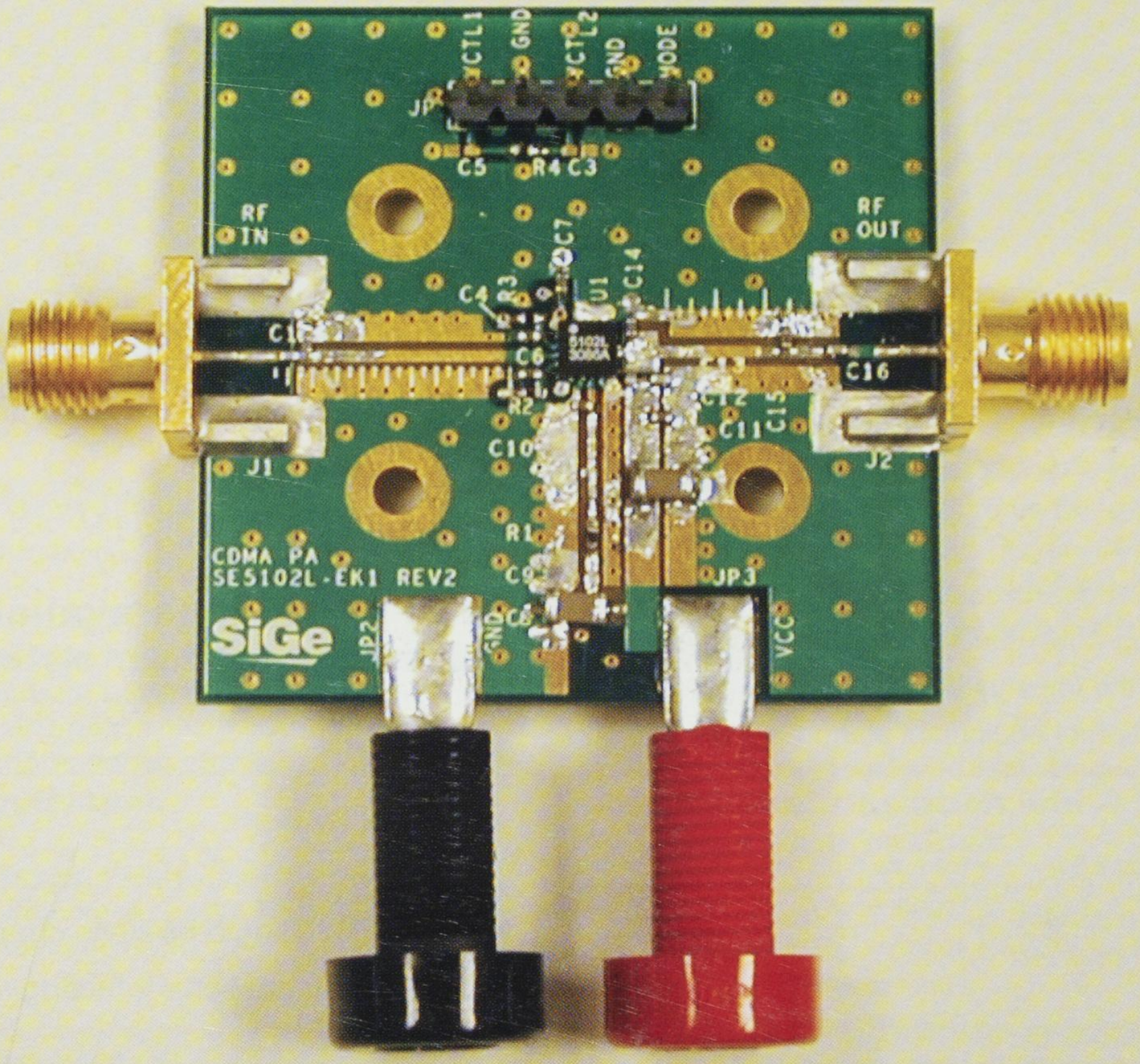
COMPOUND SEMICONDUCTOR

Three-Fives and Silicon Heterostructures

June 2003 Volume 9 Number 5

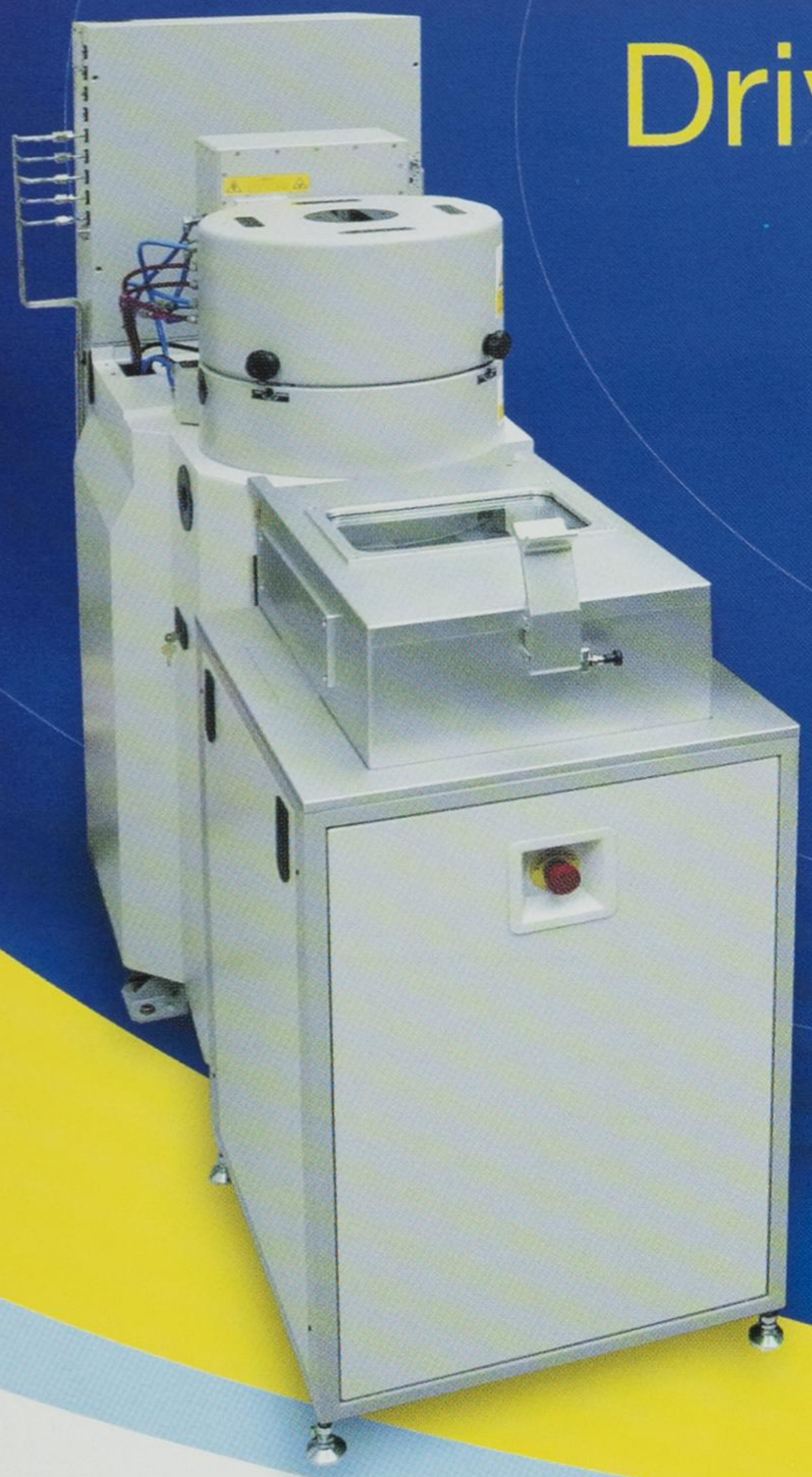


SILICON HETEROSTRUCTURES

Battle lines drawn in the GaAs versus SiGe debate

ALSO INSIDE

Avanex purchases Alcatel Optronics	Soitec and ASM in strained Si deal	White LEDs find more applications



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Three-Fives and Silicon Heterostructures

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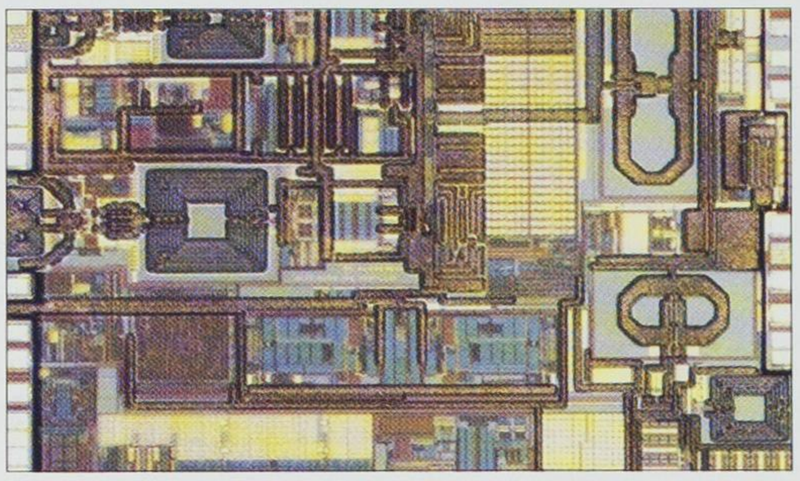

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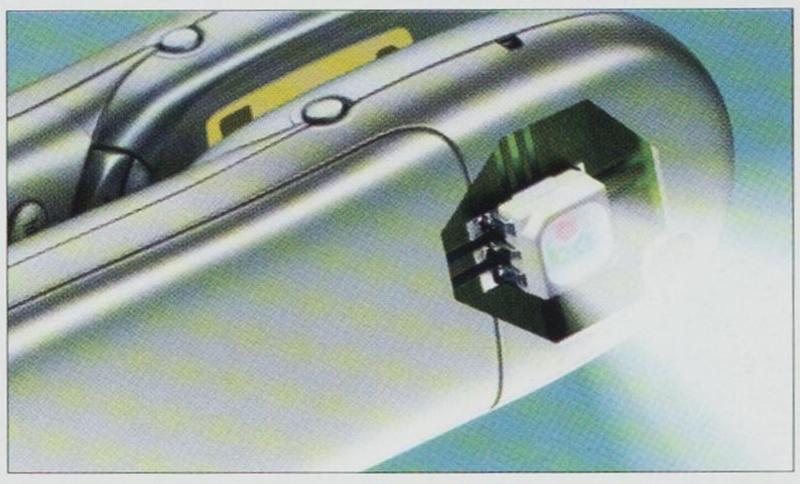

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COMPOUND SEMICONDUCTOR

Three-Fives and Silicon Heterostructures

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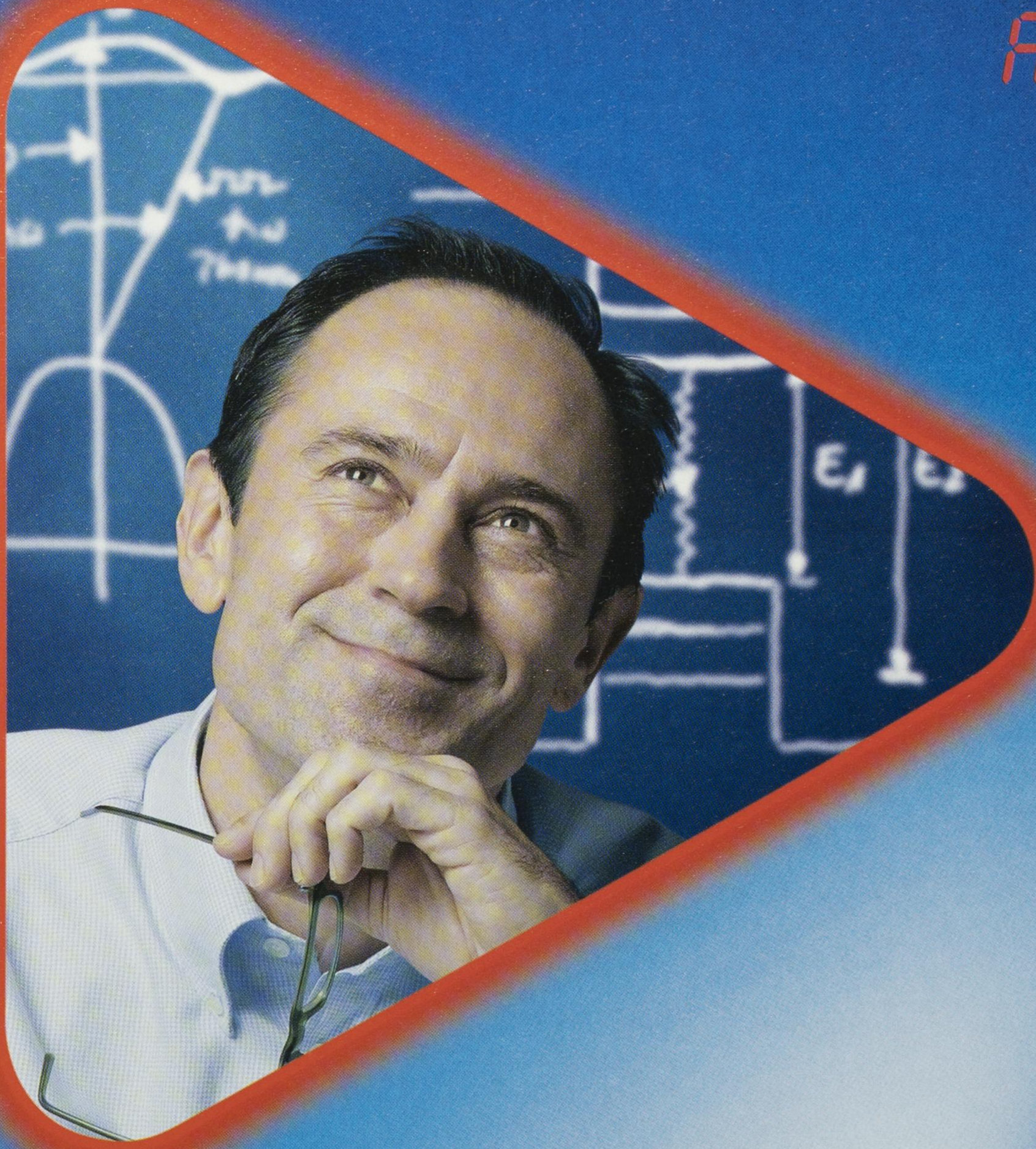

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Alcatel and Corning stop making components, sell opto units to Avanex

By Tim Whitaker

Alcatel and Corning are the latest optical networking equipment suppliers to exit the optical components business, following in the footsteps of Nortel, Agere, ADC and Marconi. The whole of Alcatel Optronics and certain assets of Corning's optical components business are to be sold to Avanex Corporation, which designs and manufactures a range of photonic processing subsystem and module products for telecommunications networks.

Avanex will acquire the Alcatel Optronics locations in Nozay, France, and Livingston, UK (formerly Kymata). Assets to be purchased from Corning include the company's optical amplifier facility in Erwin, NY, and its optical components plant in Milan, Italy (purchased by Corning from Pirelli for $3.6 billion in September 2000). Corning will also close its Lasertron pump laser facility in Bedford, MA, by the end of 2003. Corning purchased Lasertron in a $1.8 billion stock deal in November 1999.

According to Philippe Bregi, COO of Alcatel Optronics, the two components manufacturers identified Avanex together. "Alcatel and Corning were jointly looking for a partner," Bregi said in an interview with *Optical Keyhole* website. "We knew that we had complementary products and synergies."

The combined stock transaction, due to close by the end of September, is valued at approximately $63.5 million, based on Avanex's closing price of $1.12 per share on May 9, 2003. Alcatel and Corning will receive 28% and 17% respectively of Avanex's outstanding common stock. According to Bregi, Alcatel does not see the deal as a divestiture of its components unit, but rather as a way to leverage the capabilities of the business that is no longer one of Alcatel's core competencies. However, Alcatel will not influence Avanex's business decisions, and Bregi expects that Avanex will have more success than Alcatel Optronics in selling components to Alcatel's competitors.

Opto components leaders

	Opto component revenue in Q1 2003 ($ million)
JDS Uniphase	74.0
Bookham	33.0
Corning	11.0*
Alcatel Optronics	8.4
TriQuint	8.3

The combined revenues of the businesses to be acquired by Avanex will position the company as the third largest supplier of optical components. (*refers to business units bought by Avanex)

Corning will also close its Lasertron pump laser facility, which was purchased in a $1.8 billion stock deal in November 1999.

Alcatel is expected to contribute more than $110 million in cash to Avanex, while Corning will contribute more than $20 million. Avanex and Alcatel will enter into a supply agreement whereby Avanex will supply components for Alcatel's optical networking products over a three year period. Also, Alcatel and Corning will assign approximately 1,400 patents to Avanex, and will additionally license several thousand patents to Avanex as part of the transaction.

Alcatel's optical component division had sales of €7.3 million ($8.4 million) for its March 2003 quarter. For 2002, Alcatel Optronics posted a net loss of €418.8 million on sales of €84.1 million, results that prompted Alcatel to announce that the sale or closure of the optronics unit was under consideration (*Compound Semiconductor* March 2003 p6). The division's products include lasers, photodetectors, optical amplifiers, transponders and passive devices such as arrayed waveguide gratings and fiber Bragg grating filters. The unit had 950 employees as of March 31, 2003.

The business lines to be acquired from Corning had sales of approximately $11 million for the March 2003 quarter. Key products include optical amplifiers, dispersion compensation modules, lithium niobate and electro-absorption modulators, and micro-optics products. These business lines had 490 employees as of March 31, 2003.

Avanex, headquartered in Fremont, CA, had revenues of $5.4 million for the quarter ended March 31, 2003, and a net loss of $10.4 million. After the acquisitions, the company will offer a very broad portfolio of products. "Avanex's strategy is to be the leading supplier of optical solutions," said Walter Alessandrini, the company's chairman, president and CEO. "Our customers want suppliers who can deliver end-to-end solutions that are cost-effective and of the highest quality. After the acquisitions, Avanex will have the scale and resources to effectively supply our customers with their product needs."

Compound Semiconductor announces new editorial board

Compound Semiconductor magazine is pleased to announce that its editorial board has been revised and updated. The board members collectively represent all aspects of compound semiconductors and silicon heterostructures, and will help to ensure that *Compound Semiconductor* continues to provide unrivaled coverage of the industry. The board members, listed in alphabetical order by affiliation, are as follows:

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In brief...

Spire buys back Bandwidth Semiconductor

Stratos Lightwave has sold its Bandwidth Semiconductor subsidiary, which supplies epiwafers and foundry services, back to Spire Corporation. The sale was completed for an undisclosed amount of cash and the assumption of certain obligations. Bandwidth was formed in December 1999 when Methode Electronics purchased Spire's Optoelectronics division. In 2000, Methode spun off Stratos Lightwave in an IPO.

Funds save Novalux from Chapter 11

Laser manufacturer Novalux has secured $16 million in venture capital funding to continue developing and manufacturing its NECSEL (Novalux extended-cavity surface-emitting laser) technology platform. The funding has rescued Novalux from Chapter 11 bankruptcy protection, which the company filed for in March. Novalux has changed its focus from communications to bio-analytical instrumentation and other markets.

JDSU buys TriQuint's pump laser unit

JDS Uniphase has acquired TriQuint's undersea pump laser business for $6.6 million in cash. The unit came to TriQuint when it acquired various opto component segments from Agere. The undersea business comprises packaging technology that JDS Uniphase will use to develop complete pump modules.

Boston Laser takes control of SLI

In a merger of two high-power laser diode manufacturers, Boston Laser has acquired all the assets of Semiconductor Laser International (SLI). Unconfirmed reports suggest the purchase price was around $1.5 million. Boston Laser acquired Polaroid's laser division in January 2000. SLI uses MBE to grow Al-free lasers using technology licensed from Northwestern University.

AXT halts opto production

Faced with a slowdown in demand in May, AXT temporarily halted production of optoelectronic devices at its US facilities for two weeks as a cost-reduction measure. At the time of writing, the company had not indicated when and how quickly it would resume production of VCSELs, edge-emitting lasers and nitride-based LEDs. During the shutdown, the company shipped products from its existing inventory.

While AXT's optoelectronic sales in April were in line with expectations, sales in May decreased significantly. The company said that its customers reported a slow-down in demand for products that utilize optoelectronic devices, as a result of the outbreak of severe acute respiratory syndrome (SARS).

SARS has already had an even more direct effect on AXT; the company was forced to close its LED production facility in China for 10 days in late April after one employee contracted the virus.

Despite recently receiving ISO9001:2000 certification, AXT's optoelectronics division has been struggling. The business had revenues of $4.1 million, or 32.6% of total company revenues, in the first quarter of 2003. High-brightness LED revenues fell from $4.4 million in the first quarter of 2002 to $3.4 million in the first quarter of 2003. Laser and VCSEL revenues were $578,000 and $160,000, respectively, in the most recent quarter.

The company reported that its cost per LED fell due to continued process improvements. However, beginning in late February a significant price reduction for LEDs was experienced, particularly for low-end blue chips used in consumer applications. The company has been more successful in maintaining high prices for its green and cyan LEDs, which are more differentiated from competitors' products and are used in traffic signals and full-color displays. The combination of falling revenues and a decrease in average selling prices was responsible for the division's gross margin of negative 13.4% of revenue for the first quarter of 2003, compared with positive 1.7% for the same period in 2002.

In its recent quarterly report, AXT said that in order to successfully expand its optoelectronics business, it might seek potential investors. During the company's conference call, Morris Young said that AXT is "evaluating all opportunities" for its optoelectronics business. "We have most of the requirements to be a successful player in the optoelectronics market, but we are in a cash conservation mode at the moment," said Young. "If we found a potential partner to help increase our capacity, we would definitely consider the proposal."

To date, AXT's substrate business is performing in line with expectations for the second quarter of 2003. In the first quarter, the division had revenues of $8.5 million, down 27% from the year-ago period. Revenue from GaAs and InP substrates was $7.0 million and $0.56 million, respectively. Demand is currently strongest for 2 inch diameter substrates used to grow red and yellow LEDs.

Sumitomo Electric files patent lawsuit against AXT-Japan

Japanese substrate manufacturer Sumitomo Electric Industries, Ltd (SEI) has filed a patent infringement lawsuit at Tokyo District Court against AXT-Japan and MO Sangyo, AXT's sales representative in Japan, alleging that AXT-Japan and MO Sangyo sell GaAs substrates in Japan that infringe two of SEI's Japanese patents.

SEI's patents relate to its vertical Bridgman (VB) method for making GaAs substrates. One patent was granted in December 2001 (Japanese patent no. 3,156,382) and relates to low residual strain, which enables significant minimization of slip-line defects. The other patent, obtained in June 2001 (Japanese patent no. 3,201,305), relates to SEI's carbon-doping manufacturing method.

SEI's complaint, filed on April 15, 2003, asks for an injunction to halt the importation or sale in Japan of GaAs substrates manufactured by AXT that allegedly infringe on SEI's patents. The suit also requests compensation for infringement.

AXT told *Compound Semiconductor* that it "plans to defend itself vigorously against these allegations and will continue to supply high quality VGF GaAs substrates to its customers".

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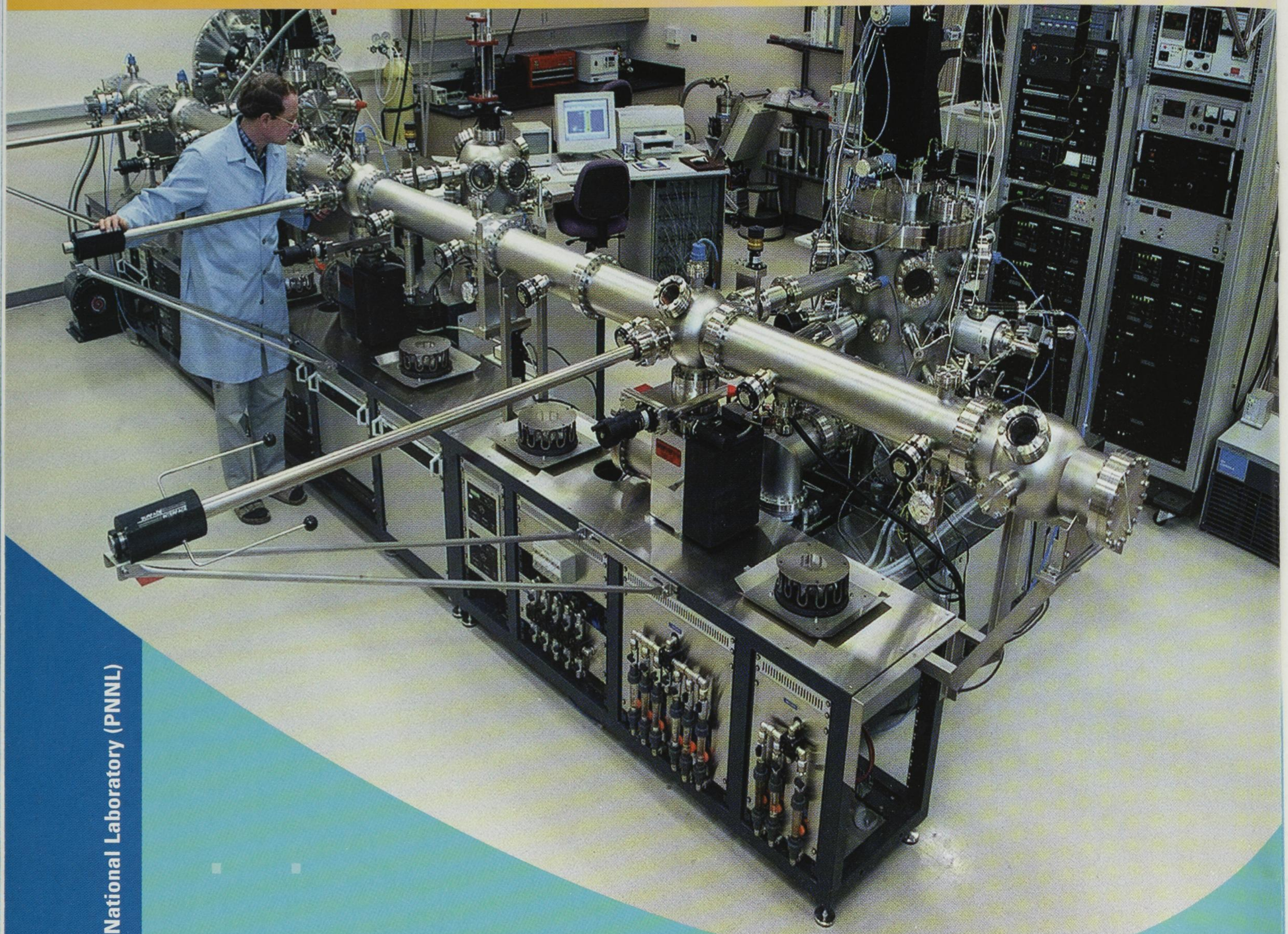

Courtesy: Dr. Scott Chambers, Pacific Northwest National Laboratory (PNNL)

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INSTRUMENTS

Violet lasers enable data storage format

The next generation of professional optical data storage technology will be a derivative of the Blu-ray technology being developed to replace DVD in mass-market consumer applications. The Ultra Density Optical (UDO) format is being established by Plasmon, an optical storage company headquartered in Cambridge, UK. Plasmon is using 405 nm violet lasers from Nichia in combination with phase-change media to create a robust, write-once storage system.

Permanent archival storage of business-critical information is vital for many corporations and government institutions, and is in many cases mandated by legislation. Typical users include banking and financial institutions, and hospitals that need to store medical imaging records. "Such systems are required where the data itself has an intrinsic value, or where it's impossible to recreate the data, or where there are legislative requirements," said Stewart Vane-Tempest, optical product director at Plasmon. "One of the biggest growth areas right now is e-mail archiving. Messages are sometimes archived for 7–10 years to allow them, for example, to be used in court."

PLASMON

Drives and media for the new UDO format, which uses violet lasers, will be the same size as existing MO storage products.

Current systems use magneto-optical (MO) technology, in which data is written using a combination of a magnetic coil and a 650 nm red laser. Magnetic hard disks are rewritable and are thus unsuitable for archiving, while MO and UDO are both write-once formats. MO drives have effectively reached their limit of 9.1 GB per cartridge, so Plasmon drew up a specification, together with Sony and HP, to adapt Blu-ray for the IT data storage market.

"We combined established technologies – violet lasers and phase-change media – with the mechanical chassis from the MO drive," said Vane-Tempest. UDO cartridges will have the same dimensions as standard ISO 5.25 inch MO cartridges, but the UDO media will store 30 GB (15 GB per side). While MO media cost about $10 per GB, UDO offers a dramatic reduction to $2 per GB, and a roadmap calls for further improvements.

The UDO media have a lower capacity than the 25 GB per side of Blu-ray, because UDO has omitted an expensive lens correction system in its first iteration. The other major difference is the method of storing the data. "In both the MO and UDO formats, the integrity of the data is verified as it is written," said Vane-Tempest. "There is defect management inside the drive, and the whole storage method is designed to be much more robust."

In contrast, Blu-ray is geared up for non-critical applications, mainly video storage and playback, in a price-sensitive market. When Blu-ray or the competing Advanced Optical Disc format eventually take off, the annual market for drives will quickly reach millions of units. Vane-Tempest says that the UDO market is much more focused on professional IT data archiving, with targets of around 50,000 drives per year. Nevertheless, UDO represents yet another application enabled by the development of nitride-based lasers.

Infineon and Epigress begin SiC epitaxial growth collaboration

Swedish CVD equipment supplier Epigress and Infineon Technologies are to co-operate on developing mass-production process technology for manufacturing SiC Schottky diodes. Infineon utilizes multiwafer Hot-Wall reactor technology from Epigress for the epitaxial growth of SiC device structures.

The two companies will develop SiC epitaxial processes to meet Infineon's cost-reduction plans for SiC devices. System performance data obtained from high-volume processing will be used to further optimize the cost of ownership of SiC epitaxial processing technology.

According to Roland Rupp, project leader for SiC device development at Infineon, the company has aims to improve the cost/performance ratio of SiC devices to further penetrate the high-power device market.

"In addition to low-cost, high-quality SiC wafers, a key target is excellent cost efficiency in all processing steps," said Rupp. Infineon has teamed with Epigress to address the very important area of SiC epitaxy cost reduction. "After SiC wafer costs this is the second most important cost factor influencing SiC device manufacturing expenses," added Rupp.

Reducing epitaxial costs will become even more important when Infineon enlarges its SiC product spectrum to include products with higher blocking voltages in the near future. Rupp says that the combination of Infineon's process know-how and the equipment-related skills of Epigress will lead to significantly reduced processing costs, and will result in another milestone on Infineon's cost-reduction roadmap for SiC power devices.

Frank Wischmeyer, director of Epigress AB, said: "Using feedback from the high-volume production of SiC device products, optimization of system capacity and utilization will lead to further enhancement of cost efficiency of epitaxial processing for the benefit of our customers."

Hoya starts 150 mm SiC wafer production

Hoya Advanced Semiconductor Technologies (HAST) of Japan has started commercial production of 3C-SiC wafers with diameters of up to 150 mm. The wafers are fabricated by heteroepitaxial growth of 3C-SiC (001) onto a silicon substrate. According to Keiichi Matsumura, the company's sales and marketing manager, special processing of the Si (001) surface is required in order to reduce the crystal defects in the 3C-SiC epilayer. After growth, selective etching of Si is used to obtain a free-standing 3C-SiC plate.

HAST began commercial production in April 2003, and started shipping wafers in May. "Our facility is able to produce 3C-SiC wafers with a maximum diameter of 150 mm," said Matsumura, "although we expect that the most common diameter will be 50.8 mm (2 inches) at first." HAST plans to make 100 wafers per month initially, and will increase its output to 1000 wafers per month during its current financial year ending March 2004, according to market demand.

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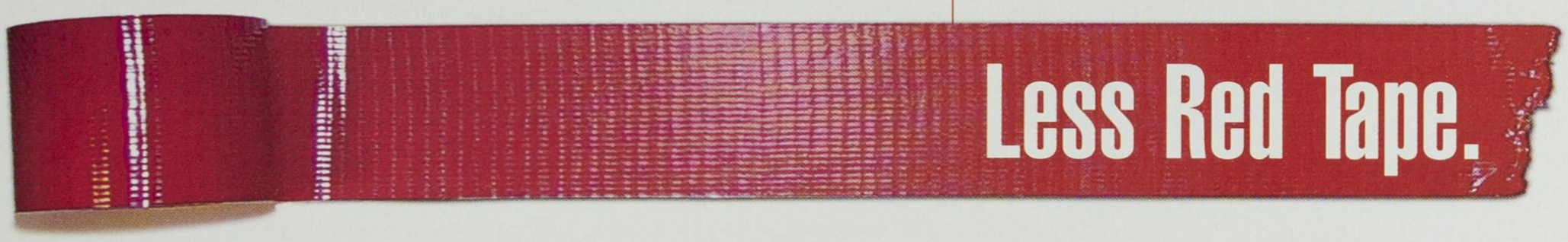

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Toshiba adapts white LEDs to yield new colors

Toshiba's US subsidiary Toshiba America Electronic Components, Inc (TAEC) has added bluish-green and reddish-purple LEDs to its line of high-luminosity devices. Like the company's white LEDs, these new devices provide a low-power, stable light source ideal for use in automotive instrument panels and other lighting applications. The new LEDs, designated TLBGA1100 for the bluish-green device and TLRPA1100 for the reddish-purple device, integrate Toshiba's phosphors and packaging with InGaN-based LED chips supplied by Toyoda Gosei, which emit at a wavelength of approximately 390 nm. The devices were developed in response to demands from specific customers, and Toshiba decided to add them to its standard portfolio of LEDs.

The new devices use the same approach as Toshiba's TLWA1100 white LED, combining UV emission from the InGaN chip with RGB phosphors in the transparent resin.

Toshiba's specialty color LEDs are fabricated using an InGaN chip emitting at 390 nm and a phosphor with an adjustable mixture of RGB components.

Phosphor mix determines color

The TLWA1100 differs from conventional white LEDs where a blue-emitting LED excites emission from a yellow phosphor. The unconverted blue light mixes with the yellow to give white light. In Toshiba's white LEDs and the new bluish-green and reddish-purple devices, the emission of the chip does not directly determine the color of the device, which is controlled by the RGB balance of the phosphor layer. As a result, Toshiba is able to offer a variety of colors through variation of the RGB balance in the phosphor.

For standard red, green and blue emitters, the adjustment of the wavelength through engineering the material structure of the chip itself is a more simple solution, but for specialty colors, the phosphor adjustment approach is significantly more effective, according to Toshiba. Another approach to achieving such specialty colors would be to use a combination of red, green and blue emitting chips in a single package. However, by this method the wavelength characteristics would be difficult to control and the cost of fabrication would be prohibitive.

Emission observed at 1.55 μm from GaAs

Researchers at Yale University have published a paper on the *Nature Materials* website (www.nature.com/nmat) in which they claim to have fabricated the first GaAs LED that emits at the crucial telecommunications wavelength of 1.55 μm. As the emitter can be pulsed at terahertz rates, the team claims that its device is ideal for use in high-speed communications networks.

Although GaAs-based devices emitting at 850 nm are already used in short-reach optical links, the bandgap of the material makes it unsuitable for the longer wavelengths needed for long-reach links. The Yale group's device operates at 1.55 μm due to the creation of artificial deep-level energy bands in GaAs grown by MBE at a low temperature of 225 °C. The growth conditions introduce As antisites (As_{Ga}) into the GaAs lattice. These are substitutional defects, in which an arsenic atom sits on a lattice site normally occupied by a gallium atom. The defects create deep-level energy bands, allowing the material to emit at longer wavelengths.

The LED fabricated from the material emits over 1.4–1.7 μm with a peak at 1.55 μm, and has an internal optical power of 24 mW at 4.25 A drive current. "The efficiency which is reported in the paper is 0.6%," Janet Pan, one of the paper's authors told *Opto & Laser Europe* magazine. "The next steps are to increase the efficiency and reduce the operating currents. Practical applications are possible in 3–5 years."

Japanese LED manufacturers deny patent rumors

The two leading Japanese manufacturers of nitride LEDs, Nichia and Toyoda Gosei, have both issued separate statements to deny rumors that they are involved in patent licensing agreements with companies in Taiwan.

Nichia's statement came in response to claims that it is licensing its LED-related patents to Taiwanese companies. "Nichia does not currently license LED patents to any Taiwanese companies," said the statement. In 2002, Nichia licensed its white LED manufacturing technology to Citizen Electronics, as well as reaching intellectual property agreements with its key rivals Osram Opto Semiconductors, Toyoda Gosei, Lumileds and Cree.

Toyoda Gosei was responding to claims that it is negotiating with a Taiwanese LED lamp manufacturer over a technical collaboration and a possible white LED technology license. Toyoda Gosei flatly denied any such involvement, stating that: "No patent license owned by Toyoda Gosei has ever been granted to any Taiwanese LED manufacturer. There is no fact, whatsoever, that Toyoda Gosei is negotiating with any such company in respect of patent licenses."

Taiwan produced about one quarter of the estimated 3 billion chips manufactured worldwide during 2002, and this proportion looks set to continue. However, Taiwanese companies in general have a weaker intellectual property position than the leading players in Japan, the US and Europe. Licensing would be a very attractive option to many Taiwanese firms in order to avoid patent-related restrictions that limit the available markets for some of their products.

Vishay's new LEDs offer intensity of up to 4000 mcd

Vishay Intertechnology has launched four new high-intensity AlInGaP- and InGaN-based LEDs with a ±15° angle of half intensity. The red (616 nm) and yellow (590 nm) LEDs offer typical luminous intensity of 4000 mcd at a forward current of 50 mA, while the true green (525 nm) and blue (470 nm) LEDs provide 2000 mcd and 700 mcd, respectively, at 30 mA.

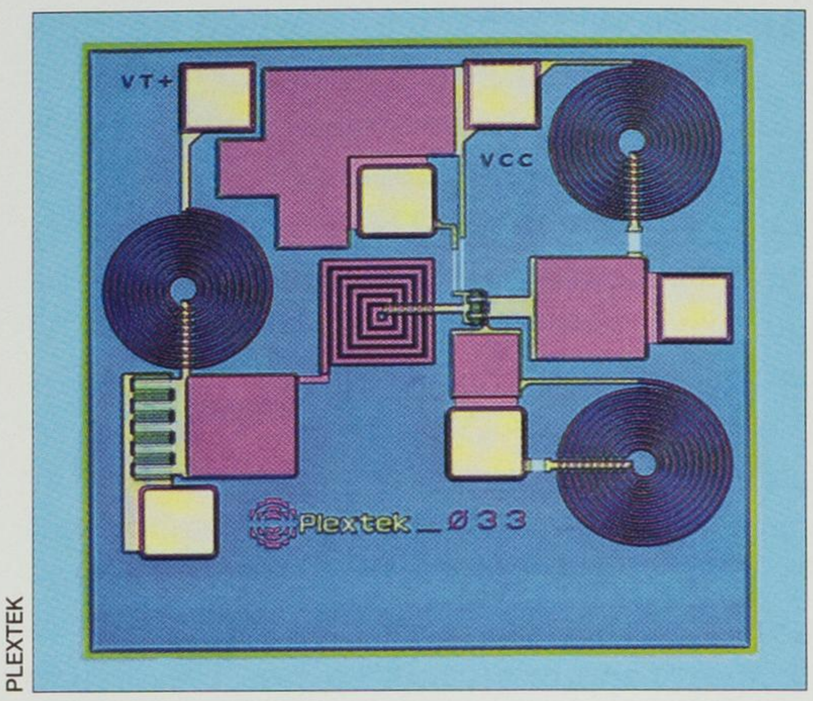
GCS, EiC improve InGaP HBTs for WLAN products

Foundry company Global Communication Semiconductors (GCS) is now offering a proprietary InGaP HBT process to address the demanding requirements of 802.11a/b/g power amplifiers in WLAN products.

"Our P2 process was developed specifically for 802.11 power amplifiers," said Sam Lee, CEO of GCS. "This process provides a better breakdown voltage and has a self-limiting current feature that prevents total burnout."

Lee says that it has long been recognized that GaAs-based PAs, and in particular InGaP HBT designs, are exceptionally suited for the more demanding linearity requirements of 802.11a and 802.11g WLAN standards.

"GCS' P2 process distinguishes itself from the competition with better gain, linearity and lower DC power consumption than SiGe and other GaAs-based technologies," said Lee, adding that GCS is currently shipping into a high-volume WLAN product program.



PLEXTEK

Plextek, a UK design house, has designed its first MMICs on GCS' InGaP HBT process, as part of an alliance between the companies (*Compound Semiconductor* October 2002 p7). A DC-coupled amplifier (shown) had a 3 dB bandwidth of 9 GHz with a gain of 11 dB and a noise figure of 2.5 dB, while a 5 GHz VCO had a measured phase noise of –105 dBc/Hz at 100 kHz offset.

Power process from EiC

EiC Corporation, which operates a 4 inch GaAs HBT fab in Fremont, CA, has developed a high-voltage version of its original InGaP HBT process. Initial evaluation of engineering devices shows values of $BV_{ceo} = 35$ V and $BV_{cbo} = 70$ V have been measured, enabling operation of the devices in the 24–28 V supply range. As an example, an amplifier die designed for 1 W Class A operation was shown to achieve 4 W performance in Class AB at 900 MHz. This power level was achieved at 28 V with 71% efficiency and an operating current of 200 mA. EiC's first products using the new technology will be introduced later this year.

Sirenza moves HQ to Colorado

Sirenza Microdevices of Sunnyvale, CA, is planning to relocate its corporate headquarters and all manufacturing operations to the Interlocken Technology Park in Broomfield, CO. The move, scheduled to be completed by July, follows Sirenza's recently completed purchase of Denver-based Vari-L Company.

Sirenza will lease around 74,000 sq. ft in two buildings in Interlocken, an advanced technology park located midway between Boulder and Denver. One building will serve as the company's new corporate headquarters, while the other will house manufacturing operations. Both buildings are undergoing significant upgrades at a total cost of approximately $1.2 million. The move will allow Sirenza to consolidate its manufacturing operations (currently located in Sunnyvale and Tempe, AZ), together with all four of Vari-L's former Denver facilities, into a single complex. The total workforce at the new complex is expected to be between 190 and 210 people.

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No Surprises!

JMAR Technologies wins $3.4 million to develop X-ray masks

JMAR Technologies, a developer of advanced lasers, lithography systems and semiconductor production services, has been awarded an additional $3.4 million in funding from the US Naval Air Warfare Center to procure sub-100 nm geometry next-generation lithography (NGL) masks. The X-ray masks procured through this program are being used to develop and produce high-performance GaAs MMICs, for use in military and commercial radar, communication, and space-borne applications. The award, funded by DARPA, extends the mask production program initiated in May 2002 by a year.

The masks are required to produce MMICs using JMAR's new Collimated Plasma Lithography (CPL) system, which is currently undergoing integration testing at the company's facility in Burlington, VT. JMAR has subcontracted IBM Microelectronics in Essex Junction, VT, to produce masks through the duration of this phase of the contract, which ends March 31, 2004.

Bob Selzer, mask program manager, said: "This award is a logical follow-on of the 130 nm mask program just completed. During 2003 and 2004 we expect to design CPL masks that demonstrate the extendibility of the CPL technology into the sub-100 nm regime."

Endwave acquires synthesizer products

Endwave, an RF subsystems provider, has acquired certain assets of Verticom, a privately held developer of radio subsystems used in wireless communications equipment. The acquisition gives Endwave the capability to design and manufacture Verticom's MTS-2000 synthesizer, which is used in satellite video links in defense imaging systems and other VSAT applications.

Also included in the transaction was an outstanding purchase agreement with Zeta; Endwave expects to begin shipping products to Zeta in the mid-2003 timeframe.

Endwave's revenues for the first quarter of 2003 were $7.7 million, up substantially compared with $4.4 million in the same period last year. However, the company's net loss was $6.5 million, or $0.72 per share.

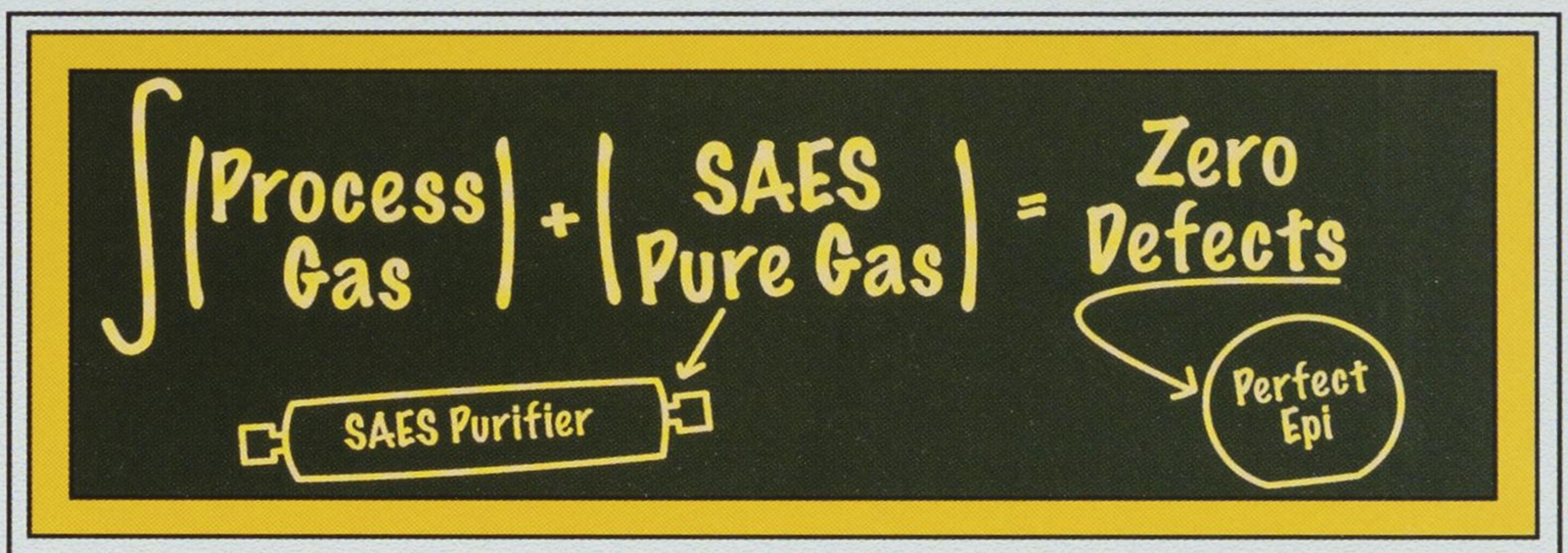
Products from TriQuint, Anadigics and Mimix

● **TriQuint** has introduced three new LNAs for millimeter-wave digital radio and Ka-Band VSAT applications. The ICs cover the 20–27 GHz, 28–36 GHz and 30–42 GHz frequency bands, and offer typical noise figures of 2.2, 2.3 and 2.8 dB respectively. They are fabricated using TriQuint's proven 0.15 μm gate length, 3MI MMW GaAs PHEMT process.

● **Anadigics** has launched two new downconverters with dual-synthesizer functions as well as a new reverse path amplifier for use in CATV set-top boxes and cable modems. The ACD2203 provides a conversion gain of 10 dB and a noise figure of 8 dB, while the ACD2204 has an integrated amplifier stage for 31 dB of gain. The ARA2008 reverse path amplifier incorporates a digitally controlled step attenuator with a range of 0–58 dB, adjustable in 1 dB increments.

● **Mimix Broadband** has released two new GaAs PHEMT-based amplifier products. The XP1005 is a four-stage PA operating in the 35–43 GHz range and has a typical small signal gain of 26 dB, with a 24 dBm typical P1dB compression point. A useful feature is that the saturated output power can be controlled by varying the drain currents, giving well defined output power levels over a >40 dB range.

The XP1004 is a three-stage buffer amplifier operating in the 16–30 GHz frequency band. The device can be biased for low noise or high power performance as required, and has a small signal gain of 21 dB with a noise figure of 2 dB across the band when biased for low noise. This device also has an 18 dBm P1dB compression point at high power bias. Backside vias and gold metallization allow conductive epoxy or eutectic solder die attach processes.



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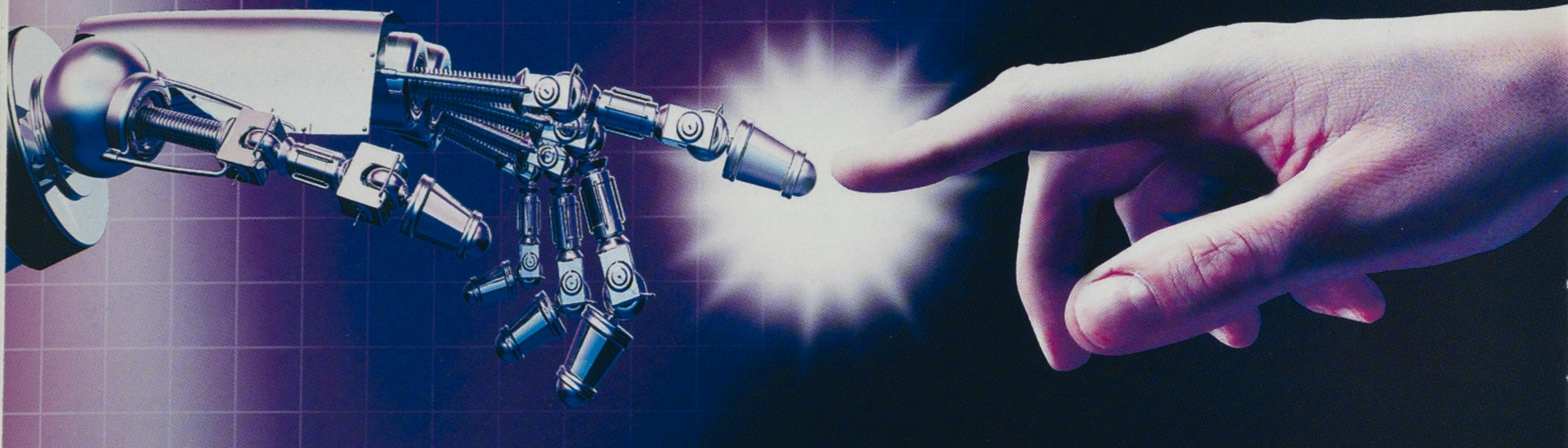

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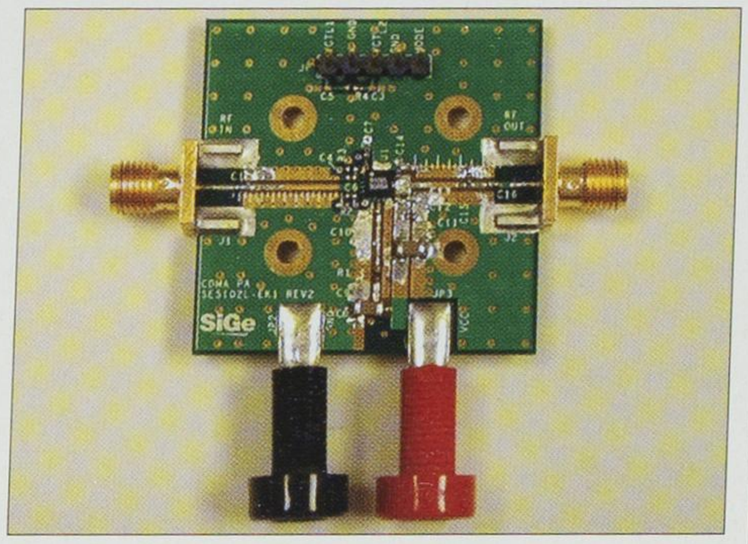
SiGe Semiconductor releases PAs for CDMA handsets

SiGe Semiconductor of Ottawa, Canada, has introduced a pair of RangeCharger PAs that the company says gives GaAs-like performance at Si prices for IS-95 and CDMA2000 1x cellular handsets operating in the 824–849 MHz band.

The SE5102 PA and SE5103 PA module are manufactured using a SiGe BiCMOS process that boosts linearity and power output to the levels of GaAs alternatives, while reducing the nominal quiescent current for longer battery life. SiGe Semiconductor, which recently secured $42.8 million of funding, has a licensing agreement with IBM for designs and other intellectual property related to SiGe-based PAs, and is confident that it has a GaAs-beating technology for cellular PAs (*Compound Semiconductor* March 2003 p10).

"The ability to achieve the high linearity and stability required of CDMA handsets with a SiGe-based PA is a significant breakthrough," said cellular director Jose Harrison. "Handset designers can now achieve the required performance at a fraction of the cost of most solutions on the market today. The added benefits of ultra-low power consumption and high integration strengthen our position that SiGe-based PAs will displace GaAs across 2G, 2.5G and 3G cellular markets."



SiGe Semiconductor's SE5102 SiGe BiCMOS PA mounted on a test board.

The SE5102 and SE5103 achieve a high power output of +28 dBm in CDMA operation with a PAE of 39%. On-chip protection circuitry ensures reliable performance under high-voltage standing-wave ratio conditions.

Low nominal quiescent current of 65 mA improves battery life, an important consideration in allowing the support of new data services while meeting consumer expectations for talk time. The SE5102 is priced at $0.75 and the SE5103 module costs $1.50.

Soitec and ASM team up to make strained SOI wafers

French wafer-bonding specialist Soitec and semiconductor-processing equipment supplier ASM International of the Netherlands have announced a strategic partnership to develop and ensure the commercial manufacturability of strained silicon-on-insulator (SSOI) substrates. The partnership combines Soitec's established wafer-bonding technology for SOI wafer production with ASM's silicon epitaxial technologies to enable the volume manufacturing of SSOI wafers.

Many of the large CMOS device manufacturers offer SOI options to their processes for higher-speed and/or lower-power devices. Some high-end microprocessors are also fabricated using SOI substrates. CMOS devices using strained Si channels are in development with many of the major CMOS manufacturers, and commercially available devices are expected to emerge in 2005. Efforts to combine the two technologies have been under way for some time, and a number of journal papers have been published on the subject. Because of the SiGe buffer layers required for strained Si growth, forming the insulating layer by implanting oxygen is difficult, and most of the work to date has concentrated on the use of various wafer-bonding techniques (*Compound Semiconductor* April 2003 p25).

As the CMOS industry moves to new material systems to maintain its progress, materials and process equipment specialists must work increasingly closely together to meet the CMOS industry's stringent requirements. Soitec and ASM will partner to combine Soitec's Smart Cut technology and ASM's manufacturing tool, the Epsilon 3000 epitaxial reactor, to create the industry's first high-volume, production-worthy SSOI substrate. The two companies have worked together in the past, and the new agreement extends a previous collaboration on the production of Soitec's 300 mm Unibond SOI wafers using ASM's Advance 400 series of vertical furnaces.

Matheson Tri-Gas adds ammonia plant capacity

Matheson Gas Products Korea, a subsidiary of Matheson Tri-Gas, has completed a new high-purity ammonia facility located in Chonan, Korea. The facility produces ammonia in both cylinder and bulk packages for the compound semiconductor, silicon and flat-panel display markets. "By adding regional production of ammonia to our already established Nanochem purification line and bulk delivery package, Matheson Gas Products Korea can now serve all nitride applications," said David Lai, director of Asia sales.

In January, Matheson Tri-Gas completed the expansion of a new facility in LaPorte, TX, to produce ultra-high-purity ammonia, which the company designates Ultima. Matheson sees the additional capacity as being critical to its continuing success within the compound semiconductor market.

"Along with increased production rates, additional purification techniques have been added to supplement the proprietary adsorption technology currently in place," said Fred Greene, the company's compound semiconductor marketing director. "This new purification will also enable further reduction in key contaminants targeted on the compound semiconductor roadmap."

Tegal Corporation transfers to Nasdaq SmallCap Market

Shares in Tegal Corporation, which manufactures plasma etch and deposition systems, are now being listed on the Nasdaq SmallCap Market, effective May 6. Tegal's common stock was transferred from the Nasdaq National Market as a result of its price having been below $1.00 since late July. Tegal now has a grace period until September 2, 2003, in which it can demonstrate compliance with the $1.00 minimum bid price per share. In related news, Tegal shareholders have given the company's board the authority to carry out a reverse stock split, which would have the effect of raising the stock price.

ASTM F1.15 subcommittee seeks participation

The F1.15 Compound Semiconductor Subcommittee, organized by ASTM International, is looking for input to help provide test methods and practices to improve the productivity of the compound semiconductor industry worldwide. ASTM International (formerly known as the American Society for Testing and Materials) is a not-for-profit organization that provides a global forum for the development and publication of voluntary consensus standards for materials, products, systems and services.

Within the ASTM F1 Committee on Electronics, F1.15 has supplied various test methods to support the SEMI Compound Semiconductor Wafer Committee, which was started almost 20 years ago. More recently, the subcommittee has set up three task groups, described below, and is planning a fourth on front-side processing.

- Backside Processing Task Group. Led by Maria Huffman of Agilent, this group is looking for feedback on its new practice draft. Electronic copies are available from Scott Orthey, ASTM F1 manager (sorthey@astm.org). Feedback, comments and corrections should be sent to Maria Huffman (maria_huffman@agilent.com) and Austin Blew, F1.15 chairperson (austin@lehighton.com).
- Mobility Round Robin Task Group. Led by Danh Nguyen of Lehighton Electronics, this group is conducting a PHEMT mobility round robin per ASTM test method F-76. The group hopes to improve F-76 and also a SEMI-proposed nondestructive test method by using and comparing destructive and nondestructive test methods. The goal is to have certified reference material available in the future as well as methods to separate the mobility and sheet charge density measurements of the 2DEG channel from the cap layer.
- Backside Processing Metrology Task Group. Led by Tom Parsons of Insaco Inc, this group is presently drafting a new ASTM test method to measure sapphire, which will include measurements of sori, sag, total thickness variation (TTV) and restrained flatness, similar to ASTM test methods F-657, F-1390 and F-1451, which pertain to silicon wafers. This new test method will be used to measure sapphire carriers used in thinning wafers, as well as other sapphire applications.

"Interested parties can become involved by providing feedback on the Backside Processing Practice Draft, and also by joining F1.15 and becoming active in the various task groups," said Austin Blew. "We will be having a meeting with the rest of ASTM F1 in Denver on June 17, which will also include a teleconference for those unable to attend."

Materials and equipment orders from China

- The **Institute of Semiconductors at the Chinese Academy of Science** (ISCAS) in Beijing has purchased an MOCVD reactor from **Thomas Swan Scientific Equipment**. The MOCVD reactor, which can accommodate 3 × 2 inch GaN-on-sapphire and 1 × 4 inch GaN-on-silicon growth, will be utilized for the development of short-wavelength laser diodes and UV photodetectors.
- The Photonics Technology Center of **Hong Kong University of Science and Technology** (HKUST) has ordered an AIX 200/4 system from **Aixtron** for the growth of epitaxial AlGaInSb/P/As and dilute nitride layer structures.
- **Air Products** has signed an exclusive multi-year agreement to supply its ultra-high-purity White Ammonia product, as well as other gases and gas supply equipment, to **Shanghai LanBao Photoelectric Materials Co Ltd** of China. Shanghai LanBao manufactures blue and green GaN-based LED epiwafers and chips.
- The Photonics Research Center of **Nankai University** in Tianjin has ordered a Compact 21 T MBE system from **Riber** to grow P- and N-containing materials.

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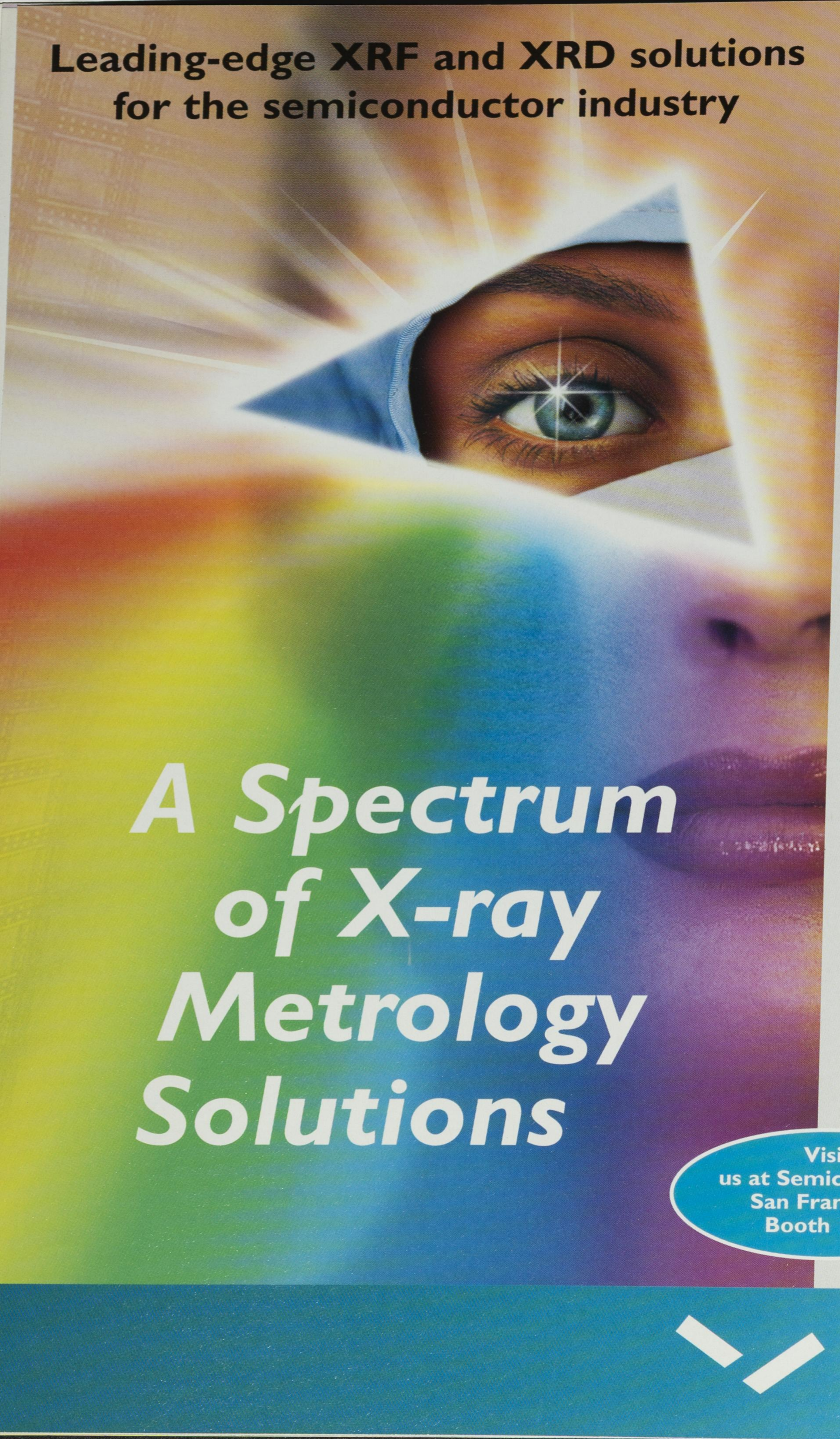

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Agility improves yield, wins contract

Tunable laser specialist Agility Communications has announced that its highly automated facility located in Allentown, PA, has achieved package and test yields of over 95% for its widely tunable lasers.

"Our manufacturing platform and single-chip architecture allows us to produce tunable lasers and monolithically integrated modulators (EMLs) extremely efficiently," said Ron Nelson, Agility's CEO and president. "This enables us to compete head-to-head with distributed feedback (DFB) lasers on a price and volume basis."

Nelson said that Agility's revenue for the first quarter of 2003 exceeded the value achieved for the whole of 2002. The company recently received a multimillion-dollar contract award from DARPA for the development of widely tunable lasers with EMLs. Valued at $5.5 million if fully funded through three phases, the contract was awarded by DARPA under its Chip-Scale WDM (CS-WDM) program. The program's goal is to develop multifunctional photonic chips for WDM networks on military platforms.

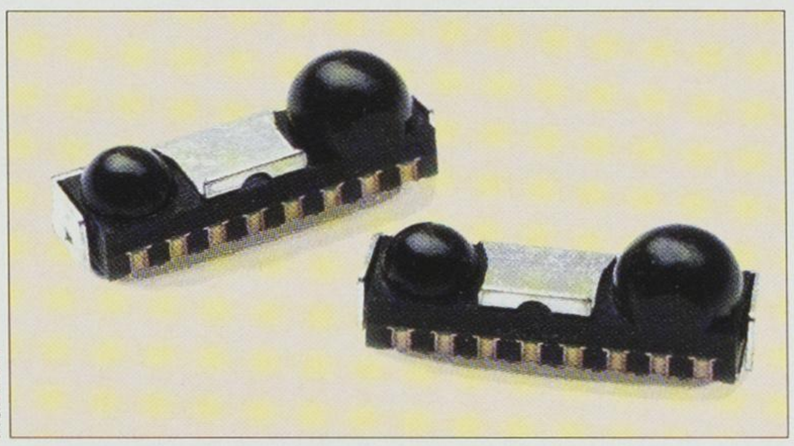
Under the CS-WDM program, the government is testing Agility's technology platforms that enable and support intelligent networks and systems for military applications. Agility's widely tunable 2.5 Gbit/s EMLs have already performed as well as a DFB laser with an external lithium niobate modulator, over a distance of 1080 km.

Agilent IR transceiver enables remote control in mobile phone

Agilent Technologies is supplying its HSDL-3002 infrared transceiver with remote control capability to NEC for use in the NEC N504iS full-color display mobile phone. The IR transceiver provides cordless communication functions such as exchanging pictures with other handsets, and can also control televisions and VCRs up to 6 m away from the handset.

A pre-installed application supports remote control of Sony, Sharp and Panasonic televisions. For other devices, users can download remote control data configurations from an NEC-operated i-mode site or, since the N504iS is a smart remote, it can record signals from existing IR remotes to control other entertainment devices and home appliances.

The HSDL-3002 contains two LEDs. One is an AlGaAs/GaAs device emitting at 870 nm to provide IrDA (Infrared Data Association)-compliant low-power serial IR operation at speeds of up to 115.2 kbit/s. The second is a 940 nm GaAs/GaAs LED that enables IR remote control transmission. The transceiver is specifically designed for low power consumption and has a shutdown current of just 10 nA, helping to extend battery life in mobile devices.



AGILENT

Agilent Technologies' HSDL-3002 infrared transceiver contains two IR LEDs and measures 2.7 × 9.1 × 3.65 mm.

Newport Corporation invests $3.5 million in Nexx Systems

Newport Corporation has invested $3.5 million to acquire 19.9% of Nexx Systems, Inc, a privately owned manufacturer of flip-chip processing equipment for back-end semiconductor manufacturing, headquartered in Wilmington, MA.

As part of the transaction, Newport will become the preferred provider to Nexx of certain components and subsystems, such as wafer-handling robots and load ports. Newport and Nexx will also engage in collaborative development, integration and marketing of their flip-chip processing solutions.

"Nexx provides very innovative and cost-effective platforms focused on several of the process steps in flip-chip packaging, including wafer metallization, electroplating, photoresist deposition and stripping, and related technologies," said Robert Deuster, president and CEO of Newport.

Deuster added that Nexx is an excellent complementary fit with automated assembly and inspection specialist MRSI, which Newport acquired in 2002.

Avalon Photonics raises $5.5 million

Avalon Photonics, a Swiss company that manufactures single- and multi-mode VCSELs, has raised $5.5 million in its second round of funding. Investors included several venture capital firms and the Swiss Center for Electronics and Microelectronics (CSEM), from which Avalon was spun off in September 2000.

"We now have a strong shareholder base from which to finance our future expansion and reach positive cash flow," said Heinz Meier, the company's CEO. "With more than nine years of experience in VCSEL design, development and manufacturing, Avalon Photonics will be in a solid position to meet present and future requirements in the short-range optical datacom segment, as well as in the sensing market."

Suss and LNL join forces to provide on-wafer probing

Suss MicroTec has teamed up with LNL Technologies to commercialize LNL's optical probe technology integrated with Suss probe systems. The technology is designed to enable makers of edge devices such as lasers, detectors and arrayed-waveguide gratings to identify known good die at the wafer level, thus avoiding time and resource investments in non-working die. On-wafer testing is particularly useful for integrated optics because each optical function on a die can be individually tested. The probe also allows for die testing between wafer processing steps, which is critical for evolutionary improvements in fabrication processes and yield management.

Honeywell sees growth in VCSELs

By Jon Newey

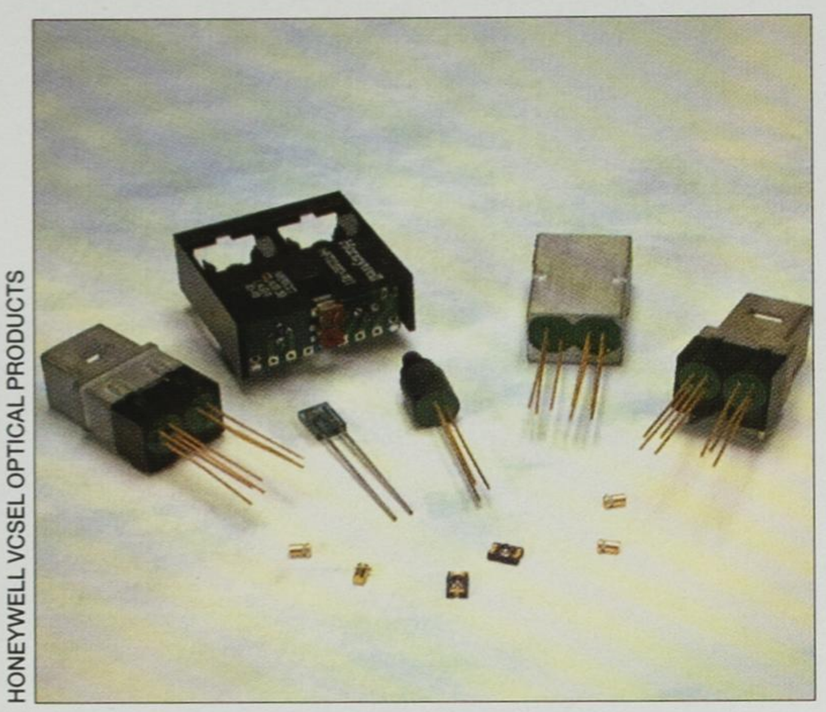
Despite the optical communications downturn, there is still life in the VCSEL market. While short-wavelength (850 nm) VCSELs continue to be a commercial success in the short-reach data communication market, devices operating at higher data rates and longer wavelengths are opening up new applications. Sales of 850 nm VCSELs in 2003 are expected to be at about the same level as last year, when around 9 million units, mostly 1.25–2.5 Gbit/s devices, were shipped in the datacom market. The leading supplier, Honeywell, believes that it has managed to maintain its market share through the downturn, helped by its track record with 850 nm devices and by being big enough to weather the storm. "Demand never really dropped, it just stopped growing," said Jim Tatum, strategic marketing manager of Honeywell VCSEL Optical Products.

In datacom, the 10 Gbit/s market appears to offer the best prospect for future growth. "We see the 10 Gbit/s VCSEL market taking off towards the end of 2003," said Tatum. "It may reach no more than 10,000 units this year, but it should grow in 2004 as people begin to aggregate some links and switches, and as Fiber Channel applications grow." Honeywell also has its eye on a number of emerging non-communication markets. Although Tatum is reluctant to reveal what these applications might be, he says they look likely to consume a large number of devices. "Volumes are potentially an order of magnitude larger than the communications market, but the price point is much more aggressive as well."

Long-wavelength devices

Above 850 nm, Honeywell has devices in development at 1310, 1490 and 1550 nm, and recently reported single-mode mW-level powers at room temperature from its 1310 nm devices, as well as operation up to 90 °C. "The exact time frame for product sampling and roll-out has yet to be determined, but the intention is that by the end of the year we will be in a sampling, reliability testing and qualification mode," said Tatum.

Initial products will operate at 10 Gbit/s and will compete with DFB lasers. "DFBs are relatively difficult to manufacture and we think VCSELs can overcome those manufacturing issues," said Tatum. "We're looking to compete with DFBs in links operating at 10 Gbit/s, and those links operating over 10 km. Here, around 1 mW of optical power is sufficient." Fabry–Perot lasers are generally adequate for speeds up to 2.5 Gbit/s over several km, and have relatively low ASPs and many competing manufacturers, so this market presents more of a challenge.



HONEYWELL VCSEL OPTICAL PRODUCTS

Honeywell makes a range of VCSEL-based products at its plant in Richardson, TX.

Honeywell will be targeting an emerging market for 1490 nm emitters, which are required for the emerging Ethernet in the First Mile standard.

Honeywell is determined not to rush longer-wavelength VCSELs into production. "Honeywell stakes its reputation on quality, reliability and performance, and we can't afford to be premature with the product," said Tatum. "Demand is softer than we want to see it at this point and there are a number of 1310 nm products that work pretty well. Breaking into the market is going to be tough, which is why we are targeting specific application areas."

Tatum applies the same reasoning to 1550 nm VCSELs, coupled with the fact that most of the 1550 nm market is in long-haul or undersea routes where power becomes an issue. Instead, Honeywell will be targeting an emerging market for 1490 nm emitters, which is not a commonly discussed wavelength. It is, however, required for the emerging Ethernet in the First Mile standard (IEEE 802.3ah), which covers bidirectional links for applications such as fiber-to-the-home. The standard requires a defined wavelength range of 1480–1500 nm to allow CATV overlay at 1550 nm in the US; this points to a controlled wavelength source like a DFB or VCSEL with a small temperature coefficient. Tatum expects that 802.3ah will be a market that drives VCSEL volumes at 1490 nm.

Visible VCSELs

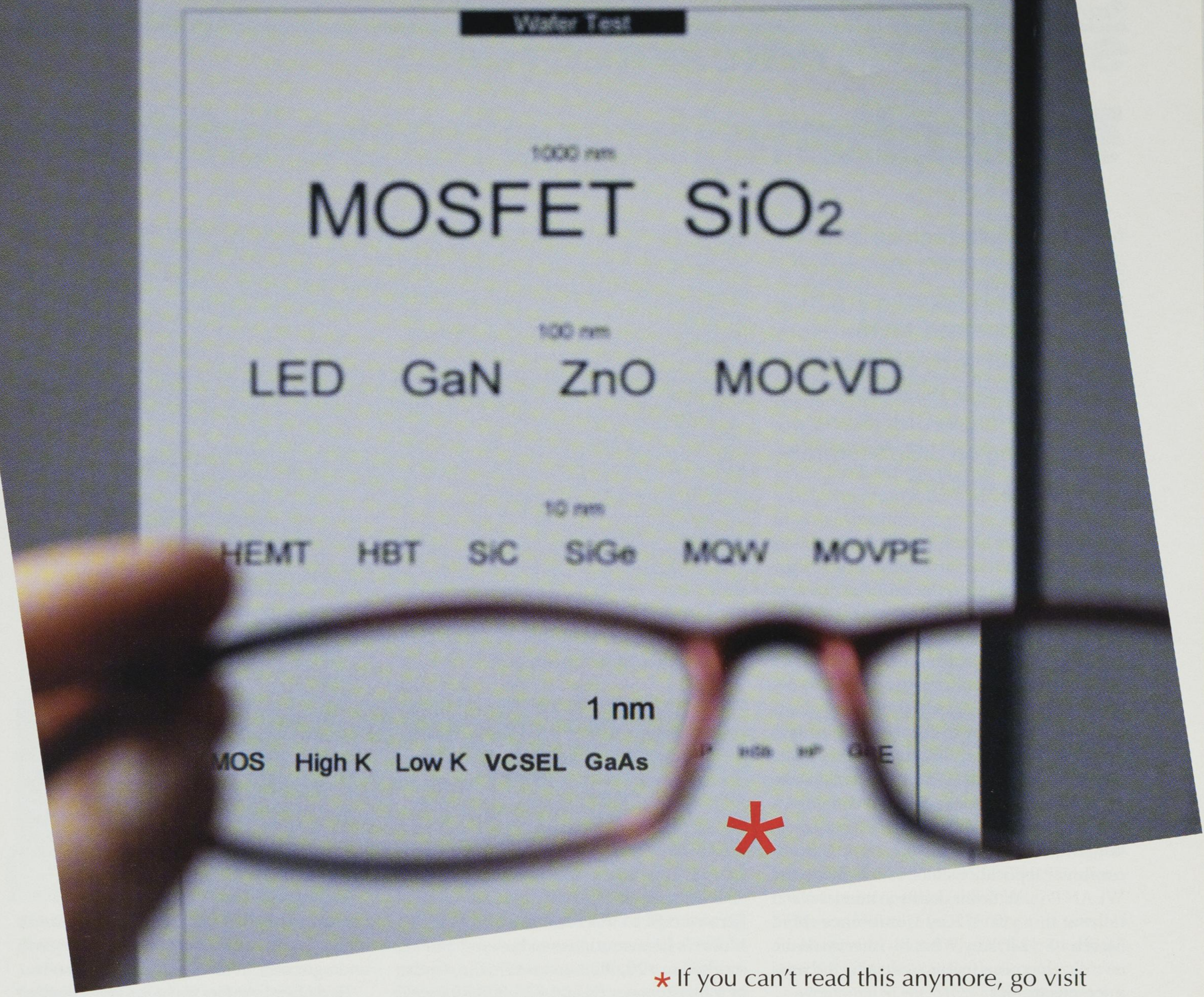
A number of groups around the world are working on VCSELs that operate at visible wavelengths, and Honeywell is no exception. Red VCSELs are of interest for industrial and consumer applications including bar code scanning and transmission over plastic optical fiber (POF) networks within buildings and even vehicles. Researchers have struggled to gain a reasonable optical power above room temperature. However, improvements to the operating temperature are being made, and Honeywell has achieved optical powers of over 1 mW at 70 °C for 670 nm devices. "We expect to have some parts [red VCSELs] that are usable in optical sensor applications towards the end of this year," said Tatum. "We are not targeting the POF market at the moment because it is still immature, but it has good potential in the future."

VCSEL arrays

VCSEL arrays are another product area that is suffering from near-zero demand. "We have an array product, but quite frankly that market is very slow today," said Tatum, adding that the development of sources operating at 10 Gbit/s removes the need to use arrays of emitters to expand capacity in many cases.

"There are applications that need arrays, but the volumes are not high enough to interest Honeywell in pursuing heavily," said Tatum. "Arrays might make sense when you have 12 channels operating at 10 Gbit/s each, and maybe when you talk about 2D array structures, but at the moment there is minimal pull from telecom providers or the system integrator companies."

As the biggest player in VCSELs, Honeywell has survived the current downturn while other companies have come and gone. "If you were to plot the number of companies that claim to make VCSELs against time, you would see a spike between 2001 and mid-2002," said Tatum. "By the end of 2003, the number will probably be half of its peak value."



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SILICON HETEROSTRUCTURES

The changing shape of the RF

New materials such as SiGe and strained Si are the key to extending silicon's reach and ensuring that the CMOS industry can prosper. But just as SiGe threatens GaAs, developments in CMOS are encroaching on SiGe's territory, writes **Jon Newey**.

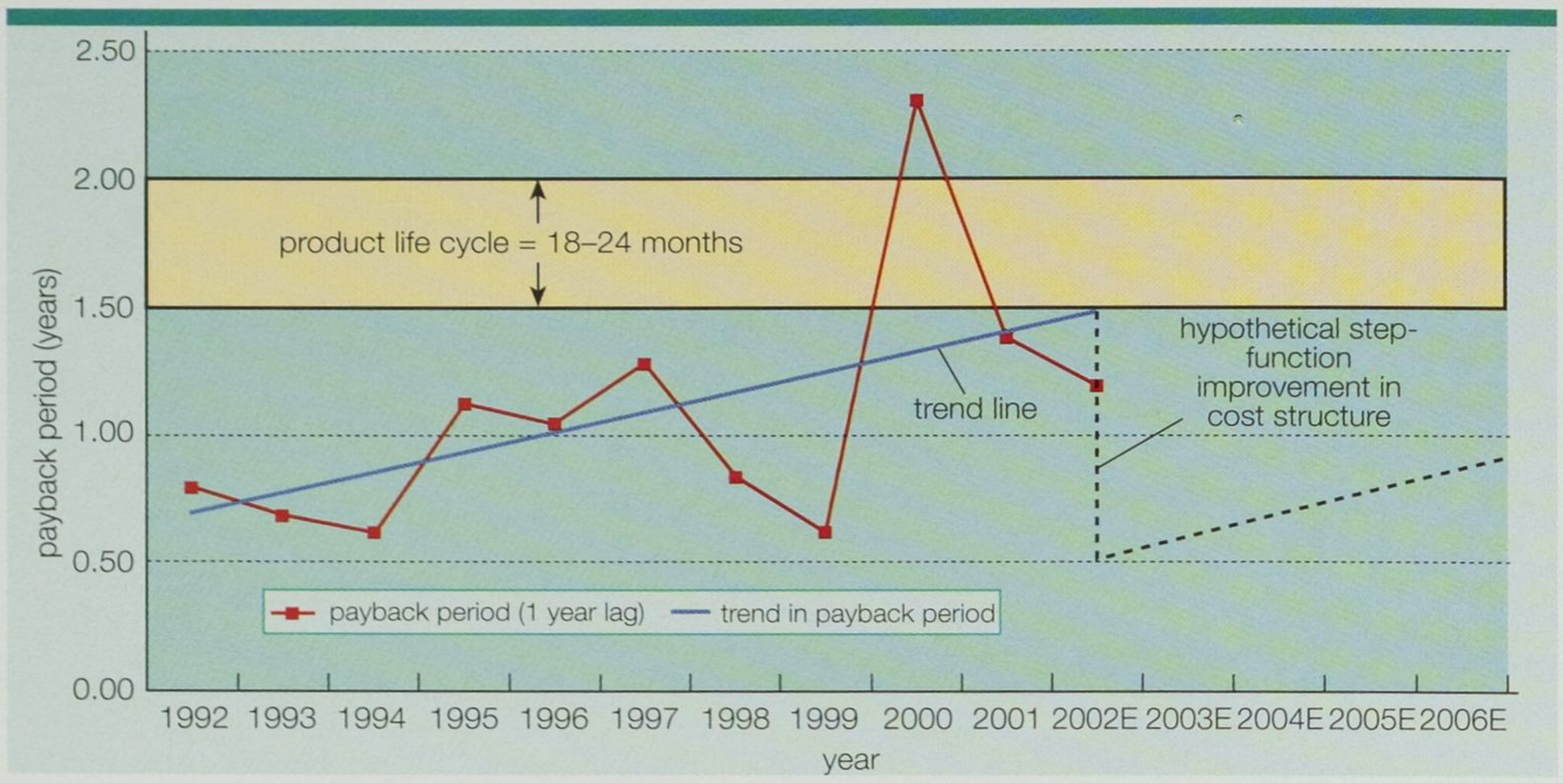

Fig. 1. Once the payback period of a fab reaches the product life cycle time, manufacturing ceases to be profitable. Strained Si could provide a correction to the trend line, reducing payback time to less than a year.

Global IC market by material

IC INSIGHTS

	2002 IC market	*2007 IC market*
silicon	98.6%	97.6%
GaAs and other III-Vs	1.2%	1.6%
SiGe	0.2%	0.8%
total value ($ billion)	120.5	190.8

Table 1. The SiGe market is expected to be worth $1.5 billion in 2007.

Those who have been involved in GaAs electronics for many years may remember when the initial excitement at the performance of GaAs devices led some to rashly describe it as a "silicon killer". Although GaAs has become a mainstream manufacturable technology, the relatively high material and device-processing costs compared with Si have kept it firmly in high-performance niches. Indeed, the tables have turned somewhat and it has been said that the performance of new Si-based technologies will displace GaAs from many of its traditional niches, especially in the cost-conscious consumer applications such as cell phone and WLAN PAs. With this debate in mind, several talks at this year's Key Conference (held March 10–12 in Key West, FL) discussed the new developments that are reshaping Si-based microelectronics.

It is generally true that compound semiconductors have a performance edge over Si in terms of speed, noise and efficiency. Conversely, the Si industry benefits from far higher levels of integration and greater economies of scale. However, as the physical limits of the current materials in use are approached and power consumption becomes a critical problem, new materials are being looked at. Trevor Yancey of IC Insights described the Si industry as one with considerable momentum behind it, which is why the industry is extending the usefulness of Si by introducing new technologies such as SiGe, strained Si and SOI. New technologies not only extend Si's abilities, but also provide solutions to some pressing problems that threaten the economics of the industry as it strives to obey Moore's Law.

Strained Si to the rescue

Moore's Law continues to be valid and has resulted in a 20,000× increase in the number of transistors per IC and a 35,000× increase in speed in the last 35 years. The two key drivers for this advance are decreasing linewidths (8 μm in 1970, 90 nm emerging now) and additional layers of interconnect (1 layer in 1970 and 6 in Intel's Pentium 4 processor). This progress has come at an economic cost to manufacturers. The cost of building a fab spirals upwards for each generation of CMOS technology, and by some estimates could reach $18 billion by 2010, compared with about $15 million in 1970. With ever-decreasing average selling prices squeezing margins, fab payback time is now approaching the standard product life cycle of 18–24 months, which is itself decreasing. An industry ceases to be profitable when the payback period for the capital equipment exceeds the time period over which the capital equipment is used. Without some sort of correction to these trends, the consumer can look forward to higher prices, while the CMOS industry will undergo consolidation and slower growth.

Brian Lord, AmberWave System's director of corporate development, thinks that the strained Si technology being developed and licensed by AmberWave will be an important part of the solution needed to prevent this gloomy scenario (*Compound Semiconductor* September 2002 p39). The higher mobility of carriers in a thin strained Si layer means that faster and/or lower power consumption devices can be manufactured without the need to shrink linewidths. "New materials are the answer to this problem," said Lord. "What the industry really needs is a step-function improvement in the trend line to reduce the fab payback period to less than a year. We need to move to a system where instead of the fab driving the performance of next-generation products, the materials – specifically engineered substrates – become the driver." (figure 1).

New materials have been a feature of new

F microelectronics landscape

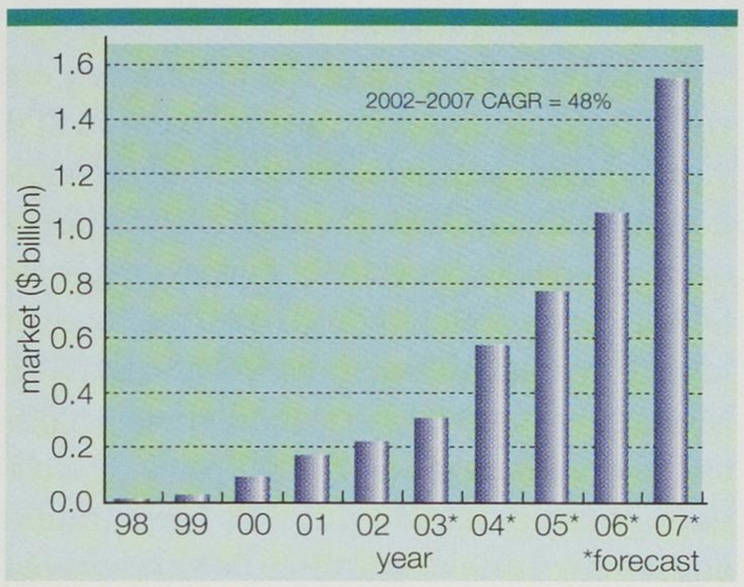

Fig. 2. The market forecast for SiGe ICs shows a CAGR of 48% from $0.22 billion in 2002 to $1.55 billion in 2007.

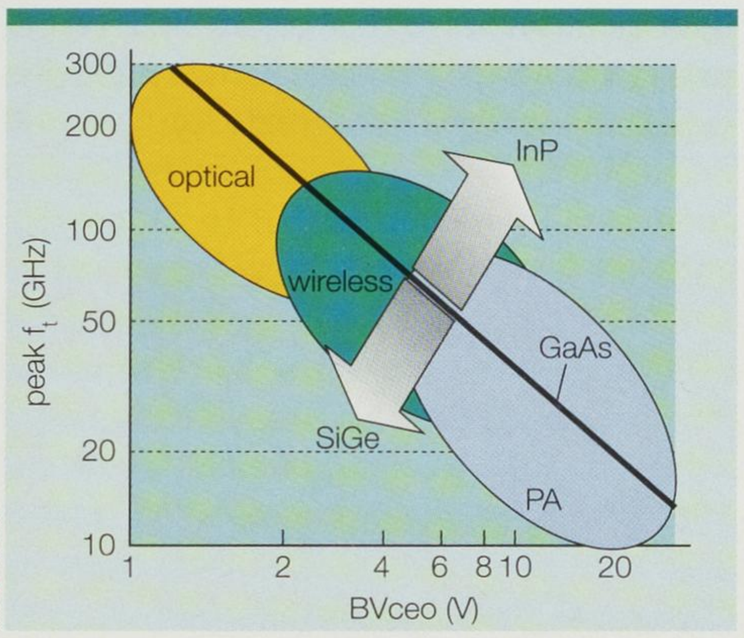

Fig. 3. GaAs will maintain its foothold in the final PA stage because it fulfills the demanding combination of breakdown voltage and f_t required in this application.

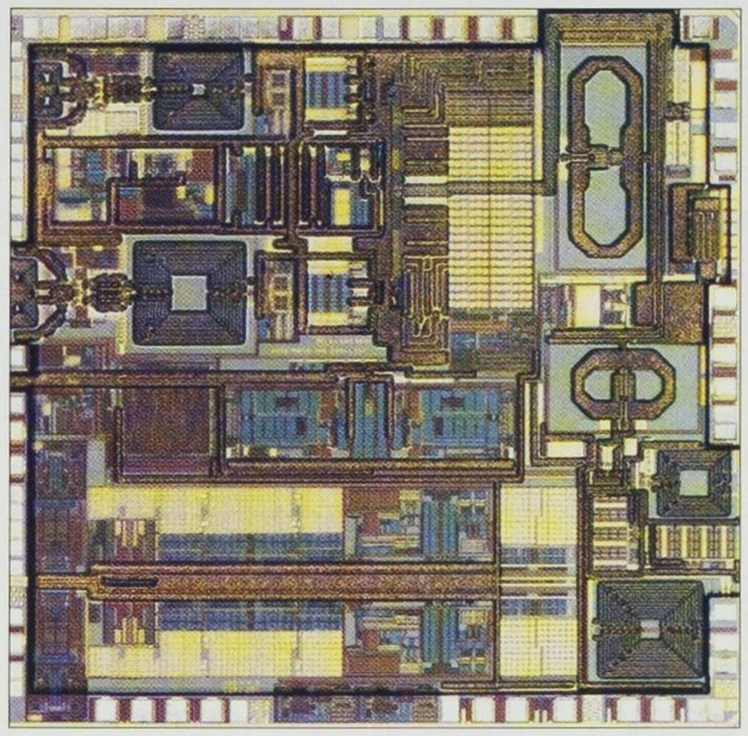

Fig. 4. Most of Motorola's RF/IF chips, such as this transceiver, are now implemented in its SiGe BiCMOS technology, but CMOS could soon be good enough to replace SiGe in such applications.

generations of CMOS processes in the past, but their introduction has been made necessary by shrinking feature sizes and more levels of interconnect. However, strained Si is different because it enables improvements in device performance without a reduction in feature size or huge capital cost increase. "The magic is in the wafer," said Lord. "Manufacturers can simply buy the strained Si epiwafers and process them on normal CMOS lines."

SiGe and cellular PAs

The semiconductor industry continues to be dominated by Si. According to IC Insights, III-V materials accounted for just 1.2% of the market in 2002, and SiGe had a 0.2% market share. The situation in 2007 will look very similar, which is perhaps surprising given the fanfare surrounding the emergence of SiGe and its perceived benefits (table 1). In 2007, the SiGe market will be worth about $1.5 billion, or 0.8% of the IC market, with III-Vs having 1.6% of the market (figure 2).

SiGe offers many of the performance characteristics of compound semiconductors, but at about the cost of Si CMOS, because standard CMOS lines can be used for processing. It also allows a previously unseen level of integration, with SiGe bipolar transistors for analog and RF functions being combined with digital CMOS logic on the same chip. This has resulted in a large number of manufacturers that now have SiGe BiCMOS processes.

SiGe has certainly displaced GaAs in a number of applications, and in some camps it is thought that SiGe will also displace GaAs from its stronghold, the cell phone PA (*Compound Semiconductor* March 2003 p10). However, SiGe also faces a challenge from the inexorable march of CMOS. In his presentation entitled "Semiconductor Technologies for a Changing Wireless World", Mark Wilson, director of technology strategy at Motorola SPS, stressed that it would be CMOS that shapes the future of the SiGe versus GaAs race.

Wilson described the semiconductor breakdown of Motorola's i.250 GSM/GPRS platform. Here, the power management functions and baseband processor are implemented in CMOS, the front-end transceiver in SiGe:C BiCMOS and the PA in GaAs (with Si for the control ICs). Given that the PA is the only area where GaAs has an impact in this volume market, and the rumblings that SiGe could even displace GaAs here, it may provide some comfort to those with a vested interest in GaAs to hear Wilson's comments on the prospects for PA technologies. "I certainly believe that GaAs HBT or E-mode PHEMT technology will [continue to] play a part in the PA socket at least in the final stage," he said. "There is a good chance that SiGe BiCMOS could find its way at least into the predriver stages and certainly a BiCMOS IC can be used for power control within the PA module."

The reason GaAs will maintain its foothold in the final PA stage lies in its ability to fulfill the demanding combination of breakdown voltage and f_t requirements in this application (figure 3). SiGe tends to lie on the wrong side of the breakdown voltage versus f_t line. "I'm not aware of any SiGe technology in or near production that offers the breakdown voltage necessary for the final stage of the PA," said Wilson. "It's very difficult to meet the ruggedness requirements for GSM/GPRS with any SiGe technology that is available."

Most of Motorola's RF/IF chips are now implemented in its SiGe BiCMOS technology, but what does SiGe really provide over conventional Si BiCMOS? The answer lies in the f_t characteristics as a function of collector current. The f_t of a SiGe HBT peaks at a lower collector current than for a Si BJT, but more importantly, the SiGe HBT gives a more rapid rise in operating frequency as collector current is ramped. The result is that the required frequency can be obtained at a collector current an order of magnitude lower in a SiGe HBT than in a Si BJT. This means an RF/IF transceiver in SiGe BiCMOS can operate with lower power dissipation than a conventional Si BiCMOS device (figure 4).

The economics of GaAs and SiGe

When comparing GaAs and SiGe, the substrate cost is a major factor. A 200 mm wafer destined for a BiCMOS line will cost about $80, while a 150 mm GaAs epiwafer will be in the region of $650. This means that on a cost

per unit area basis, GaAs is 23 times more expensive than SiGe. The cost per unit area argument crops up again when fab utilization is considered. Wafer throughput is thermally driven, and GaAs's fragility and poorer thermal conductivity mean that steps running at elevated temperatures need to be slowed down. For a typical high-temperature process, GaAs experiences a reduction in throughput of up to double that of Si, and added to this is the fact that GaAs fabs are processing 6 inch wafers, as opposed to 8 inch for Si.

Process complexity is an area where GaAs can win over SiGe. A SiGe process may have up to 25 layers, while a GaAs process may have about one-third of that number. However, typical Si fabs where SiGe processes are run are much more efficiently loaded. The capital cost of the facility is split over many more wafers than in a typical GaAs fab. For low-volume applications the story is very different, as the starting costs for getting into SiGe are significant. A typical mask set for GaAs processes might be $20,000, but for SiGe this could be $100,000.

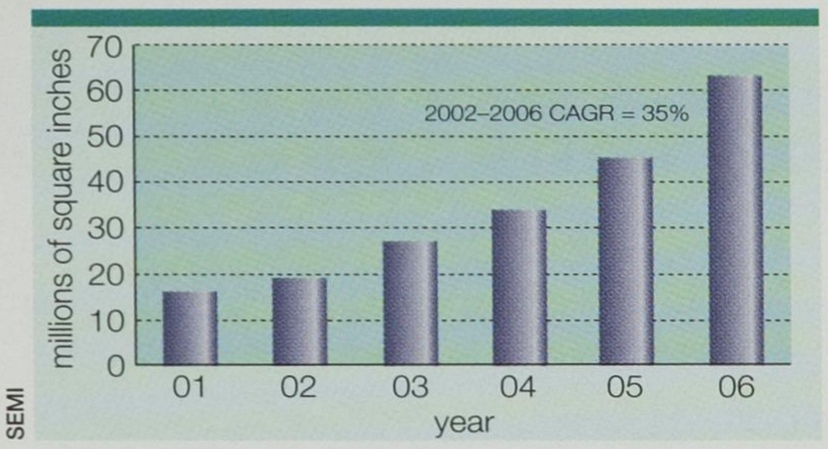

Fig. 5. Major CMOS device manufacturers are now offering SOI variants of their processes for high-speed and low-power devices. SOI substrate consumption is expected to be over 60 million square inches in 2006.

How will CMOS influence SiGe?

Just as SiGe is leaning on GaAs, SiGe itself is under threat from CMOS. High-density, low-power 90 nm CMOS processes are now emerging with gate densities almost double those in the 130 nm node. Such 90 nm CMOS processes have impressive RF capabilities, and the f_t of nMOS devices has now reached about 115 GHz. That puts CMOS at a level which, when combined with the best passive devices, can enable designers to implement the transceiver functions of a typical cell phone. "It's very likely that RF CMOS will completely push BiCMOS out of cellular handsets with the possible exception of the PA driver," said Wilson.

Added to this, most of the manufacturers with 90 nm processes are also offering an SOI variant. The resistive substrate reduces junction capacitance, which allows higher speeds or lower-power operation for a given frequency. SOI also allows chips with a better tolerance of high temperatures and radiation levels. IBM, Motorola and AMD are manufacturing high-end microprocessors using SOI, and the technology has extended into ICs for wireless communications and other battery-driven applications where low-power operation can extend battery life. The global consumption of SOI substrates (by wafer area) is expected to experience a CAGR of 35% to reach 60 million square inches in 2006 (figure 5). By comparison, the bulk silicon substrate market is expected to show a CAGR of 15%.

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SILICON HETEROSTRUCTURES

Modular concept overcomes SiGe bipolar process problems

There is still plenty of room for improvement to the SiGe bipolar processes that are now being used by many RFIC manufacturers. **Ted Johansson** and **Johan Pejnefors** describe a process that overcomes some common problems with the base layer epitaxy.

The performance of silicon-based high-speed bipolar transistors has improved greatly during the last few years. At the 2002 IEDM meeting, IBM reported a Si-based HBT with a record cut-off frequency of 350 GHz. The basis of this technology is an epitaxially grown SiGe base layer, which makes it possible to engineer the bandgap and to achieve a narrower base than in Si-only bipolar technology. The inevitable boron out-diffusion from the base layer during high-temperature processing steps can be minimized by the addition of <1% carbon.

Because of its relative simplicity, non-selective epitaxy is commonly used for this type of device. One drawback to this is the subsequent non-self-aligned patterning of the layers necessary to build up the emitter and the connections to the base (Baudry *et al.* 2001). So far, only a rather complicated process flow has been demonstrated, which includes the conversion of poly-Si to oxide for the manufacture of self-aligned transistors from a non-selective epitaxially grown base (King *et al.* 1999).

Another approach starts with a selectively grown base layer in a previously etched emitter window (Harame *et al.* 1995). However, selective epitaxy is known to suffer from severe loading effects, where the deposition rate varies with the pattern density on the wafer. This means that the epitaxial parameters need to be tuned for each layout with a different device density. Moreover, the selective process is very difficult to control, and can easily lead to voids and poor base contacts.

A common problem in all self-aligned double-poly HBT processes is related to the subsequent removal of the silicon (or SiGe) used for the extrinsic base inside the emitter opening without etching down into the underlying monocrystalline silicon. This becomes more severe for a process involving an epitaxial base formed prior to the emitter window etch, as opposed to a process where the base is formed by ion implantation through the etched emitter opening. Many solutions have been suggested in the literature. In the case of SiGe-based non-selective epitaxy, the etching problem has recently been addressed by using a boron silicate glass (BSG) layer both as an etch stop and as a diffusion source for the electrical link-up between the external and the internal parts of the base (Johnson *et al.* 2001).

The following describes a modular concept for the epitaxial formation of intrinsic and self-aligned double-poly extrinsic base regions of a SiGe:C bipolar transistor. This concept overcomes many of the problems described above. All SiGe-depositions were performed in a Unaxis Semiconductors Sirius UHV-CVD system (figure 1). The modular concept used for the extrinsic base can also be applied to a more conventional double-poly-Si bipolar process flow that uses an implanted base (Pejnefors *et al.* 2002).

Fig. 1. Transfer of a wafer cassette to the load-lock of a Sirius system.

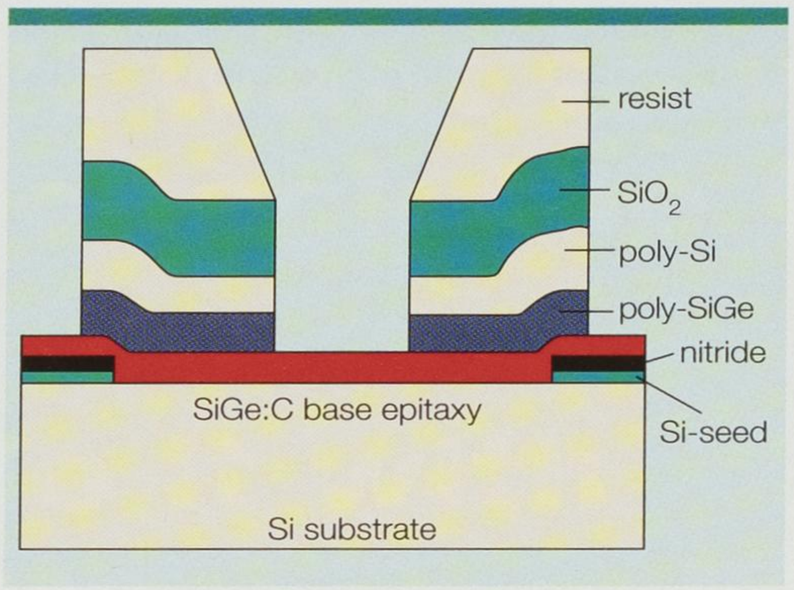


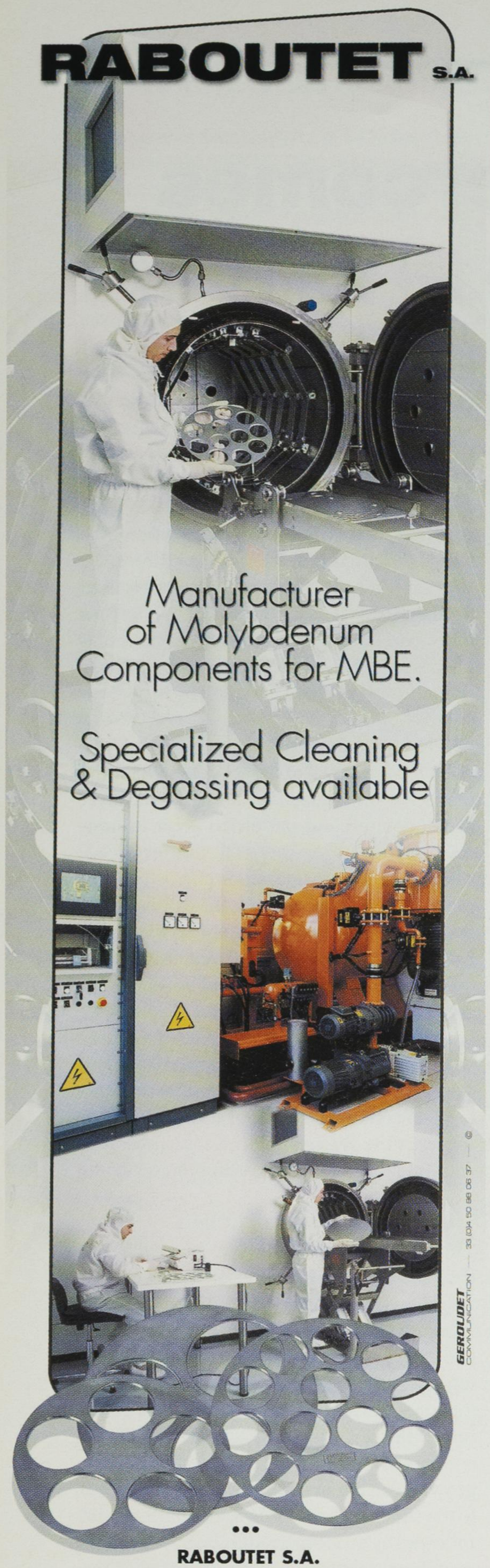
Fig. 2. The concept for the epitaxial base process. The SiGe:C intrinsic base is epitaxially grown, followed by poly-SiGe and poly-Si layers for the extrinsic base. The emitter window is etched through the extrinsic base stack.

Device manufacture

After the formation of the collector region and contact, a silicon seed layer and nitride layer are deposited and patterned prior to non-selective SiGe:C epitaxy of the intrinsic base. This is followed by the deposition of a bilayer of poly-SiGe and poly-Si for the extrinsic base layer. Before the deposition of an oxide, the extrinsic base region is implanted with a high dose of boron. The implanted boron is out-diffused later, thereby forming the extrinsic base connection. The stack is then patterned with resist and etched to form the emitter window (figure 2). Subsequent processing follows a conventional double-poly bipolar process flow. A schematic cross-section of the resulting transistor is shown in figure 3.

Intrinsic base module details

The depositions of the layers that comprise the intrinsic base region are made in a Unaxis Semiconductors Sirius UHV-CVD tool at a working pressure of approximately 1 mTorr and a temperature of about 550 °C. Secondary ion mass spectrometry has shown that the oxygen concentration in the epitaxial films is lower than 1×10^{18} cm^{-3}. The epitaxial layer consists of five different sublayers, which are grown in an uninterrupted sequence. Closest to the substrate is an undoped Si buffer layer, followed by an intrinsic SiGe layer with a germanium concentration of approximately 12%. Then follows a SiGe layer with 5% germanium, which is boron-doped to 1×10^{19} cm^{-3}. Carbon at about 0.2% is added to the boron-



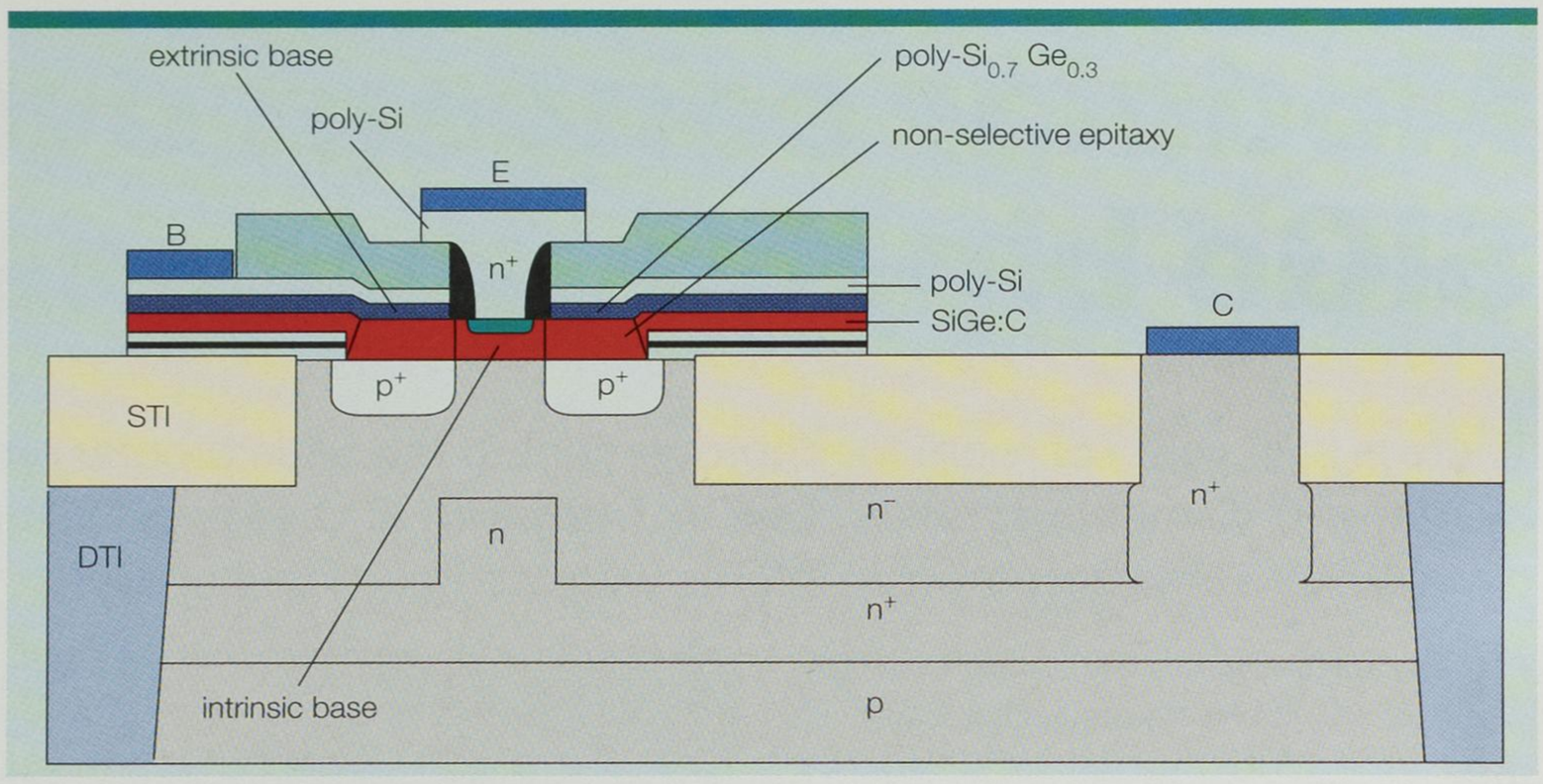


Fig. 3. Cross-section of the fabricated SiGe:C HBT with a poly-SiGe/poly-Si extrinsic base.

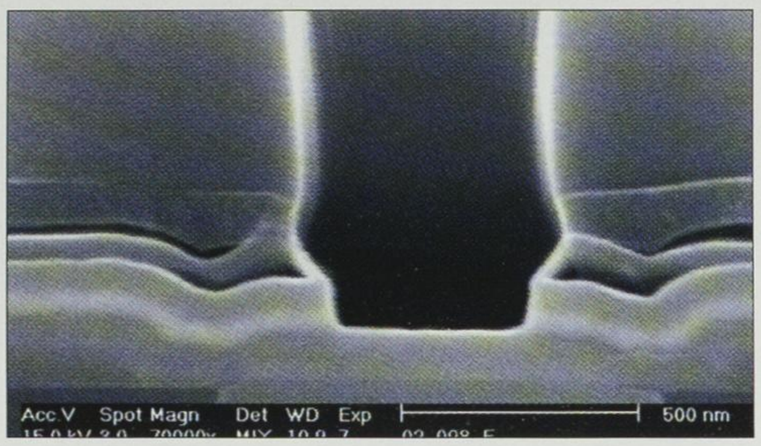


Fig. 4. An SEM cross-section of the emitter window after a timed etch of the poly-SiGe extrinsic base film.

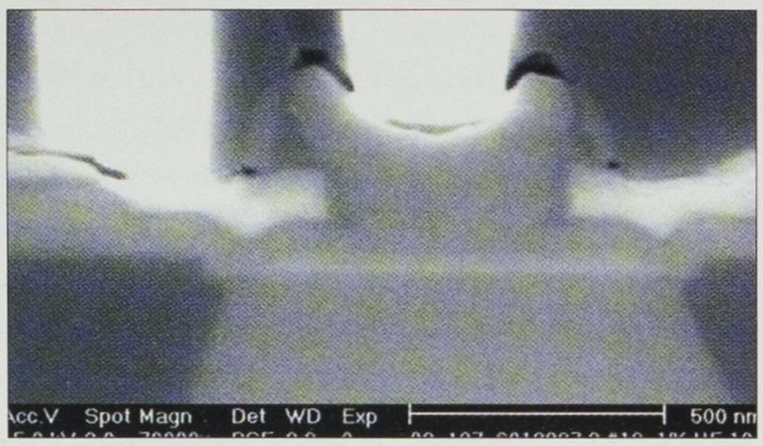


Fig. 5. An SEM cross-section of the transistor after HF treatment. The tungsten plugs and SiGe regions show as the bright areas.

doped layer in order to minimize boron out-diffusion during the subsequent device-processing in order to keep the intrinsic base narrow. Next follows a SiGe layer with 5% Ge and boron concentration of 4×10^{18} cm^{-3}. The final layer is a Si cap layer with 4×10^{18} cm^{-3} boron.

The higher epitaxial growth rate in the active areas defined by the openings in nitride layer results in an almost planar surface compared with that of the polycrystalline film which deposits away from the openings. Furthermore, as a consequence of a higher epitaxial growth rate, the commonly observed shrinkage of the active area, due to a polycrystalline over-growth during non-selective epitaxy in atmospheric pressure CVD reactors, is found to be essentially absent when the film is grown under UHV-CVD conditions.

Extrinsic base module details

After the intrinsic base has been grown, poly-SiGe with about 30% Ge is deposited at low temperature in the UHV-CVD system. The deposition starts with a thin Si seed layer in order to facilitate the nucleation of the subsequent poly-SiGe film. Then a 50 nm thick poly-SiGe film with 30% Ge is deposited and capped with a thin Si layer. AFM analysis of the poly-SiGe film has shown that the surface roughness is about 6 nm in the active and the field areas. The extrinsic base is completed by the deposition of a 60 nm thick poly-Si film using an ordinary LP-CVD furnace. The poly-Si layer is subsequently implanted with 2×10^{15} cm^{-2} of BF_2 at 35 keV. Finally, the extrinsic base stack is covered by a deposited oxide layer.

The emitter window is opened by dry etching of the isolation oxide, followed by an etch of the poly-Si and poly-SiGe layers using an HBr/Cl_2 based chemistry. Using the etch system's monochromator, the 304 nm emission line from the etch plasma is used to indicate the location of the interface between poly-Si and poly-SiGe. The endpoint of the etch is triggered by the signal reaching maximum intensity. Timed etching can then be used to etch through the poly-SiGe layer, stopping at the underlying Si layer that caps the intrinsic base stack. An SEM cross-section of the emitter opening after the timed poly-SiGe etch is shown in figure 4. We have found that the uniformity of the extrinsic base etch across the wafer is

excellent and loading effects are not detected.

Figure 5 shows a cross-section of the transistor after completed processing. Tungsten plugs and SiGe films are seen as bright areas. It has been reported that the oxidation rate of SiGe is enhanced by a factor of three compared with Si, and that Ge segregates to the interface of the growing oxide. However, the poly-Si layer that covers our poly-SiGe film protects the latter from oxidation during the densification of a sacrificial oxide layer on the base.

The poly-Si covering the poly-SiGe layer also facilitates the titanium self-aligned silicide process in the metalization step. The poly-Si is thick enough to prevent the formation of a thermally unstable germano-silicide. No difference in sheet resistance has been observed between a standard Ti silicidation of Si and the silicided poly-Si/poly-SiGe film stack.

Electrical measurements

The quality of the manufactured transistors is demonstrated in figure 6, which shows a Gummel plot for a single transistor with an emitter area of $0.4 \times 10\ \mu m^2$ at a base-collector voltage of 0.1 V. The collector current displays ideal characteristics, indicating that the epitaxial base layer is dislocation-free. The relatively low collector saturation current, extracted from the single transistor, is due to an out-diffusion of boron from the SiGe layer into the Si substrate. For the single transistor, the base current is ideal over several decades of current. A peak value of about 100 can be extracted for the current gain. Extrapolated values for f_t and f_{max} for a single device are 53 GHz and 80 GHz, respectively. Although f_{max} is considerably higher than f_t, which indicates a good extrinsic base formation, the f_t can be increased further by optimization of the base-collector region. ●

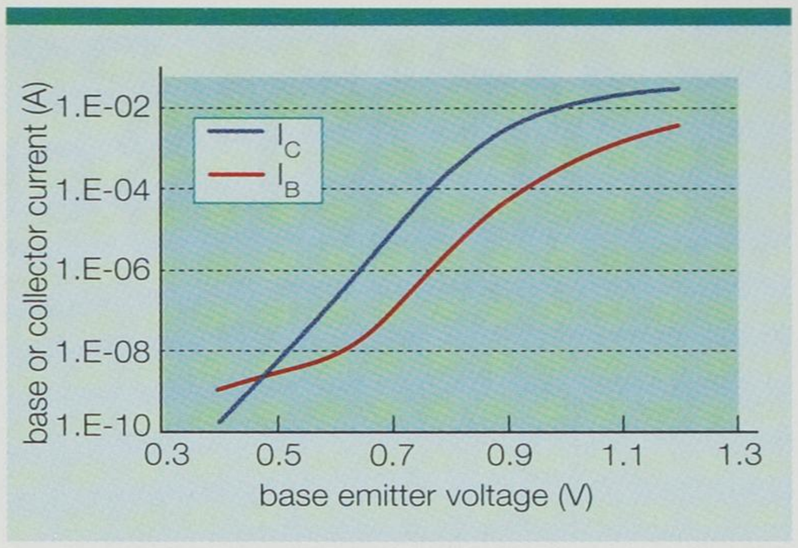


Fig. 6. Gummel plot for a single transistor with an emitter area of $0.4 \times 10\ \mu m^2$. The collector current displays ideal characteristics, indicating that the epitaxial base layer is dislocation-free.

Further reading

Baudry *et al.* 2001 *Proc. Bipolar Circuits and Technology Meeting (IEEE)* p52.
Harame *et al.* 1995 *Trans. Electron Dev.* **42(3)** 455.
Johnson *et al.* 2001 *Proc. Bipolar Circuits and Technology Meeting (IEEE)* p56.
King *et al.* 1999 *IEDM Tech. Dig.* (IEEE) p565.
Pejnefors *et al.* 2002 *ESSDERC 2002, Firenze, Italy, Sep.* 24–26.

Johan Pejnefors is a scientist at the Royal Institute of Technology in Kista, Sweden. Ted Johansson is with Infineon Technologies Wireless Solutions (formerly Ericsson Microelectronics) in Kista, Sweden.

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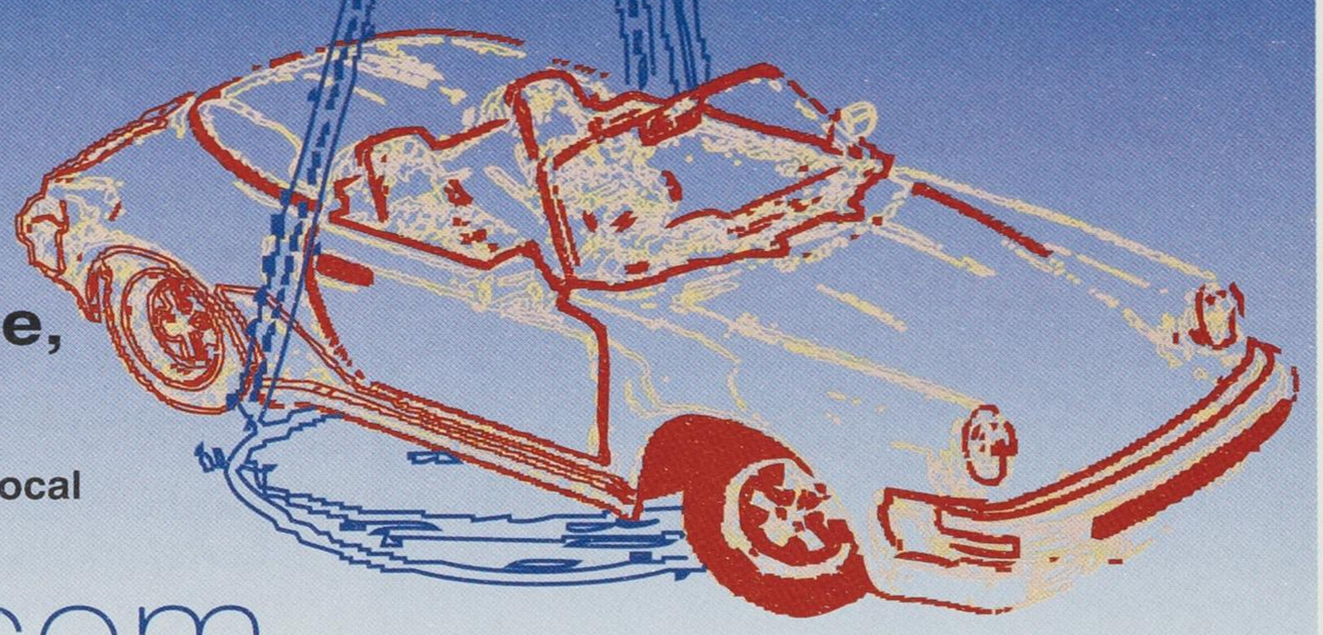

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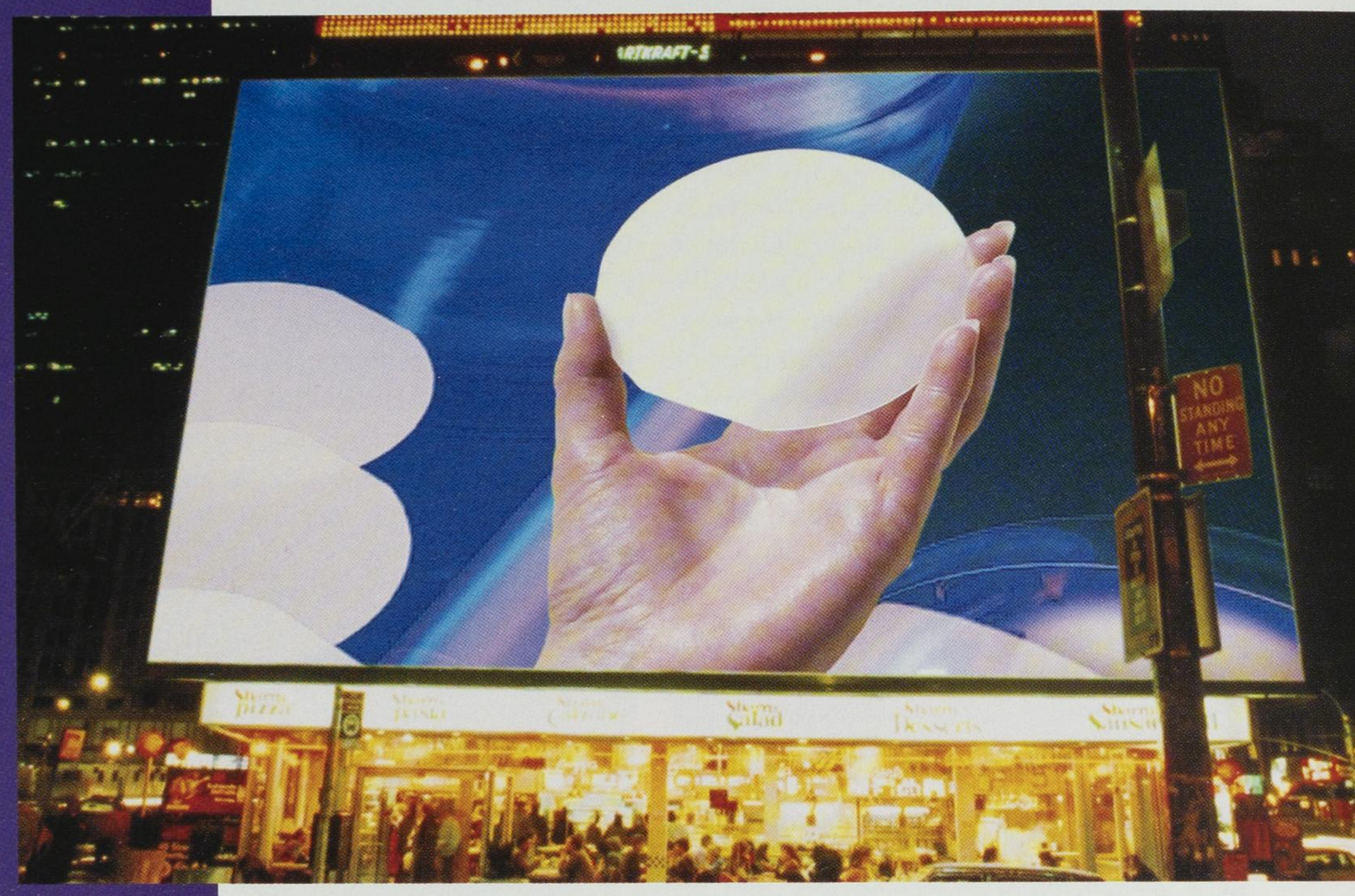

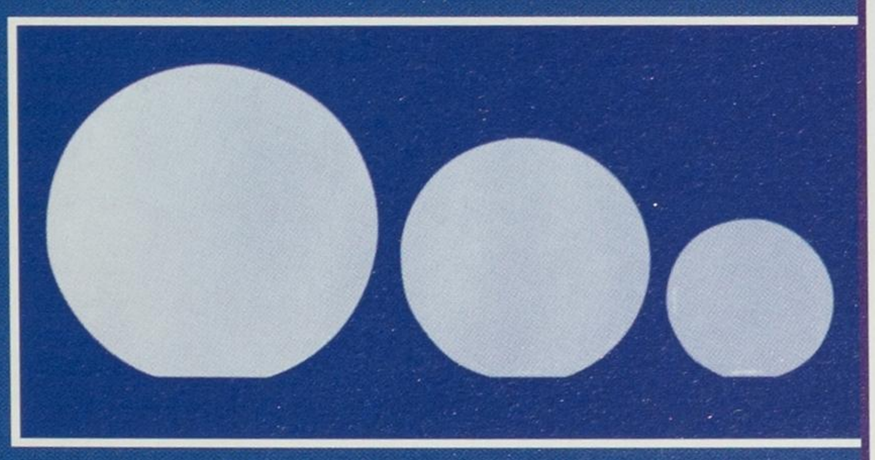

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Innovations push white LEDs towards new applications

White LED makers are making strides to improve the color consistency, white light quality, lifetime, efficiency and cost of their products, writes **Tim Whitaker**.

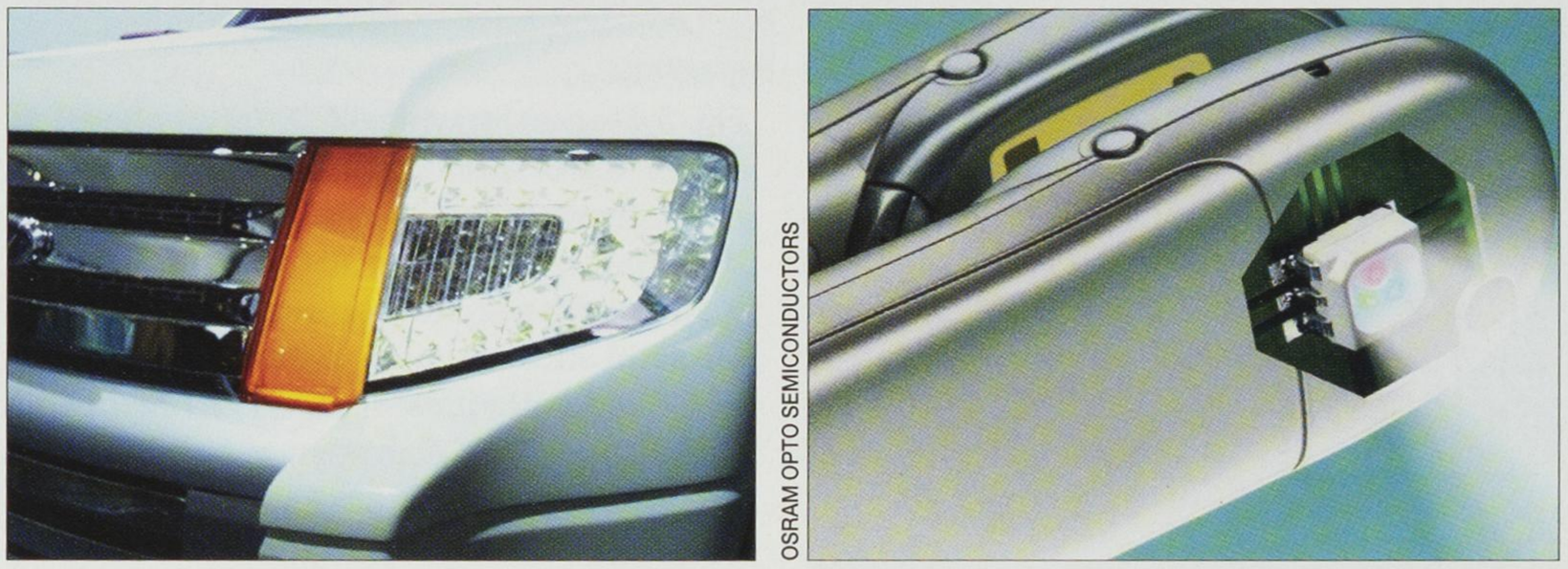

Fig. 1. Applications of white LEDs. Left: a Ford concept car uses Luxeon LEDs from Lumileds as part of an adaptive lighting system that can produce different beam patterns to suit different situations such as highway, in-town or curve driving. Right: white LEDs can replace conventional discharge lamps as the flash for mobile phone cameras. The RGB multichip version can produce a variety of color temperatures.

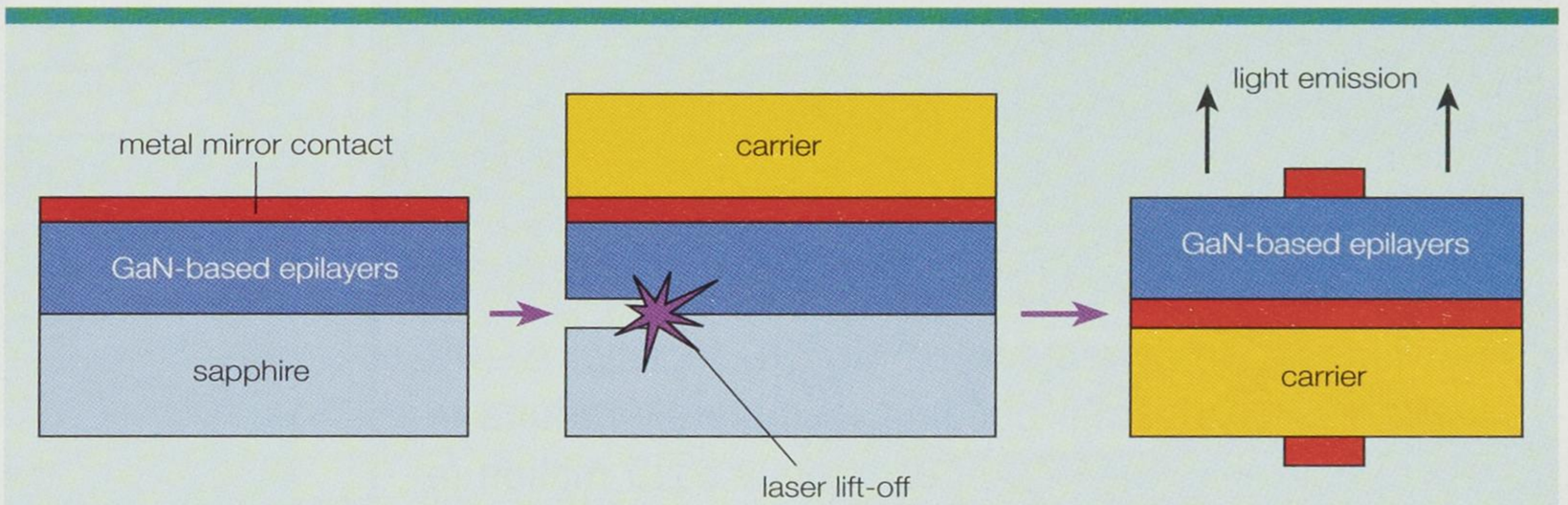

Fig. 2. Osram Opto's ThinGaN LED is made by bonding a carrier wafer to the InGaN LED structure and then removing the sapphire substrate with a laser lift-off procedure.

Backlights for color screens in mobile appliances, automotive headlights and general lighting are all at different points on the applications roadmap for white LEDs (figure 1). A number of companies are pushing the technology forward, and several of these spoke at a white LED technology forum during the Strategies in Light meeting in February (*Compound Semiconductor* April 2003 p29).

There are three basic approaches to making white light using LEDs. One is to combine the output from two or more LED chips; these could be blue and yellow, or more commonly red, green and blue (RGB). The second approach is phosphor conversion, in which a blue LED chip is combined with a phosphor. Some of the blue photons are down-converted by the phosphor to produce a broad emission centered on yellow; this mixes with other blue photons to create white. The third main approach is to use a UV LED as the pump chip for a mixture of phosphors that emit across the visible spectrum.

Gelcore

Gelcore, the joint venture between GE Lighting and Emcore, is firmly in favor of the UV approach. According to Rebecca Bompiedi, VP of technology at Gelcore, UV-phosphor blends can generate white light with excellent color rendering index (CRI) and high efficacy.

"One of the keys to designing UV-based white LEDs is to have the correct combination of the UV chip, the phosphor and the package," said Bompiedi. Requirements include high-power UV chips; packages that are tolerant to UV light and high-power operation; efficient and stable phosphors; robust encapsulants; and a high overall system efficiency.

Gelcore has developed a range of new phosphors to control UV bleed-through, and therefore to prevent the loss of unconverted UV energy. The company has also developed its ThermaLED package, which has a power rating in excess of 1 W and a low junction-to-board thermal impedance of <5 °C/W. The package can accommodate multiple die technologies and has a footprint of only 6 × 8 mm. Gelcore has also developed packaging materials with significantly improved UV and thermal aging properties.

One issue with all phosphor-converted white LEDs is the Stokes shift, which is the difference in energy between the UV or blue light from the pump LED chip and the longer-wavelength (lower-energy) light emitted by the phosphor. UV-based white LEDs will always experience larger Stokes losses than those pumped using blue chips. "However, the superior wall-plug efficiency of UV LEDs and the use of new phosphor blends compensates for these losses," said Bompiedi.

As a result, Gelcore has achieved what it claims is the world's brightest UV-based white LED, with an output of 32 lm at a drive current of 350 mA, and a luminous efficacy of 22 lm/W. Bompiedi says that the device can be designed with a correlated color temperature (CCT) at or above 2700 K, while the CRI is in the mid-80s (depending on CCT) and continuing to improve. The white LED uses a 410 nm XBright chip supplied by Cree, which has an output of 200 mW at 350 mA,

and a wall-plug efficiency of 15.6%. Gelcore estimates that a white LED pumped by a 300 mW chip could achieve 50 lm at 33 lm/W.

Osram Opto

Ruediger Mueller, president and CEO of Osram Opto Semiconductors, described his company's new InGaN chip concepts. After developing shaped InGaN-on-SiC devices (the ATON chip and its flip-chip variant, NOTA; *Compound Semiconductor* February 2001 p7), Osram Opto has now developed a ThinGaN chip. This consists of an InGaN-on-sapphire chip, which is metallized and bonded to a carrier wafer. The sapphire substrate is subsequently removed by a laser lift-off technique. The device is expected to offer an extraction efficient of around 75%, compared with 52% and 60% for the ATON and NOTA variants, respectively. The ThinGaN device could offer an external quantum efficiency (QE) of around 38% by mid-2004, compared with 25% for the ATON chip (figure 2).

Mueller also described Osram Opto's power Topled package, which uses a new chip bonding technique and improved UV-resistant encapsulation material. At a current of 30 mA, devices showed a lifetime of 50,000 h for 20% degradation and 100,000 h for 50% degradation.

Osram has also developed a 6-lead multi-chip Topled package with individual connections to each of the red, green and blue chips. Due to an optimized reflector design, the device has an output of 6000 cd/m^2 at 20 mA on a 10 mm pitch for full-color LED signs. Since it offers tunable colors across the entire range, it is applicable to general lighting, LCD backlighting and other applications. Finally, Mueller gave an estimate of the market for high-power white LEDs (meaning phosphor-converted or RGB LEDs operating at more than 50 mA) in different applications (figure 3).

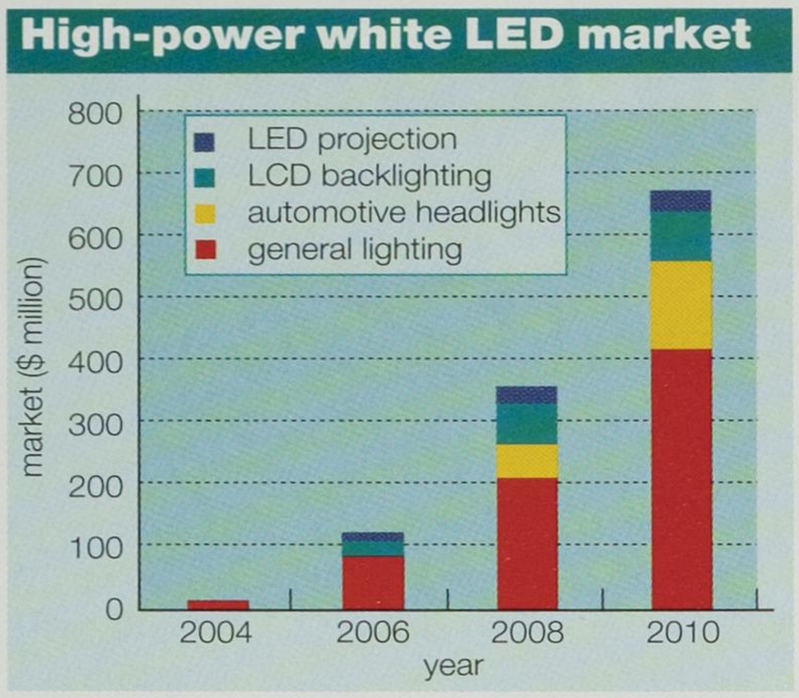

Fig. 3. Market for white LEDs (phosphor-converted or multichip RGB devices) driven by a current greater than 50 mA.

Nichia

Nichia, the first company to commercialize white LEDs, has traditionally used a blue chip/yellow phosphor approach. Such devices typically have a CCT of 5500 K or above, corresponding to "colder" white light with a high blue content that is reminiscent of fluorescent lighting. Nichia has already introduced a "warm white" LED with a CCT of 2500–3500 K, which produces light closer in appearance to an incandescent source. As well as the blue chip and standard YAG (yellow) phosphor, the device contains a new phosphor emit-

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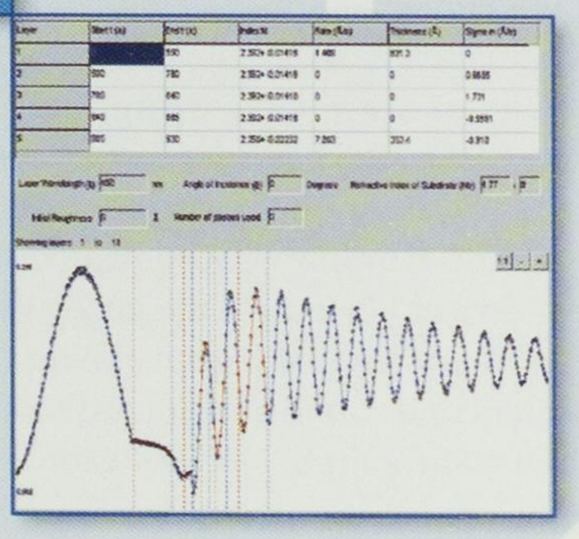

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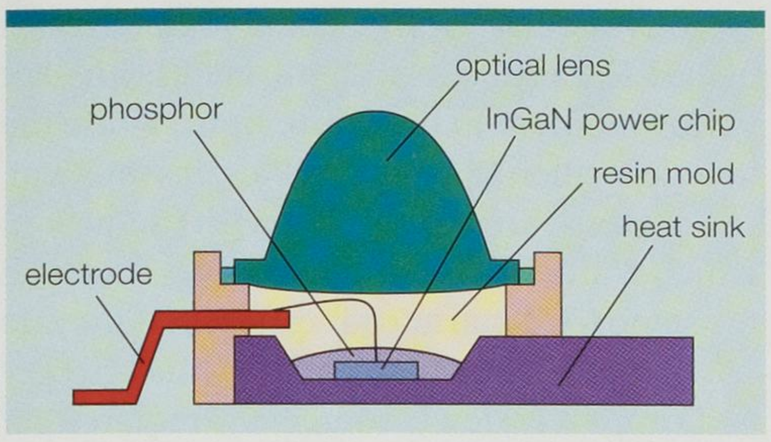

NICHIA

Fig. 4. A new high-power LED package designed to provide a power dissipation of ~1.3 W. Nichia has also developed a nitrogen-filled metal package for its high-power devices.

ting closer to the red portion of the spectrum, and has a luminous efficacy of 20–25 lm/W.

Hiroyoshi Ogawa, a senior manager with the Optoelectronics Product Division at Nichia, described the company's power package roadmap, which calls for packages that can handle an input power of 1–3 W during 2003 and 10 W by 2005. Nichia has several power package designs; one is a nitrogen-filled metal package with a power dissipation of ~2 W and a heat resistance of 15 °C/W. The company's resin package (figure 4), with 1.3 W power dissipation and 8 °C/W heat resistance, will be in production in June 2003 as white and blue-green devices.

Ogawa was very forthcoming with details of Nichia's chip designs, including a 365 nm UV power device which is separated from its sapphire substrate and mounted on a CuW heat sink. The chip has an output power of 118 mW when driven at 500 mA and 4.9 V and has an external quantum efficiency of 6.9%.

Nichia has also developed a new structure for high-efficiency InGaN LED chips. This has a patterned sapphire substrate that minimizes the absorption of light by the substrate, and a highly reflective p-electrode in a meshed pattern, which assists with light extraction. Using this structure, 460 nm blue LED chips with an output power of 18.8 mW and QE of 34.9% have been realized, along with 400 nm UV chips providing 22.0 mW and 35.5% QE.

According to Nichia's luminous efficacy roadmap, the company has already achieved 50 lm/W in the lab and plans to bring such devices into production in early 2004. The company estimates that it will achieve an efficacy of 75 lm/W by 2005.

Nichia also unveiled a new white LED technology. Instead of filling the reflector cup containing the blue LED chip with phosphor, the LED lamp is covered with a silicone cap containing phosphor. This is designed to provide more control of the white color and flexibility for customers requiring colors outside the standard white range.

Toyoda Gosei

Koichi Ota, who runs the optoelectronics business unit at Toyoda Gosei, indicated that the company plans to sharply increase its capacity for nitride-based LEDs. By March 2003, the company had a production capacity of 120 million chips per month, up from 85 million units per month in March 2002. Ota said that Toyoda Gosei will more than double its current capacity to 250 million units per month if the market requires such volumes. The company estimates that its LED sales for fiscal 2002 (ending March 2003) amounted to more than $200 million, compared with $120 million in fiscal 2001 and $148 million in the previous year.

By way of comparison, Hiroyoshi Ogawa of Nichia indicated that his company's sales revenue grew by 58% during its 2002 fiscal year, and that the company has a sales target of ¥100 billion (around $850 million) for fiscal 2003. If Cree achieves its revenue target for the June 2003 quarter, it will have reached a total revenue of almost $230 million for its fiscal year ending June 30, 2003.

Toyoda Gosei's white LED products use all three main approaches; the company's RGB LED has excellent color rendering, while its blue LED with yellow phosphor has a high luminous efficacy. After developing a so-called purple LED (operating at 374–401 nm), Toyoda Gosei used this chip to pump its white LEDs and developed red, green and blue phosphors in collaboration with Toshiba. The resulting white LED had a very low CRI and luminous intensity (table 1), so a new phosphor was developed. The resulting True White-Hi LEDs provide illumination across the whole visible spectrum and have a high luminous intensity exceeding 450 mcd.

Lumileds

In order to gain acceptance in the mainstream lighting applications, says Jason Posselt, product marketing manager with Lumileds, LEDs have to tackle several issues: lifetime and lumen maintenance; color consistency; and quality of white light.

In terms of lifetime, Lumileds has developed its Luxeon package, which shows much better lumen maintenance than traditional epoxy-encapsulated LED designs. The package does not contain epoxy materials, which can degrade, and uses a silicone encapsulant

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Different approaches to white

LED chip	Phosphor					CRI	Relative luminous intensity	Color stability
	YAG (yellow)	blue	green	red	new			
blue flip-chip	x					82	300	fair
purple (374–401 nm)		x	x	x		40	100	good
purple (374–401 nm)		x	x	x	x	91	240	good
purple (374–401 nm)		x		x	x	88	280	good

TOYODA GOSEI

Table 1. Comparison of combinations of LED chips and phosphors to produce white light.

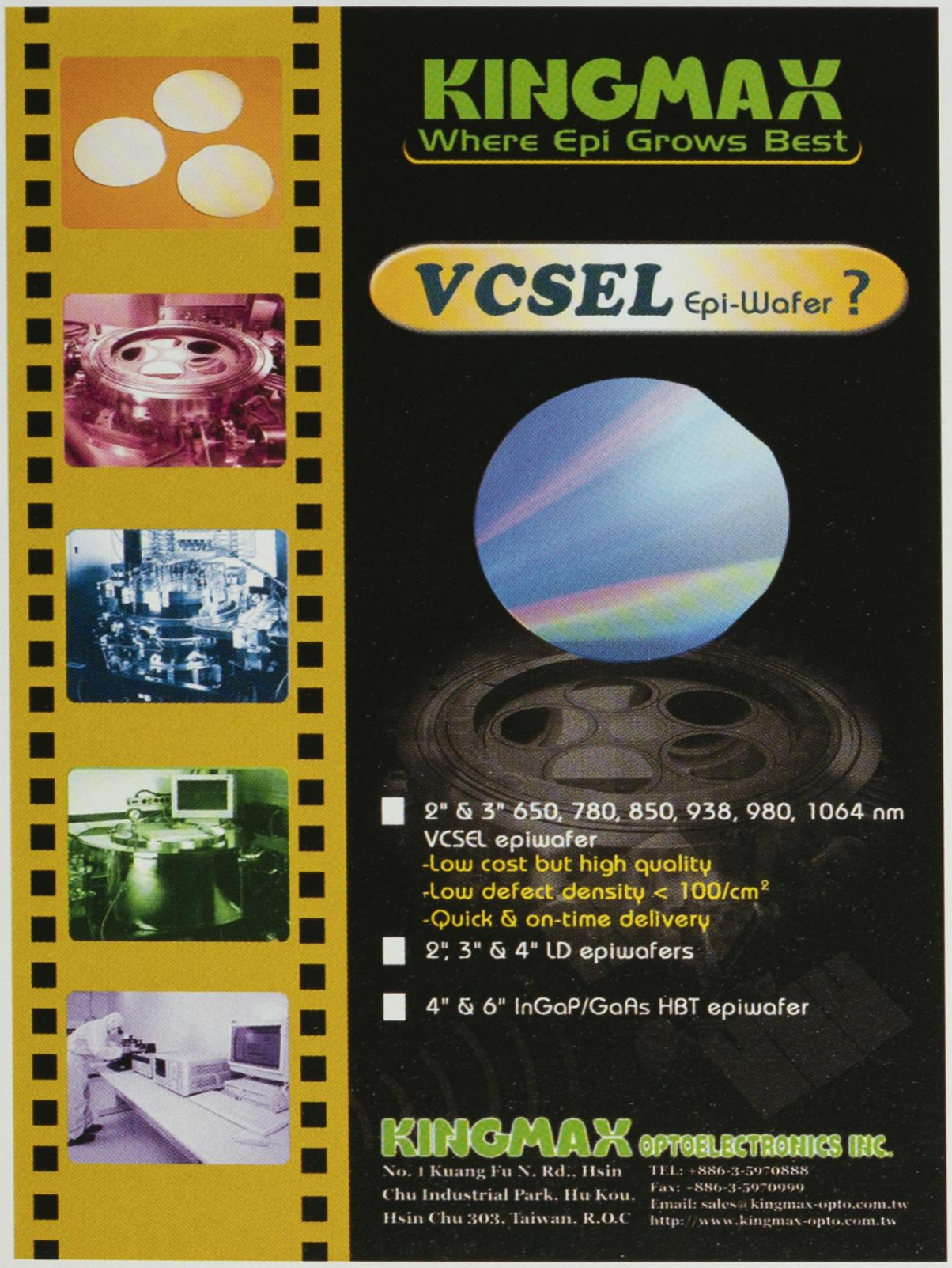
and a plastic lens. The LED is mounted on a silicon sub-mount with ESD protection, which sits on a heat-sink plug to allow easy removal of heat, enabling the device to be driven at higher power levels.

To address color consistency in white LEDs, Lumileds has introduced a new phosphor deposition method that dramatically improves the quality of white light. In the standard method, epoxy (or optical silicone gel in the case of older Luxeon packages) is loaded with phosphor and dispensed into the reflector cup, covering the die. The process is volume-dependent, and with such small volumes is difficult to control. "The new technique coats the InGaN die with an extremely uniform phosphor layer on all sides of the chip," said Posselt. "This delivers much better color consistency of white light."

Posselt demonstrated that the angular variation in CCT is reduced to <100 K, compared with around 700 K for the older deposition technique. This can cause a yellow halo to be observed when viewing the white light source as it is shone on a piece of white paper, for example. The phenomenon is caused by blue photons that exit the chip and undergo multiple bounces inside the reflector cup. Each bounce increases the likelihood that the photon will impinge on a phosphor particle and be converted to yellow. For certain portions of the LED's radiation pattern, there is a higher yellow content in the white light, while the new deposition technique avoids this problem.

There are also problems with the way in which white LEDs are binned. Devices with the same CCT can appear different if they do not sit on the black body locus. As the flux per LED improves, fewer sources are required per application, so it may be more difficult for the human eye to average out any discrepancies. Posselt suggested that a two-dimensional binning system could be adopted to make white LEDs more usable to the lighting community. "We have a proposal that we are currently evaluating with several key customers across various market segments, and plan to implement this new binning structure in the early summer of this year," he said.

Like other companies, Lumileds has been developing a white LED with a new phosphor blend that has a color temperature of around 3200 K, a CRI of 85+ and an average output of 22 lm. This warmer white LED should be on the market in August.



InP HBT technology enables digital and mixed-signal ICs at DC to 100 GHz frequencies

The advantages offered by InP HBT technology have opened up a range of new applications for high-speed mixed-signal and digital ICs, according to **Loi Nguyen** of Inphi Corporation.

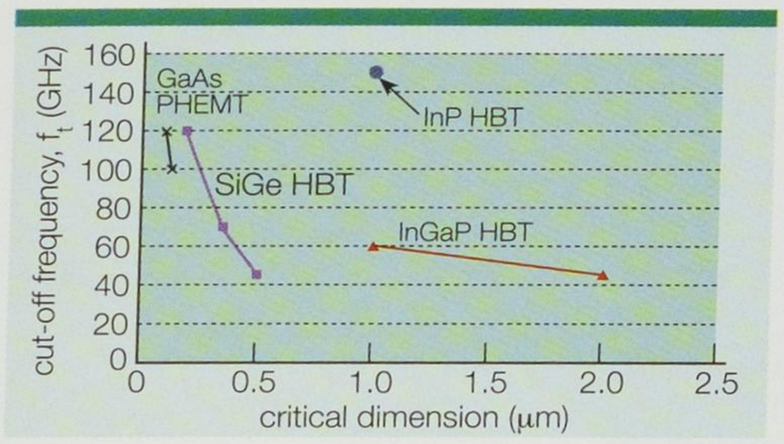


Fig. 1. Cut-off frequency (f_t) of various high-speed semiconductor technologies.

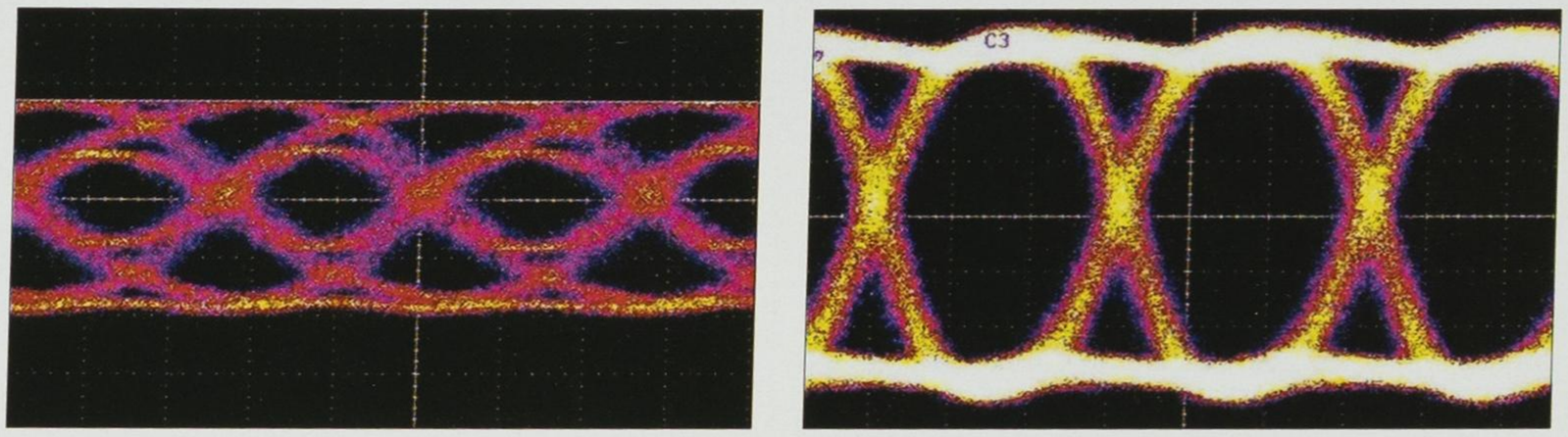


Fig. 2. Left: a noisy 50 Gbit/s input signal and (right) a clean 50 Gbit/s output signal after use of an Inphi D flip-flop. The IC is fabricated using advanced InP HBT technology.

Modern digital communications, instrumentation, electronics warfare and radar systems require high-speed digital and mixed-signal ICs operating at frequencies from DC to 100 GHz. Broadband requirements place severe constraints on available semiconductor technologies and design expertise. Indeed, commercial off-the-shelf digital and mixed-signal ICs based on SiGe or GaAs technologies are generally available only at speeds up to 13 GHz. For speeds over 13 GHz, custom solutions are the only viable option and involve significant development time and cost.

Inphi recently introduced more than 60 high-speed digital and mixed-signal ICs based on 1.0 μm InP HBT technology. The company has also demonstrated a divide-by-2 prescaler operating at a frequency as high as 92 GHz (Srivastava *et al.* 2002), which will pave the way for the development of future 100 GHz digital and mixed-signal ICs. This article describes how the advantages of InP HBT technology can benefit high-speed ICs such as D flip-flops, prescalers and XOR gates.

InP HBT technology

Inphi is a fabless IC design house that supplies high-speed digital and mixed-signal ICs based on advanced InP HBT technology. InP HBTs have long been recognized as the high-speed leaders among modern semiconductor technologies (Chen *et al.* 1989; Ida *et al.* 2002; Raghavan *et al.* 2000). The following attributes make InP HBT technology ideal for high-speed digital and mixed-signal ICs with low to medium levels of integration:

High speed InP HBTs exhibit the highest cut-off frequency (f_t) of all commercial semiconductor technologies. Indeed, they are significantly faster than competing technologies at similar or smaller critical dimensions.

High reproducibility Great progress has been made in the high-volume production of GaAs-based HBT circuits in the past decade, and this expertise can be translated to InP HBT technology. For example, the reproducibility of InP HBT turn-on voltage is typically a few millivolts, compared with hundreds of millivolts achieved with GaAs PHEMT.

Figure 1 compares the f_t of InP HBT with that of competing technologies. Today, InP HBT technology is commercially available in 1.0 μm emitter size, which exhibits an f_t as high as 150 GHz and represents a 25% improvement over competing technologies.

Inphi recently introduced more than 60 commercial ICs, including low- to medium-scale integration circuits such as D flip-flops, OR and XOR logic gates, 1:2 clock fanouts, 4:1 multiplexers, 1:4 demultiplexers, and divide-by-2 and divide-by-4 prescalers. The performance and system applications of some of these products are described below.

D flip-flops

High-speed D flip-flops are often the fastest digital circuits, and thus the most demanding components, in high-speed data transmission or test equipment. These ICs are used extensively in optical transmission systems, ground terminals for satellite communications, and high-speed test and measurement equipment. A high-speed D flip-flop retimes the data and cleans up distortions prior to transmission or makes "1" or "0" decisions on noisy received signals before further processing.

InP HBT technology is ideally suited for the realization of high-speed, low- and medium-scale integration circuits such as D flip-flops. Inphi recently introduced a family of D flip-flops operating at frequencies from DC to 50 GHz. These are available at three different speeds: DC to 13 GHz, DC to 25 GHz and DC to 50 GHz. The lower-speed circuits (13 and 25 GHz) are available in die form or in a surface-mount ceramic package. The packaged parts are also available on an evaluation board. The 50 GHz devices are available in die form or in a metal package with V connectors. Figure 2 shows the use of Inphi's 50 GHz D flip-flop to make correct "1" and "0" decisions on a noisy 50 Gbit/s input data signal.

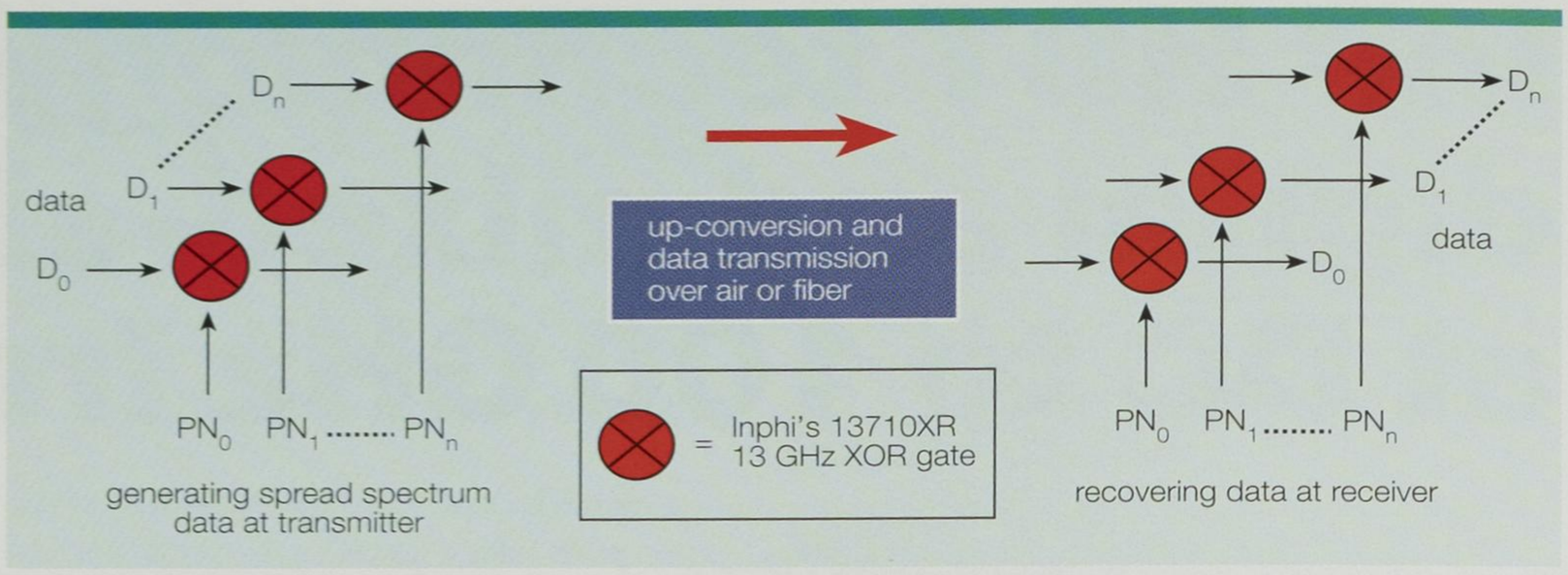


Fig. 3. Use of Inphi's 13 GHz XOR gate to generate and receive a DSSS signal.

Exclusive OR gates

High-speed exclusive OR (XOR) gates are versatile building blocks for a wide range of applications that require the direct processing of high-speed data at microwave and millimeter wave frequencies. Examples include various types of encoding schemes such as direct-sequence spread spectrum (DSSS), in which an XOR operation is performed between the transmitted data and a pseudo number (PN) sequence prior to transmission. The PN sequence modulates the carrier signal, producing a stream of encoded data. The data is recovered at the receiver by performing a similar XOR operation between the received signal and the same PN code. Figure 3 shows schematically how the encoded data stream can be generated at microwave frequencies up to 50 GHz.

Prescalers

High-frequency prescalers are critical components in phase-locked loop applications, in which the phase of an oscillator is locked to a low-frequency reference source. High-frequency sources such as dielectric resonator oscillators (DROs) or yttrium iron garnet oscillators (YIGs) currently operate above 20 GHz, but until now prescalers have only been available at frequencies up to about 14 GHz. To provide phase locking, DRO and YIG manufacturers typically rely on analog components such as step recovery diodes and/or subharmonic mixers, which are expensive and hard to manufacture in volume.

For high-performance applications, high-speed prescalers are preferable to analog components because a divide-by-n prescaler reduces the phase noise of the RF input signal by 20log(n). Inphi's new DC to 25 GHz and DC to 50 GHz prescalers enable the use of a well known digital technique to phase-lock a high-frequency oscillator above 14 GHz. Because of their very low phase noise (see figure 4), these high-frequency prescalers are ideally suited for use with high-performance DRO and YIG oscillators.

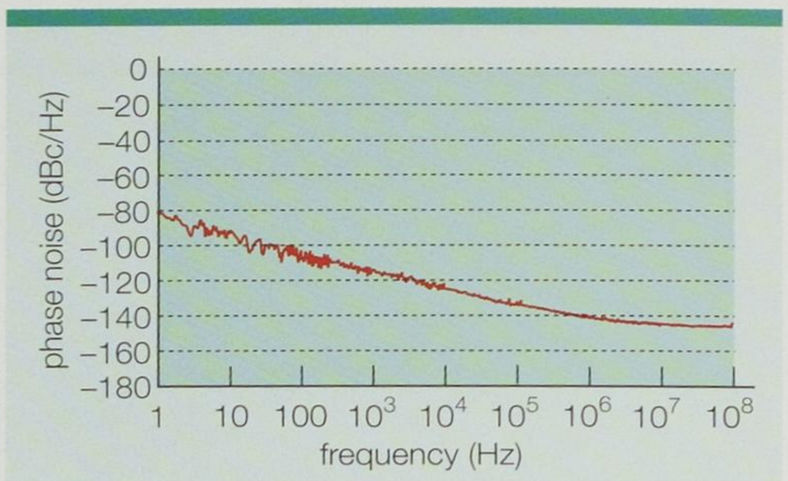


Fig. 4. Phase noise of Inphi's DC to 25 GHz divide-by-4 prescaler at 20 GHz input.

Conclusion

Technological advances have made it possible for commercial digital and mixed-signal ICs to achieve frequencies as high as 50 GHz. Inphi's high-speed InP HBT ICs are the first commercial products to enable the use of well known digital techniques for the generation, transmission, detection and processing of RF signals at frequencies as high as 50 GHz. We expect these products to facilitate the development of advanced digital communications, instrumentation, electronics warfare and radar systems at microwave and millimeter wave frequencies.

Further reading

Chen *et al.* 1989 *IEEE Electron Device Lett.* **10(6)** 267.
Ida *et al.* 2002 *IEEE Electron Device Lett.* **23(12)** 694.
Raghavan *et al.* October 2000 *IEEE Spectrum.*
Srivastava *et al.* 2002 *IEEE GaAs IC Symposium*, Late News Papers.

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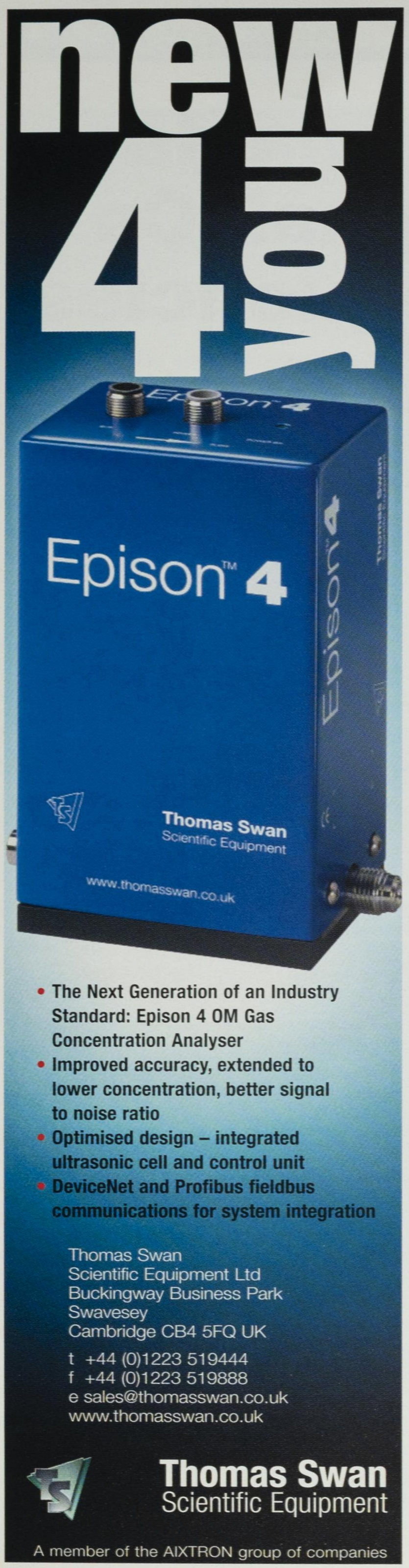

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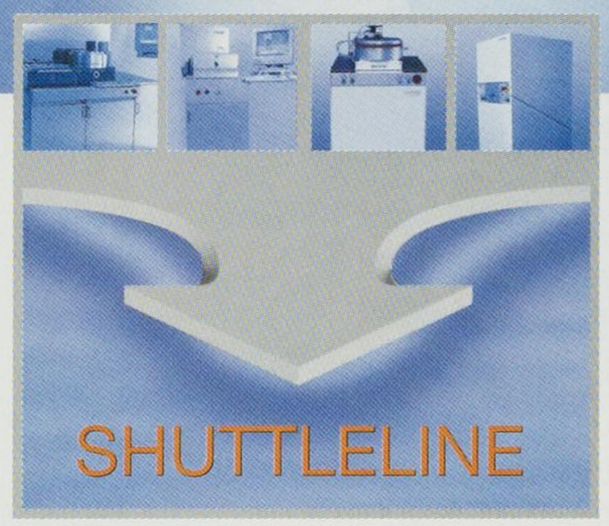

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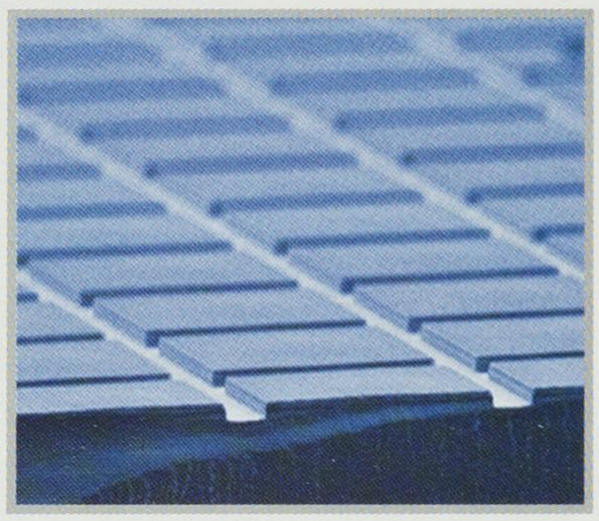

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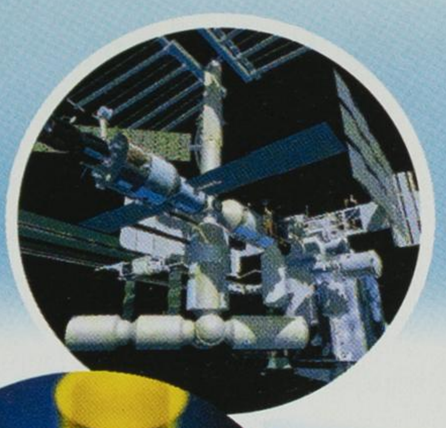

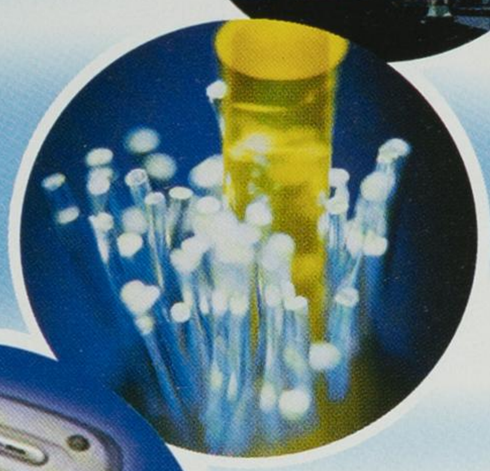

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12TH EURO-MBE WORKSHOP

MBE looks to new applications

Sales of reactors have suffered from the contraction in MBE's traditional markets, but there are new applications for MBE to keep researchers busy, reports **Richard Campion**.

The 12th European MBE conference took place in the picturesque village of Bad Hofgastein high in the Austrian Alps on February 16–19. With MBE's traditional application sectors suffering an economic downturn, it was interesting to hear discussions about the technique's application in the emerging III-nitride microelectronics field, and how MBE is making itself useful in the CMOS industry, potentially a big market for MBE system manufacturers.

GaN growth by MBE

The first session was opened by N Grandjean of CRHEA-CNRS Valbonne, France, who discussed the progress in MBE growth of GaN and compared the use of N_2-plasma with ammonia (NH_3). The two methods require different approaches; with N_2-plasma the best layers are grown under gallium-rich conditions, whereas nitrogen-rich conditions are best for NH_3. A comparison was made of growth onto sapphire, silicon and single-crystal GaN substrates. This showed that the roughening of the surface of MBE-grown GaN is due to kinetic phenomena, not edge dislocations as is often thought. Finally, the effect of NH_3 on the surface free energy of strained GaN (on AlN) was shown to be a useful tool to control (reversibly) the 2D–3D transition utilized in the formation of quantum dots.

F Semond, also from CNRS, focused on the growth of GaN on silicon and SiC substrates using NH_3. He showed that the introduction of a thick AlN interlayer on top of GaN nucleated on a thin AlN layer allows the relaxation of strain. This increases the critical thickness for cracking of a subsequent layer to several microns. Data for AlGaN/GaN HEMTs grown in this way on SiC were presented, and included mobilities of 10,000 cm^2/Vs (at 10 K) and electron sheet densities of 10^{13} cm^{-2}.

G Kobulmuller of Infineon Technologies discussed experiments that closely monitor the growth rate of GaN in the early stages of nucleation by line-of-sight mass spectrometry of the Ga desorption rate from the surface. A drop in desorption rate is associated with the opening of the nitrogen shutter, and thus the growth rate can be deduced. This study, combined with AFM and RHEED data, shows that growth starts instantly on sapphire but in two stages on an AlN buffer. The detail of this two-stage process is dependent on both temperature and III/V ratio. The change of the growth rate from being linear to exponential occurs at 2.5 monolayers, which coincides with 2D–3D transition to Stranski–Krastanow growth (figure 1).

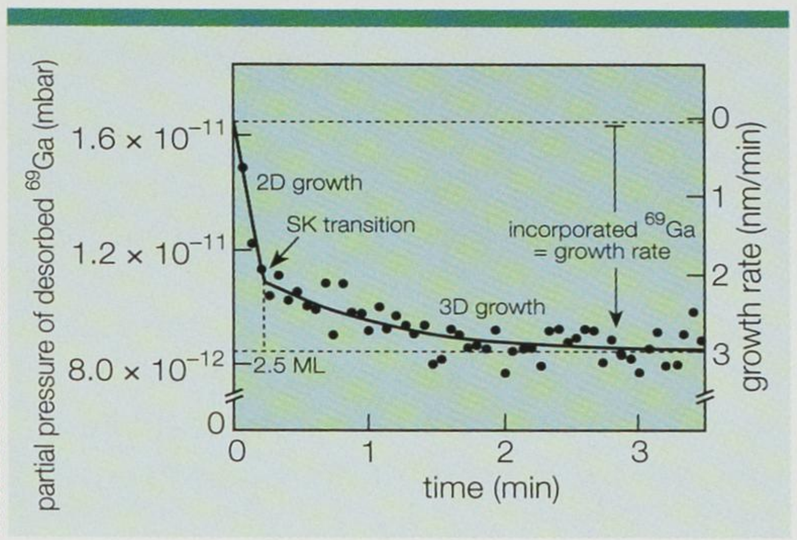

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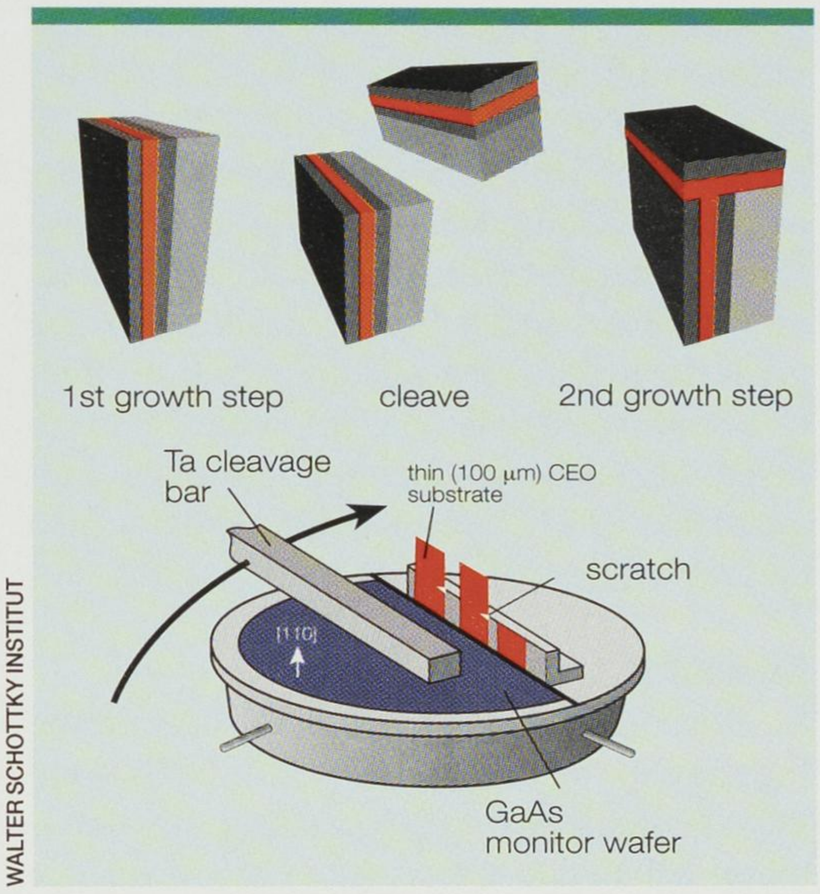
Fig. 1. The change in the growth rate during the early stages of GaN growth onto an AlN buffer layer is related to the partial pressure of desorbed Ga. The rate changes from linear to exponential at 2.5 monolayers.



WALTER SCHOTTKY INSTITUT

Fig. 2. A method for CEO, originally developed at Bell Labs, used to grow high-quality FQHE samples.

GaAs-based materials

J Schmitz of the Fraunhofer Institute, Freiburg, Germany, talked in detail about the wide variety of heterostructures afforded by the type-I and type-II band alignments in the (AlGaIn)(AsSb) system. This allows the formation of structures with effective bandgaps between <0.1 and 0.7 eV for use in infrared photodetectors and lasers. The importance of a detailed knowledge of the strain at the superlattice interfaces was discussed, facilitated by precise shutter and temperature control. Devices have been fabricated for operation in the 1.7–2.7 μm range and also in the 3–5 μm and 8–12 μm atmospheric windows.

W Wegscheider of the Walter Schottky Institut, Garching, Germany, presented an intriguing technique for sample cleavage in the MBE system's vacuum and overgrowth on the newly-exposed non-polar (110) plane of a GaAs sample (figure 2). This was referred to as cleaved-edge overgrowth (CEO). Reproducibly high mobilities and the observation of the fractional quantum Hall effect (FQHE) in the overgrown material were reported, indicating extremely high material purity. Wegscheider's group was able to perform unambiguous four-point measurements on the CEO material without parallel conduction, owing to a contacting procedure that allows the n+ contacts to feed directly into the 2D-electron system. A mobility of 2×10^6 cm^2/Vs at a carrier density of 1.4×10^{11} cm^2 was reported. This was the first reporting of four-point measurements on CEO material.

M Lynass of the Max Planck Institute, Stuttgart, Germany, reported the fabrication of ultra-high mobility 2DEGs in AlAs (>20 m^2/Vs and carrier densities of $4–5 \times 10^{15}/m^2$). He reported a novel low temperature/low growth rate method for a 15 nm AlAs QW with AlGaAs spacers above and below, which separate the QW from Si-doped regions above and below the spacer layers. The low growth temperature prevents Si migration into the AlAs well. Hall data showing the integer Hall effect and FQHE were presented, demonstrating the high quality of the samples.

MBE finds a niche in CMOS

Aggressive scaling in CMOS devices is leading to ever-thinner gate oxides. As electron tunneling increases exponentially with decreasing oxide thickness, the CMOS industry is now looking for new materials with higher dielectric constants (K) to replace SiO_2. Single-crystal metal oxides are likely high-K candidates, and MBE is being explored as the deposition method.

Hans-Jorg Osten of the University of Hannover, Germany, presented a road map for the future development of CMOS devices with particular focus on the equivalent oxide thickness (EOT) of the gate insulator layer. Because of the strength of the Si-O bonds, the matching of the oxygen sublattice with the silicon lattice is of critical importance. After consideration of several candidate metal oxides, work involving praseodymium oxide (as Pr_2O_3 in the bixbyte structure) was described. Growth on Si (001) leads to orthogonal (110) domains and overgrowth with Si has not yet been achieved. However, Osten's group has obtained perfect oxide growth on Si (111) and overgrown the oxide layers with Si. The layers showed extremely good properties with K of about 30, compared with 20 for SiO_2, low leakage, high breakdown voltage and, importantly, high thermal stability.

J Fompeyrine of IBM's Zurich labs continued Osten's theme with a discussion of other candidate materials. The work focused on (La,Zr) oxides using sequential deposition approach to tune the lattice match of the oxide layer to the silicon (*Compound Semiconductor* September 2001 p35). The most successful single-phase layers have been grown on Si(111), and show promising properties.

There is much interest in using strained Si channels for future generations of CMOS devices (*Compound Semiconductor* September 2002 p39). S Mantle of the Jülich Research Center, Germany, reported a novel method of obtaining relaxed SiGe on which to grow strained Si. This starts with the growth of strained SiGe on Si(001), followed by ion implantation of He^+ ions at 18 keV into the Si substrate to create a defect-laden layer just below the SiGe. A carefully controlled anneal causes the formation of "bubbles", creating dislocation loops that move to the interface and yield strain relieving misfit dislocations. The degree of relaxation depends on the He dose.

Growth kinetics

B Voigtländer and J Myslivecek of the Jülich Research Center gave a joint talk to introduce the session on Si growth kinetics. They described equipment that can take real-time STM images of the evolving growth surface (figure 3). The audience was treated to astounding "movies" showing details of the growth process on the atomic level. Examples of these can be seen at www.fz-juelich.de/video/voigtlaender. They then addressed the problem of step bunching in the growth of Si on vicinal Si (001) and introduced the results of kinetic Monte Carlo simulations. These showed that the diffusion anisotropy inherent on the observed 2 × 1 reconstructed surface gives rise to a sticking anisotropy and an effective downward mass current, which leads to instability and step bunching. The model suggests that this behavior will only occur in a certain window of growth temperatures.

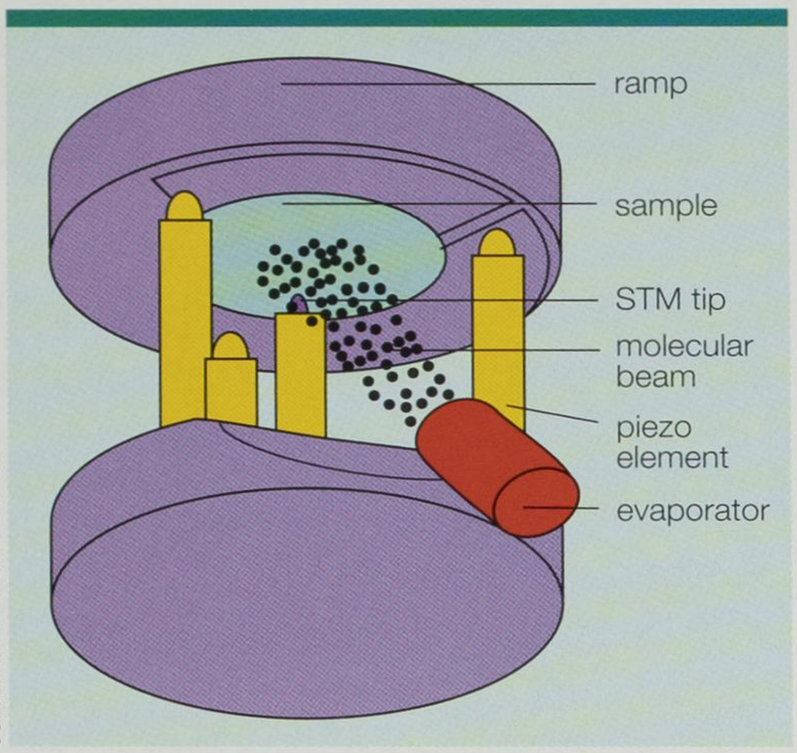


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Fig. 3. A schematic of the apparatus used to take real-time STM images of a growth surface. The images were used to make a movie of the evolving surface during growth.

Metallic MBE

S Andrieu of CNRS, France, introduced the meeting to the field of MBE of metals. One main advantage of MBE for metal film deposition is that, due to the relatively low surface diffusion energy, growth can take place at or near room temperature. This allows for the alloying of normally non-miscible metals such as AgCu and AuNi. Also, due to the elasticity of metals, thin highly strained metastable structures can be grown, including face-centered cubic Co or Fe, and body-centered cubic Ni. Thus there are many possible substrate to epilayer relationships.

The discussion then moved to the growth of magnetic tunnel junctions, which consist of two magnetic layers separated by a thin (~1 nm) oxide layer. In such a device the electrons tunnel through the barrier while preserving their spin state. In an ideal device where magnetic polarization is 100%, if the magnetization directions of the two layers are parallel then current will pass; if they are anti-parallel then current will not pass. In real devices using Fe, Co, Ni and associated compounds, the polarization of the electrodes is not 100%, but the search is on for new materials (e.g. Fe_3O_4, CrO_2 and $LaSrMnO_3$), and MBE is at the forefront of this work.

Spintronic materials

In a related area to the session on metals, L Daweritz of the Paul Drude Institute gave an introduction to the field of ferromagnetic semiconductors and their possible use in spintronic devices (*Compound Semiconductor* July 2001 p27). Compound semiconductors are ideal candidates for spintronic devices because ferromagnetic metals can be epitaxially deposited on their surfaces, opening another application for MBE. Daweritz discussed two possible routes to forming the magnetic semiconductors. First, there are dilute magnetic semiconductor (DMS) materials (e.g. GaMnAs) which are intrinsically ferromagnetic, and second, there are materials where nanoparticles of magnetic material are embedded in a semiconductor matrix. For the nanoparticle materials, the importance of obtaining the correct nanocrystal size was stressed, since crystals that are too small will behave superparamagnetically. Careful annealing of GaMnAs grown with a high Mn concentration gives rise to Mn-rich hexagonal crystallites of an appropriate size, which are ferromagnetic at room temperature. Work on the overgrowth of GaAs with a MnAs layer was also discussed, and again the importance of obtaining the correct phase was stressed.

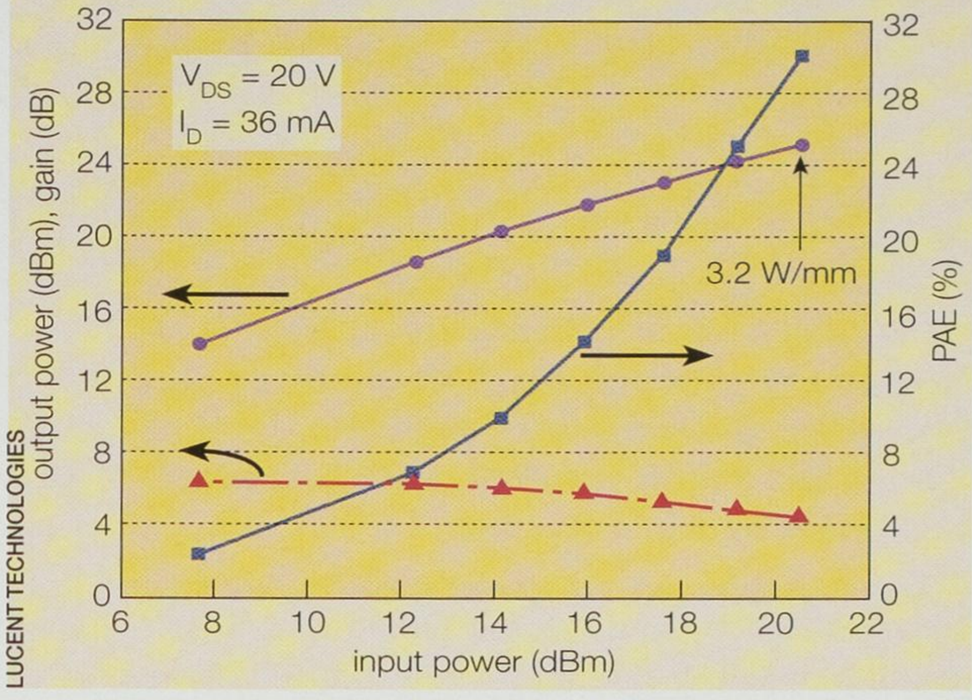
Richard Campion discussed the work at Nottingham University, UK, on the DMS material GaMnAs. Currently the DMS materials are only ferromagnetic at temperatures well below room temperature, but the maximum Curie temperature of this material system has risen from 100 K in 2001 to a current value of 160 K. Campion's talk concentrated on the mapping of the low-temperature growth-phase diagram and the annealing procedures that have led to this improvement in Curie temperature. The detrimental role of interstitial Mn and arsenic antesite defects was discussed, along with strategies to reduce these. Data presented showed that the increase in Curie temperatures can be directly related to increased hole densities, which is consistent with theoretical predictions.

MBE growth benefits GaN HEMTs

While most groups use MOCVD to grow the AlGaN/GaN epilayers required for HEMTs, there is significant effort being made to exploit the advantages of MBE growth. MBE users cite benefits including excellent uniformity, doping control, and the ability to grow atomically sharp interfaces. These properties have already made MBE the method of choice for growing GaAs-based pseudomorphic and metamorphic HEMTs. Two recent papers have highlighted the progress being made in MBE-grown AlGaN/GaN HEMTs.

A joint effort by researchers at DaimlerChrysler (Ulm, Germany) and CRHEA (a CNRS laboratory in Valbonne, France) has resulted in 6.6 W/mm output power at 2 GHz from an AlGaN/GaN HEMT grown by MBE on silicon (*Elec. Lett.* 2003 **39(7)** 626). To take advantage of the low cost and the good thermal dissipation of the Si substrate, CRHEA has developed a growth process based on the low-temperature nucleation of a 50 nm thick AlN layer on a (111) oriented Si substrate. The effect of the high thermal mismatch between GaN and Si was minimized by the use of a 0.5 μm GaN/AlN stack allowing the growth of a 1.5 μm thick, crack-free GaN buffer with a threading dislocation density in the range of $5–7 \times 10^9$ cm^{-2}. This process was established on 2 inch resistive Si substrates in an ammonia source Riber Compact 21 MBE reactor.

The active layers consisted of a 30 nm undoped $Al_{0.27}Ga_{0.73}N$ barrier and a 1 nm GaN cap. Devices with 0.25 μm gates and 2.5 μm drain-source spacing were fabricated and measured. The process included Si_3N_4 passivation and provided 1.1 A/mm maximum drain-current density, a peak transconductance of 240 mS/mm and a pinch-off voltage of about –5 V. Room-temperature Hall measurements showed a sheet carrier density of 9.6×10^{12} cm^{-2} and a mobility of 1440 cm^2/Vs. Devices with 2 × 50 μm gate width exhibited an f_t of 27 GHz and an f_{max} of 81 GHz at the bias point $V_{DS} = 15$ V and $V_{GS} = -4.5$ V. Large signal measurements were carried out on-wafer without any cooling of the chuck. At 2 GHz and $V_{DS} = 30$ V the two-finger transistors with a gate width of 2 × 125 μm delivered a CW output power density of 6.6 W/mm with a PAE of 49%.



Data taken at 25 GHz for the Bell Labs MBE-grown AlGaN/GaN HEMT on SiC. The device exhibits linear gain and for an input power of 20.5 dBm the output power is 25.1 dBm corresponding to a current density of 3.2 W/mm.

Moving beyond the K-band

There is currently great interest in developing AlGaN/GaN HEMTs for power amplification above 20 GHz, for applications such as satellite communications that would benefit from the high-power, high-efficiency and lightweight PAs that GaN may one day provide. Researchers at Bell Labs have reported AlGaN/GaN HEMTs grown by plasma-assisted MBE on semi-insulating 6H-SiC substrates operating with 3.2 W/mm power density at 25 GHz, demonstrating the potential for MBE-grown AlGaN/GaN HEMTs operating in the K-band and higher (*Elec. Lett.* 2003 **39(8)** 694).

The buffer layer consisted of an AlN nucleation layer, followed by a 2 μm thick undoped GaN layer. The structure was completed with a 30 nm $Al_{0.34}Ga_{0.66}N$ barrier and a 5 nm GaN capping layer. The top half of the AlGaN barrier and the GaN capping layer were Si-doped. This MBE growth recipe consistently produced 2DEGs with a room temperature mobility of 1400 cm^2/Vs at a sheet density of 1.2×10^{13} cm^{-2}. Typical sheet resistances were 350–380 Ω/sq.

HEMTs with gate dimensions of 0.2 × 100 μm displayed maximum drain currents over 1.6 A/mm. Small-signal measurements on unpassivated devices yielded an f_t of 53 GHz and an f_{max} of 109 GHz. On-wafer CW load-pull measurements were performed without substrate cooling at 25 GHz under class AB bias conditions. At a drain-source bias of 20 V, the devices exhibited a linear gain of 6.4 dB. At an input power of 20.5 dBm, an output power of 25.1 dBm was recorded, corresponding to a power density of 3.2 W/mm. The power-added efficiency was 30% and the drain efficiency was 44% with 1.8 dB gain compression.

New light falls on the InGaP HBT burn-in effect

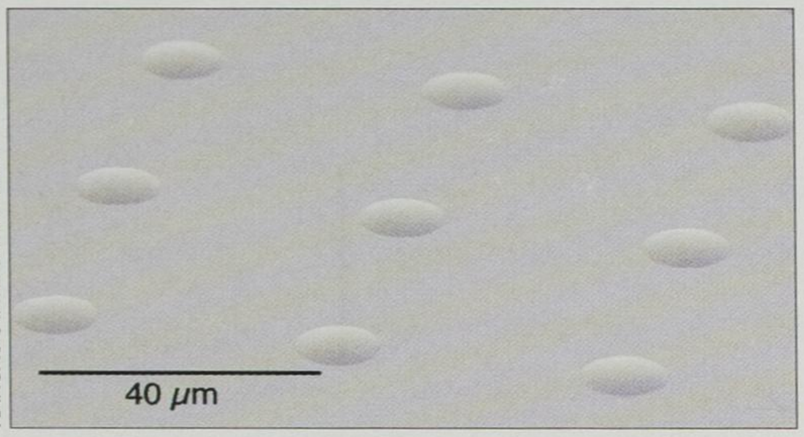
The increase in the current gain shown by MOCVD-grown InGaP HBTs when they are initially placed under normal bias conditions is known as the "burn-in effect", and has been linked to the presence of hydrogen in the carbon-doped GaAs base. A collaboration between the National Polytechnic Institute in Mexico and IQE in Cardiff, UK, has studied the charge transport properties of InGaP HBTs, the base layers of which were annealed *in situ* for different times, to eliminate the hydrogen contained in the carbon-doped GaAs layer, prior to growth of the rest of the structure.

The results show that the burn-in effect is mainly due to an increase in the minority carrier diffusion length in the Si-doped InGaP emitter, which is independent of the base anneal time (*Appl. Phys. Lett.* 2003 **82(17)** 2910). The burn-in effect appears when H^+ recombination centers in the InGaP emitter layer are passivated, according to the following model. When the emitter-base voltage is 0 V, the energy level introduced by the H impurity in the bandgap crosses the Fermi level at some point in the emitter-base space charge region. Beyond this crossover point (towards the base layer) the H impurity occurs as H^+, which acts as an active recombination center. When the junction is forward-biased, H^+ initially behaves as a recombination center, but as V_{EB} increases further, electrons become available for the $Si^+ + H^+ + 2e \rightarrow SiH$ reaction, which passivates the H^+ recombination centers and Si donors. The SiH complex is stable at room temperature and the current gain becomes stabilized at a new increased value.

The detailed understanding of the burn-in effect is important, as it indicates that the emitter growth conditions need to be carefully tailored to reduce hydrogen incorporation or even eliminate its presence to lessen the burn-in effect.

Microlenses bring new applications for III-nitrides

Microlenses have been developed for numerous applications, such as optical communication, optical computing, and in optoelectronic devices for laser beam shaping or in CCD arrays for collecting light power to increase the detector's sensitivity. Most previously reported microlenses have been fabricated by melting photoresist, and could only cover the visible to infrared region. More recently, microlenses have been fabricated from transparent materials such as silica, extending them to shorter wavelengths (>350 nm), but monolithic integration with active devices is still not possible.



A GaN microlens array with 40 μm lens spacing. It is feasible to control the focal length through adjustment to the refractive index by carrier injection.

Recent advances in nitride technologies have enabled the successful fabrication of micro-size optoelectronic devices such as III-nitride UV/blue microdisplays and planar UV detector arrays (*Compound Semiconductor* January/February 2003 p11). Hongxing Jiang and Jingyu Lin's group from Kansas State University has successfully fabricated arrays of microlenses from GaN and AlN epilayers with lens diameters down to 10 μm (*Appl. Phys. Lett.* 2003 **82(21)** 3692). The successful fabrication of microlens arrays based on the III-nitride materials creates the possibility of monolithically integrating nitride-based micro-size photonic devices, as well as of coupling light into, out of, and between arrays of III-nitride emitters, especially in the green/blue to deep UV (200 nm) region. The achievement of microlens arrays is expected to enable many new applications for III-nitrides, such as spatially-resolved fluorescence spectroscopy studies of biological and medical systems and UV detector arrays.

The GaN and AlN epilayers used for the arrays were grown by MOCVD to a thickness of 3–3.5 μm on sapphire substrates with 30 nm GaN or AlN buffer layers. The lenses were fabricated by patterning resist using photolithography to form cylindrical resist posts. Surface tension during a resist bake causes the posts to take up hemispherical shapes. The resist then acts as an etch mask to transfer the hemispherical shape onto the III-nitride surface. GaN microlenses are transparent down to a wavelength of 370 nm, below which AlN is required for wavelengths down to 200 nm.

Another interesting aspect of nitride microlenses is that it is feasible to make active lenses with focal length that can be adjusted by controlling the refractive index of the nitride materials through carrier injection. This cannot be done using microlenses in insulating materials.

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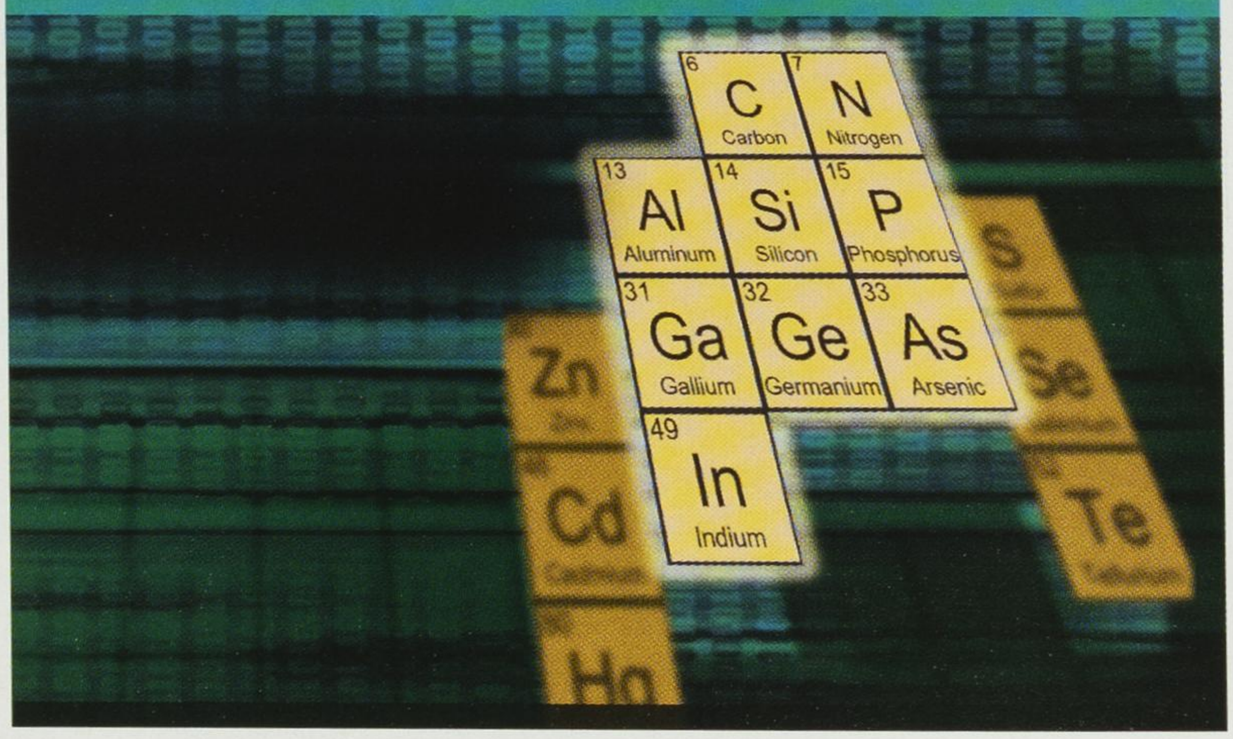

Source Materials Suppliers Guide

Selected suppliers of source materials to the compound semiconductor industry

Company name	Web address	Telephone number	Contact	Metalorganics	Solid MBE sources	High-purity metals	Materials for bulk crystal growth	Gases	Gas purification	Sputter targets	PBN crucibles	Dielectric materials
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ARNAUD Electronics	www.arnaudelectronics.com	+33 144 731 070	Elie Prudhommeaux		●	●	●				●	
BOC Edwards	www.bocedwards.com	+1 800 848 9800	Lisa Gagnon					●	●			
EMF Limited	www.emf.co.uk	+44 1223 352 244	James Dixon	●								
Epichem	www.epichem.com	+44 151 334 2774	Sarah Leese	●				●				●
GEO Gallium	www.geosc.com	+33 1 5662 7600	Terry Guckes		●	●	●					
Indium Corporation of America	www.indium.com	+1 315 381 7554	Rick Short		●	●	●			●		
International Advanced Materials	www.iamaterials.com	+1 845 352 5800	Rodger Cary		●	●				●		
Johnson Matthey	www.pureguard.net	+1 800 624 2204	Melanie Pastore						●			
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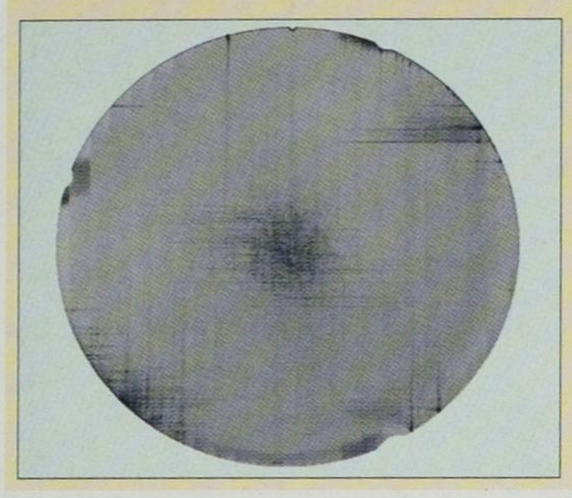

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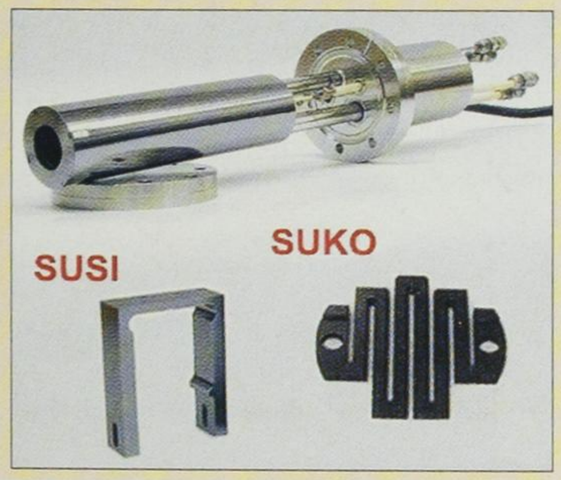

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Springtime brings changes

The events of recent months have meant changes to the portfolio, while the March quarter results revealed shifts at some companies in the product lines that are the best revenue earners.

This month sees a number of changes to the portfolio table, largely due to the ongoing consolidation in the optical components world. The sale of Agere's optoelectronics businesses to Emcore and TriQuint signaled its departure from the list, along with Alcatel Optronics, which leaves the portfolio after being sold to Avanex (see p5).

Soitec, listed on the Paris Stock Exchange, joins the list as it diversifies into compound semiconductors with the purchase of epiwafer vendor Picogiga, which in turn departs from the portfolio. Soitec is aggressively pushing its successful silicon wafer-bonding technology into new areas including SiC, III-V materials and strained silicon. Another addition is Unaxis, a large company quoted on the Zurich Stock Exchange with a current market capitalization of €920 m. Some familiar names come under the Unaxis umbrella, including coatings specialist Balzers and vacuum system supplier Leybold. Unaxis Semiconductors supplies a range of semiconductor processing equipment, and the compound semiconductor industry is one of the main targets for its deposition, etching and metalization tools.

Market overview

Company	*Symbol*	*Closing price on May 23*	*52-week low–high*	*Market cap**
GaAs IC companies				
Anadigics	ANAD	2.86	1.59–11.77	87.7 m
Celeritek	CLTK	7.98	5.01–9.50	98.5 m
Endwave	ENWV	1.85	0.32–3.80	16.5 m
RF Micro Devices	RFMD	5.10	4.55–18.74	933.5 m
Sirenza Microdevices	SMDI	1.60	1.05–4.70	48.0 m
Skyworks Solutions	SWKS	6.89	2.89–12.73	955.3 m
TriQuint	TQNT	3.98	2.55–10.55	530.1 m
Vitesse	VTSS	4.44	0.62–6.38	912.7 m
Opto companies				
Agilent	A	16.26	10.50–29.99	7.662 bn
Cree	CREE	21.03	8.989–25.42	1.541 bn
JDS Uniphase	JDSU	3.17	1.58–4.43	4.534 bn
Semiconductor materials and equipment companies				
ATMI	ATMI	20.48	11.75–33.39	630.0 m
AXT	AXTI	1.31	0.66–10.654	29.5 m
Emcore	EMKR	2.30	0.98–8.37	85.0 m
Kopin	KOPN	5.06	1.93–8.60	351.1 m
Tegal	TGAL	0.62	0.13–1.34	9.9 m
Trikon	TRKN	3.36	2.60–14.49	47.1 m
Veeco	VECO	18.06	9.14–31.39	528.2 m
European companies (currency data in €)				
Aixtron	AIXG.F	2.83	2.06–17.20	186.9 m
Bede	BED.L	0.17	8.00–30.75	4.97 m
Bookham	BHM.L	1.00	64.00–87.00	206.5 m
IQE	IQE.L	0.07	1.00–7.50	12.56 m
Riber	RIBE.LN	0.85	0.58–1.14	17 m
Soitec	SOIT.LN	5.09	2.22–5.20	253.1 m
STS	SRTS.L	0.12	4.00–11.00	3.72 m
Unaxis	UNAXZN.VX	71.50	64.00–199.25	920 m

**Market capitalization = # shares × current share price.*

Ortel's revenue flows into Emcore

Emcore has reported a 19% sequential increase in revenues to $27.7 m for its second fiscal quarter ending March 31. The increase came as the first $7.1 m contribution arrived from its Ortel division, acquired from Agere in January. When reporting its results, Emcore helpfully breaks its data down into systems-related and materials-related figures. The company's systems-related revenues for the first quarter of 2003 were $10.8 m, a sequential decrease of 22%. However, materials-related revenues were up 80% sequentially at $16.9 m, thanks mainly to the contribution from Ortel, which is part of the fiber-optics group. Exclusion of the Ortel contribution results in a 48% drop in materials revenue compared with the previous quarter.

Revenues for the six months ended March 31 were $50.9 m, an increase of 21% from the $42.2 m reported in the year-ago period. Systems-related revenue over this period increased 68% to $24.6 m compared with the year-ago period, while materials-related revenues decreased 5% to $26.3 m. Emcore says that despite the overall decline in MOCVD system sales, it has increased its market share recently. The Ortel acquisition, weakness in satellite infrastructure spending and the changing business model of a major customer has resulted in a shift in emphasis within Emcore's materials-related business. For the six months to March 31, revenue from photovoltaics was $2.5 m lower than in the six months ending March 31, 2002. Over the same time frames, revenue from fiber-optics grew to nearly $12 m from $3.8 m, meaning that this part of the business generated 24% of Emcore's revenue in the six months to 31 March 2003. Revenue from electronic materials and devices dropped by $6 m for the half-year ending March 31 from the $11 m reported in the six months to March 31, 2002. This came as Motorola, which accounted for 13% of Emcore's total revenue in fiscal 2002, switched on more of its own capacity to supply epiwafers for its internal needs. Emcore can take some comfort from the fact that much of that capacity comes from two of its reactors recently purchased by Motorola.

Emcore's revenues by product line

Product line	Revenue for the 6 months ending March 31 ($ million) 2003	2002
MOCVD systems	24.62 (48%)	14.64 (35%)
photovoltaics	10.29 (20%)	12.79 (30%)
fiber optics	11.97 (24%)	3.74 (9%)
electronic materials and devices	4.04 (8%)	11.04 (26%)
total revenue	50.92 (100%)	42.21 (100%)

*figures in brackets are the percentage of total revenue

Emcore's revenues by geographic region

Region	Revenue for the 6 months ending March 31 ($ million) 2003	2002
North America	26.51 (52%)	31.88 (76%)
Asia	15.83 (31%)	4.79 (11%)
Europe	8.58 (17%)	5.54 (13%)
total	50.92 (100%)	42.21 (100%)

*figures in brackets are the percentage of total revenue

Aixtron continues to develop products for new markets, including a tool for organic film deposition for OLED production and refinement of its Tricent technology for the silicon industry.

As a result of increased operating expenses due to the Ortel acquisition, Emcore's net loss for the March quarter increased on a sequential basis to $12.5 m, compared with $2.9 m in the December 2002 quarter. Emcore estimates that its revenues will increase by around 20% in the June 2003 quarter to around $32–34 m, helped by a full quarter's revenue from Ortel.

Restructuring costs bite at Aixtron

The only other publicly traded manufacturer of MOCVD systems is Aixtron. Depressed revenues and restructuring charges caused Aixtron to record a net loss of €4.4 m ($5.2 m) in the March quarter. Revenues for the quarter were €18.7 m, a drop of 60% compared with the €47.2 m reported for the same period in 2002. Almost two-thirds of the company's revenues came from Asia, while North America accounted for 28% of revenues and Europe for 7%.

A major factor contributing to the reported losses was that all of Aixtron's restructuring expenses were charged in the first quarter, including workforce reduction settlements that occurred sooner than previously expected. Also, R&D expenses were accelerated to €3.4 m compared with €2.4 m in the first quarter of 2002, as the company continues to develop products for new markets, including a tool for organic film deposition for OLED production and refinement of its Tricent technology for the silicon industry.

Looking ahead, the company expects to return to profitability in the second half of 2003 as a result of proportionally higher revenues in the remaining reporting periods and the completion of its cost-saving measures. Aixtron has orders worth €88.2 m on its books compared with €118 m a year ago, and is guiding for revenues for the whole of 2003 of €110 m, down around 27% compared with 2002. Net income is expected to be €0.8 m compared with €15.3 m in 2002.

Shifting product balances at Kopin

Kopin's financial results for the March quarter included $1.3 m revenue from its CyberLite LED, which is expected to become an increasingly significant revenue earner for the company. Overall, Kopin increased its revenue by 9% sequentially to $18.0 m during the March 2003 quarter. For the first quarter of 2002, Kopin posted revenue of $17.6 m. The company's net loss for the quarter was $2.2 m. This compares with a net loss of $15.1 m in the previous quarter, and a net loss of $3.2 m in the first quarter of 2002.

Significantly, Kopin's III-V revenue increased 68.5% sequentially to $9.5 m in the first quarter of 2003, and was up 23.2% compared with the year-ago quarter. The company said that the revenue increase reflected a weak final quarter of 2002, but also a heavier than anticipated order book, particularly for epiwafers destined for wireless LAN devices.

The revenue split between CyberDisplay and III-V products has generally been about 45% III-Vs and 55% displays. The stronger than expected showing from III-Vs in the quarter and a 21% drop in CyberDisplay revenue reversed that pattern. The company expects growth in display revenue to resume in the current June quarter, and in the longer term it will be interesting to watch how the ramp-up of CyberLite production and the qualification of the company's new GaInAsN HBT wafers affects the revenue balance.

During the June quarter Kopin expects to see revenue grow a further 10%, with CyberLite revenue rising to above $2 m. In the coming year, the company expects to invest $7–10 m in capital equipment to raise output of its CyberLite LED and CyberDisplay products.

JDS Uniphase slowly stabilizing

Sales at JDS Uniphase grew slightly in the March quarter, reaching $166 m compared with $157 m for the final quarter of 2002. However, sales were down 37% compared with the $262 m reported for the first quarter of 2002. The company is no longer dominated by communications, with the Communications Products Group bringing $74 m, or 44% of total sales, while the Thin Film Products Group represented $92 m, or 56% of total sales. This is a very different situation to the 2001 fiscal year, when communications products accounted for 78% of the company's $3.2 bn revenues.

The company's losses continue to narrow and the net loss for the quarter was $137 m, compared with a net loss of $215 m for the December 2002 quarter. In the March quarter of 2002, before the company's aggressive downsizing began, the net loss was $4.3 bn. The cost cutting is not over yet, and JDSU anticipates further workforce reductions and site closures that have already seen the headcount fall from 28,000 in early 2001 to the current 6500. The company is forecasting net sales during the June quarter 2003 of $155–165 m, and a net loss of $27–55 m with revenue from communications products remaining flat.

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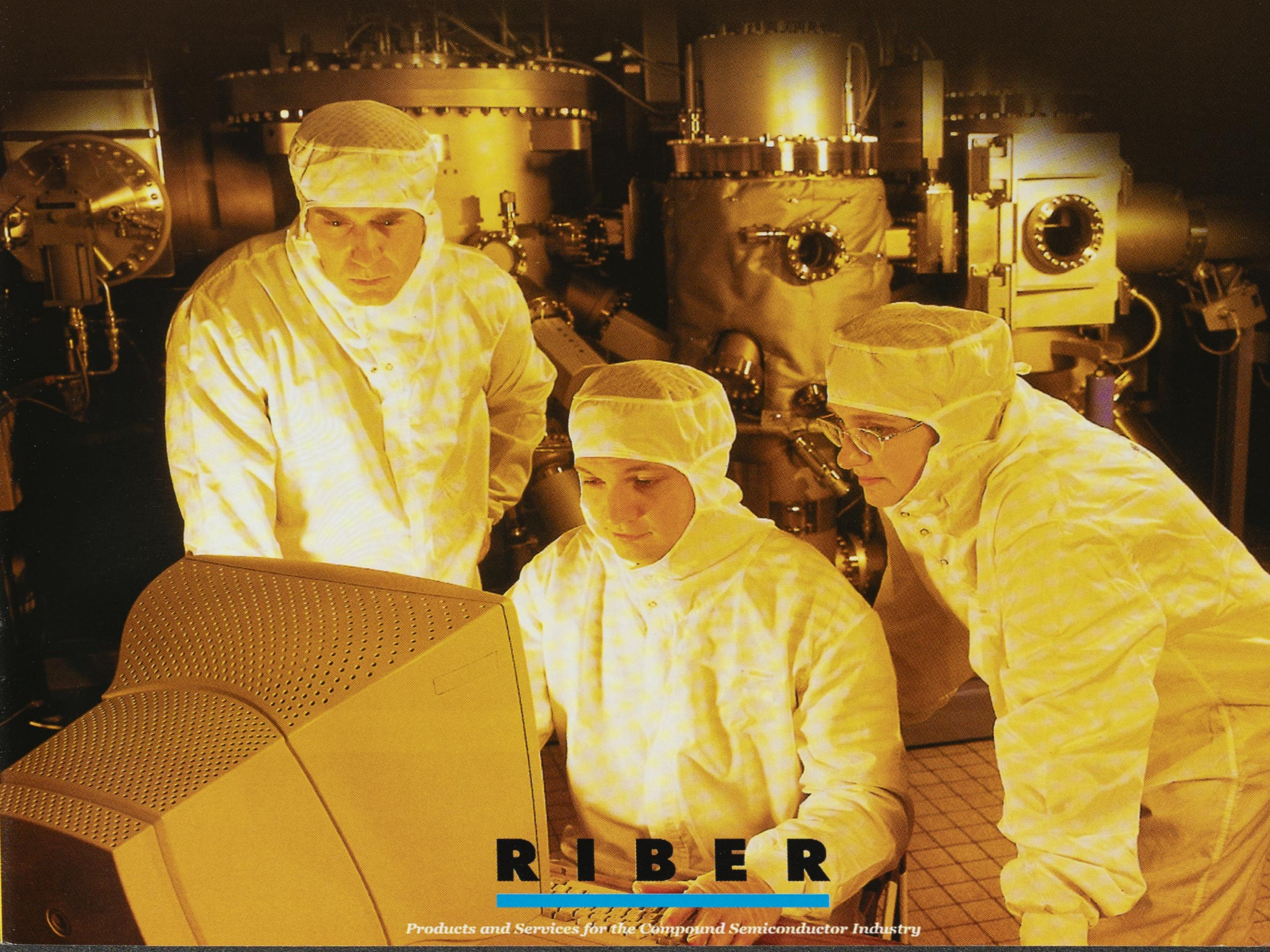

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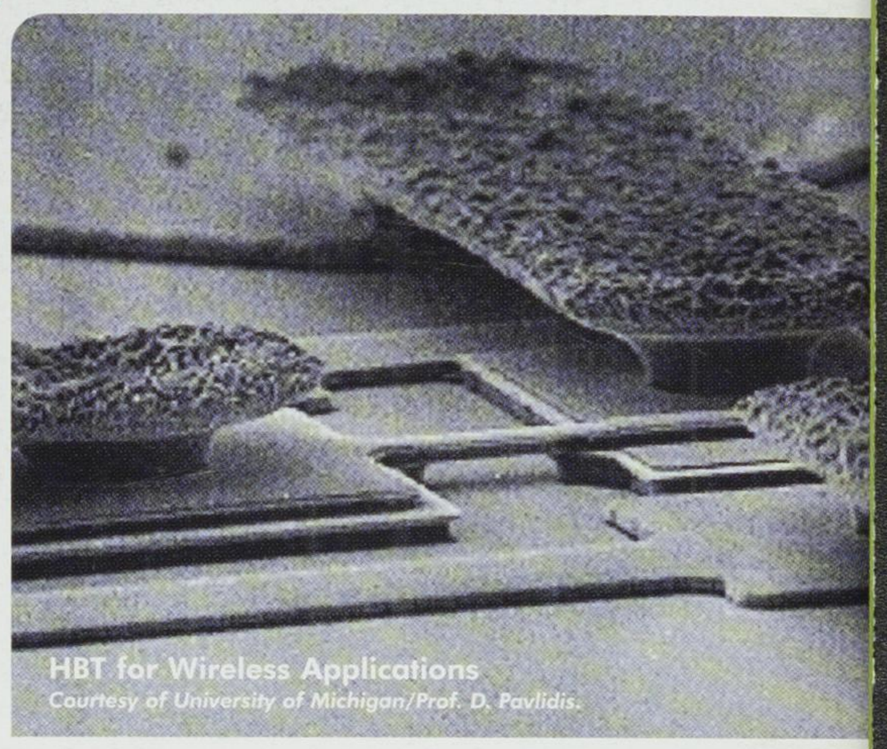

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