameter a number of times. For SPC to be meaningful, measurement errors must be low, otherwise a value could be solely due to a measurement error, and not a reflection of the process itself.

For a measurement to be effectively employed in SPC, the R&R values should be less than 10% of the allowable tolerance. R&R values greater than 30% make the gauge useless for SPC. Between 10 and 30%, the gauge can be employed for SPC with additional precautions such as averaging.

HIGH-VOLUME PRODUCTION

Table 1 shows the R&R results obtained as part of an MSA for the In composition and layer thickness of an InGaAs PHEMT channel. In line with expectations, both of the parameters are statistically robust, and so the majority of the variability is attributable to the grown material rather than to the measurement technique.

Conversely, extracting the relative thicknesses of the AlGaAs and GaAs layers above the channel is not as robust. The limited strain associated with AlGaAs, and the resolution of a (004) XRD measurement, makes changes in either layer difficult to detect directly. In this case, applying SPC would simply result in noise and numerous false alerts. A far better parameter to track is the total thickness above the channel (AlGaAs plus GaAs), since this is more clearly evident in the fringe patterns of the X-ray spectra. Excursions of the additive growth rate imply a shift of one or more of the growth rates and/or the alloy mole fraction.

Process capability

Figure 2 shows the PHEMT InGaAs channel thickness (a) and the In composition (b), tracked over a typical growth campaign. The data are taken from 150 mm AlGaAs/InGaAs PHEMT wafers grown in an Emcore E400 reactor using a 5 × 150 mm wafer configuration. One wafer from each growth run is sampled. The data is normalized to a thickness of 150 Å and an In composition of 15%. The plots show the variation in the two parameters between the largest acceptable upper and lower limits. The limit for the In composition is ±1%, and ±15 Å for the InGaAs thickness.

Process capability, or Cpk, measures the relationship between the distribution of measured values and the upper and lower specification limits. A high Cpk value means that the process will yield a large number of good parts. Cpk values are often used as a gate for ramping production. It is generally accepted that a Cpk of more than 1.3 is production capable, corresponding to a predicted reject rate of approximately 6000 ppm. Calculated Cpk values from figure 2 are 1.3 for the thickness and 2.2 for the In mole fraction.

Non-destructive eddy current sheet resistance (R_{sh}) measurements are a commonly used method for monitoring the electrical properties of epitaxial layers. The speed, simplicity and mapping capability of the eddy current method makes it very attractive for production use. This is born out by gauge R&R data, as in table 2, which shows good

Sheet resistance R&R results

	Sheet resistance (% contribution)	Sheet resistance uniformity (% contribution)
total R&R	0.09	0.3
repeatability	0.04	0.3
reproducibility	0.05	0
part to part variation	99.91	99.70
total variation	100	100

Table 2. The gauge R&R results for eddy current sheet resistance measurement.

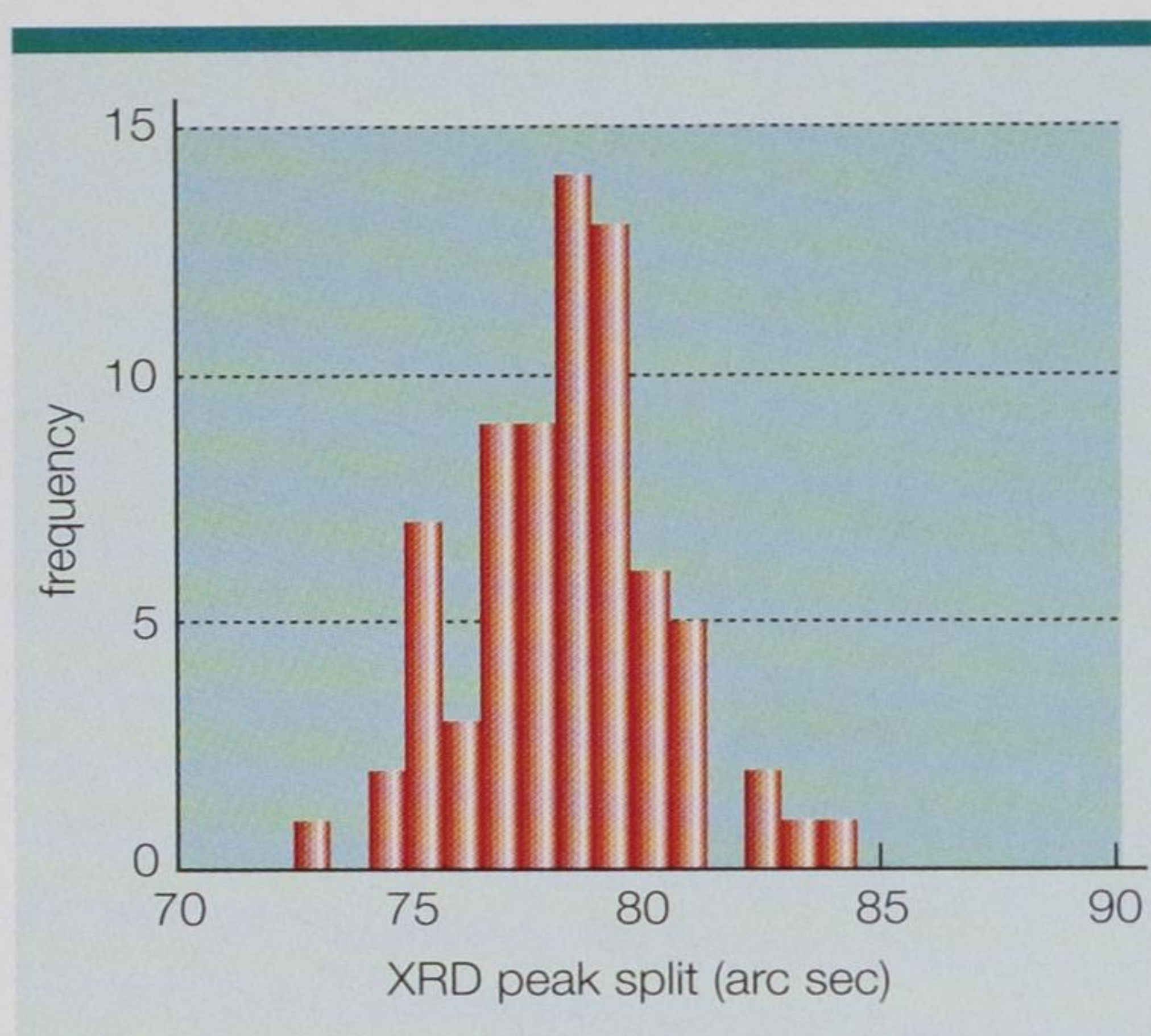


Fig. 4. The distribution of XRD peak splitting over an extended set of C-doping calibration runs. All the growths had a nominal doping level of $4.0 \times 10^{19}/\text{cm}^3$. The C level from XRD peak splitting, correlated with Hall data, is $3.75 \times 10^{19}/\text{cm}^3$.

Effective SPC depends on the quality of the data collected, and the ability to respond to it in a timely fashion.

gauge capability for both mean R_{sh} and the cross-wafer uniformity of R_{sh} in the 40–60 Ω/sq range of a typical PHEMT.

Figure 3 shows the SPC data of R_{sh} for a PHEMT growth campaign. The total population of wafers in the campaign was 150 and the target final R_{sh} was $55 \pm 3 \Omega/\text{sq}$. The cap (contact layer) of the PHEMT dominates the measurement, but the data shows minimal variation in R_{sh} , reflecting the combined thickness and doping control inherent in the growth process. The calculated Cpk is greater than 2.5, despite the offset from the target value of 55 Ω/sq . The min-

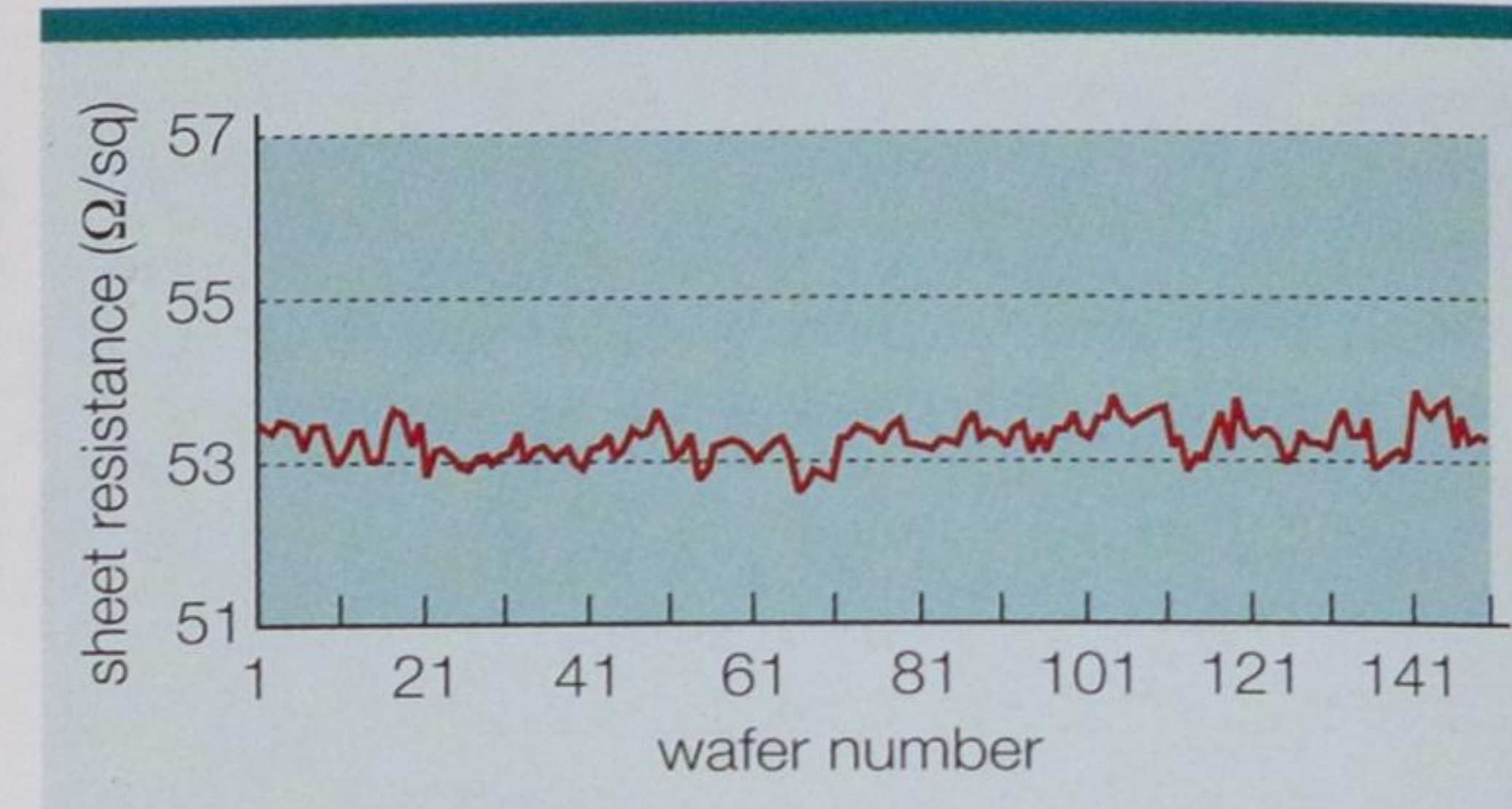


Fig. 3. The SPC data for sheet resistance (R_{sh}). The target value was 55 Ω/sq . Although the average value is below the target, the variation in R_{sh} is small and so process capability is maintained.

imal variation in R_{sh} enables the mean to be slightly off the target value and still not greatly impact the Cpk value.

Sheet charge and base doping

A critical parameter for PHEMT growth is the incorporated sheet charge (n_{sh}). This is ubiquitously specified by Hall measurements. Simple Hall testing is subject to highly undesirable variation, which is mostly, but not exclusively, associated with sample preparation, contact placement and contact resistance. Refinement of the Hall technique is possible, but at the expense of cycle time, a critical factor in controlling throughput and therefore manufacturing costs. For a given carrier mobility in the channel, the R_{sh} of capless PHEMTs can be correlated to the n_{sh} . This enables eddy current testing of R_{sh} to be employed in order to give a quick, robust measurement of the electrical properties. Any deviation in the R_{sh} values for a capless PHEMT can trigger further testing, such as Hall or CV measurements, to determine the root cause of the excursion.

Control of the base doping and thickness is critical for HBT production. The lattice distortion that is associated with high C-doping has been reported several times and, in principle, XRD can be employed to track both doping level and thickness. Unfortunately, the typical base thickness for a HBT, and the presence of a relaxed InGaAs emitter contact, preclude obtaining reliable XRD data on complete HBTs. Specific calibration structures employing thicker and simpler C-doped GaAs epilayers are more suited to evaluation. Furthermore, by using XRD mapping, the cross-wafer doping and thickness uniformity can be extracted. Alternative strategies involving photoluminescence measurements for bandgap shrinkage are possible, but this technique is less robust, and therefore less

capable of tracking doping.

Figure 4 shows the distribution of XRD peak splitting over an extended set of C-doping calibration runs. The data covers several InGaP HBT growths. All the growths were on 150 mm substrates with a nominal doping level of $4.0 \times 10^{19}/\text{cm}^3$ and a nominal thickness of $0.5 \mu\text{m}$. Mean doping, inferred from XRD peak splitting and correlated back to room-temperature Hall data, is $3.75 \times 10^{19}/\text{cm}^3$.

Correlation to SIMS gives a mean value of $4.2 \times 10^{19}/\text{cm}^3$. Whereas SIMS measures the atomic concentration of carbon, Hall only measures the electrically active atoms. The presence of low levels of residual hydrogen is known to have a compensating effect on the dopant, reducing the amount of carbon that is electrically active.

Large-area HBT device fabrication is extensively employed to track epiwafer performance. The destructive testing nature of large-area device fabrication makes MSA more difficult to conduct. However, estimates can be obtained from the analysis of within run and run-to-run components of the observed variation.

DC parameters

Figure 5 shows a normalized subset of the DC parameters tracked by SPC for an InGaP HBT production campaign. These include V_{be} , base R_{sh} and the current gain (β). The sampling interval was varied during the campaign. For an MOCVD-grown C-doped InGaP HBT, V_{be} is very well controlled. This is directly attributable to the low diffusivity of C in GaAs and the conduction band offset between InGaP and GaAs. Exceptional process capability is readily obtained. Taking arbitrary $\pm 10\%$ specification limits, Cpk can be estimated as 1.46 for base R_{sh} and 1.3 for β measured at a nominal $1 \text{ kA}/\text{cm}^2$ current density. The slightly lower Cpk for β reflects additional factors impacting its value beyond base R_{sh} .

A key area for production control is the determination of the correct set of run rules to apply to any tracked parameter. Setting precautions against drift and oscillation may or may not be applicable to a given epitaxial process. There is a trade-off between detecting the salient trends of a data set, and over responding to false alarms. Examination of the expected failure modes (such as source depletion and heater or thermocouple failure) and response characteristics can be used to build up a process failure mode and effect analysis chart. This can serve as the basis for setting initial alerting conditions.

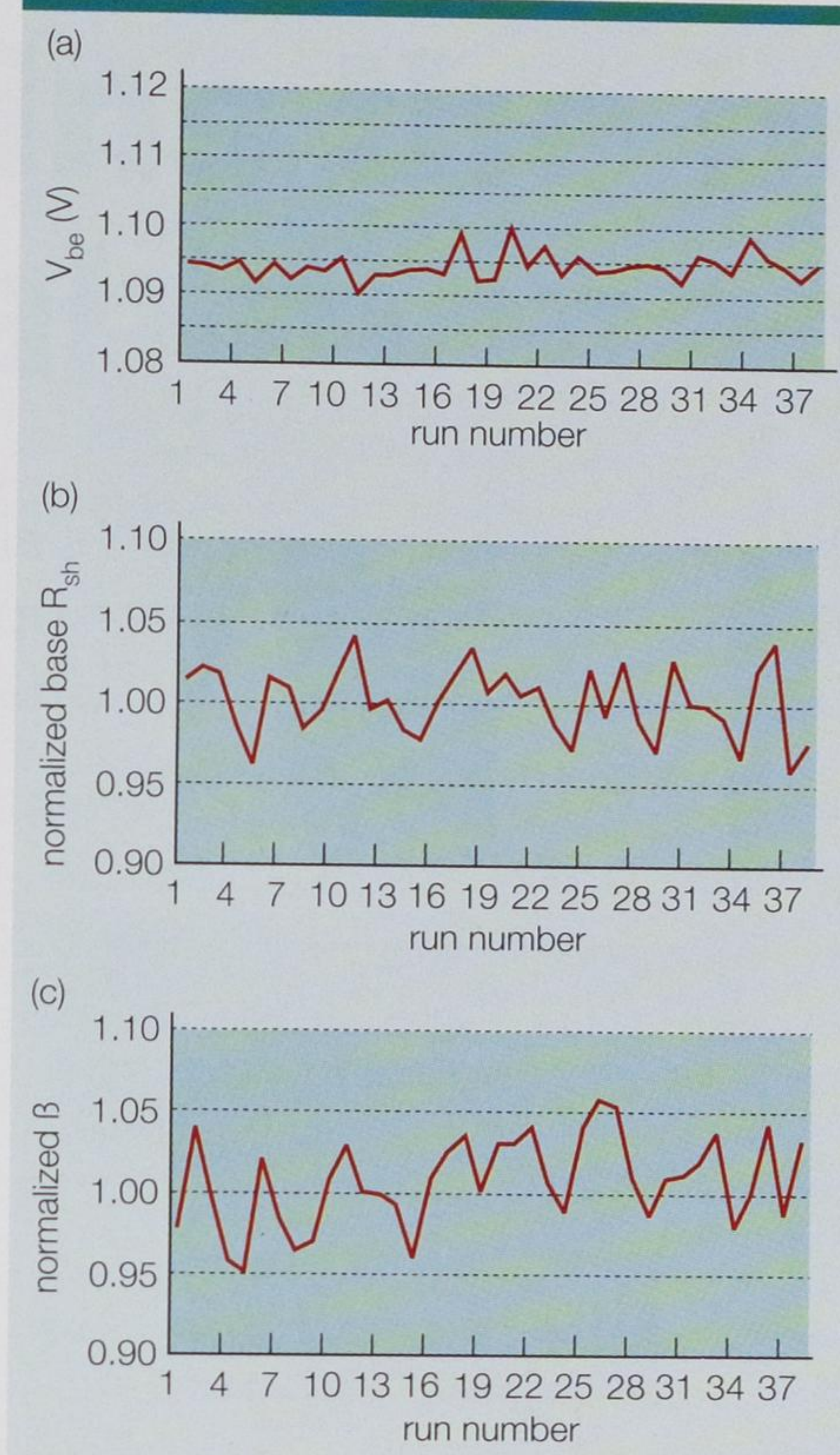


Fig. 5. The DC parameters V_{be} (a), base R_{sh} (b), and current gain β (c), from an InGaP HBT growth campaign.

SPC requires careful attention to underlying detail and clearly defined responses to the signals it produces.

Maintaining effective SPC

Effective SPC depends on the quality of the data collected, and the ability to respond to it in a timely fashion. Although conceptually simple, to be of any use SPC requires careful attention to underlying detail and clearly defined responses to the signals it produces. Once established, periodic review and revision is essential in order to maintain its effectiveness. With ever-increasing demands on customer die yield, SPC is and will remain a key element in ensuring a viable and sustainable epitaxial process.

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HIGH-VOLUME PRODUCTION

GCTC gains the benefits of careful fab management

The manufacturing of GaAs ICs is a high-volume business, and as such is subject to the same production management techniques used in other industries. **Roger Yin and colleagues** describe the successful implementation of the KMTI model at GCTC.

Increasing competition in the GaAs industry is forcing manufacturers to consider and implement a total solution in GaAs fab management. Since controlling all of the activities of a fabrication line in the presence of a lengthy qualification process is a requirement, a well-executed fab management plan can result in a faster cycle time, accelerated production ramp and yield enhancement. However, to our knowledge, there is no formal strategy that is being advocated for GaAs foundry operations. Leveraging the silicon foundry experience in Taiwan, Global Communications Technology Corporation (GCTC), a provider of GaAs MMIC foundry services based in Taiwan, has successfully implemented an innovative approach for managing its manufacturing facilities. This approach is based on the knowledge, multi-skill, teamwork and innovation (or KMTI) model, and it has yielded some very encouraging results.

The model addresses five key elements: human resource management, machine utilization, dispatching methodology, epitaxial wafer inventory and organization structure, all of which can be represented using a star as shown in figure 1.

Human resource management

To achieve the optimal utilization of human capital, the total workforce in the fab line must be considered. Cross training of staff members is executed within the fab. This broadens the experience base of the operating staff, and creates what are known as responsible account engineers, who play a role similar to that of a project manager. The fact that people have widely differing work skills and habits has necessitated the evaluation of individual performance from the standpoint of his or her ability, and also on his or her motivation. We have created some new training and incentive programs such as personal

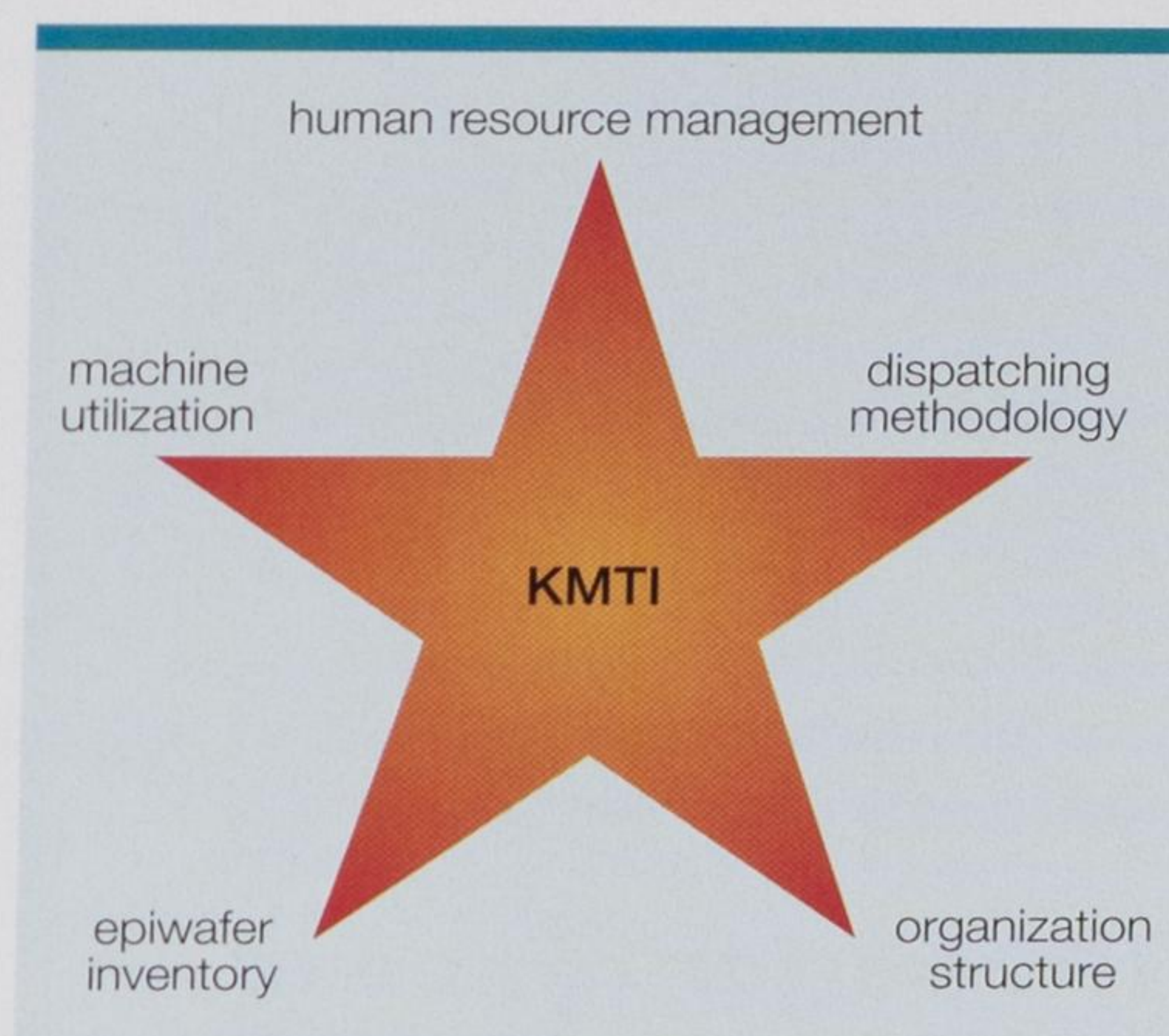


Fig. 1. The KMTI model is represented by a star showing the five key elements.

Good epitaxial wafer inventory management is essential to the successful operation of a GaAs fab.

growth, on-the-spot cash rewards and a listening center, in addition to the more traditional incentives such as stock options and year-end bonuses. These help to stabilize the labor force and encourage extra efforts from each individual. We have also established better communication channels at various levels to provide improved face-to-face communication for employees. This has resulted in greatly improved problem solving and goal achievement with greater efficiency.

Since implementing this approach, GCTC has seen a significant drop in its staff turnover rate, from 15% before implementation to 7% afterwards. Productivity has also increased and fab staff report enhanced job satisfaction. Staff turnover is an important consideration because of the demands for operating stability, the extended qualification

periods with customers and the hands-on nature of processing even for those steps with highly automated equipment sets.

When recruiting new employees, personality as well as interests and capabilities are evaluated in an effort to place new staff members in a position that is challenging and interesting, and considers their skills and physical and mental strengths.

Machine utilization

A process variability management system has been introduced that is designed to identify and reduce local variability and improve productivity at process bottlenecks. Since the variability can be additive and can migrate from one operation to another, the root causes are determined by correlating any variability to potential sources. In particular, variability has a detrimental effect on the process bottlenecks.

The management of process tool set-up time is a good example of where process variability monitoring is important. The goal of set-up time management is to achieve the production of small lots of products with high efficiency, by increasing the equipment flexibility and optimizing the set-up procedures. The success of this process depends directly on the ability to perform equipment set-ups in a minimum amount of time, and also requires well-organized spare-parts management. Moreover, preventative maintenance is monitored and controlled by automatic systems. These systems remind operators when preventive maintenance should be done, and constrain the release of the machines following maintenance, ensuring that the proper release procedure is used. Various sets of rules have been established, as well as guidelines to ensure that machines are properly qualified after preventive maintenance. These prevent production under abnormal conditions that would lead to variation in the process.

HIGH-VOLUME PRODUCTION



After implementing its innovative KMTI model for fab management, GCTC has seen its staff turnover halved, and its lot processing time and costs fall.

Through set-up time management, a number of unnecessary or non-essential activities have been eliminated during machine set-up and maintenance. This has resulted in a 40% cycle-time reduction and a corresponding increased machine utilization rate.

Dispatching methodology

Implementing a work in process (WIP) diagnosis system enables a WIP profile to be built up to predict when lots will be completed and where any process bottlenecks occur, or identify batching points where process loads will place a heavy demand on a tool set for a short period of time. At GCTC, a dispatching methodology has been implemented that groups together lots at various batching points to more efficiently consume high-cost materials. Lot priority setting is automatically adjusted according to the delivery date or the customer's request. All lots processed in the GCTC fab line are dispatched in compliance with a manufacturing execution system that tracks all activities and resources through the production process to realize on-time (or early) delivery.

Good epitaxial wafer inventory management is essential to the successful operation of a GaAs fab because of the high cost of the starting materials. Inadequate control of the wafer inventory can result in both understocking and overstocking of these mat-

The performance of GCTC's operation following the KMTI implementation has been monitored by reporting systems to aid in making continuous improvements.

erials. Understocking results in missed deliveries, lost sales and dissatisfied customers. On the other hand, overstocking unnecessarily ties up capital that might be used more productively elsewhere.

At GCTC, wafer-inventory management addresses two main concerns, which are the level of customer service and the cost of carrying inventory. The system in use tracks the additions and removals from the inventory stocks and provides the current status in real time. When the epiwafer inventory reaches a predetermined minimum, a request for a reorder is then generated. The required amount in the reorder is determined by an economic order quantity model, which arrives at the optimal order quantity by considering delivery schedules and by minimizing the sum of certain costs that vary with order size (Stevenson).

Organization structure

From the outset, the organization structure at GCTC was designed to be simple, with a low degree of departmentalization and wide spans of control. The strength of the structure lies in its simplicity. It provides fast responses, flexibility and clear accountability. This structure is clearly advantageous in the early stages of a GaAs enterprise. Now that products have been qualified and operations stabilized, the company has gradually migrated to a matrix management structure.

This approach has its strength in grouping similar specialists together. It facilitates the efficient allocation of specialists without the drawbacks of the traditional functional organization, where individuals with highly specialized skills are lodged in one functional department or product group for a long time. The matrix management approach has the advantages of economies of scale by providing the organization with both the best resources and an effective way of ensuring their efficient deployment (Robbins). With a direct labor force, GCTC has adopted seven day/24 hour working across four shifts, allowing for flexibility in scheduling staff and providing a responsive service for customers.

The results of successful KMTI

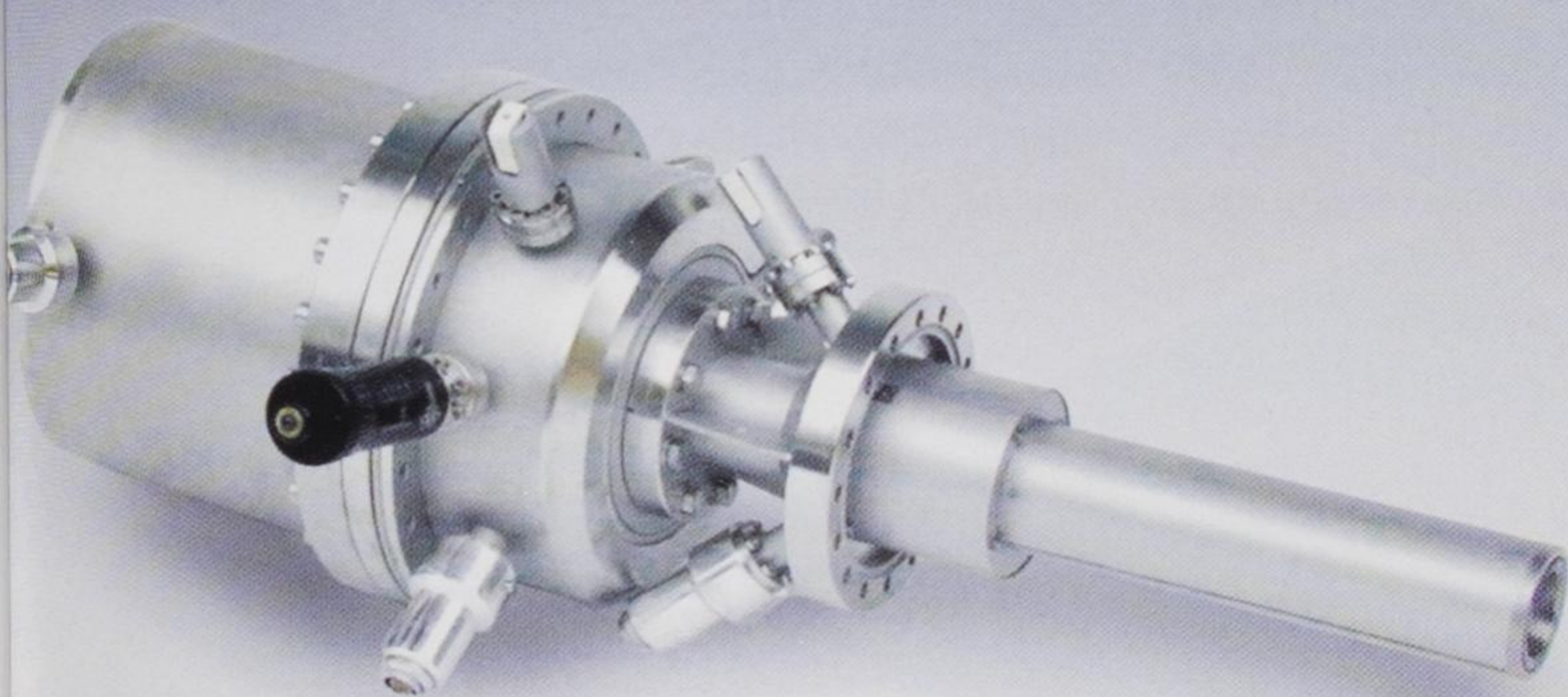
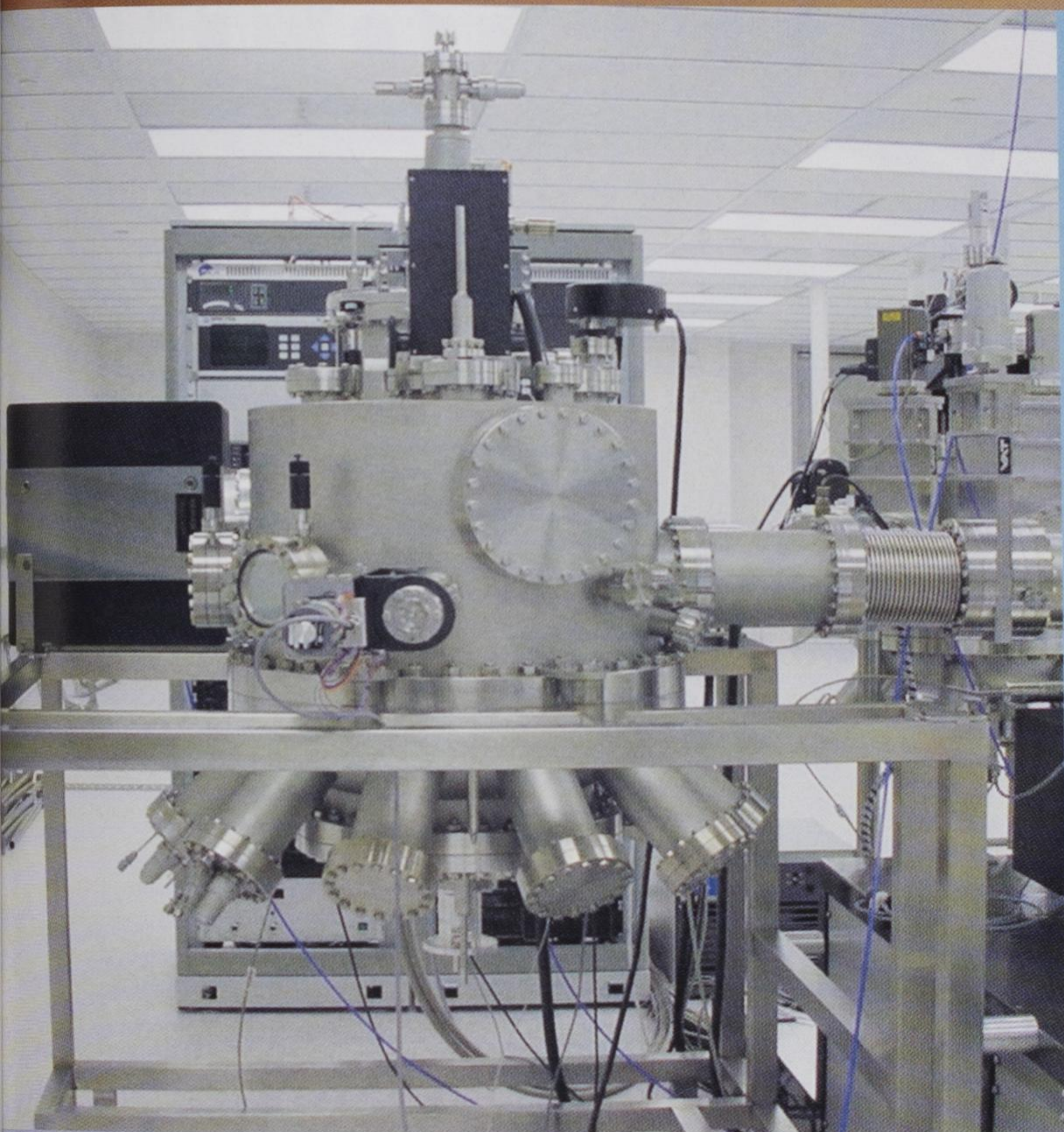
The trend in recent years has been towards a knowledge-based economy. GCTC is no exception to this concept, as evidenced by the implementation of the KMTI model to reduce costs, speed up lot processing, increase flexibility, get closer to customers and empower employees. The performance of GCTC's operation following the KMTI implementation has been monitored by reporting systems to aid in making continuous improvements. The approach is result oriented, focuses on management by objectives, and organization performance is evaluated by indices and baseline experiences. Our implementation has resulted in a stable, highly motivated workforce, with increased productivity and very competitive services and products in the marketplace. ●

Further reading

W Stevenson 2001 *Production Operation Management* (Irwin McGraw-Hill).
S Robbins 2001 *Essentials of Organizational Behavior* (Prentice Hall).

Paul Lin, Jack Wu, Roger Yin and Jenn-Hwa Huang are with GCTC in Taiwan.
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HIGH-VOLUME PRODUCTION

FMEA speeds time to market in photonic IC manufacturing

Failure mode and effects analysis provides a framework for rapid design and manufacturing implementation that has contributed to the successful launch of a new product suite by MetroPhotonics, according to **Steven Martin** and **Bedwyr Humphreys**.

Failure mode and effects analysis (or FMEA) is a simple yet powerful proactive engineering quality method that is designed to help identify and counter weak points in the early conception phase of products and processes. The structured approach makes it easy to use, and the benefits far outweigh the investment in time and resources needed to execute the analysis. Put simply, FMEA is a rigorous risk-analysis tool that is used during the product concept phase to evaluate high-risk stages, serving to focus and define development effort.

FMEA is fast gaining favor across a number of industries, including the silicon IC industry. Its application to the compound semiconductor industry yet again reinforces the industry trend of shifting away from laboratory practices towards well-defined large-scale manufacturing methods, as the industry matures and cost becomes an important driver.

Added value

The added value of the FMEA process, as compared with other quality techniques, is that it is a continuous process and not an event. Corrective action requests (i.e. customer issues) are resolved, continuous improvement initiatives are identified, and future advanced designs and the product Control Plan are evolved. It is a disciplined technique that can help companies committed to continuous improvement (i.e. lean manufacturers) identify and eliminate potential waste.

Broadly speaking, there are three types

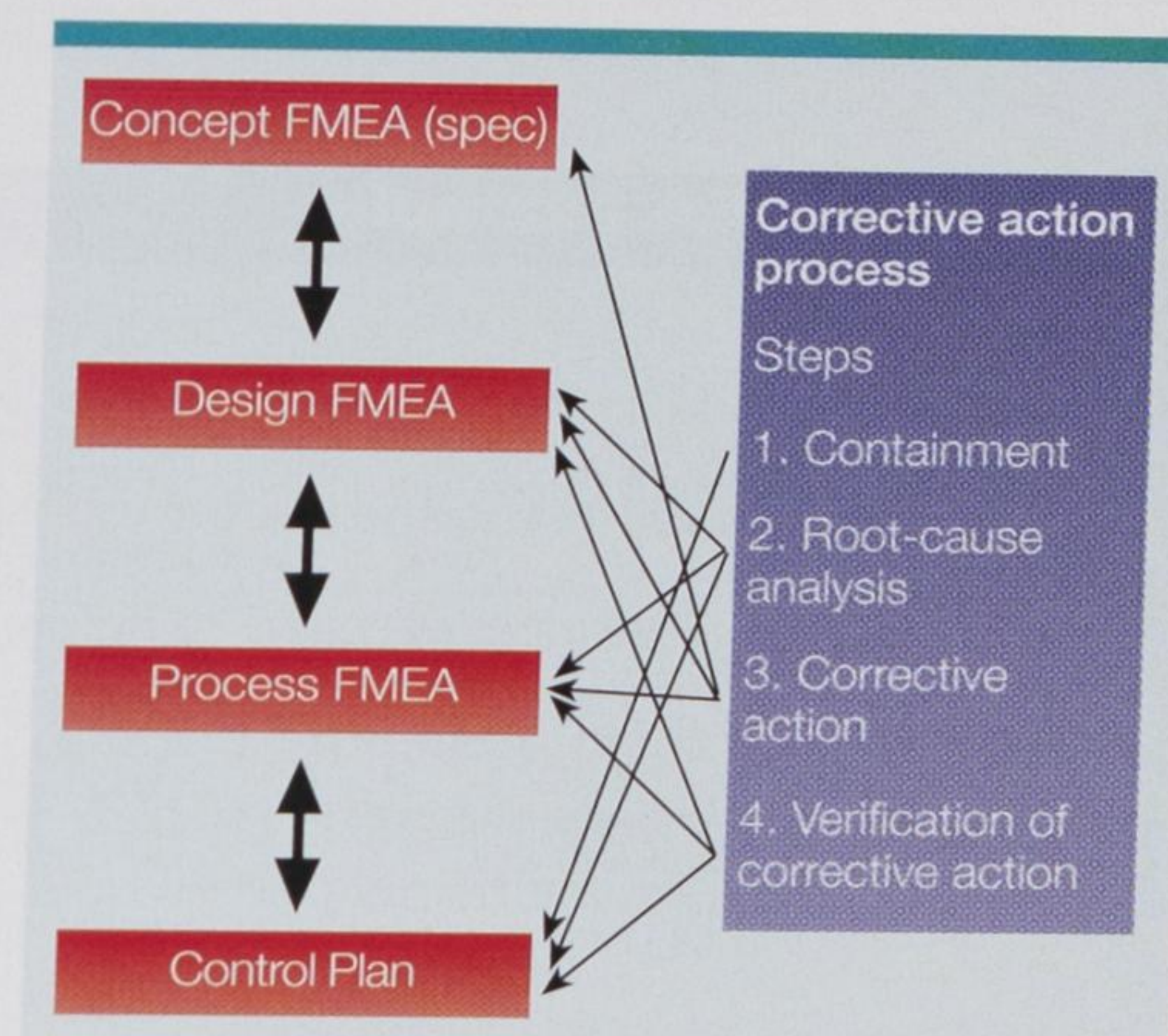


Fig. 1. An idea flow chart during FMEA.

FMEA is a rigorous risk-analysis tool that is used during the product concept phase to evaluate high-risk stages, serving to focus and define development effort.

of FMEA, namely Concept FMEA, Design FMEA and Process FMEA. Each represents a stage in the product development cycle where one follows the other as the new product is brought into production.

Concept FMEA (C-FMEA) is used to optimize system alternatives, which helps formulate a customer specification. In terms of being applied at MetroPhotonics, many of the system alternatives had already been established and it was more important to implement a product rather than review a well-established path. However, the benefits of a C-FMEA are as follows.

- Generates failure-mode occurrence ratings that can be used to estimate whether a particular concept alternative can achieve its reliability target.
- Increases the likelihood that all potential effects of the concept proposal failure

mode will be considered.

- Identifies potential failure modes caused by interactions within the concept and helps to determine if hardware redundancy is required within a design proposal.
- Forms the basis for developing system-level diagnostics procedures.
- Forms the basis for developing system-fault management techniques and helps determine changes to system-design specifications.

Based on the specifications defined in the C-FMEA, the Design FMEA (D-FMEA) helps in the objective evaluation of design requirements and alternatives for manufacturing and assembly needs. In this industry it helps with the planning of thorough and efficient design, test and development programs. At completion, the D-FMEA prioritizes design improvements and develops testing actions that can be managed in a project management format.

Based on the D-FMEA, the Process FMEA (P-FMEA) assists in the analysis of new manufacturing and assembly processes. It identifies process deficiencies, thus enabling engineers to focus on controls for reducing the occurrence of, or increasing the detection of, unacceptable products. On completion, the P-FMEA establishes a priority for process improvement actions and hence another round of project management.

The timing for using these tools is as follows. A C-FMEA is started as early in the program as possible, to establish the specifications. A D-FMEA is initialized before the design concept is finalized, and completed before the production drawings of parts are released. Finally, the P-FMEA is started before tooling for a production process or the feasibility state when all processes and parts are being considered for production.

FMEA analysis

The basis for FMEA analysis is to categorize failure modes based on their severity, occurrence and detection. Three tables are generated that grade each of these characteristics on a scale of 1 to 10. Each table can be customized, and so specific product requirements are

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captured, allowing for tailored analysis. For example, in the automotive industry safety is critical and would be graded a 10 in terms of severity given a particular failure mode. In the photonics industry, a severity of 10 would be attributed to the complete failure of a product in the field, shutting down a customer's major systems with no (redundancy) backup. Occurrence and detection tables do not normally need to be modified unless it is very difficult to establish a ranking where all failure modes fall within the same occurrence or detection rating.

A typical FMEA form (spreadsheet) lists all of the critical requirements for the FMEA under the following headings.

- **Item/Function:** the functional part of the product design to be analyzed.
- **Potential failure mode:** the manner in which the function could potentially fail to meet design intent (this is determined under group brainstorming).
- **Potential effects of failure:** the effects of the failure mode on the function as perceived by the customer.
- **Severity:** ranked from 1 to 10, 1–2 indicates a failure so minor that the customer will probably not detect it, 10 indicates a failure that will result in major customer dissatisfaction and cause system non-operation or non-compliance.
- **Classification:** used to classify failure modes other than by severity, occurrence and detection. This is because of special government regulations, customer satisfaction, safety etc, and these are identified as either critical characteristics or significant characteristics.
- **Potential cause:** describes the design weakness that causes the failure mode. The D-FMEA does not rely on process controls to overcome weaknesses.
- **Occurrence:** ranked from 1 to 10, 1 indicates a very low probability of occurrence, 10 indicates a high probability of occurrence, i.e. once a week.
- **Current design controls:** methods or tests used to detect a first level cause of a failure mode, or the failure mode itself.
- **Detection:** ranked from 1 to 10, 1–2 indicates that verification and/or controls will almost certainly detect the existence of a deficiency or defect, 10 indicates a very low (or zero) probability that the defect will be detected.
- **Risk priority number (RPN):** product of the severity, occurrence and detection rankings, in which the potential design weaknesses are ranked for possible redesign actions.

Design FMEA example

Item (specification requirement)	Singlemode waveguiding
Potential failure mode	Guiding becomes multimode
Potential effect of failure (severity)	Greater on-chip loss and degraded channel cross-talk performance. Severity = 9
Potential cause of failure (occurrence)	Design of waveguide structure is too wide. Occurrence = 2
Controls (detection)	Computer modeling and tolerance analysis of final device performance. Detection = 4
Risk analysis	Overall rating is $9 \times 2 \times 4 = 72$ (out of a possible 1000)

Process FMEA example

Process function	Singlemode waveguide fabrication
Potential failure mode	Waveguide structure is too wide
Potential effect of failure (severity)	Greater on-chip loss and degraded channel cross-talk performance. Severity = 9
Potential cause of failure (occurrence)	Photoresist too thick. Occurrence = 5 Exposure dose too low. Occurrence = 3 Excessive dry etch polymer. Occurrence = 2
Controls (detection). X bar and R charts used throughout	SPC and in-line process inspection. Photoresist tracks qualified daily. Detection = 7 Exposure dose matrix completed daily plus in-line CD measurement. Detection = 3 Dry etch process qualified weekly plus in-line CD measurements. Detection = 3
Pareto (risk analysis)	Photoresist too thick. $9 \times 5 \times 7 = 315$ Exposure dose too low. $9 \times 3 \times 3 = 81$ Excessive dry etch polymer. $9 \times 2 \times 3 = 54$

During FMEA, the severity, occurrence and detection values are multiplied together. The item with the highest score has the highest risk and so needs the most urgent attention.

The lessons learned from a set of FMEAs for one product group can be applied to others.

- **Recommended actions:** actions that will reduce the severity, occurrence or detection of a particular failure mode so as to reduce the size of the RPN.
- **Responsibility and target completion dates.**
- **Actions taken, severity, occurrence, detection and RPN:** once actions have been taken, the analysis is reconducted and a new RPN derived.

As the information flows from the C-FMEA through the D-FMEA to the P-FMEA and the Control Plan, the level of data increases exponentially. One item in the C-FMEA may raise three items in the D-FMEA, each of which raise a further three in the P-FMEA, which ultimately raises another three for control (see figure 1). This may appear to make things more complicated, but facing up to potential problems as early as possible in the

development is essential, providing a means to more accurately determine realistic timelines and project costs.

To determine which item is most in need of attention, the severity, occurrence and detection values are multiplied together. The item with the highest score has the highest risk. In the example shown in the process table above, the main focus for process development would be to improve the score for the photoresist dispensing process. This could be done by either improving detection (reducing the score), by measuring every product wafer prior to exposure (not a manufacturable solution), or by reducing the occurrence through improved hardware control (spin-speed repeatability) and greater preventative maintenance frequency, in order to eliminate uncontrolled process variability.

The Control Plan

The final output of the P-FMEA is the Control Plan. The Control Plan is a table that lists, in order of process step, the detection modes of the P-FMEA that really are the controls to the future process. The other columns of this table

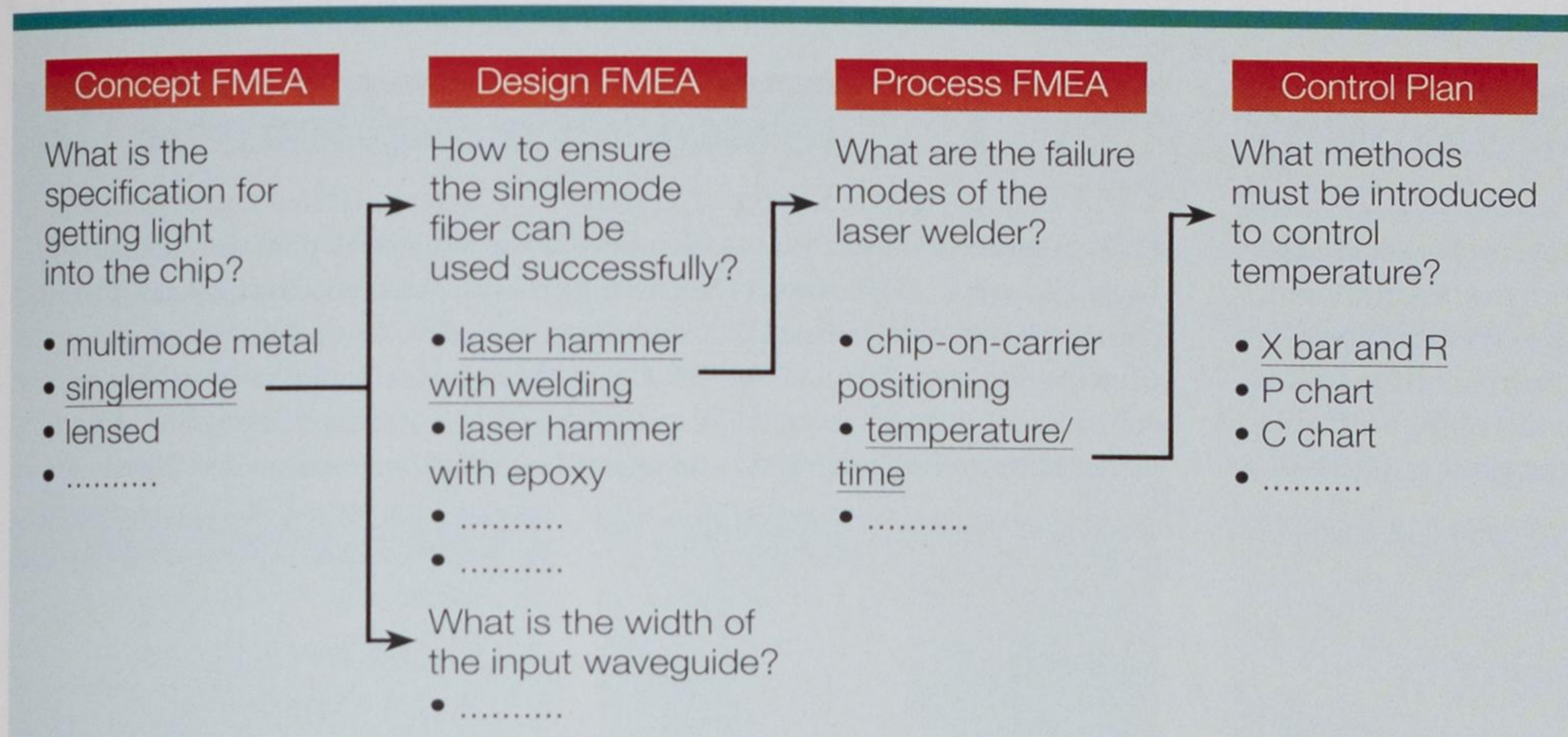


Fig. 2. The process steps used in the customer corrective action feedback loop.

are used to describe the detection mode (process control), e.g. P chart, C chart, X bar etc.

Because of the FMEA analysis, any weaknesses in the design or process get automatically summarized and characterized into the Control Plan. When a review of the production line for product approval and launch is required, the Control Plan is used to step through the process.

Corrective action feedback loop

As the corrective actions process is evaluated, it becomes apparent how the information for completing the report gets developed through the Control Plan and the FMEAs. Containment is based on the failure and how it escaped the Control Plan. The Control Plan is then adjusted to detect the failure. During root-cause analysis, the failure mode should be reflected somewhere in the P-FMEA/D-FMEA. If the failure mode cannot be fixed by an action taken in the P-FMEA, then the D-FMEA is analyzed. If it cannot be fixed by action taken in the D-FMEA, then the specification has to be adjusted (see figure 2). Finally, as a verification of a corrective action, the updated specification or FMEAs and Control Plan are signed off by the customer representative.

Continuous improvement loop

Based on the lean manufacturing (value stream mapping) objectives, different aspects of the process will need stabilization, and so as continuous improvement becomes a factor, the P-FMEA document outlines all the failure mechanisms that cause variability in production. Leveraging "Six Sigma" methodology, taking actions on this variability is achieved by simply dividing up the failure mechanisms and addressing them one at a

time using Pareto analysis to establish a priority. Ultimately, the actions taken in the P-FMEA reduce lead times and inventory, thereby reducing the working capital and the cost of goods sold.

The lessons learned from a set of FMEAs for one product group can be applied to others using the same processing techniques and fundamental design functions. Hence the practice of verifying the development of other products as similar process techniques and design functions come up. FMEA therefore allows for the design process to become easier and easier each time it is used.

Conclusions

FMEA provides the documentation system that forms the framework for rapid design and manufacturing implementation. With a project management approach, FMEA focuses on critical issues and provides a means of risk assessment. Once the product is launched, the history and lessons learned are contained within the FMEA documentation, providing a ready framework for future product introductions, and also preventing the same mistakes from being repeated.

The FMEA technique has been successfully implemented at MetroPhotonics, aiding in the rapid development of and the successful launch of the SurePath product suite. Time to market and development costs were greatly reduced through the selection of optimum system alternatives (via FMEA), resulting in a successful product launch within four months of concept.

Steven Martin (industrial engineer) and Bedwyr Humphreys (director device fabrication) are with MetroPhotonics Inc, Ottawa, Canada. Web www.metrophotonics.com.

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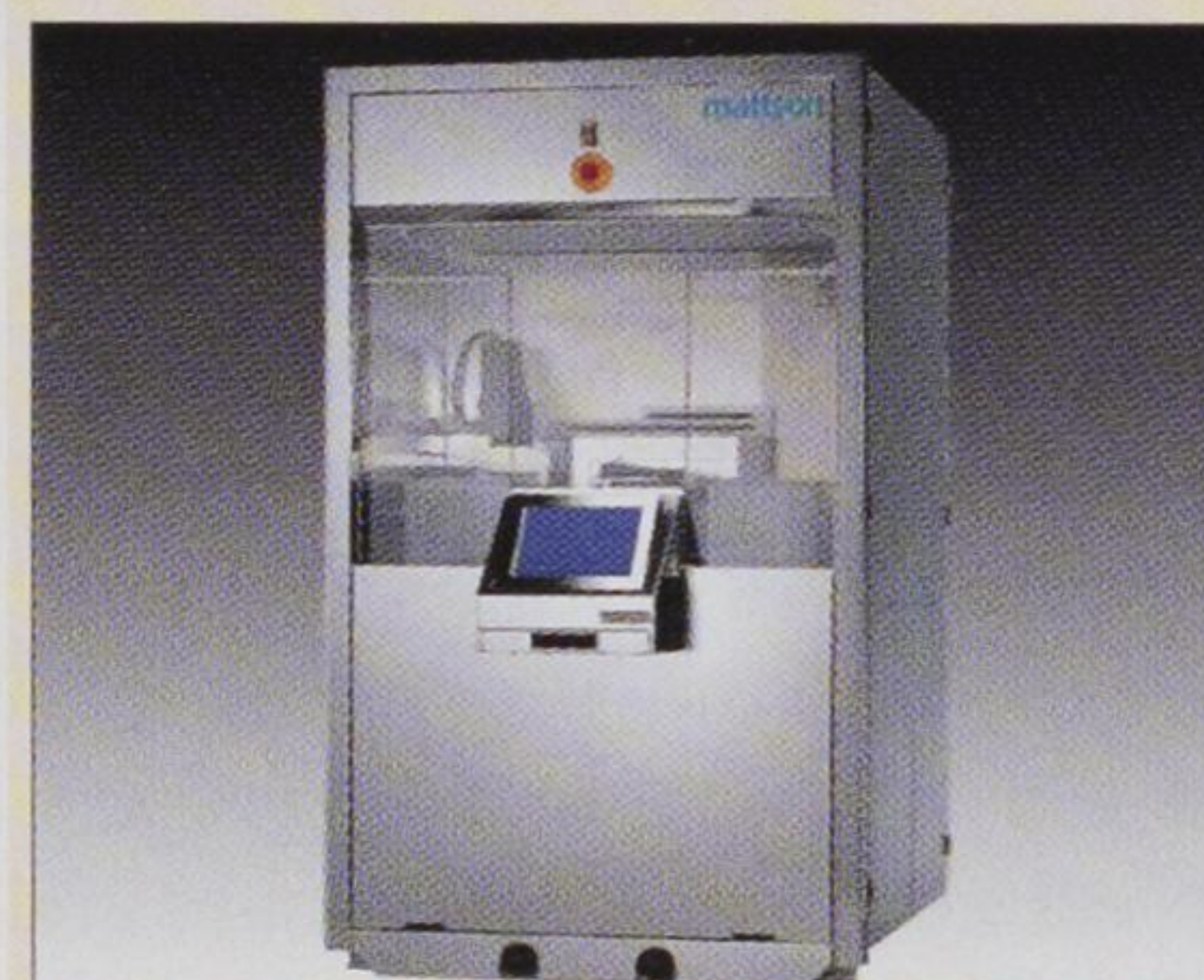
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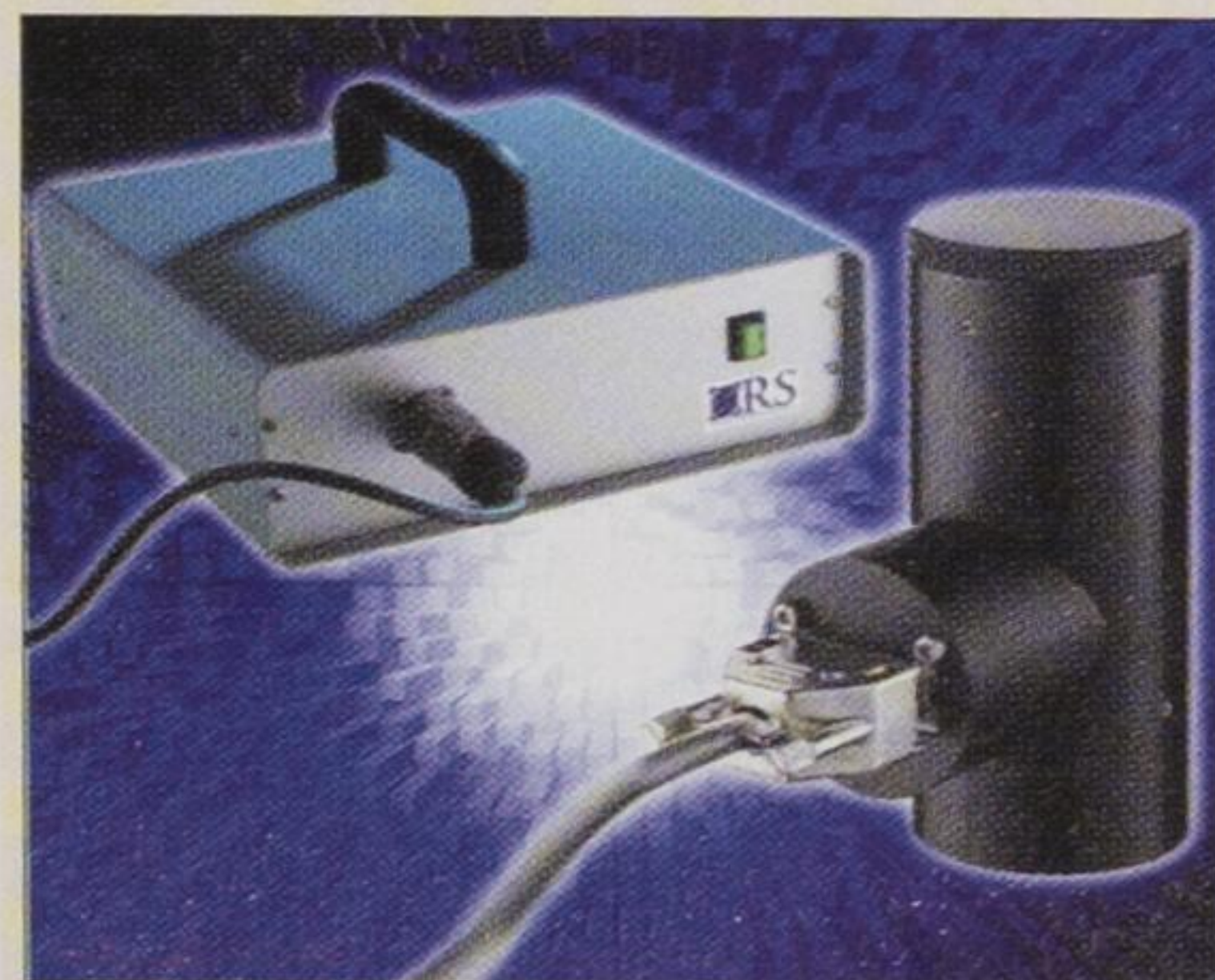
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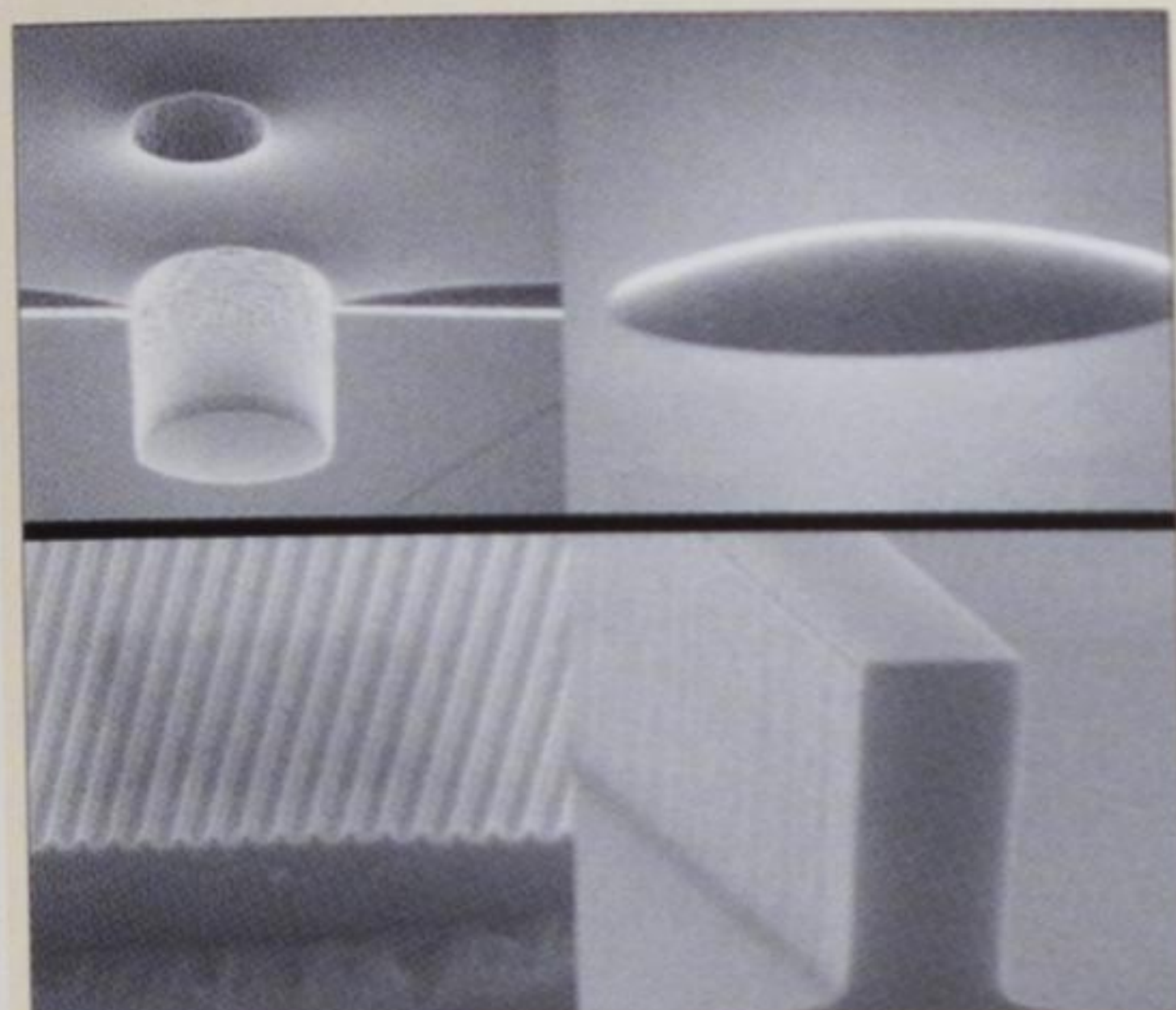
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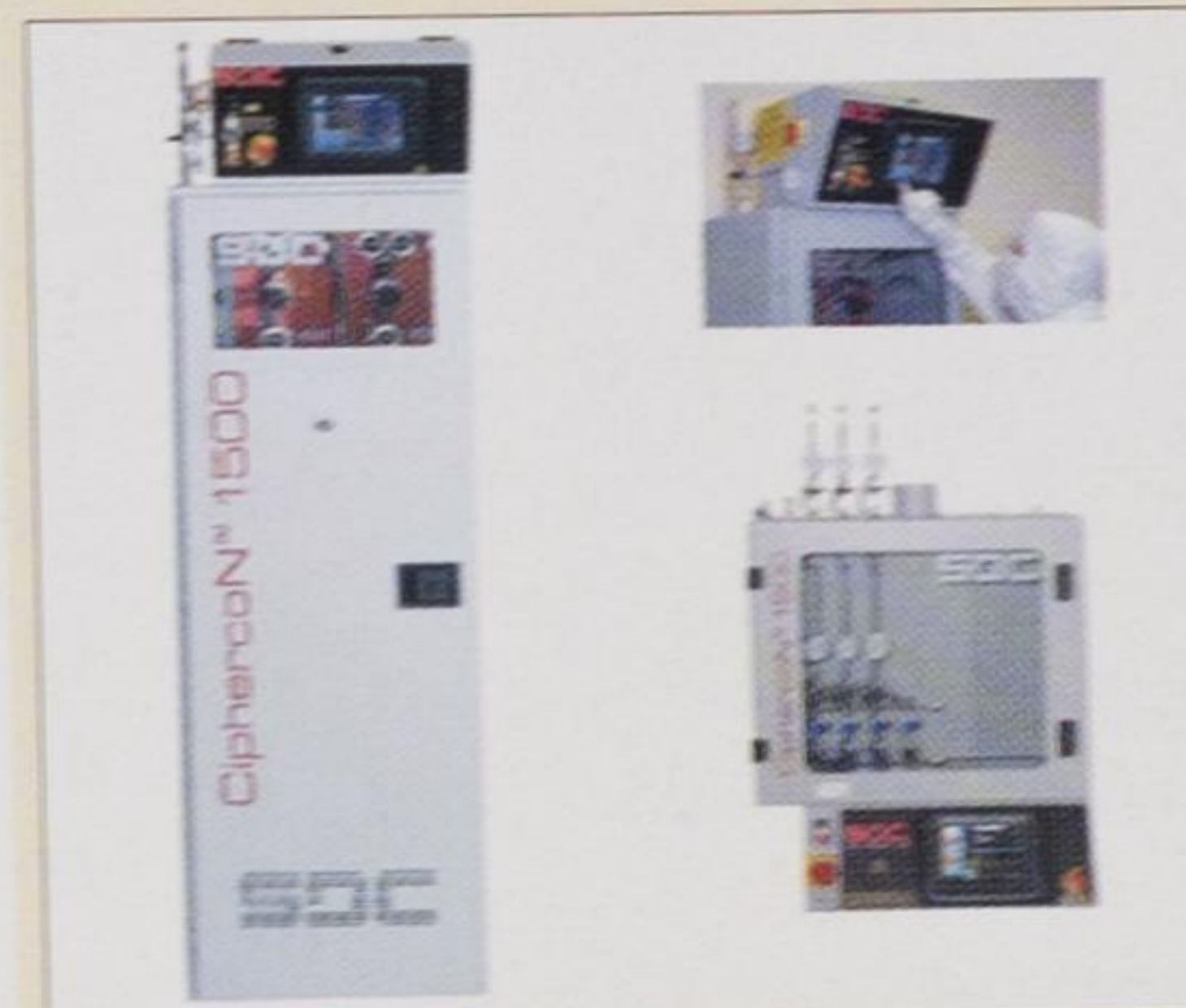
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