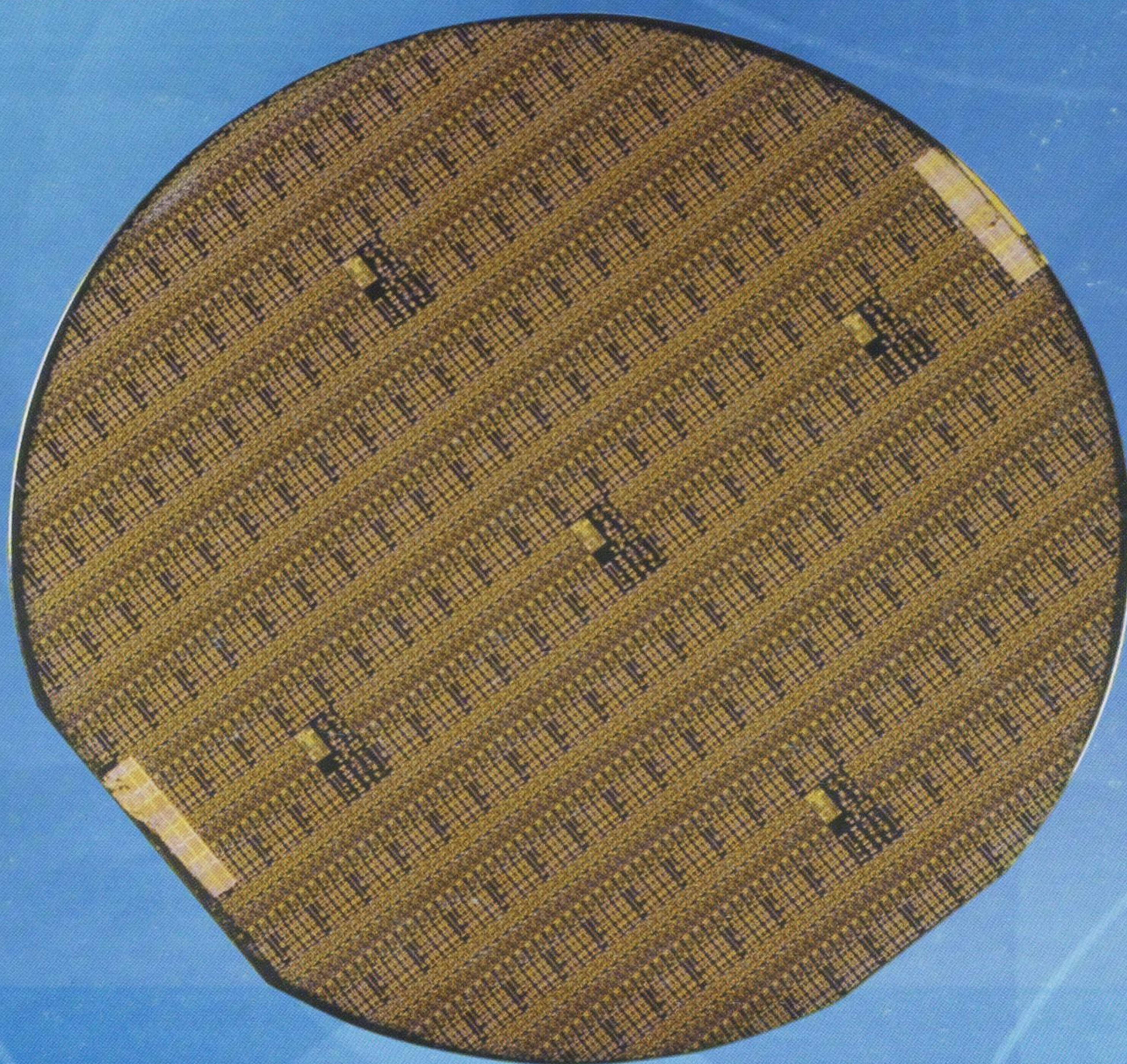


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Three-Fives and Silicon Heterostructures

May 2005 Volume 11 Number 4



GAAs ICs **Improving margins through component integration**

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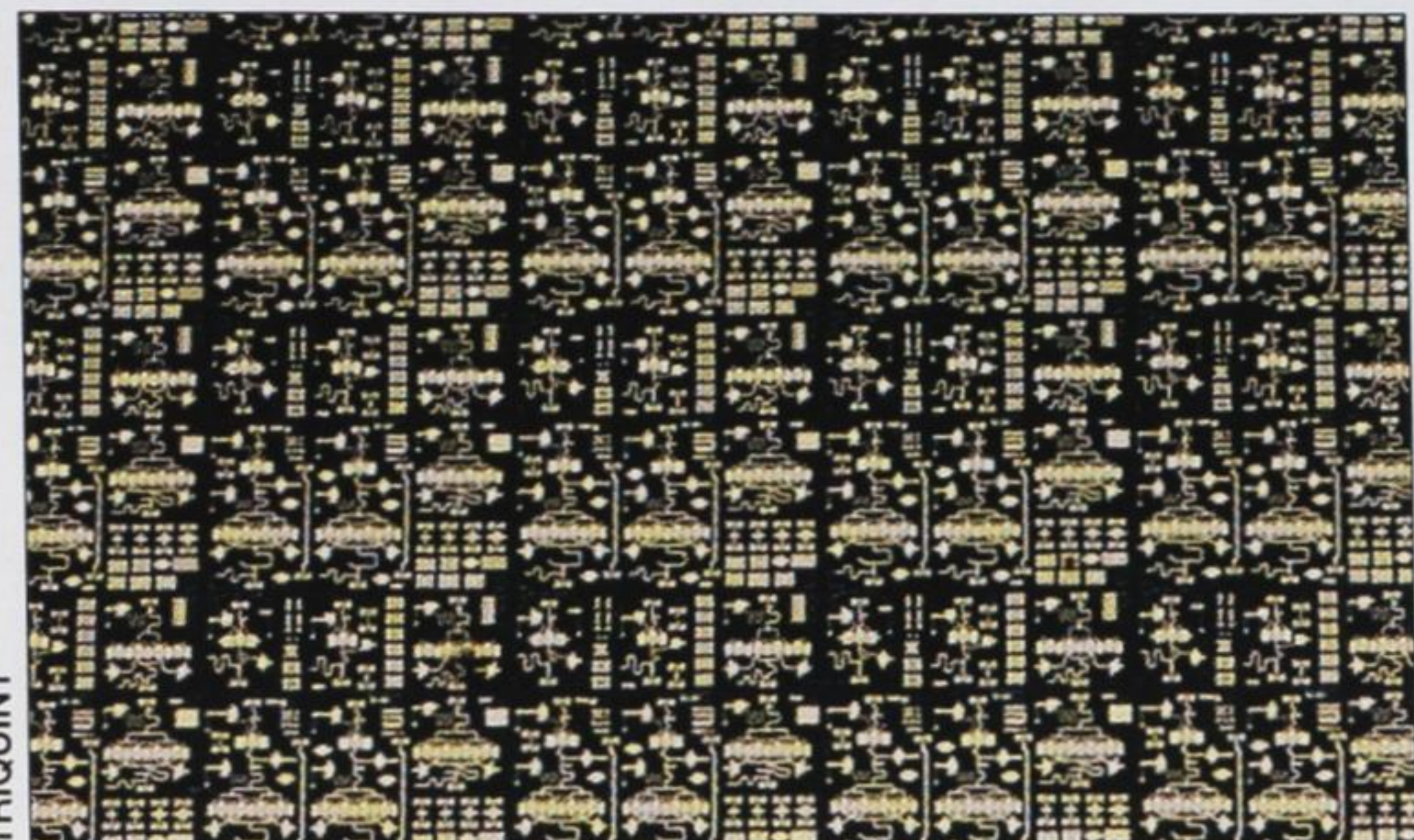
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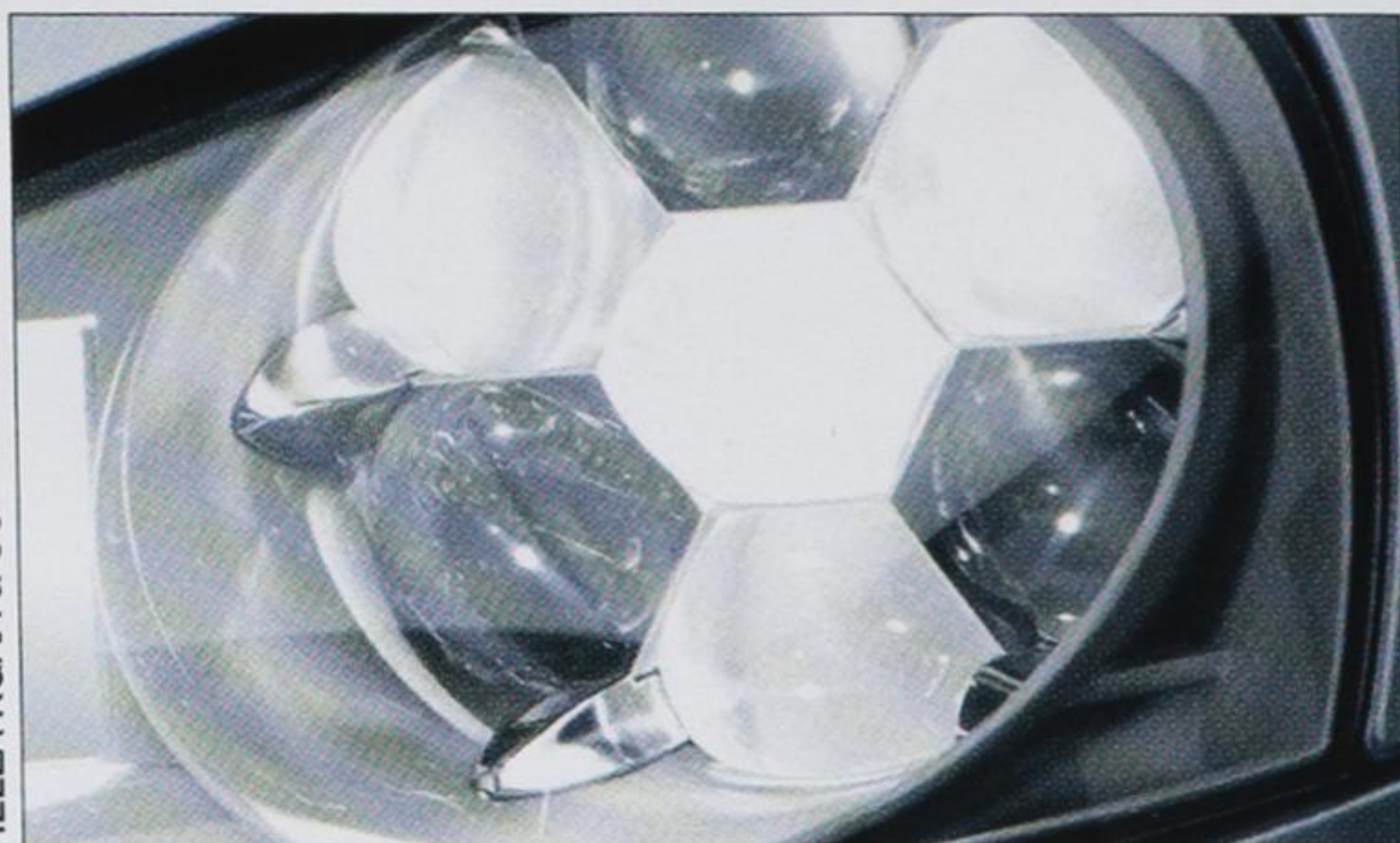
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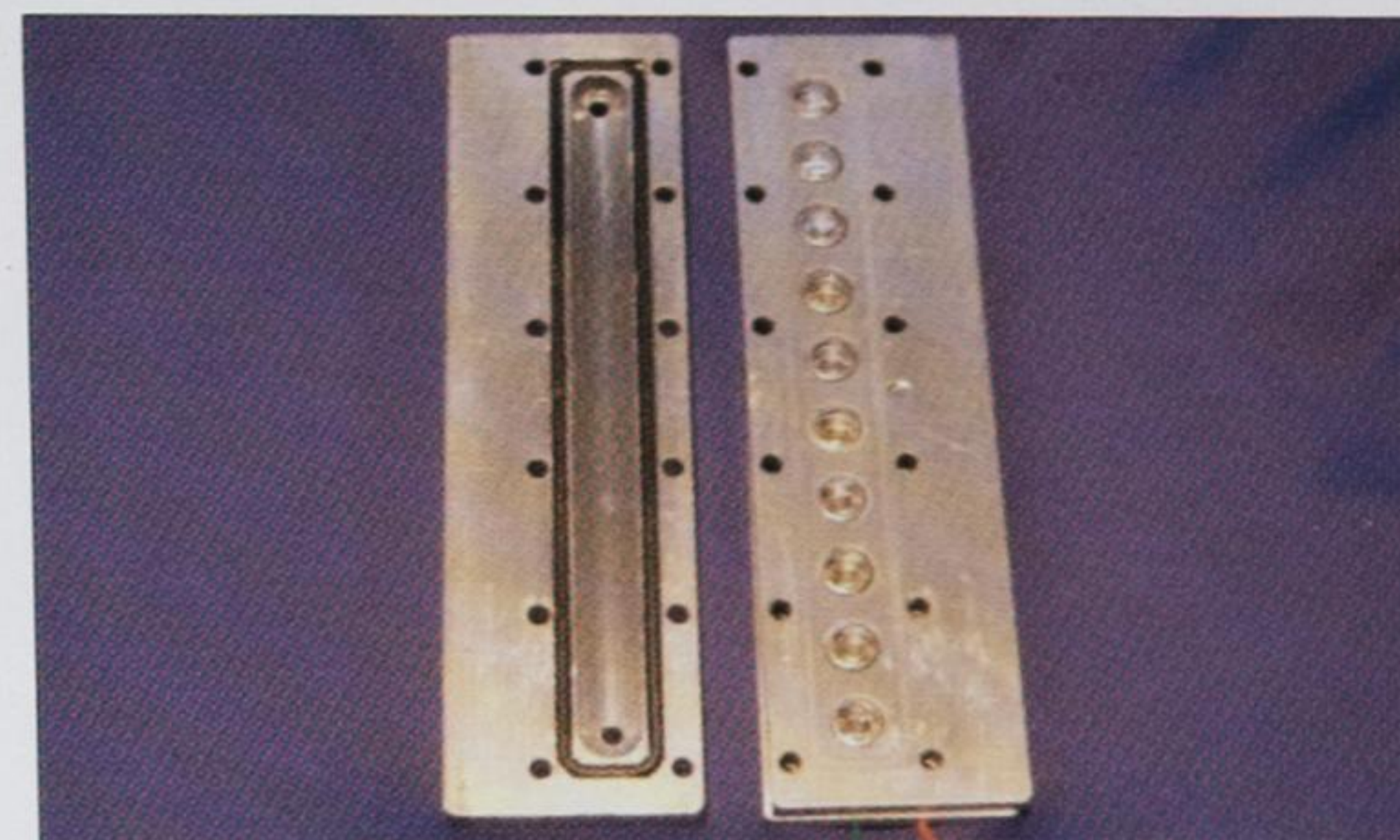
TRIQUINT

Improving the reliability of GaN devices is the number-one challenge, says DARPA. **p5, 31**



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On the cover: TriQuint has developed a new E-/D-mode PHEMT process in response to market demand for cheaper, more complex wireless components (image courtesy of TriQuint).

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Keeping silicon armies at bay



Ten years ago, when the mobile industry was in its infancy, silicon chips were at the heart of 90% of cell-phone power amplifiers (PAs). Today, around 80% of PAs are GaAs powered, with the remainder using silicon LDMOS technology. So GaAs has clearly won that particular battle.

However, while the GaAs industry needs to expand its horizons to break free of its dependency on cellular applications and the inevitable cycles that will ensue, it must also keep an eye on the rear-view mirror. Dwarfing the GaAs industry, silicon has whole armies of researchers and engineers working to drive the performance of CMOS transistors to the terahertz regime.

And although the threat to GaAs posed by silicon CMOS PAs from the likes of Silicon Labs is yet to materialize, this cannot be said of other key GaAs applications within the cell phone, such as antenna switches.

In a keynote address to the III-V manufacturing community last month, Paul Augustine – general manager of the Nokia product line at the Finnish firm's key PA supplier RF Micro Devices – identified such switches as a major growth area for GaAs PHEMTs. However, the silicon competition could be stiffer when it comes to this application, with Peregrine Semiconductor already shipping "millions of units" that exploit its UltraCMOS technology – its own version of the silicon-on-insulator approach that uses sapphire substrates – destined for switches in GSM handsets.

Perhaps the compounds industry could do with emulating the collaboration between companies that exists in the silicon world. According to some, this will certainly be necessary if GaN devices are to make a serious commercial impact. Just as GaAs had to take on incumbent silicon technology in handsets a decade ago, so GaN will face the same challenge in cellular base-stations. And GaN is up against a moving target: those silicon armies have a roadmap and they have a history of following it.

Michael Hatcher

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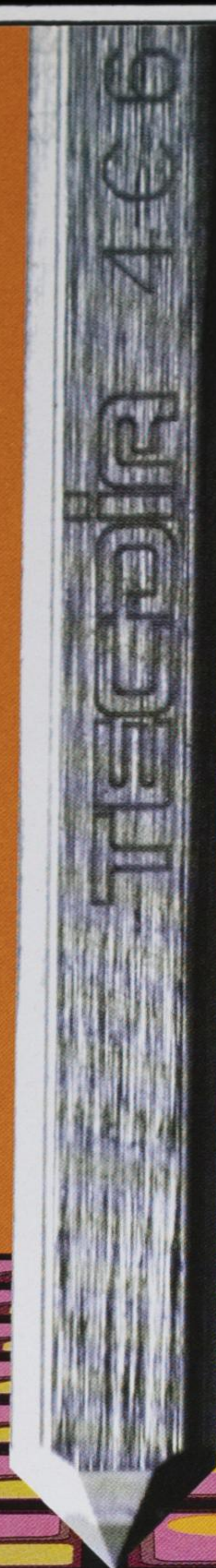
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TriQuint sells opto business to CyOptics

Pennsylvania-based fiber-optic component and module supplier CyOptics is to acquire TriQuint Semiconductor's InP chip manufacturing business. In a twin deal said to be worth \$32 million overall, TriQuint is also selling its Breinigsville, PA, optoelectronics facility and surrounding property to Anthem Partners, which is planning transform the site into an advanced-technology center.

TriQuint's assembly operation in Matamoros, Mexico, will be transferred to CyOptics through the acquisition, which also includes products, manufacturing equipment and intellectual property.

CyOptics, which already has a chip manufacturing facility in Yokneam Illit, Israel, raised \$10 million in fourth-round funding in September last year. It will lease the Breinigsville plant from Anthem. "The CyOptics team plans to hire the vast majority of our [approximately 250] employees in Pennsylvania and Mexico," said TriQuint CEO Ralph Quinsey.

TriQuint had moved into the optoelectronics sector through its acquisition of Agere Systems' business for \$40 million cash in October 2002. The enterprise had a strong pedigree, having been based on technology developed at Bell Laboratories and Lucent Technologies prior to the spin-out of Agere.

However, despite that pedigree, sales from the venture never matched up to TriQuint's expectations. According to Quinsey, annual sales of \$50 million–60 million were predicted initially. However, the business brought in only \$36.5 million in 2003 – now considered to be the year in which the fiber-optic sector bottomed-out – and just \$34 million in 2004, when the market began its slow recovery. Despite restructuring the operation in November last year, these difficulties remained. "The optoelectronics market will only support a few right-sized and nimble players," commented Quinsey.

Quinsey adds that TriQuint will now be able to focus squarely on its core business of

RF chips and products for wireless handsets, base-stations and broadband access, as well as the defense market. The company is retaining some GaAs capacity for optoelectronic products in the form of transimpedance amplifiers and driver ICs.

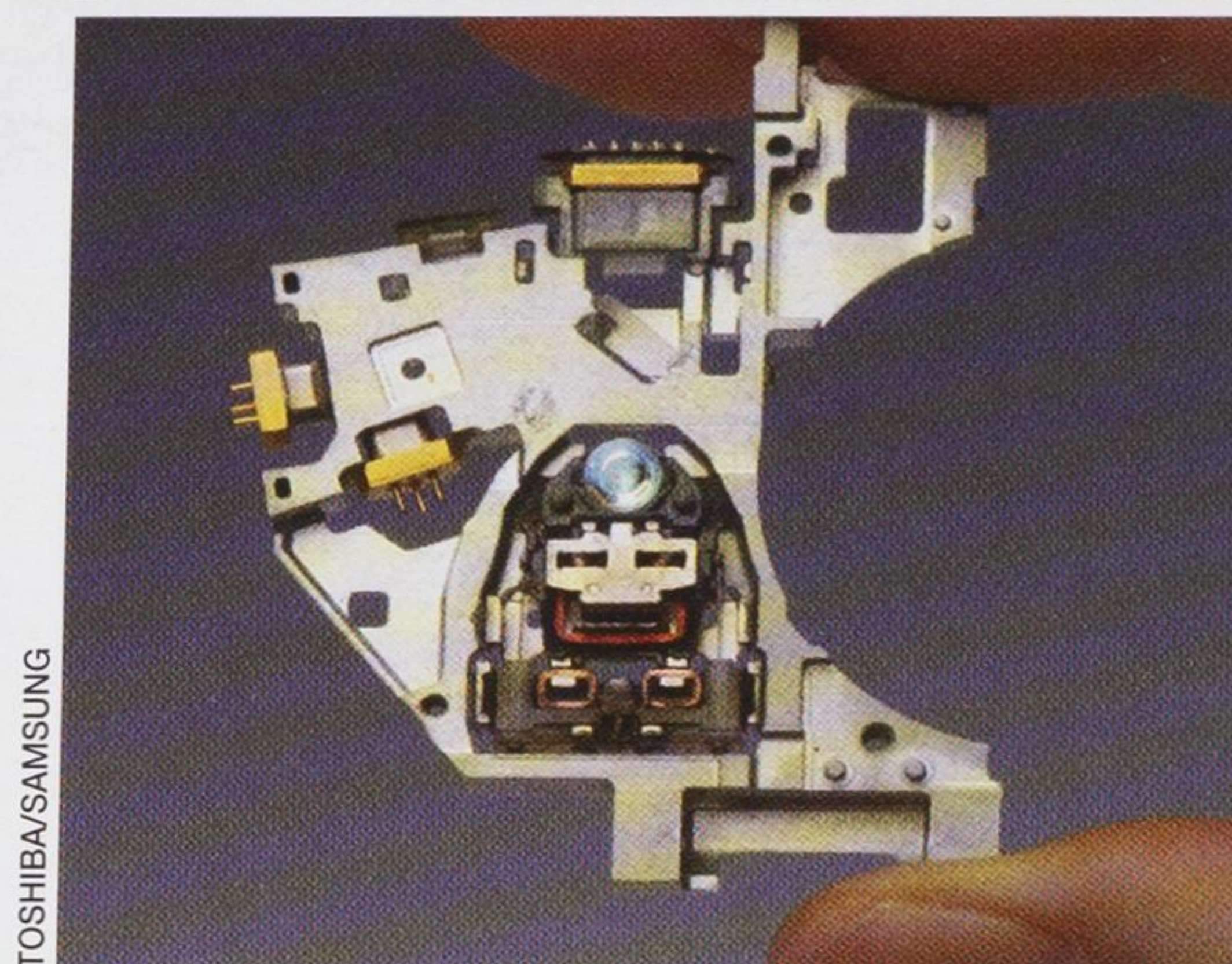
Ed Coringrato, CyOptics' CEO, said: "Industry consolidation is much needed and with this acquisition, CyOptics is well positioned...to serve the once-again growing telecom-equipment market." He adds that the acquisition, which was expected to have closed by the end of April, will make CyOptics a "top-five" supplier of InP-based optoelectronic chips and components.

TriQuint says that the overall deal is worth around \$22 million in cash, with the \$10 million balance a combination of a loan note and equity. It will retain a small share in CyOptics, and expects to record a one-time gain of \$7 million–9 million on the deal. It may raise another \$1 million–2 million through the sale of remaining assets.

DVD war may be off as rival camps seek hybrid standard

The industry split over the two next-generation DVD formats – Blu-ray and HD-DVD – could soon be resolved, according to reports in the Japanese press. Both formats use GaN-based blue lasers, but there have been fears that the split could confuse consumers and hamper the take-up of next-generation optical data-storage technology.

The Blu-ray Disc Association (BDA), which is led by Sony, Matsushita Electric and



Sony and Toshiba are discussing a hybrid format for next-generation DVD.

others, told *Compound Semiconductor* that it "remains open to exploring ways to avoid a format war at the consumer level", although it could not confirm whether the two camps are close to agreeing a truce.

Toshiba is still planning to release notebook computers with HD-DVD drives in the fourth quarter of 2005, but the company says it believes that a single format would be best for consumers, and that it will work toward that aim through "necessary discussions" with the BDA. Meanwhile, the Toshiba-led HD-DVD camp held its first general meeting in Tokyo last month. "HD-DVD is making the move from specs to products," said the group.

DARPA describes GaN challenges as Cree confirms Track 1 role

Device reliability is the number-one challenge facing the companies working on the three technology tracks that make up the Defense Advanced Research Projects Agency's (DARPA's) wide-bandgap semiconductors for RF applications program.

That's according to Mark Rosker, DARPA's program manager for the effort, who outlined the aims of the project to the compound semiconductor community at last month's CS Mantech conference in New Orleans, LA.

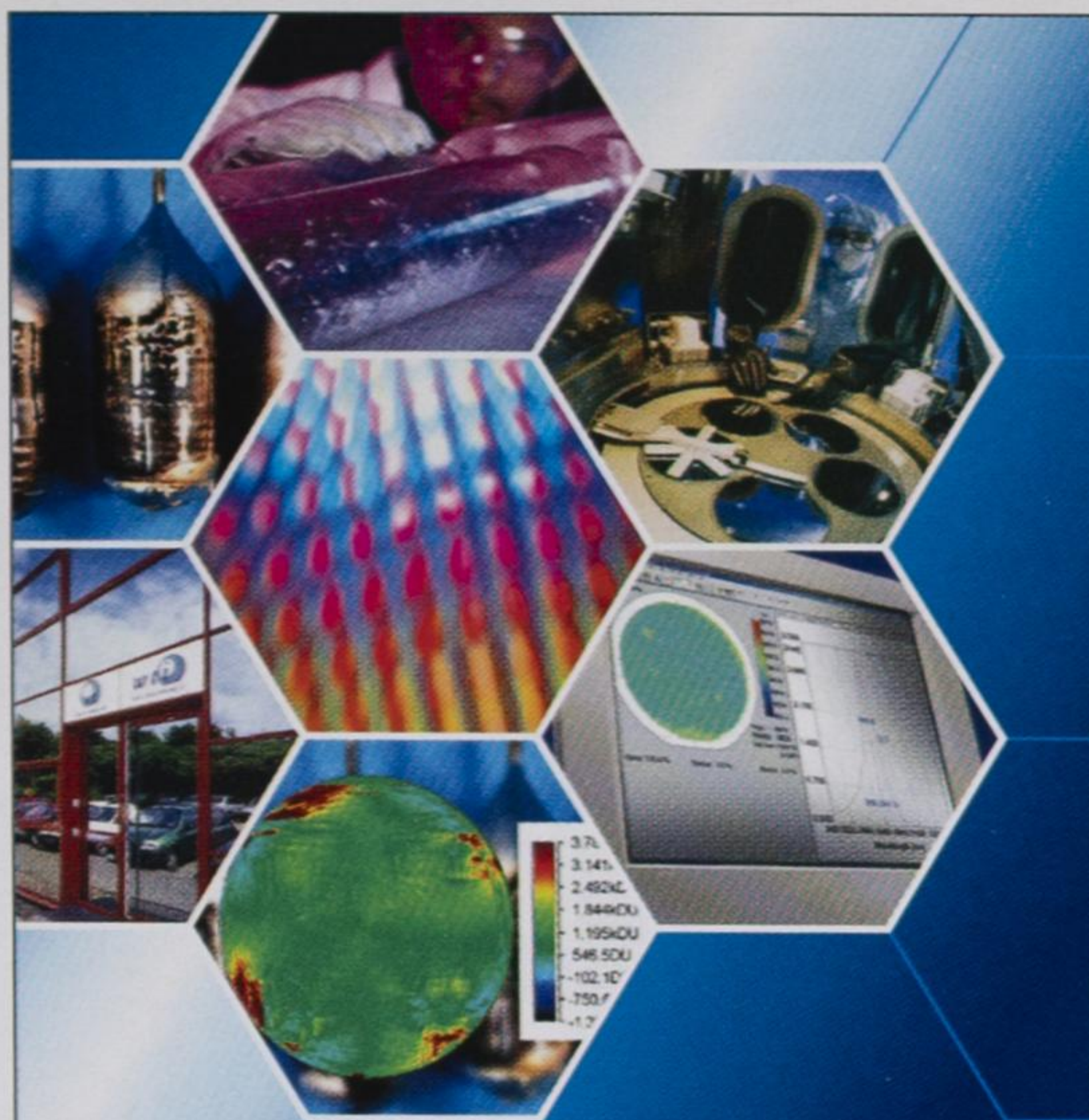
With the two-year Phase I effort, which focused primarily on materials development,

completed, Phase II and Phase III will take place over the next five years and concentrate first on device fabrication, then on MMIC design, before moving on to tackle module development for military applications.

Raytheon has now confirmed that it is the prime contractor on the Track 1 development, the aim of which is to produce an X-band transmit-and-receive module. Worth an initial \$26.9 million for Phase II, Track 1 could be worth \$59.4 million in all. Cree is Raytheon's key subcontractor and is set to receive \$11 million under Phase II.

Rosker told Mantech delegates that a key focus of the Track 1 effort is device efficiency for radar applications at 8–12 GHz. To produce the desired power output, a substantial improvement would be required at the MMIC level, he added, saying that is the case for all three technology tracks.

Both MBE and MOCVD growth options will be tried in the program, since it is not clear which is the better technique. Rosker said he believed that GaN would become cheaper than GaAs in terms of the key cost-per-watt metric during the DARPA program.



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Transistor breaks 600 GHz barrier

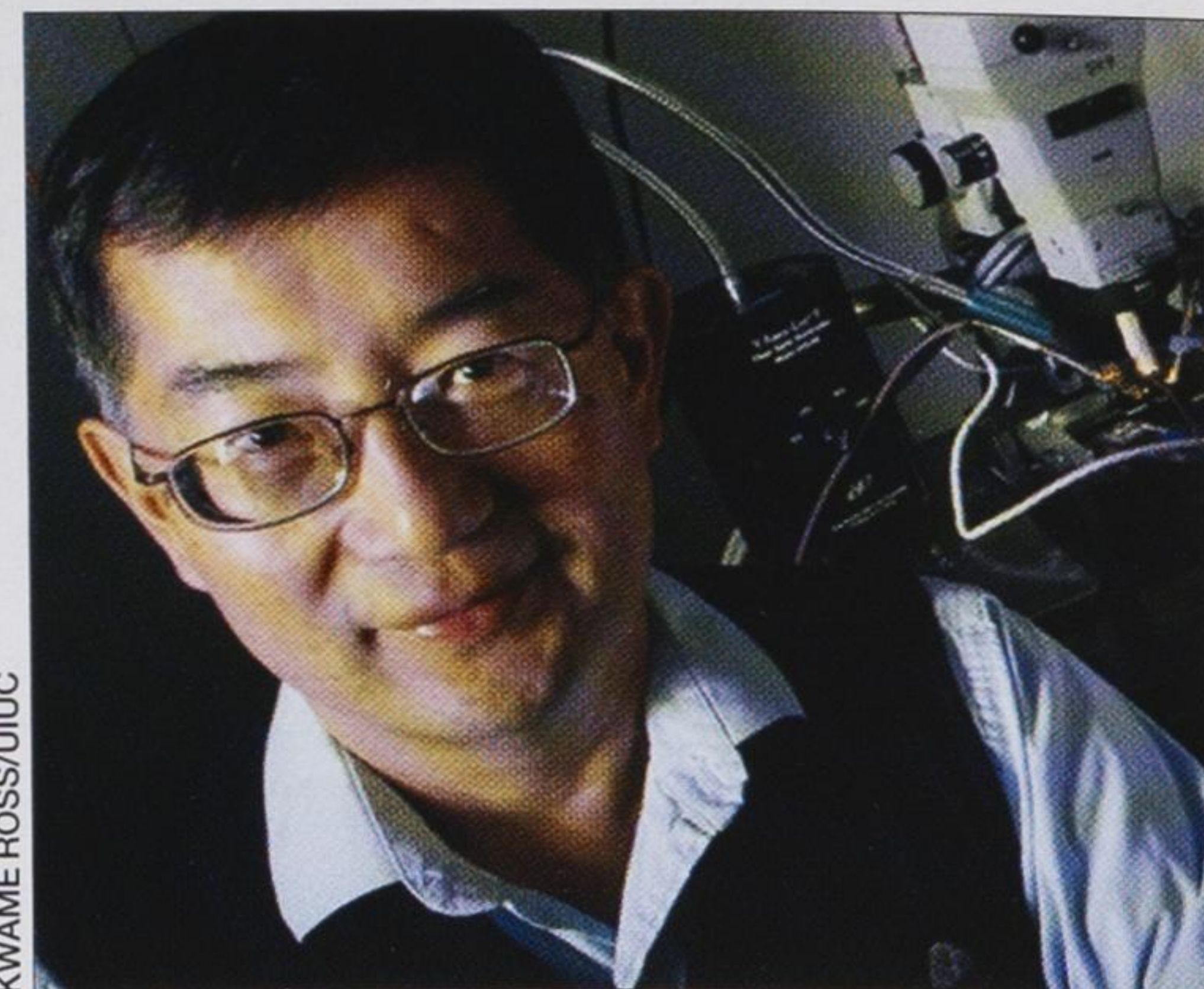
Researchers from the University of Illinois at Urbana-Champaign (UIUC) have broken the transistor-speed record with a pseudomorphic HBT operating at 604 GHz (*Appl. Phys. Letts* 86 152101).

The InP/InGaAs transistor, which was fabricated by Milton Feng and Walid Hafez, contained a compositionally graded collector, base and emitter to reduce transit time.

"Pseudomorphic grading of the material structure allows us to lower the bandgap in selected areas," explained Feng. "This permits faster electron flow in the collector and improves the current density."

According to Feng, the modifications to the transistor will help to produce a terahertz transistor: "To achieve such speed in a typical HBT, the current density would become so large that it would melt the components. In our pseudomorphic HBT, we can operate at higher frequencies with a lower current density."

The pseudomorphic HBT, which was produced at the UIUC Micro and Nanotechnology Laboratory, was grown by MBE on an InP substrate and fabricated using an all-wet-



KWAME ROSS/UIUC

Feng's UIUC research group has broken another transistor-speed record with its latest pseudomorphic HBT.

etch process. The device, with a $0.4 \times 6 \mu\text{m}$ emitter, achieved an f_T value of 604 GHz and an associated f_{max} of 246 GHz at a collector current density of $16.8 \text{ mA}/\mu\text{m}^2$.

Transistors operating at higher speeds could lead to faster computers, more flexible and secure wireless communication and improved electronic combat systems.

Switches will boost GaAs use in cell phones

By Michael Hatcher in New Orleans

Increased use of PHEMTs in antenna switches is set to drive up the amount of GaAs in future cell-phone handsets.

Paul Augustine, general manager of the Nokia product line at RF Micro Devices, told CS Mantech delegates in New Orleans, Louisiana, that GaAs content would grow by 40% to around 3.4 mm^2 per phone by 2007 and to 4 mm^2 in 2009.

While *pin* diodes have been the incumbent technology in switch applications until now, these devices are too big for highly integrated modules, which require six throw switches.

"GaAs PHEMT is well positioned to capture significant antenna switch volumes during the next few years," said Augustine.

He added that cost-effective integration of power amplifiers will become the most critical issue to address as handset OEMs demand smaller modules and significantly fewer components in future high-end phone designs.

Widening the applications base for GaAs RF components will be necessary as the industry faces a slowdown in the growth of the cell-phone-handset market.

According to Asif Anwar, director of Stra-

tegy Analytics' GaAs service, year-on-year revenue growth will fall to 1% at best in 2005, compared with an increase of 7% last year. Sales are expected to accelerate in 2006 and 2007, before tailing off again toward 2009.

The cell-phone market accounts for 52% of sales of GaAs microelectronic components, Anwar said. Strategy Analytics expects handset shipments to increase by only 6–7% this year, far less than the 25–26% growth experienced between 2003 and 2004.

"The saving grace is that as you move toward 3G you move toward multiband, multimode handsets," added Anwar. "While the price per band may be much less than a dollar now, when you have three or four bands in a cell phone, you can bump that [module] price up to around two dollars." However, he still expects GaAs revenues from cellular applications to decline from 2007 onwards.

Anwar also thinks that application areas such as WLAN and automotive radar will provide further opportunities for the GaAs industry. However, he doesn't expect these emerging markets to grow sufficiently to free the GaAs industry from its cellular-handset dependency by 2009.

● See "TriQuint ups PHEMT integration", p21.

Oki aims its GaAs MESFETs at WiMAX

Oki Electric is starting to ship samples of its new GaAs metal-semiconductor field-effect transistor (MESFET) for use in 3G-mobile base-stations, and is planning to develop the technology for WiMAX applications.

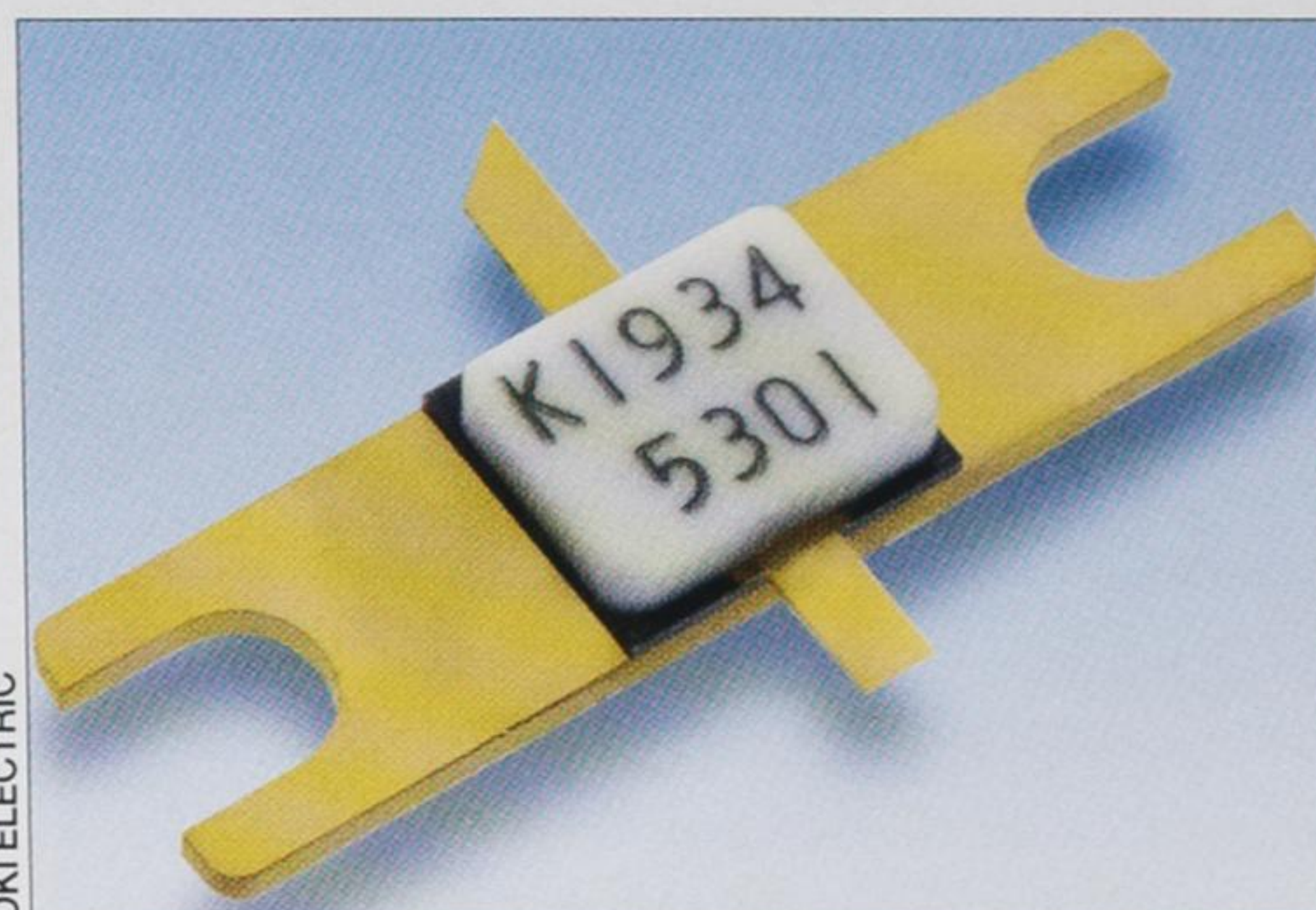
The Tokyo-based chip manufacturer claims that its KGF1934 transistor has a record-breaking drain efficiency, which is the ratio of RF output power to DC input power.

The company expects to see the device used in urban "microcell" base-stations – small transmitters located in shopping malls, for example, that require power transistors with low power consumption, high efficiency and good heat dissipation.

Oki used a gate-recess structure in its MESFET, which reduces parasitic resistance between the transistor's source and gate regions, and lowers the surface leak current.

Drain efficiency is quoted as being more than 55% with a 10 W output power, and 25% at the normal operating power of 2 W.

The firm says that as a result of this



OKI ELECTRIC

Oki says that its latest GaAs-based MESFET has a record-breaking drain efficiency.

improved drain efficiency, the power consumption of the driver-stage amplifier in which the MESFET is used is reduced by 40%.

With volume production of the transistors slated to begin in June, Oki is aiming to sell 10,000 units per month.

And the company has its sights set on another target: the high-throughput next-generation wireless standard known as WiMAX.

"Oki plans to look into developing high-frequency power transistors that are highly efficient with high output covering the 6 GHz range," said the company.

WiMAX, known officially as the IEEE 802.16 wireless-networking specification, is set to offer a maximum communication speed of 75 Mbit/s over a range of up to 50 km. It will operate at between 2 and 11 GHz, and could be a substantial future market for GaAs chip and component makers.

The WiMAX Forum, a group of companies including some of the semiconductor industry's biggest names, is developing the next-generation standard. Intel has just released its first WiMAX product, with several service providers announcing plans to begin commercial WiMAX trials based on Intel's silicon products later this year. In its latest report, the Telecommunications Industry Association says that the US market for WiMAX infrastructure will increase from \$15 million in 2004 to \$290 million in 2008.

Anadigics' HBT PAs pull in volume orders

Anadigics says that it has received volume orders for InGaP HBT power amplifiers (PAs) for 3.5 GHz WiMAX applications. The firm says that its highly integrated 4.5×4.5 mm AWM6430 module provides an integrated step attenuator and output-power detector, thereby minimizing external component count, PCB space requirements and development costs for new designs.

The US-based RFIC manufacturer has also shipped its 25 millionth InGaP HBT PA for wireless LAN applications.

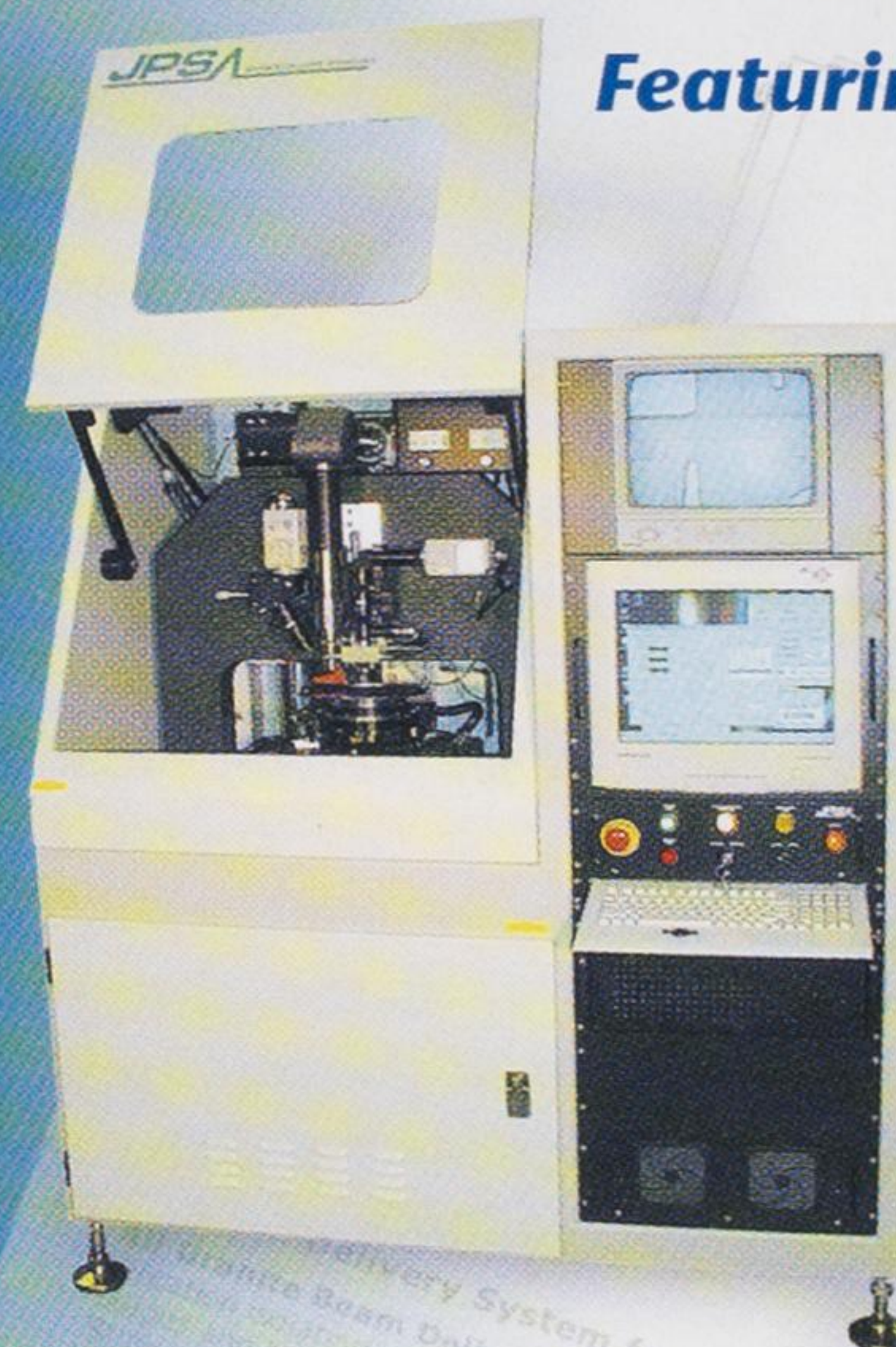
Sirenza says delays caused revenue fall

Sirenza Microdevices has recorded revenue of \$12.2 million for the first fiscal quarter of 2005, down \$2.9 million sequentially.

"We are disappointed that our sales did not track the forecasts of our major OEM customers," said the Broomfield, CO, company in a statement. The RF component supplier blamed its poor sales on "substantial order deferrals and shipment delays resulting from revised OEM forecasts".

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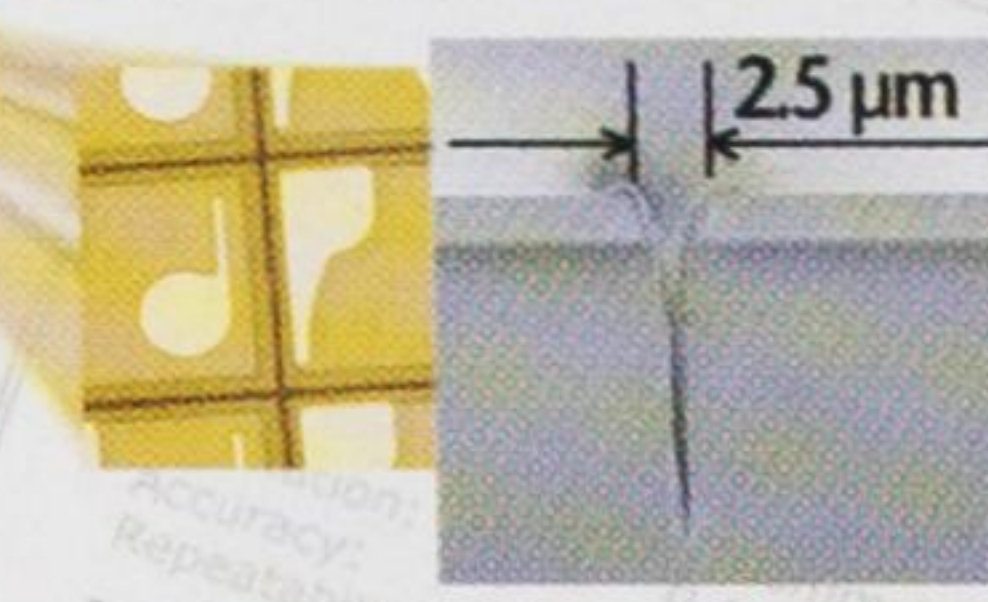
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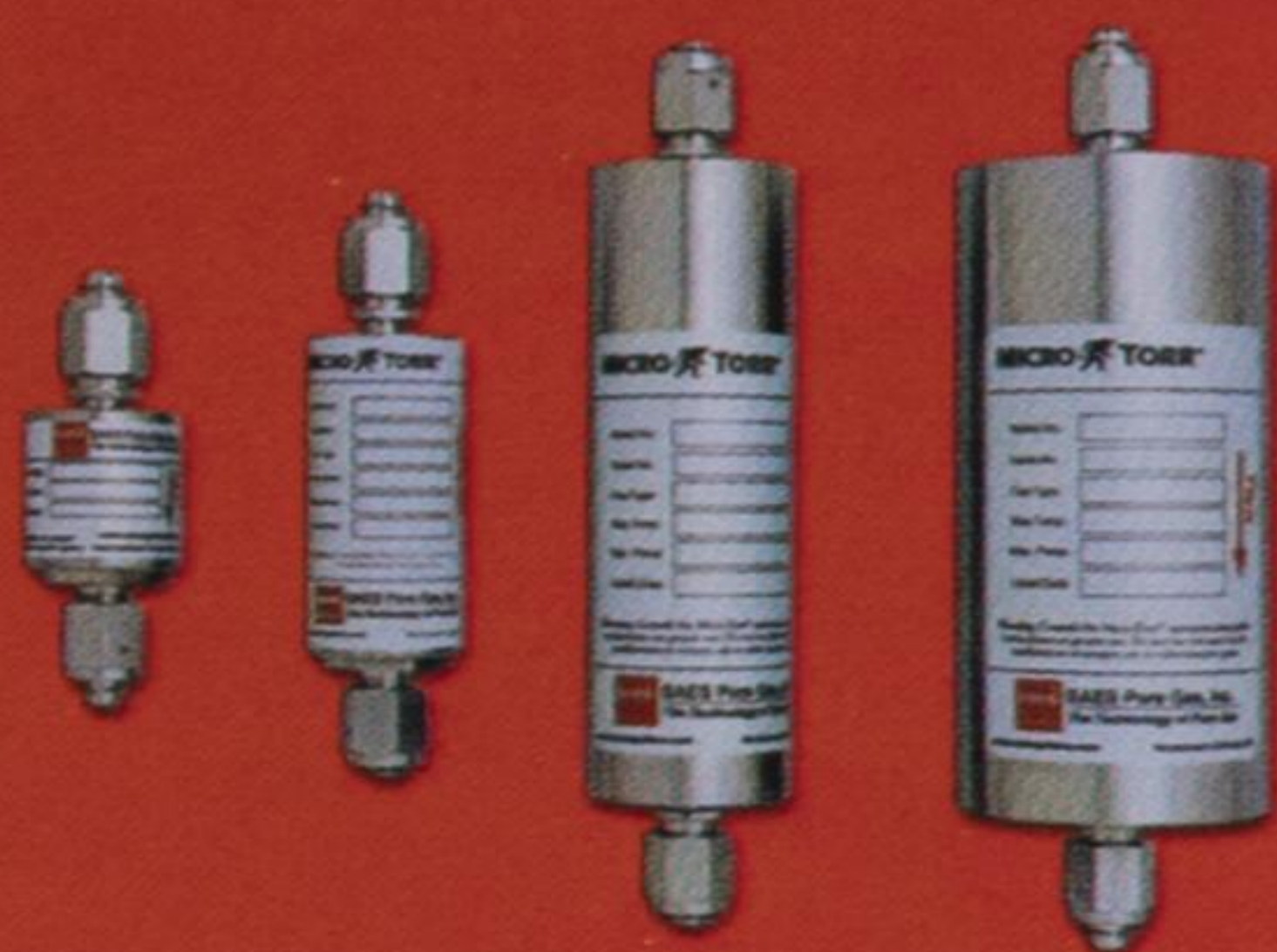
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LED NEWS

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Toshiba to volume-manufacture its high-performance white LEDs

Toshiba Corporation will soon be offering customers white LEDs suitable for general lighting and LCD backlighting. The company's flagship LED, the TL10W02-D, which generates 60 lm at 2 W and 500 mA, will begin sampling in July. Production of one million units per month is expected by October.

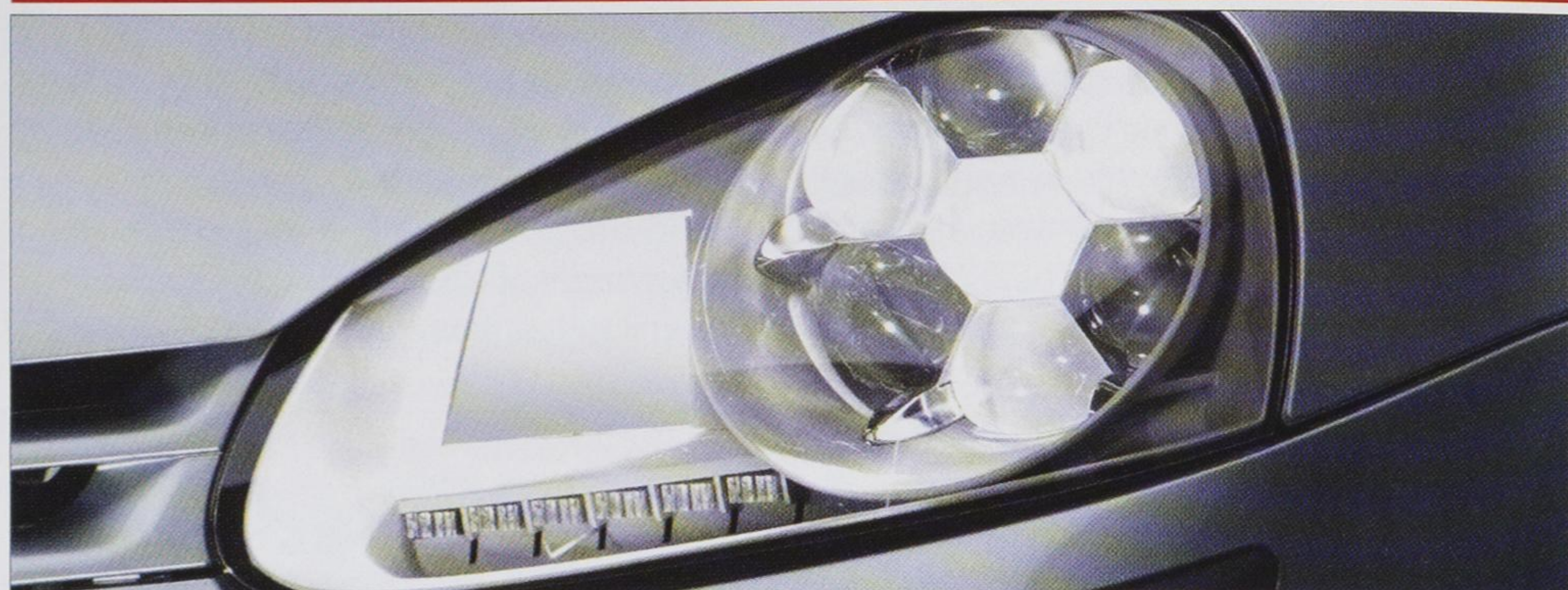
According to the company, the LED's high-performance characteristics result from improved chip-mounting technology and better thermal management due to a low-thermal-resistance package.

Toshiba says that the excellent heat-dissi-

pation characteristics also maintain the chip's luminous linearity at a drive current of up to 700 mA.

The firm will also begin sampling the 30 lm TL10W01-D in June, with the manufacture of one million units per month to follow in July.

Although Toshiba is not a company strongly associated with GaN LEDs, back in 2001 it teamed up with Toyoda Gosei to produce white emitters. The LEDs, which combined Toyoda's chips with Toshiba's phosphors, were marketed by both companies under their own brand names.



HELLA KGAA HUECK & CO

Germany-based automotive-lighting company Hella says that it expects to be making LED-based headlamps in volume from 2008. The company has recently developed this seven-element concept headlamp for Volkswagen. Seven pentagonal lenses arranged in a honeycomb pattern focus light from Lumileds and Osram Opto Semiconductors' white LEDs to produce a daytime running lamp, a low beam and a high beam. Hella says that the crucial luminous flux of 1000 lm has been achieved for the low beam – a figure that is equivalent to that of existing xenon headlamps. However, a high-quality high beam is yet to be realized. The company expects European authorities to have approved the validity of LED headlamps by 2008. The technology has already been approved in the US.

Nichia settles out of court with retailer

Litigious LED maker Nichia has settled its dispute with US retailer Sharper Image. The Japanese firm filed a lawsuit last April alleging that some of the products sold by Sharper Image, such as flashlamps and booklights, infringed US patent 5,998,925 on white LEDs.

Nichia believed that Sharper Image had purchased devices used in its consumer products from an unnamed third-party Asian LED manufacturer that had not signed the Japanese company's licensing deal.

While Sharper Image denied those claims, it has now come to a "business arrangement"

with Nichia. Awarded in December 1999, patent 5,998,925 details a nitride-based emitter and a fluorescent yttrium aluminum garnet (YAG) phosphor.

● According to a report in the *Nihon Keizai Shimbun* newspaper, Nichia is planning to grow sales of LEDs by 30% under an aggressive new four-year expansion plan.

The firm says it will invest around ¥30 billion (\$277 million) in plant and equipment, and ¥17 billion on research and development.

By 2008, Nichia is expected to make 25% of its LED sales from the backlighting of screens in cell phones and other small devices. Meanwhile, large-display applications will grow to represent 18% of sales and automotive applications will contribute 15%.

HB-LED sales boost Cree's profit margin

US-based chip maker Cree reported revenue of \$96.7 million for the third fiscal quarter of 2005, down \$0.8 million sequentially, but up \$19.5 million year on year.

Profit in the third quarter was \$20.7 million, a fall of \$4.7 million against the previous quarter, but \$5.7 million higher than the equivalent period last year.

According to Cree CEO Chuck Swoboda, strong growth in high-brightness (HB) LED sales offset softness in the company's mid-brightness category and shifted the product mix toward the higher end. Average selling prices were up 6% as a result.

Swoboda also says that sales of HB-LEDs were boosted thanks to their use in the popular Japanese pinball game Pachinko, which compensated for a slowdown in the growth of the cell-phone-handset market.

On the development front, Cree says that it will have a renewed focus on green LEDs, as well as blue-violet lasers fabricated on GaN substrates.

Revenue in the next quarter should be \$98 million–102 million, says Cree, with a profit of around \$20 million.



The distinctive "Hot Pink" illumination of the Torana concept car built by General Motors Holden made an impression at the 2004 Australian Motor Show, says Osram Opto Semiconductors, the firm that provided the LEDs used to light the dashboard and the external features. The Torana was fitted with lighting modules based on Osram's new MultiLED, which integrates Osram's red (625 nm), green (525 nm) and blue (470 nm) chips in one package.

Tridonic, Toyoda Gosei embark on general-lighting joint venture

By Tim Whitaker

A new European alliance will develop technology for high-power white LEDs for general-lighting applications.

TridonicAtco GmbH & Co KG, the lighting components and control-gear division of the Zumtobel Group, has signed a joint venture agreement with Japanese LED manufacturer Toyoda Gosei with the aim of advancing the development of high-power white LEDs.

The 50:50 joint venture has been established with a fund of €2.6 million (\$3.5 million) and further capital investments will be made in the future. The firm will be based at Jennersdorf in Austria and will commence business in May, with production expected to start by the end of this calendar year.

The joint venture will make high-power LED packages and components for the general-lighting market. White LEDs will be developed with a focus on color temperature, tolerance, homogeneous white light and

color rendering.

These LEDs will be destined for worldwide use in innovative lighting solutions, but the company is also aiming to develop LED applications specifically for the European market, not least for the automotive and communications industries.

Austria-based Zumtobel Group is a global lighting maker (boasting sales of €1.14 billion in the year ending April 2004) with divisions including Thorn Lighting, Zumtobel Staff and TridonicAtco. As early as 2001, the lighting-components division assigned its LED activities to a separate subsidiary, Tridonic Optoelectronics GmbH, based in Jennersdorf.

As the joint venture is set up at the Technology Centre in Jennersdorf in the Austrian state of Burgenland, TridonicAtco's existing facility there will be expanded. The general-lighting project qualifies for subsidies from technology promotion schemes financed by the EU and Burgenland.

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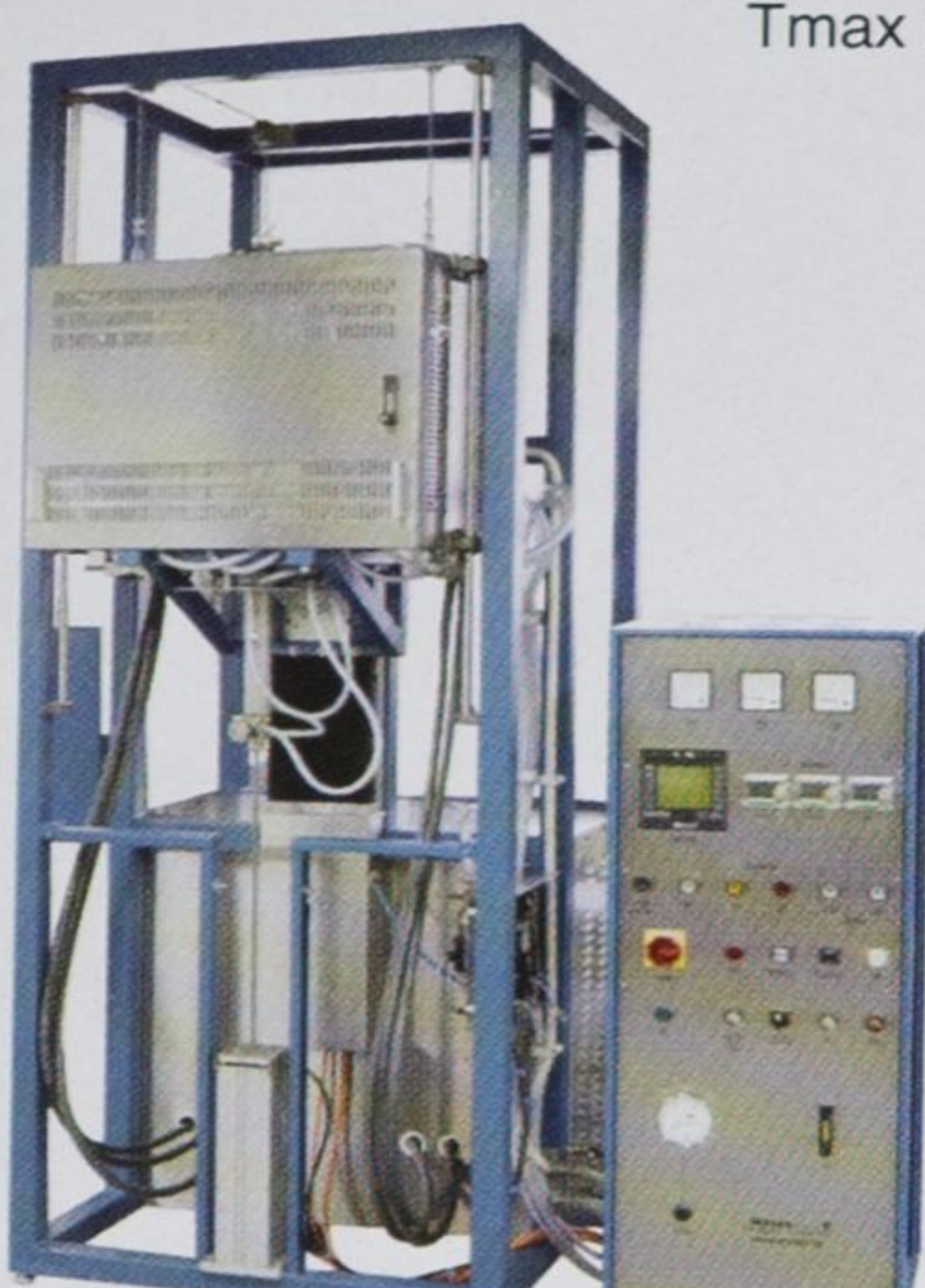
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WIDE BANDGAP NEWS

Non-LED applications are set to bolster GaN sector

The value of the worldwide GaN device sector is set to hit \$7.2 million in 2009, by which time non-LED applications of the technology will account for 17% of the market.

According to a new report from market-analyst company Strategies Unlimited, the blue laser-diode market will be worth \$900 million five years from now. If the prediction is correct, that would equate to a 13% share of the overall GaN device industry.

Significant shipments of GaN-based blue-violet laser diodes are expected in the second half of this year as the DVD industry launches its next-generation recorders and players.

Bob Steele, who compiled the report, told *Compound Semiconductor* that the current GaN market, worth \$3.2 billion in 2004, is overwhelmingly dominated by LED sales. And sales of blue, white and green LEDs will still account for 83% of the market, or \$6 billion, in 2009, he says.

However, by that time GaN-based electronic devices will also be making their presence felt, with an expected market value of

\$300 million, or 4% of the overall sector.

"For GaN-based electronic devices, the principal application will be HEMTs for use in power amplifiers in base-stations for mobile networks, and for the emerging WiMAX fixed-wireless base-station market," predicted Steele.

The industry analyst adds that less significant applications will include power switches for high-voltage power supplies and high-voltage rectifiers.

Aside from regular visible-range LEDs, Steele is expecting some demand for ultra-violet LEDs based on GaN to emerge over the next five years. However, the market for applications such as water purification and ultra-violet curing is expected to remain relatively small during the forecast period.

GaN-device development is proving to be a strong research topic among academics, with 394 universities and research centers now involved in the material – a 35% increase over the past two years. It's a similar picture in the commercial world, confirms the report, with 232 firms involved in GaN development.

II-VI constructs SiC facility in Starkville

SiC substrate manufacturer II-VI will partner with SemiSouth Laboratories and Mississippi State University (MSU) to build a manufacturing facility for 2, 3 and 4 inch SiC substrates in Starkville, MS.

According to Tom Anderson, general manager of II-VI's Wide Bandgap Materials

Group, the company chose Starkville for its long-term volume manufacturing because of its favorable business climate and its close proximity to MSU and SemiSouth.

The collaboration will start in the Power Center at MSU, but when demand for its SiC material exceeds capacity the partnership will build a larger facility in Starkville.

II-VI will continue to develop wide-bandgap materials technology and products at its technical center in Pine Brook, NJ.

GaN amplifier exhibits a record efficiency

By Michael Hatcher in New Orleans

US chipmaker Cree says that it has developed a GaN-based RF amplifier with record power-added efficiency (PAE).

Cree's Jim Milligan told CS Mantech delegates that the device, which operates at between 1.9 and 2.1 GHz, has a power output of 10 W and a PAE of 84%. The company has also made highly efficient chips operating at 2.7–2.9 GHz and at 3.3–3.5 GHz.

Milligan was keen to stress Cree's progress with SiC RF chips. "SiC is ready now," he

emphasized, adding that sales of SiC MESFETs were increasing rapidly. Having recently completed a 2000-MMIC demonstration, Milligan said that the technology has "taken off" in the last six to nine months.

Although mostly used by the US military, SiC devices could fall in cost if they are ordered in high volumes – opening the door to commercial applications, said Milligan.

Currently costing \$3 per watt in quantities of 100,000, this price should fall when Cree moves to 4 inch substrate production, which is scheduled for 2007.

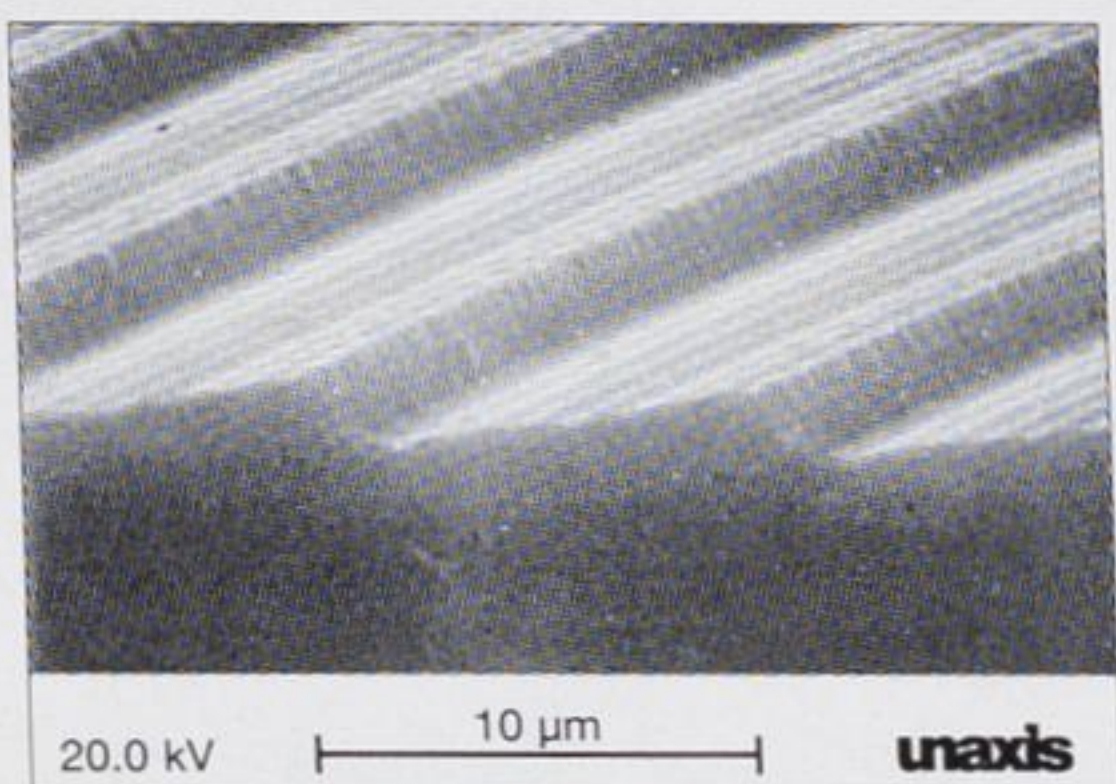
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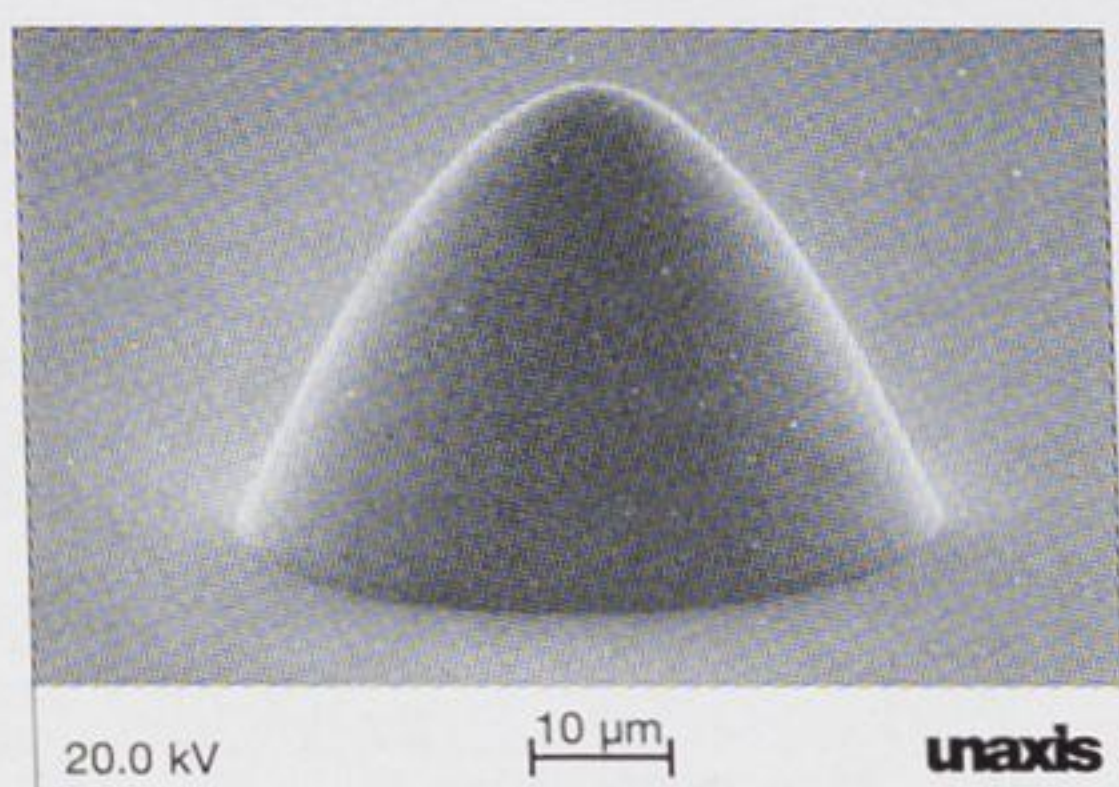
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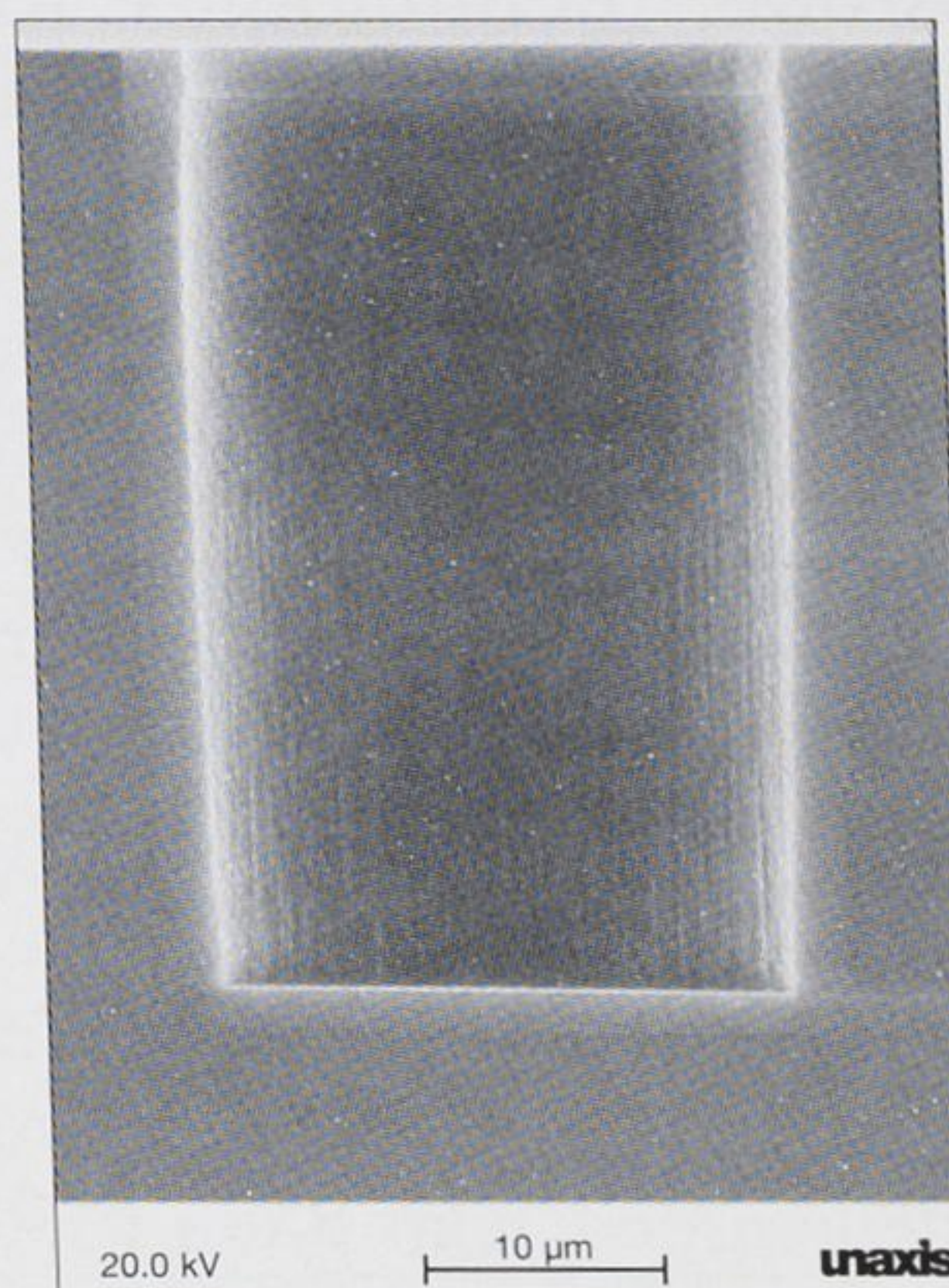
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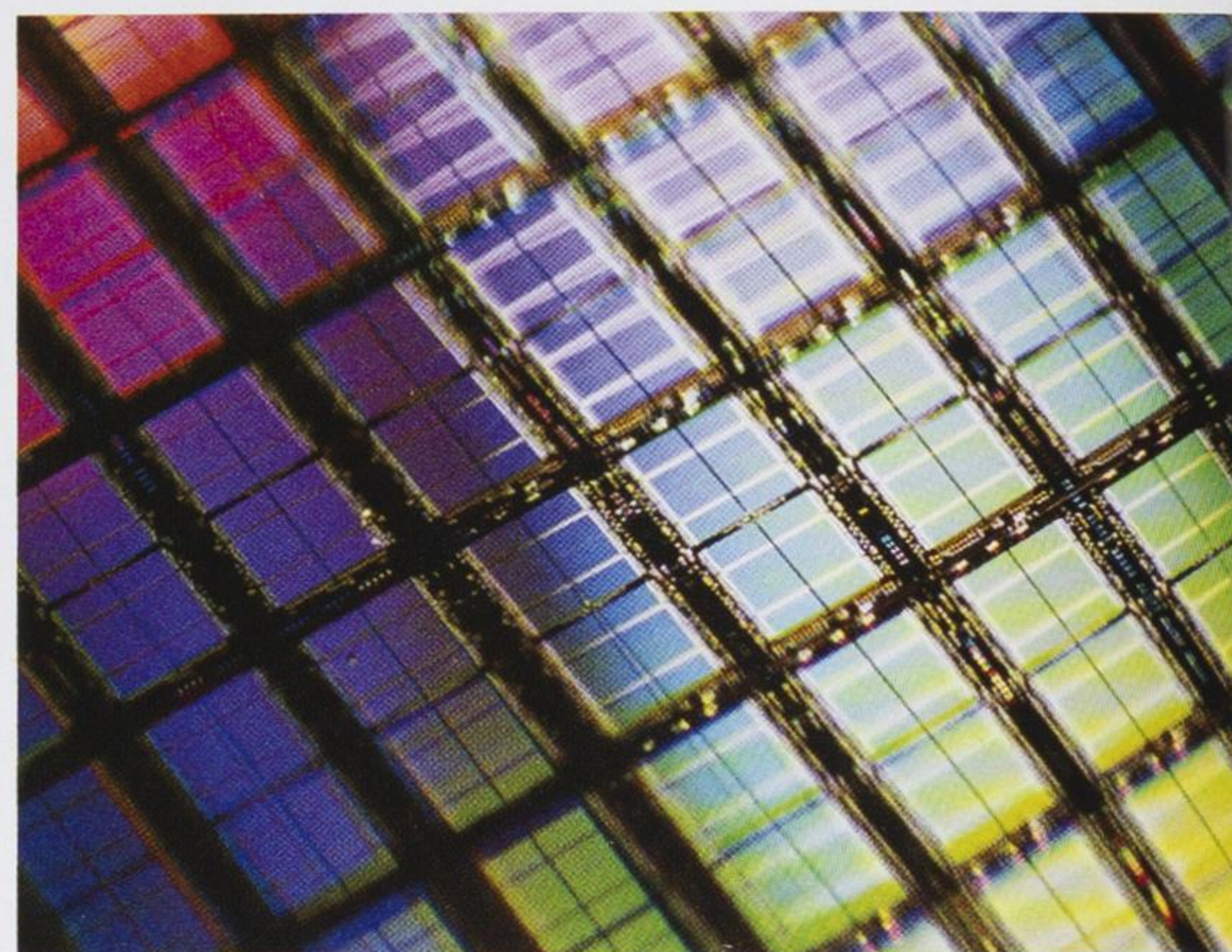


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SURFACE TECHNOLOGY SYSTEMS

Avanex powers UK-India fiber upgrade

Optoelectronic chip and module manufacturer Avanex is to supply pump laser modules for an upgrade to part of the world's longest fiber-optic communications link.

The order came from France-based telecommunications system builder Alcatel (which sold its optical-components division, Alcatel Optronics, to California-based Avanex in 2003) after it won a contract to upgrade part of the 38000 km Sea-Me-We 3 submarine cable network, which runs from the UK all the way to Perth, Australia. The upgrade to the UK-India section of the link is due to be completed by the end of this year.

The upgrade is required to provide the net-

work with sufficient capacity to support the increase in traffic driven by the widespread roll-out of broadband services.

Alcatel will use GaAs-based 980 nm-emitting laser modules from Avanex to pump erbium-doped fiber amplifiers as it deploys its latest dense-wavelength division multiplexed submarine line terminal.

Alcatel will also upgrade all terrestrial stations along the course of the link, which passes through France, Portugal, Egypt, Saudi Arabia and Somalia en route from the UK to India.

For Avanex, the contract comes at a time when the company is still struggling to reduce its financial losses as the fiber-optic market

finally starts to regain momentum.

The company was forced to reduce its expectations on revenue for the most recent quarter: "We have seen some pressure due to the deteriorating dollar/euro exchange rate and annual product-pricing negotiations," reasoned CEO Jo Major.

Major adds that Avanex is actively considering further restructuring of the company to reduce its cost base, with its major competitors in the optical component space enduring similar struggles.

● Avanex is to cut the manufacturing workforce at its Nozay, France, facility by 60% at a cost of \$26 million in severance payments.

\$13 m of funding will see 1310 nm VCSEL production ramp up

Following its latest funding round, and sensing "steadily improving" market conditions for fiber-optic components, Picolight says that it will now increase the production volume of its 1310 nm vertical cavity surface-emitting lasers (VCSELs).

The Boulder, CO, company, which makes short- and long-wavelength VCSELs, as well as transceivers based on the components, raised \$13 million in capital and is looking to close another deal worth \$4 million-7 million in the current quarter.

Coral Capital Management led the recent funding round, and Coral's managing director Todd Ortberg now takes a seat on Picolight's board of directors. "This funding round validates the progress we made through the second half of 2004 and into the first quarter of 2005, and will help us commence volume shipments of 1310 nm VCSEL-based products," said Picolight CEO Steve Hane.

Picolight says that its revenue has more than doubled in the past year, fueled by demand for applications such as 10 Gbit/s Ethernet and parallel optics. Hane adds that Picolight is aiming to become profitable by the end of this year.

Picolight had already raised \$90 million in capital prior to the most recent round of funding, and the company built its VCSEL fabrication facility in 1998.

In February 2002, the company released its "Extensus" range of optical transceivers, which are based on 1310 nm lasers.



Consolidation in the European fiber-optic sector continues apace, with Swedish companies at the forefront. France-based Highwave Optical Technologies has acquired Northlight Optronics, while Transmode and Lumentis are set to complete an all-Swedish merger. Transmode's Michael Crossey says that the merger would create a strong wavelength division multiplexing (WDM) systems company – under the Transmode brand – to capitalize on the return to growth of the metro WDM systems market. "This market will grow by almost 20% in 2005," predicted Crossey, who is Transmode's vice-president of marketing and business development.

Bookham signs \$50 m Nortel agreement

Optoelectronic component manufacturer Bookham has struck a new deal with its number-one customer, Nortel Networks, that includes the shipment of \$50 million worth of products from a product line that will soon be discontinued.

Nortel's 12-month order will extend the lifetime of Bookham's Paignton site in the UK, where these products are to be made. The contract cannot be fulfilled with current inventory, and so additional component manufacture will take place at the facility. The agreement will also see Bookham sell components at slightly higher prices than under the previous Nortel deal.

"As a result of this agreement, Bookham anticipates that revenue, gross margin and operating cash burn will improve significantly beginning in the fourth quarter of fiscal 2005,

ending July 2," said the firm in a statement.

Bookham adds that it is in the final stages of signing another agreement with Nortel, covering a supply of products made at its Shenzhen, China, location.

Investors reacted positively to the deal, with Bookham's share price near doubling after the announcement.

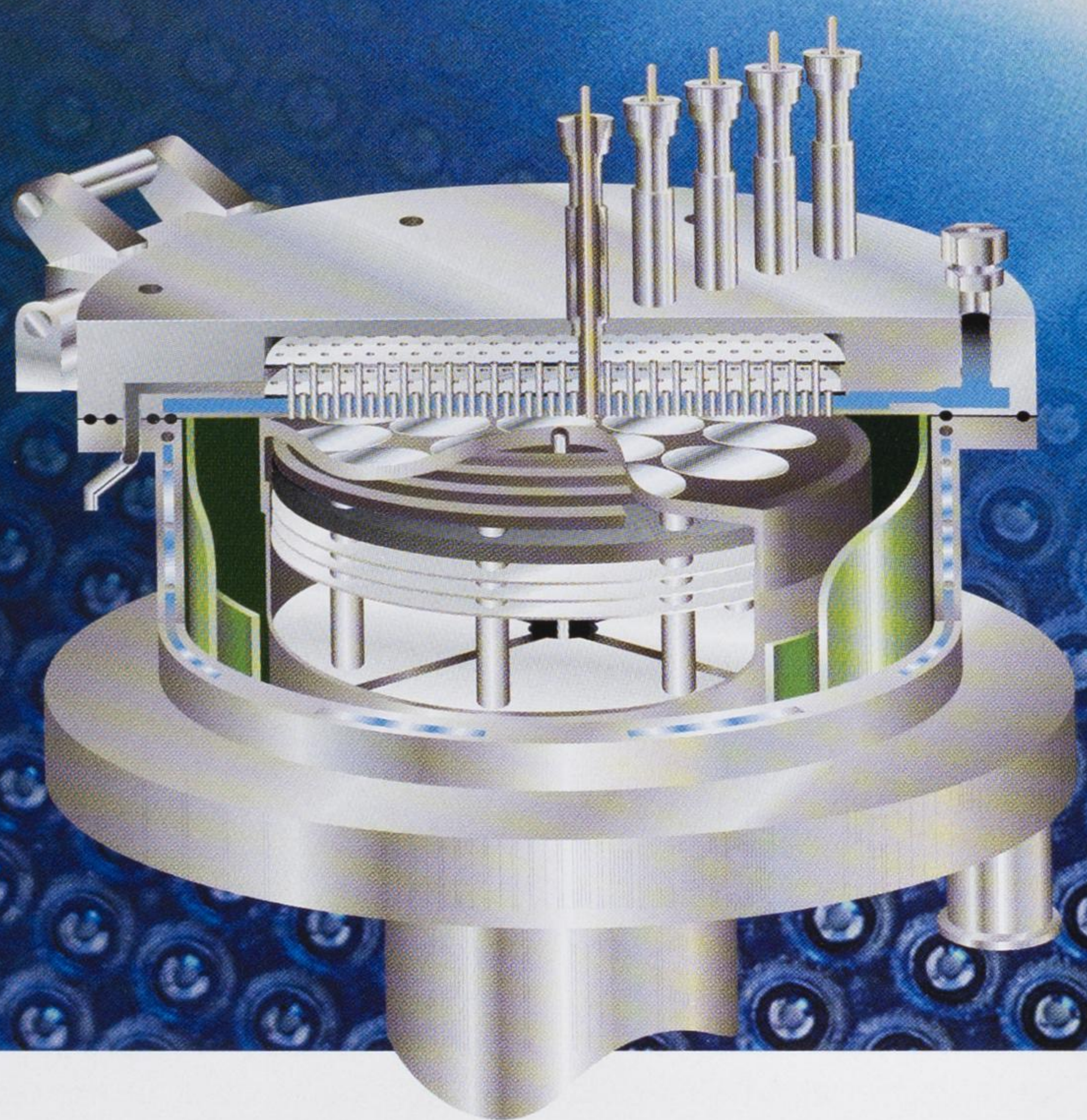
Nortel has been Bookham's most important customer for several years, and in the quarter ending January 1, the Canada-based firm accounted for \$17.9 million of sales, or 44% of Bookham's total revenue.

Bookham and Nortel have also altered the loan agreement that was signed when Bookham bought Nortel's optical components division in 2002. The firm says that it has provided Nortel with additional guarantees relating to the continuity of supply of its products.

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LED modules make dirty water potable

Two US teams working on a water-sterilization module that uses AlGaIn-based ultraviolet LEDs have demonstrated its ability to kill harmful bacteria in flowing water.

One of the concepts developed is a module that does not require an external energy source to power the LEDs, instead relying on the flow of water to generate the required drive current.

Such purification modules, which would be far smaller and more convenient than those that use mercury lamps to kill bacteria, could become a high-volume market for UV-LEDs.

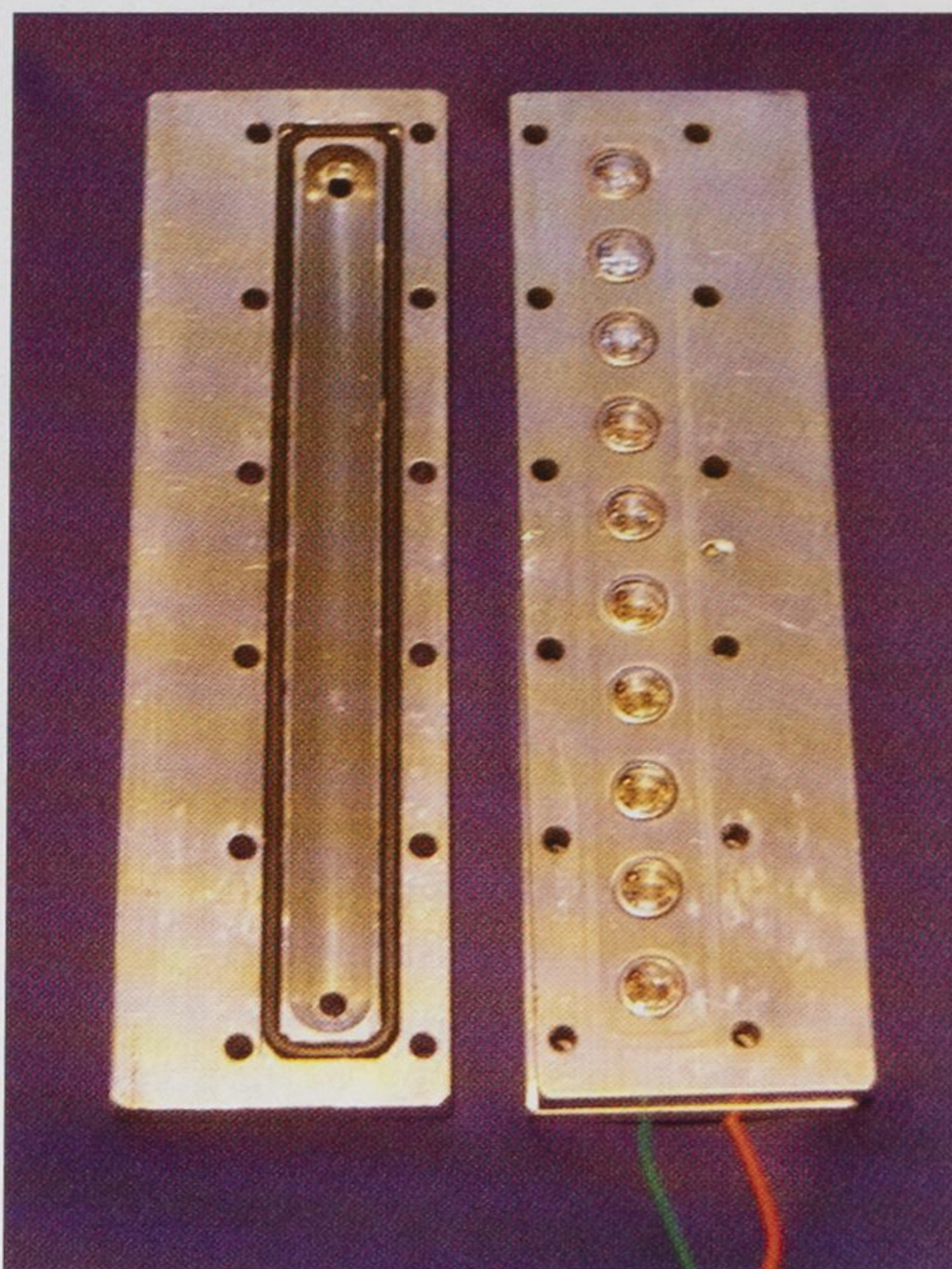
Although the concept of bacteria destruction with UV-LEDs has been shown before with a static water sample, the purification of flowing water is critical for the technology to become commercially viable.

In collaboration with microbiologist Anne Hanson at the University of Maine Orono, Hydro-Photon, a Blue Hill, ME, company, developed a bench-level prototype flowing water-treatment module that uses 10 AlGaIn LEDs made by the South Carolina firm Sensor Electronic Technology (SET).

The SET devices used in the module, which were developed in collaboration with Asif Khan's group at the University of South Carolina, emit at 280 nm, and the 4 cm³ aluminum treatment chamber is designed to maximize light reflection at this wavelength.

In tests using sterile tap water contaminated with a 10,000 microbes/ml concentration of *E. coli*, the UV-LEDs destroyed at least 95.5% of the bacteria. The best results were seen at lower flow rates, where the germ destruction was close to 100%.

"The results put us another step closer to demonstrating the basic viability of the flow-through UV-LED water-purifier concept," said Miles Maiden, CEO of Hydro-Photon. "At this point, the challenge is to continue improving LED efficiency and power output.



Water purifier: Hydro-Photon's 10-LED module has virtually eliminated bacterial contamination in flowing water.

More power means faster flow and more purified water per minute."

Meanwhile, a second firm – Ohio-based start-up company Oh Technology (OHT), which is also working with SET's LEDs – claims to have reduced bacteria levels in flowing raw sewerage by 60%.

OHT's first battery of tests, which began in February this year, looked at the effect of a prototype module containing 16 AlGaIn LEDs on raw fecal sewerage at a local wastewater-treatment facility.

According to the team, which included third-party testers at Tri State Laboratory, the influent samples that contained fecal coliform bacteria showed a 60% reduction in bacteria concentration after a one-second flow-

through. These bacteria are found in the digestive tract, and include classes such as *enterobacter*, *citrobacter* and *E. coli*, and concentrations of these bacteria are commonly used as an indicator of sewerage contamination in water supplies.

"Our goal is to alleviate inadequate water situations that have become a global epidemic," said OHT chief executive Damien Lieggi. "The test results have provided proof of the basic viability and instant kill efficiency of the LEDs." Lieggi added: "We want to turn the worst possible conditions into drinking water. We feel that we have achieved tremendous results at this level."

Lieggi describes OHT's technology as "self-sustaining", as it does not rely on an external energy source: "[Our] patent-pending technology uses the flow of water, which is converted into electrical energy [to power] the LEDs, which in turn sterilize the water."

The LEDs in the current set-up emit about 1 mW at around 270 nm, while OHT and SET are testing new, improved devices. Lieggi says that a commercial product will be unveiled within a few months: "What sets our product apart [is that] it eliminates the need for batteries, solar panels and ballasts."

SET makes the short-wavelength LEDs used in the module using a novel growth technique called migration-enhanced MOCVD (*Compound Semiconductor* April p27). This approach, which differs from conventional MOCVD in regard to the way gases are flowed into the reaction chamber, improves the quality of AlN and AlGaIn in particular, while increasing the material-deposition rate.

Remis Gaska, SET's CEO, said of the Hydro-Photon work: "We consider this to be a significant milestone in bringing our deep-UV technology to such high-volume markets as water, air and surface sterilization."

nLight claims diode-laser-output record

nLight, which is developing high-power, high-efficiency lasers based on GaAs and InP material systems, says that it has set a new world record for output power from a single 1 cm InP laser bar.

A water-cooled InP bar made by the Vancouver, WA, company produced 88 W of continuous-wave power at 1470 nm. The sig-

nificance of the breakthrough, says nLight, is that diode bars based on the technology could substantially improve high-power diode-pumped solid-state (DPSS) lasers that emit in the so-called "eye-safe" 1400–1600 nm range.

These large laser systems are usually pumped with high-power GaAs diodes emitting around 800 nm. However, they require an additional system, known as an optical parametric oscillator (OPO), to shift the output wavelength into the eye-safe range.

Using InP-based diode bars, says nLight,

means that an OPO is not needed. That's because the 1470 nm output can be used to pump an erbium-doped crystal, which emits directly in the eye-safe range. And so the DPSS systems can be made smaller and more cheaply, and could find more applications.

The physics of the erbium-doped crystal structure also means that less pumping power is required: "The number of diode-laser bars required to reach a given pulse energy [with an erbium-doped crystal] is reduced by at least an order of magnitude," claimed the company.

Emcore secures solar-cell contract but shuts US fab

Despite involvement in two new NASA development contracts, Emcore is to close its solar-panel fabrication facility in City of Industry, CA, and consolidate the business into its Albuquerque, NM, location.

The move, which is expected to save the company \$3 million annually, should be completed by the end of this year.

Emcore says that the Albuquerque solar-panel facility will be highly automated, resulting in more consistent product performance and reduced manufacturing costs.

"Our modern wafer-fabrication line in Albuquerque employs state-of-the-art manufacturing methods, which will be applied directly to the solar-cell assembly and panel-manufacturing operation," said the Somerset, NJ, chip manufacturer in a statement.

Emcore competes primarily with Boeing subsidiary Spectrolab for a share of the III-V solar-cell market, which is dominated by satellite applications.

However, Emcore believes that by reducing its costs it will be able to broaden its photovoltaics product portfolio to compete in terrestrial solar-cell concentrators that can be hooked up to electrical grids. Solar cells based

on III-V materials are currently regarded as being too expensive for terrestrial use (*Compound Semiconductor* November 2003 p25).

Emcore's photovoltaics division is also involved in two NASA contracts, which were recently won by the Keller, Texas, firm Entech. Entech makes solar-power arrays for both space-based and terrestrial applications, and is collaborating with Emcore on projects sponsored by NASA's Exploration Systems Mission Directorate.

Under a \$0.6 million phase II small-business innovation research contract, the team will develop a solar-cell concentrator system capable of collecting both sunlight and infrared laser light.

The idea is that spacecraft at the north and south poles of the Moon, which are known to contain hydrogen but which do not receive any direct sunlight, could be powered by a long-range laser beam fired at the solar array from an orbiting craft.

In another Emcore-Entech contract worth an initial \$1.8 million, a very-high-power array is set to be developed. If deemed successful, this contract could receive additional funding of \$12.5 million.

NASA builds first four-color infrared camera

By Richard Stevenson

A collaboration between NASA's Jet Propulsion Laboratory (JPL) and UK-based epiwafer supplier IQE claims to have produced the world's first four-band infrared camera.

Based on quantum-well infrared photodetector (QWIP) technology, the camera is suitable for applications including weather prediction and remote sensing of pollution, such as nitrous oxide in smog. It has already been used as part of an international project investigating the environmental impact of vegetation burning and related ecological effects in Africa.

The camera's four QWIP channels allow detection of radiation at wavelengths of 3–5, 8–10, 10–12 and 13.5–15.5 μm , and combine to give an array of 640×512 pixels.

"This technology will revolutionize the way we develop new remote-sensing instruments," said JPL senior scientist Sarath Gunapala. "One such example is the detec-

tion of smog. Smog contains a range of chemicals that only appear in certain infrared ranges. The multiband capacity of the camera array will allow researchers a full spectral view to identify them."

Other technologies, such as microbolometer- and HgCdTe-based cameras, are more limited in terms of their spatial resolution, while HgCdTe cannot detect beyond 12 μm .

The QWIP camera contains GaAs-based material that was grown at IQE's US facility, located in Bethlehem, PA. Infrared light excites carriers within the wells, which are then accelerated by an electric field to generate a photocurrent.

The detector will also be used to form the basis of a hyperspectral infrared camera, which may comprise more than 64 wavelength bands. The project is the combined effort of JPL, IQE and the US Army Research Laboratory, and will include quantum-well structures fabricated on 6 inch GaAs substrates.

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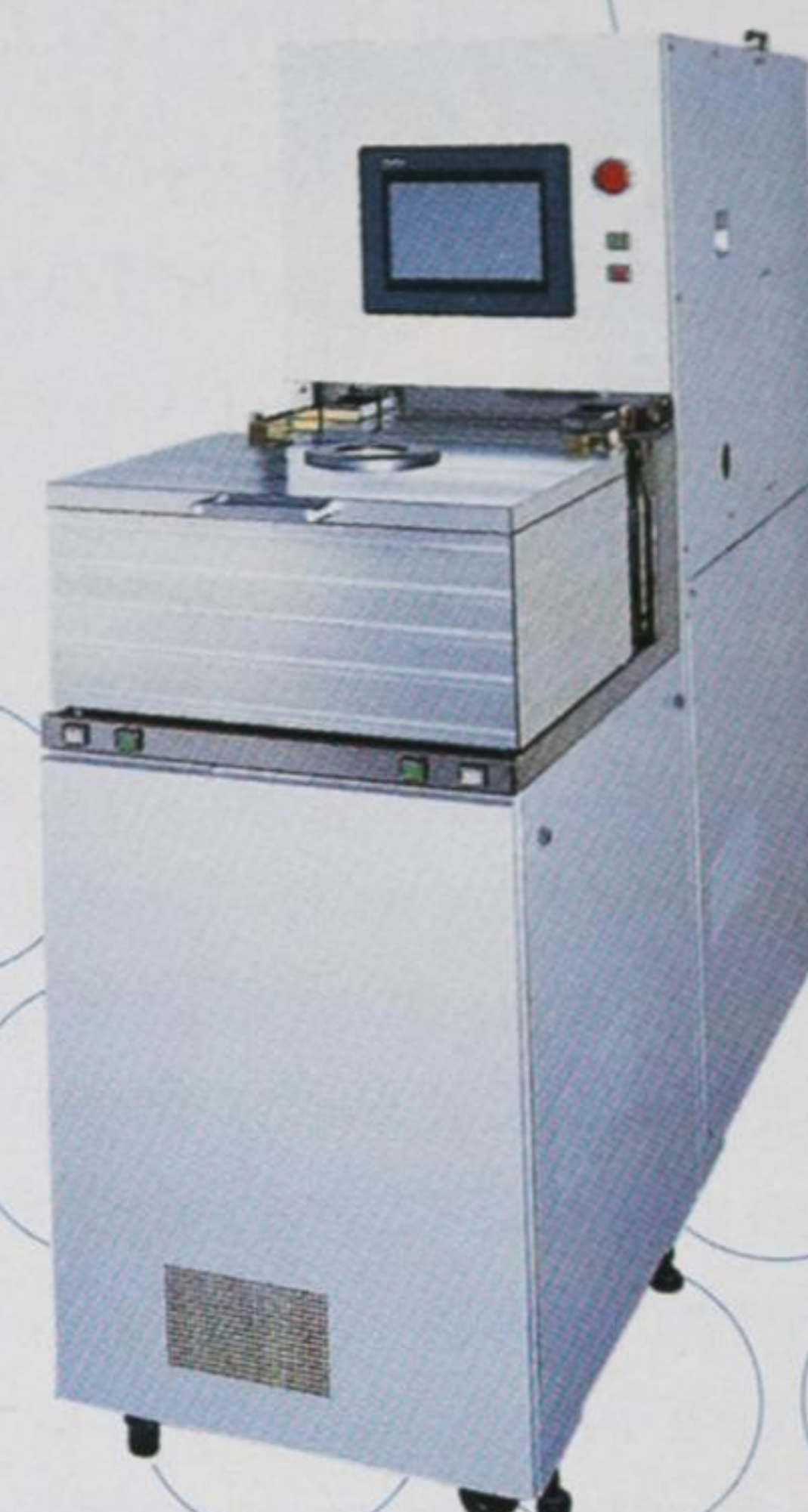
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Switch technology delivers

The challenge for today's RFIC makers is to produce front-end modules for cell-phone handsets that can deliver increased talk time in a small footprint. According to Agilent Technologies, this can be achieved by integrating E-PHEMT transistors and sophisticated switching. **Richard Stevenson** reports.

Cell-phone customers, vendors, and component manufacturers are united in their quest for longer handset talk times. One of the key aims for RFIC manufacturers is to increase the efficiency of their amplification stages, thereby reducing power consumption and increasing the time between each battery recharge.

Agilent Technologies, which is following this route, believes it can grasp the winning formula now that it has acquired the Korean power-amplifier (PA) specialist Wavics (*Compound Semiconductor* March p9). According to Agilent mobile and wireless industry analyst Joe Madden, the combination of the firm's existing filter technology, which discriminates between call signals and far more powerful electromagnetic radiation, its E-PHEMT technology, and Wavics' advanced circuit design will propel Agilent up the RFIC vendor rankings. Currently placed ninth in RF and microwave, the California-based chip maker has its sights set on the top spot.

Penetrating Korean markets

"Before the [Wavics] acquisition, Agilent's biggest strength was in duplexers and filters fabricated in our Fort Collins fab," revealed Madden. "We were shipping about 2 million GSM amplifiers per month to some large European OEMs [original equipment manufacturers], and we had introduced an EDGE amplifier. However, we had not got very far in terms of CDMA amplifiers, so our product portfolio for the entire RF space for mobile handsets was limited. We had a hole in the portfolio." With the addition of Wavics, a firm with customers including Samsung and LG and a specific strength in CDMA amplifiers, Agilent has now plugged that gap.

Incorporating Wavics' HBT technology into Agilent's product line is not a trivial matter, because Agilent has always used an E-PHEMT process that was developed at its own labs. But although the fundamental transistor technol-

ogy is quite different, Madden doesn't see this as a problem, because Wavics' technology is not specific to any particular type of amplifier. "[Wavics' technology is] agnostic in terms of the transistor or process used," said Madden. He adds that Wavics' success has resulted primarily from its circuit design: "Wavics has this great circuit technique and Agilent has an inherently efficient transistor process for amplifiers. When we put those two together we'll have the most efficient power amplifiers on the market by far."

Cool and efficient

Wavics' amplifiers use patented "CoolPAM" technology, so-called because the circuit techniques deployed allow amplifiers to run cooler and more efficiently, thereby increasing handset talk time. According to Madden, this technology is particularly well-suited to efficient power amplification for handsets operating in the low-power regime, and integrates well with the high-power output provided by Agilent's E-PHEMTs.

If you're out in the countryside and you want to use your cell phone to call several miles back to your base-station, all of the amplifier stages in the phone would be used. "We would be sending the signal through the two output stages to get the maximum output power, and in that case the E-PHEMT technology is quite strong," said Madden, who claims that Agilent's amplifiers are 5% more efficient than those based on HBTs. But that subtle difference isn't enough to make cell-phone OEMs chose an Agilent product, says Madden, because handsets don't normally operate at maximum power. "Most of the time people's phones are backed off by about two orders of magnitude in power. What that means is that phone designers care much more about low-power operation."

Wavics' circuit design offers high efficiency at low operating powers. "The CoolPAM technique is a way of bypassing those output stages



Joe Madden, Agilent's analyst for the mobile and wireless industry, thinks that the combination of its E-PHEMTs and Wavics' circuit design will allow the company to produce front-end modules that deliver longer talk times. Above right: Agilent's CoolPAM amplifiers use a sophisticated switching technique to achieve high-efficiency at low operating powers.

so that for low-power operation in class AB mode, we can have up to 15% better efficiency than traditional HBT amplifiers," said Madden. Although other companies are also switching-out their output stages, Madden says that the key to Wavics' technology is the absence of physical switches on the MMICs. "Essentially [Wavics' technology] characterizes the impedance of the output stage in both the on and off state," he said, explaining that this is achieved by inserting a matching circuit. Switching off the output transistors presents a different impedance to the output of the

rs longer cellular talk times

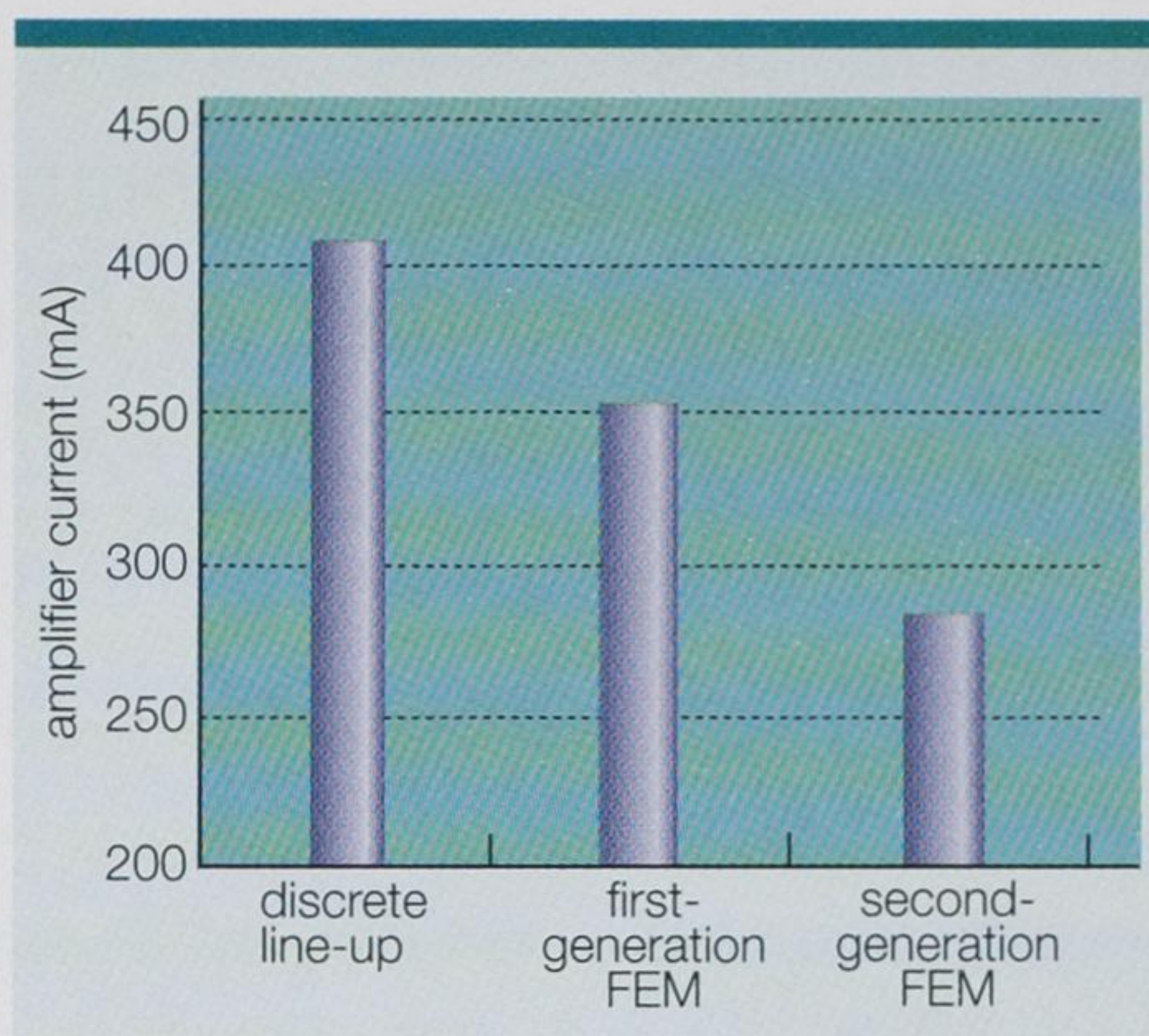
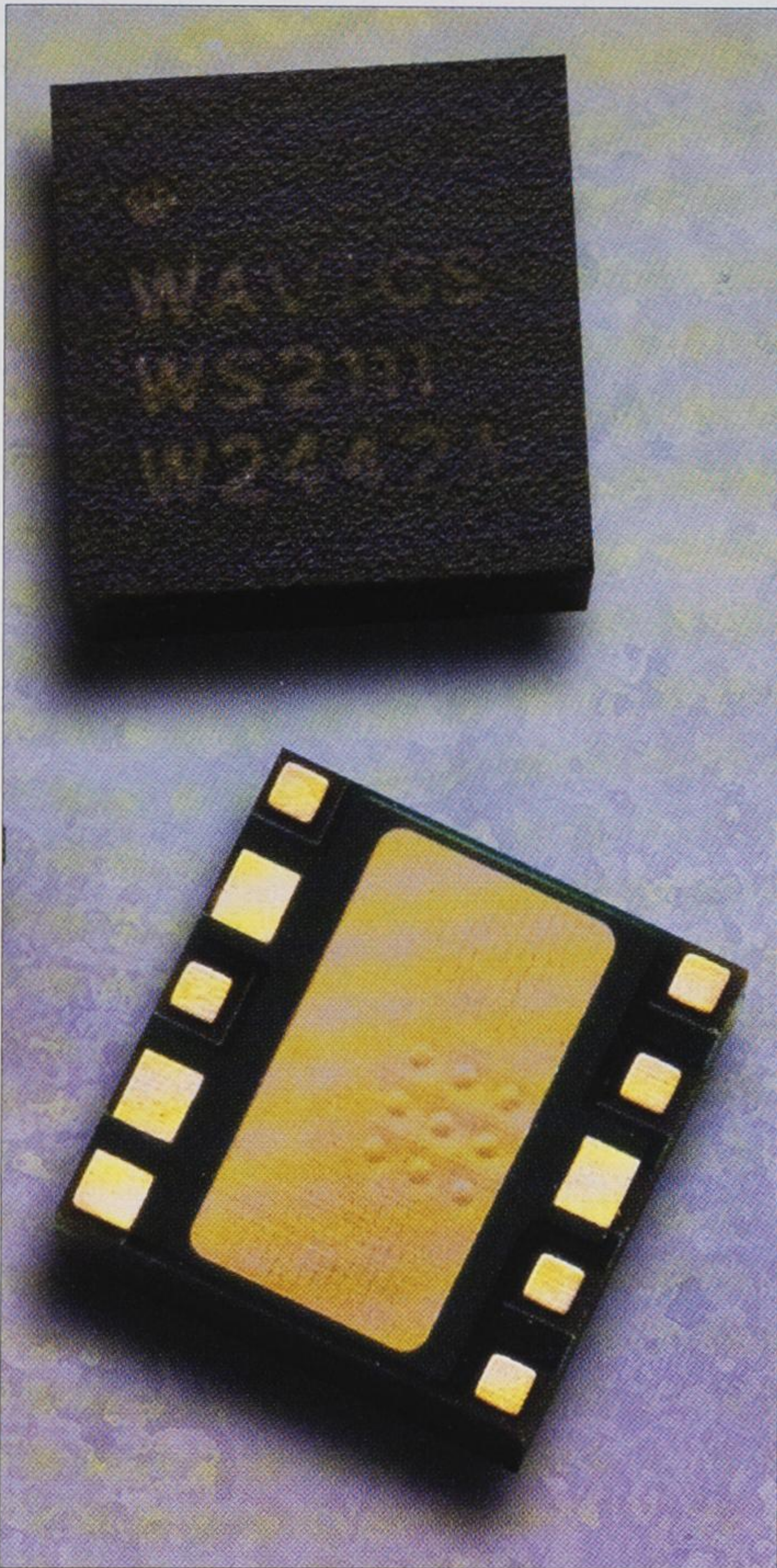


Fig. 1: Agilent's transition from supplying discrete components to front-end modules (FEMs) decreases the amplifier current, thereby increasing talk time. The data shown above were collected from Agilent's labs using the same amplifier, but with the filter and RF components integrated in different configurations. The discrete line-up contained a separate module for the amplifier mounted on a board matched to 50 Ω , matched to a separate duplexer at 50 Ω . The first-generation FEM brought the die onto a common board, and the second generation involved a co-design approach, with impedances not fixed and the efficiency of the two die optimized together.

driver stage, which in turn causes the output signal to take a different route. "We are able to take advantage of that to reduce the insertion loss within the amplifier and improve the efficiency," said Madden, who reveals that this process also reduces manufacturing costs by using 15% smaller die.

Outsourcing strategy

Prior to Agilent's acquisition, Wavics was producing reliable devices in large volumes and was on the verge of becoming a top-tier supplier to companies such as LG and Samsung. According to Madden, however, these big customers were nervous about using Wavics exclusively, because the company, which was fabless and working with foundries, had an unproven supply chain.

Offering an interesting perspective on winning contracts with LG and Samsung, Madden claims that their barrier to entry is lower than with other OEMs: "[LG and Samsung] are

open-minded when it comes to trying new things. If something doesn't work, they move on and try something else very quickly. That's their mode of operating in Korea, and that's why Wavics had the opportunity to get in."

Madden explains that Agilent will continue with the foundry model that Wavics established for HBTs. "[The outside fabs] have done a good job for Wavics. That business has been successful, and we see no reason to change."

"The strength of Agilent is that we have armies of people that know how to fabricate devices and we can specify to a much greater level of detail what we want these foundries to do. That's part of the synergy," he said.

According to Madden, Agilent's efforts to date have focused on developing discrete components: "We've taken the individual duplexer and E-PHEMT power amplifiers and simply put them together on the same board."

Agilent's approach in 2003 was to mount a filter and amplifier on the same substrate, but

its next-generation modules will be influenced by Wavics' design principles. "Rather than using a 50 Ω interface between the filter and amplifier we can design for optimal impedance for the filter you choose to use," said Madden. "That will allow us to shrink the filter and improve the insertion loss between components by eliminating several steps of matching and fine-tuning. And you'll see another step of improved efficiency for talk time."

Integration policy

Madden now expects Agilent to enter into a period of increased integration: "We'll have these multiband or multifunction filters and put them together with multiband amplifiers. For example, you might have a CDMA front-end module that has both CDMA frequency bands, 800 and 1900 MHz, with the two different duplexers, all in one sort of super module." The natural extension of this, he says, is a phone with one chip from Qualcomm that handles the RF transceiver and baseband components, one chip from Agilent that handles the non-CMOS components, and an antenna.

The improvements that are expected from Agilent's increased integration are illustrated in figure 1. Next year the company plans to extend the integration to include Wavics' circuit technique. The result should be an improvement in talk time of up to 90 minutes.

Madden believes that Wavics' circuit design is already giving Agilent an edge, by offering talk times at power outputs of 10 dBm that are 25–30 minutes longer than those of its competitors. He believes that this advantage is significant: "Customers like Samsung, Nokia and Siemens are very much focused on the talk time. From what I hear, half an hour is a significant improvement. Ten to 15 minutes might not be noticed by a consumer but when we get to half an hour, that starts to be a differentiator for the OEM."

As Agilent continues to turn around the fortunes of its semiconductor products group, the RF sector offers the greatest room for improvement. If successful, the integration of E-PHEMT and CoolPAM technology should see it move up the RFIC ranks quickly. ●

Further reading

Compound Semiconductor May 2004 p23.

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TriQuint ups PHEMT integration

Severe pricing pressures are affecting the entire supply chain in the cellular and wireless local-area network (WLAN) industry, with GaAs chip and power-amplifier (PA) manufacturers struggling to make a profit despite booming sales of cell phones.

At the same time, products such as handsets are undergoing continuous revision, with an increasing demand for greater device functionality and complexity as additional wireless bands such as EDGE, W-CDMA/UMTS, WLAN a/b/g/n and WiMAX are accumulated.

TriQuint's latest offering, based on E-/D-mode PHEMT technology, provides one option to increase integration and reduce testing costs. The technology has advantages over competing transistor designs that use a combination of HBTs and D-mode PHEMTs and MESFETs. These include low-voltage operation, low control currents and more desirable breakdown characteristics. In production, transistors have shown consistent characteristics on epitaxy from various sources.

GaAs and silicon integration

Handsets contain a mixture of silicon and GaAs ICs. The front-end transmit-and-receive portion uses technologies such as GaAs HBTs, GaAs PHEMTs, filters and silicon LDMOS, while the transceiver and baseband elements use exclusively either silicon MOSFET or BiCMOS. The front-end transmit-and-receive modules have to accommodate PAs, antenna switches, power-control circuits, power-detect circuits, electrostatic discharge (ESD) devices, low-noise amplifiers (LNAs) and filters.

Component and configuration choices depend on the wireless bands required, the customer's design and the interface between the terminal's transceiver and baseband elements.

The general trend toward smaller, cheaper, yet more complex front-end modules has forced RFIC manufacturers into greater component integration and has promoted the acceptance of disruptive technologies. As GaAs epitaxy costs have fallen, manufacturing yields and throughput have increased. The cost of "known-good-die" testing, packaging and assembly can now exceed the basic component-fabrication expense. To combat this, device integration on a wafer can be increased, which cuts test costs and reduces module size.

The integration of HBT and FET technolo-

Demand for smaller, cheaper and yet more complex RF modules from cell-phone handset manufacturers is driving increased GaAs component integration and the development of disruptive RFIC technologies. **Walter Wohlmuth** details TriQuint's E-/D-mode PHEMT process, developed in response to that demand.

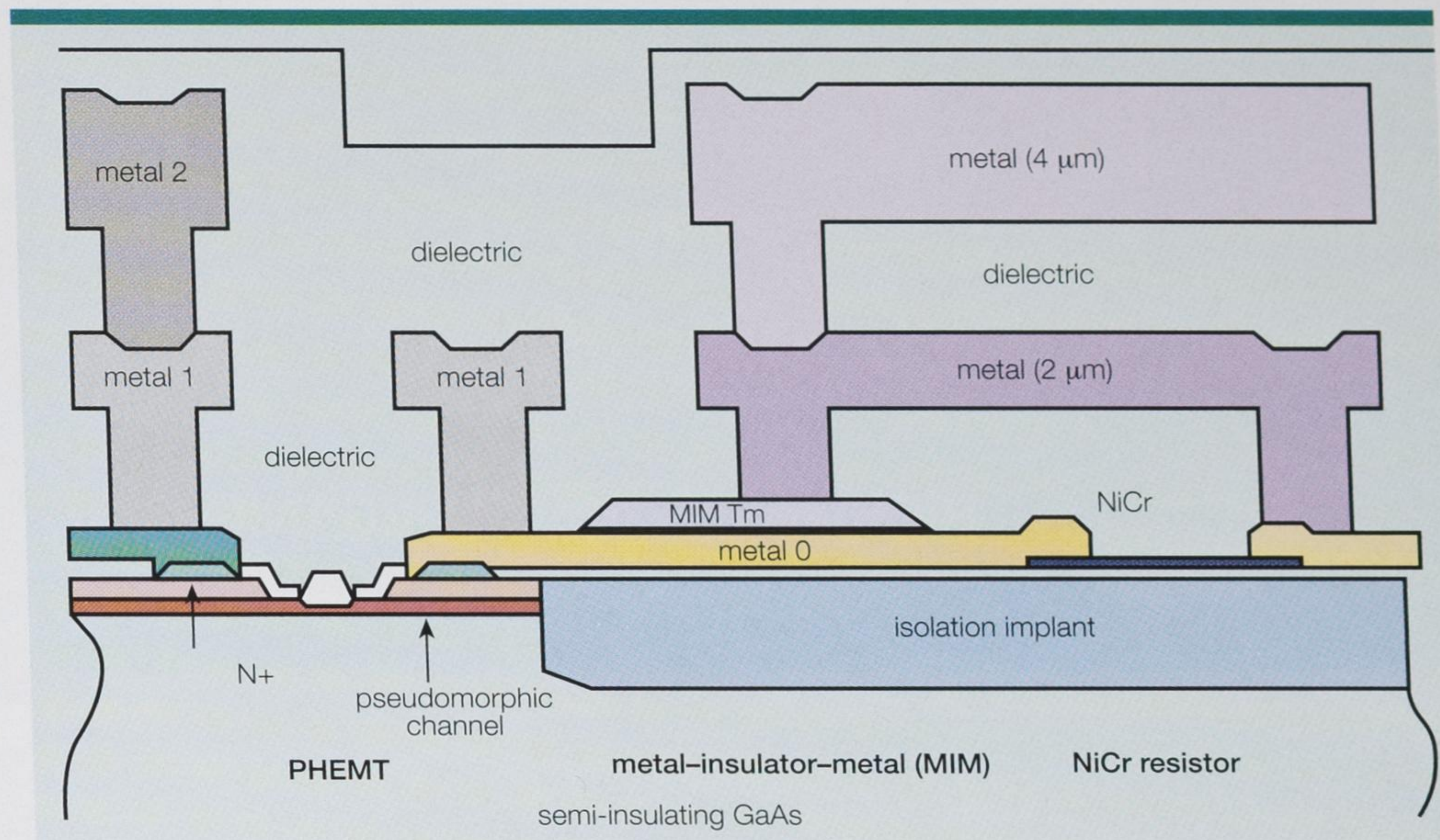


Fig. 1: TriQuint's E-/D-mode PHEMT process offers a high level of integration and reduced testing costs. A module can be produced with D-mode Schottky diodes, ESD protection devices and low-current source devices. Options include NiCr thin-film resistors with a sheet resistance of $50 \pm 3 \text{ W/square}$, a temperature coefficient of almost zero, metal-insulator-metal capacitors with $0.63 \pm 0.01 \text{ fF}/\mu\text{m}^2$ and a maximum voltage rating of 40 V.

gies (box p23) enables a host of devices, including HBT-based PAs, FET power detect and sense circuits, FET antenna switches, FET bypass stage switches to alter PA characteristics and deliver improved efficiency at low output power and ESD protection with HBT-based implementations through *pin* diodes.

Since the optimum, low-cost, high-throughput method is to form a FET underneath the HBT in a single epitaxy sequence, the precise delineation of fine-line features such as gate electrodes is important. This is of most concern in high-performance antenna switch components requiring multigate structures and minimal gate-to-gate pitch to enable the trade-off of insertion loss, isolation, control current, and harmonic and cross-modulation performance. The issue also affects high-performance LNA components because gate length primarily limits low-noise performance.

E-mode PHEMTs have advantages over

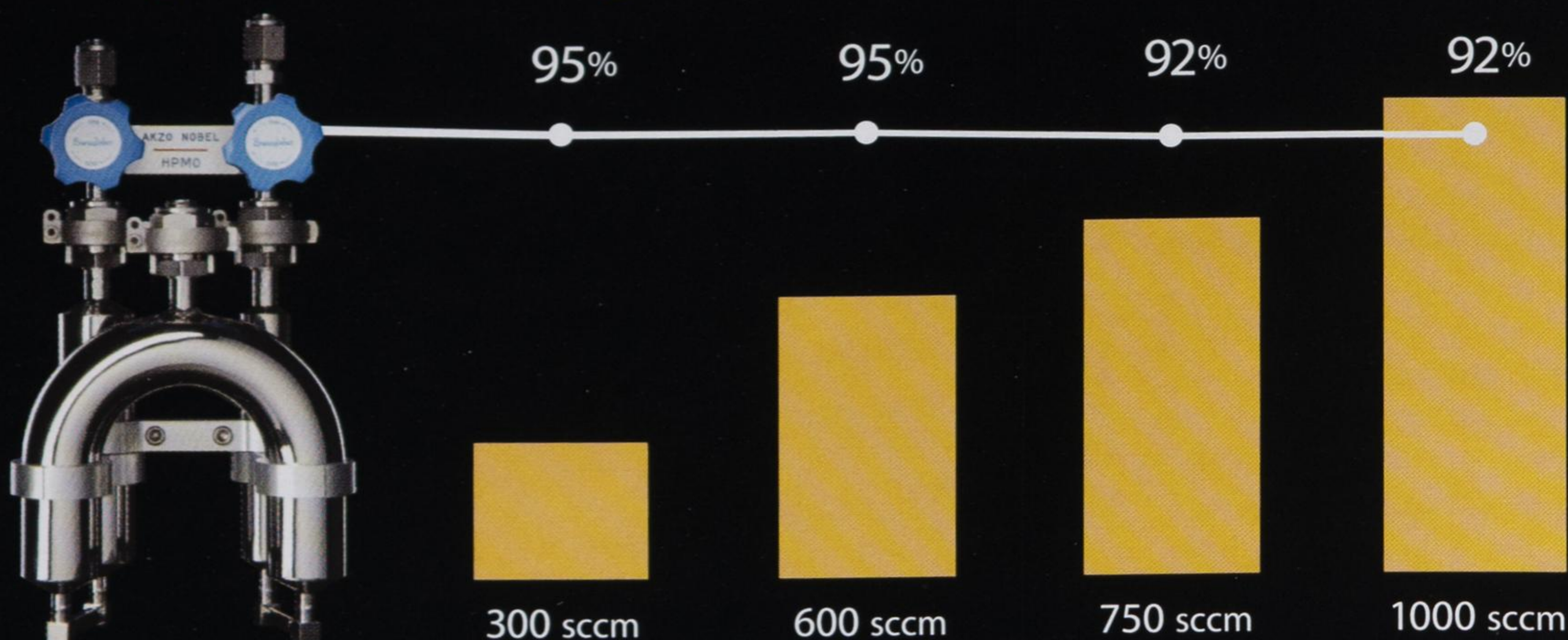
HBTs for PA applications: they have no thermal runaway, they exhibit softer breakdown characteristics, they do not have large voltage drops due to *pn* junctions and have a low turn-on voltage. They also offer easier interstage matching due to higher impedance and have high transconductance at low quiescent current, enabling sub-class B operation. However, HBT technology offers higher output power.

Integrating the E- and D-modes delivers similar circuit-building block functions to HBT and FET combinations, but benefits from a greater variety of logic architecture over a D-mode-only technology. This results in low control current logic cells and decoders.

One disadvantage of PHEMT technology is the difficulty in fabricating bias circuits that are stable in terms of process variation and temperature. ESD protection devices are also more difficult to produce in PHEMTs than in HBTs because the deep dopant layers – or regions

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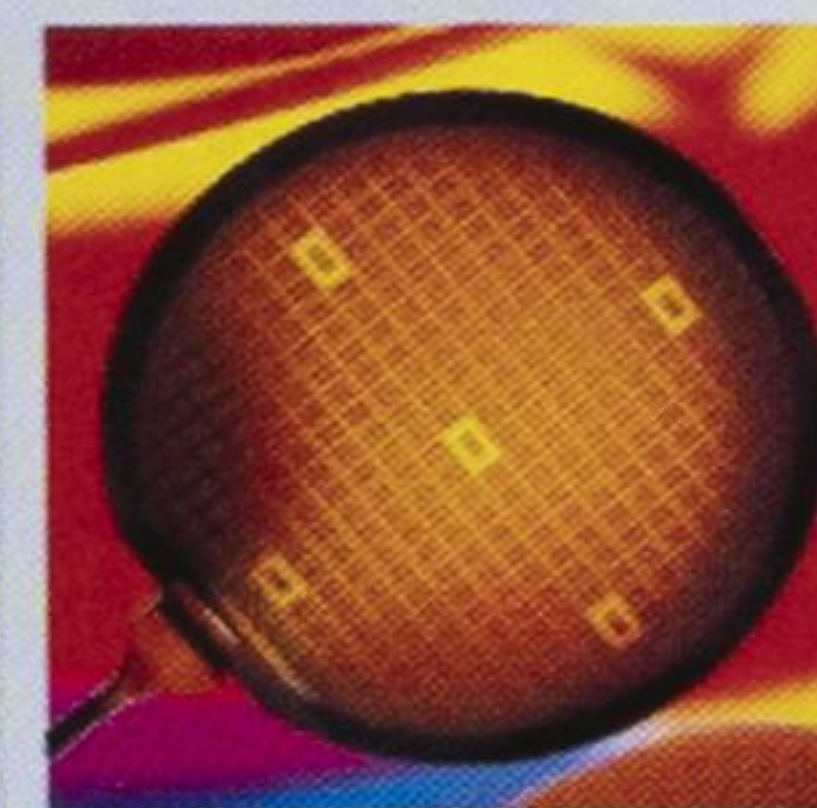


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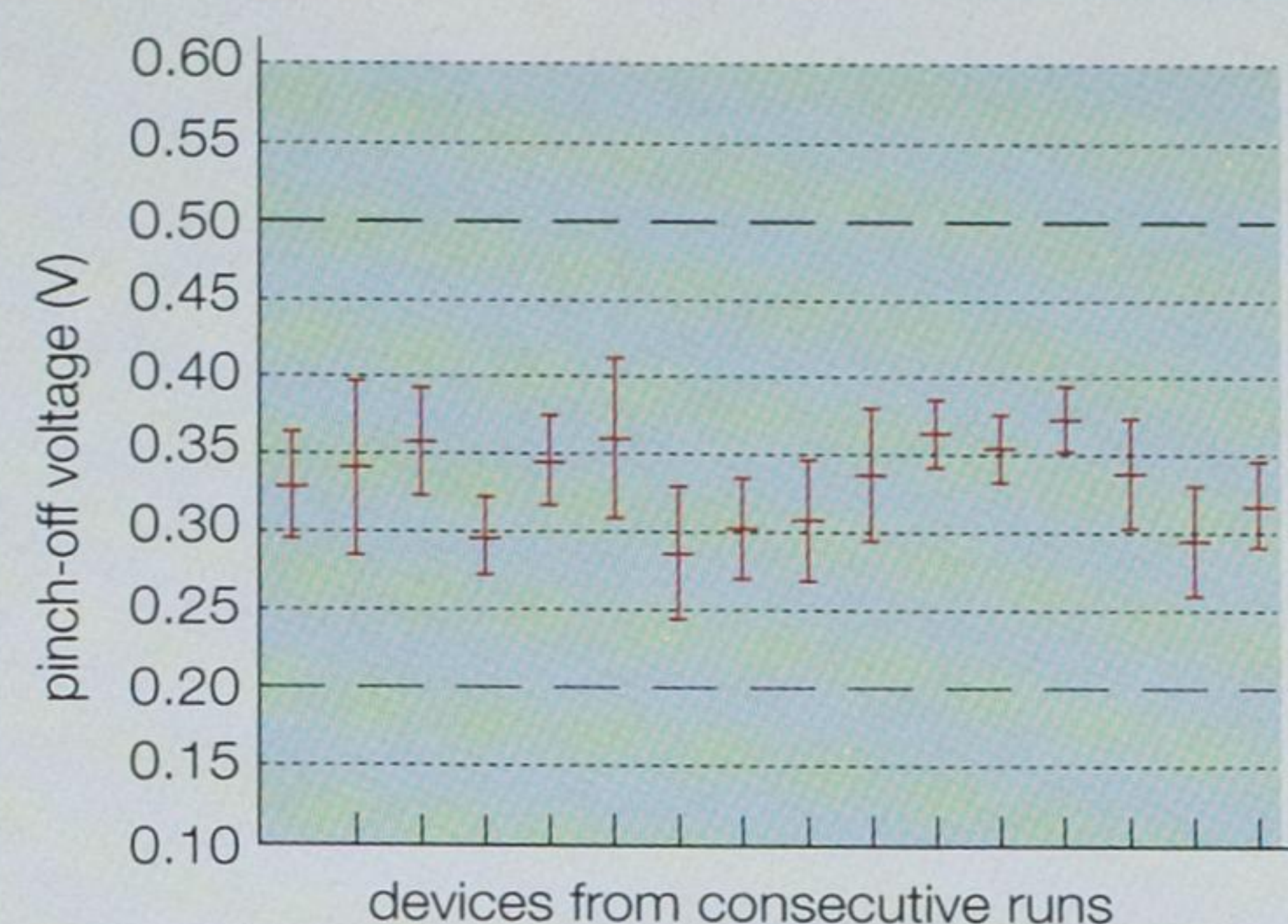


Fig. 2: TriQuint's improved E-mode PHEMT manufacturing process delivers a run-to-run mean value for pinch-off voltage of 325 mV with a standard deviation of 45 mV.

used as current sinks to deal with the ESD pulse – are not readily available. Novel PHEMT ESD protection devices are needed instead.

Manufacturing issues

TriQuint's second-generation integrated E-/D-mode PHEMT technology uses planarizing low-k dielectrics to enable transmission line, filter, balanced/unbalanced transformer and flip-chip integration (figure 1).

Improvements delivered by this second-generation technology over its predecessor include a 20% increase in saturation drain-source current (I_{dss}) for the D-mode devices and a 10% boost in the maximum current (I_{max}). The E-mode current drive has been increased by 30%, while transconductance of the D- and E-mode devices is 5 and 12.5% higher, respectively (table 1).

Only small variations in device characteristic across each wafer and between process runs were seen, even though three different epiwafer and various substrate suppliers were used. In terms of E-mode PHEMT pinch-off voltage (V_p), the results indicate a consistent, stable, controllable process (figure 2).

Full-wafer testing of V_p from a typical run showed a standard deviation of 23 mV across a 150 mm wafer, discounting data from a 5 mm edge exclusion zone.

Device optimization required extensive cross-functional collaboration between circuit design, device modeling, device geometry and layout, unit process steps and epitaxy design. Correlation analysis between design, process, and epitaxy variants used fixed standard designs that enable on-wafer measurements, plus "known-good-die" testing and packaged testing. Significant effort improved the yield of unit process steps required to form the transistors. In certain switch components,

On-wafer device integration

Device integration on a common substrate has already been demonstrated in many forms, for example HBT and D-mode MESFETs [1], HBTs and D-mode HEMTs (sometimes referred to as Bi-FET technology) [2–3], and E-/D-mode HEMTs [4]. The HBT and D-mode HEMT route was used by Itakura *et al.*, with the collector region of the HBT forming the heavily n -doped contact layers of the underlying D-mode modulation-doped FET. Usually the FET structure is grown below the HBT, as the reverse causes the high electric fields of the FET structure to penetrate the underlying HBT and create

parasitic conduction channels which degrade FET performance.

David Cheskis and co-workers fabricated a D-mode MESFET on top of an HBT and observed variations in the pinch-off voltage with base bias voltage, and high speed performance degradation caused by the heavily p -doped base layer.

Streit and colleagues used selective epitaxy: growing the HBT first, and then depositing a SiN dielectric structure on top, before growing a HEMT within the dielectric opening. The dielectric and the epitaxy on top of the dielectric were then etched

away. This approach permits independent device optimization of the HBT and the HEMT. The downside is that multiple epitaxy growth cycles reduce throughput, require strict control of surface cleanliness and stoichiometry, and add cost through additional epitaxy and consumption of valuable wafer area.

References

- [1] Cheskis *et al.* 1992 *IEDM Technical Digest* p91.
- [2] Itakura *et al.* 1989 *IEDM Technical Digest* p389.
- [3] Streit *et al.* 1995 *IEEE Trans. on Electron Dev.* **42** p618.
- [4] Wohlmuth *et al.* 2004 *IEEE CSICS Digest* p115.

Table 1

Parametric	D-mode			E-mode		
	<i>min.</i>	<i>max.</i>	<i>nominal</i>	<i>min.</i>	<i>max.</i>	<i>nominal</i>
V_p (mV)	–1000	–600	–800	200	500	350
I_{dss} (mA/mm)	130	330	240	0.00001	0.01	0.0004
I_{max} (mA/mm)	390	640	525	220	420	320
I_{gss} –2.5 (A/mm)	0.01	10	0.7	-	-	0.03
G_m (mS/mm)	300	450	365	475	750	620
R_{on} (ohm-mm)	0.5	2.5	1.4	-	-	2.2
$B_{v dgo}$ 1 (V)	15		21	15	-	21
F_t (GHz)	15	40	27	20	50	33
G_m/G_{ds}	15	60	35	50	100	75
F_{max} (GHz)	-	-	> 80	-	-	>100
MSG [2 GHz] (dB)	16	30	22.5	22	28	25

V_p : pinch-off voltage; I_{dss} : saturation drain-source current; I_{max} : maximum current setting; I_{gss} : reverse gate leakage current; G_m : maximum transconductance; R_{on} : on resistance; $B_{v dgo}$: two-terminal breakdown voltage; F_t : maximum unity gain cut-off frequency; G_m/G_{ds} : maximum transconductance to output ratio; F_{max} : maximum oscillation frequency; MSG: maximum stable gain.

The 0.5 μ m transistors offer an improvement over their forerunners in terms of current drive and transconductance. They have been optimized to maximize current drive, G_m , and the ratios of F_{max} to F_t and G_m to G_{ds} . At the same time, R_{on} and the product of R_{on} to C_{off} have been minimized, while maintaining a minimum breakdown voltage of 15 V.

a robust gate delineation process is required because the total gate width per wafer can be upwards of 1.3 km for 0.5 μ m gate length devices with gate–gate separations of 2.0 μ m.

Wafer-level and packaged-part reliability qualification tests have shown the commercial viability of a high-volume, low-cost E-/D-mode PHEMT process using multiple mate-

rials suppliers. The highly integrated components that result should improve profitability in a market faced with tough technical challenges and declining average selling prices. ●

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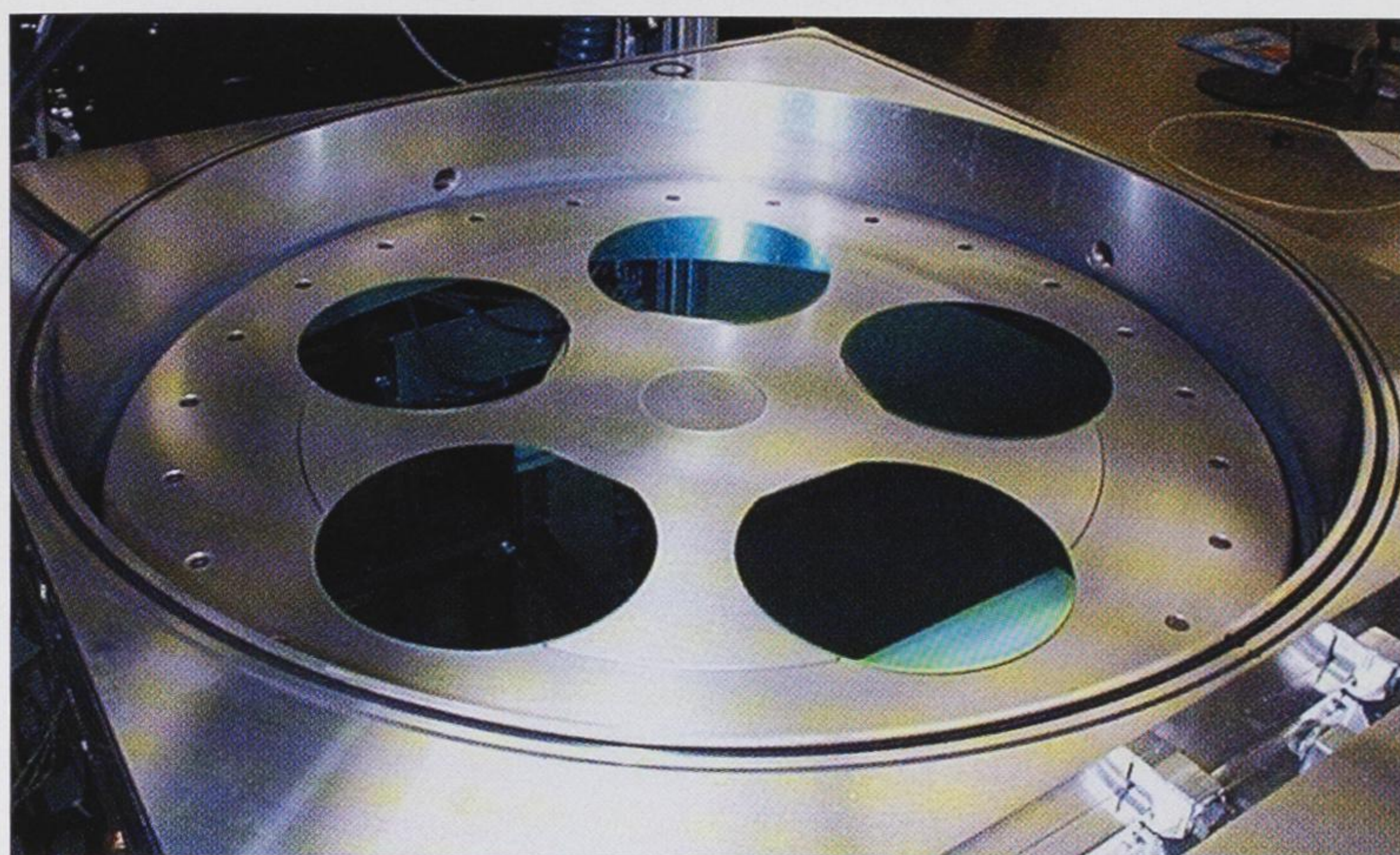
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Batch-deposition module cuts downtime and material waste

Maximizing yield, increasing throughput and reducing scrap is becoming increasingly critical for GaAs device manufacturers as customers demand cheaper products. **David Lishan** from Unaxis, **Mike Fresina** of RF Micro Devices and their colleagues describe how a large PECVD module has more than proved its worth in a high-volume production environment.



The large-area batch PECVD system – used to deposit SiN_x films – holds up to five 150 mm-diameter GaAs wafers.

With the average selling price of many compound semiconductor devices sliding by up to 20% year after year, it is becoming ever more critical for chip makers to improve margins by maximizing wafer yield, throughput and manufacturing uptime, while reducing the amount of scrap material produced.

Investment in a new, larger tool to increase manufacturing capacity is part of the solution, but the economics of nearly all device production requires attention to a myriad of variables in cost-of-ownership calculations. As might be expected, process system performance provides many of the critical variables. Obtaining a favorable cost analysis for tool operation implies systems that guarantee long uptimes and high throughput while maintaining a low level of scrap. Critical though this data might be for making decisions relating to production and capacity, collecting it is usually a tedious process and as a result such information is often unavailable.

Several years ago, Unaxis introduced a production batch plasma-enhanced chemical vapor deposition (PECVD) module for sili-

con nitride (SiN_x) deposition. Using the same basic technology and process regimes of earlier systems, a new, larger module has now proved itself under high-volume production conditions, and the data presented here confirm its usefulness.

Controlling film thickness

PECVD SiN_x is used in many different III-V-based devices such as MESFETs, HBTs and HEMTs in the roles of passivation and encapsulation (figure 1). In particular, the large dielectric constant of SiN_x makes it attractive for use as an intermetallic insulator material in metal-insulator-metal (MIM) capacitors. To meet circuit and device-design criteria as a capacitor dielectric, SiN_x film thickness and insulator properties need to be tightly controlled.

A SiN_x deposition process was developed for GaAs monolithic microwave integrated circuits (MMICs) and used in high-throughput batch PECVD production at RF Micro Devices. PECVD is well suited to the low-temperature constraints of GaAs-device manufacturing, as the technique allows growth of high-quality SiN_x films below 400 °C with

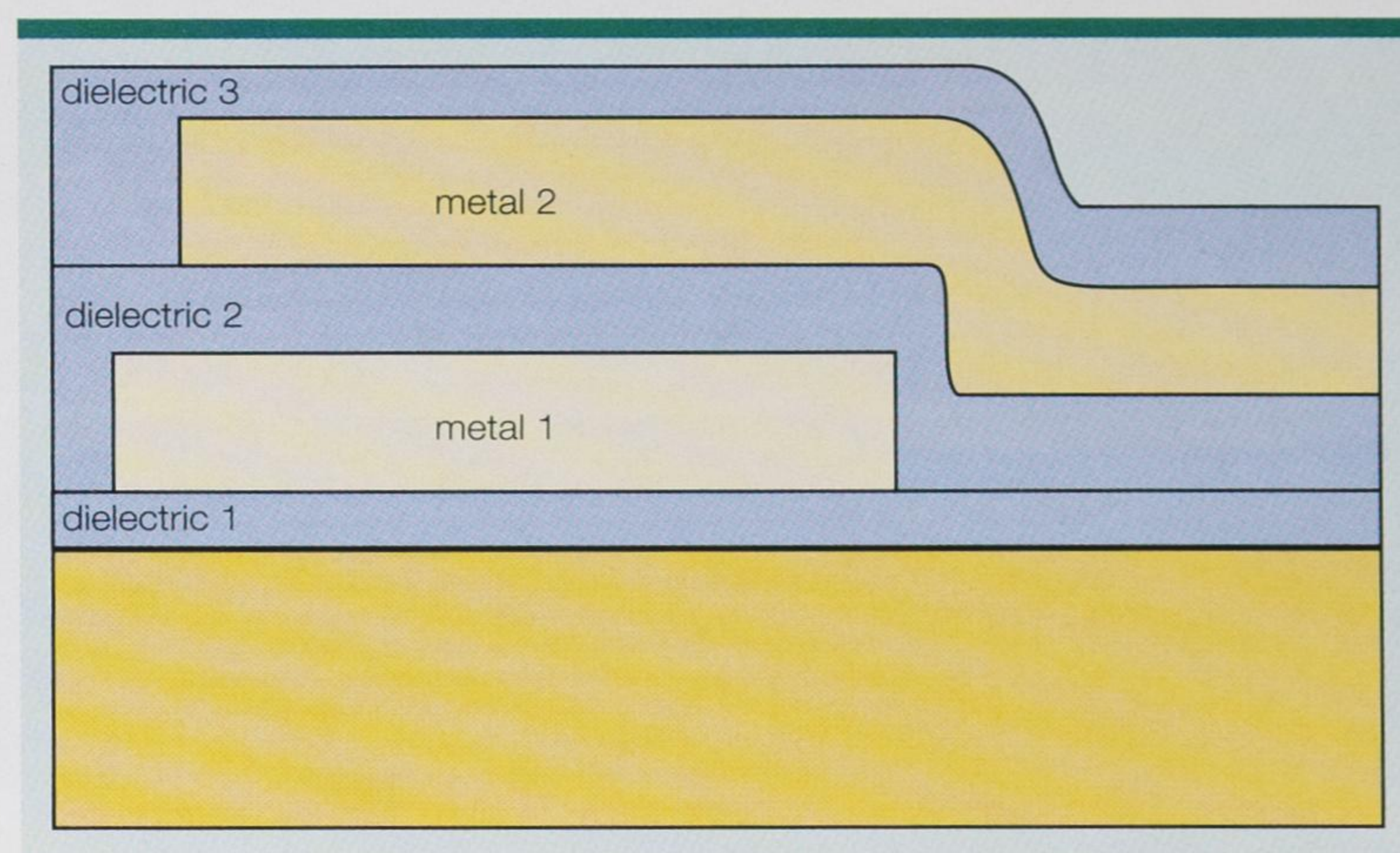


Fig. 1. Silicon nitride is used for passivation (dielectric 1), MIM-capacitor (dielectric 2), and glassivation (dielectric 3) applications.

deposition rates of approximately 100 Å/min.

The PECVD system uses a conventional parallel-plate configuration operating at 13.56 MHz. Dilute silane in nitrogen and ammonia are combined in a plasma to form the SiN_x film. Nitrogen is used as a carrier gas, and it is also introduced as a separate gas in the deposition process. It is possible to control the film stress over a stress range of about -300 (compressive) to 300 MPa (tensile) by modifying the plasma chemistry [1].

Controlling film stress is critical because it strongly influences the mechanical integrity and electrical characteristics of the manufactured device. It is also useful for maintaining either low composite stress in device layers or for introducing a desired level of stress to define specific film properties. A stress of around zero ensures that even relatively thick SiN_x films will have a small absolute stress.

Film specifications for the batch PECVD production solution exceed the requirements for most MMIC applications. In general, SiN_x film specifications cover within-wafer, wafer-to-wafer and batch-to-batch film thicknesses, since a highly uniform target film thickness



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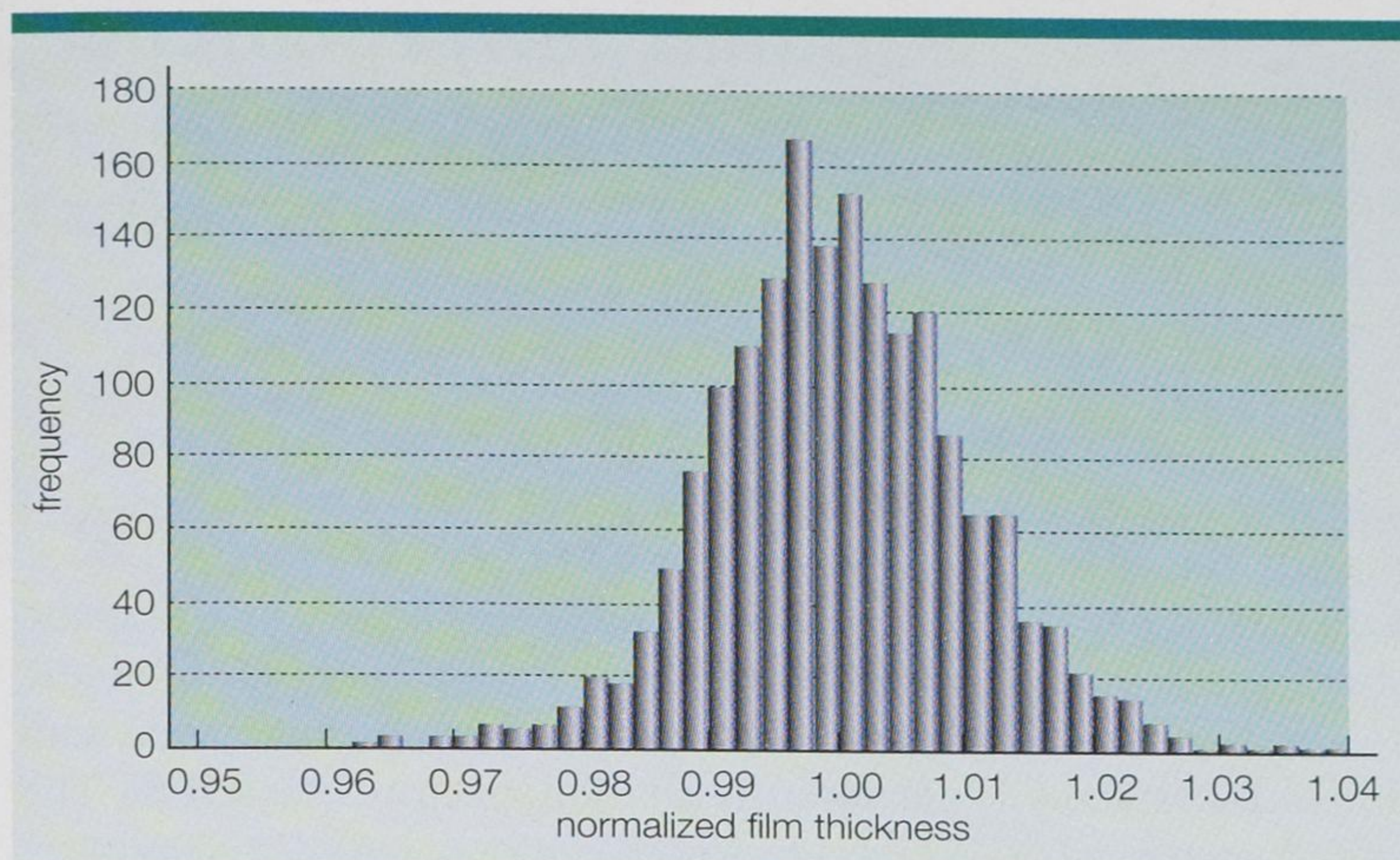


Fig. 2. A near-Gaussian distribution of the deposited SiN_x film thickness indicates sufficiently high reproducibility for the batch PECVD process with more than 1700 samples collected.

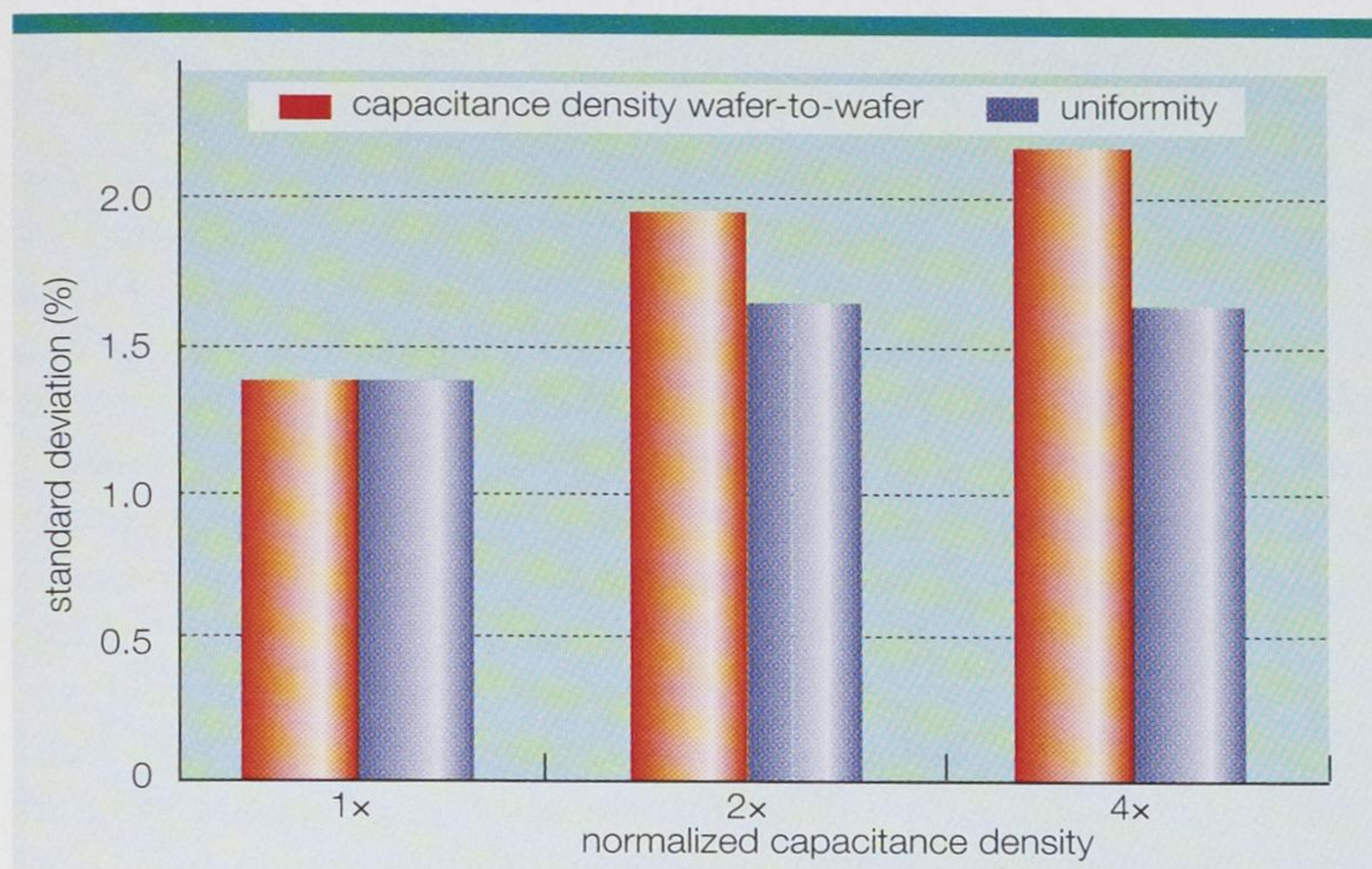


Fig. 4. Capacitance density, an important indicator for device performance characteristics, showed adequate reproducibility within a single wafer (blue) and between different wafers (red).

is essential for meeting capacitance design criteria. Statistically speaking, the standard deviation of a film thickness must be within 2.5% of the specified target.

To establish whether these targets had been successfully met, more than 1700 samples of film thickness were collected over a more than a year using a spectroscopic reflectometer (figure 2). The data shown correspond to SiN_x films deposited on five different systems and have been normalized to the target thicknesses. The narrow, near-Gaussian distribution levels reveal a normalized standard deviation of 0.0097, and this confirms a tight distribution around the target film thickness.

Similar results to this have been found with three other film-thickness goals that spanned a range of between one and 10 times the thickness of the thinnest film. For proprietary reasons, the film thicknesses shown in figure 3

have been normalized to the thinnest film produced (that is, film thicknesses were two, four, and nine times that of the thinnest film).

Wafer-to-wafer thickness reproducibility was also demonstrated to be within the 2.5% target window (figure 3). More important was that the within-wafer uniformity over the measured production runs also met the required level of reproducibility. All of this was achieved, in part, because the reactor encourages deposition uniformity owing to the careful design of a showerhead for process-gas introduction and the use of a unique pumping manifold.

Reproducible film quality

Being able to reproduce high-quality film is as important as meeting film-thickness targets. In the case study presented in figure 4, the films were used as capacitor dielectrics.

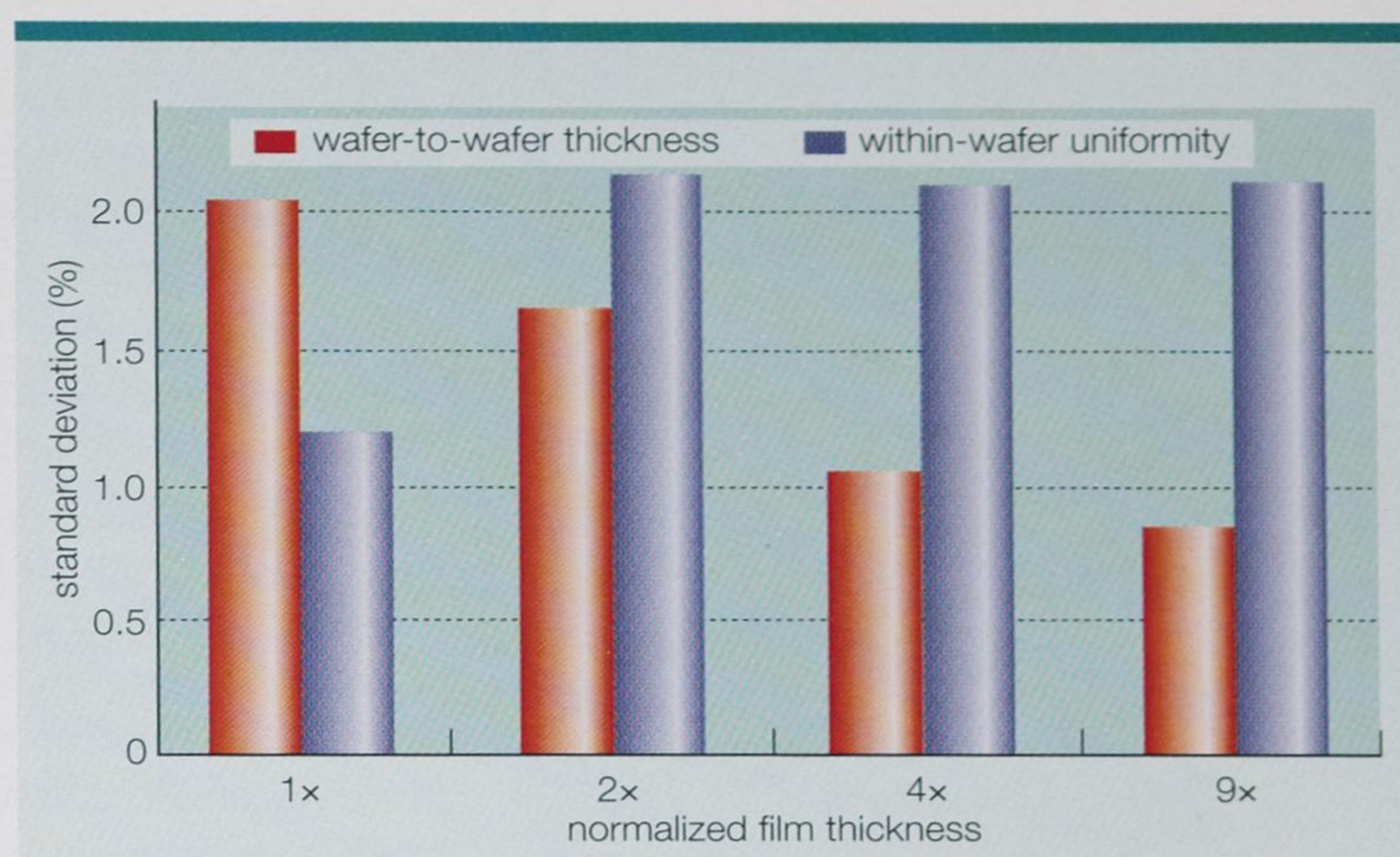


Fig. 3. Variations in the within-wafer (blue) and wafer-to-wafer film thickness (red) were well within the 2.5% target range. Keeping within this range is essential to meet capacitance design criteria.

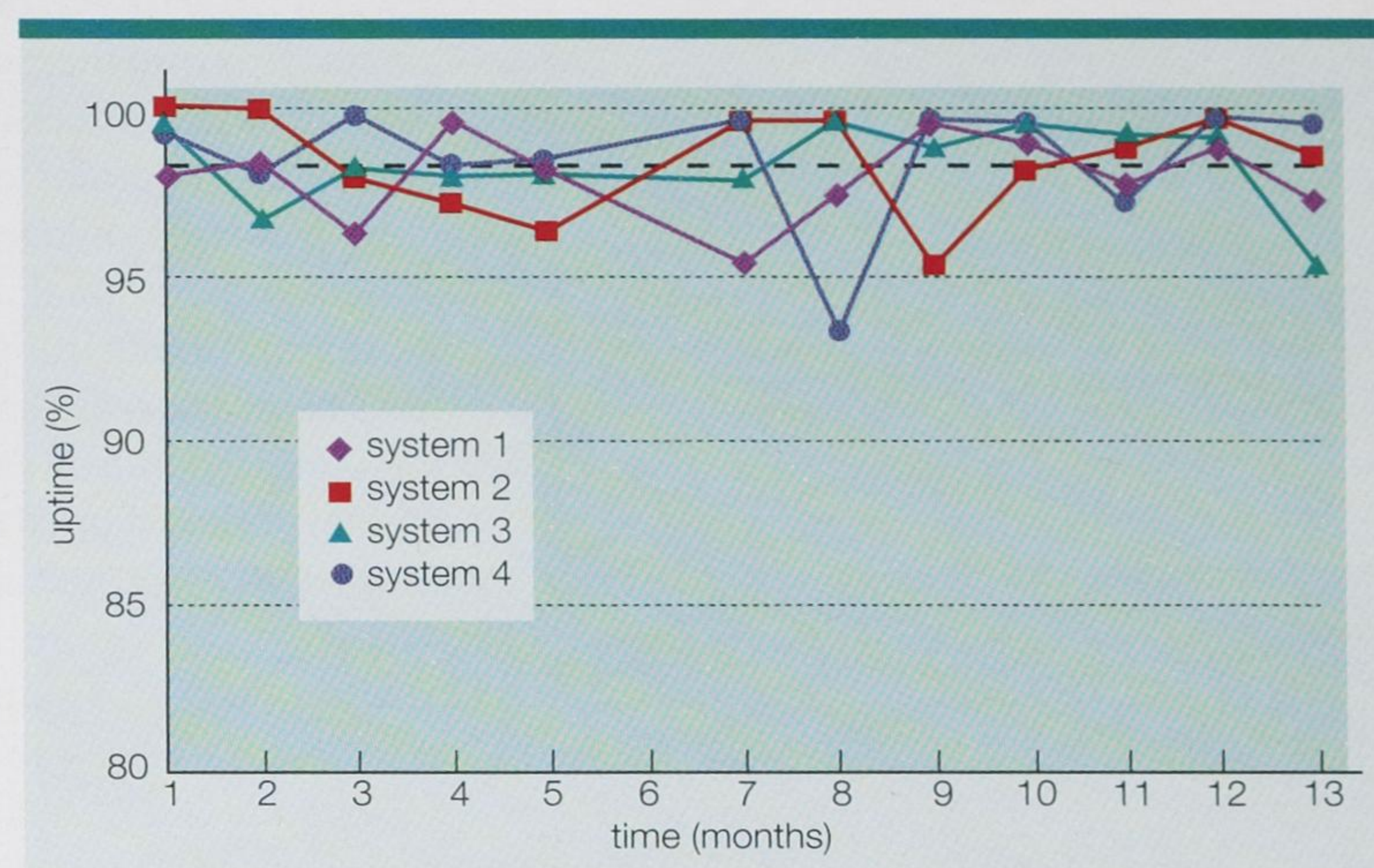


Fig. 5. As well as film uniformity and quality, uptime is crucial for GaAs-device manufacturers. Four batch PECVD systems were monitored over 13 months, resulting in an average uptime of 98%.

Wafer-to-wafer capacitance-density reproducibility is presented for three different films and, as with the film-thickness measurements, the capacitance-density figures are normalized to the smallest value. Again, the reproducibility surpasses the 2.5% specification goal for both capacitance density and for wafer-to-wafer uniformity.

By achieving the desired process stability, a high yield is ensured. After device performance, yield improvement is often considered to be the next most critical goal in a manufacturing environment. Device-function requirements, along with process capability determine the level of qualified product. Reproducibility within upper and lower bounds, as described by statistical process control, is determined by many variables, including maintenance schedules and process stability (of gas flow, pressure, RF power and

Uptime performances were consistently above 95% with an average of greater than 98%.

performed more frequently (after approximately 1.5 μm of deposition) and is based on a fluorine plasma etch.

To achieve and consistently maintain the reactor in a clean, known state, an automatic plasma etch-back sequence is integrated with an optical emission spectrometer (OES). The OES ensures that effective *in situ* cleaning is completed in the shortest possible time. Typical *in situ* cleaning proceeds at a rate of approximately 2500 $\text{\AA}/\text{min}$ and thus cleaning takes around six minutes or about 4% of the deposition time. As a result, manual cleaning has to be carried out only once a year.

A number of important features are available on the batch PECVD system to improve system maintainability and uptime. These were all implemented based on experience with the standard PECVD system and include clean-chamber design. Modifications were made to minimize the number of parts of the reactor that tend to collect deposited material and become difficult to clean. A heated top electrode improves processing ability and system cleanliness, while port access to the main pump manifold allows for easier manual cleaning of the main vacuum manifold.

Now proved at various customer production sites, we conclude that the batch PECVD system provides advanced III-V device manufacturers with a high-throughput solution for depositing high-quality SiN_x at low process temperatures. Extensive testing has demonstrated that these results are not only repeatable for production with 150 mm-diameter substrates, but they are also achieved with uptimes of approximately 98% and with negligible scrap generation.

Reference

[1] K D Mackenzie, B Reelfs, M Devre, R Westerman and D J Johnson 2004 *Proc. CS Mantech Technical Digest* pp319-322.

David Lishan, Ken Mackenzie and Dave Johnson are with Unaxis Wafer Processing in St Petersburg, Florida. Mike Fresina, Doug Wend and John Erickson are with RF Micro Devices in Greensboro, North Carolina. E-mail David Lishan at david.lishan@unaxis.com or Mike Fresina at mfresina@rfmd.com.

temperature, for example).

In this case, the reproducibility is attributed to a highly robust system and routine maintenance procedures. The tighter the capacitance distribution, the better the final product yield will be of devices with crucial characteristics such as high efficiency and high gain.

The batch deposition module used in this work was intended not only to provide SiN_x films of the required quality, but also to increase throughput. To do this, it uses an appreciably larger chamber than is typical, and can, therefore, accommodate significantly more wafers in each batch. The two standard batch sizes are eight 100 mm-diameter wafers and five 150 mm-diameter wafers. Available on a cluster tool platform, the large-area PECVD batch system offers fully automated, cassette-to-cassette processing, and batches are loaded from the cassettes using a rotating indexer in the process chamber.

Equally important to the throughput figures used in cost-of-ownership calculations is the system's operational uptime. Figure 5 shows the uptime of four different batch PECVD systems recorded over a period of a year. Except for a single month on system 4, where the operational uptime dipped to 93%, the uptime performances were consistently above 95% with an average uptime of more than 98%. Scheduled maintenance time is counted as downtime, as described in the international semiconductor guidelines provided by Semi E10-0701. This preventative maintenance averaged approximately 2% of measured downtime per system over the reviewed period.

Interpreting these uptime figures requires at least a rudimentary understanding of the maintenance cycle and practices involved when using a batch deposition module. The PECVD reactor includes several features to maintain system cleanliness that all serve to enhance yield and minimize system downtime. For example, the chamber walls and the upper gas-distribution electrode of the reactor are heated to minimize particulate formation during SiN_x deposition. As might be expected, SiN_x is deposited on the wafer and also on exposed surfaces in the chamber. If this material were allowed to build up indefinitely, issues with process repeatability and particulate control would arise.

Preventative measures

To help maintain consistent levels of efficiency, the standard PECVD SiN_x process incorporates both a regular *in situ* clean and a manual cleaning process. The *in situ* clean is

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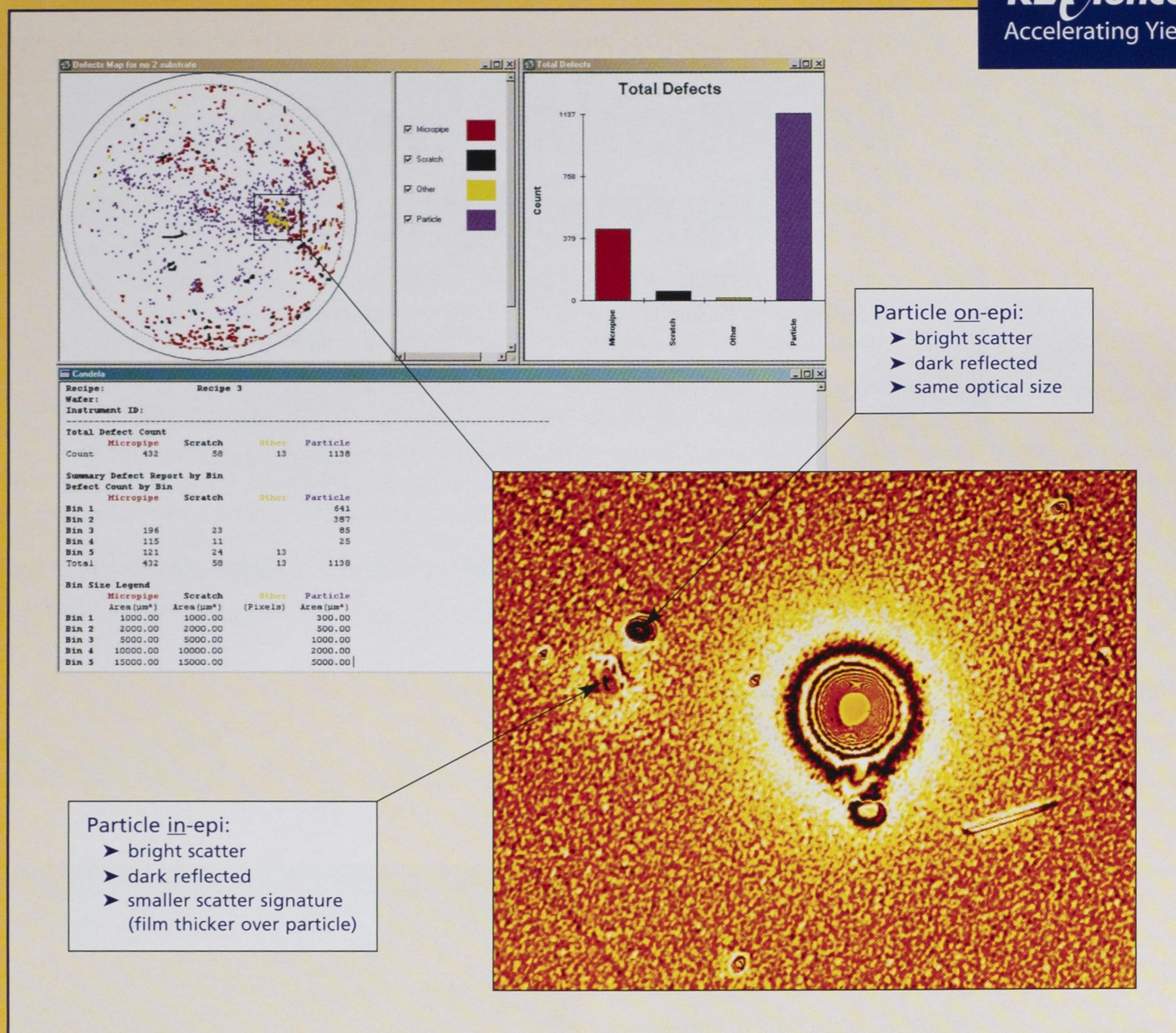
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Reliability is the central issue for DARPA's triple play on GaN

The overall level of funding that DARPA is putting into GaN microelectronics under its wide-bandgap semiconductors program may have disappointed some, but the agency is certainly fast-tracking the technology. **Michael Hatcher** takes a look at the three teams on the wide-bandgap roster.

DARPA has adopted a triple-pronged approach to speed up the development of GaN-based microelectronics. As detailed in its original broad agency announcement, Track 1 relates to an X-band transmit/receive module; Track 2 is focused on a Q-band high-power amplifier module; and Track 3 requires the development of a 2–20 GHz high-power amplifier module.

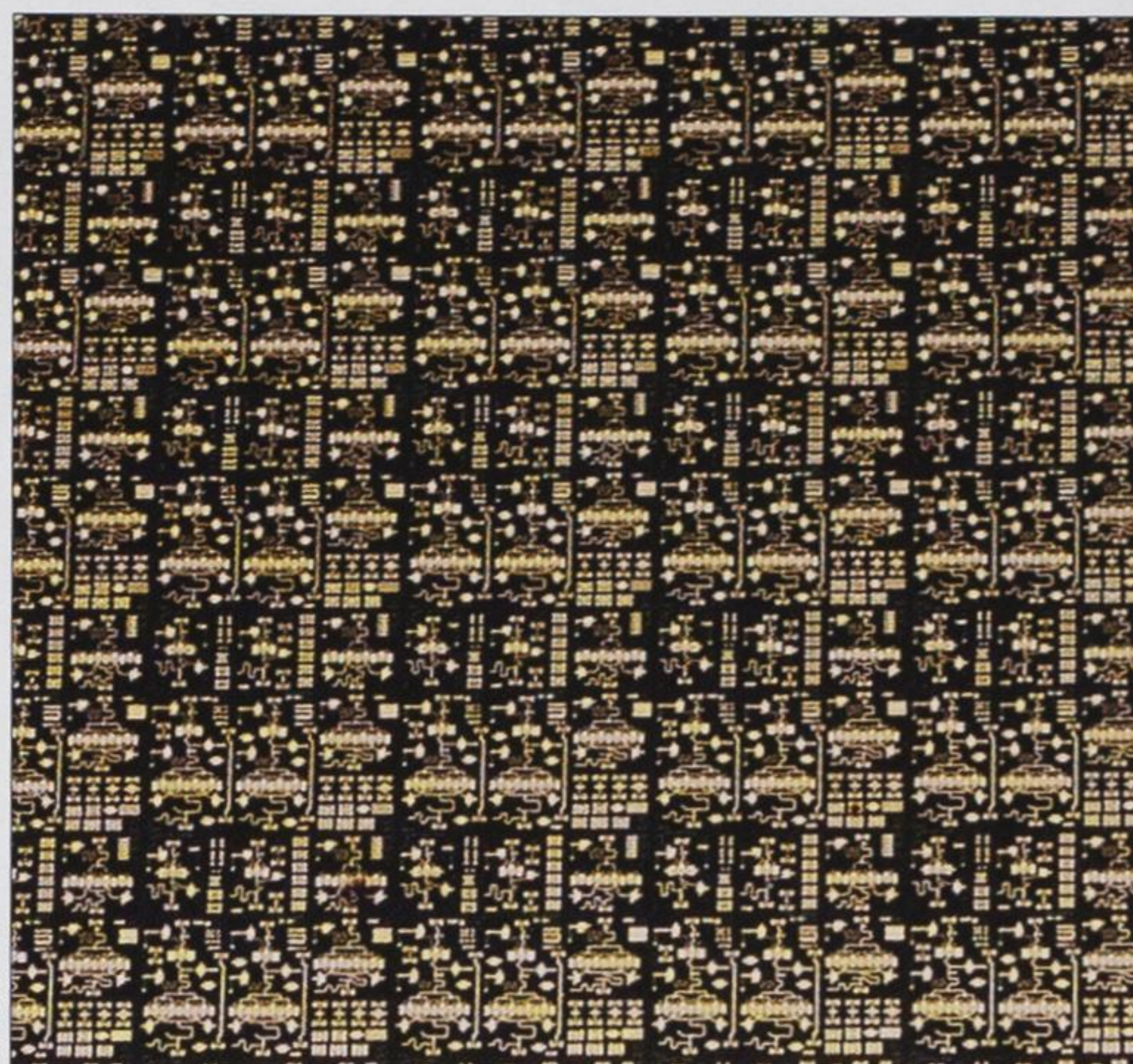
Raytheon is the lead contractor on Track 1, which itself is worth an initial \$26.9 million. Track 2 is headed up by Northrop Grumman Space Technologies (NGST) and could eventually be worth up to \$53.4 million, while TriQuint is taking charge of Track 3, worth an initial \$15.8 million.

“A key objective of this program will be a rapid transition of the technology developed into military systems,” said DARPA in its proposal document, a sentiment echoed by DARPA program manager Mark Rosker, who described the technology as a “coming revolution” at the CS Mantech event in New Orleans. DARPA also aims for a “great” improvement in understanding the physical reasons behind device failures and the development of physical models to predict performance, as well as a reproducible device and MMIC fabrication process, and improved thermal management and packaging.

Triple-track development

Track 1 is focused on the development of an X-band transmit/receive module containing both power-amplifier and low-noise amplifier MMICs. If all of the program options are exercised, this contract could, ultimately, be worth a whopping \$59.4 million.

For Raytheon, teaming up with Cree is all about accelerating the development of GaN devices. By combining the capabilities of both companies, the technology should become available to the military and commercial worlds much sooner, they claim. Raytheon's part of the project will take place at Raytheon RF Components in Andover, Massachusetts,



DARPA's wide-bandgap semiconductor program is aimed at improving the reliability of GaN microelectronic devices through better epitaxial growth, and developing a volume-manufacturing process.

while Cree's efforts will be conducted at its Durham headquarters in North Carolina, as well as at its Santa Barbara Technology Center in California.

For NGST, the primary contractor on Track 2, the focus is on moving its GaN research and development work into volume production – the demand from DARPA is for at least 384 three-inch wafers to be delivered over the course of the program. Historically, NGST has been a key member of DARPA's programs to develop III-V devices, having worked on the MIMIC GaAs-development program in the early 1990s and also on the successful development of InP-based MMICs that are used today in advanced satellite applications.

According to Dwight Streit, NGST's vice-president of foundation technologies, the expectation is that GaN will sit beside GaAs and InP MMICs as a complementary technology. NGST's ultimate goal is to produce a Q-band (> 40 GHz) module with a continuous-wave power output of 20 W (see tables).

Under the Track 3 effort, which kicked off in mid-February, device development will

take place at both TriQuint and BAE Systems, with the relevant teams from both companies working together on the process. TriQuint's Tony Balistreri, the firm's research and development program manager in Hillsboro, Oregon, says that the manufacturing process will be finalized at TriQuint.

Balistreri and Rosker highlight reliability as the key challenge for all three teams. Track 3 is to produce a wideband high-power amplifier module operating at frequencies of 2–20 GHz for applications such as jamming and electronic attack. Balistreri says that this window takes advantage of TriQuint's strength in X-band power output and efficiency, while BAE Systems brings expertise in devices operating at higher frequencies and higher gain to the table.

“Developing this band gives us a path to higher frequencies,” said Balistreri. If successful, the development should lead to modules being manufactured for a range of commercial applications such as local multi-point distribution services, two-way satellite links and cellular back-haul.

While it is clear that in all three tracks SiC will be the substrate material of choice, a crucial part of the initial two years (denoted Phase II) of this project will involve gaining a more thorough understanding of the effects of different substrate types on device performance. For example, BAE Systems has vast experience in making GaN-based low-noise amplifiers on native GaN substrates.

Nitronex, also a Track 3 partner, is focused on GaN-on-silicon transistor development, and Balistreri says that the Raleigh, NC, company is on board to help the reliability drive. The team wants to understand why GaN-on-silicon devices have superior lifetimes, and how this knowledge can then be applied to GaN-on-SiC devices.

The TriQuint team also has two academic partners that will take on crucial roles. Michael Shur from the Rensselaer Polytechnic Institute in Troy, NY, is one of the

Table 1. DARPA's three-track attack

Track/module type	Prime contractor	Funding (Phase II)	Required module output power	Companies also on team
1: X-band transmit/receive module	Raytheon	\$26.9 million (up to \$59.4 million)	60 W continuous wave	Cree
2: Q-band high-power amplifier module (more than 40 GHz)	Northrop Grumman Space Technologies	\$16.5 million (up to \$53.4 million)	20 W continuous wave	Monolithics, Emcore, Boeing, Sirenza Micro Devices
3: Wideband high-power amplifier module (2–20 GHz)	TriQuint Semiconductor	\$15.8 million (up to \$31.7 million)	100 W continuous wave	BAE Systems, Lockheed-Martin, II-VI, Nitronex, Emcore

Taken from DARPA's broad agency announcement

Table 2. DARPA's 18 and 30 month "go/no-go" targets

Target	Track 1	Track 2	Track 3
18 months	8–12 GHz transistor with a 1.25 mm gate periphery operating at 40 V with 39 dBm continuous-wave output power, 12 dB gain, a PAE of 60%, a wafer yield of 50% and 10 ⁵ hours' projected performance	Q-band transistor with a 0.5 mm gate periphery operating at 25 V with 39 dBm continuous-wave output power, 8 dB gain, a PAE of 35%, a wafer yield of 50% 10 ⁵ hours' projected performance	As for Track 1
30 months	8–12 GHz power-amplifier MMIC operating at 48 V with 15 W continuous-wave output power, 16 dB gain, a PAE of 55% and a wafer yield of 50%	Q-band MMIC operating at 28 V with 4 W continuous-wave output power, 7.5 dB gain, a PAE of 37% and a wafer yield of 50%	2–20 GHz power-amplifier MMIC operating across a decade of bandwidth at 48 V with 15 W continuous-wave output power, 16 dB gain, a PAE of 30%, and a wafer yield of 50% (at least 12 three-inch wafers)

Taken from DARPA's broad agency announcement – actual program goals have been modified slightly.

world's leading exponents in the physical modeling of devices, while Jesus del Alamo at the Massachusetts Institute of Technology will lend his experience to the reliability drive through extensive physics-of-failure analysis.

Wideband operation will enable multiple functions in a single system that transmits and receives a range of communications at the various frequencies it employs. For TriQuint, the 18 month technological goals (table 2) call for a wideband device operating at 40 V with 39 dBm continuous-wave output power, 12 dB gain and a power-added efficiency (PAE) of 60%. TriQuint's state-of-the-art performance is exhibited by a 40 V, 1 mm device with an output of 5 W/mm at 10 GHz, 11–12 dB gain and a PAE of a little under 50%.

While the performance achieved so far is fairly close to the X-band goals, significant development is required to push up to the higher frequencies needed for the wideband MMIC. "Device performance is a challenge, but it isn't the main one," said Balistreri. "The number-one challenge is reliability." To improve reliability there are two key steps:

optimization of epitaxial structures and the development of a manufacturing process that maintains reliability.

"Getting to 10⁴ and 10⁵ [hours reliable performance] maybe tough," said Balistreri "but reaching 10⁶ is the real tricky part." All devices degrade under stressful conditions such as high-temperature operation or RF under bias, with effects such as a degradation of drain current with time manifesting.

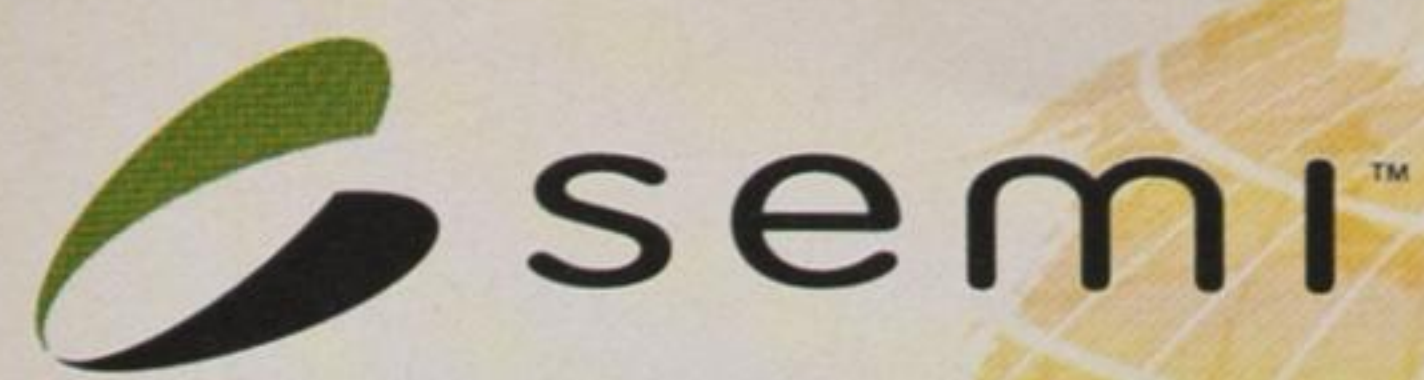
Like NGST, TriQuint sees the development of a volume-capable manufacturing process as a priority, and as a recognized volume supplier of MMICs already, it is putting its own money and resources into this aspect of the program: "We are a large volume producer of III-V devices, and we expect to become a large supplier of GaN devices as well," said Balistreri. "At the end of the day, TriQuint expects to have both a GaN foundry process as well as standard GaN products."

While DARPA's development of GaN has led to inevitable comparisons with the GaAs MIMIC program of the early 1990s, there is some disappointment within the industry

regarding the amount of funding allocated to the effort, which is smaller in scale than the GaAs program. In comparison, the GaN teams are working with what might be termed a "tiger" budget.

However, it seems clear that DARPA is trying to fast-track GaN development in another way, with the agency wanting to see GaN technology in live systems as soon as possible. While there is usually an intermediate step between the technology-development programs and system insertion, that is not the case with the GaN projects. In the second phase of the current efforts (denoted "Phase III"), project partners are under instructions to come up with business plans that will identify system-insertion points at the earliest opportunity.

By taking this relatively aggressive approach, it is reckoned by some that three to five years may have been taken out of the entire commercialization process. Module development and engineering may commence in around five to six years, while volume production should become a reality within a decade.



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Indium price soars as demand for displays continues to grow

Demand for InP-based devices may just be crawling out of an extended slump, but its main raw material, indium, is highly sought after – it is currently trading at its highest price for the last 60 years. **Thomas Jansseune** looks at the market forces that could be problematic for InP manufacturers.

Indium and InP, although closely related to each other, are going in different directions. While InP chip makers can only dream of filling their existing manufacturing capacity, firms are now concerned about whether they will be able to get hold of enough indium. This perceived shortage has led to a spectacular increase in the cost of the material over the last three years, with prices rocketing 10-fold since 2003 and now standing at their highest level since the Second World War.

The reason for this soaring price is that some non-InP applications of indium have recently witnessed stellar growth. On top of that, the future supply of indium is unclear, with production of the raw material dropping by more than 12% last year.

Rapid growth in displays

The use of indium in coatings, mainly indium tin oxide (ITO), has increased steadily and it now accounts for 70% of total indium consumption, up from 45% a few years ago (see *Compound Semiconductor* September 2003 p33). This demand is linked closely to the strong growth that has been shown by flat-panel displays, and by LCDs in particular.

The flat-panel-display market is expected to continue growing until at least 2008, although perhaps at a slower pace than in the past couple of years. Because of this, most ITO producers have also announced capacity increases: Umicore doubled its capacity in 2004; Mitsui and Nikko will follow in 2005 or 2006; and Tosoh is looking at hiking its capacity, provided that it can secure enough indium. The use of ITO coatings in architectural glass, on the other hand, has decreased considerably because of the increasing price of indium.

Semiconductors and electrical components account for a stable 12% of all indium consumption, and demand from InP device makers is not expected to change considerably over the next few years. Strategy Analytics forecasts an annual growth rate of 6% between 2003 and 2008, but recent statistics from

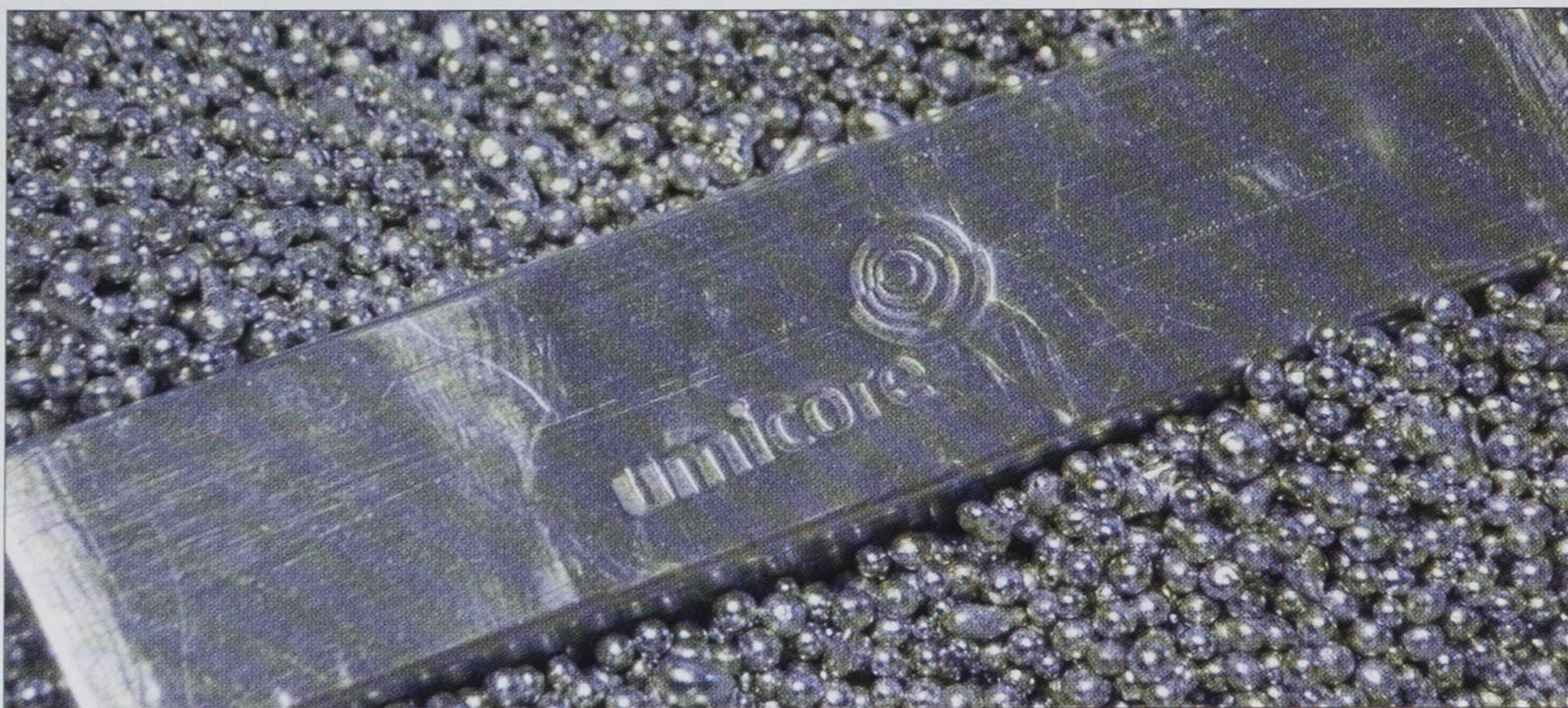


Fig. 1. Demand for indium is on the rise, but production and supply remain uncertain.

Indium production 2003–2004

Country	2003 production (MT)	2004 production (MT)
Belgium	40	40
Canada	50	50
China	100	110
France	65	10
Germany	10	10
Japan	70	70
Peru	5	5
other	30	30

Fig. 2. Worldwide indium production fell from 370 MT in 2003 to 325 MT in 2004. It is clear from this table that the reduction was a result of a drop in production in France.

Japan show that indium use in compound semiconductors stagnated between 2002 and 2005 at 7 MT/year.

The use of indium in solders and alloys is thought to have dropped to just 12% of all indium consumption, mainly because different metals are now used. Other applications of indium that may take a more prominent role in the future include thin-film solar cells, where a pressing shortage of solar-grade silicon may allow copper indium diselenide solar cells to break into the market.

According to the US Geological Survey, total indium production dropped from 370 MT/year in 2003 to 325 MT/year in 2004 (figure 2). A number of indium mining activities have closed in recent years. In France, Metaleurop ceased production entirely and in China several mining and smelting operations were halted because of concerns over safety and the effect of indium extraction on the local environment. It does seem, however, that Chinese output in 2004 was similar to that of 2003, probably because the high price of indium made it economical to recover every scrap of the metal that was available.

Indium is a by-product of zinc, tin and lead production, so increasing output is not simply a case of extra mining. Rather, it involves investment in the refining equipment that is able to extract increasingly small concentrations of indium from other material streams. This requires time and money.

Business closures and start-ups have been announced for the near future. Nippon Mining in Japan will close its exhausted Tohoya mine in 2006. This is likely to remove up to 30 MT/year from the supply chain and cut Japanese production by between one-third and one-half. In Canada, Teck Cominco will keep its 2005 output stable at 40 MT. New indium

SOURCE: METAL BULLETIN



Fig. 3. Owing to the success of the flat-panel-display industry and a drop in production volume of indium, the price of the material has risen 10-fold over the past two years.

production has been announced in China and South Korea, where Korea Zinc will start recovering as much as 34 MT/year or more of indium from its zinc concentrates.

Umicore is the only established, fully integrated ITO producer. Thanks to output from its precious-metals refining plant in Belgium, it is able to produce its own indium products.

One important point to consider is that a large amount of secondary indium can be recovered via recycling. Application of ITO

coatings is a wasteful process and only around 20–30% of the material actually ends up on the substrate. Dowa Mining, Nippon Mining and Umicore all recycle ITO.

With indium demand remaining strong and supply of the material uncertain, its value is likely to remain high, although its price may also be subject to the activity of metal traders. However, the cost of indium has created a base for more investment in the recycling and recovery of indium. This should, ultimately,

lead to an equilibrium between supply and demand, but not in the short term.

The business closures and start-ups that have been announced could trigger a shift in the supply base. Integrated manufacturers of indium products, which have indium production and recycling in house, will be in a winning position. For whatever application, be it InP chips or ITO coatings, control over the supply chain will be crucial.

Acknowledgments

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Further reading

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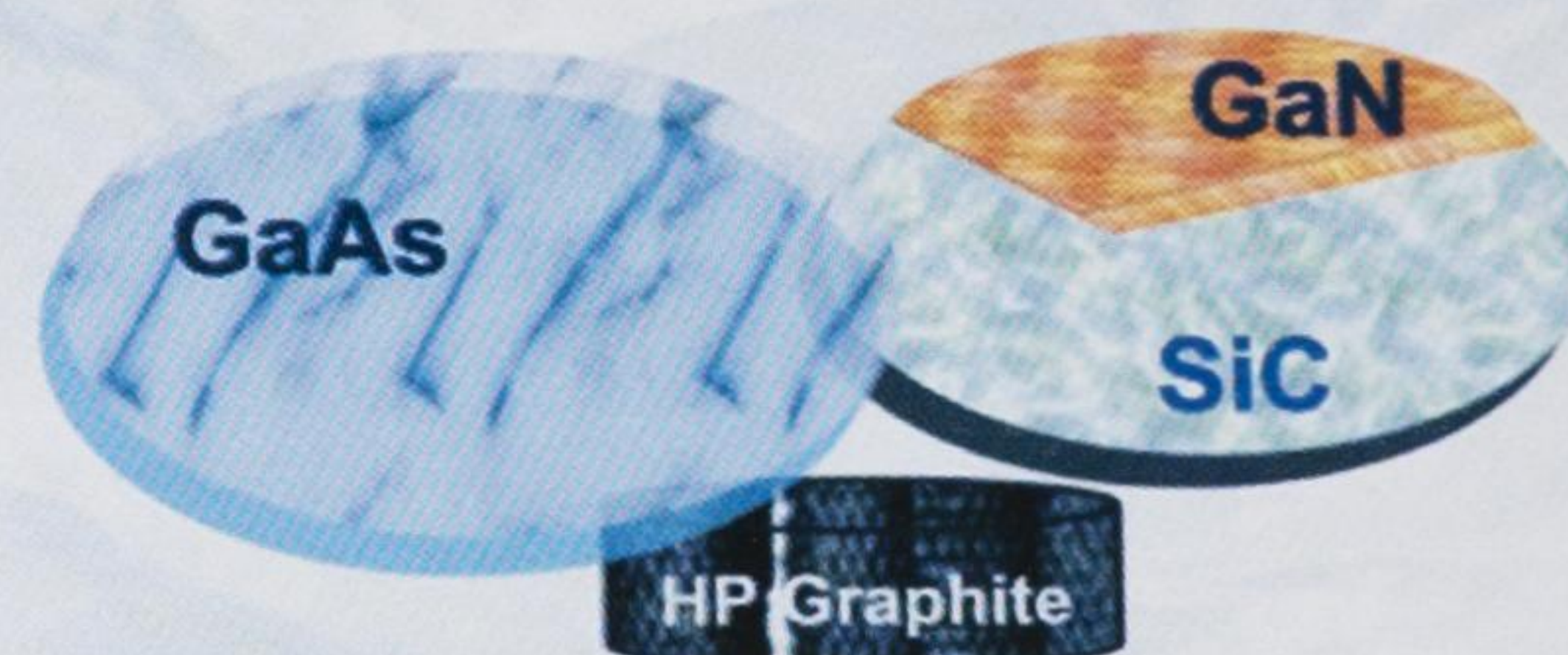
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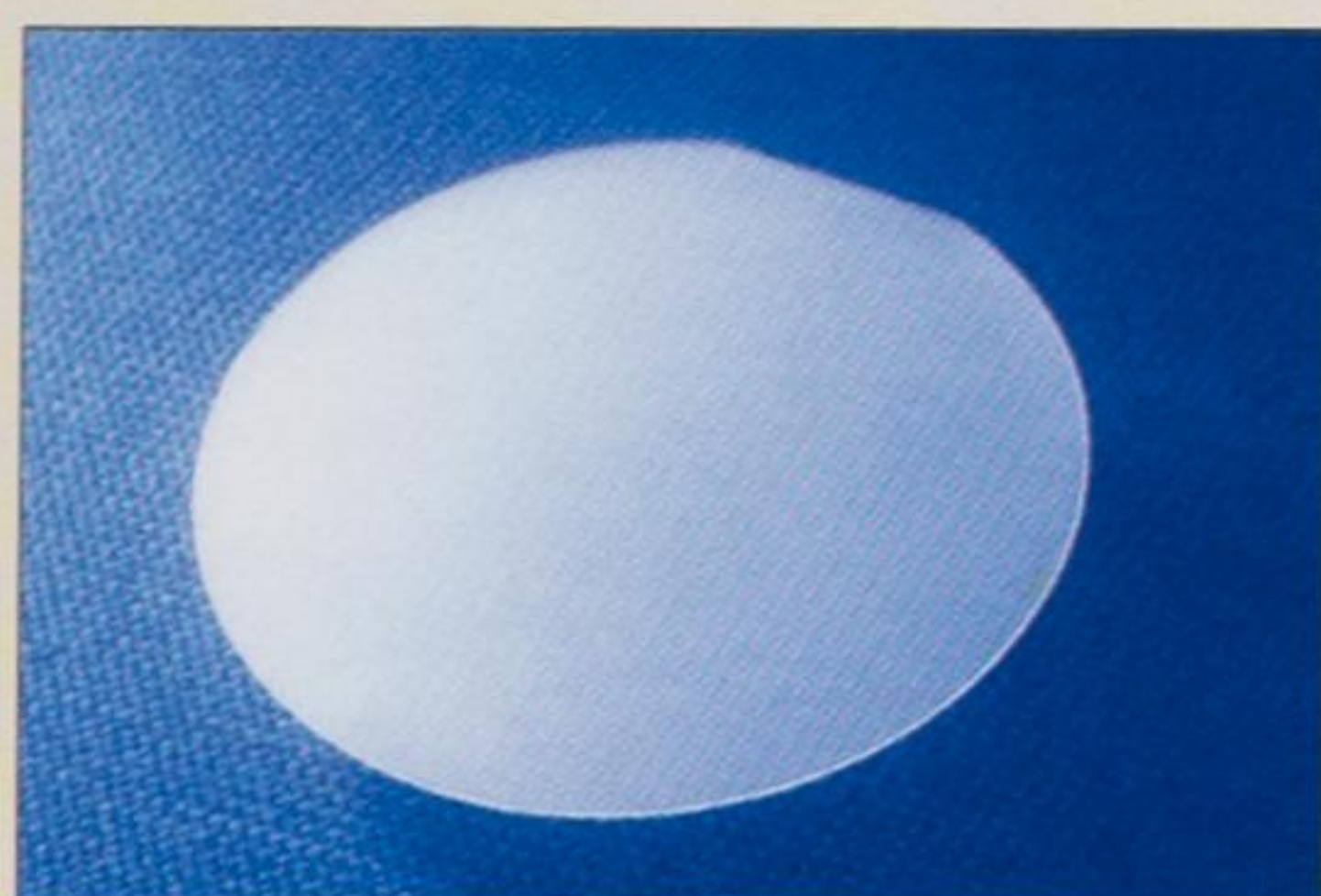


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'Stormy' market makes profitable Aixtron wary

MOCVD equipment supplier Aixtron returned to profitability in 2004 after posting full-year sales of €140 million (\$180 million).

That represents a 55% increase on the 2003 revenue figure, which was carried through to the bottom line as the Aachen, Germany, firm posted a profit of €7.1 million.

In 2003, a year that Aixtron described as "the most difficult in its 20-year history", the company made a loss of €17.8 million.

The burgeoning LED market was largely responsible for the improvement, with the sector accounting for 81% of equipment dispatched in 2004. In 2003, that figure was 74%.

The outlook appears positive too, with orders up 40% on the previous year, while the company claims to be maintaining its sales prices and taking market share from its competitors. Regionally, the Asian market has been responsible for much of the recovery, representing 77% of Aixtron's revenue in 2004.

However, Aixtron CEO Paul Hyland warns that some more difficulties may lie ahead. "As is being predicted by many market

watchers, we believe that the business climate may remain difficult for the next 12 months," he said, adding that after a very strong first half to 2004, the market appeared to weaken in the later part of the year.

"The market confidence recovery we saw in late 2003 and 2004 is still fragile. I believe it will be another tough year. One in which we may still experience some stormy weather," said Hyland. Since its debut on the NASDAQ stock exchange in mid-March, the company's share price has dipped by around 30%.

As well as being upbeat on the prospects for the newly acquired Genus division, which specializes in atomic-layer-deposition tools, Aixtron says that the emerging application for LEDs to backlight large displays, and GaN lasers used in next-generation DVD, will benefit the company in the near future.

"The manufacturers of next-generation DVD players are waiting in the wings, and several have already chosen Aixtron equipment for the intended mass production of blue lasers."

IQE wafer shipments grow 27%

UK-based IQE shipped 140,000 III-V and silicon epiwafers and III/V substrates in 2004, a 27% year-on-year increase.

The company's revenue for the half-year ending December 31, 2004 was £7.3 million (\$13.9 million), down £0.7 million sequentially, and 19% lower than that for the equivalent half of 2003.

According to IQE, the decline in sales resulted from the combination of a weak dollar, aggressive pricing to attract more business, and a weakness in the optical-components market.

Gross loss and operating loss

for the second half of 2004 were £1.9 million and £5.1 million, respectively. These losses hit IQE's reserves and the company exited 2004 with £9.9 million in cash, compared with £21.7 million at the end of 2003.

The IQE Group has also lost the services of Martin Lamb, managing director of its Wafer Technology business, who has resigned and was due to leave the company on April 29.

Former Qinetiq man Andy Johnson takes over as operations director at Wafer Technology, based in Milton Keynes, UK.

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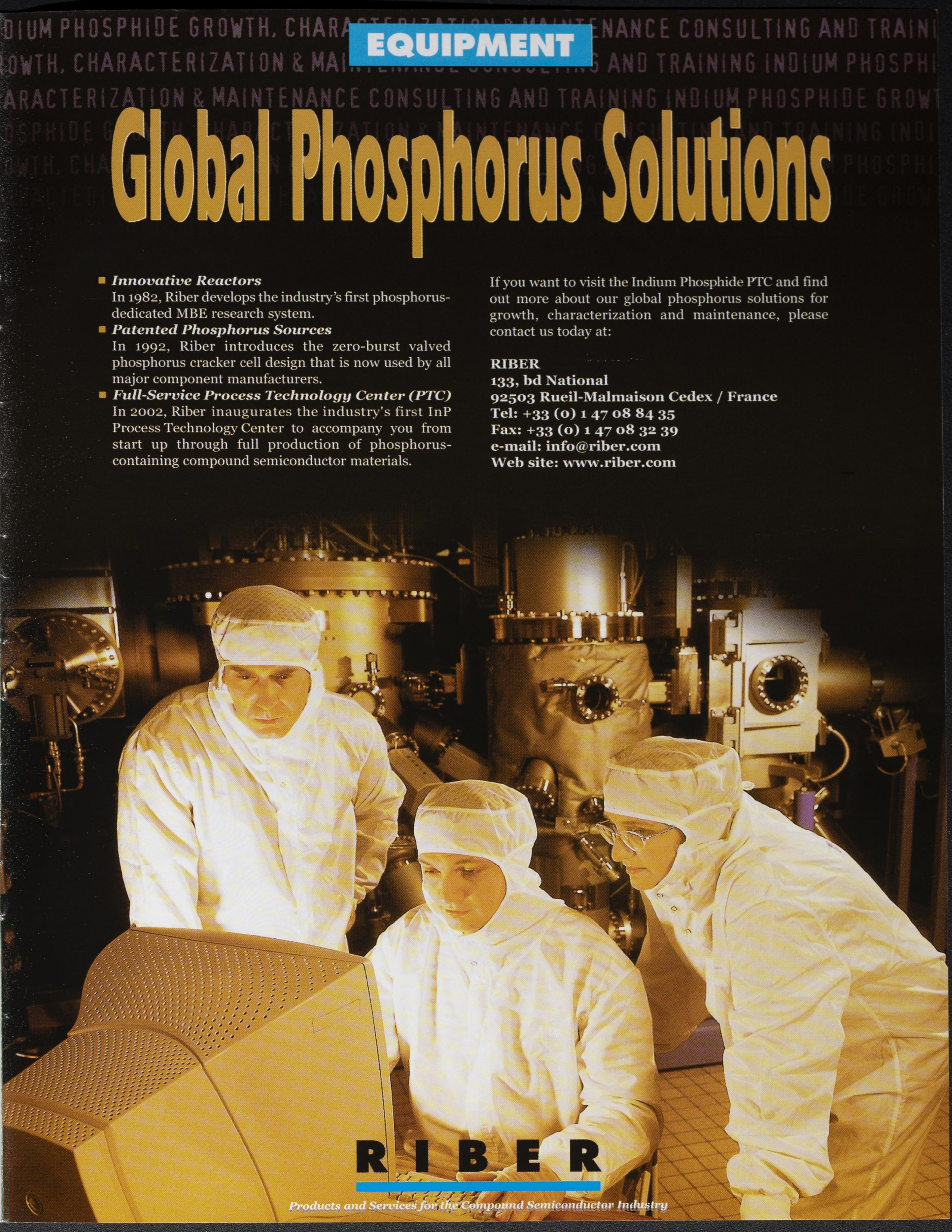
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