

COMPOUND SEMICONDUCTOR

Three-Fives and Silicon Heterostructures

December 2004 Volume 10 Number 11



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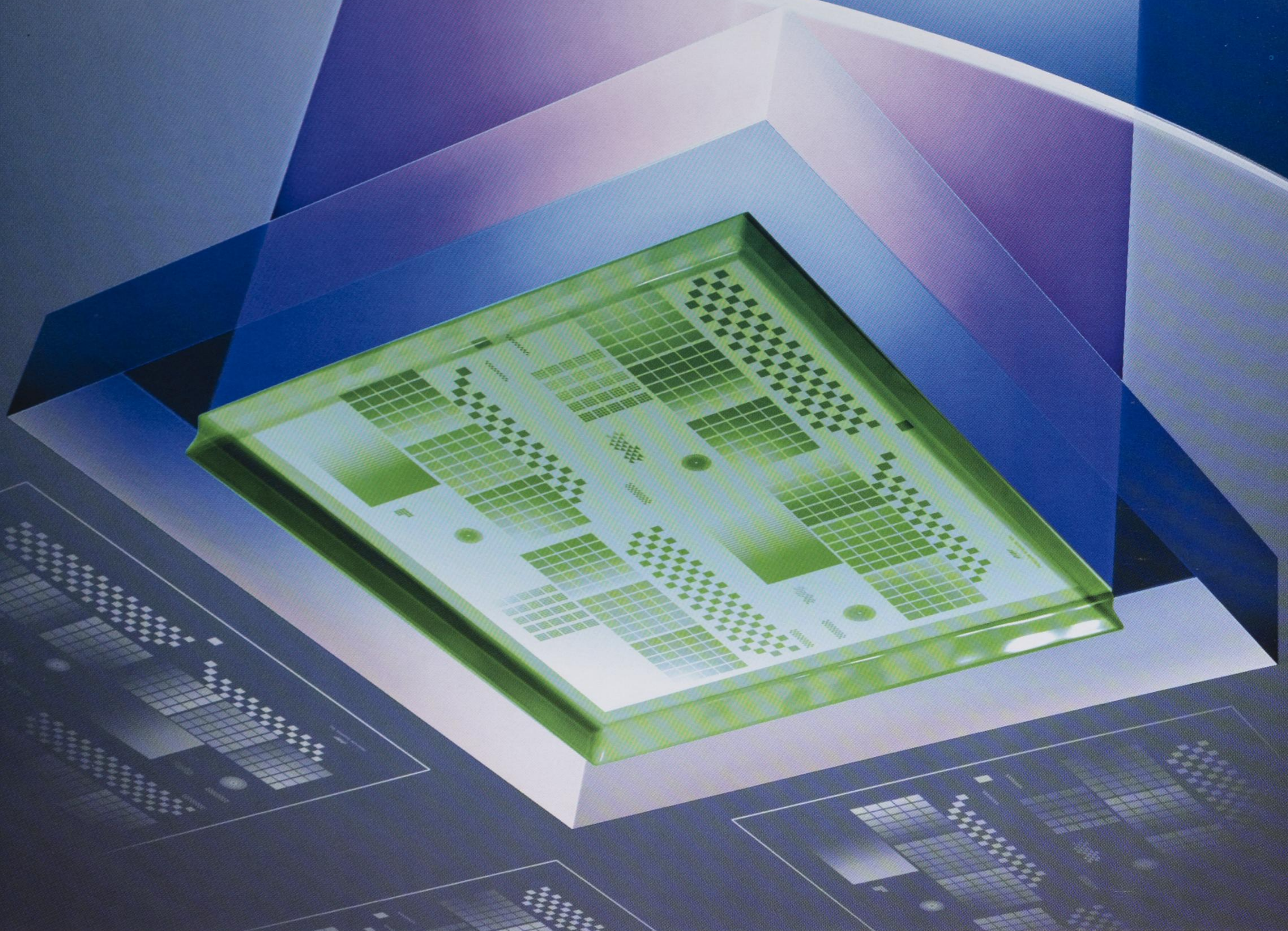
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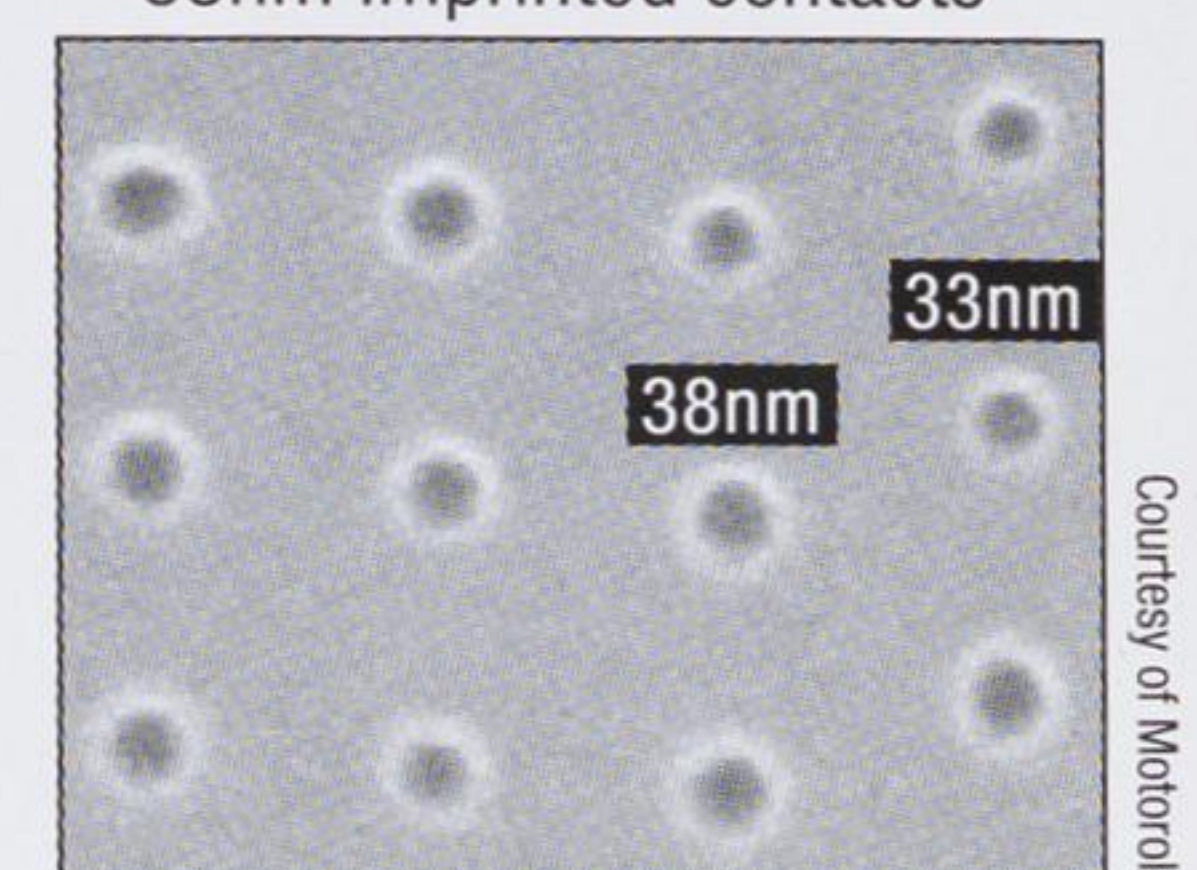


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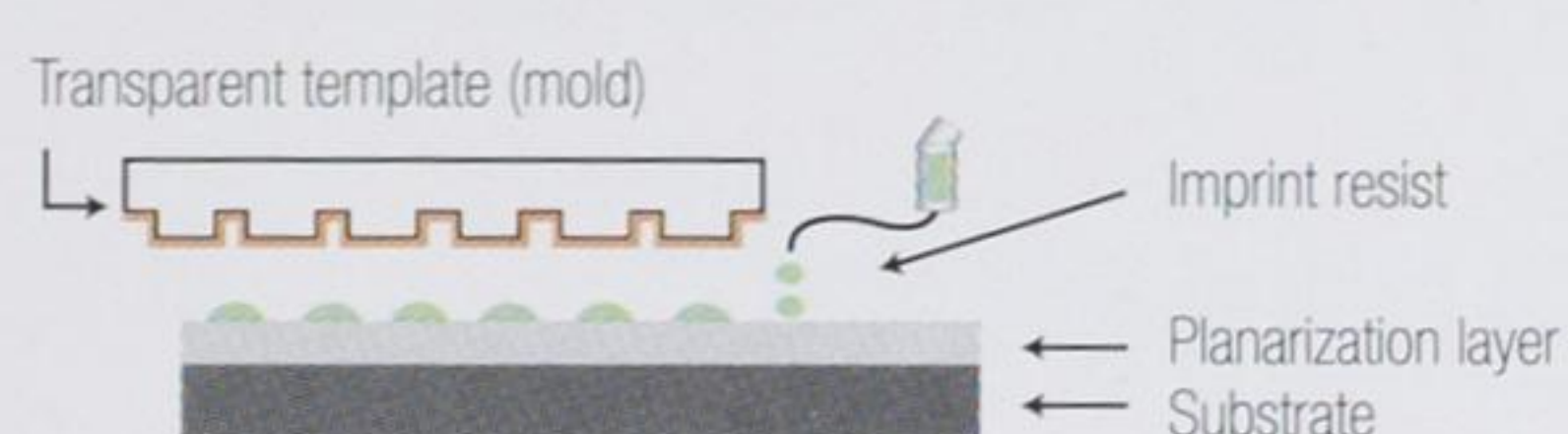
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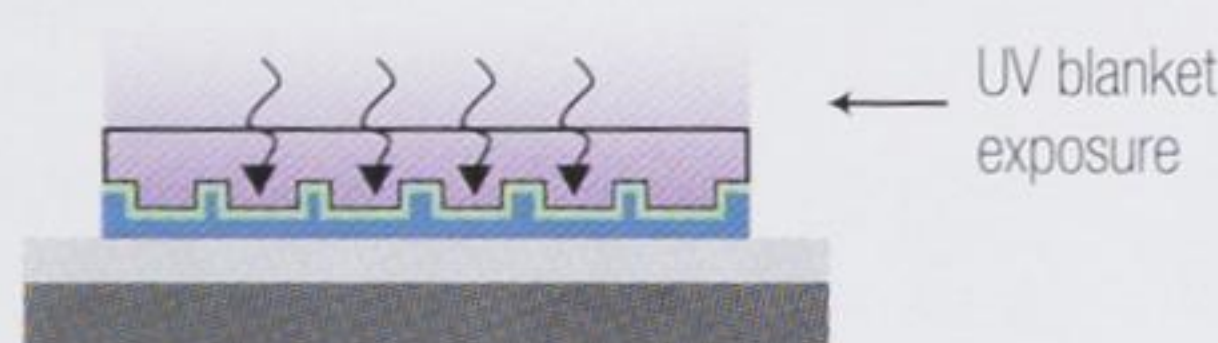


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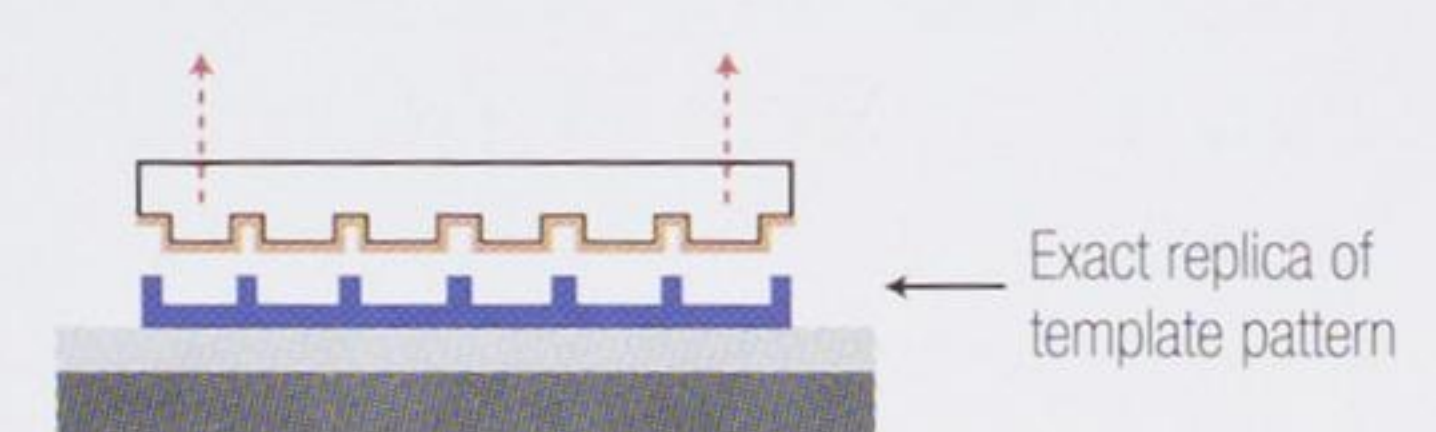
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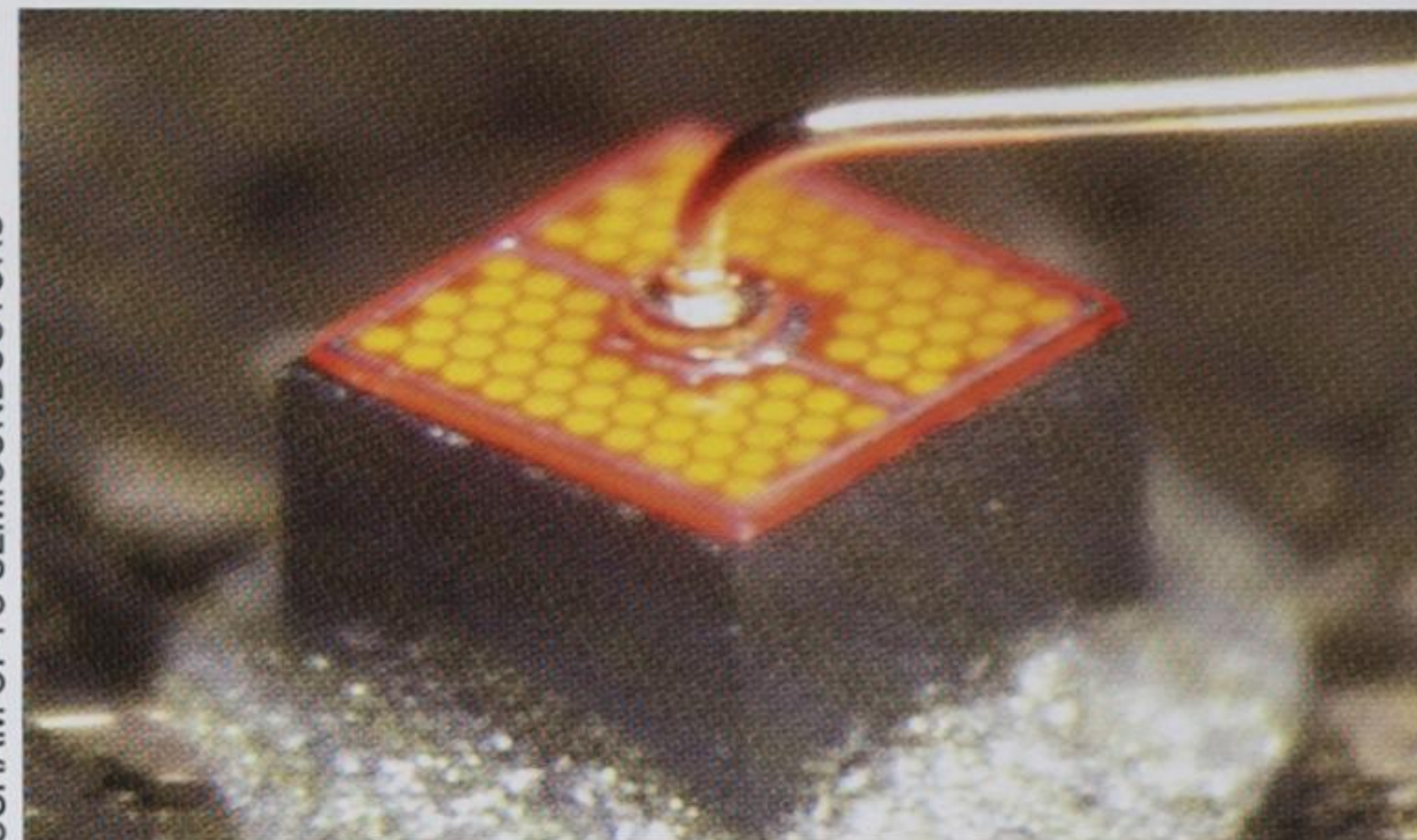
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On the cover: Osram Opto Semiconductors' high-power AlGaInP LED chips, which incorporate microprism structures and metallic reflectors to improve light-extraction efficiency. See page 18. (Photographs courtesy of Osram, Lamina Ceramics and Ken Sakuma.)

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Editorial

Déjà vu as consolidation makes a return to the GaAs industry



When I became editor of *Compound Semiconductor*, consolidation was one of the key requirements for an industry recovery. And so it remains, one year on. 2004 appears to have been a year characterized by stuttering recovery, somewhat typified by developments in the pure-play GaAs foundry business.

Why the proposed merger between the Taiwanese foundry Global Communication Technology (GCT) and its US counterpart Global Communication Semiconductors (GCS), which was announced late last year, went off the rails remains unclear. GCS's close relationship with the US military is one possible explanation, but the upshot was that the necessary consolidation in this particular segment of the III-V industry was delayed by several months until the apparently spurned GCT decided to get hitched with fellow Taiwanese outfit WIN Semiconductors instead.

No doubt a healthy move for the industry, the merger is expected to result in a pure-play foundry output of some 2600 6 inch wafers each month. Both WIN Semiconductors Corporation (the proposed name for the newly merged company) and GCS claim to be nearing profitability. Speaking at Compound Semiconductor Week, GCT's Huan-Chan Yen said he expected the new company to break even early next year, while Dave Wang from GCS said that the US operation had just posted its first break-even quarter.

Nevertheless, many in the GaAs industry believe that more manufacturing consolidation is required, especially with some of the major device manufacturers still operating at only 30–40% of their fab capacity.

In the photonics industry, duplication of chip-manufacturing capacity is an even more pressing issue, with all the major players suffering big losses. Avanex, JDS Uniphase and Bookham are all in the midst of restructuring their manufacturing operations. Don't be surprised if the next merger deal in our industry is in the optical-components sector.

Michael Hatcher

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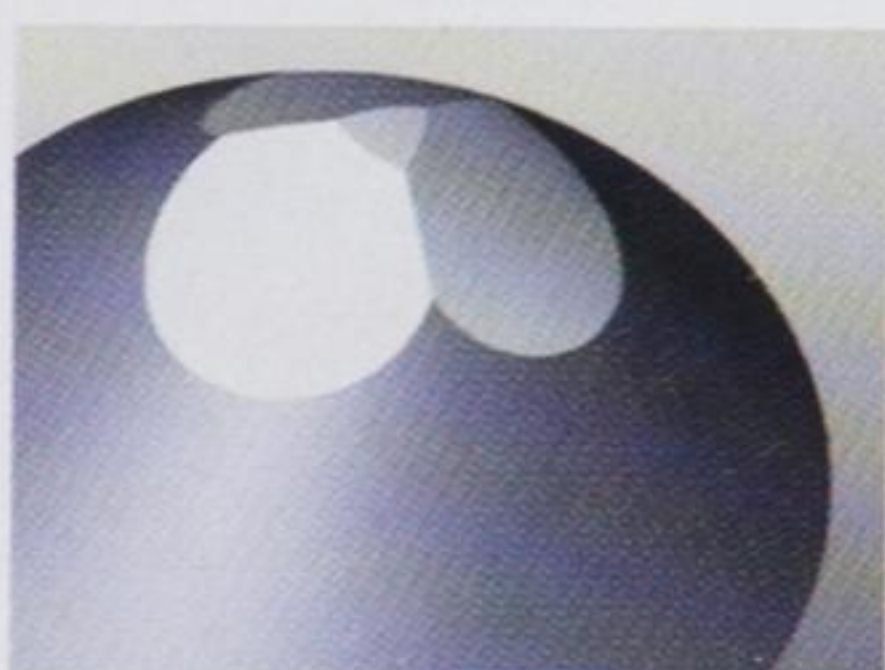
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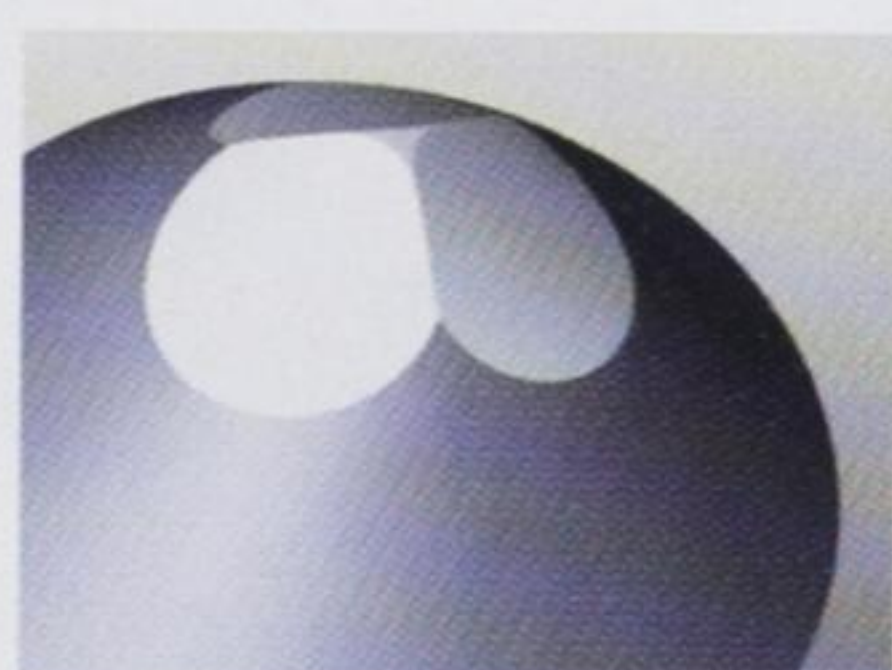
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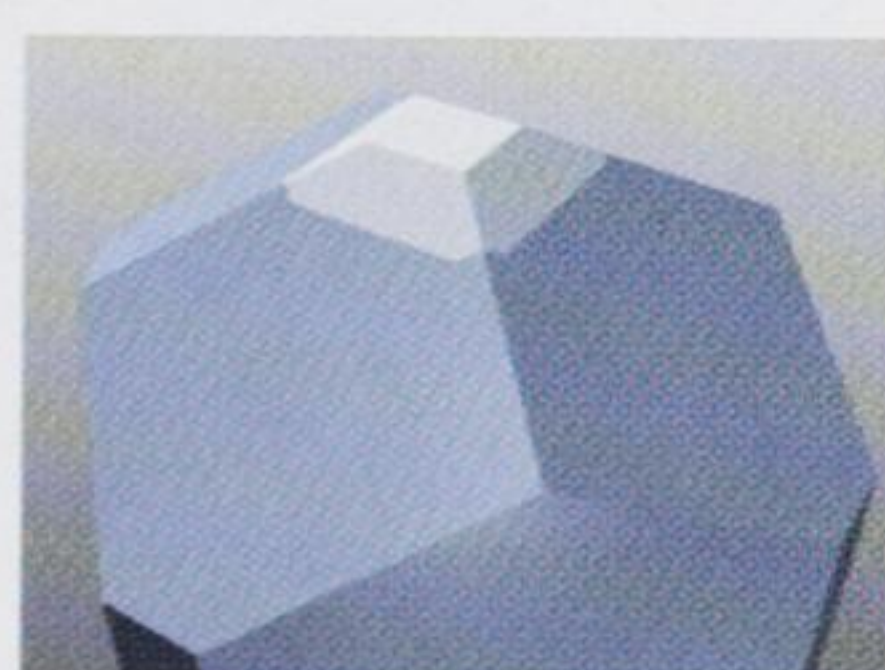
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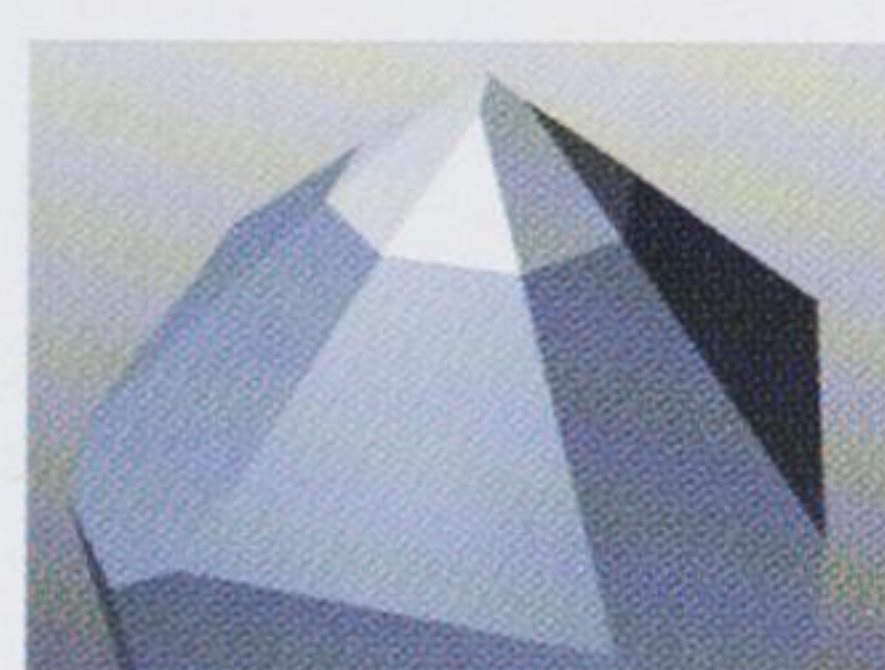
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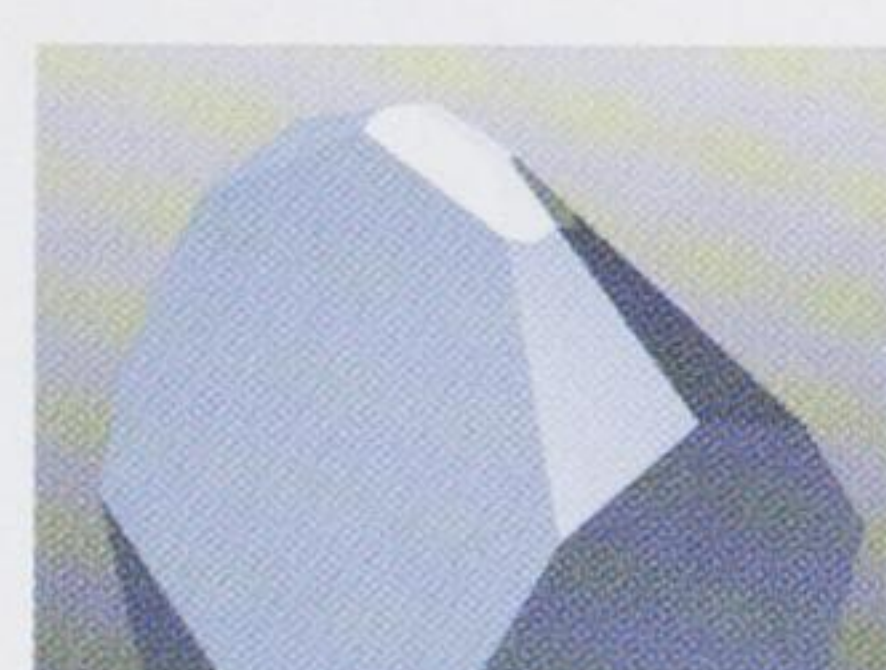
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WIN-GCT foundry to ramp up capacity

By Richard Stevenson

WIN Semiconductors and Global Communication Technology (GCT) have joined forces to create Taiwan's biggest GaAs foundry. The companies announced the merger at the recent Compound Semiconductor Week event in Monterey, CA.

The combined company, named WIN Semiconductors Corporation, will initially maintain both its manufacturing sites independently, but plans to integrate its two sales operations. The WIN fab provides expertise in PHEMT and HBT technology, while GCT has developed a mature HBT technology for cellular power amplifiers.

With WIN scheduled to ramp monthly production at its 6 inch facility from the current level of 1100 to 1600 wafers, the additional capacity will give a monthly output of 2600 wafers. That makes it larger than its one remaining Taiwanese rival – Advanced Wireless Semiconductor Company, which primarily makes GaAs HBTs. WIN added that more resources will be invested in research and development activities following the deal.

The merger comes almost exactly one year after GCT announced that it would unite with US-based Global Communication Semiconductor (GCS). However, for reasons that

have yet to be made clear, the marriage never took place. One possibility is that GCS's links to the US military affected the deal.

The latest consolidation, which comes after the collapse of Suntek in the wake of the Procomp Informatics scandal (*Compound Semiconductor* August p5), leaves just two players in the Taiwan foundry business.

Speaking at CS-MAX 2004, GCT's Huan-Chan Yen said that the combined revenue following the merger deal would be worth \$32 million in 2004, and rise to \$45 million next year. Yen expects the GaAs foundry business to eventually follow the silicon model, with production largely driven by the requirement for low-cost RF components such as those used in wireless LAN applications.

Additional insight into the merger was provided by Robert Donahue, vice-president of marketing and sales at WIN semiconductors, during a panel session held at Compound Semiconductor Week. Donahue claimed that the merger would create the largest pure-play foundry in the world. He expects profitability by the first quarter of 2005 and believes that with a customer base including fabless semiconductor manufacturers, GaAs IDMs, and university and research institutions, "virtually anybody can use us".

Another perspective on pure-play's future was given by GCS's chief operations officer David Wang. He says that capacity still exceeds demand by up to five times. Despite saying that "today everyone is losing money", Wang still believes that outsourcing is a viable alternative. He outlined some basic requirements for a successful pure-play foundry – a support team that provides modeling and CAD services, applications engineers that understand and support products, and sound financial management.

Broadly agreeing with Wang, Rob Christ, director of foundry services at US-based GaAs IDM and foundry TriQuint Semiconductors, believes that complete IP protection has to be the number-one priority. He claims that TriQuint's share of the GaAs foundry market stands at 60%, leaving only 15,000 wafers per year accessible to the competition.

"The market is much too small for pure-play foundries," said Christ. The TriQuint director of foundry services also believes that the demise of Suntek hurt a lot of customers, who are now unwilling to take chances and prefer a manufacturing partner with a stable business model. Christ predicts that the market can only support TriQuint and one or two other foundries.

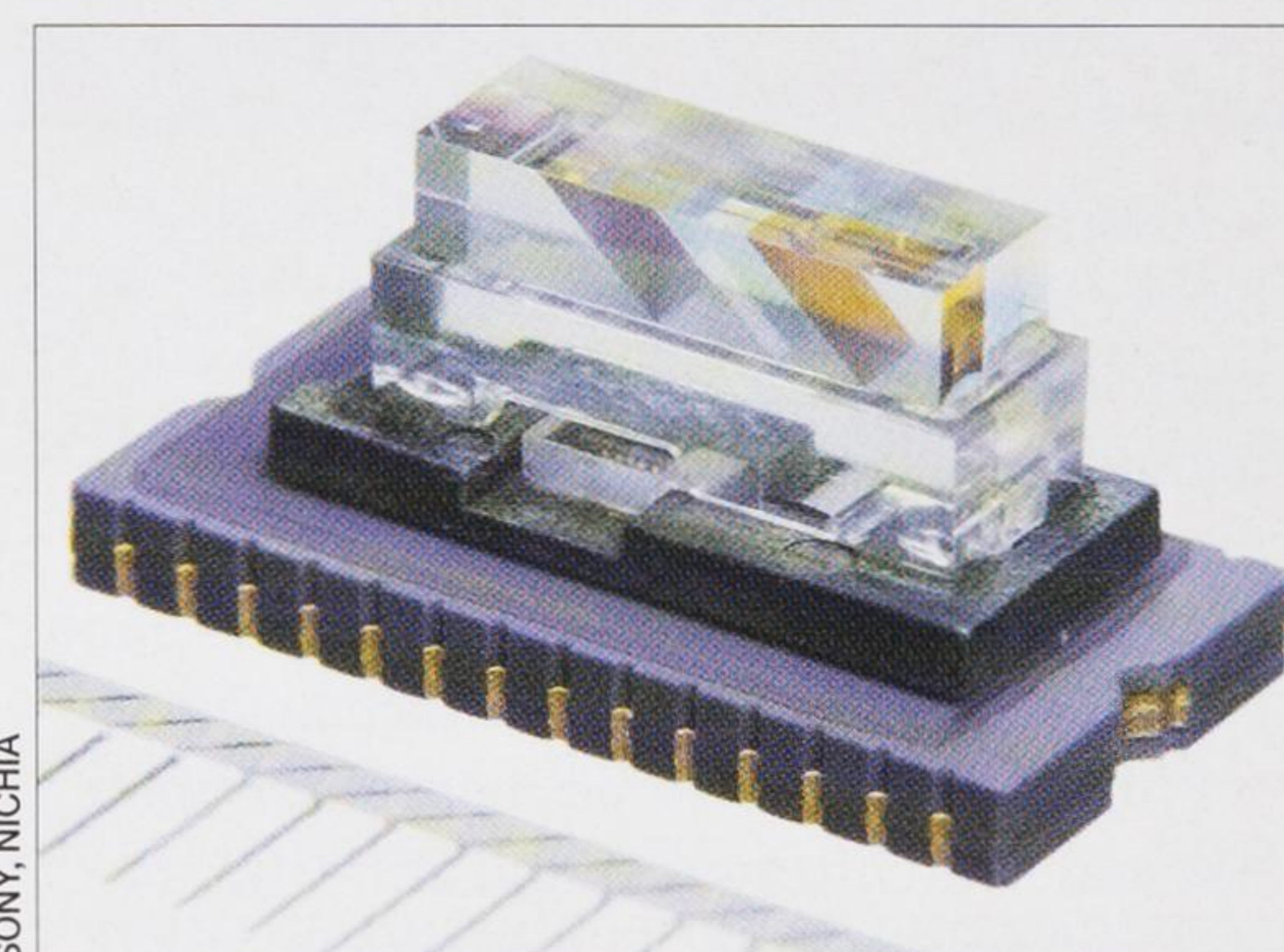
Nichia, Sony build dual-wavelength solution

A collaboration between Nichia and Sony has led to the development of a wholly integrated, dual-wavelength coupler that is compatible with DVD and Blu-ray storage formats.

The coupler, which will be mass produced by the end of 2005, is a single integrated device containing a red laser (660 nm) for DVD playback and a blue-violet laser (405 nm) for blue-violet optical disc playback.

Today's combined DVD and blue-violet laser optical disc systems contain separate laser diodes and optical receivers for each wavelength. However, Nichia and Sony's coupler incorporates these two separate functions into a single element, forming a smaller, simplified system with enhanced reliability.

Sony and Nichia's co-development of GaN laser diodes, which began more than two years ago, led to a cross-licensing agreement being set up in April. "With the dual wavelength laser coupler in development, our target is to establish a stable supply for next-generation optical storage," remarked Nichia's R&D



Sony and Nichia's dual-wavelength coupler offers an elegant solution for combining DVD and Blu-ray formats.

manager, Gen-ichi Shinomiya.

Osamu Kumagai from Sony added: "We are aggressively supporting Blu-ray Disc [BD] standards. The dual-wavelength laser coupler will ease finished product development, assist realizing a smaller product size, and lead to applications such as small-size BD players."

TDI demonstrates 6 inch GaN epitaxy

Technologies and Devices International (TDI), a privately held Maryland corporation, says that it has fabricated the industry's first 6 inch diameter GaN epitaxial materials.

The epiwafers were fabricated at TDI using its patented hydride vapor phase epitaxial (HVPE) process and equipment on sapphire. The company says that its demonstration of large-area GaN epitaxy creates a new horizon for the entire nitride community. US-based Rubicon supplied the 6 inch sapphire substrates used under a Missile Defense Agency program.

Although there is a strong development and commercialization effort for GaN devices worldwide, the industry standard is to use 2 inch diameter epiwafers in production, with R&D effort in 3 and 4 inch sizes. Cree is currently converting its production facilities to use 3 inch SiC substrates.

● See p15 for more details of TDI's work on GaN epitaxy.

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GAAs & WIRELESS NEWS

Power-amplifier suppliers target 3G cell phones with new modules

With major carriers rolling out 3G-mobile-phone services across the globe, III-V component suppliers TriQuint and Agilent have introduced power amplifier (PA) modules for the new breed of handsets.

TriQuint's dual-band module, which uses InGaP technology, is said to significantly increase 3G-handset talk time. It has been designed for phones that support GSM and EDGE standards, as well as the new high-speed universal mobile telecommunications system (UMTS) links, using a single antenna. UMTS is a 3G standard for regions in Europe and Asia that currently use GSM.

Looking to enter the same handset application area, California-based Agilent has also released a UMTS module, which it claims has a typical power-added efficiency of 46%—the highest in the industry for wideband code division multiple-access (W-CDMA) applications.

Agilent's PA module is based on its GaAs E-PHEMT technology (see *Compound Semiconductor* May p23) and features an output power of 28.5 dBm.

Meanwhile, Skyworks Solutions is ramping production of its PA modules for W-CDMA applications following a volume order from a top-tier cell-phone manufacturer. The modules are said to allow 3G handset

owners to send and receive data at up to 2 Mbit/s. They use the company's load-insensitive PA (LIPA) technology, which is said to maximize power efficiency in both high and low RF power ranges.

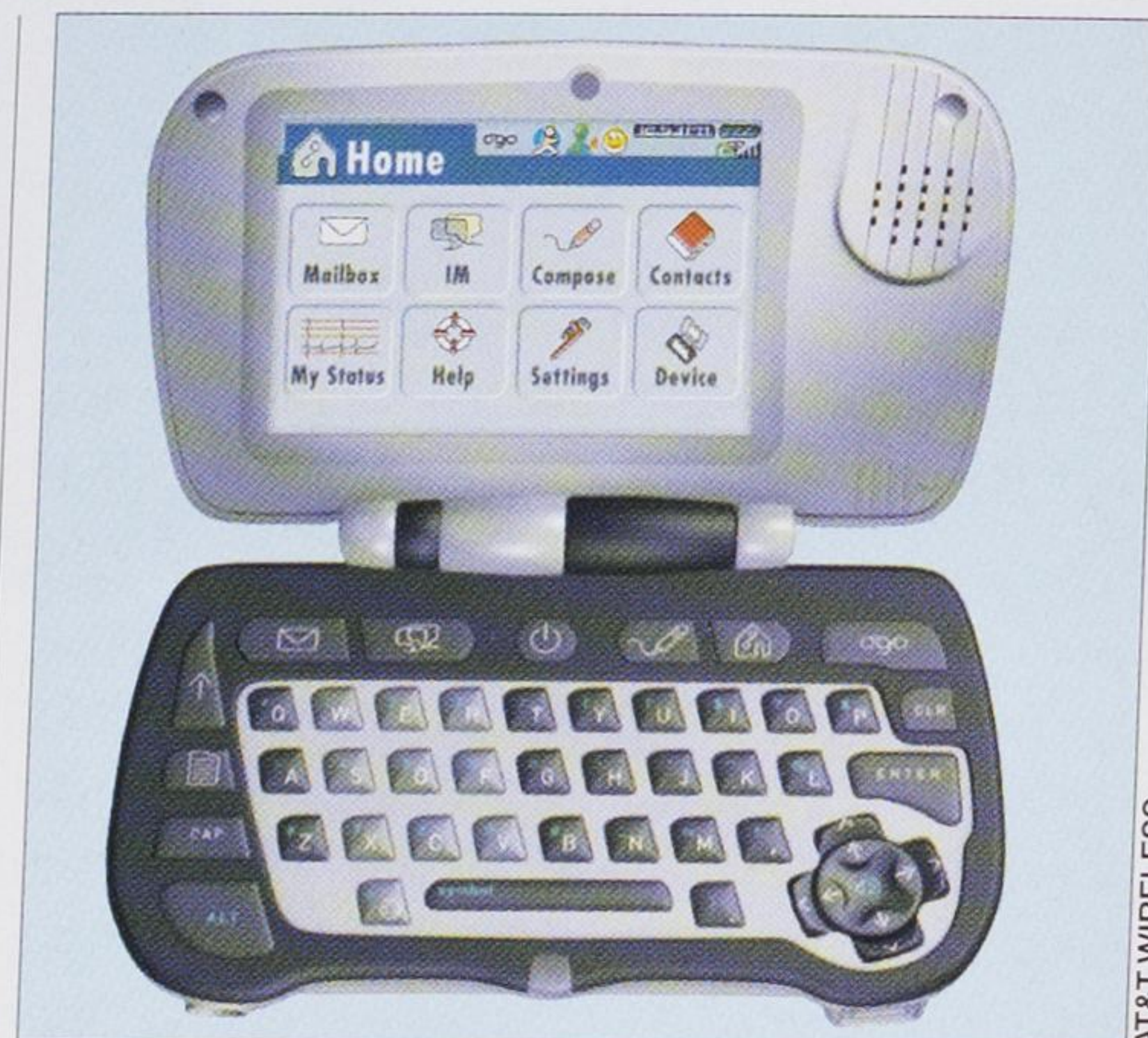
Incorporating LIPA means that handset OEMs can use a single PA to cover multiple frequency bands, so that the handsets are suitable for use around the world. The devices used in the modules are manufactured using Skyworks' 50 GHz GaAs HBT process and feature an InGaAs emitter.

Meanwhile, at the lower end of RF applications, the Woburn, MA, company has received an order from Beijing-based handset maker Xinwei Telecom Technology. Xinwei will integrate RF subsystems from Skyworks in phones targeted at China's huge rural population. Xinwei recently agreed a similar deal with Anadigics, another US manufacturer of PA modules.

The Xinwei handsets will support the low-cost synchronous code division multiple-access (SCDMA) standard, and sales are expected to begin by the end of this year. SCDMA, which is also known as the "Big Smart" wireless phone service, was developed by Xinwei and operates in the 400 and 1800 MHz spectra.

In brief

- **Anadigics** has introduced a dual-band power amplifier (PA) for WLAN applications based on its InGaP HBT technology. The Warren, NJ, firm says that the small-footprint AWL6950 is the industry's most highly integrated dual-band PA, requiring only two external capacitors.
- Philips-owned **Ommic**, based in France, has added an ultrawideband amplifier to its product portfolio. The device, based on Ommic's low noise and driver amplifiers for 40 Gb/s optical transmission systems, is said to provide an excellent noise figure and compression point at up to 45 GHz.
- **Toshiba**, Japan, has released a small, low-profile GaAs MESFET single-pole dual-throw switch that is said to be suitable for multiband cellular antenna switch modules, Bluetooth modules and WLAN applications.



RF Micro Devices is shipping its Polaris Total Radio RF subsystem to AT&T Wireless for use in the firm's "Ogo" mobile device. Polaris comprises the company's GSM/GPRS transceiver and PowerStar power-amplifier module. Ogo features instant messaging, e-mail and text messaging, and can communicate with other consumer peripherals such as digital cameras.

Skyworks steals a lead as RFIC makers feel the heat

Skyworks Solutions was the only major US-based GaAs IC manufacturer to post a net profit in the recent round of earnings releases. The Woburn, MA, company saw revenue increase 45% year-on-year to \$218 million. The figure also represented a 5% increase on the prior quarter.

On the bottom line, Skyworks recorded a net profit of \$18.1 million, up from \$14.8 million in the previous quarter and a reversal of the \$43 million loss it posted one year ago.

Meanwhile, RF Micro Devices (RFMD) saw its revenue drop 10% on the previous quarter to \$149.1 million. The figure also represents a fall of almost 9% year-on-year. That translated to a net loss of \$6.7 million, compared with a \$10.6 million profit in the equivalent quarter last year. RFMD says that the drop in revenue reflected a weak cellular handset market in Asia.

Of the other GaAs device manufacturers, TriQuint Semiconductors and Anadigics recorded a loss. TriQuint's revenue was \$89.7 million, down \$2.9 million on the previous quarter, turning the break-even bottom-



All smiles: Skyworks CEO David Aldrich and other executives from the company opened the NASDAQ stock exchange on October 28 to celebrate the firm's second anniversary.

line figure recorded then into a \$4.1 million loss this time round.

A raft of orders for its power-amplifier products, mainly from Chinese handset makers, and a revenue increase of \$2.4 million on the prior quarter, narrowed Anadigics' loss to \$8.3 million from \$11.7 million previously.

HRL bags further \$6.4 m for HBTs, imaging

HRL Laboratories, the corporate R&D facility based in Malibu, CA, has attracted a further \$6.4 million from DARPA for two compound semiconductor technology projects.

The lab, which is part-owned by Boeing, General Motors and Raytheon, received \$4.5 million under phase two of the technology for frequency agile digitally synthesized transmitters program, bringing HRL's total funding for this project to \$9 million.

HRL says that the extra injection of cash will be used to demonstrate direct digital synthesizer circuits incorporating 5000–10000 HBTs. "While transistor speed will be increased to more than 400 GHz [the cut-off frequency], lower-power devices will be crucial to realize circuits with a high device count. The key to phase two is to demonstrate large circuits with this technology," said HRL.

The firm's InP-based HBTs have already reached a 370 GHz cut-off frequency and a 430 GHz maximum frequency of oscillation. These devices were used to produce a static divide-by-eight circuit clocking at 150 GHz

with a power dissipation of less than 100 mW per static current mode logic flip-flop.

Phase two will see Raytheon and Boeing using the technology developed to deliver systems that allow direct digital synthesis of 20 GHz signals and beyond. HRL says that the technology should appear in military systems in around five years.

The Malibu operation has won an additional \$1.9 million from another DARPA program to develop microantenna arrays. HRL's proposal is to demonstrate a low-cost, high-sensitivity imaging array of microantennas and detectors in a focal-plane array.

The technology could help helicopters to land in fog, detect fires through thick smoke and improve missile guidance in difficult conditions. HRL's millimeter-wave detector diode uses an inexpensive antimonide-based process instead of a conventional Schottky diode. Whereas the Schottky devices require constant bias to reach an adequate level of sensitivity, the lower noise of the HRL device means that it does not need an RF amplifier.

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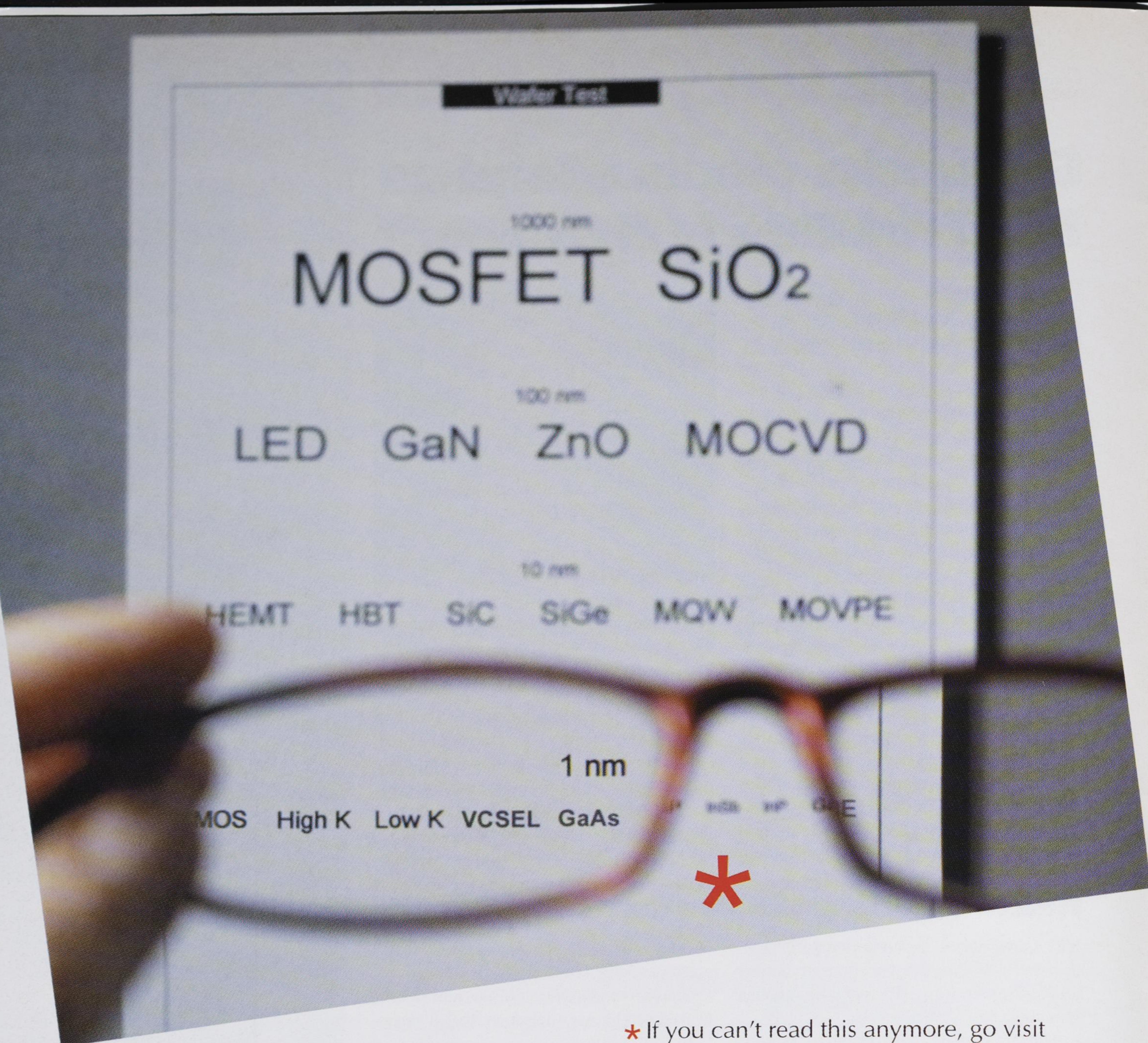
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Osram Opto focuses on automobile applications

Osram Opto Semiconductors, the Germany-based LED manufacturer, has launched a host of new products including high-power laser diodes and warm-white LEDs.

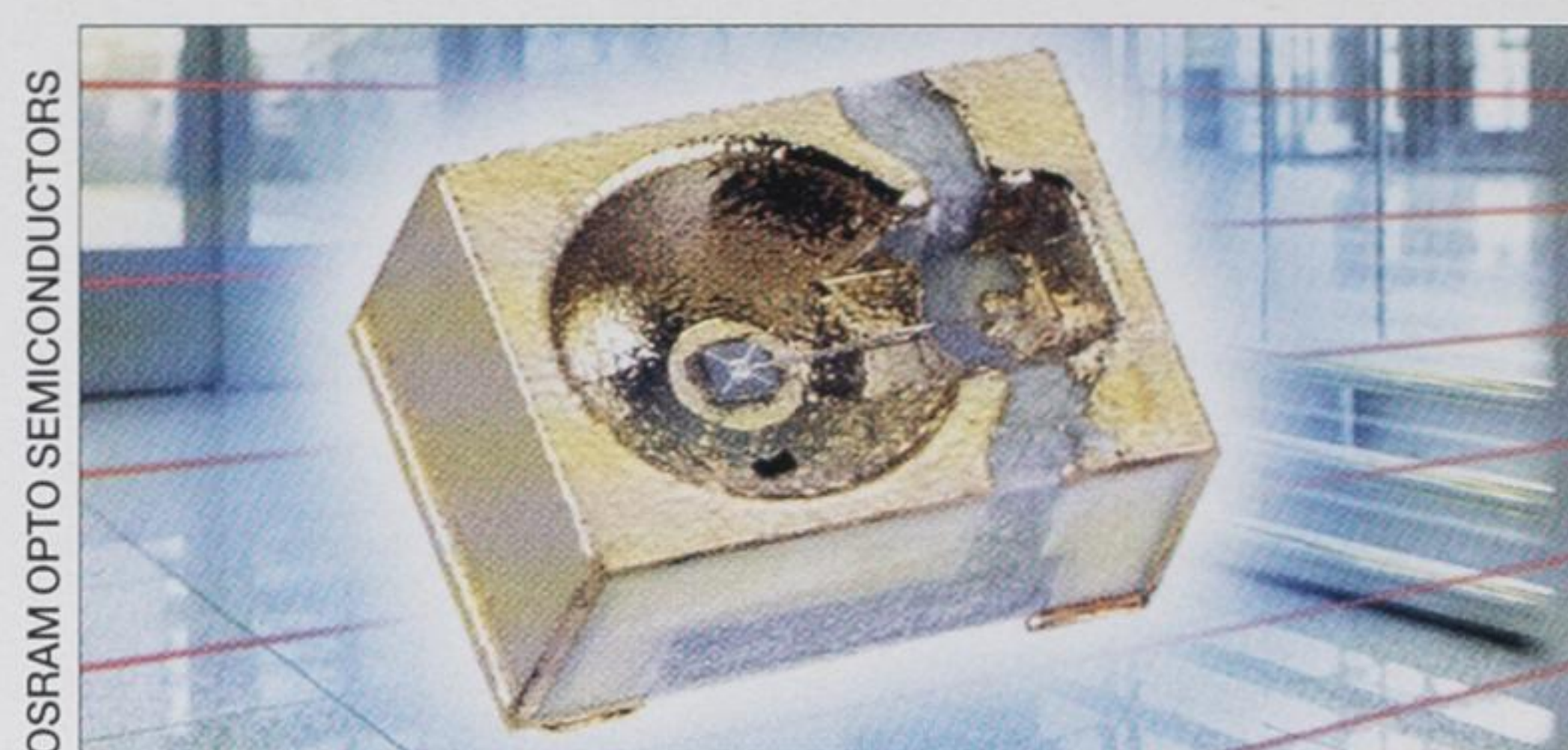
Targeting the automotive industry, its new laser diodes emit in the infrared (800–1000 nm) with output powers of up to 10 W in pulsed mode. Even higher output powers have been achieved by epitaxial growth of a collection of laser diodes arranged in a vertical stack called a “nanostack”. These devices have output powers of up to 75 W in pulsed mode, with emission appearing to come from a single source due to the close proximity of the emitters. Osram believes these lasers could be used in adaptive cruise control sensors and infrared night-vision systems.

Osram has also expanded its range of Golden Dragon LEDs with a warm-white version of the technology. The color, similar to that of incandescent and halogen lamps, is produced by adding a red-converting phosphor to the LED package. With a color temperature of 3200 K, the package is suitable for reading lights, display cabinets and car interiors.

Agilent considers Korean LED plant

Agilent Technologies is considering whether to increase its low-power LED business, which targets mobile applications, by creating an LED manufacturing plant in Korea. The US-based company has held preliminary discussions with the Korean government concerning Korea's wish to promote LED technology and investment in the Gwangju province.

The company's Semiconductor Products Group also intends to establish an R&D cen-



Osram's MIDLED integrated die-cast reflector for infrared components.

Another addition to the LED portfolio, filling the gap between the Golden Dragon range and the Power TopLED, is the Advanced Power TopLED. This device, available as a red, yellow or white emitter, is suitable for tail-light clusters, industrial signage, vehicle interiors, and backlighting dashboards and instrument panels.

Osram has also released an integrated die-cast reflector, a package for infrared components. The company's MIDLED is suitable for applications requiring tightly focused infrared light, including distance, range and steering angle sensors.

ter studying wireless applications in Korea. Agilent has established a “memorandum of understanding” with the Korean government, and has told *Compound Semiconductor* that it is currently exploring several options.

Expanding its line of extra-bright InGaN LEDs for the outdoor electronic sign and signals market, Agilent has also added devices in 4 mm (T-1) and 5 mm (T-1 3/4) domed through-hole packages with oval radiation patterns. With typical dominant wavelengths of 470 and 521 nm for blue and green, respectively, they are considered to be well suited to color mixing in full-color signs.

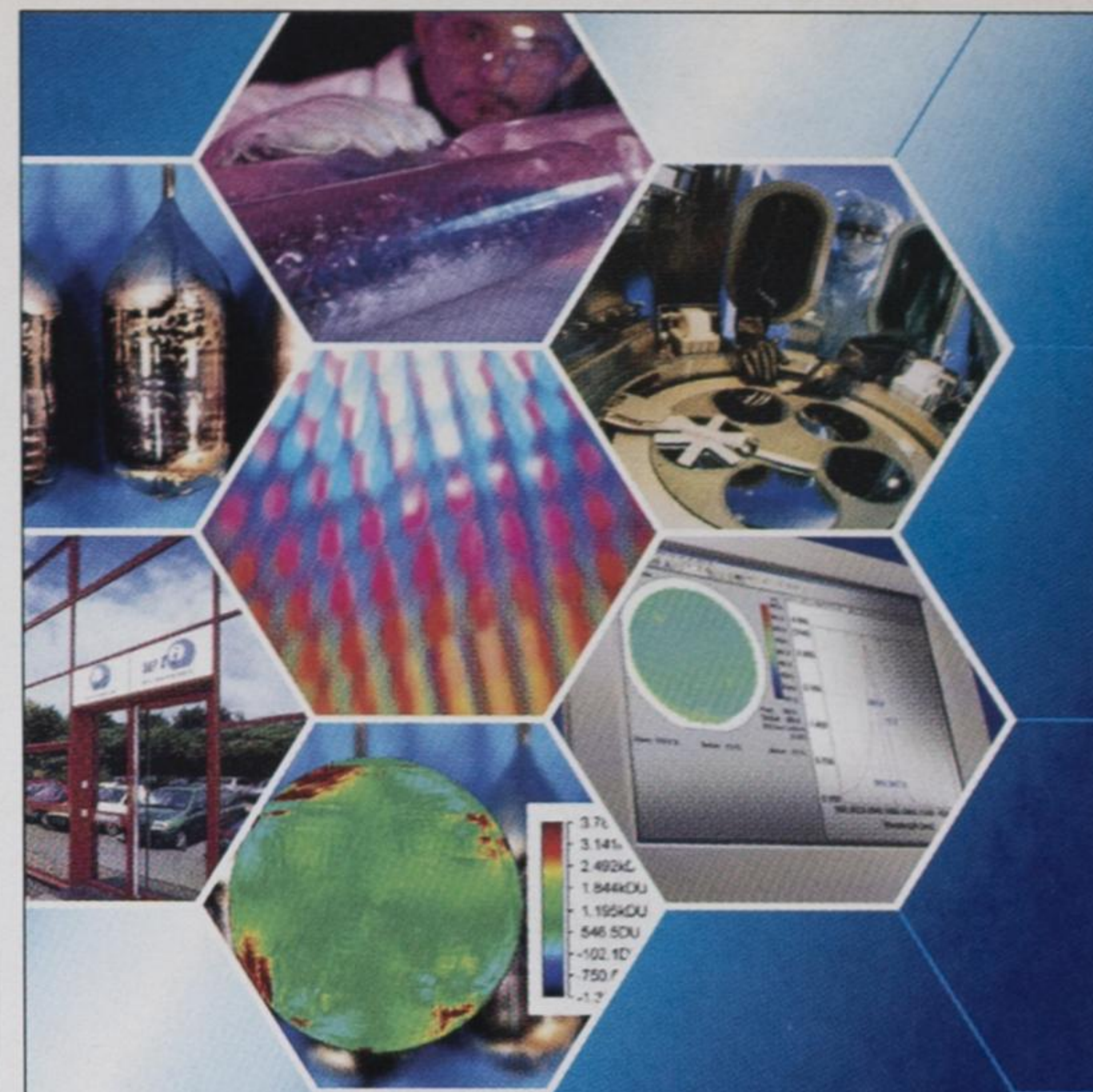
LEDs Magazine offers a new perspective

The new publication *LEDs Magazine* covers the many end applications of high-brightness LEDs, as well as the technology behind LED-based systems.

Containing a mixture of case studies, technical articles, news and in-depth features, *LEDs Magazine* covers markets such as mobile-phone handsets, automobiles, traffic signals, message signs, full-color video dis-

plays, architectural and entertainment lighting, and the emerging application of solid-state illumination.

LEDs Magazine is currently a free electronic publication, comprising a website (see www.ledsmagazine.com) and a regular e-mail update service. For further information contact Tim Whitaker, editor of *LEDs Magazine*, at: editor@leds.iop.org.



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Showa Denko builds plant to produce blue HB-LEDs

Showa Denko KK (SDK) of Japan has developed a 12 mW blue LED, and will start marketing the product next year for applications such as mobile phones, outdoor displays, illumination and automotive devices.

The device is designed for flip-chip mounting, which together with the inclusion of a reflector layer enhances light extraction through a transparent substrate. SDK says that compared with existing products on the market, the newly developed LED has additional advantages of low forward voltage and low electricity consumption.

The product is expected to be used in back-lighting of LCDs and in photoflash units of mobile phones. Furthermore, as the flip-chip structure provides better heat dissipation and higher reliability, it is expected to find uses in automotive lighting and general illumination.

SDK is now building a plant in Chiba, Japan, to produce 30 million GaN-based blue LED chips per month. Sample shipment

began in November, with commercial production set to start in 2005. SDK plans to sell 30 million units per month by year-end. The firm plans to expand production capacity to meet growing demand and to increase revenue from sales of the chips to ¥20 billion in 2008.

SDK currently makes other LED chips and epitaxial wafers in a range of materials, namely GaP (yellow-green), GaAs (infrared), AlGaAs (red, infrared) and AlInGaP (red to yellow-green). It also makes AlInGaP and AlGaAs epitaxial wafers for optical pickups used in CD and DVD applications, respectively, as well as InP-based substrates and epitaxial wafers for fiber-optic communications. It claims that, except for GaN, it has the largest share in the world market of compound semiconductors for optoelectronic devices.

SDK classifies the compound semiconductor operation as one of its "strategic growth businesses", allocating a substantial portion of its resources into the operation.

In brief

- US-based substrate and LED manufacturer **Cree** claims that its XLamp 7090 white LED product has achieved the highest commercially available brightness in the industry, offering 40–60 lm at 350 mA. With a typical brightness of 45 lm, the product is said to significantly reduce energy consumption by producing more light per unit volume and using less electrical power. The first XLamp power LEDs were introduced in July, with the white-light version generating 28 lm at 350 mA. Cree is believed to have secured design wins for blue keypad LEDs in Nokia's 7610 megapixel handset, as well as Samsung's E700 clamshell handset.
- Osram Opto Semiconductors continues to rely on photolithography solutions from Germany-based **Suss MicroTec** for its high-volume LED production. The LED maker has placed a follow-on order for the Suss LithoFab200 Production Lithography Cluster, which is used in nitride and arsenide/phosphide-based LED fabrication.
- Taiwanese surface-mount LED makers have reported mixed success of late,

according to the website *DigiTimes.com*. In the third quarter of 2004, shipments were up at **Unity Opto Technology** and flat at **Everlight Electronics**, but fell at **Bright LED Electronics** and **Harvatek**.

- An undisclosed German LED marketing and distribution company was threatened with legal action by **Nichia** for selling white LEDs produced in Taiwan that infringed Nichia's patented LED technology. The German company has stopped offering Taiwanese LEDs, and now stocks Nichia's products instead.

- **Formosa Epitaxy**, a Taiwan-based LED manufacturer, has inaugurated its second plant in the Lungtan Industrial park where it plans to install more MOCVD capacity, according to the website *DigiTimes.com*. The reactors, used to produce high-power white LEDs, have a combined monthly capacity of 200 million chips.

- **Lumileds Lighting** and parent company Philips will develop and market new modular LED lighting solutions for the automotive industry that incorporate Lumileds' Luxeon technology.

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NTT upgrade cheers III-V vendors

Japanese telecommunications giant Nippon Telegraph and Telephone (NTT) says that it is planning a massive investment in broadband networks.

According to the firm's "medium-term management strategy" document, NTT will spend ¥5 trillion (\$47 billion) upgrading networks, which includes replacing fixed copper lines with optical links, and building new wireless infrastructure, by the end of the decade.

"A number of problems are becoming evident, [to do with] quality and connectivity between IP networks, security against cyber terrorism at Internet weak spots, and policing illegal transactions," said NTT. "Solutions to these problems must be found before a ubiquitous broadband society can develop."

NTT identified a smooth transition from copper-wire links to optical fiber as one of three key company objectives. Combining the optical infrastructure with mobile services to provide services accessible through PCs, televisions and mobile handsets will be another

key feature of the next-generation network. The company expects to shift 30 million customers to fiber-optic access by 2010.

"The next-generation [service] will provide total connectivity from the user to the network," said NTT. The development could be a shot in the arm for suppliers of III-V-based components such as laser diodes and photodetectors used in optical networks. And it could be an indication of better times to come for JDS Uniphase, Bookham and Avanex in particular. The three component and module makers all reported heavy losses recently as the fiber-optic sector continued its slow recovery.

However, chip manufacturers may need to improve manufacturing efficiencies to keep NTT happy. The Japanese company said that it intended to substantially reduce the cost of equipment used for access through technical advances and better production methods.

● For more in-depth coverage of the recent earnings at fiber-optic component manufacturers, see "Portfolio" on p35.

Chinese team builds 1.33 μm QD laser

A research team at the State Key Laboratory in China has fabricated a 1.33 μm quantum dot (QD) laser on a GaAs substrate.

The Chinese Academy of Sciences says that the laser structure – containing InAs QDs formed by a self-assembly process – can operate in continuous-wave mode at room temperature. GaAs-based QD lasers offer faster switching and lower power consumption than alternative InP structures.

Four years ago, the same Chinese team first fabricated MBE-grown InAs-based QD lasers emitting at 0.9–1.1 μm. By 2002 this range had been extended to 1.3 μm, and since then efforts have focused on further increasing the emission wavelength and achieving a QD density of $4 \times 10^{10} \text{ cm}^{-2}$.

The researchers plan to improve the laser for practical applications and are investigating alternative materials, including GaInAs/GaAsSb, that allow the fabrication of lasers with emission wavelengths of up to 1.55 μm.



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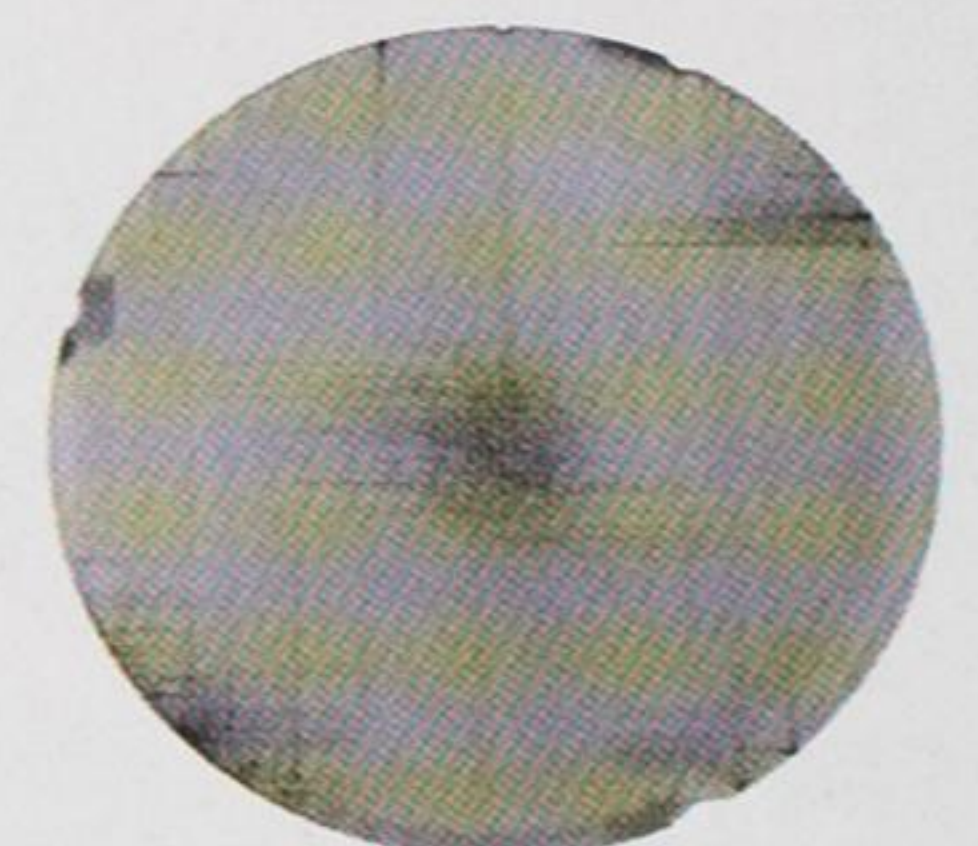
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JDSU sells off transceiver manufacturing facilities

Having announced its intention to further reduce its manufacturing "footprint", JDS Uniphase (JDSU) has consolidated its transceiver-assembly operation with the sale of two facilities to contract manufacturer Fabrinet. The deal is part of JDSU's strategy to streamline its overall manufacturing base as it struggles to return to profitability.

The agreement includes the sale of two datacom-transceiver manufacturing sites for an undisclosed sum. These facilities are located in Bintan, Indonesia, and Singapore, and the switch affects 450 employees at the two plants. In return, the two companies have signed a "long-term" supply agreement.

Fabrinet, which has its manufacturing headquarters in Bangkok, Thailand, has similar agreements with Northlight Optronics, Sweden, and Opnext, based in New Jersey.

JDSU has also taken steps toward ration-

alizing its component operations, with the merger of its previously separate "components" and "transmission" product groups.

Michael Ricci takes charge of the merged entity, as the company's new senior vice-president of the "components and modules" product group. The group has more than 200 product lines, and is said to have the broadest portfolio in the industry.

JDSU is in the process of closing its semiconductor manufacturing facility in Eindhoven, the Netherlands, with the production of active GaAs and InP components now transferred to its San Jose, CA, base. A spokesperson for the company says that all critical equipment has been moved from the leased European facility to San Jose and that there are no plans to further restructure manufacturing operations affecting compound semiconductor device production.

Japan team creates 1 Tbit/s optical tool

Researchers at Mitsubishi Electric and the Japanese Femtosecond Technology Research Association (FESTA) have developed a III-V optical device suitable for 1 Tbit/s data transmission, according to Japanese newspaper *Nihon Keizai Shimbun*.

Optical exchanges operating at these extremely high switching speeds could, in principle, handle data throughput equivalent to 25 movies each second. Practical versions of the switch, featuring stronger signal outputs and other improvements, will be available in 2008, claims the report.

The switch was fabricated from a 50-layer superlattice comprising alternate AlGaAs and AlAs layers.

Other topics in FESTA's research program include developing mode-locked semiconductor lasers with terabit-per-second repetition rates, semiconductor pulse-compressing light sources, and epitaxial techniques to control the site and size of quantum dots.

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In brief

- **K2 Optronics**, the fabless semiconductor laser provider based in Sunnyvale, CA, has attracted a further \$6.4 million in financing, bringing the total investment in the firm to more than \$45 million. K2 specializes in external-cavity lasers for fiber-optic telecom and cable-TV applications. The lasers are said to be the only sources to combine direct modulation with long reach, high power, low chirp, low distortion and a narrow laser linewidth.
- Deployment of fiber-to-the-home networks by SBC Communications, US, will be accelerated after what the company views as a favorable ruling from the Federal Communications Commission. SBC now plans to provide 18 million US households with a fiber-optic link by the end of 2007, two years ahead of its original plan. Alcatel will be SBC's primary supplier.
- The market for photonic integrated-circuit subsystems and components will reach \$5.6 billion in 2009, according to a report from Business Communications Company, a research analyst firm based in Norwalk, CT.

AMD and Albany hook up

Leading silicon chip manufacturer Advanced Micro Devices (AMD) has chosen to partner with Albany Nanotech in a research project that looks set to advance the development of strained-silicon technology.

A team at Albany's recently opened College of Nanoscale Science and Engineering (CNSE) will collaborate with scientists at AMD's material analysis laboratory in Dresden, Germany, on a near-field optical metrology technique. The new technique, which exploits the enhancement of the optical field at the tip of a nanoprobe, will be used to measure the stress state in strained silicon.

Strained silicon, which improves transistor speed while reducing power consumption by vastly increasing carrier mobility, is expected to find widespread use in future

high-performance processors (see *Compound Semiconductor* September p18).

Under the supervision of CNSE's Robert Geer, the research team hopes to be able to make nanoprobe strain measurements with a spatial resolution of better than 10 nm. This high degree of resolution is said to be critical for both controlling and improving strained-silicon IC performance.

Progress on the probe will be relayed directly to AMD's Dresden laboratory and used to characterize transistor performance. AMD says that it expects to manufacture strained-silicon ICs at the leading-edge 300 mm fabrication facility.

Albany NanoTech's 450 000 sq. ft complex is said to feature the only 200/300 mm silicon-wafer facilities in the academic world.

SiGen is awarded US patent for its strained-silicon process

Silicon Genesis (SiGen), a US company that is developing strained-silicon technology for next-generation semiconductors, has won a patent covering a key aspect of the wafer fabrication process. US patent 6,790,747 is entitled "Method and device for controlled cleaving process", and describes a layer-transfer process that could be used to create chips for high-speed, low-power semiconductor applications.

According to SiGen, one of the limitations that has prevented mainstream adoption of the technology thus far is the continued presence of germanium in the substrate and high defect levels in the device film.

SiGen's patented process uses the layer transfer approach to mount a film of strained silicon onto a target substrate, forming a

"stressed region at a selected depth below the surface". The technique is said to be applicable to the manufacture of both a strained-silicon layer on top of a bulk-silicon substrate, and strained-silicon-on-insulator technology. Low-temperature processing inherent in the method also limits germanium diffusion and defect propagation effects present in other, higher-temperature methods, says SiGen.

"Coupled with our high-yield layer-transfer process and our new uniaxial strain technology, this new capability will allow SiGen to offer the best solutions for next-generation engineered substrates," claimed SiGen president Francois Henley. "We believe that these structures will be utilized in mainstream semiconductor applications."

Peregrine nets \$17.6 million fund

Peregrine Semiconductor, a supplier of high-performance RF CMOS and mixed-signal communications ICs, has closed a \$17.6 million round of Series C financing led by Ridgewood Capital and Palisades Ventures. Peregrine is based in San Diego, CA, and makes high-performance sapphire-based semiconductor products for a range of wireless communication and defense applications.

"As the frequency spectrum becomes more crowded, Peregrine's sapphire-based semiconductors have an unassailable competitive advantage," said Elton Sherwin, senior managing director of Ridgewood Capital.

Peregrine's technology is a variation of the silicon-on-insulator process that uses a rugged sapphire substrate to extend IC performance and integration, which Peregrine says cannot be matched by GaAs and SiGe technologies. Its patented UltraCMOS technology is said to deliver better linearity and isolation in a smaller package.

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Rajiv K. Agarwal, Ph.D.

Lead
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I am experiencing high n type background doping levels in my MOCVD process when I grow GaAs and AlGaAs devices. I think the problem is in the arsine I use. I'm buying the best grade available. What can I do?

A

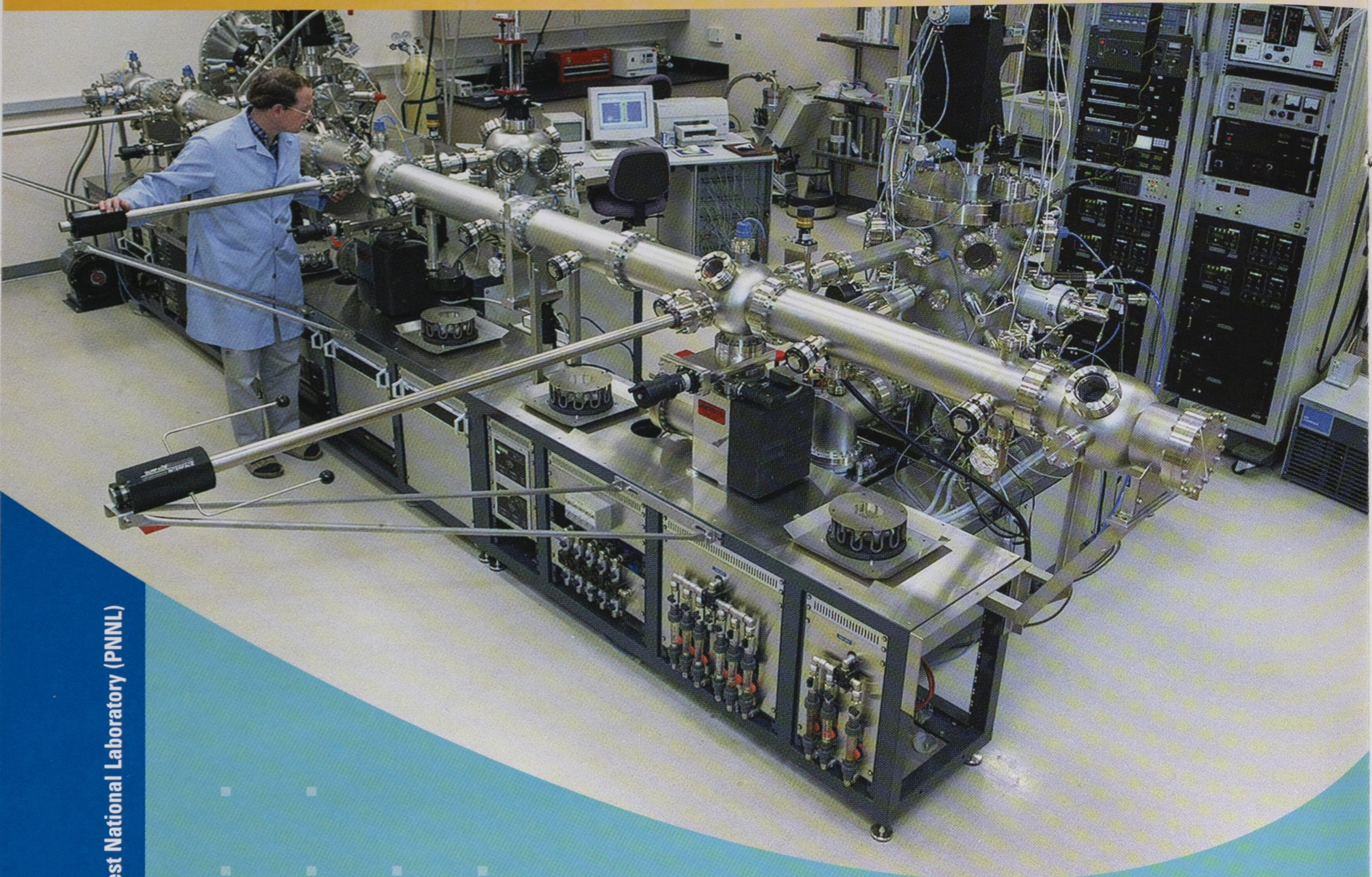
Higher background levels of n type dopants in GaAs and AlGaAs structures are caused by trace levels of germanium, silicon and sulfur species present in the arsine. As customer applications evolve, the purity requirements for arsine must as well. Until recently, background doping levels of $10^{15}/\text{cm}^3$ were considered acceptable in most applications. In general, most currently available high-purity grades of arsine can satisfy these requirements. However, process changes and demand for more sophisticated devices have resulted in the need for lower background doping levels. To address these more stringent requirements, Air Products is introducing Megabit™ III arsine, our purest grade available. Our new Megabit III arsine has significantly reduced the amounts of germanium, silicon and sulfur species. Testing done at an independent laboratory proved the effectiveness of Megabit III on thick gallium arsenide films, with excellent results. In all cases, the background doping level was $<10^{14}/\text{cm}^3$. Our research has shown that Air Products' Megabit III arsine will perform more consistently and produce fewer defects in our customers' finished products.

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HVPE offers alternative route to AlGaN-based UV emitters

The combination of higher growth rates and a lower defect density gives HVPE an edge over techniques such as MOCVD for the growth of UV LEDs. TDI's **Vladimir Dmitriev** and **Alexander Usikov**, and **Heikki Helava** and **Barney O'Meara** from the Fox Group outline their progress.

Today, semiconductor LEDs emitting in the blue, ultraviolet (UV) and deep UV spectral regions are the subject of intense development. Interest has been driven by technical achievements in GaN and AlGaN materials, which cover bandgaps from 3.4 to 6.2 eV, and the growth of commercial devices by MOCVD technology. However, despite this substantial progress, allied to outstanding results obtained in the blue spectral range, several challenging problems remain, preventing the routine production of efficient UV light emitters. These barriers include reducing defect density in UV-emitting epitaxial structures; achieving reliable and controllable growth of AlN and AlGaN alloys; and obtaining p-type doping of AlGaN materials.

At TDI, a novel epitaxial approach, hydride vapor phase epitaxy (HVPE), has been developed to produce advanced GaN and AlGaN materials and device structures for UV optoelectronic applications. One key outcome of this work, involving a multidisciplinary team of scientists and industrial engineers, is the formation of several proprietary processes for commercial production of UV LEDs operating at wavelengths of 365 nm and below. This effort was a logical extension of the team's previous accomplishments that led to successful commercial production of blue LEDs by the "dismissed" HVPE process (*Compound Semiconductor* August p23).

HVPE, a technique developed in the 1960s, was the first epitaxial method used for the fabrication of single GaN crystals. Thanks to its high growth rate (at up to 100 μm per hour, it is two orders of magnitude faster than typical MOCVD and MBE processes), thick GaN layers and free-standing GaN wafers can be produced. The fabrication of a thick GaN layer is critical, since the defect density of GaN layers decreases dramatically as the layer thickness increases. Since both MOCVD and MBE have relatively low growth rates, HVPE is the

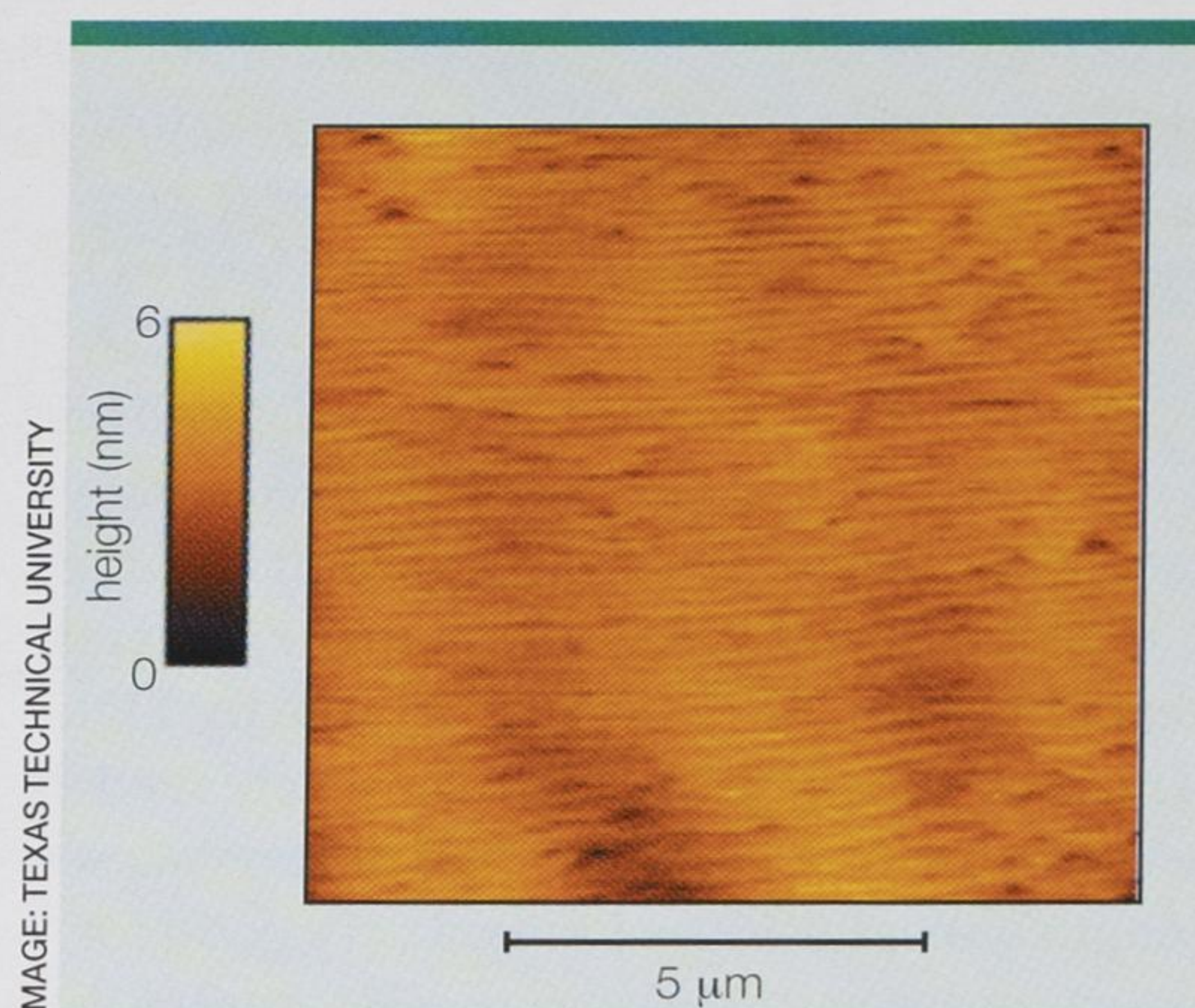


Fig. 1. The surface morphology of TDI's HVPE-grown GaN layers is suitable for LED production. This AFM image reveals a surface roughness (root mean square) of 0.44 nm, for a 17 μm thick GaN layer deposited on sapphire substrate.

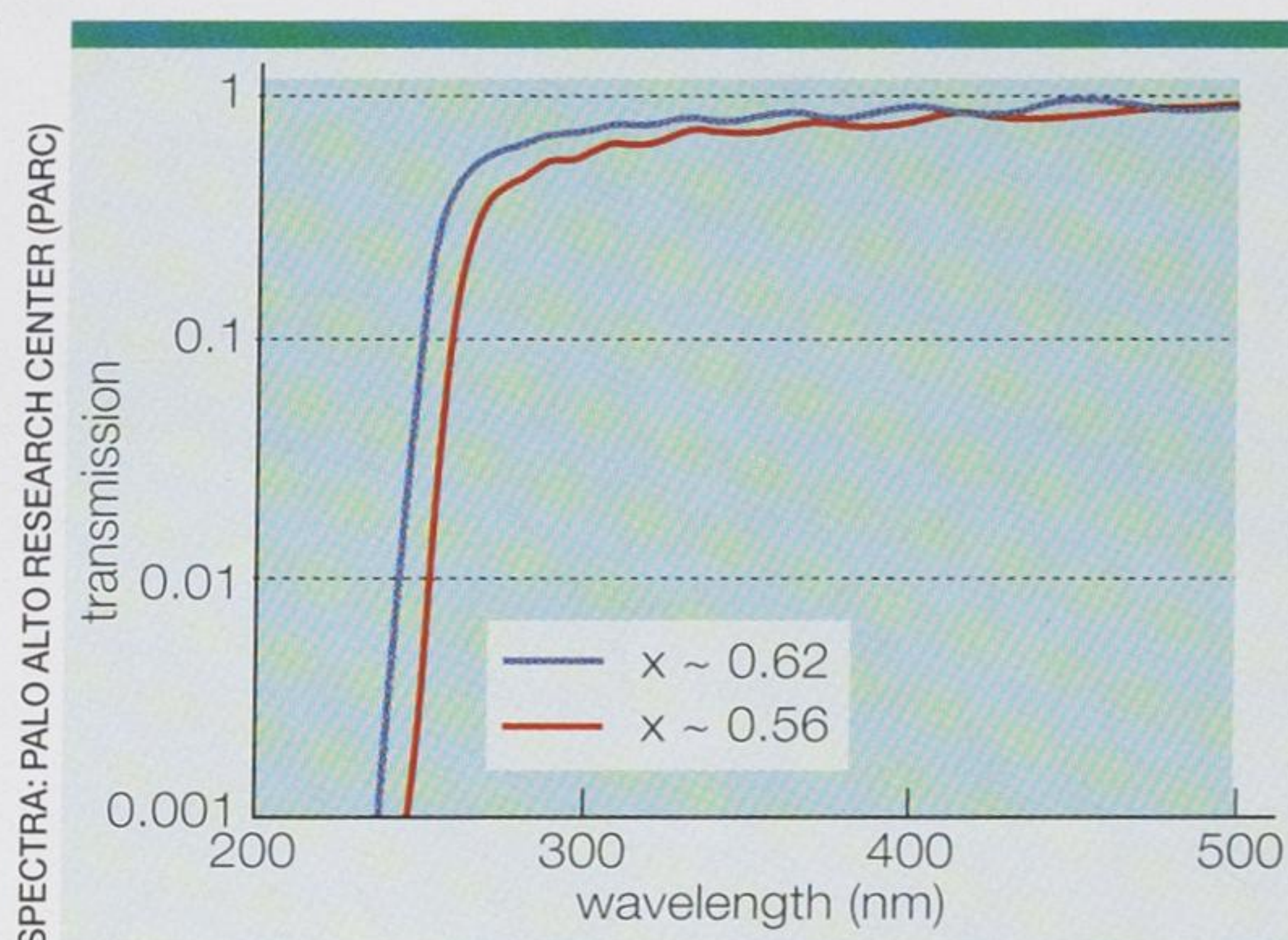


Fig. 2. Optical transmission spectra of TDI's HVPE-grown $\text{Al}_x\text{Ga}_{1-x}\text{N}$ -on-sapphire templates with two different aluminum concentrations. Transmission in the deep UV improves with higher aluminum content.

only practical technique available for growth of thick, low defect density GaN layers.

Other significant advantages of HVPE are the low costs associated with raw materials, the deposition process and capital equipment. All

these benefits are exploited by the Fox Group, which is the exclusive licensee of worldwide rights from TDI for certain patents related to HVPE for light-emitting applications. It has recently started commercial production of GaN-based blue LEDs by HVPE, and will compete with manufacturers using MOCVD and MBE processes for blue light emitters.

HVPE cuts defect densities

As well as the low manufacturing cost, HVPE has other inherent advantages for producing shorter-wavelength emitters. First, it allows growth of low defect density material that incorporates a high proportion of aluminum in the AlGaN layers without severely degrading the crystal quality. In addition, the technique is suitable for growing thicker high-quality AlGaN-based active regions, which have a high radiative recombination efficiency – an essential feature for high-efficiency UV LEDs. The HVPE process is also a "carbon-free" technology, as gaseous hydrogen chloride used in the epitaxial growth provides an impurity self-cleaning effect. This results in low background material contamination and more efficient doping. Finally, HVPE's high growth rate allows favorable batch cycle times, an important consideration for volume production.

TDI's HVPE development has enabled the fabrication of an entire family of III-N devices and structures, including HVPE-grown p-n diodes, p-type GaN and AlGaN layers, and low-defect AlN and AlGaN epitaxial layers (Usikov *et al.* 2004). The surfaces of GaN layers have a very smooth morphology with a roughness of less than 0.5 nm (root mean square value), even for thick layers (figure 1). TDI has also demonstrated the industry's first HVPE-grown, multilayer, sub-micron AlGaN/GaN heterostructures, including AlGaN/GaN/AlGaN double heterostructures for optically pumped lasers (Lam *et al.* 1998)

GAN EPITAXY

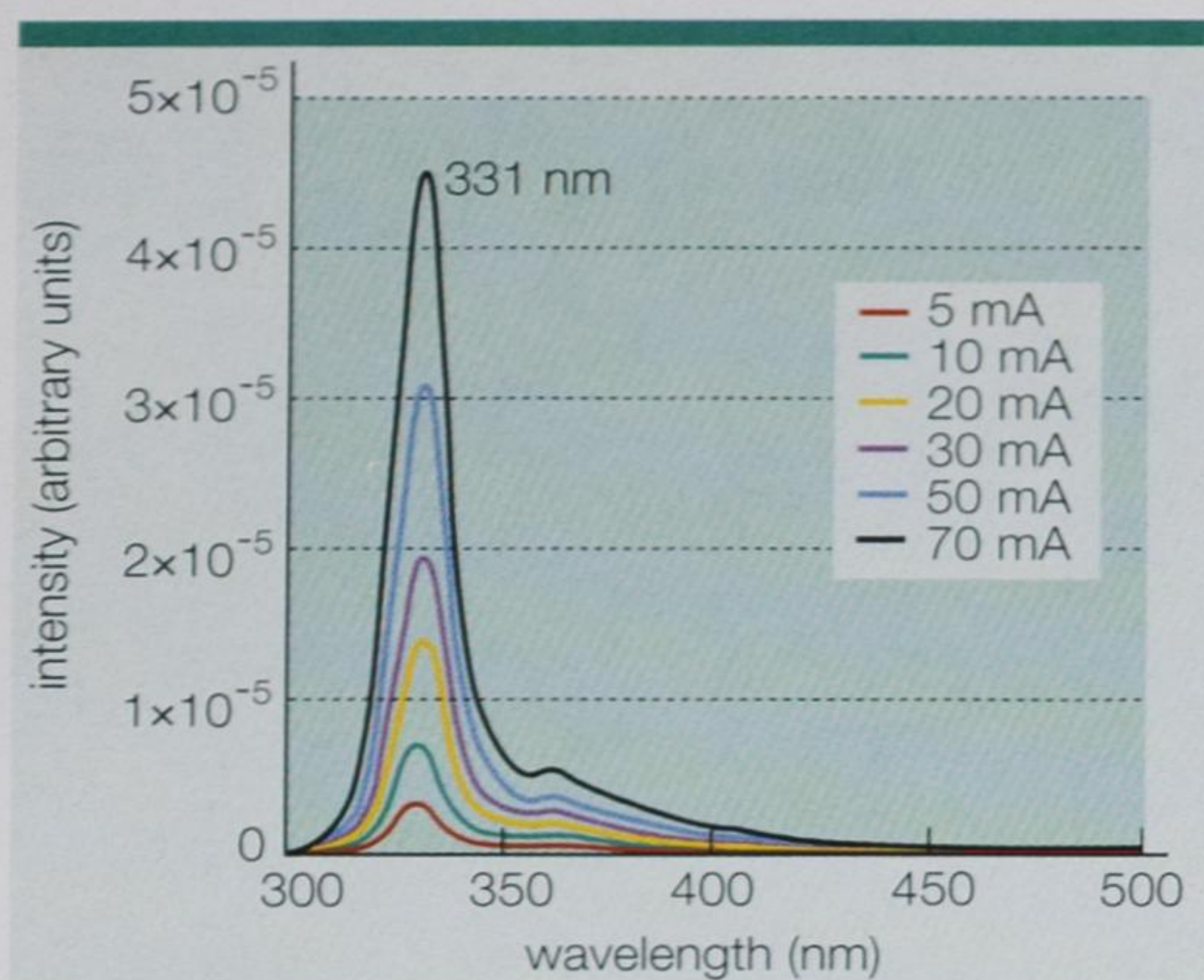


Fig. 3. Electroluminescence spectra of HVPE-grown LED structure based on p-AlGaIn/n-AlGaIn/n-AlGaIn heterostructures.

and AlGaIn/GaN high electron mobility transistors.

For UV optoelectronic applications, recent modifications to TDI's HVPE technology has enabled fabrication of UV transparent AlGaIn-on-sapphire templates spanning the AlGaIn composition range from 5 to 85 mol.% of AlN. These AlGaIn layers typically exhibit a standard deviation in alloy composition over a 2 inch diameter wafer of less than 2%. The templates are targeting substrate applications for deep UV AlGaIn-based emitters, and provide a suitable lattice-matched foundation for device fabrication. The excellent UV transparency (figure 2) improves the device efficiency by allowing light extraction through the substrates. TDI will start volume production of UV transparent AlGaIn-on-sapphire templates in 2005.

Advanced HVPE developments at both TDI and the Fox Group have been incorporated in complete UV LED structures, such as devices based on AlGaIn/AlGaIn p-n heterostructures with a peak wavelength of 305–350 nm (figure 3). The diode structures consist of a silicon-doped n-type AlGaIn photon-emitting layer with a thickness of typically 50–100 nm sandwiched between n-type and magnesium-doped p-type AlGaIn cladding layers with a higher AlN concentration (Smith *et al.* 2004). These structures, with chip dimensions of 330 × 330 μm, were processed and subsequently packaged into TO cans. The packaged LEDs have a peak wavelength of 341 nm and a full-width half maximum of typically 14 nm, and generate output optical powers of 0.5 mW and 2 mW for pulsed injection currents of 20 mA and 110 mA, respectively. Although this LED structure is not optimized for UV light extraction and contains a partially absorbing p-GaN cap layer, output powers are



Fig. 4. Monochromatic 32 × 194 pixel sign, with dimensions of 0.45 × 1.2 m, using Fox Group's blue LEDs. The devices were not subjected to binning for color or forward voltage. Halftones were achieved by employing lower drive currents.

still comparable to state-of-the art MOCVD-grown UV light emitters.

Commercialization of the UV LEDs will be pursued by the Fox Group, which has already successfully launched production of blue LEDs on customized, automated epitaxial reactors based on designs pioneered by TDI. These blue-emitting devices have achieved a very high color consistency (dominant wavelength typically 460 ± 1 nm), a very good forward voltage consistency (V_f typically 3.6 ± 0.1 V), and reasonable uniformity, repeatability and yields. Today's available products, all measured in continuous-wave mode, include blue (460 nm) epitaxial wafers and LED lamps, die with typical optical powers of 2 mW and die brightness of more than 30 mcd, and lamps of more than 1000 mcd in narrow viewing angle packages. Superior color consistency is a significant issue for display and sign manufacturers, who are beginning to utilize the Fox Group's blue LEDs (figure 4).

Commercialization of UV emitters

Although the current blue LED production at the Fox Group is based on 2 inch diameter sapphire substrates, scalability of HVPE technology to 3 and 4 inch technology has already been proven. Further progress in this direction was achieved very recently, when TDI demonstrated the world's first 6 inch GaN epitaxy (see p7).

The Fox Group has also started to test third-generation prototypes of its 360–365 nm UV LEDs, and plans to offer UV dies and lamps before the end of 2004. Preliminary specifications, measured in continuous-wave mode and at 20 mA, include a peak wavelength of 361 nm, a radiated power of 0.5–1 mW and a forward voltage of 3.7 V. The structures are reasonably robust, and with proper thermal

management they will operate continuously at currents of more than 100 mA.

TDI and the Fox Group are also investigating the use of UV LEDs to generate more aesthetically pleasing white light by pumping a mixture of currently available phosphors, such as those developed for the fluorescent lighting industry. Both companies acknowledge that low-cost, high-efficiency white light emitters are the key to enabling rapid adoption of solid-state lighting, but in the short term they will target the attractive niche markets that exist for UV LEDs, such as medicine, biomedicine and industrial applications.

The key scientific challenges to achieving high-power UV LEDs by HVPE are similar to those faced by MOCVD, MBE or any other deposition process: to improve carrier injection in the light-emitting active area of the device structure and to increase the internal and external quantum efficiencies. The HVPE process enables competitively priced high-quality growth of GaN and AlGaIn materials with low background-impurity-level characteristics, and may provide the winning ingredients for cost-effective, high-efficiency UV light emitters. ●

Further reading

B Lam *et al.* 1998 *Mater. Res. Soc. Symp. Proc.* **639** G6.4.1.
G A Smith *et al.* 2004 *J. Appl. Phys.* **95** 8247.
A Usikov *et al.* 2004 UV Solid-State Light Emitters and Detectors. *NATO Science Series* **144** 15–29.

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Barney O'Meara, the Fox Group's vice-president of marketing and sales, can be contacted at bomeara@thefoxgroupinc.com.

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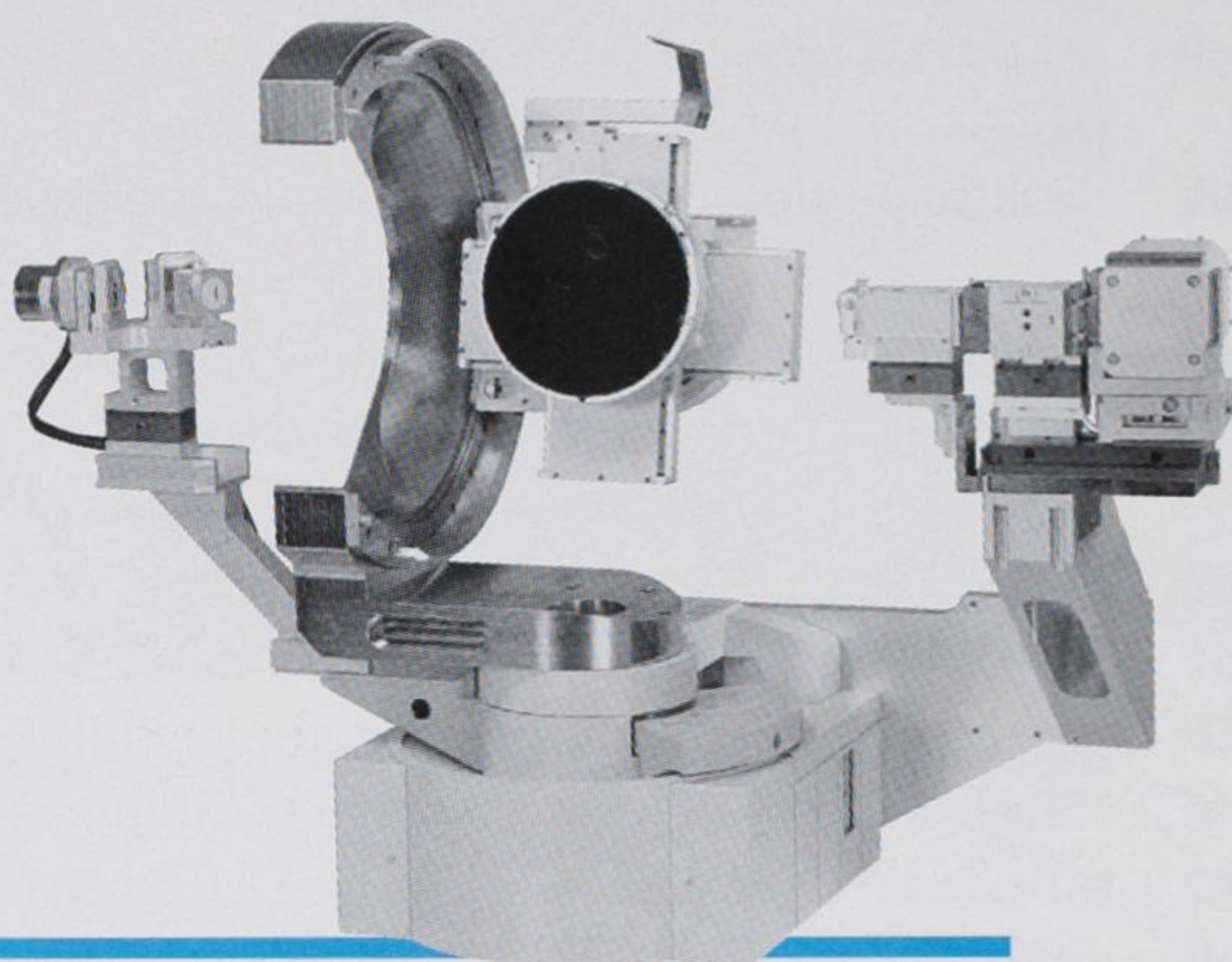
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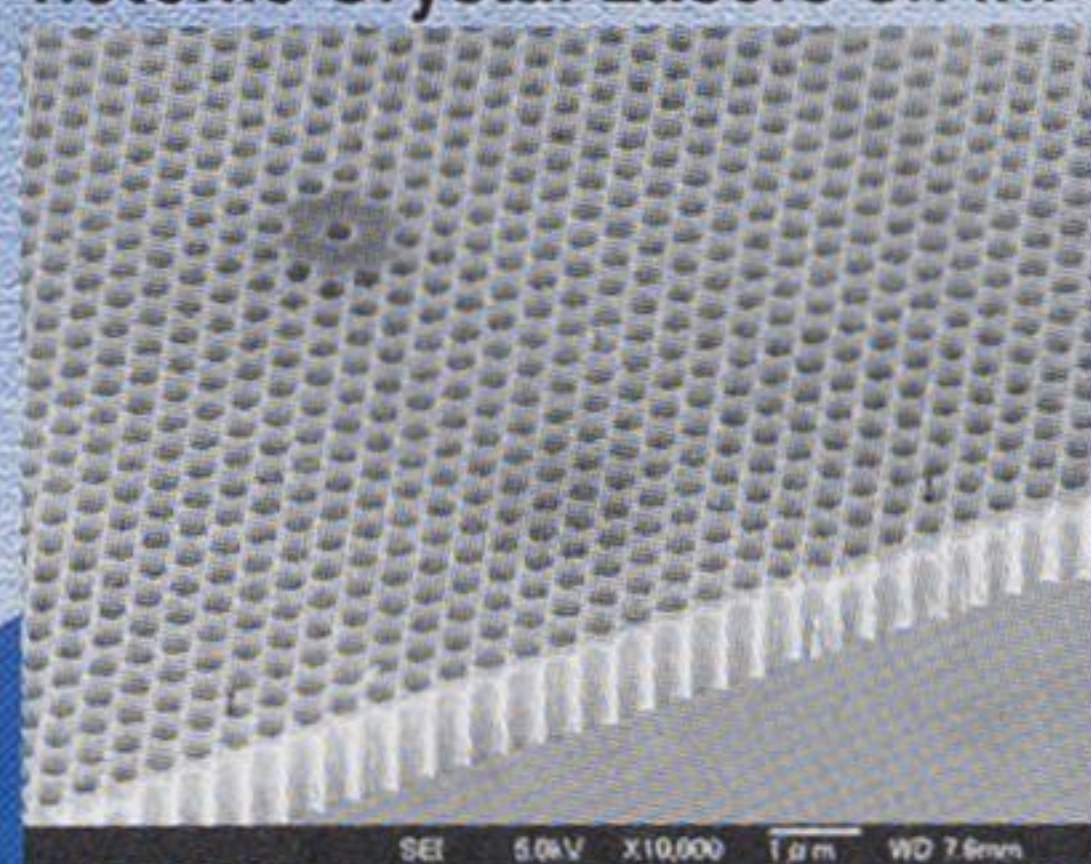


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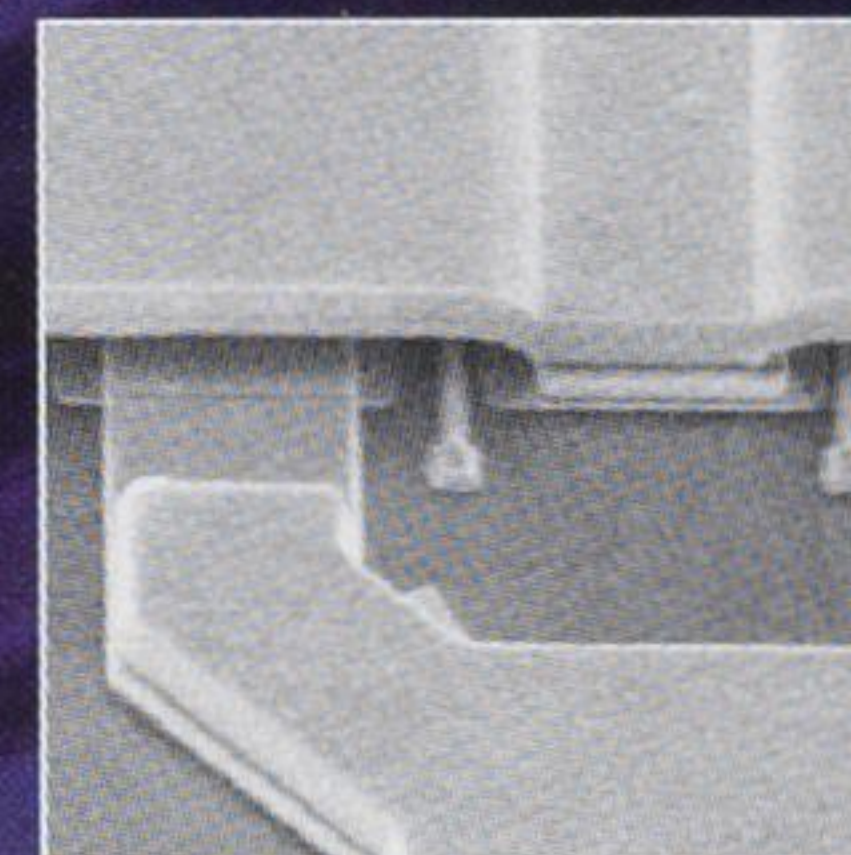
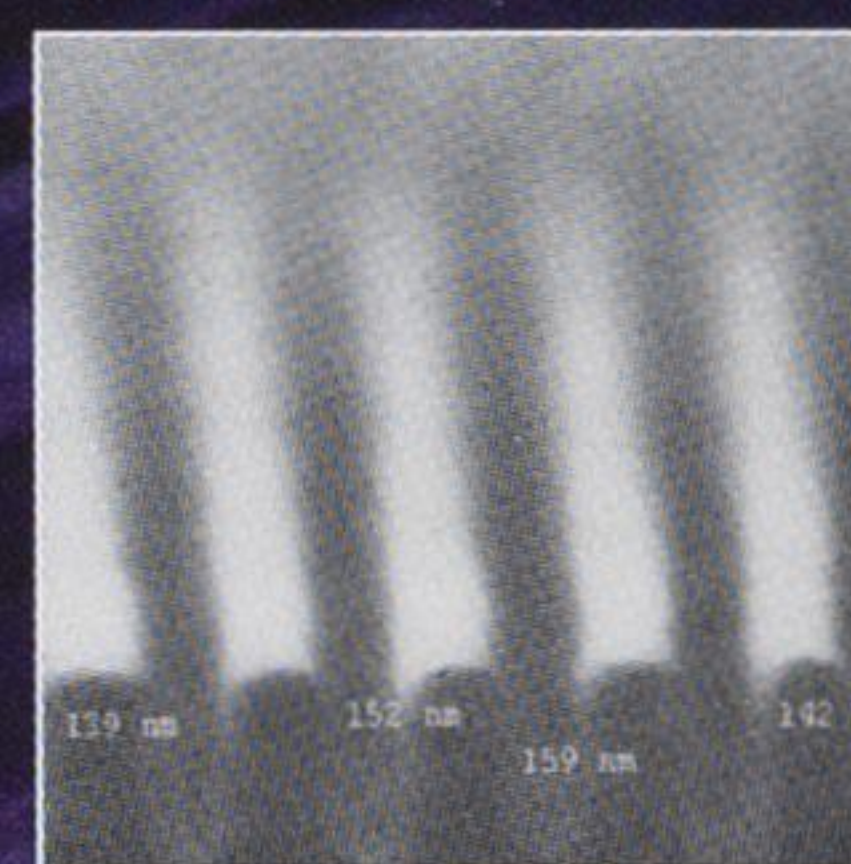
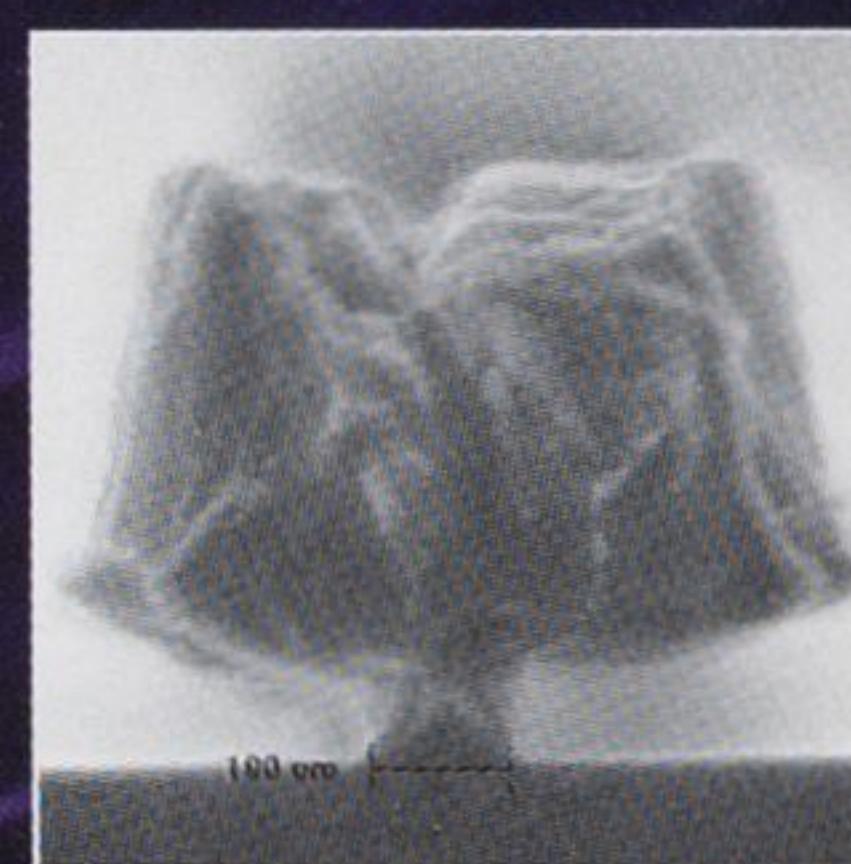
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LED makers reveal performance r

Improvements in LED efficacy at Cree, Osram and Nichia were all voiced at Intertech LEDs 2004, alongside Evident's progress in the commercialization of nanocrystals for phosphor converters and emitter devices. **Tim Whitaker** and **Richard Stevenson** describe the highlights of the conference.

At the Intertech LEDs 2004 conference, held in San Diego on October 20–22, a number of manufacturers described continued improvements in the performance of LEDs. Representing Cree Lighting was Bernd Keller, who outlined the progress of the company's XThin XT-27 chips for white-light emission.

Keller detailed white LEDs with a color temperature of 6000 K, a record efficacy of 82 lm/W at 20 mA, and a flux of 5.2 lm. At the lower color temperature of 4600 K, efficacy and flux are improved (92 lm/W and 5.8 lm, respectively). These developments have resulted in a record quantum efficiency of 50% – not far short of that exhibited by today's best red AlGaInP LEDs. Cree has demonstrated equally impressive results with white LEDs fabricated using its much larger XB900 chips ($900 \times 900 \times 250 \mu\text{m}$), including a flux of 67 lm at 350 mA and an associated efficacy of 57 lm/W. At a higher current of 1 A, the efficacy drops to 34 lm/W but the total lumen output from a single chip is 142 lm.

One size does not fit all

Keller believes that further improvements will be possible through optimizing the light extraction from the chip and the epitaxial quality of its various layers. He cited chips with high efficiencies at high current densities as the key to future progress. Providing an insight into Cree's evaluation methods, Keller described the reliability tests on its 7090 series XLamp products. Although these devices are not hermetically sealed they can withstand conditions of 85 °C and 85% humidity.

One of Cree's intentions is to tailor its lineup of LED chips to meet the needs of different applications. To this end, the company has developed a $500 \times 500 \mu\text{m}$ chip (XB500) designed to run at 125 mA with a radiant flux of 90 mW. This will bridge the gap between the XB900 (200 mW at 350 mA) and the XT270 (64 mW at 20 mA).

According to Nichia's Drake Stalions, the

Japanese company agrees with Cree's philosophy and also provides a choice for its customers by placing its white LEDs into four categories: 5 mm; surface mounted; mid-flux (named Rigel); and high-flux (Jupiter). While the first two have a flux of around 3 lm, the Rigel packages provide 15 lm for channel letters and task lights and the Jupiter LEDs provide 42 lm with a range of available optics.

Despite the 5 mm and surface mounted white LEDs having a low flux, they exhibit a high efficacy of around 50 lm/W. Stalions revealed that the efficacy of 5 mm LEDs has doubled since 2002 and that targets for 2007 and 2010 are 70 and 100 lm/W, respectively.

Klaus Streubel from Osram Opto Semiconductors described progress with the company's thin-film technology, which resulted in very high brightness LEDs, emitting in the red (AlGaInP), infrared (AlGaAs) and blue/green (InGaN) regions of the spectrum.

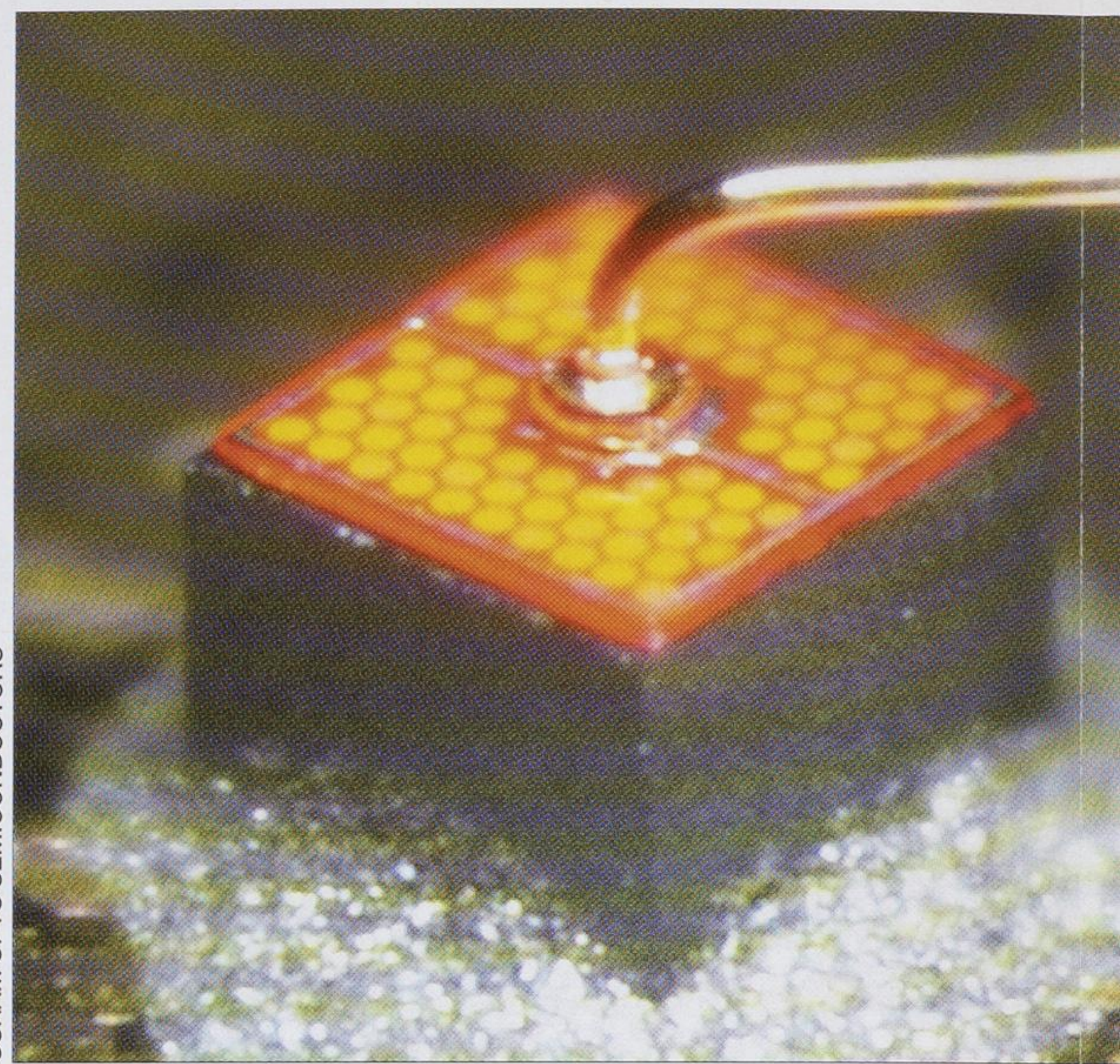
The fabrication process for its AlGaInP thin-film LEDs starts with epitaxy of the LED structure on a 4 inch GaAs wafer. A gold/tin alloy is deposited over this structure and a 4 inch germanium carrier wafer. These two wafers are soldered together before a wet chemical etch process removes the GaAs substrate. This allows the metal layer at the bond interface to act as a highly reflective mirror and an electrical contact.

Buried prismatic structures, which have been used in Osram's commercial LEDs for a few years, are inserted to improve extraction efficiency. According to Streubel, these features have dimensions of about $10 \mu\text{m}$. Osram has also investigated smaller structures with dimensions similar to the wavelength of visible light, although these "photonic structures" did not improve the device efficiency.

Osram has reported 614 nm LEDs with an efficacy of 108 lm/W. Streubel said that at longer wavelengths its LEDs are more efficient, but their efficacy drops because of the eye's sensitivity curve. Efficiency at shorter wavelengths is lower due to reduced carrier



EVIDENT



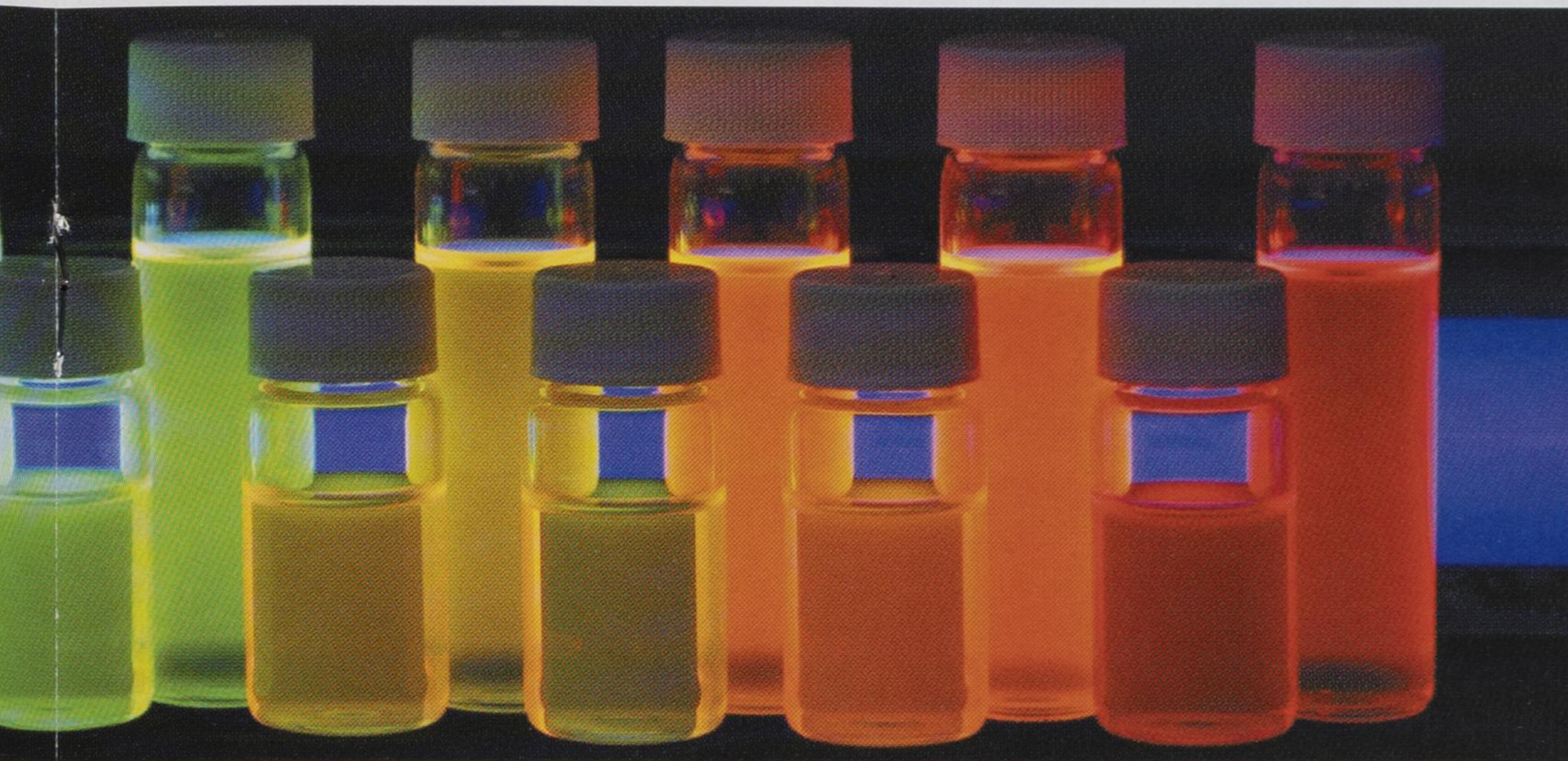
OSRAM OPTO SEMICONDUCTORS

confinement arising from the smaller band offsets between the active and cladding regions of the structure.

For larger-area (1 mm^2) AlGaInP devices operating at 627 nm, Streubel reported a flux of 96 lm with a current of 1 A, and a wall-plug efficiency of 40% at around 100 mA. He added: "There's no difference in yield between different chip sizes." Encouragingly, the larger chips are also slightly more efficient, but Streubel said this can be attributed to a more fortunate distribution of the buried prisms.

Similarly, high-performance AlGaAs thin-film devices with infrared emission at 850 nm were reported to have a flux of 500 mW for a single, 1 mm^2 chip operating at 1 A.

records and high-power products



which were also demonstrated at CEATEC in Japan, the lumen output was listed as follows: red: 35 lm; orange: 40 lm; yellow: 30 lm; green: 25 lm; blue: 15 lm; and white: 35 lm.

Rohm also displayed side-emitting white LEDs with a very high brightness of 600 mcd at 20 mA. The surface-mount package has a thickness of 0.8 mm, making it suitable for thin, full-color liquid-crystal-display designs.

A low-cost solution?

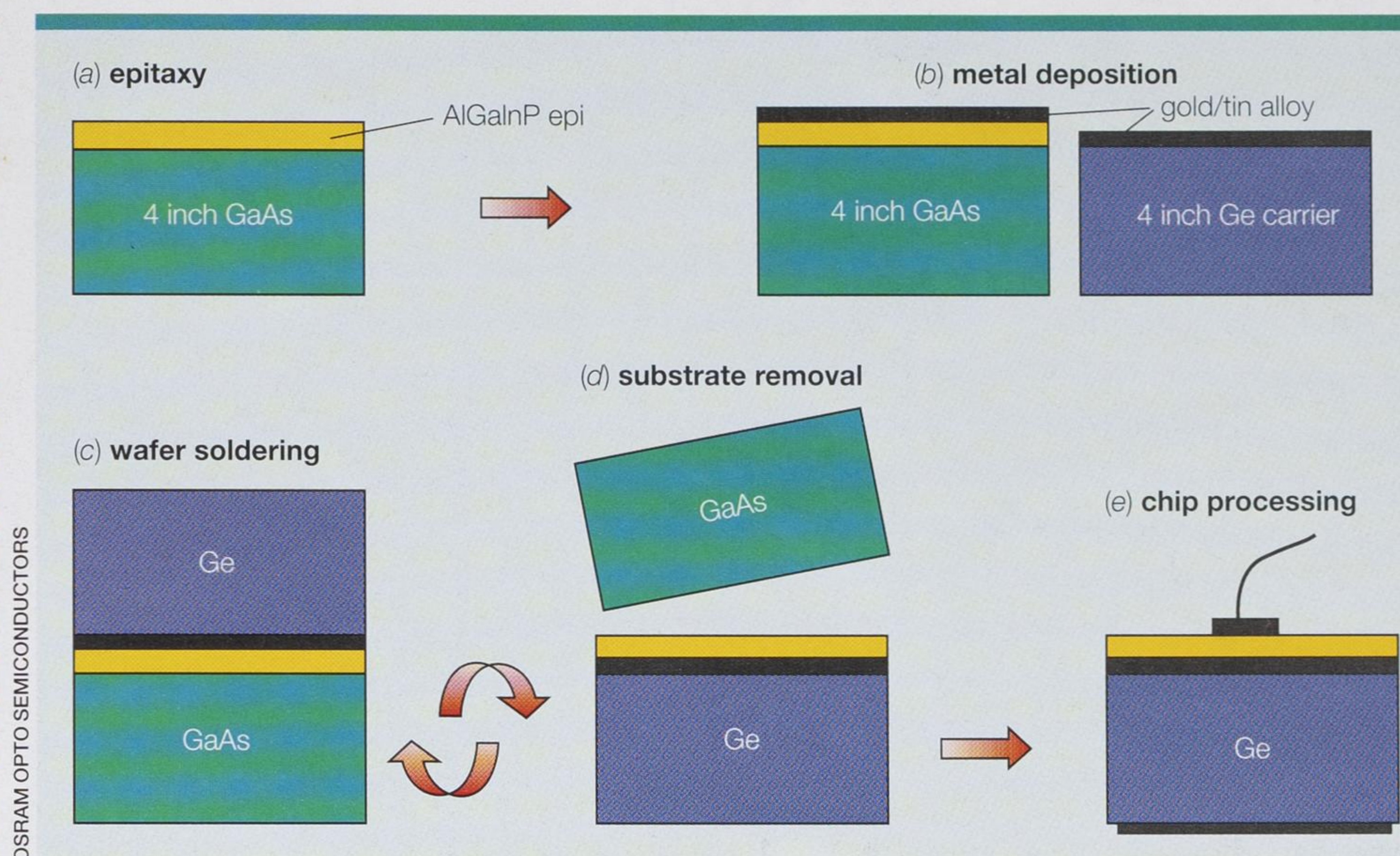
An alternative approach to LED fabrication, namely replacing either the emitter or color-converting phosphor with nanocrystals, was outlined by Clinton Ballinger, CEO of US-based Evident Technologies. Ballinger explained that nanocrystals may be thought of as quantum dots formed in solution by a method akin to liquid-phase epitaxy, instead of being grown on a substrate. As with quantum dots, a nanocrystal's emission wavelength depends on its size. "If you want to make a larger nanocrystal, heat it for longer," revealed Ballinger. At Evident, online monitoring allows control of the emission properties of nanocrystals to within a few nanometers.

Evident's first nanocrystals were made from CdSe, but devices containing cadmium will soon be banned in Europe and Japan, so the firm is now working with InP-based nanocrystals. According to Ballinger, these nanocrystals – expected to be released commercially during 2005 – are better suited to LED applications. This superiority arises from the larger difference in wavelength between emission and absorption of the InP-based material, which reduces re-absorption of emitted light, thereby increasing device output.

Ballinger expects Evident to start impacting on the LED market in 2005, initially with a purple LED. This color is produced by mixing the emission from a blue emitter with the red light from down-converting nanocrystals. The white LED market is seen as a mid-term project, two years from revenue generation.

Evident has also made LEDs with an active region that contains nanocrystals with conducting ligands embedded in a conducting polymer matrix. The devices will probably not rely on expensive epitaxial techniques.

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



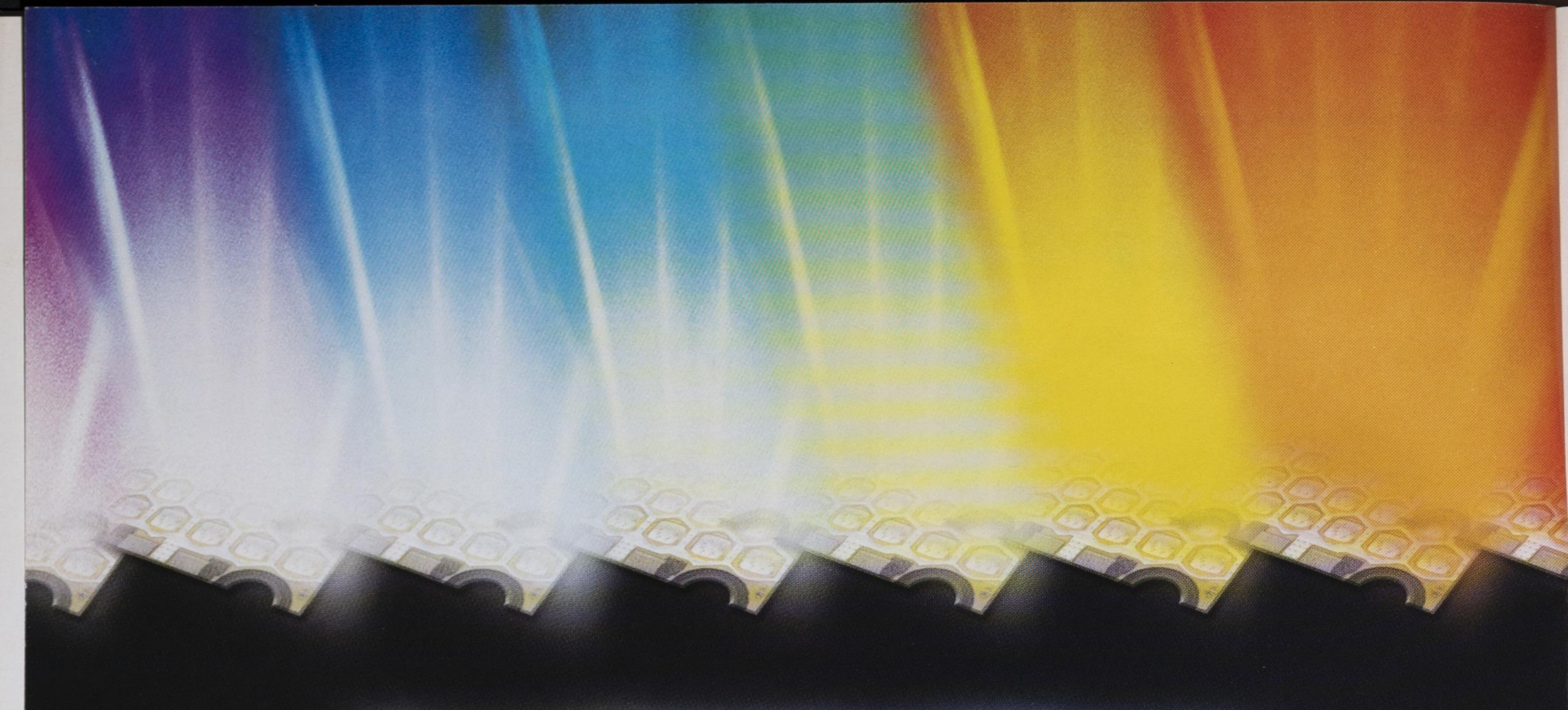
Above: Osram's five steps to producing an LED with a metal layer inside a chip.

(a) Conventional epitaxy is followed by (b) deposition of a gold/tin alloy on both an epiwafer and a germanium carrier wafer. (c) The two wafers are soldered together before (d) wet chemical etching removes the GaAs substrate. (e) Chip processing, including defining metal contacts, completes the process. Left: Osram's AlGaInP-based thin-film LEDs use microprisms to improve light-extraction efficiency. Top: Evident can produce colors across the entire visible spectrum by controlling the size of the nanocrystals used.

Thin-film InGaN emitters have also been produced with a process similar to that used to fabricate AlGaInP LEDs. Device structures were grown on 2 inch sapphire substrates with the substrate removed via laser lift-off. Osram's green LEDs have a low forward voltage of 3.1 V, and, according to Streubel, when housed in a lensed Golden Dragon package, produce output powers of 55 lm at 350 mA and

110 lm at 1.4 A. By comparison, white LEDs in a Golden Dragon package without a lens produced a flux of 48 lm at 350 mA and 3.1 V (equivalent to an efficacy of 44 lm/W), and 110 lm at 1.4 A (25 lm/W).

Japan's Rohm Electronics exhibited a series of high-power LED packages based on chips from Cree and other suppliers. Although little information was available on the products,



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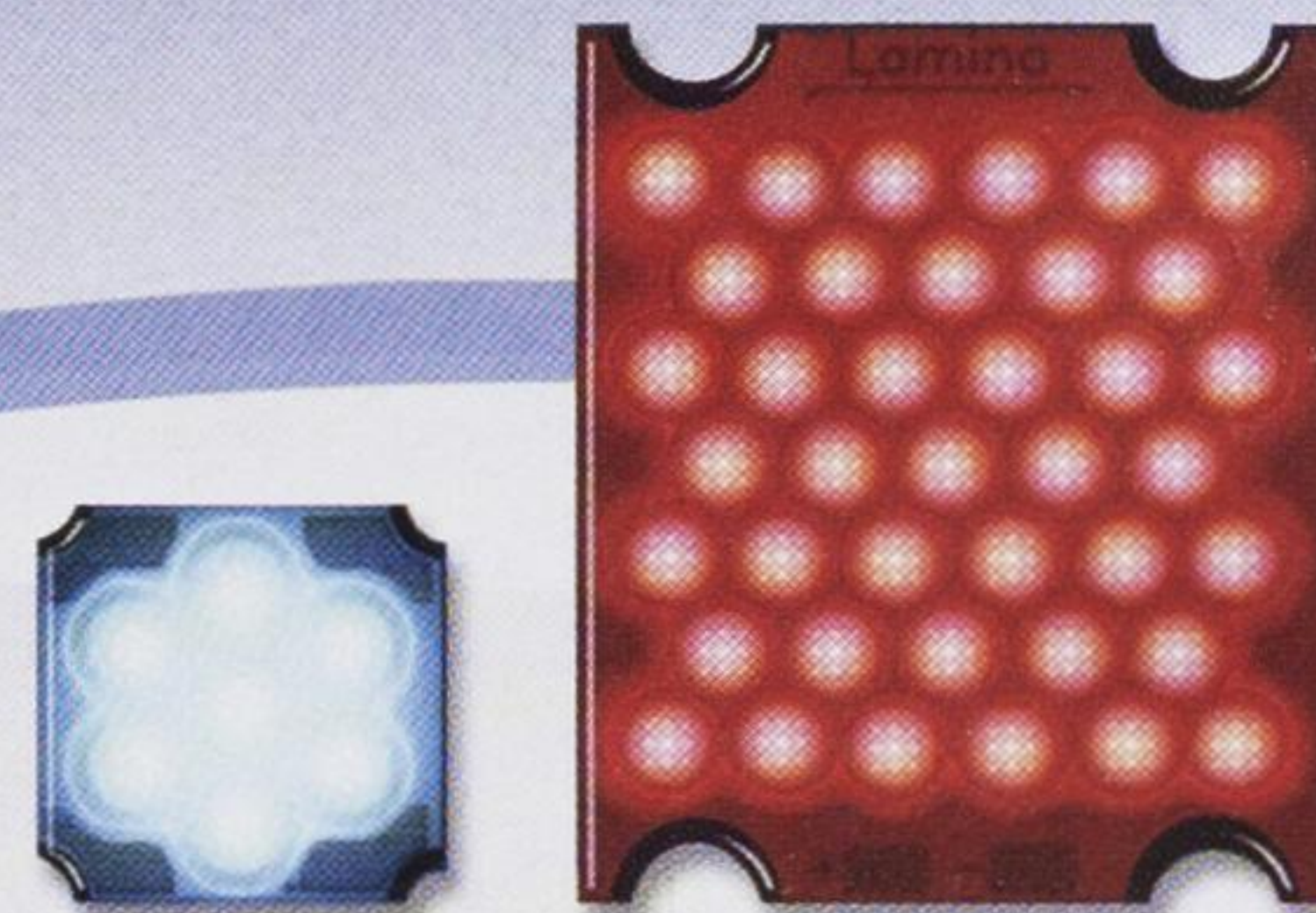
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LCD backlighting continues to thrive as pricing pressure bites

As long as people keep buying cell phones, unit LED shipments will continue to expand, but with increasing downward pressure on selling prices, it will be new applications of ultrahigh brightness sources that drive future market growth. **Michael Hatcher** reports.

This year is the point at which high-brightness LEDs (HB-LEDs) officially started to dominate the overall LED market. That's according to the latest report from US-based market analyst iSuppli.

iSuppli senior analyst Jagdish Rebello noted at the recent Intertech LEDs conference in San Diego, CA, that the HB-LED sector will account for nearly 60% of the total 2004 market for the devices. In 2003, the market was evenly divided, while "standard" LEDs dominated the picture before that.

And with both the standard and HB-LED markets set to enjoy further steady growth in the next four years, it is in the emerging ultrahigh-brightness (UHB) sector that more rapid expansion will be seen, says Rebello.

The iSuppli definition of standard, HB- and UHB-LEDs is as follows. Standard LEDs include those used in established applications such as indicator lights and alphanumeric displays, and have a luminous intensity of less than 100 mcd. HB-LEDs produce an intensity of between 100 mcd and 10 cd, while UHB-LEDs have a minimum luminous intensity of around 10 cd. Examples of UHB-LEDs include Lumileds' red and red-orange Luxeon emitters, which produce 11 cd and 24 cd respectively, and Nichia's 9.2 cd white device. Cree, Osram Opto Semiconductors and Toyoda Gosei are the other key players in this sector.

The overall forecast provided by iSuppli is predictably rosy, with the total LED market set to grow rapidly from around \$4.7 billion this year to reach \$6.8 billion in 2008. That represents a compound average growth rate (CAGR) of almost 13%. The combined HB- and UHB-LED market will grow at about 20% per annum, and will command two-thirds of the total market in 2008, according to the report. At that stage, UHB-LEDs alone will represent a \$1.6 billion market.

Myriad applications are driving this market growth, and broadly speaking the key appli-

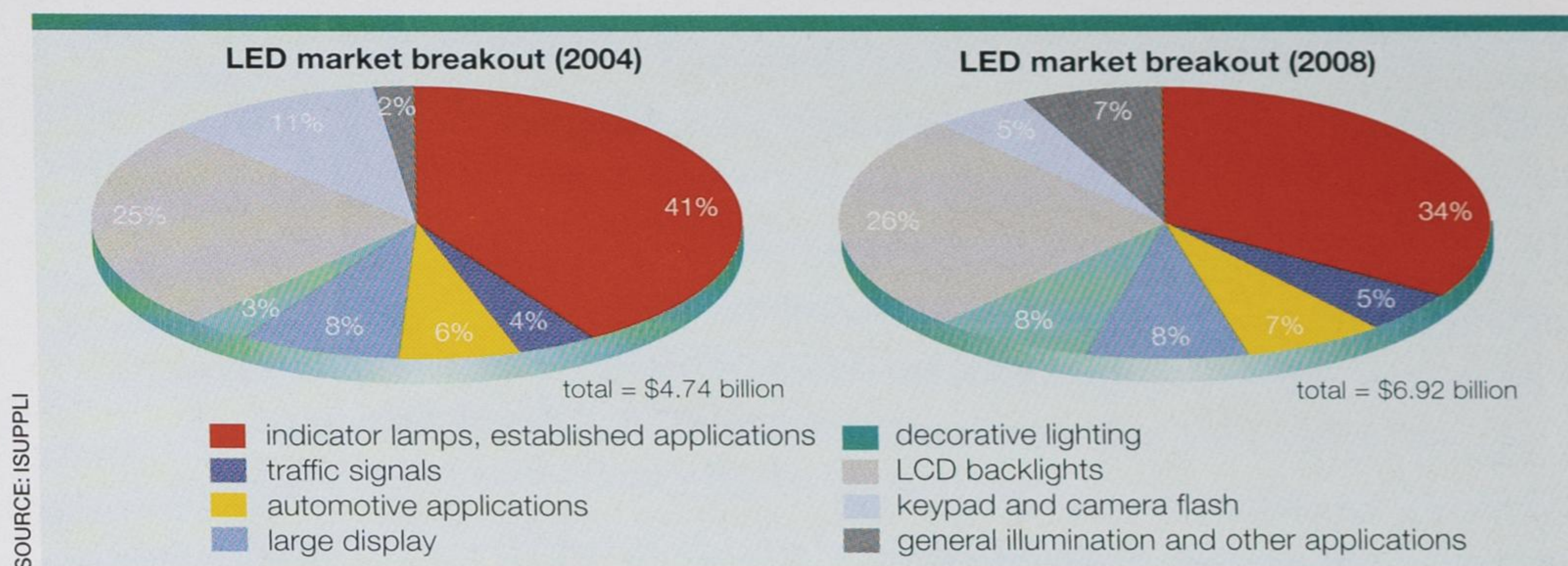


Fig. 1. 2004 and 2008 LED market breakouts. Aside from traditional LED applications in simple displays and indicator lights, LCD backlighting is the biggest single sector for the technology with around 25% of the overall market. By 2008, decorative lighting and general illumination will gain market share at the expense of traditional LED applications.

cations of today are set to remain the key applications of tomorrow (figure 1). However, a close look at the iSuppli figures suggests where there may be some changes, as applications incorporating brighter devices, particularly in decorative and general illumination, begin to emerge. In terms of chip materials, the market for GaN-based LEDs will grow faster than that for AlGaInP, but despite this the latter is expected to maintain the larger market share through 2008 (figure 2).

Keypad backlight market falls

The share of the market driven by cell-phone keypad backlighting is expected to decline markedly as pricing pressures take hold and handset OEMs look to use fewer devices in their products. After enormous growth in the 2002–2004 period, iSuppli predicts that the dollar value of this market will peak this year, with a 13.5% decline expected in 2005 and a similar trend to follow (figure 3).

Part of that trend can be explained by the predicted slow-down in the growth of the cell-phone market itself. This phenomenal application sector, which is now expected to reach around 670 million units this year, will con-

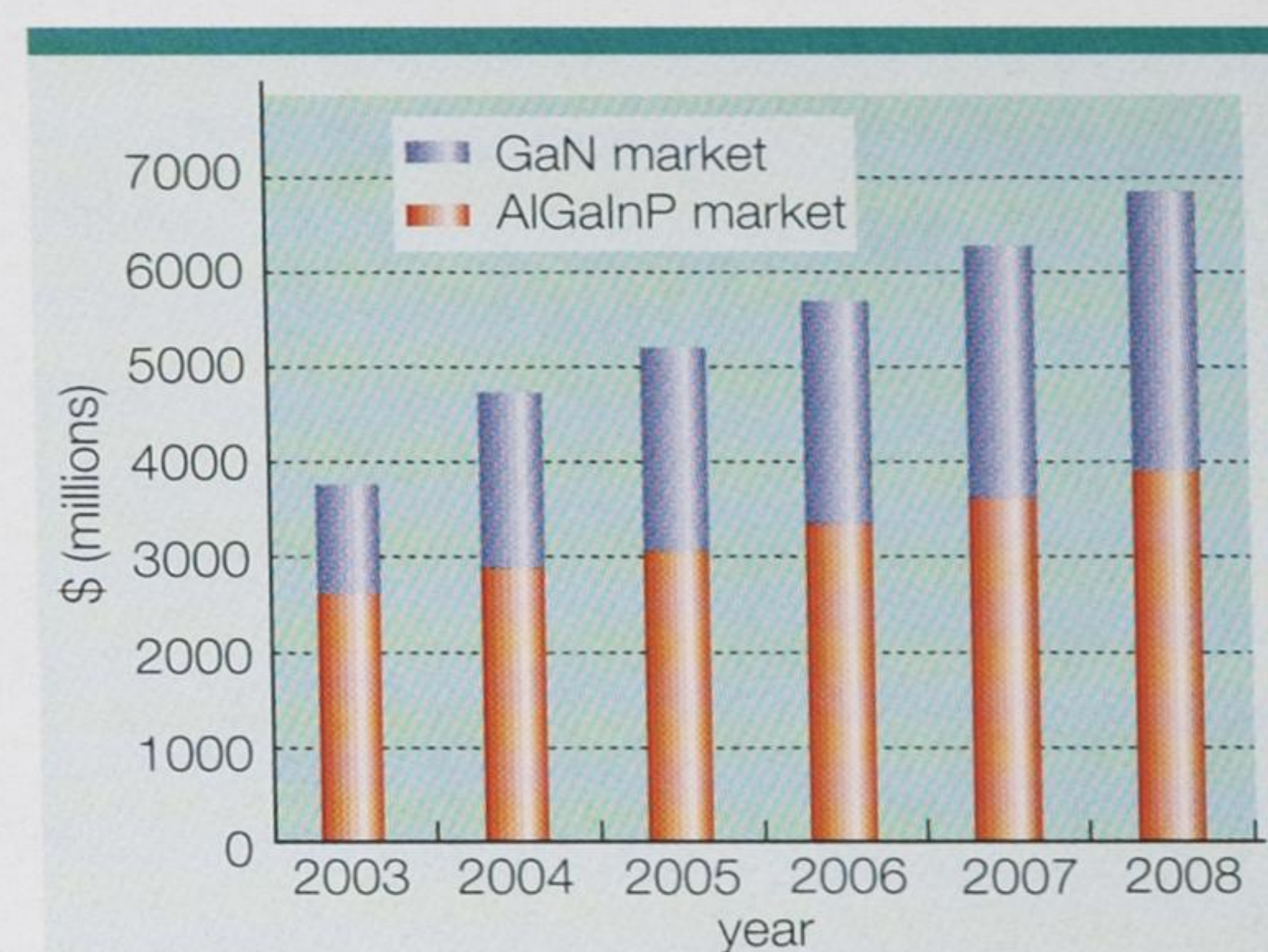


Fig. 2. LED market projection by chip material type. Despite more rapid growth in manufacturing of GaN devices, AlGaInP-based LEDs will still represent the bigger sector in terms of chip material by 2008.

tinue to grow, but at a slower rate than has been witnessed in recent years. Coupled with declining average selling prices for blue HB-LEDs typically used to backlight keypads, this will drive the sector's value down.

However, by far the most dominant LED application in cell-phone handsets is display backlighting. It accounts for the lion's share of the wider LCD backlight sector, which is

worth an estimated 25% of the overall LED market.

LCD backlighting with LEDs already represents a billion-dollar industry. Currently accounting for around half of the HB-LED market, such backlights for LCD screens are set to appear in camcorders, notebook computers and desktop monitors, and will propel this segment towards the \$2 billion mark, maintaining its share of the overall LED market at around 25% (figure 4).

LED-illuminated LCDs are also now penetrating the TV industry – Sony is using products from Lumileds and others to improve the color reproduction of images on screen (see feature on p27).

All of the other application areas for HB-LEDs are much smaller than the cell-phone handset market, but together they will account for around 35% of the overall LED market in 2008, and more than half that of the HB and UHB-LED sectors.

Traffic signals currently represent some 4.4% of the total LED market, a share that is set to grow as UHB-LEDs are incorporated into high-visibility lamps and the proportion of HB-LEDs used in this application declines. “With the development of UHB-LEDs, some vendors are supplying standard traffic-signal products with 6, 8 and 10 UHB-LEDs for red, yellow and green traffic lights,” said Rebello in the report. He predicts that next year a significant fraction of these signals will migrate to UHB-LEDs. Currently worth around \$200 million, the market is dominated by HB-LEDs, which have a market share of more than 80% in the application. The situation is set to reverse by 2008, when UHB-LEDs are expected to take an 80% share of a sector that will be valued at around \$330 million.

LED headlamps – not until 2008

The automotive market for LEDs is being targeted by many vendors, and is viewed as one of the key applications that the industry must penetrate if it is to make significant progress. However, this will be complicated by the fact that car manufacturers in different countries have different reasons for incorporating LEDs into their vehicles. “While American car makers favor LEDs for their styling and design flexibility, Japanese and European manufacturers tend to value the longer lifetimes and lower power consumption,” said Rebello.

According to the report, the market for LEDs used in automotive lighting will grow at a CAGR of 13.6% from \$281 million at present to \$446 million in 2008.

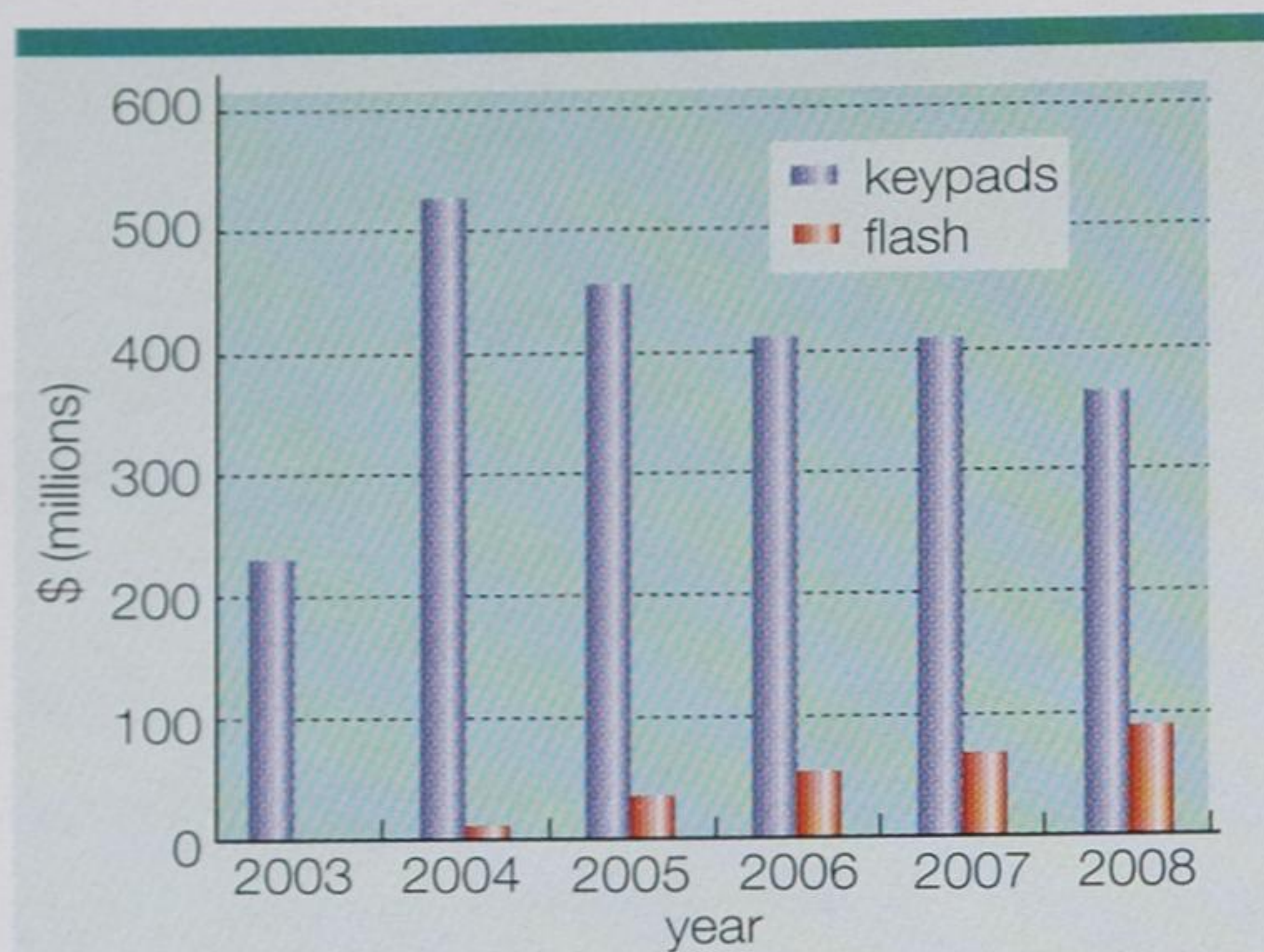


Fig. 3. Cell-phone keypad and camera-flash market 2004–2008. Downward pressure on average selling prices and the trend toward using fewer LEDs for backlighting of cell phone handset keypads means that this particular application sector will drop in value after peaking this year.

With around 30% of new cars sold in 2003 using at least one LED lighting system, there is clearly plenty more of this market still to penetrate. In 2004, automotive applications emerged to become the third-largest market sector for HB-LEDs and the fifth largest sector overall. And although car headlamps powered by white LEDs are often seen in concept cars, Rebello believes that these will only begin to emerge around the 2008 time frame at the very earliest, as UHB-LED manufacturers work to improve output powers.

Video market doubles

Measured by area, the market for large LED-based video signs is expected to double from 40,000 m² in 2003 to 80,000 m² in 2008. In terms of dollar value, this represents a CAGR of 9%. Currently dominated by HB-LEDs, iSuppli expects that UHB-LEDs will have around half of the market share by the end of its forecast period.

So-called “decorative” lighting, where LEDs are used to illuminate public spaces such as hotels, retail stores and gardens, represents one of the biggest growth areas for the technology. Despite being a small market currently, iSuppli predicts a CAGR of around 50% as designers increasingly exploit the flexibility of LED emission regarding different colors and brightnesses. Although accounting for just 2% of the overall LED market in 2003, this figure is set to rise sharply to around 8% in 2008 as UHB-LED manufacturers in particular feel the benefits of a market that is primarily geared up to grab customer attention.

Worth an estimated \$12–14 billion annually, the general illumination market remains

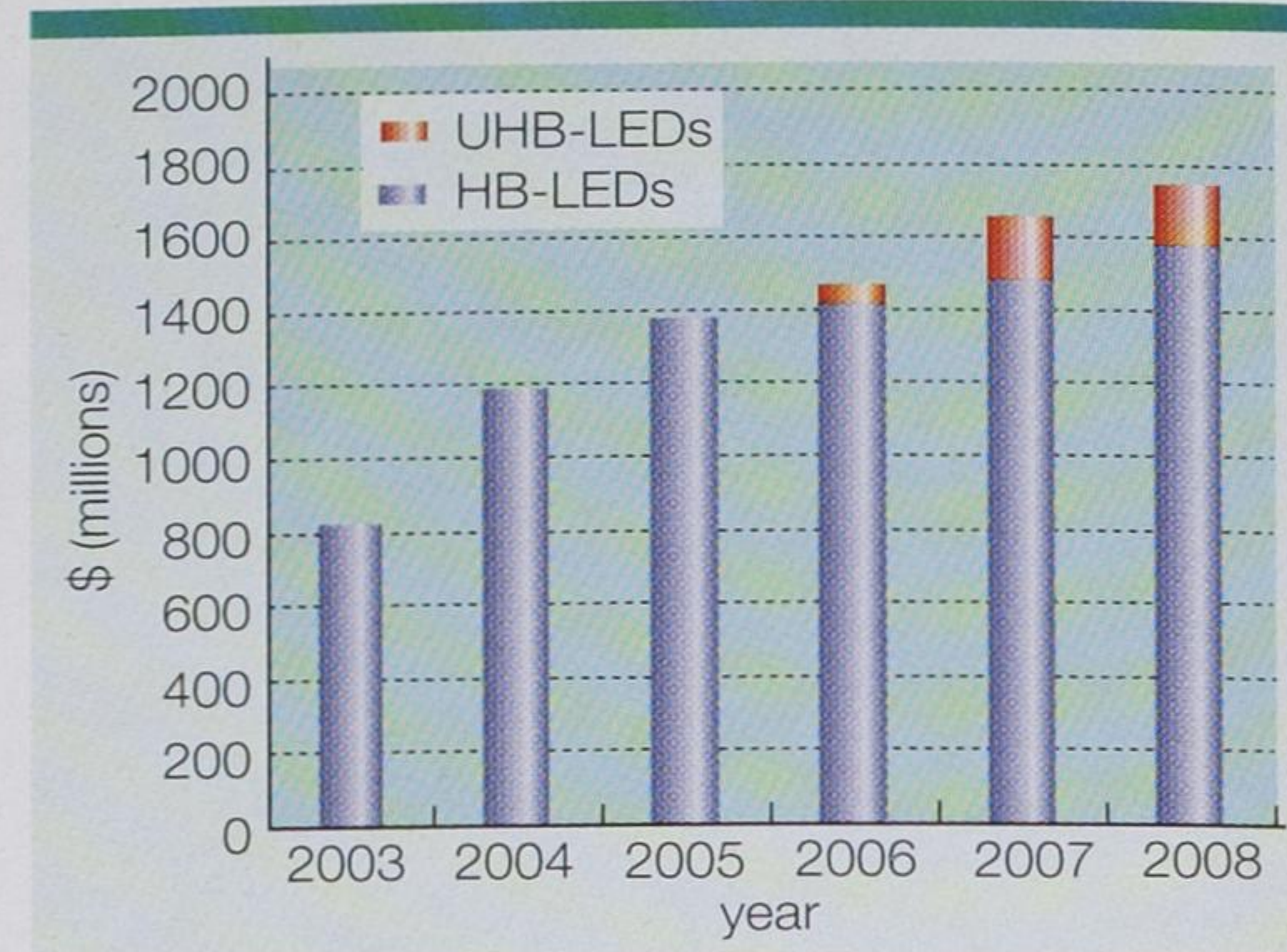


Fig. 4. LCD backlight market 2004–2008. After very rapid growth over the past two years, the LCD backlighting sector will start to level out as the wider cell-phone market itself begins to flatten. Despite growth in cell phones slowing, similar backlighting applications in other consumer products such as TVs are expected to help the sector retain its market share at around 25%.

the single biggest addressable market for LED technology. Acknowledging that serious penetration remains a long way off, iSuppli says that LEDs account for a “negligible” percentage of the current market. This is likely to remain the case for the next few years, with Rebello predicting that we will have to wait until 2015 before LEDs appear in general lighting to any significant degree. The biggest reason for this is price, with LED lamps currently costing around 100 times as much as traditional lamps. “The days of the light bulb, as we know it, are not yet numbered,” said Rebello in his report.

He also warned against LEDs being developed simply as a replacement technology: “If all LEDs do is replace traditional sources in lighting applications, then their success will be limited. Lighting designers, OEMs and module manufacturers must look to harness the power of LEDs in new applications and advance the overall lighting industry.” But even as penetration does begin, an interesting tension may arise from the longevity of semiconductor-based lights. As LED-based lamps need replacing far less frequently than traditional light bulbs, the replacement market will undergo a “dramatic contraction”.

Requirements for growth

Rebello highlighted some key developments needed to drive the next “growth spurt” in the industry. The primary requirement is for new applications, particularly those that use UHB-LEDs. One example of this – in the short term – could be head-up displays (HUDs) in cars,

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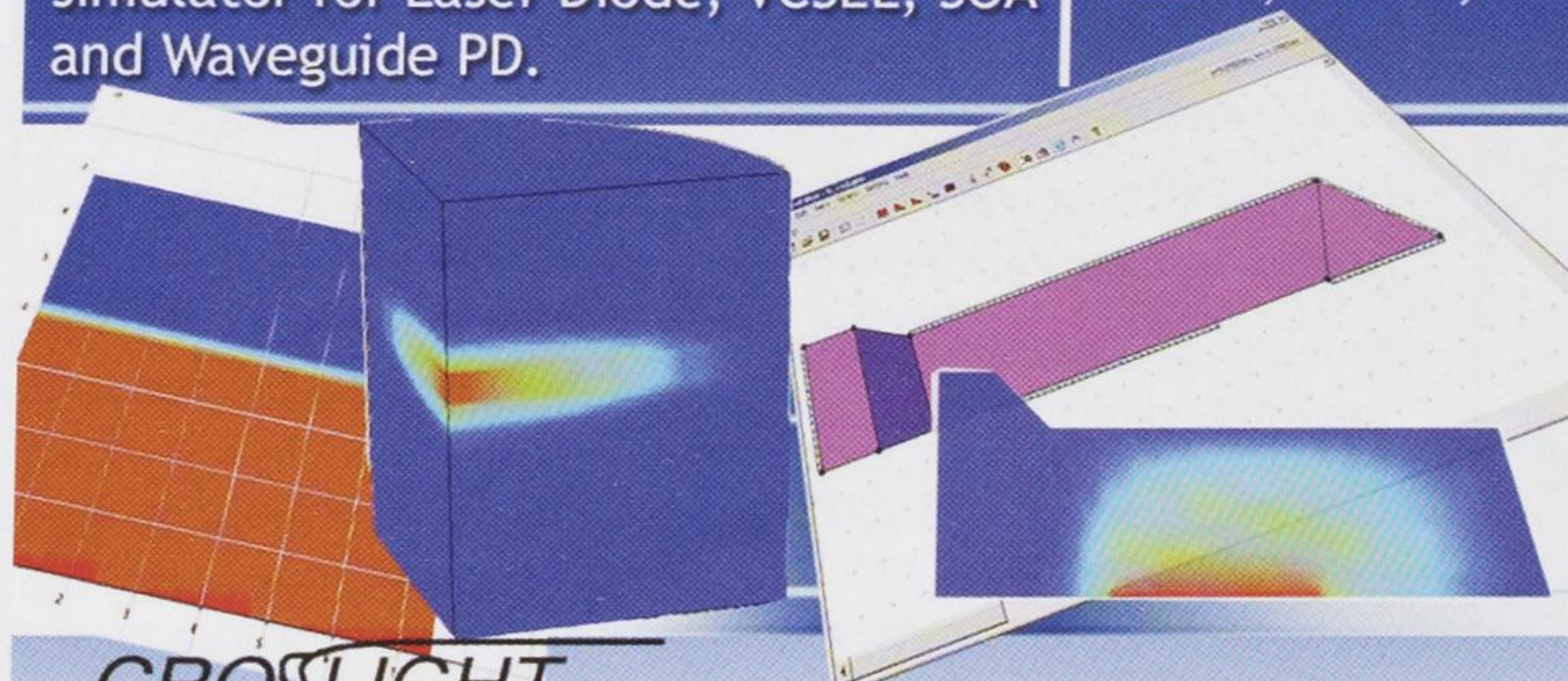
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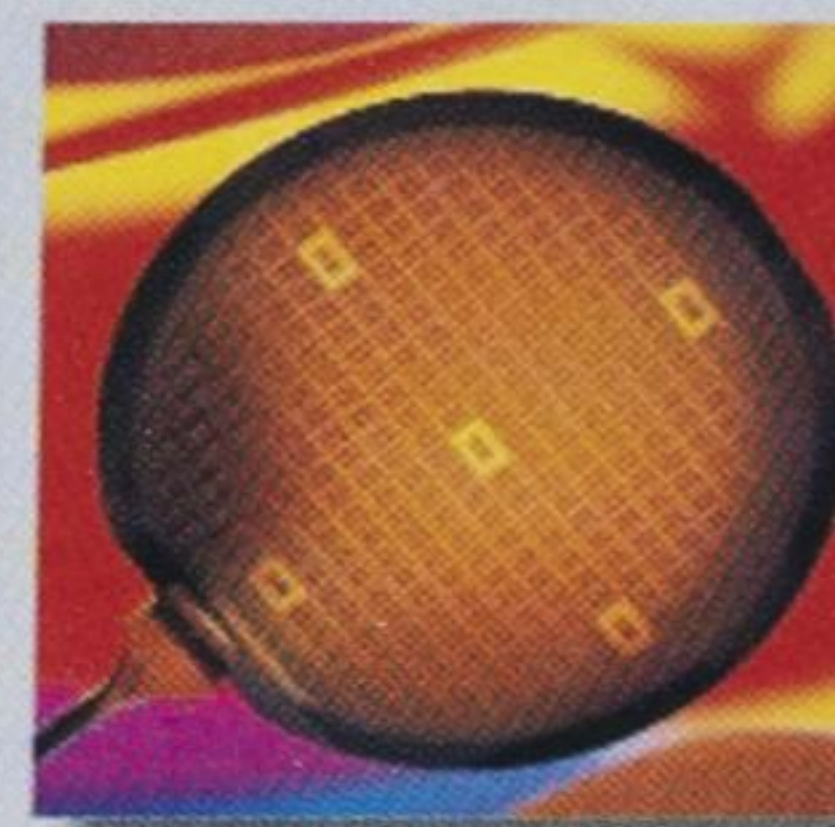


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LED MARKET

in which a UHB green emitter projects information traditionally displayed on the dashboard onto the front windscreen. Another possible growth driver is the application of high-power white LEDs in LCD projectors.

Osram has made some progress in both these application areas, having recently released its new "O-star" white LED. O-star is a high-power RGB source that uses the Regensburg-based company's thin-film chips, which minimize light loss through the edges of the device. It emits more than 120 lm from its 3 x 1 cm profile, with the source consisting of one red, one blue and two green thin-film chips, a ceramic carrier for connecting to the heat sink, and electrostatic discharge elements that are said to provide reliable protection against high voltages. Osram is targeting projector backlight applications, noting advantages such as a much reduced warm-up time, plus the oft-quoted improvement in lifetime.

The German LED maker has also developed a red and green light source for automotive HUDs. The technology is being used by Siemens in a driver information system that it is supplying to Germany-based car manu-

Table 1. All LED lamps

Company	Market share (% by revenue) in 2003
Nichia	24.9
Osram	7.3
Citizen Electronics	7.1
Agilent Technologies	6.7
Toyoda Gosei	6.2

SOURCE: ISUPPLI

Tables 1 and 2: leading suppliers of packaged LEDs and market share. *The quoted figure for Cree, which sells mainly LED die and relatively few packaged LEDs, likely reflects sales of lamps by Fairchild Semiconductor and Sharp Electronics. Both use Cree LED die.

facturer BMW (*Compound Semiconductor* April p8).

Other developments identified by Rebello as critical to future growth include: a need for average selling prices to drop at "high double digit" rates per year; additional manufacturing capacity to come online by 2006; more LED vendors; the development of semiconductor drive circuitry for dynamic control of LEDs; and stimulation of the corporate and retail lighting markets, which have been slow to take off.

On top of that, Rebello called for the indus-

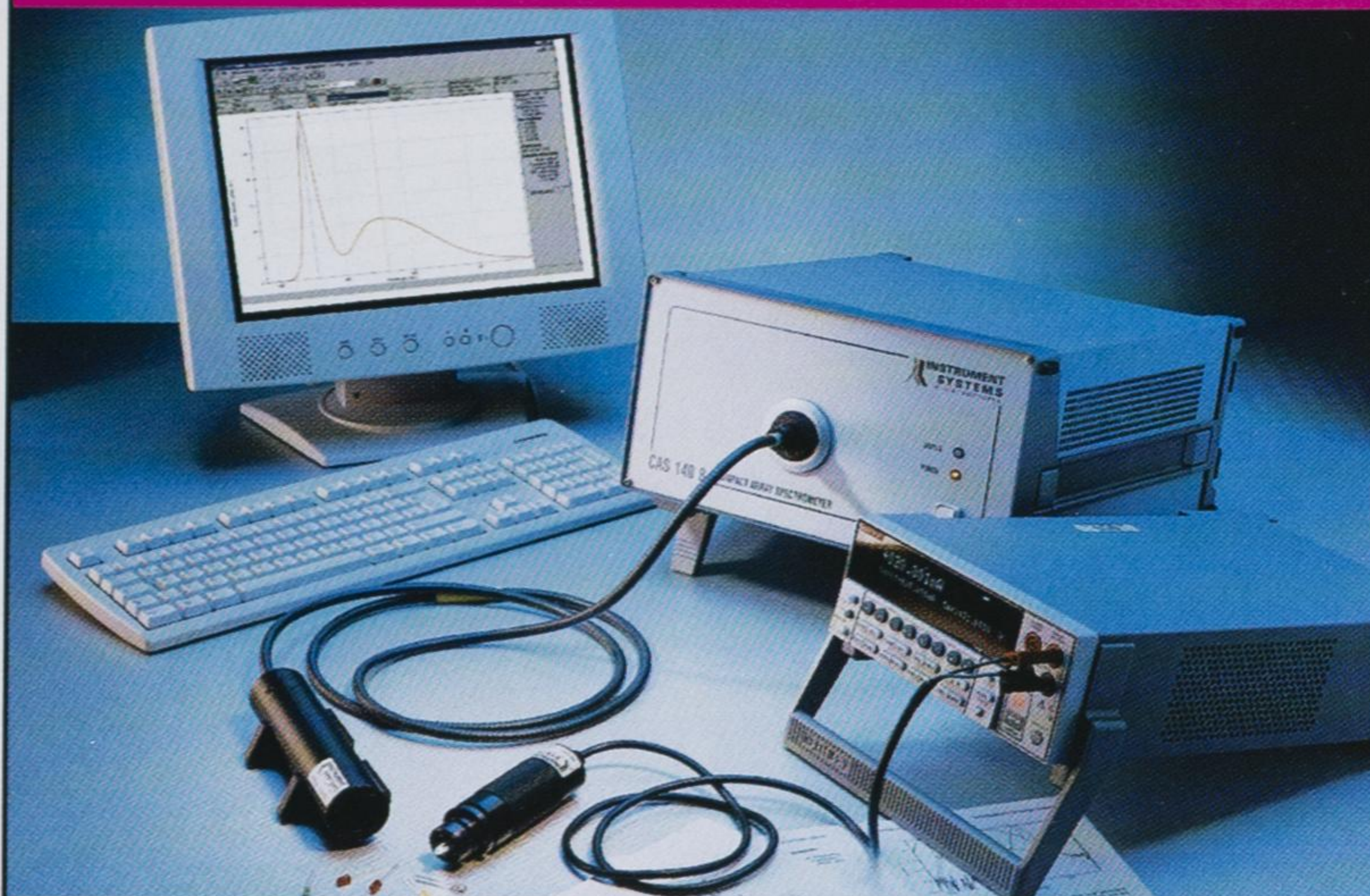
Table 2. GaN-based LED lamps

Company	Market share (% by revenue) in 2003
Nichia	63.1
Toyoda Gosei	10.4
Citizen Electronics	9.1
Cree*	4.7
Osram	3.4

try to develop standards – particularly for package designs, and to stay aware of developments in organic LEDs (OLEDs). "Every OLED display will replace an LCD display and reduce the available market for LEDs," he said, while projecting that the OLED market would mushroom to around \$3.25 billion by the end of the decade – mostly through applications in cell-phone displays.

● iSuppli's latest LED market report "Solid-state lighting: brighter LEDs continually expand illumination application" is available at www.isuppli.com.

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LED MANUFACTURING IN CHINA

China seeks LED solution to an energy-resource problem

Despite being a vast country, China's energy resources are relatively scarce. As a result, the government sees LED manufacturing as a key part of the country's future as its rapid economic expansion puts an increasing strain on power. **Michael Hatcher** reports.

With its fast-growing economy, China is using energy at an ever-increasing rate. The total electricity consumption in the world's most populous country is estimated at 2000 billion kWh this year, with 10–12% of that figure devoured by lighting applications.

With electricity use growing at 10% per year on average, it's not surprising that the Chinese government sees efficient semiconductor-based lighting as a key part of its – and, for that matter, the wider world's – economic future. In 5–10 years, China's lighting energy demand is expected to double.

Energy savings

Until about a month ago, Gordon Liu was the president of China-based Lumei Optoelectronics, the company that acquired the LED manufacturing technology previously owned by US-based substrate supplier AXT last year. Speaking at the recent CS-MAX conference in Monterey, CA, Liu estimated that, if widely implemented, LEDs could save China 400 billion kWh of energy over the next decade.

To put this figure in perspective, it is worth noting that China's six operational nuclear power stations have a combined annual output of around one-tenth of this figure. The three-gorge dam power plant, the biggest of its kind in the world, is expected to produce 33 billion kWh in 2004.

This requirement for greater energy-efficiency, plus the Chinese government's motivation to compete with Taiwan's successful entry into the global optoelectronics industry, has propelled LEDs to the top of the political agenda. What the Chinese government is desperate to avoid is a repeat of the way the silicon industry's IC manufacturing model developed, where China was left behind as Taiwanese firms such as United Microelectronics Corporation and Taiwan Semiconductor Manufacturing Company became two

LED manufacturing firms and locations in mainland China

Company	Location	Technology	Status	LED products
Lumei	Dalian	AXT	volume production	blue, green
San'an	Xiamen	mixed	volume production	all
BlueLight	Shanghai	Beijing University	pilot production	blue, green
LanBao	Shanghai	Physics Research Institute	pilot production	blue, green
LianChuang	NanChang	NanChang University	pilot production	blue, green
XinLei	NanChang	unspecified	volume production	yellow, red
Fangda	ShenZhen	NanChang University	volume production	blue, green
LuiYuan	Beijing	Semiconductor Research Institute	company established	n/a
LiDe Huinen	HeBei	HeBei 13th Research Institute	volume production	all
Huagang	Shangdong	Shangdong University	volume production	yellow, red
YinKeLai	Shangdong	Qinghua University	research	blue, green
Aurong	QingDao	QingDao University	research	yellow, red



The Chinese government is using funds to build up both a domestic market for high-brightness LEDs and the manufacturing base to meet the anticipated demand.

LED MANUFACTURING IN CHINA

of the biggest device foundries in the world.

Already established as a prime location for light-bulb manufacture, China has now set up four geographical bases with a remit to develop semiconductor-based lighting. These bases are located in Dalian, Xiamen, Shanghai and NanChang (see map), and so far China has more than 10 chip-manufacturing firms and more than 200 LED packagers. Liu now expects to see more companies established as an acceleration in government funding over the next five years kicks in.

Of the 12 chip manufacturers identified by Liu, six are said to be producing devices in volume, while three are in pilot production. The remaining three companies are at an earlier stage in their development (see table).

Although “traditional” LED manufacturing was first established in China back in the 1980s, it wasn’t until 1996 that the country’s first AlGaInP project was initiated. Volume production followed in 1998, and a similar nitride project that kicked off in 2000 spawned the country’s first foray into volume production of GaN-based devices only last year.

Lumei, which was spun off from AXT in September 2003, finished construction of its manufacturing facilities a year ago and began pilot production in May, says Liu. It has since ramped up its production volumes of blue and green high-brightness LEDs (HB-LEDs; Lumei’s devices emit in the 450–540 nm range) and is now said to be making and selling these devices in large volumes.

Boom time

With the formidable size of the domestic market, plus the backing of the Chinese government and the likely positive effects of events such as the 2008 Summer Olympics in Beijing, the opportunities for Chinese LED makers appear to be very good. However, Liu does warn against some negative aspects of the emerging industry that must be addressed before China can develop into the dominant force that it threatens to become. These include the lack of a complete industry food chain in the country; a system that tends to alienate some high-quality staff; and a substantial lack of intellectual property originating from within the country. Allied to this, says Liu, is the failure to convert some high-quality research at the country’s universities and research centers into industrial processes.

Perhaps most tellingly, there is as yet no sign of a company emerging to become the Chinese equivalent of a Cree or a Lumileds; no true technology pioneer that could become

“Chinese LED manufacturers will not continue to be bottom feeders.”

JAGDISH REBELLO, iSUPPLI

a leading brand among high-power chip manufacturers with high-end products to compete with those of the leading companies in Japan, Europe and the US.

Lumei’s brightest devices emit up to 290 mcd in the green region at 525 nm, and could therefore be justifiably rated as HB-LEDs, but their brightness still lags well behind that of the leading power chips produced by the likes of Nichia.

The Chinese government is trying to change that situation with the sponsorship of technological programs to develop power LEDs, including the Ministry of Science and Technology’s semiconductor lighting program set up in late 2003.

Kate Conway is an independent technical consultant for energy-efficient lighting, specializing in LEDs. She has been involved in helping to draft the Chinese government’s “five-year plan” for energy efficiency, which begins in 2006. Conway says that the government’s plan is to quickly fund a market for high-power LEDs, while simultaneously building up the technological capability to meet that demand through local production. Although building up the market through funding shouldn’t prove problematic, Conway is less confident about the ability of the Chinese to meet technological requirements.

China already has a voluntary program aimed at building market share for energy-efficient lighting. The China Green Lights project has been running since 1995, and Conway is hoping that its remit will soon be extended for another five years. She says that if it is, then from 2006 the program would focus on leapfrogging incandescent and fluorescent lamps with LED-based technologies.

Similar programs include the Efficient Lighting Initiative (ELI), which resumes in 2005 with its administrative headquarters moved to China. It should help to address the quality concerns over Chinese products with its quality export mark for devices such as LEDs used in traffic signals. The ELI is funded by the International Finance Corporation and the Global Environment Fund.

The World Bank has also been heavily involved in a project that is seeking to bring

solar-powered LED lighting to families in rural China who do not yet have access to an electricity grid. Purchasers of a photovoltaic system receive a fluorescent lamp and a 1 W LED lamp made by Sunpu Solar PV Technology of Beijing under the scheme.

Changing attitudes

iSuppli analyst Jagdish Rebello believes that China’s reputation as a source of only low-value LED products will soon change. “Chinese LED manufacturers will not continue to be bottom feeders,” Rebello told *Compound Semiconductor*. “It would be foolish to expect the region to remain focused on low-value devices.” Having used its low-cost advantage to gain entry into LED manufacturing, Rebello says that it is only a matter of time before China competes on both price and performance through licensing deals and the development of proprietary technologies.

As always with China, there is a question mark over whether that technology will be developed “ethically” through licensing deals and proprietary technologies. Certainly it appears that high import taxes are currently deterring Chinese companies from working with those in the West. But one important area where there has been some progress is in product-testing procedures, with Conway saying that Chinese companies involved in LED test and measurement are keen to employ standard CIE tests within the next year.

Rebello estimates that around 7–10% of LED chips are currently made in China, and that the industry will follow the precedent set by companies in the telecoms industry, where Chinese operations that started off making low-value passive products have now moved into higher-value active components.

Although massive investment from the government would undoubtedly be required before China can become a serious producer of high-power chips for general lighting, Liu is certain that the increase in production capacity will eventually pay dividends. He says that if semiconductor technology became responsible for 20% of all lighting in the country, the energy demand from LEDs would be 100 billion kWh per year. The power needed for this would be 50 GW.

His estimate is that to produce this output from LEDs in one year would demand a \$7.5 billion investment in MOCVD equipment. A huge expense, for certain, but the alternative facing China is to build more facilities like the three-gorge dam – and at \$120 billion, the cost of that really is prohibitive. ●

LEDs attempt the jump from small screen to large screen

Several recent announcements indicate that liquid-crystal-display manufacturers are increasingly interested in using LED modules as the backlights in larger screens for PCs and televisions. However, the market may not grow as rapidly as some predict. **Tim Whitaker** reports.

For several years, cell-phone manufacturers have used arrays of LEDs to provide backlighting for keypads and for liquid-crystal-display (LCD) screens. The evolution from monochrome to full-color screens has seen a shift in demand from blue and green LEDs to white. Now, with the advent of higher-performance white LEDs, manufacturers of much larger displays are evaluating whether to use these devices to replace traditional backlight technologies, such as cold-cathode fluorescent lamps (CCFLs).

Some display manufacturers have already gone as far as developing products with LED backlights. In May, NEC-Mitsubishi Electronics Display of America unveiled prototype 21.3 and 23 inch LCD monitors with LED backlights incorporating Lumileds' DCC technology. And in August, Samsung unveiled 17 and 21 inch LCD monitors.

The Korean company says that the LEDs used in these models deliver greatly improved brightness: the 17 inch monitor has a brightness of 500 cd/m² (compared with other models that average around 250 cd/m²). In addition, the high color saturation of 92% means that the colors are much closer to appearing natural than those produced by a standard monitor.

Ahead of the game

Also in August, Sony became the first to unveil LCD televisions that use an LED backlighting system. It said that in Japan, from November, it would start shipping 40 and 46 inch screen televisions from its high-end Qualia range that features LED devices. However, the technology doesn't come cheap: the two Sony televisions will reportedly be priced at ¥840,000 (around \$7500) and ¥1.1 million (about \$10,000), respectively.

LED manufacturers are also getting involved, with Nichia, Toyoda Gosei and Osram Opto Semiconductors having demonstrated LCD displays with LED backlights at

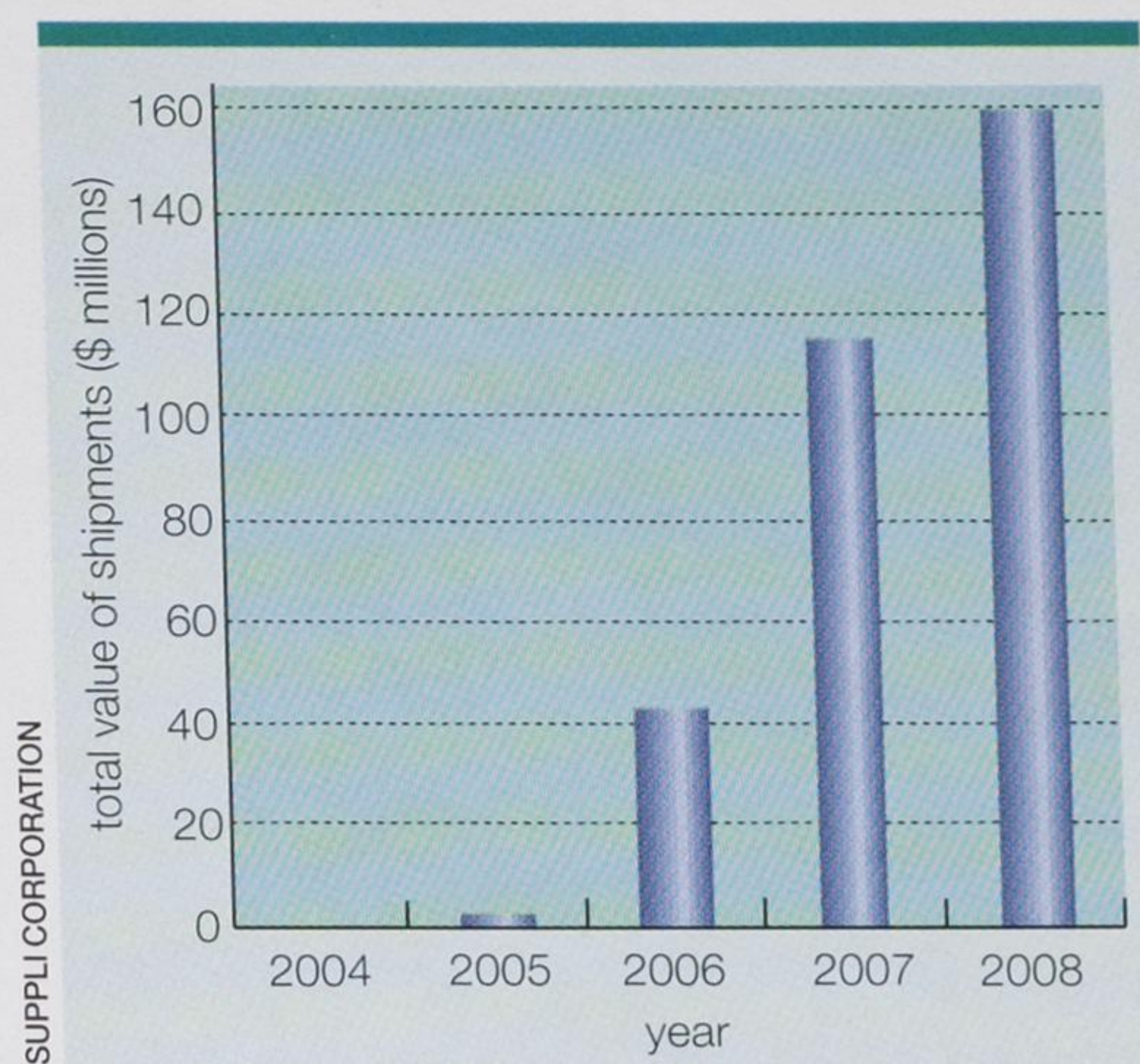


Fig. 1. The large-screen LCD backlighting market for LEDs is expected to reach \$3 million by 2005 and \$160 million by 2008.

Table 1. LEDs versus CCFLs

	CCFL	LED
Color gamut (%)	72	105
Color temperature	fixed	variable
Blinking driving	no	yes
Rise/fall time	500 ms	20 ns
Lifetime (h)	50,000	100,000
BLU power (W)	110	415
Thickness (mm)	32.5	45
Number of lamps/LEDs	16	455

Source: Samsung Electronics

Head to head: LED and CCFL backlights have an equivalent brightness. However, the advantages of using LEDs include a high contrast ratio and long lifetime. With high-brightness devices, the number of LEDs in an application can be reduced.

various shows throughout this year.

LEDs have a number of advantages over conventional light sources such as CCFLs, including long lifetime, ruggedness and the absence of mercury. More importantly from a

user's point of view, LEDs provide extremely good color quality.

The use of LEDs significantly enhances the color gamut (the range of colors) that a display can produce. The display system used in Sony's Qualia televisions has a color gamut that is 105% of the color space defined by the US National Television System Committee, while conventional technologies only produce 65–75% of the same color space. The more hues and tones that can be produced means that finer and more precise color definition can be achieved, so that on-screen color definition is more lifelike. The use of LEDs can also introduce real-time, dynamic color and brightness control, as well as a reduction in the blurring effect of fast-moving images.

LED drawbacks

Inevitably, the use of LEDs presents certain challenges. Since each LED acts as a point source, rather than a line source, like the CCFL, new optical designs are necessary to take advantage of the attributes of LEDs and to maintain luminance uniformity across a screen. Most computer LCD panels use an edge-lit light guide as the backlight. Simply replacing the CCFL with discrete red, green and blue LEDs on a linear PCB (which would require several tens of LEDs for a 15 inch screen used in typical notebook computer) would mean that the colors of the individual devices could be seen near the edge of the screen. To solve this problem requires the development of a mixing zone to combine the colors before they enter the light guide.

The main drawbacks of using LED backlights in LCD displays are cost and power consumption, both of which increase as the display size increases. Table 1 lists the attributes of backlighting sources, as described by Jong-Tae Lim of Samsung Electronics at the recent Intertech LEDs conference. Lim discussed Samsung's designs for backlighting

DISPLAY BACKLIGHTS

units (BLUs) using LEDs, which incorporate a heat pipe to maintain the metal-core PCB at the target temperature of 45°C.

There are a number of ways to produce backlights for LCD screens. Table 2 summarizes three approaches that have been pursued by Lumileds, which are all suited to different market segments. One approach, termed "white", is suitable for smaller screens, such as those used in automotive displays (figure 2). It involves coupling the light from side-emitting white LEDs into an acrylic light guide positioned around the edge of the display.

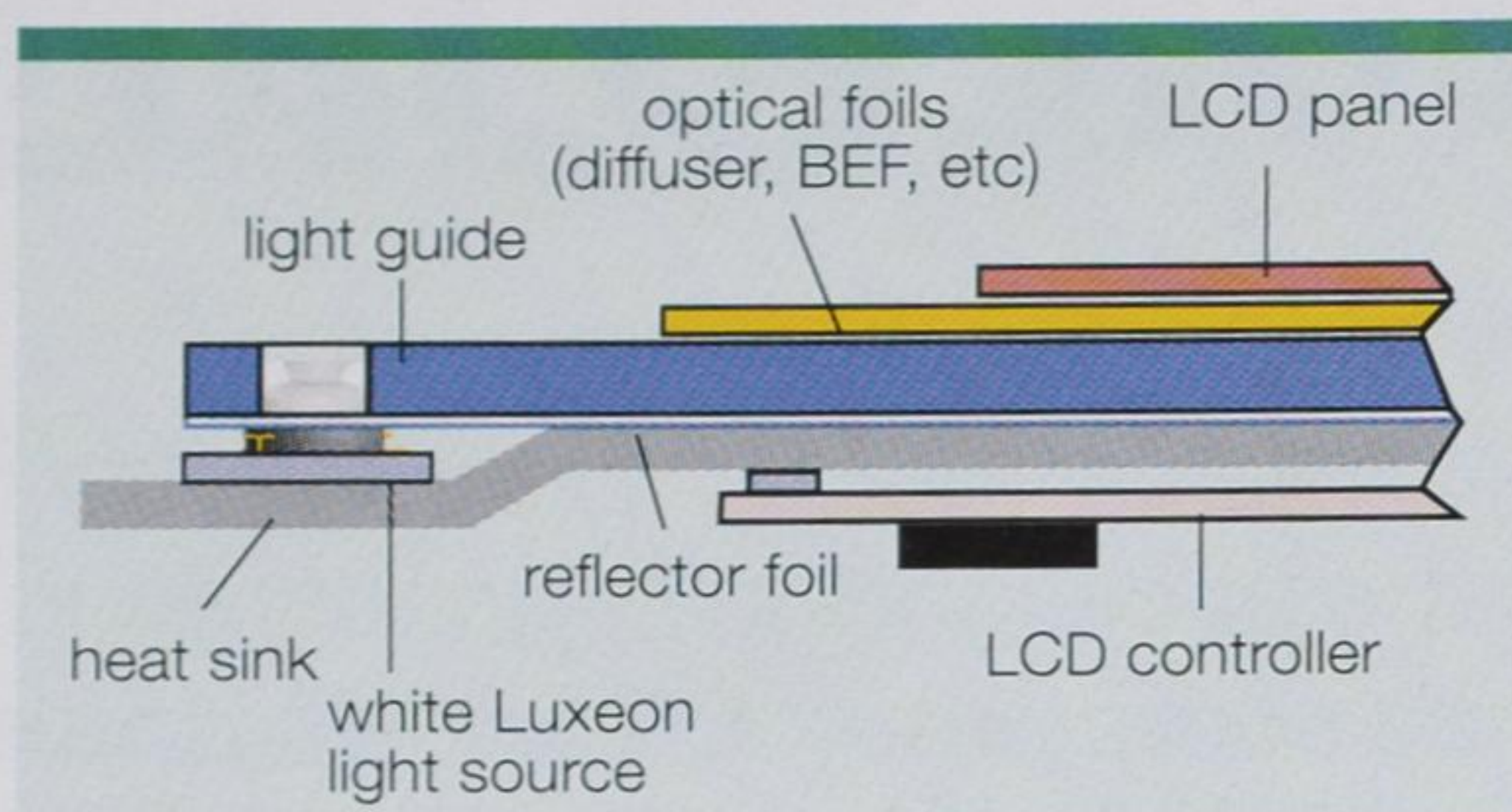
For larger display applications, such as computer monitors, the use of RGB LEDs provides the benefit of a wide color gamut. In Lumileds' DCC approach, used in NEC-Mitsubishi monitors, the light from LEDs with a Lambertian emission profile is mixed inside a folded light guide. The optical system mixes and distributes the white light evenly over the whole panel.

For still-larger displays, such as LCD televisions, the edge-lit system's light guide becomes too heavy, and other factors also point toward an alternative approach using direct backlighting – in other words, the LEDs are placed on the backplate of the display, rather than around its edge. Color mixing takes place within the cavity (or light box) behind the LCD panel. A series of diverters and diffusers helps to spread the mixed light over the entire panel, and prevents the light from the front of the individual LEDs from forming color spots on the screen.

Growing demand

According to Norbert Hiller of Cree Lighting, color quality is the main reason to use LEDs as backlights, and this determines the requirements passed on to the LED firms. "Display manufacturers want a wide color gamut, so they are looking for a precise combination of red, green and blue wavelengths," he said. "Also, they want high light output and low power consumption." Now that Cree has commenced its XLamp packaged LED activity, Hiller says that Cree's products are being designed-in by LCD-monitor and television manufacturers. "We have had good feedback for the XLamp package in this application."

In terms of market growth, Hiller believes that demand for LCD televisions and monitors is growing rapidly. "The question is how quickly will LEDs replace CCFLs," he said. "The markets haven't made up their mind yet, and end-users haven't seen many LED solutions, so the situation is unclear." Equally,



Small screens such as this in-car LCD (above) can be backlit using Lumileds' white Luxeon emitters (top, left). As the diagram (center) shows, the Lumileds devices emit into a light guide that distributes uniform emission from a row of sources across the LCD screen. Different approaches are used for larger LCDs (see table 2).

Table 2. Lighting approaches

	White	DCC	Direct
Color	white	RGB	RGB
Wide color gamut	no	yes	yes
Position of LEDs	edge	edge	backplate
Backlight thickness (mm)	6	18	50
Application	car navigation	LCD monitor	LCD TV
Screen size (inches)	6–10	12–21	>22
Emitter	side	Lambertian	side
Secondary optics	light guide	light guide	shallow reflector

Source: Lumileds Lighting

A comparison of Lumileds' different approaches to LCD backlighting. All three share the advantages of low-voltage operation, ruggedness, long lifetime and absence of mercury, and can be operated dynamically with blinking and dimming.

there are no design standards – for example, regarding the choice between edgelights and true backlights for different applications. Nevertheless, this is a technology that is being widely evaluated. "I'm pretty sure that all the main LCD manufacturers are pursuing LED solutions at the moment," said Hiller.

Despite this interest, Jagdish Rebello of market research company iSuppli Corporation, who recently wrote a report on the LED industry (see p21), does not think this market will grow tremendously quickly. "There are no overwhelming advantages driving the demand for LEDs in this application," said Rebello. "Benefits such as wide color gamut are not essential, except in some niche markets such as medical monitors, and the [extra] cost puts this technology out of reach for most customers – the cost-benefit analysis is not favorable."

Pricing pressure

LEDs typically cost about 10 times as much as the CCFL alternatives they seek to replace. Even though the price of LEDs will inevitably fall in tandem with rising performance, Rebello thinks that this market is under tremendous pricing pressure. "People are always demanding free monitors with their computers," he said. "Any technology adding several percentage points to the cost is something they need to look hard at."

As shown in figure 1, iSuppli expects the large-screen LCD backlighting market for LEDs to grow from zero in 2004 to around \$3 million in 2005, eventually reaching \$160 million in 2008. Most of this growth will come from applications in LCD televisions, especially for large-screen (> 40 inch) models. These are big-ticket items costing several thousand dollars, so adding LED backlights that may cost an extra few hundred dollars is acceptable to these particular consumers.

There is not expected to be any significant take-off for smaller LCD televisions with LED backlights until about 2007. The market for desktop monitors and for industrial, financial and medical monitors will each amount to only a few million dollars by 2008, says Rebello. "Besides cost, there are issues with heat dissipation, and the need to obtain uniform illumination across large displays," he said. "We really see this being a niche market for some time."

Tim Whitaker is the Editor of LEDs Magazine (www.ledsmagazine.com), a new publication covering applications of high-brightness LEDs and the technology of building LED systems.

Silicone delivers thermal stability to LED packaging

Until recently, HB-LED-related research concentrated on the development of light-producing chip material. Now, as very-high-volume applications such as solid-state lighting beckon, investigations into encapsulant technology have become equally important. **Bill Riegler, Stephen Bruner and Rob Thomaier** from NuSil Technology discuss the merits of silicone encapsulants.

The race to produce high-brightness light-emitting diodes (HB-LEDs) began with an intensive study of the semiconductor light source. While this work still continues, manufacturers of LED products have turned their attention to an equally important consideration: chip packaging.

LED packaging materials must enhance the light transmission, reliability and longevity of a device. However, with a recent move to using lead-free solders requiring reflow temperatures of up to 260 °C, HB-LED packagers have had difficulty in maintaining the quality of light transmission. Traditional epoxy-based encapsulants crack or yellow when exposed – even for a short time – to these higher soldering temperatures.

Highlighting the importance of encapsulants, a patent application from Cree submitted earlier this year (US patent 6,740,906) notes that certain die-attach methods involving high thermal cycles can discolor clear epoxy encapsulants, resulting in unwanted light attenuation.

Encapsulant of choice

In a recent paper regarding the performance of high-power LED illuminators, Lumileds Lighting states: “Key elements for high power, [long] lifetime, and high-efficiency operation are the LED chip itself, the soft silicone gel [which is used as an encapsulant], the metal slug directly below the actual LED chip [providing a very low thermal resistance path for heat conduction] and a high-temperature resistant plastic lens.” Lumileds has confirmed that testing the physical and optical characteristics of silicone have proved it to be the encapsulant of choice for its HB-LEDs.

In fact, Lumileds now uses silicone to encapsulate its Luxeon products, and rival manufacturers Osram Opto Semiconductors and Nichia also use the material in their



OSRAM OPTO SEMICONDUCTORS

Osram Opto Semiconductors uses silicone encapsulants in its Golden Dragon LEDs. Shown here is the new warm-white version.

Golden Dragon, Jupiter and Rigel HB-LEDs.

While the soldering process represents a temporary temperature spike in the life of the LED, engineers must also consider the operating conditions of the diode. Both temperature and UV exposure can affect the optical properties of the encapsulant material.

Researchers at Lumileds recognized that materials such as glass, acrylic, polycarbonate, optical nylon, and cast-molded epoxy all suffered from a degradation in optical transparency over time under normal LED operation. However, they found silicone to be stable following extensive temperature and humidity tests and exposure to ambient UV radiation, and this is one of the reasons that the Californian company's devices have such a long lifetime.

Silicone materials work well in encapsulation applications because, typically, they have higher coefficient of thermal expansion (CTE) values than epoxy, acrylic and other adhesive systems (see table). This means that silicones are more flexible and are thus ideal bridge materials between two substrates with dissimilar CTE values. Another factor to consider is the stress that expanding or contracting materials exert on wires in packaged assemblies. Stresses associated with high modulus values can break these wires or compromise the wire bond. However, silicone has a relatively low modulus value compared with other encapsulant materials, eliminating this problem.

A material with an industrial history spanning 60 years, silicone maintains its elastomeric properties in continuous temperatures of 260 °C. The polymer structure contributes significantly to the material's stability and versatility. Maintaining elastomeric properties after extreme temperature cycling or radiation exposure can be attributed to a relatively small rotational energy in a silicone polymer. This low energy is due in part to the negligible inter-

Table

Adhesive/ encapsulants	Coefficient of thermal expansion ($\times 10^{-6}$ mm/mm/°C)
silicone	155
filled epoxy	70
PMMA	85
unmodified epoxy	70

LED CHIP PACKAGING

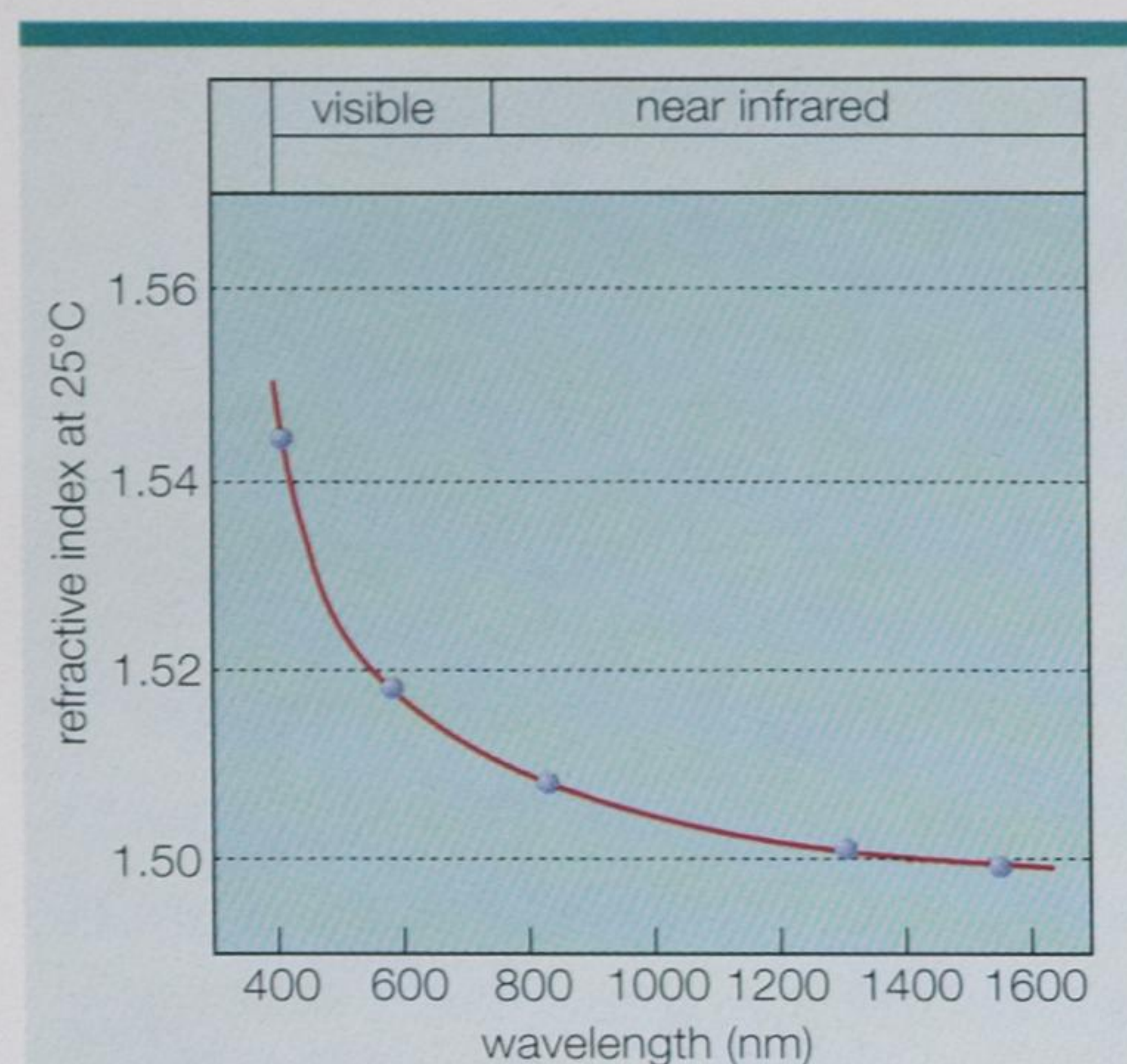


Fig. 1. The change in the refractive index of a silicone encapsulant with wavelength. At 25 °C, measurements were taken at 411, 589, 833, 1306 and 1550 nm.

actions between siloxane chains. Additionally, siloxane elastomers have physical properties that allow engineers to easily incorporate additives such as phosphors with little effect on the function of the elastomer system.

The high refractive index outputs of the dies

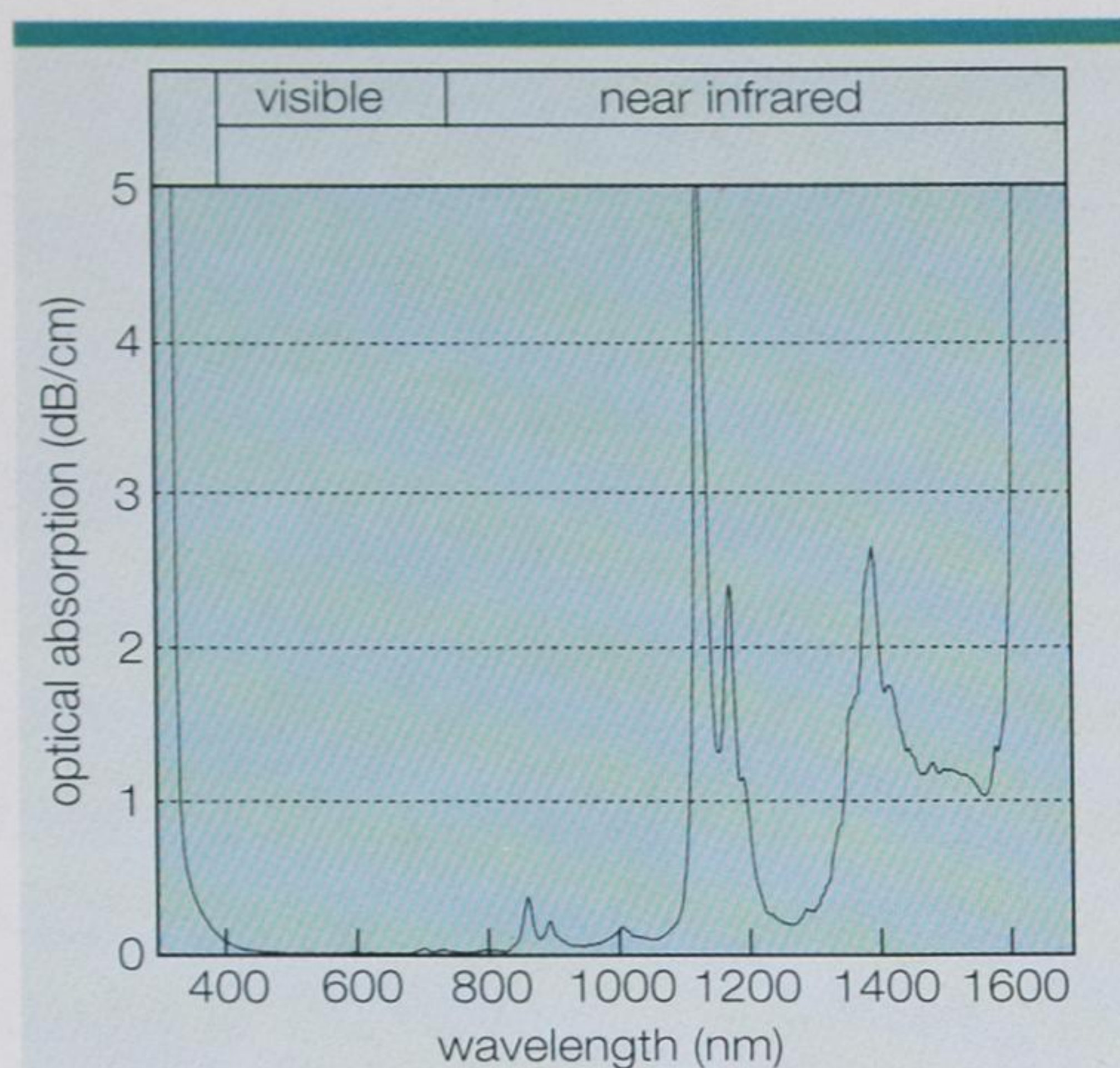


Fig 2. The optical absorption of a silicone encapsulant in the 300–1700 nm range shows low absorption at wavelengths in the visible region of interest to HB-LED makers.

used in HB-LEDs, which can be as great as 2.5, ideally require an encapsulant with a similarly high refractive index. Modifying the silicone backbone by incorporating relatively large molecular groups such as phenyls can boost the refractive index of these silicone

encapsulants from 1.38 to 1.57.

According to a recent patent application submitted by Emcore (US patent 6,746,889), this index-matching material should be lens-shaped to improve light extraction from the device. The Emcore team further states that this material should have a refractive index “substantially equal” to the geometric mean of the epitaxial region and surrounding light-guiding-media refractive indexes. Light-guiding media can include glass fibers and light pipes. The index-matching material may be a polymer, and silicone is suggested as a material option for this application.

Further reading

Performance of high-power LED illuminations in projection displays, G Harbers *et al.* Lumileds Lighting (white paper). US patent application 6,590,235.

Bill Riegler, Stephen Bruner, and Rob Thomaier are at NuSil Technology, a firm based in Santa Barbara, CA, that formulates and supplies silicone materials. E-mail: steveb@nusil.com.

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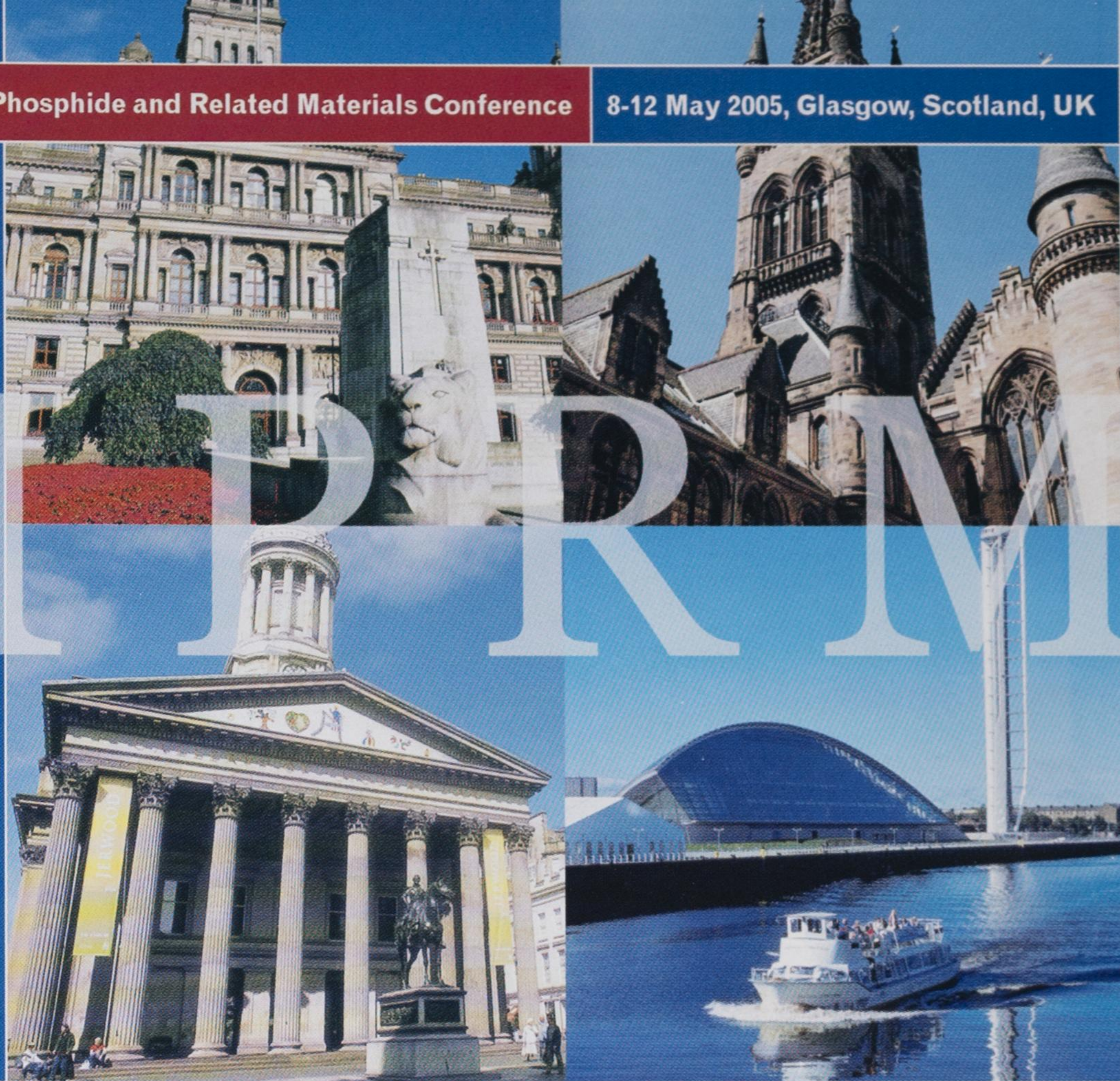
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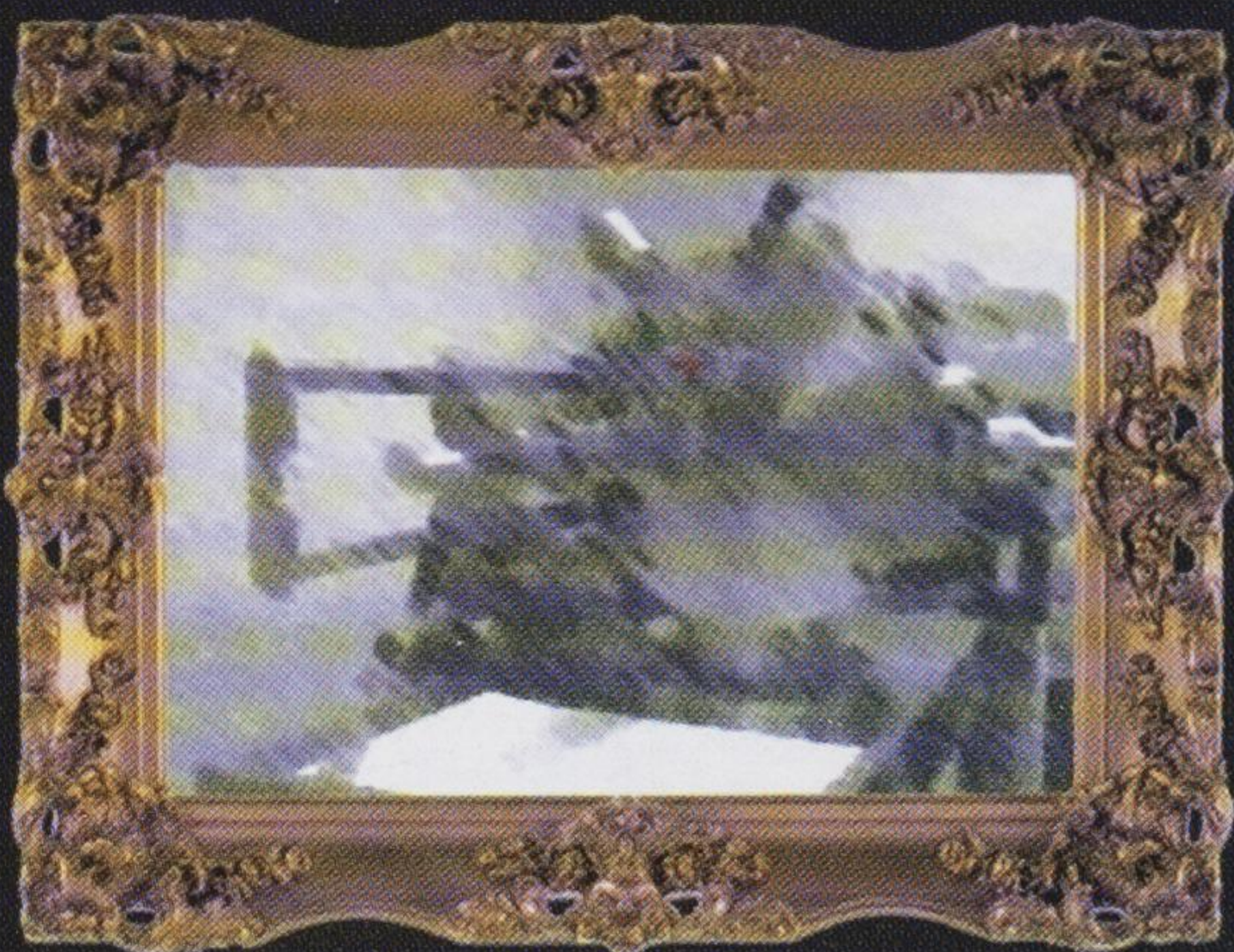
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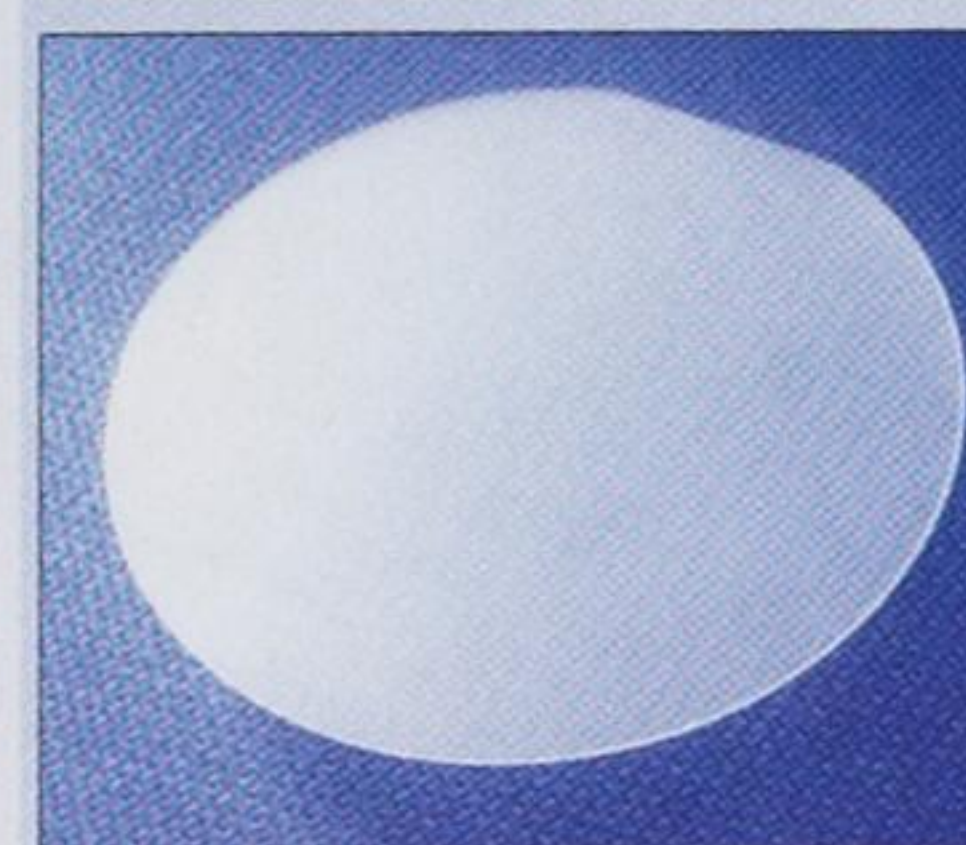


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Alfalight raises the bar in electro-optical efficiency

Diode-laser maker Alfalight claims to have set a record with its 50 W laser bar operating at up to 73% electro-optical efficiency. "The past few months have yielded several breakthroughs that took us from 65% efficiency in a 4 W single emitter to over 71% in a 50 W laser bar," said Alfalight CTO Tom Earles.

Emitting at 976 nm, the aluminium-free devices have been developed under DARPA's super-high-efficiency diode sources (SHEDS) program. At room temperature, the laser bar operates at a power-conversion efficiency of 71%, a figure that rises to 73% at 10°C.

Wanted by the US military to provide extremely high-power lasers with a small footprint, the high-efficiency devices could also find commercial use in high-power sys-

tems for materials-processing applications.

Along with other chip makers and developers involved in SHEDS, Alfalight had been set two targets by DARPA: to deliver 65% efficient diode laser bars by March 2005 and to reach 80% efficiency by 2006. Having met the first target ahead of schedule through incremental improvements to device design, Alfalight says that more radical thinking is required to make the second target: "[Achieving] the 80% goal will likely incorporate more aggressive techniques that confine the carriers in two or even three dimensions."

Other US-based firms working under SHEDS, including nLight Photonics and JDS Uniphase, have also developed laser devices with efficiencies of around 70%.

Dual-spectrum camera gets funding boost



Images from Sensor Unlimited's combined visible and infra-red camera (left) are far superior to those obtained from either visible (center) or infra-red (right) cameras on their own.

Sensors Unlimited (SU) has received \$750,000 from the US Air Force to improve its dual-spectrum InGaAs-based camera, which can detect light between 400 and 1700 nm. One of the contract's objectives is to improve sensitivity in the visible waveband.

According to Martin Ettenberg, SU's director of imaging products, the firm is targeting a threefold improvement for the quantum efficiency of the detector at 400 nm. He explains that the improvements to the detector, which

is based on a *pin* structure, are expected to come through doping the InP layer, thus altering the absorption properties and allowing greater transmission in the visible.

Ettenberg also revealed that the device will require special processing steps beyond the normal hybridization process, including removal of the InP substrate. High quality epitaxial material is required to ensure a low dark current and enable a highly-repeatable manufacturing process.

NEC's blue laser hits 300 mW output power

As semiconductor manufacturers look toward volume production of blue lasers for next-generation DVD applications, NEC researchers have developed a powerful GaN source that ought to boost the writing speed of rewritable drives based on the technology.

Developed at the Japanese company's System Device Research Laboratories, the 405 nm laser emits a world record 300 mW in continuous-wave mode. Fabricated using

NEC's proprietary technology, the laser diode features a planar structure with a buried AlN inner stripe. The structure is grown using "multiple epitaxy technology", the research team told *Compound Semiconductor* magazine.

NEC's subsidiary, NEC Compound Semiconductor Devices, will have a prototype laser ready for sampling to customers in 2005, and volume manufacturing will take place at the company's Kansai plant in Otsu, Japan.

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The EpiTT sensor – the most advanced *in situ* tool for LED production on the market – is equipped with easy-to-handle software for simulation and analysis of measured reflectance data. Beyond precise online growth rate/film thickness calculations, it allows fitting of complete multiwafer LED growth runs with just one click, including fits of the refractive index and the absorption coefficient of the material. For the first time, even the composition of ternary materials can be determined online. Its batch-mode calculation feature makes it a handy tool for quick reproducibility checks

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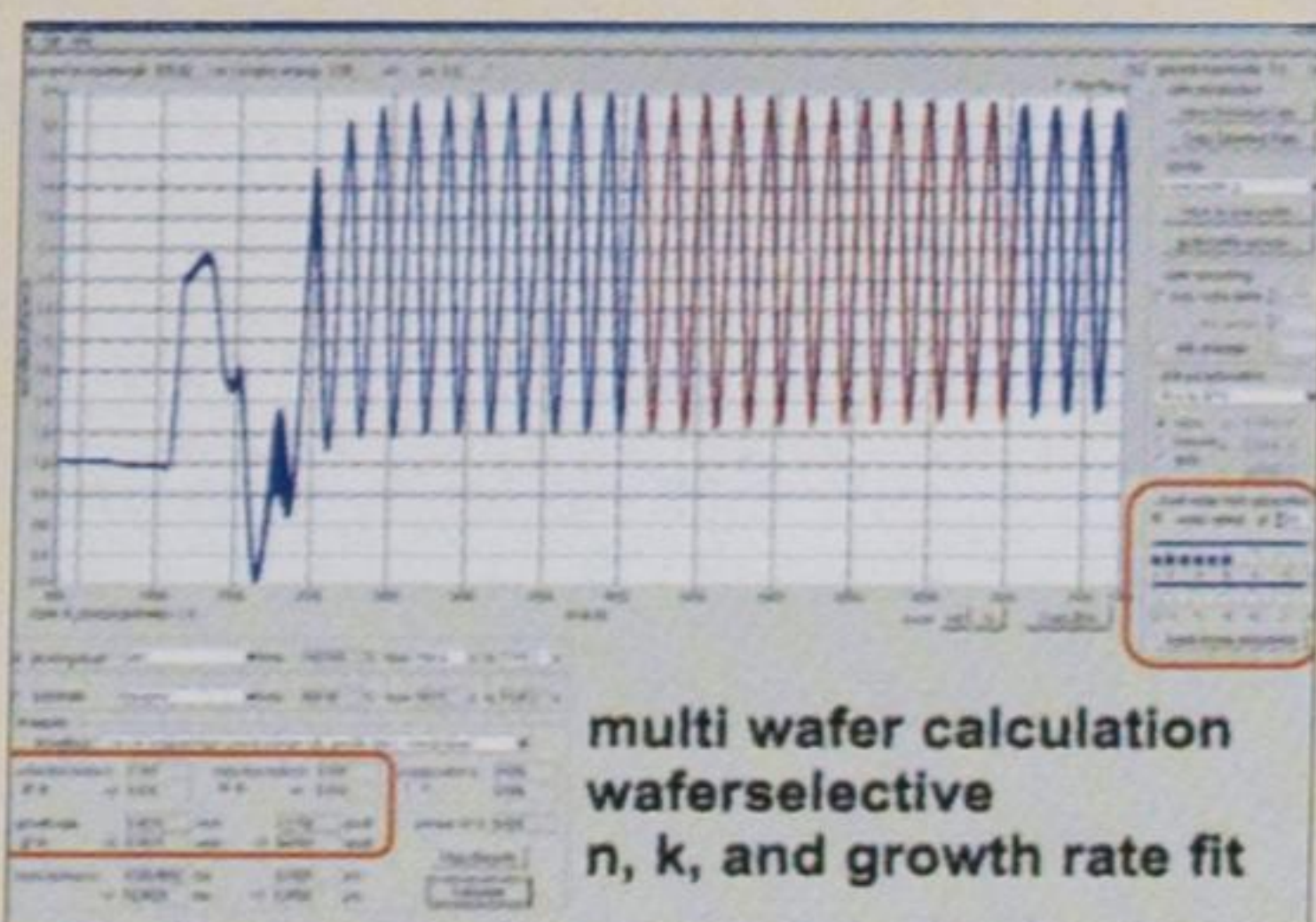
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Epitex Inc

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IQE celebrates contract win worth up to \$25 m

UK-based epiwafer supplier IQE has won a contract, potentially worth up to \$25 million, with an undisclosed US RF component manufacturer. The two-year deal is effective from November 1. It involves IQE supplying more than 90% of the anticipated demand for the customer's epitaxial material, which is used to produce components for mobile handsets.

IQE's customer, which it has worked with for several years, is to cease epiwafer manufacture at its own site. The epiwafers will

instead be produced at IQE's US site, located in Bethlehem, PA, which specializes in MBE growth.

"This agreement with such a prominent supplier of RF components for the cellular-phone market demonstrates a clear movement toward the outsourcing model within the compound semiconductor industry," said Drew Nelson, IQE's CEO.

IQE's recent annual revenue has been in the region of \$30 million, so this deal could increase the firm's top-line figure by 40%.

Aixtron's orders tumble by 30%

Germany-based equipment maker Aixtron received orders for the third fiscal quarter of 2004 worth €25.9 million (\$33.4 million), down €11.0 million on the previous quarter.

"After five consecutive quarters of increasing equipment order intake and an exceptional second quarter of 2004, this quarter does not necessarily indicate a market trend. However, such quarterly swings in order intake do validate our diversification strategy," remarked Paul Hyland, Aixtron's CEO.

Recently Veeco, a rival equipment manufacturer, announced substantial falls in revenue. It

blamed a spending freeze by Asian customers for the 70% decrease in orders placed for its MOCVD equipment.

Aixtron's third fiscal quarter revenue was €30.4 million, down €3.8 million sequentially, but €8.9 million higher than the equivalent quarter of 2003.

However, profit was up, with the recent quarter generating €3.2 million, compared with €0.5 million for the previous period. The company has cut its guidance, expecting that full-year 2004 figures will show a revenue of €125 million–130 million, and an associated net income of €3million–4 million.

In brief

- French MBE equipment manufacturer **Riber** reported a revenue of €4.6 million (\$6.1 million) for the nine-month period ending September 30. Sales consisted of one MBE 49 production machine and four research machines, of which three were Compact 21s. Since October 1 the company has received orders for an MBE 49, due to

be delivered in 2005, and for a Compact 21 HeM, which will be installed at the University of Hamburg, Germany.

- **Sumitomo Electric Industries** has seen increasing demand for its GaN substrates thanks to growing interest in blue lasers for high density optical discs, according to Japanese newspaper, *Nihon Keizai Shimbun*.

Whiff of consolidation surrounds chip makers in rocky fiber market

After a year that began with hope of a recovery, chip manufacturers supplying the fiber-optic telecom industry have seen a slump in share prices to well below those at the start of 2004. But as talk of consolidation returns, carriers are at last announcing some major fiber network build-outs.



At the beginning of this year, there was a swell of cautious optimism in the fiber-optic telecom community. Off the back of this, some of the III-V chipmakers serving the industry enjoyed something of a surge in their stock prices. JDS Uniphase, Bookham Technology and Avanex all saw 50% added to their stock value in late January (see graph overleaf).

But after that initial peak, it was all downhill in 2004, with Bookham's stock faring the worst. By mid-November, the company, which recently switched corporate domicile from the UK to the US, had lost 75% of its stock value in one year. Finisar, which is in the process of acquiring Infineon's fiber-optic division, has seen a similar tumble in its value.

One of the sector's better-performing stocks since the February peak is that of JDSU, but even the market leader has seen its value halve since then, and the company was trading at around 10% below its November 2003 price as *Compound Semiconductor* went to press.

Those falls in share price came as all the companies in the sector reported strong increases in revenue, but remained some way from profitability.

For the three months ending September 30, JDSU, which controls an estimated 20% market share according to a recent report (see *Compound Semiconductor* July p15), saw its revenue from communications-based products rise 24% sequentially to \$106.1 million, representing 55% of the company's total sales. However, this rapid upturn was described as anomalous by the company as it projected a downturn in overall revenue in the forthcoming quarter thanks to ongoing market uncertainty.

Despite that strong upturn, the San Jose-based company still reported an overall net loss of \$36 million, with the communications product group posting an operating loss of \$10.3 million. The upshot is that JDSU has

consolidated three communications product groups into two, while also rationalizing its manufacturing operation. Michael Ricci takes over as senior vice-president of JDSU's new components and modules product group. That division was created through the merger of the former components and transmission product groups. With 200 product lines, Ricci's new group has the broadest portfolio of components and modules in the industry.

One casualty of the restructuring is the firm's fab in Eindhoven, the Netherlands, which JDSU acquired from Philips' semiconductor laser business in April 1998. "We have identified two possible manufacturing partners," said CEO Kevin Kennedy, describing how JDSU plans to reduce its "manufacturing footprint".

These measures, which will include a reduction in headcount at the company's North American manufacturing operations, will save JDSU "tens of millions of dollars" per year, Kennedy said. Inventory reduction and restructuring is expected to take one year.

JDSU has also streamlined its transceiver manufacturing operation by way of a contract manufacturing deal with Fabrinet. The agreement – for an undisclosed sum – will see JDSU sell its Singapore and Bintan, Indonesia, facilities to Fabrinet while providing a long-term source guarantee between the two companies. About 450 employees will transfer to Fabrinet as a result, although JDSU will retain its design and development team in Singapore.

A similar set-up is continuing at Bookham, which is increasingly resembling JDSU with its San Jose base and Shenzhen facility, as well as at Avanex in nearby Fremont. On revenue up 12% sequentially at \$43.6 million, Bookham made a \$38.3 million net loss (the company revised this figure after discovering an accounting error in its initial report of a \$37.1 million loss) in its

Recent quarterly results for publicly listed fiber chip manufacturers

Company	Symbol	Quarterly revenue (sequential change, %)	Net loss (\$m)	Closing share price (\$) on Nov 24 (52-week range)
Avanex	AVNX	35.8 (+12)	22.3	3.06 (1.79–7.57)
Bookham*	BKHM	43.6 (+12)	38.3	5.10 (4.08–8.25)
Emcore	EMKR	25.5 (+20)	11.3	2.85 (1.46–7.93)
Finisar	FNSR	61.9 (+9)	22.1	1.54 (1.13–4.27)
JDS Uniphase**	JDSU	194.5 (+11)	36	3.13 (2.84–5.89)

*Bookham restated figures after initially posting a net loss of \$37.1 million.

**JDSU's communications group, which includes the III-V device operation, posted a revenue of \$106.1 million and an operating loss of \$10.3 million.



SOURCE: YAHOO FINANCE

The relative share performance of photonics chip manufacturers JDS Uniphase, Bookham, Finisar and Avanex over the past year. Despite wide optimism in early 2004, all four companies have seen their value drop since November 2003.

first quarter, which ended October 2. Although aiming to break even at the gross margin level in the next quarter, Bookham still expects to burn through up to \$22 million in cash over the next three months. The company reported that it now has \$79 million in cash and short-term investments on its balance sheet, down almost \$38 million from the prior quarter's figure.

Bookham CEO Giorgio Anania pointed to some positive signs, however. In the company's first-quarter conference call he said that the first \$1.6 million worth of products had shipped from Bookham's Shenzhen facility during the quarter. And if sales from the JCA Technology business (which was sold to RF subsystem maker Endwave in July) are ignored, Bookham's sales showed a 17% sequential increase.

Meanwhile, orders from Canada-based Nortel Networks, Bookham's number-one customer and the previous owner of its state-of-the-art 3 inch InP wafer-fabrication facility, are said to be ramping up after rising \$3 million sequentially. Revenue from sales to Huawei Technology, the Chinese telecom equipment maker that is also based near Shenzhen, hit \$4.6 million as Bookham's decision to ship from its Chinese packaging facility began to bear some fruit.

Anania sounded particularly upbeat about Bookham's impending penetration of customers outside its traditional client base of Nortel and Marconi (the companies accounted for 46% and 9% of sales respectively in the quarter). Revenue from those other customers was up 19% in the first quarter, he said, with the figure set to increase. Deals with many of the top 10 system builders are said to be in the pipeline.

But with cash still burning away rapidly, Anania must also address costs. Among the measures being taken is a "simplification" of the company's product platform. "We will remove a whole layer of overheads," said the CEO, while adding that Bookham would be using more Asia-based suppliers in the future.

He is also minimizing the company's locations, specifically closing the Milton Park, UK, facility where

Bookham first originated. The closure of the GaAs fabrication facility in Caswell, UK (announced earlier this year), will save \$2 million per quarter, while after an injection of \$4.2 million, the Shenzhen facility should enable further quarterly savings amounting to \$7 million. All this reorganization should be complete by mid- to late 2005. Coupled with a reduction in R&D spending, those savings are expected to bring the company close to break-even at the gross margin level.

In his outlook, Anania said he expected a sluggish increase of around 4% in revenue in the second quarter, citing "lumpiness" in the market. "The light at the end of the tunnel appears to be coming closer," he remarked. Although a 4% increase would bring the top-line figure to around \$45.5 million, it would still be a long way short of Bookham's net break-even revenue target of \$60 million.

Despite the slowly improving situation, particularly in the metro network sector, Anania expects yet further consolidation in the industry. "[Among component suppliers] there is a massive fixed cost and, frankly, duplication," he said, telling investors that they should expect more consolidation among players large and small.

New sheriff in town

Results at Avanex mirrored those of its rivals, as the company recorded a net loss of \$22.3 million on sales of \$35.8 million. With new CEO Jo Major, formerly at JDSU, announcing himself as the new "sheriff" in charge of restructuring, Avanex is also set to undergo organizational changes as it moves to a "dramatically different cost structure". Having already outsourced some manufacturing operations, more of the same is set to follow in the form of contract manufacturing, as Avanex seeks to move up the value chain during what Major described as the industry's "rocky" recovery.

Despite limited visibility, both Major and Anania pointed to increased spending by carriers to upgrade core networks as a sign of better things to come. The bigger picture does seem to be improving, and recent announcements from some of the industry's biggest players have set that upbeat tone. NTT, for example, is to spend ¥5 trillion (\$47 billion) between now and 2010 on communications infrastructure build-out that will include a massive fiber-optic deployment, while the US carrier SBC Communications and Alcatel have agreed a fiber-to-the-premises deal worth \$1.7 billion.

Under the agreement, Alcatel will be SBC's primary supplier of network infrastructure as SBC targets the deployment of fiber links to some 18 million households by the end of 2007. Alcatel is a key customer for Avanex, which acquired the French company's optical components business in May 2003. When exactly these big spending plans will trickle down to the coffers of the companies supplying individual components and subsystems is anybody's guess, but Anania hopes to see more in the way of dollars, as opposed to announcements, in the first half of 2005.

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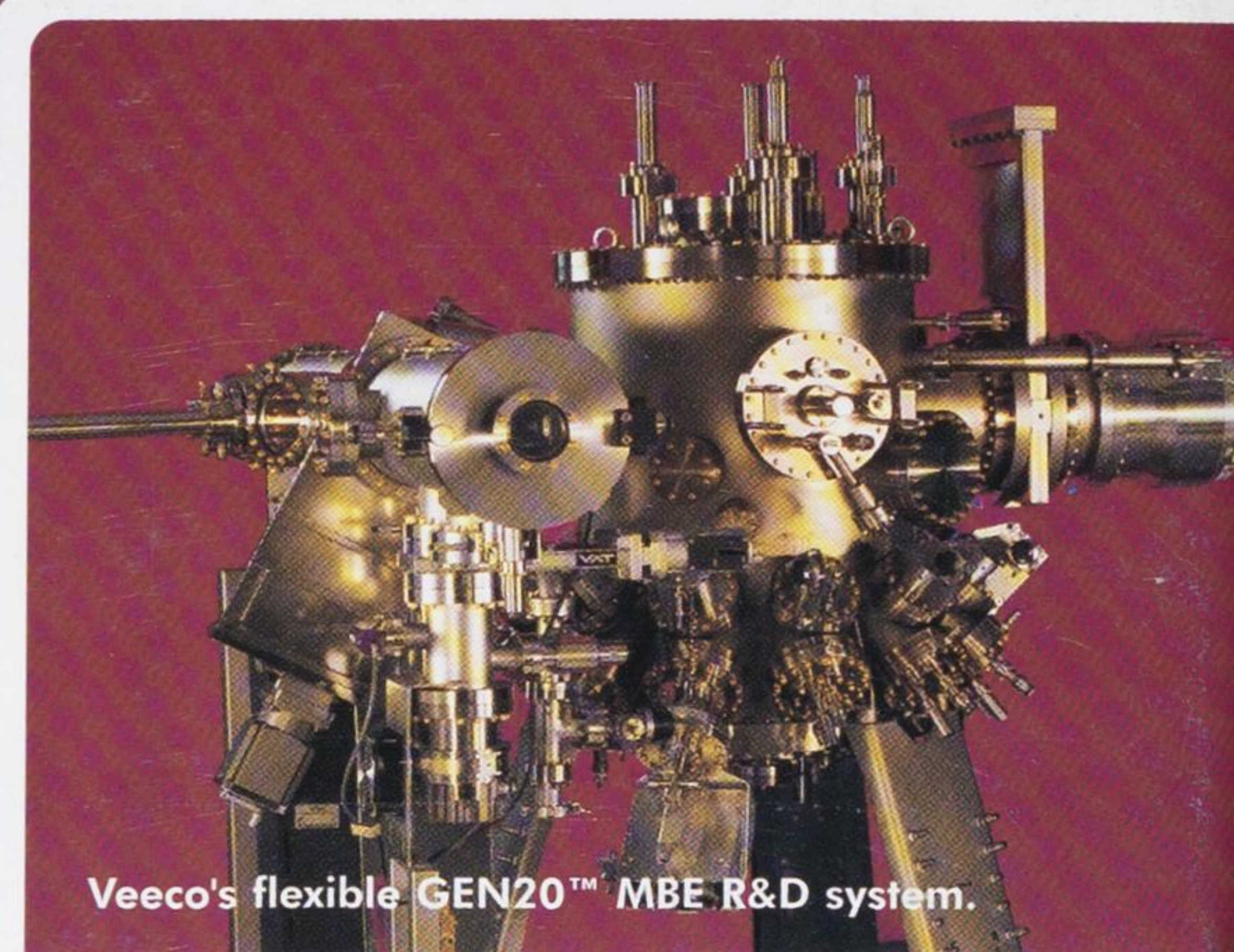
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