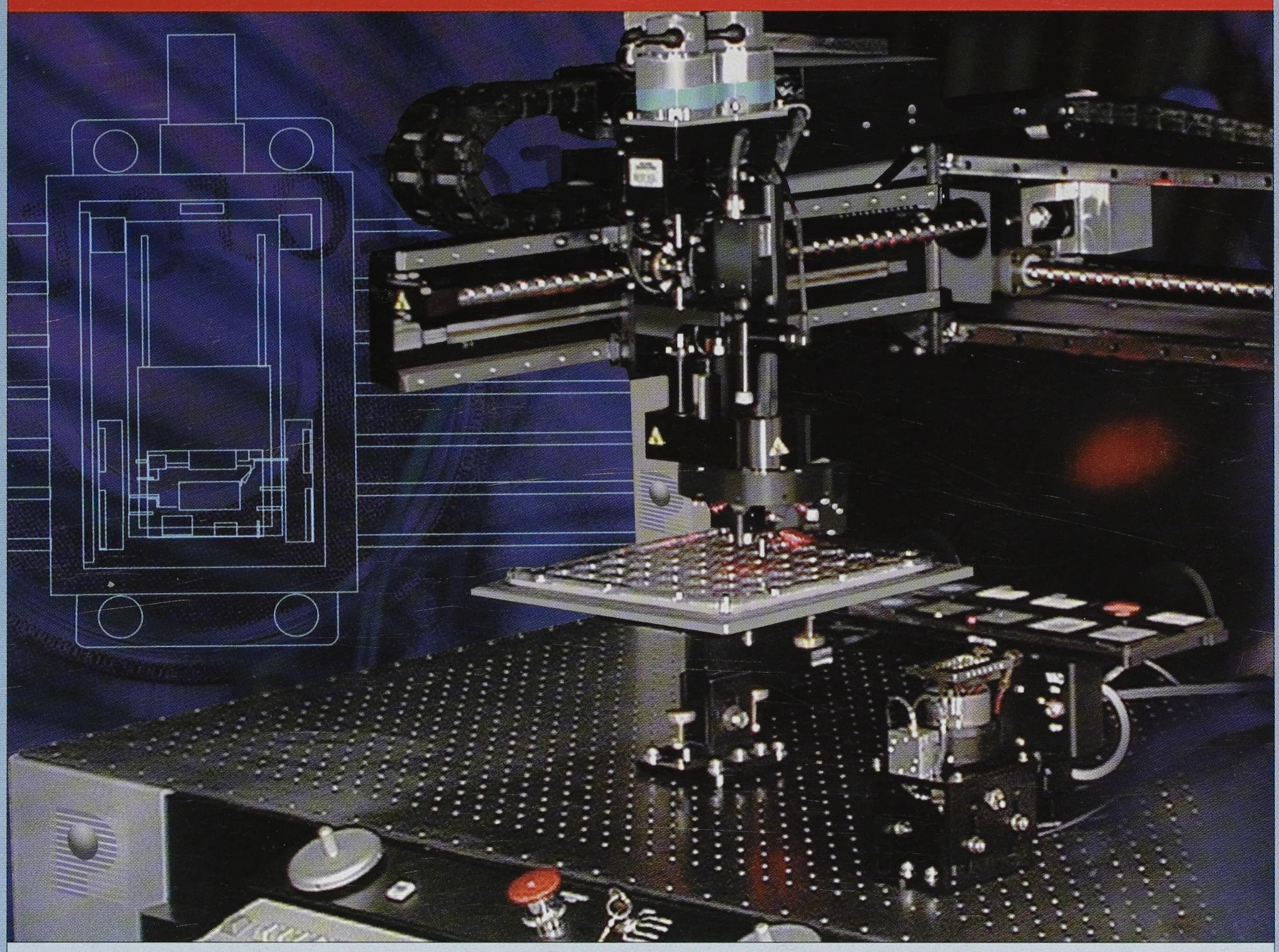
COMPOUND SEMICONDUCTOR

December 2001 Volume 7 Number 11

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Outlook for the handset and fiber markets

ALSO INSIDE

Motorola invests in IQE	**Cree and AXT boost LED output**	**Gas purification for MOCVD**

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USA Head Office
American Xtal Technology
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Fremont, CA 94538
U.S.A.
Tel: 510-226-4300
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Taiwan
Conary Enterprise Co., Ltd.
9F No. 28, Sec. 3
Nan-King East Road
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E-mail: sale@conary.com.tw

United Kingdom & Scandinavia
West Associates (Europe) Ltd.
73 Lodge Close
Cobham, Surrey
United Kingdom, KT11 2SQ
Tel: (44) 1932-868-006
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France & Germany
Sofrasil S.A.
109 Rue de Javel
75015 Paris
France
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Korea
Mythos Corporation
5-11 Noyu 1 dong
Kwang Jin Gu
Seoul, Korea
Tel: (82) 2-497-3131
Fax: (82) 2-497-3151
E-mail: dkekorea@nownuri.net

Japan
AXT-Japan
302 Urban Plaza Izumi
2-26-4 Myojin-cho
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Novotech Optical Semiconductor, Inc.
Lakeside, AZ
Bob Gambichler
Operations Manager
928-368-5013 x 223
bgambichler@cybertrails.com

Novotech, Inc.
Acton, MA
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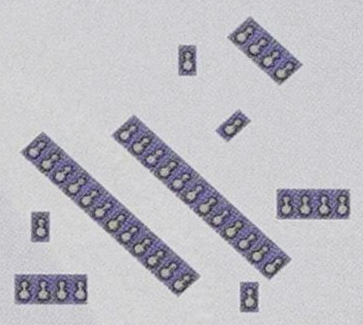
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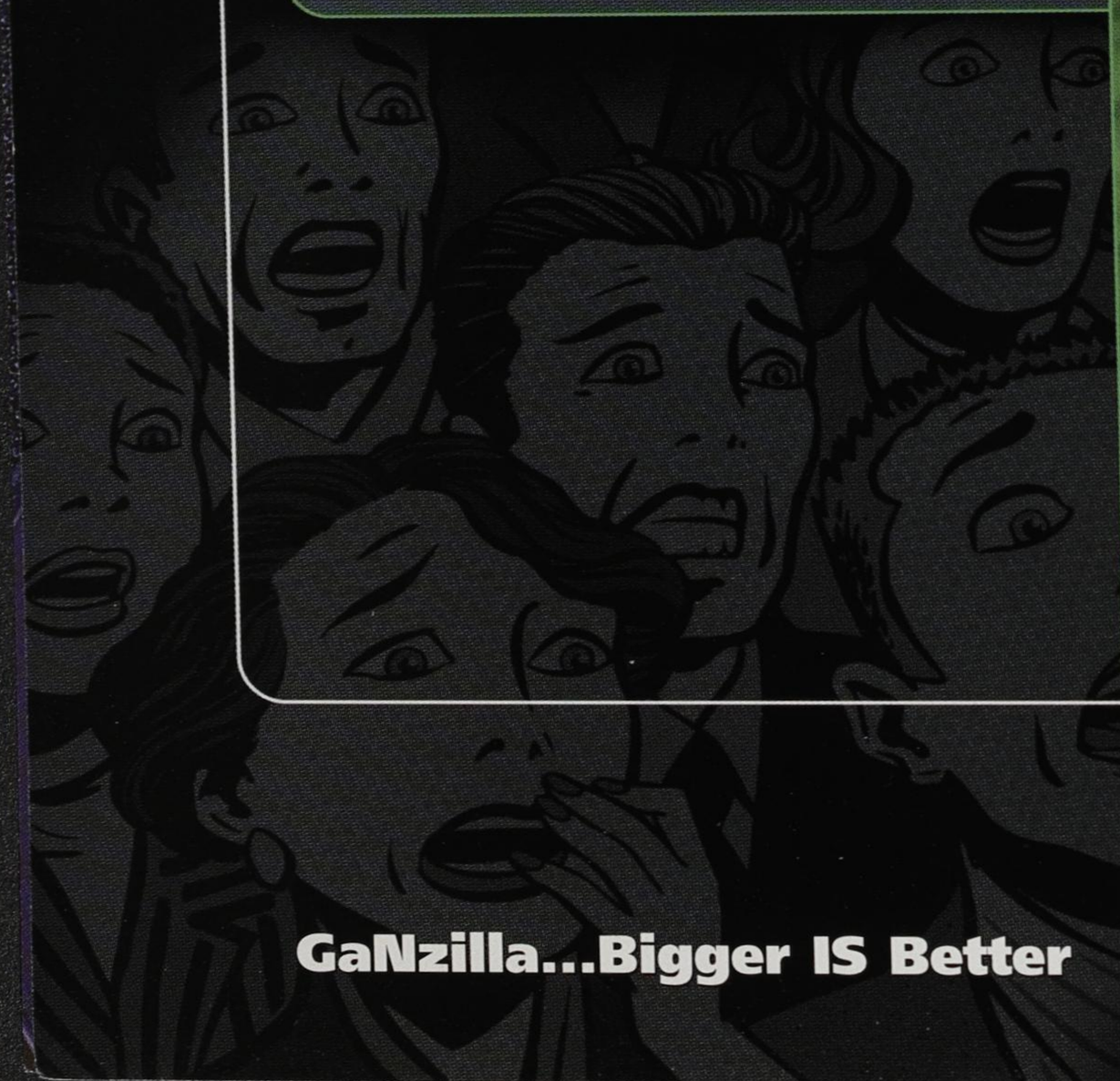
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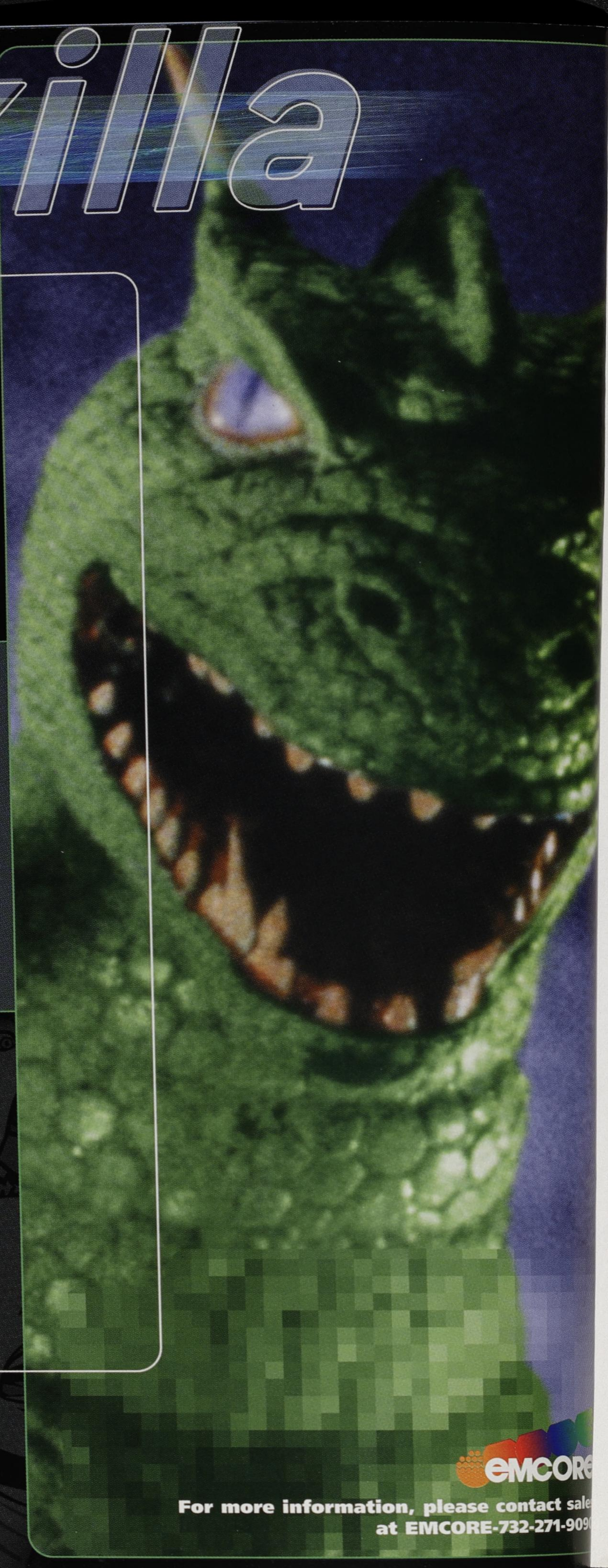
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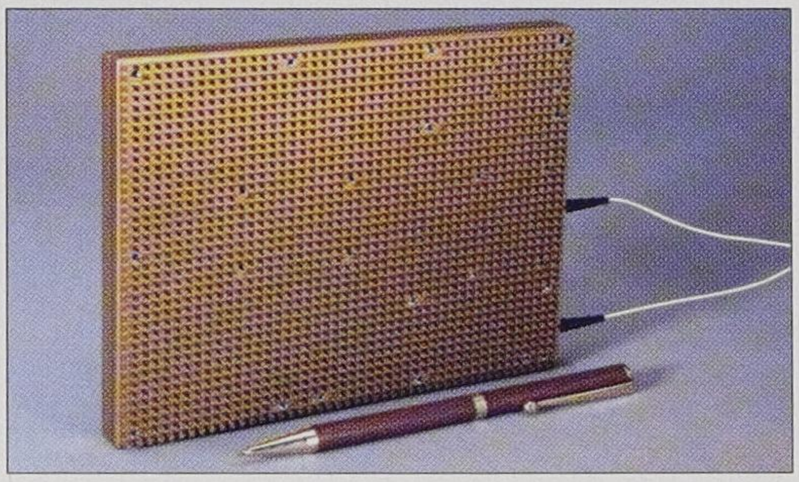
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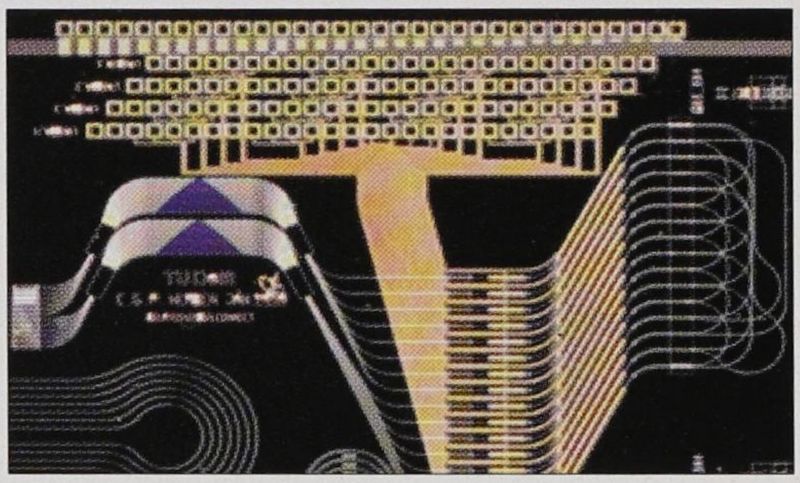
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Osram Opto Semiconductors has doubled the efficiency of its LEDs **p10**



GTRAN and Inphi have integrated InP components for OC-768 networks **p13**



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COMPOUND SEMICONDUCTOR

Editor Tim Whitaker
tim.whitaker@compsem.com
Tel. +44 (0)117 930 1233
Fax +44 (0)117 925 1942

News editor Richard Dixon
rdixon@compsem.com
Tel. +1 617 666 1720

Technology editor Jon Newey
jon.newey@iop.org
Tel. +44 (0)117 930 1192

Contributing editor Robert Metzger

Managing editor Marie Meyer
marie.meyer@iop.org
Tel. +44 (0)117 930 1034

Publisher Geraldine Pounsford
geraldine.pounsford@iop.org
Tel. +44 (0)117 930 1022

Production Ruth Aspinall, Esther Woodman
Ad production Joanne Scriven
Circulation So-Mui Cheung
Art director Andrew Giaquinto
Technical illustrator Alison Tovey
Publishing director Richard Roe

Advertising sales Joanne Hook
joanne.hook@iop.org
Tel. +44 (0)117 930 1033
Fax +44 (0)117 930 1178

Subscriptions

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Motorola invests in IQE and forms GaAs-on-Si subsidiary Thoughtbeam

By Jon Newey

Since their announcement of the successful production of GaAs epilayers on large-area silicon substrates (see *Compound Semiconductor* October 2001, p47), Motorola and IQE have been busy refining the process and formalizing their relationship. The two companies have signed a number of agreements, including a license allowing IQE to manufacture GaAs-on-silicon wafers. Under the terms of the licensing agreement, IQE has been granted 15 months of exclusivity for the manufacture of wafers up to 6 inches in diameter. Discussions are ongoing over the terms and conditions for licenses covering the production of 8 and 12 inch wafers. Under a separate agreement, IQE has stated its intention to begin the shipment of sample wafers to potential customers in the first half of 2002, allowing these companies to assess the technology and to "accelerate the learning curve for the industry".

In order to commercialize its new compound semiconductor-on-silicon technology, Motorola has created a focused business unit and a wholly-owned subsidiary, Thoughtbeam Inc. The unit will be lead by Motorola corporate VP, Padmasree Warrior, who was previously CTO and director of the central R&D organization for Motorola Semiconductor Products Sector. "This breakthrough semiconductor technology has the potential to benefit multiple industries, from semiconductors to communications to optoelectronics, and we plan to license it broadly," said Warrior. "The next step is to ensure that a supply of GaAs-on-silicon wafers is made available to potential customers for their internal evaluation. So we have now authorized IQE to produce and supply GaAs-on-silicon wafers for our evaluation program."

Motorola boosts IQE's finances

Furthermore, to assist IQE's efforts to commercialize the technology, Motorola has taken a stake in IQE by committing to purchase an aggregate total of $10 million new shares as part of IQE's upcoming equity financing. Motorola will also have an option to invest a further $10 million over the next five years. To facilitate future production expansion, a £14 million ($20 million) equity drawdown facility has also been made available to IQE by two institutional investors. This enables IQE to raise up to £14 million from the investors in exchange for shares.

- In its latest financial news, IQE reported a loss of £2.23 million for the quarter ending 30 September. This compares to a profit of £380 000 for the same period in 2000. Sales were down 37% on the second-quarter 2001 figures, but up 28% on the third quarter of 2000. Commenting on the figures, executive chairman of IQE, Drew Nelson, said, "The current trading environment continues to be extremely challenging, particularly in the optoelectronics sector. Continued weakness in this area is being offset by the improving environment in the wireless sector."

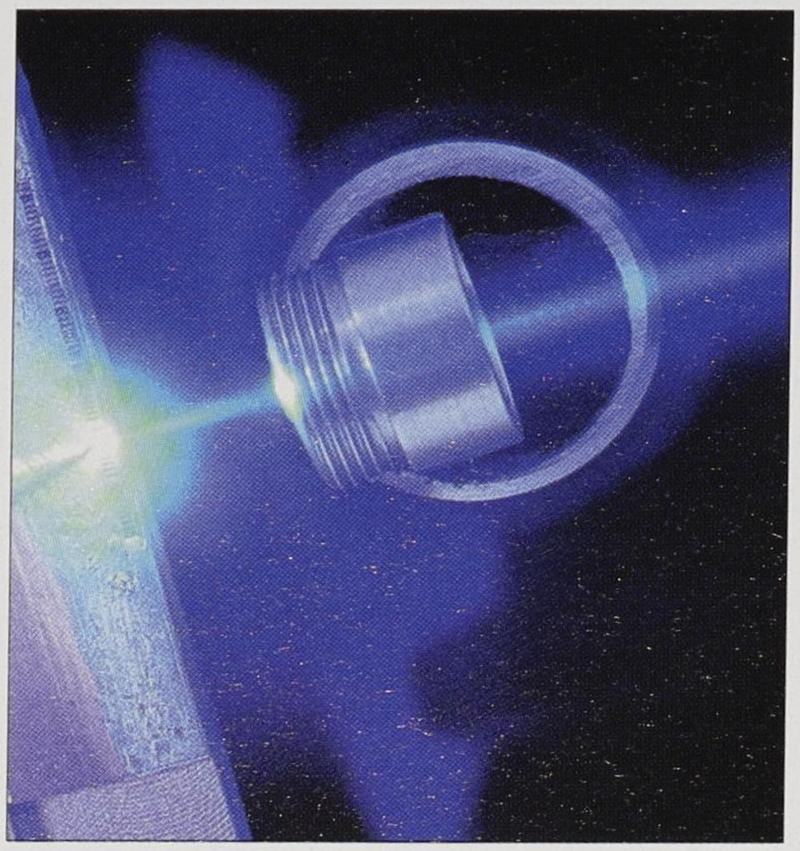
Cree's blue lasers pass one thousand hour mark

By Richard Dixon

Cree has announced that its short-wavelength laser diodes have demonstrated operating lifetimes in excess of 1000 hours, together with improvements in threshold operating characteristics. The company intends to begin sampling to customers by the end of the year, and plans to have a qualified production process by mid-2002.

Compared to the red lasers used in current DVD systems, blue and UV lasers offer the potential to increase optical storage density by a factor of 4–5×. At present, Nichia is the only company to have commercialized a blue laser diode, although Toyoda Gosei also appears close to offering devices to the market. Pioneer and Rohm are jointly developing blue lasers, and Sony, Matsushita, NTT and NEC are among the many other companies to have reported their research results so far. Osram recently reported Europe's first CW blue laser (see *Compound Semiconductor* November 2001, p11), but the lifetime was only several minutes.

"Most manufacturers currently make blue or UV lasers on sapphire substrates and this material does not have a natural cleavage plane," explains Cree's president and CEO, Chuck Swoboda. "Cleaving imparts a high-quality facet for the mirror structure, and we believe that the natural cleavage plane and structure of SiC will render our laser the preferred choice among packaging companies and system suppliers."



CREE

Cree is sampling a 400 nm blue laser diode with a lifetime of 1000 hours and expects to have a qualified production process in place by the middle of next year.

Swoboda also believes the company is still ahead of recent developments in optical storage markets. "We intend to qualify our production process by the end of next June," says Swoboda. "However, we don't believe that there will be a significant volume market for these products for some time, as there is still some work to be done in order to establish a standard for these lasers in optical storage systems. The blue laser release at this stage is really designed to provide our customers with the technology so that they can establish those standards."

MBE Technology receives $11 million investment – see page 19.

Nortel auctions off its assets in fab clearance

In an astonishing reflection of Nortel Networks' retrenchment in the face of huge losses in the last year, the company auctioned over 10 000 lots of equipment from its fabs at the end of November. In Ottawa, Canada, Nortel offered over 500 major pieces of 4 inch GaAs wafer fab equipment and 2 and 3 inch InP laser processing equipment, including Tegal and Trikon RIE systems, Leica e-beam evaporators and many others. Also included in the auction was equipment from the former JDS Uniphase 980 nm pump laser fab in Zurich, Switzerland, and over 1000 items from the CoreTek fab in Boston, MA.

In the past few years, Nortel made a huge investment in automated equipment at its facility in Paignton, UK, where many of its optoelectronic modules were assembled. This whole activity has essentially been shut down, and the assembly steps have been transferred to new facilities in Ottawa, to sit alongside the company's main wafer fabrication lines. As part of the auction, Nortel was selling wire and die bonders, optical spectrum analyzers, and a wide variety of manufacturing, optical test and visual inspection systems.

A further auction is scheduled for 22 January at Nortel's Harlow, UK, laboratories. This will include processing tools for 4 inch silicon wafers and 2 inch InP laser processing equipment, as well as optical test and measurement instrumentation.

GEO and Furukawa delay plans to increase output of Ga and As

GEO Specialty Chemicals will delay the start-up of its new gallium extraction plant located in Pinjarra, Australia, until at least the fourth quarter of 2002, according to the company's president and CEO, George Ahearn. "Despite the current unprecedented slow-down in semiconductor demand, we are confident of the industry's prospects," said Ahearn. "Due to the poor market conditions and because of limited visibility, the plant start-up will be delayed until at least the fourth quarter of 2002. However, we continue to believe that a significant draw-down in gallium-related end-user inventories is underway and we expect that the potential exists for a shortage of gallium, particularly in the second half of next year."

With a capacity of up to 100 metric tons per year, the plant will be the largest of its kind, and will employ GEO's patented process technology to produce 99.99% pure gallium metal. GEO has 19 plants worldwide and is currently the world's largest producer of virgin gallium metal. The Pinjarra plant will nearly quadruple the company's capacity to over 130 metric tons per year.

Meanwhile, GEO has reached an exclusive agreement with Alcoa of Australia Ltd, under which the latter company will provide feedstock for GEO's planned gallium extraction plant in Pinjarra. The feedstock is a by-product of Alcoa's aluminum extraction facility located at the same site.

Furukawa suspends operations

Furukawa Co is to suspend production of high-purity metal arsenic at its existing plants for about three months, starting from January 2002. The company is building new production facilities within its plant in Fukushima Prefecture and will invest about ¥2.2 billion ($18 million) in the project. The company will then transfer all of its high-purity metal arsenic production to the new facilities, which will be completed in January.

Demand for high-purity metal arsenic has been declining sharply due to a downturn in the information technology industry. Furukawa's production of high-purity metal arsenic dropped to 2.5 metric tons in October, compared with slightly more than 11 tons in April. The average monthly production level for Furukawa's fiscal year ending March 2002 is expected to be about 4 tons.

High-purity metal arsenic is the company's mainstay product for its electronic materials operations. The company hopes to achieve profitability by integrating production into the new facilities, which have higher productivity than the existing plants.

NEC plans to build new Kansai fab

NEC Corporation has announced plans to move its core research and development activity to its Kansai facility, and plans to construct a new building at this location. NEC Kansai is home to newly formed subsidiary NEC Compound Semiconductor Devices Ltd (NCSD), which manufactures fiber-optic and microwave devices and ICs. The company will invest ¥3 billion ($24 million) to construct the new building, which has a floor area of 11 200 m^2 and a cleanroom area of 2000 m^2. The building will begin operation, in stages, in the spring of 2002, and will accommodate staff transferred from the company's Photonic and Wireless Research Laboratories. It will also be the key location for NEC's R&D&P system, which promotes close co-operation between research and development activities and production lines. The company believes that this move will support its expansion and growth in the broadband fiber-optic and mobile communications markets.

SIA predicts slow recovery in 2002

Semiconductor sales SIA

	market ($ billion)	*change over previous year*
2000	204	
2001	141	–31%
2002	150	+6%
2003	181	+21%
2004	218	+21%

In its annual forecast, the Semiconductor Industry Association (SIA) projected that global semiconductor sales would decrease by 31% this year to $141 billion, compared with $204 billion in 2000. However, spurred by sales of personal computers, wireless and consumer products, the industry will recover from the inventory build-up that occurred in 2000 and the weak end-market equipment demand in 2001. The SIA predicts slow recovery in 2002, with 6% growth to $150 billion, followed by 21% growth in the following two years, reaching a total market of $218 billion in 2004. The Americas suffered a 43% decline in 2001, while Asia Pacific decreased by only 23% this year, and will show the most rapid rebound, with 14% growth next year.

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E-mail: info@aixtron.com
www.aixtron.com

US Headquarters
Chicago, IL
AIXTRON Inc.
1670 Barclay Blvd.
Buffalo Grove
IL 60089

Phone: +1 (847) 215 - 7335
Fax: +1 (847) 215 - 7341
E-mail: usinfo@aixtron.com
www.aixtron.com

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AIXTRON cshs
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358-1, Yatap-Dong
Bundang-Ku, Sungnam City
Kyoungki-Do, 468-828

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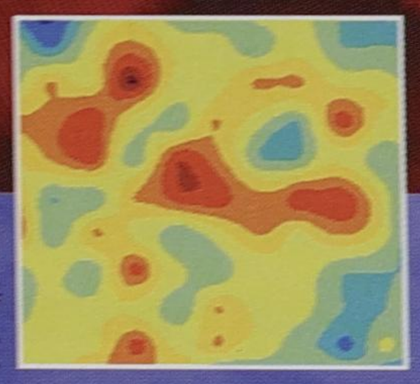
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1-4-22 Yaesu, Chuo-Ku
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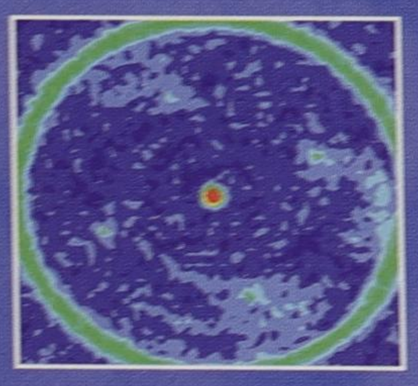
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Pateh Road No. 1
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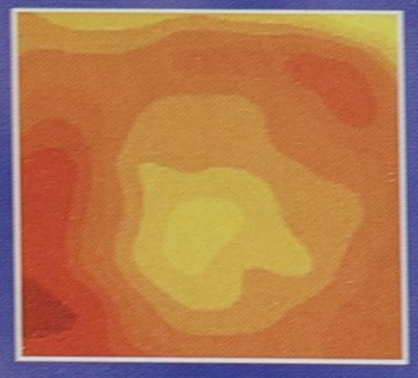
software with bite



SiGe Wafer Map; data collected on a Bede QC200™. Data courtesy of Dr Peter Zaumseil, IHP, Germany.



Texture pole figure – MnFe/Co/Cu Spin Valve Stack – taken on a Bede D1.



Rocking curve analysis of GaN (10-12) reflection taken on a Bede QC200™. Data courtesy of Dr Joong Seo Park, EpiValley, Korea.

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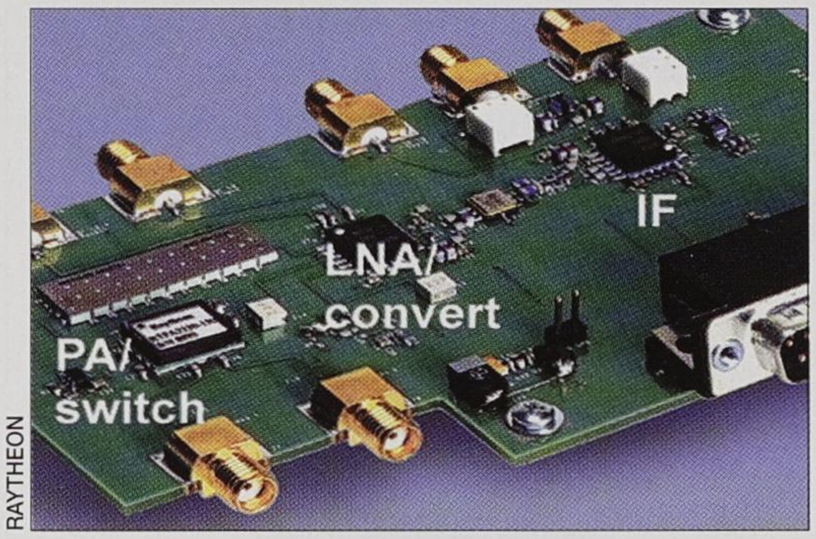
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Systemonic combines expertise with Raytheon

Raytheon's Commercial Electronics business has signed an agreement with Systemonic, a German manufacturer of CMOS baseband chipsets, to commercialize Raytheon's 5 GHz high-speed RF connectivity devices. As part of the deal, Systemonic takes over Raytheon's RF Networking business unit located in Marlboro, MA, and will employ all the unit's former staff. While the terms of the agreement have not been disclosed, the deal involves an exchange of Raytheon's intellectual property for an equity interest in Systemonic.

Currently the 5 GHz band is generating interest for WLAN and broadband wireless connections up to 54 Mbit/s. Raytheon will receive a broad license to this technology for use exclusively in its defense business while Systemonic, a manufacturer of baseband chipsets, gains RF design services and front-end technology. This includes Raytheon's front-end WLAN chipset, Tondelayo, which was developed for links defined by the IEEE 802.11(a) standard. This chipset will be matched with Systemonic's baseband IC, which enables operation across several different WLAN protocols.

Systemonic will initially operate out of Raytheon's 246 000 sq. ft manufacturing facility in Marlborough, MA. Ultimately the company will move to a separate location in Massachusetts, and continue to leverage its RF technology agreement with Raytheon.



RAYTHEON

RF front-end evaluation board showing the GaAs HBT PA/switch, SiGe converter/LNA and SiGe IF circuits. This is combined with a baseband processor to form Systemonic's 5 GHz WLAN radio chipset.

"We are delighted to welcome a world-class team of RF and protocol firmware designers, and marketing and RF operations personnel," said Ruediger Stroh, president and CEO of Systemonic. "Our organization is now poised to realize our vision of enabling transparent connectivity for end users."

Raytheon's Tondelayo chipset includes a SiGe LNA up/down-converter and the RTPA-5250 power amplifier/switch module, which was developed using the company's 0.5 μm GaAs PHEMT process (see *Compound Semiconductor* April 2001, p32).

"We will be sampling the entire front-end for 802.11(a) applications, including the PA, RF and IF filters and other components, in the next few weeks," said Nick Bahram, VP of Raytheon's corporate ventures. "By the beginning of the second quarter of 2002, we intend to ramp into full volume production."

Systemonic, based in Dresden, Germany was spun off from the University of Dresden in 1999. It uses CMOS baseband technology to accommodate multiple protocols – IEEE's 802.11a and 802.11b protocols in the US, and HiperLAN2 standard in Europe – using a system-on-a-chip approach. The company says that while most manufacturers require a separate chip for each protocol, its product accommodates up to three protocols.

In brief...

Alpha receives module orders from Siemens

Alpha Industries has received production orders from a wireless handset OEM for its InGaP HBT power amplifier module. The customer, which has designed Alpha's AP134 module into multiple handset platforms, is believed to be Siemens. Alpha estimates the new orders should generate sales in excess of $20 million in 2002.

Anadigics wins orders from Korean handset makers

Anadigics has received production orders from two Korean handset manufacturers for its InGaP HBT power amplifier modules. The orders are for two of its recently launched products designed for Korean CDMA handsets and wireless modem cards.

RFMD and Hitachi sign cross-supply agreement for RFICs

RF Micro Devices and Hitachi have announced a cross-supply agreement for GaAs HBT wafers and module design and manufacturing, which is to take effect immediately. This is an alliance between two of the top suppliers of RFICs for handsets. RFMD is the largest manufacturer of high-end power amplifiers and Hitachi claims to be the world's number one supplier of RF components for the GSM market. Hitachi supplies PA modules for around 40% of the world's GSM phones, according to Earl Lum of CIBC World Markets.

RFMD has already begun supplying GaAs HBT power amplifier die to Hitachi which, in the past, has used silicon exclusively. Under the terms of the agreement, Hitachi will provide design and assembly services for RFMD's module products. Over the past year module manufacturing has become the most important strategic thrust at RFMD, currently accounting for more than 40% of revenue (see *Compound Semiconductor* November 2001, p19).

Hitachi has several years of experience in making RF modules, having introduced its first module in 1994. Lum sees this new deal as a "win-win" for both companies, giving RFMD access to "five or six generations of module manufacturing technology", and at the same time giving Hitachi access to GaAs and HBT technology for the first time. RFMD's VP of sales and strategic development, Jerry Neal, said, "We expect this alliance will increase utilization in our fabs. We're eager to tap into Hitachi's module design and assembly capabilities."

Each company will maintain independent control of product design, development and marketing. At present the agreement applies to RFMD's AlGaAs HBT technology, but it can be extended to InGaP in the future.

Hitachi also has a development deal in place with TRW spin-off Velocium to develop next-generation PAs based on InP.

Our report on the prospects for the handset market begins on page 27.

Conexant unveils quad-band PA

Conexant has announced the first quad-band PA module designed for GSM operation. The CX77314 supports GSM handset operation in more than 150 countries, including the new GSM850 band in the US. The module also supports GPRS.

Conexant has added the extra band to allow manufacturers to qualify and stock a single device for all of their GSM handsets, regardless of geographic region or frequency band. The company has also upgraded its tri-band design, using a broadband AlGaAs HBT PA circuit which is capable of being tuned across the 825–915 MHz band. The higher DCS1800 and PCS1900 bands are served by a PA covering the 1710–1910 MHz range, and the two blocks are integrated onto a single piece of GaAs. The CX77314 also includes 50 Ω fully matched input/output ports to reduce the number of external components required in the design.

"The approach we've taken is very similar to our tri-band amplifier," says product manager Doug Maki. "Essentially we've extended the range of the lower-frequency 915 MHz amplifier down to 824 MHz. There is no increase in die size, but we've changed the components we use for external matching."

The GaAs circuits, a Si CMOS amplifier controller and all of the passive components are integrated onto a compact multi-layer laminate substrate, prior to encapsulation inside a compact $8 \times 10 \times 1.5\ mm^3$ package. The module is expected to reach volume production by December.

"While the GaAs die features some internal matching, it does not have the external 50 Ω matching on chip," adds Maki. "By putting the match circuitry on the laminate substrate, we are able to take advantage of the higher inductance values we can achieve with either lumped or distributed elements compared with GaAs. We save GaAs area and also obtain better performance."

Ericsson selects Anadigics' power amplifier chip

Anadigics (Warren, NJ) is shipping production volumes of a power amplifier chipset for use in Ericsson's new R300d WAP tri-mode phone. Anadigics will supply a circuit with two amplifiers and an amplifier driver, which it says enables the handset to deliver 6 hours of talk time and up to 400 hours of standby using a lithium-ion battery.

Ericsson's TDMA handset covers the analog 800 MHz and digital TDMA 900/1900 MHz frequencies. The R300d is Ericsson's fourth Web-ready phone for the Americas.

"While the excellent performance of our PA components translates directly to extended battery life and longer talk times, Anadigics' ability to manufacture these products in high volumes and at the right price has been key to our success," said Ali Khatibzadeh, Anadigics' VP of wireless products.



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Helping You Grow Your Business!

Cree and AXT make brighter LEDs

By Richard Dixon

While the use of LEDs in general illumination applications is still some way off, established markets in automotive brake lights and interior lighting, cell phone backlights, displays and traffic lights all benefit from improvements in brightness. Cree and AXT have both recently reported considerable gains in the output of their respective GaN-based products for such applications.

Cree's new X-Bright chip

Over the past year, Cree has increased the brightness of its LEDs three-fold. Its latest commercial product is the X-Bright, which forms the basis of a new family of InGaN-on-SiC LEDs that are up to 50% brighter than Cree's MegaBright chips. The new devices include a blue LED at 470 nm and shorter wavelength UV versions at 395 and 405 nm. These chips will be sampled by the end of the year, with production expected soon after.

The preliminary data sheet for the blue device reveals a radiant flux of up to 16 mW, achieved using a DC forward current of 20 mA and a voltage of 3.7 V. This compares with 10 mW for the blue MegaBright chip.

Cree has also added new green LEDs to its MegaBright portfolio. The 505 nm device, which is currently sampling, offers 8 mW at 20 mA. This chip and a 525 nm version are expected to enter production in the next few months for use in traffic signals and signs.

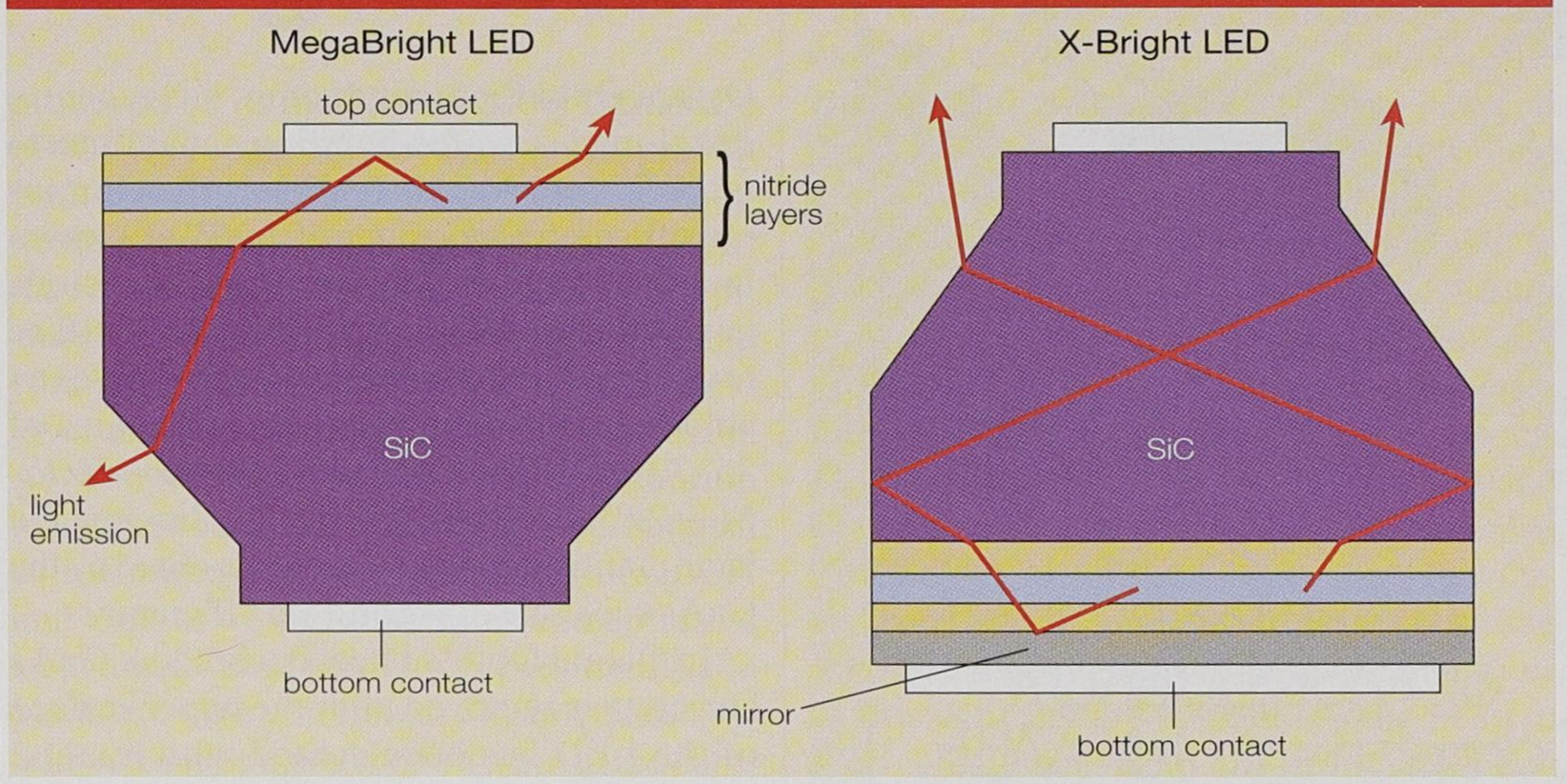
LED world turned upside down

In common with Cree's earlier UltraBright and MegaBright LEDs, the X-Bright device employs a shaped chip design to reduce total internal reflection losses. The die size is also the same; the top area is $300 \times 300\ \mu m^2$ and the p-n junction measures $250 \times 250\ \mu m^2$. The principal difference is that the X-Bright chip is inverted and has a mirror layer to reflect light back towards the front surface.

According to CEO Chuck Swoboda, the majority of the gain in output has been made through the chip geometry. "By inverting the chip and including a reflector, we are able to collect all the light that would normally diffract downwards into the backside contact, and reflect it out of the chip," says Swoboda. "By inverting the chip, much of the light is coupled into the SiC, which now acts as a light guide. In our conventional design, a lot of light was going into the SiC substrate and reflecting out through the sides, but turning the die over has made it easier to extract the light."

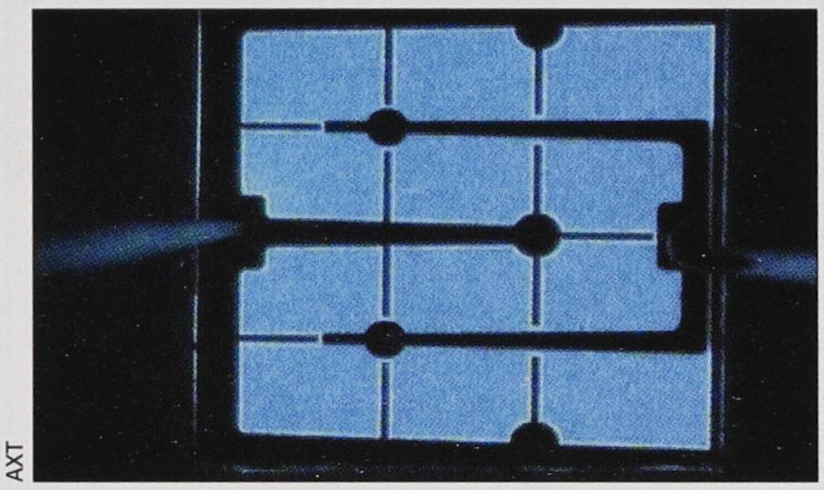
Swoboda says that while Cree has demonstrated UV LEDs with an efficiency of 32% and an output of 21 mW (see *Compound Semiconductor* April 2001, p11), its production X-Bright UV chip will operate at an external efficiency of about 25%.

Cree's InGaN-on-SiC chip designs



CREE

Cree's new X-Bright LED uses the shaped chip deployed in the earlier MegaBright design to provide light paths that reduce internal reflection. The inverted design has a mirror to reflect light away from the back contact, increasing light extraction in the forward direction.



AXT

AXT's new large-area P2 series AlInGaN LEDs can be driven at high currents and have an optimized top contact geometry to improve current injection.

AXT goes for large-area die

AXT has introduced, in production quantities, new high-flux AlInGaN-on-sapphire LED chips covering the 450–525 nm range. At $1260 \times 1260\ \mu m^2$, the new P2 series die are much larger than the company's standard die size of $325 \times 375\ \mu m^2$. This allows the device to be driven at a higher current, and provides LEDs for applications requiring a higher luminous flux, including automotive lighting, dental curing and general illumination.

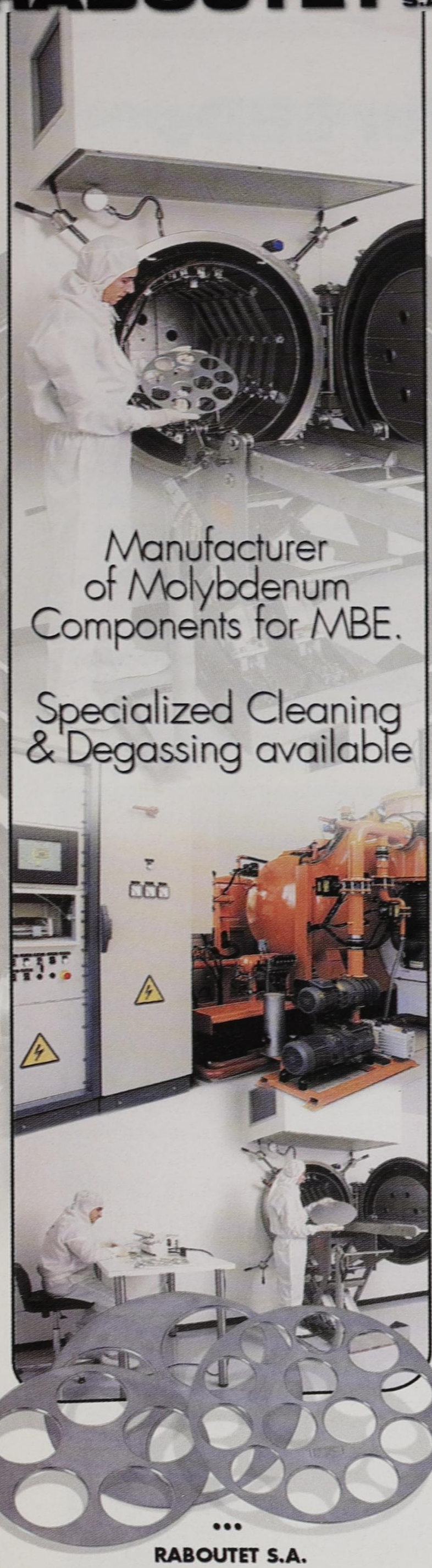
AXT's 525 nm green AlInGaN device operates at a driving current of 350 mA, and provides a radiant flux of 27 mW and an efficiency of 17.5 lm/W. The cyan die, designed for use in traffic signals, offers 30 mW with 12.5 lm/W efficiency. In addition, AXT has a 450 nm blue variant with a flux of 35 mW and efficiency equivalent to 6 lm/W.

AXT has also increased the brightness of its standard green, cyan and blue LEDs by 30% over the previous generation. Operating at 20 mA, these new AlInGaN-based LEDs are now in production and feature typical output powers of 2.0, 2.2 and 3.0 mW, respectively. Packaged, these emitters are expected to provide 4.0, 4.4 and 6.0 mW.

According to Heng Liu, AXT has resisted chip shaping to improve light extraction from its LEDs. "All the advancements made in the last 18 months have come from improvements in the internal quantum efficiency," says Liu. "This is achieved by optimizing the MOCVD crystal growth process."

In common with Cree, AXT's chips are sold as unpackaged die. "Die are provided to customers so that they can develop their own proprietary packages," says Liu. "However, the design of the P2 chip includes improved current spreading, an optimized geometry for specific current injection, and a back reflector to enhance light extraction."

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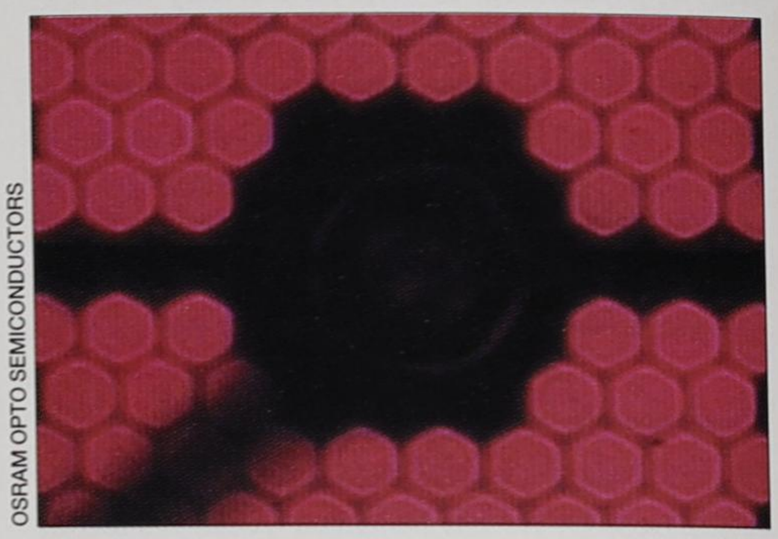
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Osram Opto doubles its AlGaInP LED efficiency

Osram Opto Semiconductors has recently developed a wafer-bonding technique to manufacture AlGaInP LEDs with a luminous efficacy of more than 50 lm/W at a wavelength of 615 nm. The company's previous generation of AlGaInP devices used surface texturing in order to improve the light extraction, resulting in luminous efficacies of 25–30 lm/W (see *Compound Semiconductor* May 2001, p59). In this design, however, a large number of photons were absorbed by the GaAs substrate, lowering the efficiency.

In Osram Opto's latest design, the GaAs substrate is removed after the upper surface of the LED has been coated with a metal layer and then bonded to a thin carrier. This metal film doubles as both an electrical contact and also as a highly reflective mirror. The process is compatible with 4 inch wafers, which should lead to higher yields.



OSRAM OPTO SEMICONDUCTORS

Osram's 615 nm AlGaInP LED has a luminous efficacy of over 50 lm/W.

Toyoda Gosei to unveil white LEDs

Toyoda Gosei has developed what it describes as a new type of high-brightness white LED. The TG White Hi incorporates a GaN-based blue LED with a newly developed phosphor to achieve a luminosity level as high as 400 mcd at a drive current of 20 mA from a 3 mm surface-mount format device.

The white LED product is being developed in order to challenge Nichia's dominance in the lucrative market for backlights for color liquid-crystal displays in cellular phones. In collaboration with Toshiba, Toyoda Gosei is also developing another white LED that uses its 380 nm InGaN UV chip, and a red, green and blue phosphor developed by Toshiba (see *Compound Semiconductor* April 2001, p67).

The new phosphor was developed by an Austrian company called Tridonic Optoelectronics and two German companies, Leuchtstoffwerk Breitungen and Litec, and has been licensed by Toyoda Gosei. Together with the three European companies, the Japanese manufacturer has jointly applied for a worldwide patent on the white LED, which will be offered in a number of packaging options including surface-mount devices and lamps. The new emitter is currently sampling and is expected to be in production by February 2002.

Developments in the LED patent war

Nichia has continued to pursue its "conspiracy theory" by filing an antitrust claim against Rohm and Cree. The claim, filed in the US District Court in Pennsylvania, asserts that Rohm and Cree entered into a conspiracy to exclude Nichia from selling nitride-based LEDs in the US. Nichia's latest lawsuit follows a complaint made by Rohm to the US International Trade Commission (ITC). Although Rohm's complaint was subsequently withdrawn, the ITC ordered Rohm to explain why the complaint was lodged in the first place (see *Compound Semiconductor* September 2001, p22).

Nichia's conspiracy theory is based around the license agreement which was signed by Rohm and Cree just three days before Rohm filed the original ITC complaint. Nichia also claims that the ITC complaint asserted patents which Rohm knew to be invalid and which had been fraudulently obtained.

- Toyoda Gosei has filed an additional lawsuit against Nichia, claiming ¥15.5 billion ($125 million) in damages for the period from April 1998 to June 1999. The lawsuits concern two patents owned by Toyoda Gosei, no. 2 737 053 and no. 2 681 733, both of which were ruled invalid by the Japanese Patent Office and then subsequently validated in the Tokyo High Court.

Okmetic AB develops methods for SiC growth

Okmetic AB, a materials company based in Vantaa, Finland, has jointly developed a method for SiC crystal growth with Sweden's Linköping University and ABB Corporate Research. Okmetic's SiC effort is based at Linköping University, where the company has developed and is now commercializing its high-temperature CVD (HTCVD) process for the growth of 4H semi-insulating and doped SiC substrates with diameters of up to 2 inches. In addition, Okmetic is introducing a process for CVD-grown epitaxial layers. As part of this development, the company recently ordered a SiC epitaxial reactor and a high-temperature CVD crystal growth reactor from Epigress (see p19).

Okmetic, which also manufactures SOI wafers and silicon wafers for MEMS applications, has been developing SiC since the early 1990s, with the first devices being produced on its material in 2000. Okmetic's HTCVD process employs gas-phase growth from a seed crystal in a vertical hot-wall chamber at over 2100 °C, using SiH_4 and C_2H_4 as the source gases. Okmetic produces SiC epiwafers with dopant concentrations of Al and N ranging from 1×10^{15} to 1×10^{19} cm^{-3}, and layer thicknesses ranging from 0.1 to 50 μm.

"The addition of these new production reactors to our R&D reactors reflects our goal of becoming a commercial manufacturer and vendor of SiC substrates and epitaxial structures," said Okmetic's president Asko Vehanen. "We will initially install these systems at Linköping University, but in the coming months expect to move the SiC activity to more industrial surroundings. To date, we have mostly pursued markets for semi-insulating SiC in MESFET applications, as well as doped SiC for high-power devices."

Cree reports SiC power records

Cree has demonstrated record results for PIN power diodes and power MOSFET transistors based on SiC. Reporting the results at the recent SiC conference in Tsukuba, Japan, Cree stated that device power levels have increased by more than a factor of 10 since last year, due to scaling to much larger sizes. Cree described a rectifier based on a 10 kV SiC *pin* diode with an area of 9 mm^2 that operated up to 10 kV. The device had a current-carrying capability of 20 A, and a pulsed power capability of 200 A. In pulsed mode, power levels of up to 2 MW were attained, which Cree claims are the largest reported for a single SiC chip.

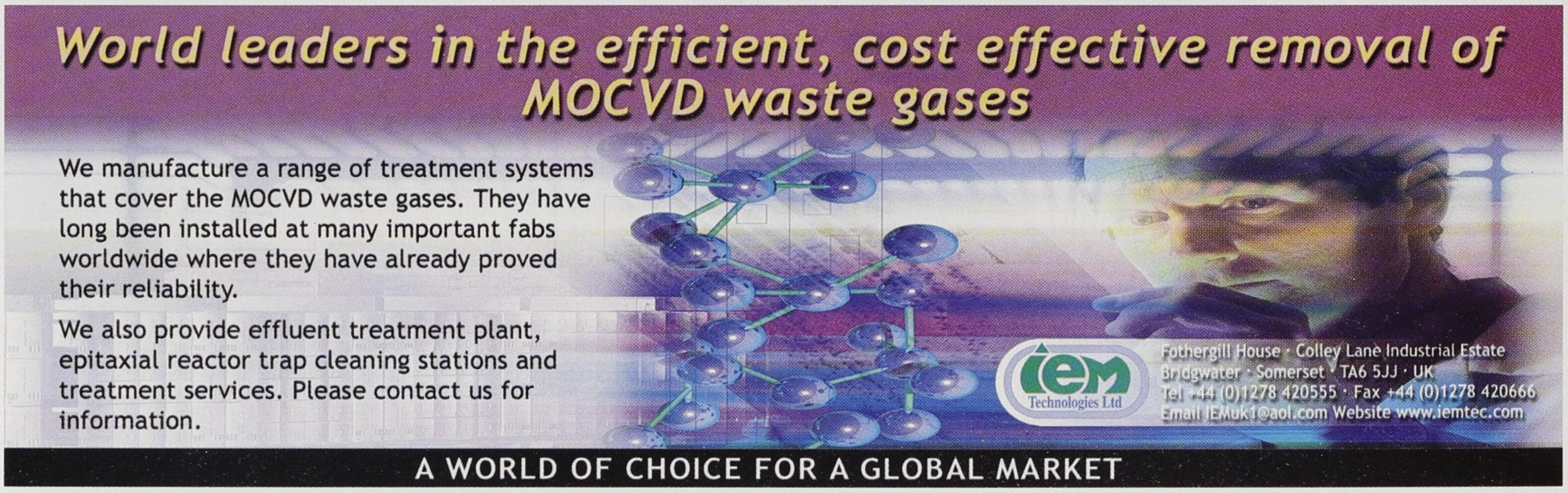
The SiC power MOSFET reported was a large-area device with a total chip area of 11 mm^2. The circuit demonstrated a high voltage rating of 2.4 kV, with a current capability of up to 10 A and power output rated at 24 kW. The on-resistance was less than one-fortieth that of an equivalent silicon MOSFET, leading to much lower conduction losses.

Cermet gains GaN funding from BMDO

Cermet has recently received two separate two-year contracts from the Ballistic Missile Defense Organization (BMDO) to develop GaN-based technology. One contract, valued at approximately $1.1 million, is for the development of GaN-based high-frequency FETs in conjunction with Virginia Commonwealth University. The Department of Defense is actively pursuing high-power, high-frequency nitride transistors to incorporate into advanced radars, on-board monitoring systems and communication systems. Commercial applications for nitride transistors include wireless base station devices, as well as consumer wireless devices. The technical objectives of this contract are addressing the need to fabricate devices with low defect densities and the need to develop proper thermal management techniques.

Under the second contract, which is valued at $770 000, Cermet is required to demonstrate bulk crystal growth technology for GaN wafers up to 2 inches in diameter. The numerous military and commercial applications of GaN-based devices all require high-quality GaN substrates with a diameter of at least 2 inches.

Cermet develops and produces GaN, AlN and ZnO wafers and devices and has an 11 000 sq. ft facility in Atlanta, GA, which houses facilities for bulk crystal growth, epitaxy and wafer processing. Cermet recently became a member of Yamacraw, an economic development initiative which was formed to establish Georgia as a world leader in the design of broadband communications systems, devices and chips.



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Adept and JDS Uniphase form automation alliance

JDS Uniphase and Adept Technology have entered into a development alliance for optical component and module manufacturing. Adept will partner JDS Uniphase in the development of optical automation processes and solutions, and JDS Uniphase will make an investment of $25 million in Adept in the form of convertible preferred stock.

Located in San Jose, CA, Adept manufactures robots, controllers and software products for precision process applications. For fiber-optic assembly, the company produces systems that use robotics and machine vision to automate processes such as positioning, epoxy bonding, laser welding, fiber stripping and cleaving, and fusion splicing.

The alliance extends the two companies' existing 12 month development and supply relationship. Adept will continue to work with JDS Uniphase's Optical Process Automation organization on component and module manufacturing processes for sub-micron tolerance assemblies. JDS Uniphase will have sole rights to new technologies related to the fiber-optic products that are developed during the alliance, while Adept will be able to develop and market such technologies for use in other industries.

"Adept's vision and motion controls are an excellent complement to our existing automation approach," said Greg Dougherty, executive VP and COO for JDS Uniphase. "We believe the integration of Adept's flexible automation platform and technologies into our automation systems will provide a lower cost, higher quality and scalable manufacturing capability throughout the JDS Uniphase organization in the future."

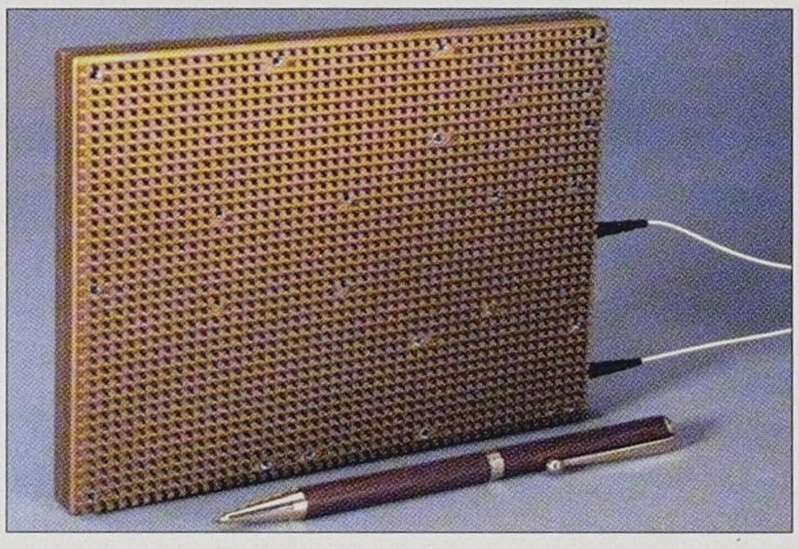
Inphi and GTRAN integrate InP components for 40 Gbit/s systems

Inphi and GTRAN, two fabless IC manufacturers, have developed 40 Gbit/s InP circuits for use in the initial development and design phases of OC-768 optical networks. Both companies are supplying mux/demux ICs that operate above 40 Gbit/s to enable forward error correction, as well as featuring low power consumption and the potential for integration with optical components.

The two companies have introduced ICs that integrate a 4:1 mux and a clock multiplication unit (CMU) for the transmit side, and a 4:1 demux and a clock and data recovery (CDR) circuit for the receive side. GTRAN's circuits are manufactured by external foundries (including GCS) using the company's own InP HBT process, while Inphi uses the InP HBT process developed by GCS.

In GTRAN's chipset, the mux/CMU has a power consumption of 2.5 W and the demux/CDR dissipates 3 W. The demux incorporates a post-amplifier at the input to achieve high input sensitivity. GTRAN is offering a VCO source which is tunable from 38 to 51 GHz and features a low phase noise figure.

Inphi's design uses CMOS-based 16:4 mux and 4:16 demux chips to interface with the InP 4:1 mux and 1:4 demux ICs. Using this the module consumes 10 W of power in total, compared with an estimated 25 W for comparable chipsets. "When designing the architecture, our strategy was to select the right technology for the right application," said Inphi's CTO, Gopal Raghavan. "For OC-768 data rates, we believe the combination of CMOS and InP is the perfect match in terms of density, power consumption and speed. CMOS meets high-gate-count requirements, and InP meets the high-bandwidth low-power requirements of OC-768 fiber-optic links."



GTRAN

A 40 Gbit/s fiber-optic module currently being manufactured by GTRAN.

WJ and Fujitsu ally on 40 Gbit/s fiber-optic ICs

WJ Communications (formerly known as Watkins Johnson), a GaAs IC manufacturer based in San Jose, CA, has formed a partnership with Fujitsu Quantum Devices to jointly develop 40 Gbit/s fiber-optic components.

The companies have shipped an initial product, a 43 Gbit/s OC-768/STM-256 driver amplifier module with forward error correction. The driver offers an adjustable output voltage swing of 6.0 Vpp, and features an output level detector and feedback loop to stabilize the output swing. Products which result from the partnership will be jointly produced at WJ Communications' module integration factory in San Jose, CA, and at Fujitsu Quantum Devices' manufacturing facility in Yamanashi Prefecture, Japan.

Intense launches 980 nm pump lasers and opens a new fab

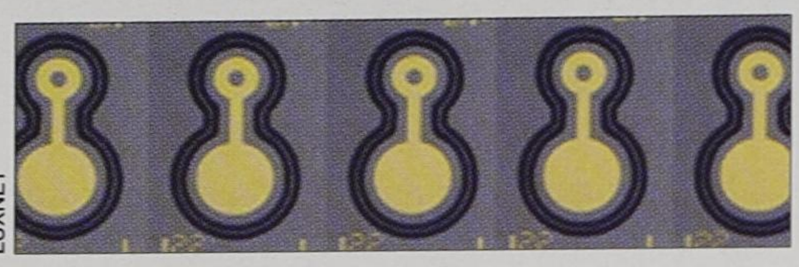
Intense Photonics has begun production of its first commercial product, an array of 980 nm EDFA pump lasers which have been fabricated using the company's quantum well intermixing technology (see *Compound Semiconductor* September 2001, p63). Customers for the IP0980 are able to specify the number of lasers (up to a maximum of 10), the spacing and interface angles (to improve the connection to arrayed waveguides), and the output power levels (up to 250 mW). The flexibility to specify such parameters is expected to yield substantial cost savings to the system builders.

Intense Photonics officially opened its new manufacturing facility in High Blantyre, Scotland, in November. The company purchased the former Dupont photomask production plant earlier this year (see *Compound Semiconductor* August 2001, p16) and installed equipment for prototyping and testing. The installation of tools for volume manufacturing of products such as the new laser array will begin in January 2002, with the first commercial wafer start scheduled for the second quarter of 2002. The plant's modular construction enables easy expansion when extra capacity is required.

LuxNet unveils new array

Optical component manufacturer LuxNet has released a 1 × 12 array of 850 nm VCSELs. Operating at 2.5 Gbit/s per channel, the array supports an aggregate data rate of 30 Gbit/s and is intended for parallel optical transceivers used in VSR, Gigabit Ethernet and InfiniBand applications. The array joins LuxNet's portfolio of 1.25 and 2.5 Gbit/s 850 nm VCSELs, and has a typical threshold current of 1.7 mA. The slope efficiency is 0.35 mW/mA and the parameters are uniform within 15% across the array. Available in chip form, the array is due to enter volume production early in 2002.

According to Andy Liao, VP of engineering, the devices have been subjected to 300 000 hours of elevated temperature testing at 100 °C and three times the operating current. LuxNet is also developing long-wavelength edge-emitting lasers. "We're watching carefully to see how the long-wavelength VCSEL market develops," says Liao. "Long-wavelength VCSELs are more challenging to produce than 850 nm emitters, but the yardstick is whether they can be introduced at a comparable price and performance. Therefore, we plan to introduce 1310 nm edge-emitting lasers to serve the long-wavelength OC-192 market, and we are developing 850 nm single VCSELs and arrays, and also detector arrays, each operating up to 10 Gbit/s."



LUXNET

850 nm VCSEL elements are employed in LuxNet's 1 x 12 channel array.

E2O's 1300 nm VCSEL hits 4 mW

E2O Communications has demonstrated a long-wavelength VCSEL with 4 mW of CW output power, a figure the company believes is among the highest reported for a 1300 nm VCSEL operating at room temperature. The device operates at 2.5 Gbit/s and features a spectral line width of less than 0.2 nm, in addition to a side mode suppression of 40 dB.

E2O is currently shipping serial and parallel fiber-optic transmitters operating up to 3.125 Gbit/s, in addition to receivers and transceivers to support Gigabit Ethernet, Fibre Channel and other applications. E2O, based in Calabasas, CA, says its long-term aim is to introduce 10 Gbit/s long-wavelength VCSEL transceiver and transponder modules in 2002.

"Long-wavelength VCSELs have the greatest potential to displace DFB lasers," said Julian Cheng, VP of R&D. "This is due to low fabrication costs, single longitudinal and transverse mode operation. In addition, such devices offer a narrow linewidth and are less susceptible to feedback noise."

Cheng adds that designing long-wavelength VCSELs with high output power while maintaining the single transverse mode is challenging. "Several other companies are also developing these [long-wavelength] devices, but the singlemode output power has been limited to less than 1 mW, which is not sufficient to meet 10 Gigabit Ethernet requirements," he says.

PowerNetix releases first 980 nm laser

PowerNetix, a start-up component and package design company located in San Jose, CA, has released its first high-power singlemode 980 nm pump laser. Using chips obtained from external suppliers, the company's modules are available in 200 and 300 mW versions in standard 14-pin butterfly packages.

"These high-performance devices are the result of a combination of the laser chip power and how much of this power can be transferred into the fiber lens," explains VP of marketing, Lalit Goel. "A further limiting factor is the losses incurred by welding the laser to the fiber, which are limited by the thermal coupling efficiency. We have achieved a coupling efficiency of around 80% for our high-power modules, which in turn optimizes the power of the chip."

PowerNetix has developed a proprietary packaging and process technology called Uniline, which targets the bottleneck caused by the need for repeated fiber-to-laser alignment steps and subsequent stabilization cycles. The system features a single-step fiber align and lock process that delivers a final stable pump laser product.

Long-wavelength VCSEL start-up gets $3.8 million

Lytek Corporation, a start-up company developing 1310 nm VCSELs for data-communication applications, has received $3.8 million in funding from its Series B equity financing round. The lead investor in this round, Wasatch Venture Fund, was joined by Intel Capital, which also provided a $1.5 million seed round of financing in June 2000. Lytek was founded in May 2000 by Yong-Hang Zhang, a professor at Arizona State University (ASU). The company intends to commercialize the technologies invented at ASU by Zhang's MBE & Optoelectronics Research Group, under an exclusive license agreement with the university.

"Lytek's technology provides dominant advantages and tremendous value in the optoelectronic device industry," commented Todd Stevens, MD of Wasatch Venture Fund. "Our investment enables Lytek to accelerate its development of their VCSEL technology and deliver products next year."

In brief...

Qusion completes its indium phosphide fab

Qusion Technologies has finished building an 8000 sq.ft fabrication area at its vertically integrated InP fabrication facility in North Brunswick, NJ. The new facility will enable the company to begin manufacturing InP-based modules operating up to 40 Gbit/s, and includes 3000 sq.ft of class 1000 cleanroom space and a 400 sq.ft class 100 area for photolithography processing.

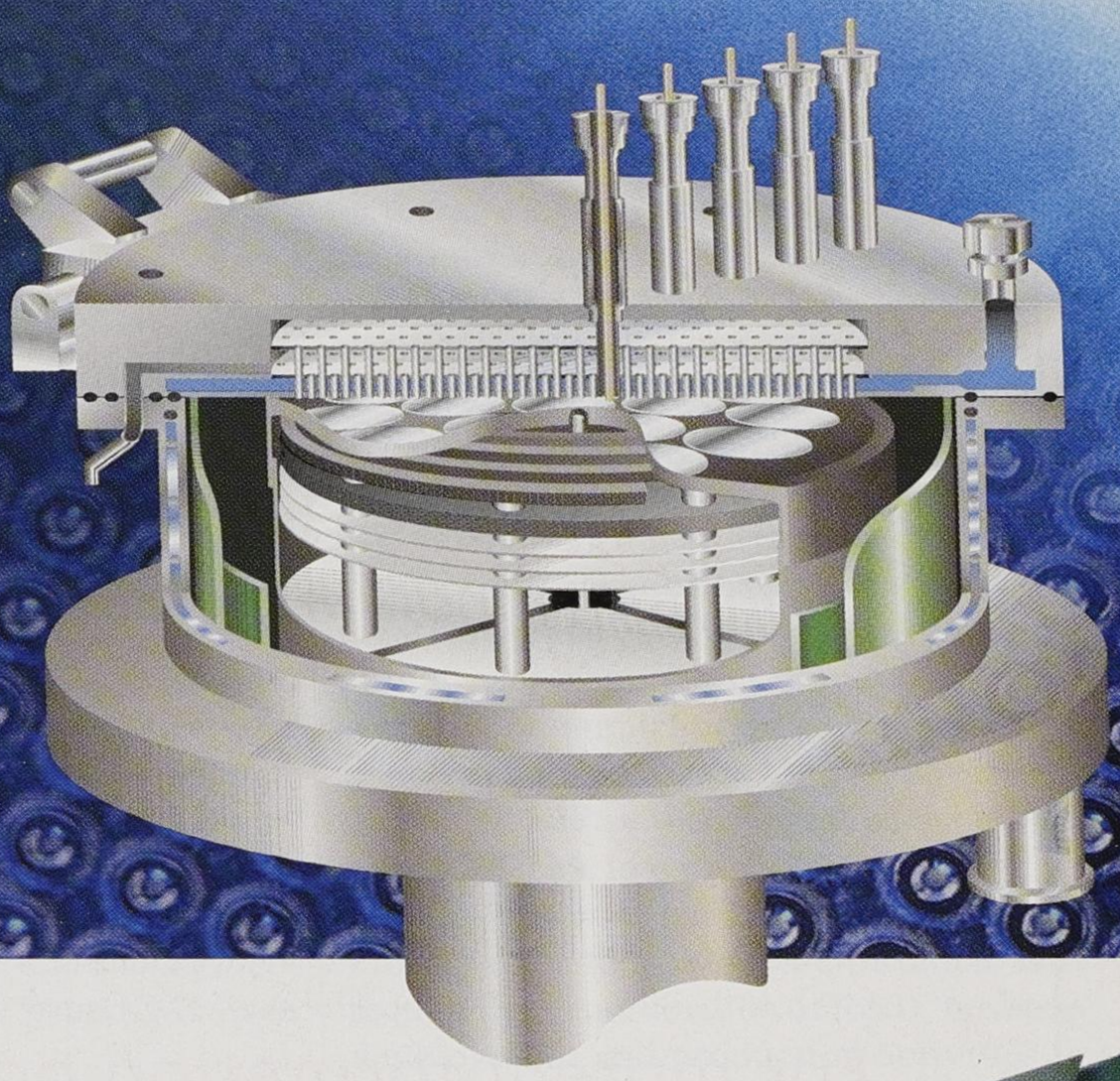
C-band tunable laser developed at Marconi

Marconi Optical Components has recently developed a new tunable laser which gives coverage across the full C-band. The InP-based "digital supermode" DBR laser has several front gratings which allow the selection of the desired range of wavelengths, or supermode, within the C-band. The remaining fine-tuning is performed using a rear grating.

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Microwave radio market to reach $9 billion in 2006

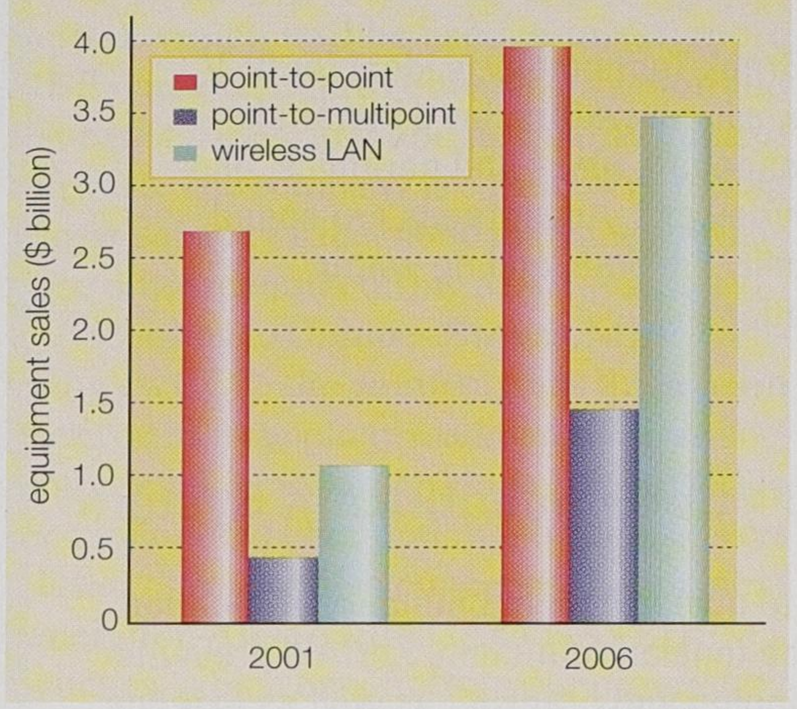
Worldwide purchases of microwave radios used in point-to-point, point-to-multipoint and wireless LAN applications declined slightly in 2001, to $4.3 billion, but are expected to grow to $9 billion by 2006, according to a recent report by Strategies Unlimited. The North American market was hit hard in the second half of 2001 by telecommunication capital spending reductions, although Asian markets have remained particularly strong.

The worldwide point-to-point radio market will reach $2.7 billion in 2001, a slight increase over 2000. By 2006, this market is expected to grow to over $4 billion as a result of robust growth in the cellular back-haul, wireless trunking and Internet access markets in Asia and Latin America.

The point-to-multipoint market, which includes MMDS, LMDS head-end systems and customer premise equipment, is expected to triple in the next five years, reaching $1.5 billion in 2006. For these systems, the European, Asian and Latin American markets remain strong. In North America, MMDS has seen a downturn recently, and LMDS has yet to take off. The current market for WLAN, access points and bridges is estimated at $1.1 billion, and will more than triple in size to $3.5 billion in five years, representing a CAGR of 26%.

"*Microwave Radio Market – 2001 to 2006*" is available from Strategies Unlimited – see www.strategies-u.com.

Microwave radios



More fiber to the home and curb

Homes served by FTTH and FTTC

	installations in 2001	*installations in 2006*	*cumulative total in 2006*
fiber-to-the-home (FTTH)	66 000	1.15 million	2.65 million
fiber-to-the-curb (FTTC)	130 000	260 000	1.9 million

A report from KMI predicts that fiber-to-the-home (FTTH) will reach 2.65 million homes in the United States by 2006, while another 1.9 million homes will be served by fiber-to-the-curb (FTTC) systems. Market demands and cost factors are expected to drive all or most of the regional Bell operating companies to begin FTTH deployment in new housing developments, then in network rebuilds. The FTTC market will grow at a slower rate as the cost difference between FTTH and FTTC narrows. FTTH market growth could be accelerated by applications that drive demand for bandwidth to bit rates greater than those provided by non-fiber-based technologies.

"*Residential Broadband Access in the United States: Fiber-to-the-Curb and Fiber-to-the-Home*" is available from KMI – see www.kmicorp.com.

The markets for wireless handsets and fiber-optic components are discussed in our Cover Story, beginning on page 27.

Market troubles delay tunable laser deployment

The market for tunable lasers, tunable filters and wavelength converters is expected to reach $1 billion by 2005 but remains stalled for the near term, according to a new study by Strategies Unlimited. In recent months, carriers have sharply reduced their capital spending on next-generation networking equipment, a situation that is tempering the advances currently being made in laser performance and in the lowering of manufacturing costs. Instead, tunable laser manufacturers will have to fine-tune their products to the particular economic and technical requirements of the carriers in order to succeed.

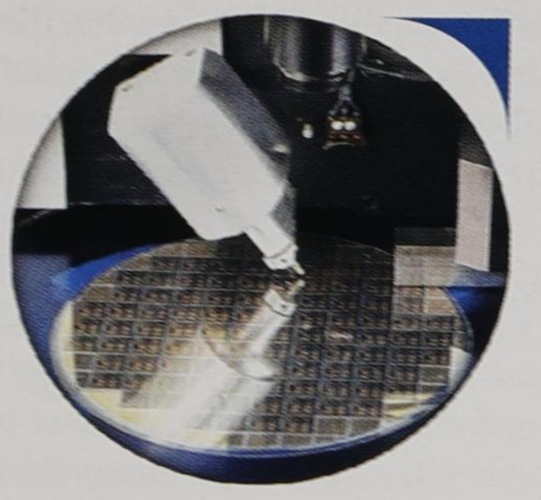
Tunable components offer considerable promise for cost savings and improved network performance. The advantages include a reduction in the inventory of spare line cards and in-process inventories, and a lowering of operating costs resulting from the use of 1:N channel protection schemes. Tunable lasers also provide dynamic provisioning with optical add–drop multiplexers, and wavelength conversion in photonic cross-connects and optical-packet switching. They can also be used to monitor optical channels.

While most devices are currently employed for test and measurement purposes, new applications are emerging. Start-up network suppliers such as Atoga Systems and Cinta Networks have introduced innovative new products based on tunable lasers, and mainstream network suppliers such as Fujitsu, Ciena and Alcatel have deployed equipment using narrowly tunable lasers. Among the vendors, unscheduled funding and retrenchment reflect the current malaise within prepublic ventures such as Bandwidth9 and Agility Communications, as well as established vendors such as Alcatel Optronics, Agere and Fujitsu. The report concludes that all companies, in particular the early-stage start-ups such as ChiLight Technologies, Fiberspace and Princeton Optronics, will require tight coordination of R&D, business development and production activities in order to succeed.

"*Tunable Lasers, Filters, and Wavelength Converters: Applications and Markets – 2001–2005*" is available from Strategies Unlimited – for further information see www.strategies-u.com.

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Strong demand for opto packages

Optoelectronic packaging

	2000	2005
standard packages	42%	39%
custom packages	58%	61%
total market	$407 million	$1.12 billion

ELECTRONICAST

New market figures from ElectroniCast reveal that the global consumption of optoelectronic and fiber-optic component packages will almost triple from $407 million in 2000 to $1.12 billion in 2005. Standard packages (e.g. TO can and butterfly) represented 42% of the 2000 market, while the proportion of custom packages employed is set to increase slightly by the end of the study period.

"The rapid growth of custom package consumption will be driven significantly by multi-fiber transceiver packages, with up to 256 fiber links, for VCSEL-based telecom transceivers," explained ElectroniCast founder and chairman Jeff Montgomery. "In addition, the continuing drive towards greater miniaturization and increased automated assembly and test will have a major impact on the package designs."

"*Optoelectronic Packages and Packaging Forecast*" is available from ElectroniCast – see www.electronicast.com.

Exchange sees 10x growth in net traffic

A recent report on the FT Market Watch Web site claims that Europe's largest Internet traffic exchange is planning for a ten-fold increase in traffic in the next 24 months. The London Internet Exchange (LINX), a not-for-profit organization that routes Internet messages to their destinations, said that the roll-out of broadband Internet access, increased use of the Web by businesses, and the emergence of new services such as video-on-demand, would all drive bandwidth demand. As part of its infrastructure expansion, LINX plans to install 10 Gigabit Ethernet technology. LINX's sales and marketing manger Vanessa Evans reported a surge in demand following a period of steady, linear growth. "We don't know how far through the bad times we are, but traffic has continued to grow and Internet service providers continue to report more and more demand for business," said Evans.

MBE Technology gets funding injection

MBE Technology, an epiwafer foundry based in Singapore, has received investment totaling S$20.5 million ($11 million). The funds were supplied by the company's management together with 3i, an international venture capital company, and EDBI, the investment arm of the Singapore Economic Development Board. 3i, EDBI and the management team now have a combined majority stake in the company, while the former owner retains a minority interest.

"The partnership and support offered by 3i and EDBI as shareholders adds significant strength to our business," commented LG Yeap, MBE Technology's founder and CEO. "MBE is consistently ranked ahead of the competition in terms of quality, on-time delivery and price competitiveness. We have a strong competitive advantage, particularly with our proprietary production techniques which increase yield, enhance quality and optimize equipment utilization."

Founded in 1993, MBE Technology manufactures GaAs epitaxial wafers, mainly PHEMTs and MESFETs, for wireless applications. The majority of the company's business is in the US, with customers including TriQuint, Alpha and Anadigics. MBE's second largest market is Taiwan, with WIN Semiconductors being a key customer. LG Yeap believes the company is well positioned to compete in the growing GaAs market in Asia.

The funding injection also included growth capital, which will be used to install more MBE reactors, improve characterization and test capabilities, and update quality control software. The company is currently installing a large-capacity Riber 6000 machine, and has three other manufacturing MBE systems.

According to Dhrubes Biswas, MBE Technology's CTO, the company has three main tracks on its technology roadmap. "We are currently developing carbon-doped InGaP HBTs for wireless and fiber-optic applications," says Biswas. "We are also concentrating on next generation AlGaAs/InGaAs/GaAs PHEMT switches, which benefit from our proprietary low temperature growth technology." This results in higher power handling capability and lower insertion losses. "The other key area will be the development of InP HBT and PHEMT epiwafers for 10 and 40 Gbit/s applications," says Biswas. "It's important to note that MBE Technology is focused on device aspects rather than purely on materials. We look at the devices our customers want, and work backwards to develop the appropriate epiwafers that meet the necessary device requirements."

- MBE Technology also announced the appointment of Donald J Capo as CEO North American Operations. This is effective from 1 January 2002.

New manufacturing facility for Lehighton

In September, Lehighton Electronics Inc (LEI) broke ground for a new 10 000 sq. ft manufacturing facility in Lehighton, PA, which is scheduled for completion in January 2002. LEI makes contactless test and characterization equipment, including bulk resistivity and sheet resistance measurement systems, and doping and CV profilers. The new facility will allow a ramp-up in production to twice the current level, as well as a reduction in delivery times. "The new site will give us maximum isolation from road vibration and stray RF and EMI noise," said Austin Blew, founder and president of LEI. "This is an opportunity to truly optimize the sensitivity of our instruments."

Implant companies set to join forces

Ion Implant Services and Implant Center have joined forces to form a major ion implantation supplier called Innovion. The new company, which has a combined implant experience of 40 years, has closed a financing round of over $21 million, providing operational liquidity and funds to complete its new facilities in Gresham, OR and Phoenix, AZ.

Innovion's vice-chairman, Wesley Weisenberger, said, "Innovion is committed to building worldwide regional centers of excellence to deliver such cost-effective implant technology, without impacting customers IP or control issues."

In brief...

Name change for Karl Suss

Karl Suss (Munich, Germany) has adopted the name of its German holding company, Suss MicroTec. The company says that the change reflects its position as a global supplier of processing equipment for large-scale production.

Aixtron expands in Taiwan

Aixtron will open a new subsidiary in the Science-Based Industrial Park in Hsin-chu, Taiwan at the beginning of next year. The company will undertake research and development with its Taiwanese partners in industry and academia, which is a list that contains around 20 companies including UEC, Epistar, Arima, VPEC and Procomp, in addition to Kingmax and Kopin Taiwan.

In related news, ITRI/OES and Aixtron Taiwan have allied to promote co-operation in the Taiwanese compound semiconductor industry. The campaign includes an Industrial Affiliation Program and other programs that offer industrial or scientific partners in the region benefits from MOCVD technology and R&D.

Palladium purifier deal

Matheson Tri-Gas has signed an agreement with Power+Energy which will enable it to become a second manufacturing and distribution source of hydrogen purifiers. Power+Energy's PerfectH2 palladium membrane purifiers deliver the hydrogen typically employed as a carrier gas for metalorganics used in the manufacture of compound semiconductor devices.

Metalorganics for GaInAsN

Aixtron and Mochem have expanded their co-development program for liquid MOCVD precursors to include nitrogen-containing materials such as dimethyl hydrazine. This is used to grow dilute nitrides such as GaInAsN. Mochem recently qualified its liquid group V As and P precursors for use in Aixtron's reactors. A qualification program is currently running in Mochem's application laboratories at the University of Marburg in Germany, and at Aixtron's headquarters in Aachen.

Brooks and PRI combine to form new factory automation giant

Brooks Automation has signed an agreement to acquire PRI Automation in a stock deal worth around $380 million. The new company will be called Brooks-PRI Automation and aims to be a leading supplier of automation systems, software and services with combined 2001 sales of $700 million. On completion of the transaction in the first quarter of 2002, the combined enterprise will be headquartered in Chelmsford, MA.

Compound semiconductor device manufacturers form a small but growing segment of the group's customer base. "The compound semiconductor industry is by its nature less mature and less automated than the silicon industry," said Brook's VP of marketing, Mike Biasi. "For example, the market for automated materials handling almost doesn't exist in this segment, because the fabs are much smaller. But while this area forms a smaller part of our combined businesses, there is a market for computer software to control manufacturing processes. Eventually, when the industry reaches the same economy of scale as the silicon business, we will see a lot of growth."

The combined Brooks and PRI group manufactures vacuum and atmospheric robots, cluster tool platforms and modules, and ultra-clean mini-environments for isolating processing equipment and wafers. Brooks-PRI Automation is also intending to make factory and tool automation software and integration services, in addition to computer-integrated manufacturing systems.



PRI AUTOMATION

Brooks-PRI Automation intends to become a major supplier of factory automation software and equipment, including this wafer transport system.

InPact plans major growth program

InPact, a French manufacturer of InP substrates, is planning an aggressive growth program to expand its output and to introduce 4 inch wafers. During 2001, the company's factory in Penchiney was expanded to increase InPact's production capacity for 2 inch InP wafers; the cleanroom size was tripled and the number of pullers doubled. InPact has also installed a 4 inch pilot line and plans to ship samples by the end of the year. Volume production is expected by the third quarter of 2002, and manufacturing will be carried out at a second fab being built in Montmelian, near Grenoble, France. InPact claims to have 10% of the InP substrate market, behind Sumitomo, AXT and Nikko Materials. Two-thirds of InPact's customers are in the US, with 20% in Europe and the rest in Asia.

JMAR receives X-ray contracts

JMAR/JSAL NanoLithography, a division of JMAR Technologies based in Burlington, VT, has received a $1.2 million contract from a major New England-based aerospace firm to provide X-ray lithography (XRL) support services. JSAL will collaborate with the University of Vermont on device development using point source XRL, and the company intends to improve the wafer throughput of its current stepper model by automating certain alignment functions. In a second contract, JMAR/SAL has joined Mitsubishi Electric and four universities to further develop XRL. As part of this program, the company has received $1.7 million from the University of Wisconsin to upgrade one of its XRL steppers into a Model 5C stepper capable of sub-50 nm circuits.

In further news, JSAL has been awarded a US patent for a method of improving sub-100 nm X-ray lithography techniques for use in the manufacture of high-frequency devices.

Equipment sales

- **Sterling Semiconductor** has purchased a SiC reactor from **Epigress**, which will be installed in the Uniroyal facility in Tampa, Florida. The new order is for a VP508 GFR hot-wall CVD system, which is designed to expand Sterling's epitaxial capacity for R&D and pre-production qualification purposes. The reactor provides a flexible platform with the capacity for 3 × 2 inch to single 3 and 4 inch wafers.

- **Nova Crystals** has purchased a Nexus ion-beam etch system from **Veeco Instruments**. The new system will be delivered to Nova's facility in San Jose, CA, in the final quarter of the year, and will be used in the production of 1310 nm surface-emitting lasers.

- **Thales** (formerly Thomson-CSF) has ordered an **Aixtron** production reactor to add to its smaller capacity InP/GaInAsP and GaN reactors. The AIX2400/2600G3 will be used for the growth of various HBT structures on 4 inch substrates.

- **ThetaDelta Technologies** (Lawrence, MA) has shipped thermal conditioning systems and reliability testing equipment to two manufacturers of GaAs circuits located in South Korea. The first will be installed at **Knowledge*on**, a GaAs manufacturer and foundry service, while the second is to be employed in the research facility of another major Korean GaAs device supplier.

- **Okmetic** has ordered an **Epigress** VP508 SiC hot-wall CVD reactor. The system features Aixtron's gas foil rotation technology and accommodates either 3 × 2 inch or single 3 and 4 inch wafers. Okmetic has also ordered the first VP508HT production system from Epigress. This SiC crystal growth reactor is based on a high-temperature CVD process, and will be used for doped and semi-insulating SiC substrate production.

- **Tegal** has received an order for a plasma etch system from a leading manufacturer of LEDs. The i901 tool will be used to etch GaAs and silicon wafers for the production of LEDs at the customer's facility in Germany.

Oxford Applied Research, a UK supplier of atom and ion sources, e-beam evaporators and gas crackers, has appointed **Steven Rothstein** and **James Vance** to tackle sales in support of the company's new US subsidiary in Newark, NJ.

BOC Edwards has appointed **George Courville** to the new position of global VP of its compound semiconductor business. Until recently Courville was VP of marketing for the company's semiconductor business group. BOC Edwards previously announced its intention to support a growth initiative for the fiber-optic market, and the new role complements that endeavor. Also BOC subsidiary **Temescal** has signed **John Freeman** to represent its interests in northern California.

Palomar Technologies, a manufacturer of optoelectronic and RF wireless component assembly systems, has promoted **Kevin Conlon** to president. Since joining the company in 1997, Conlon has held the positions of VP of sales and marketing and COO.

Unaxis Semiconductors has appointed **Ralf Kuhlmann** to the new position of international sales and marketing manager based in Truebbach, Switzerland.

Doug Doty has joined **Cutting Edge Optronics,** a TRW company that manufactures high-power lasers, as its quality manager.

Steffen Koehler has joined tunable laser manufacturer **Sparkolor** as VP of marketing. Koehler is a former employee of both Ciena and Kymata.

InP component manufacturing start-up **Qusion Technologies** has added Emcore's CEO **Rueben Richards** to its board of directors. The company has also hired **Timothy Brophy**, former director of photonic technology at Motorola as its new VP of product development.

Princeton Lightwave has appointed **Didier Le Lannic** as president and CEO.

Bandwidth9 has appointed **Paul Murphy** VP of its Manufacturing Components division. The former National Semiconductor employee will oversee the volume manufacturing of tunable lasers.

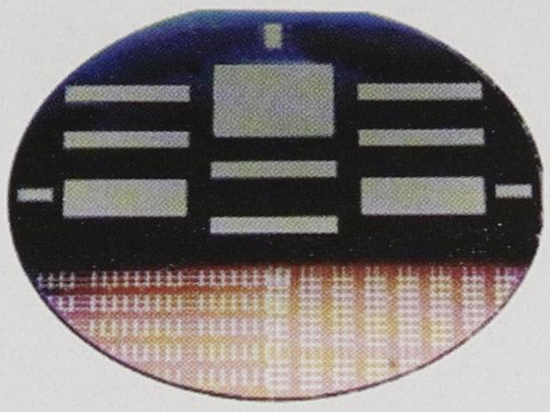
Nova Crystals has appointed **Mike Bottini** its new VP of product operations. He will oversee the production and delivery of long-wavelength VCSELs.

William Slakey has joined GaAs IC manufacturer **WJ Communications** as its new chief financial officer.

Bookham Technology has enlisted **Steve Turley**, formerly with Nortel, as chief commercial officer.

Dan Paulson has joined **Signal Technology Corporation** as VP of mobile appliance sales and marketing.

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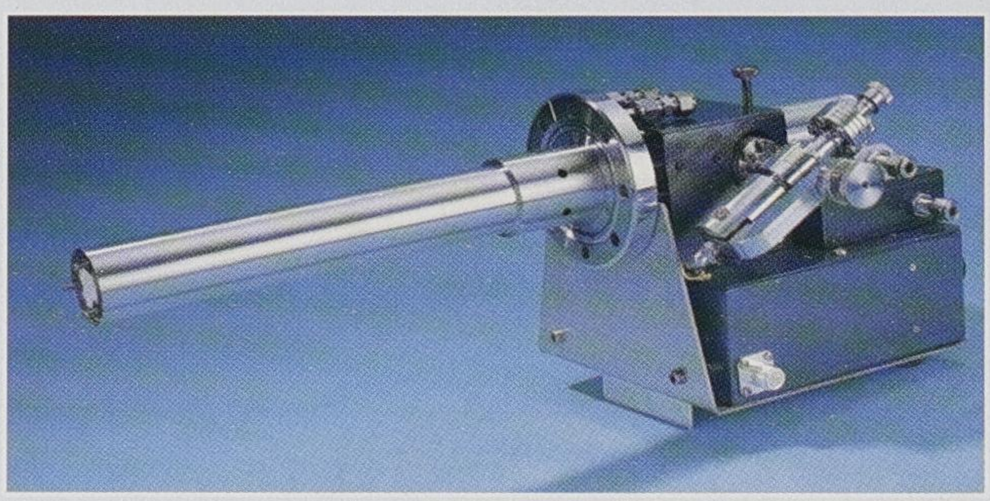
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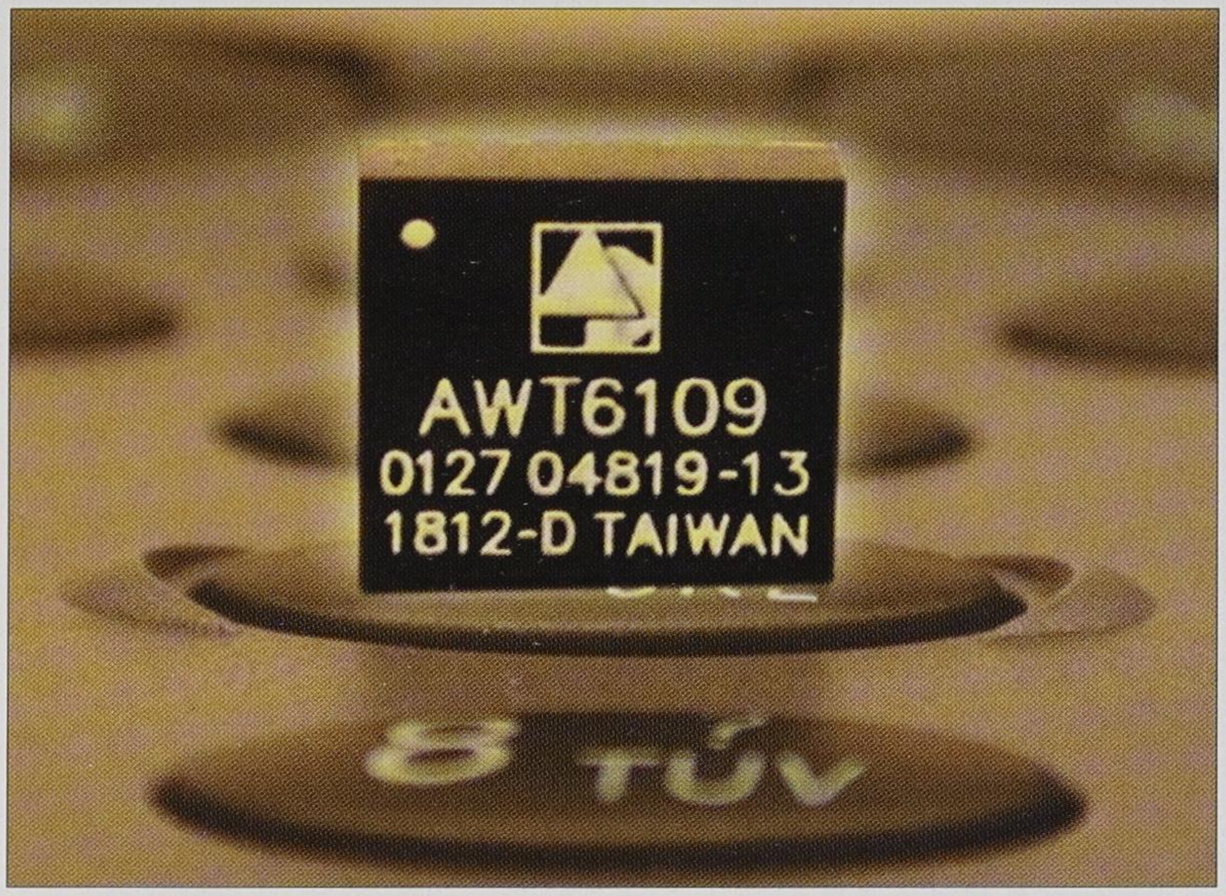
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InGaP PA module from Anadigics

Warren, NJ Anadigics is targeting the Korean PCS CDMA handset market with its new InGaP HBT PA module. The AWT6109 operates from a 3.5 V supply and is compliant with both IS95/98 and 1XRTT system specifications.

The maximum power output is achieved for a quiescent bias current of 65 mA. The module also features a fixed bias mode, which eliminates the need for switching between low and high output power levels.

Currently sampling, the device offers an adjacent channel power rejection performance of –53 dBc and 35% power added efficiency. The module is packaged in a 6×6 mm^2 low profile housing, which has 50 ohm input and output matching.

www.anadigics.com

25–32 GHz MMIC for radio links

Orsay, France United Monolithic Semiconductors (UMS) has recently released a 25–32 GHz MMIC that has been designed to integrate a local oscillator (LO) buffer amplifier and sub-harmonically balanced diode mixer. Manufactured using the company's GaAs PH25 process, the CHM1291 has been designed for point-to-point radios and LMDS applications, and is suitable for both up- and down-conversion.

In the LO frequency range, which covers 12–15.5 GHz, the device provides an input power of +5 dBm. The conversion loss is 11 dB and the balanced mixer offers an image rejection of 15 dBc, while the buffer supplies 2 × LO to RF leakage, which is equivalent to –35 dBm for a +5 dBm LO input level. Typically the IP3 value is set at +13 dBm, which is achieved using a bias of 3.5 V while consuming 55 mA of power.

www.ums-gaas.com

Conexant shrinks the size of its PAs

Newport Beach, CA Conexant's new family of InGaP HBT PA modules, designated the CX77105, CX77106 and CX77107, support IS95/CDMA2000 1×EV operations, as well as AMPS, Korean PCS and US PCS, respectively. Each device is offered in a 10-pin 4×4 mm^2 package, which the company claims is half the size of comparable 50 ohm matched CDMA modules.

Conexant's modules meet linearity requirements up to 28 dBm output power, and can be driven beyond 31 dBm for high efficiency FM mode operation. A low current digital pin provides improved efficiency for the low RF power range of operation. The



new amplifiers are currently sampling, with volume production slated for the first quarter of 2002.

www.conexant.com

OPTO PRODUCTS

Fitel's DFB laser hits the 40 mW mark

Clinton, NJ Fitel Technologies, a subsidiary of Furukawa Electric, has announced the release of a 40 mW continuous-wave DFB laser designed for long distance signal transmission in DWDM systems. The new module is currently among the highest power commercially available DFBs operating in CW mode.

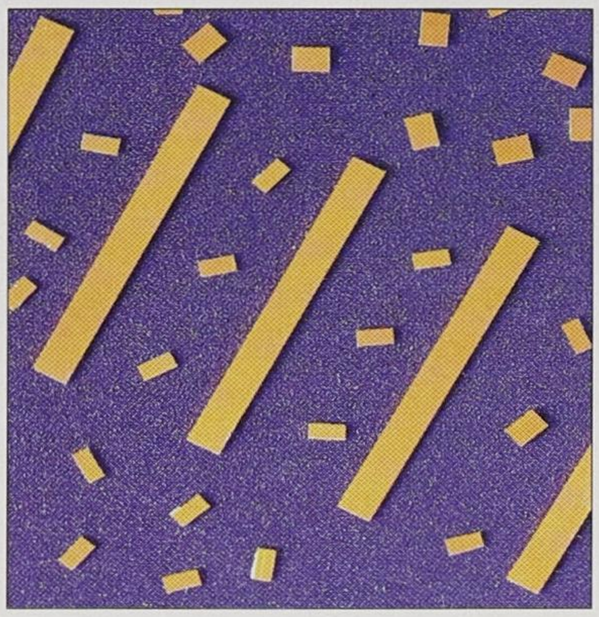
The laser is available in production quantities, and can be combined with a $LiNbO_3$ modulator and wavelength division multiplexer to enable low chirp and long-distance high-capacity transmission.

Manufactured by Furukawa at its Japanese production facility in Chiba, the module has a drive current of less than 200 mA and side-mode suppression ration of 40 dB. A range of wavelengths is available covering 1500 to 1625 nm in support of high channel counts and L- and S-band transmission.

www.fiteltech.com

High power laser bars reach 100 W

Santa Clara, CA Coherent Semiconductor Division has released a new series of high power unmounted diode laser bars. With emission in the 900 nm wavelength range, the new lasers operate in quasi-CW mode and consist of 90% fill-factor and 100 W peak output power. Target applications for the bars include solid-state laser pumping applications, as well as direct-diode illumination markets.



Housed using packaging technology provided by the Lawrence Livermore National Laboratory, the bars deliver their peak power at 900 nm using a drive current of 115 A.

The pulse width is 1 ms at a duty cycle of 1%. The power conversion efficiency is 45%, while the spectral width is less than 3 nm FWHM. The beam divergence is rated at less than 35° by 10° FWHM.

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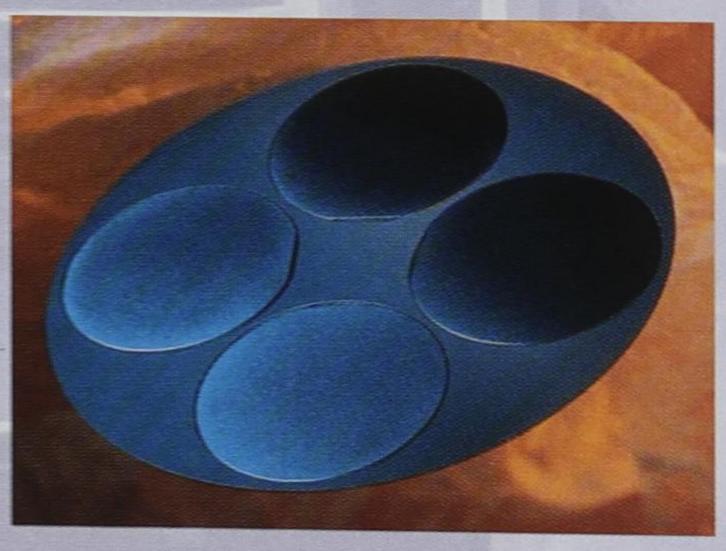
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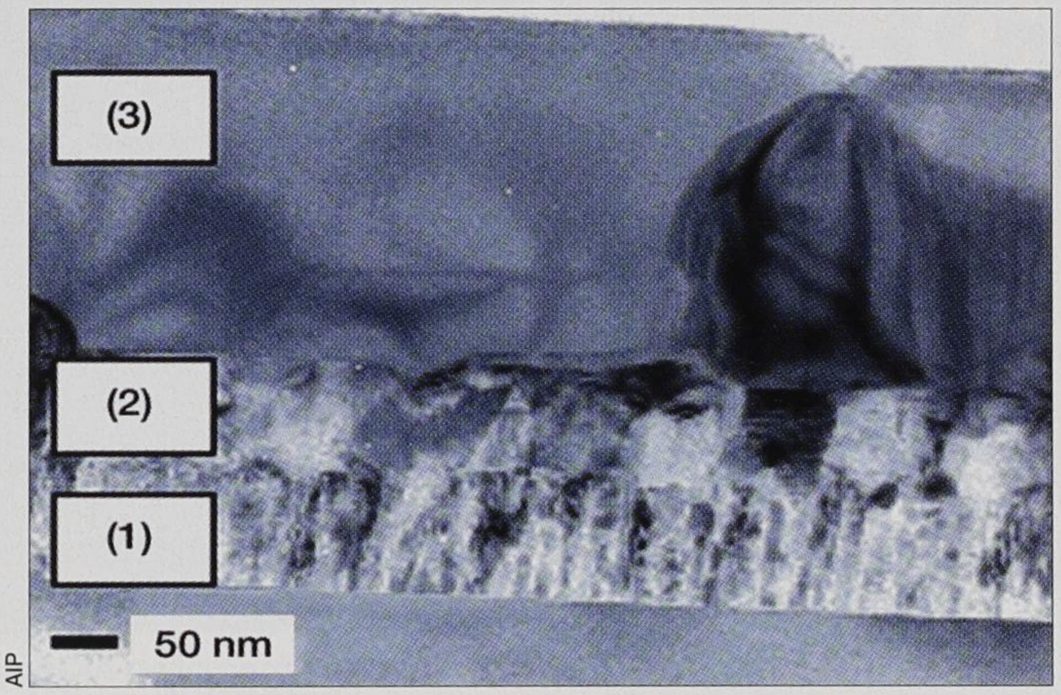
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Low-cost crack-free GaN films grown on silicon (100) substrates

Given the large diameter and low cost of silicon substrates compared to SiC or sapphire substrates, there has been great interest in growing GaN-on-Si to reduce the cost of high power, high frequency electronic devices, LEDs, lasers and photodetectors. To date, hexagonal GaN layers have been successfully deposited on Si (111) substrates by both MOCVD and MBE as a result of the hexagonal template offered by the Si (111) substrate. However, for the monolithic integration of GaN and Si devices, the Si (100) substrate is preferred as it is the most widely used in mainstream silicon technology.



Cross-sectional TEM image of GaN-on-Si showing the 0.1 μm sputtered AlN (1), 0.1 μm MOCVD-grown AlN (2), and final 0.4 μm GaN layers (3). The resulting hexagonal films can be grown to a thickness of 2 μm with no cracking.

Generally, a mixture of cubic and hexagonal GaN grows on Si (100) substrates, with the cubic poly-type being the dominant phase. J Wan and colleagues from Purdue University (*App. Phys. Lett.* 2001 **79(10)** 1459) have reported the growth of purely hexagonal GaN templates on Si (100) substrates using magnetron sputtering to deposit a buffer layer of AlN followed by another MOCVD-grown AlN buffer layer.

The sputtered first buffer layer was deposited on samples with a substrate temperature of 500°C. The second buffer layer was deposited by MOCVD at a growth temperature of 1150°C. This produced AlN films with a structure composed of hexagonal columns containing a preferred orientation along the *c* axis, but with a random in-plane twist. The sputter deposited layer maintains the hexagonal structure, providing a good template for further AlN and GaN growth on Si (100) substrates.

The authors noted that the column orientation of the GaN layer is affected by the thickness of both the sputtered AlN layer and the MOCVD AlN layer. TEM studies showed that thick layers of both types eliminated cracking of the GaN layers up to a thickness of at least 2 μm.

Impressive power density from AlGaN/GaN-on-silicon HEMTs

A collaboration between Aixtron and the Institute for Thin Films and Interfaces, Germany, has yielded impressive performance data for AlGaN/GaN HEMTs grown onto silicon substrates (*Elec. Lett.* 2001 **37(22)** 1364). An unspecified buffer layer was used between the silicon and GaN to achieve crack-free layers with high-quality surfaces. Under static conditions, the drain saturation current at a gate voltage of +1 V was 0.82 A/mm, a figure comparable to that of AlGaN/GaN HEMTs grown on SiC. A high drain saturation current was measured out to a drain-source voltage of 20 V, indicating that the devices could handle static heat dissipation up to 16 W/mm. This is promising for the future application of AlGaN/GaN-on-Si HEMTs in high-power electronics.

Green emission from thin CdS films by two-photon excitation

A 2.45 eV bandgap makes CdS a candidate for green light emitting devices. However, photoluminescence (PL) from CdS via the Stokes process, excited using photons with energies above the bandgap, has strong contributions from the red portion of the visible spectrum. B Ullrich and R Schroeder from Bowling Green State University, OH, achieved green PL from thin CdS films without visible red emission using two-photon excitation, an anti-Stokes process, with 200 fs laser pulses at 1.54 eV (*J. Quantum Electron.* 2001 **37** 1363). This shows that whilst material quality is important in emitted wavelength and intensity, the excitation method also impacts the PL spectra. The researchers hope this will open up new directions for light emitting device engineering.

Bremen team produces ZnSe-based 560 nm lasers

A team from the University of Bremen, Germany, has developed what are believed to be the first semiconductor laser diodes to emit at 560 nm (*Appl. Phys. Lett.* 2001 **79(16)** 2523). This is an important wavelength as it corresponds to the attenuation minima for polymethyl methacrylate plastic optical fibers. The ZnSe-based laser structures are grown by MBE onto GaAs substrates. A MgZnSSe layer that closely lattice matches to GaAs is used as a lower cladding layer between the GaAs and 4 nm CdZnSSe QW active layer. By carefully optimizing growth conditions, high Cd content QWs could be grown onto the cladding layer. An upper MgZnSSe cladding layer is grown onto the QW and a ZnSe/ZnTe multiple QW serves as a p-side contact layer.

Under pulsed conditions, the lasing threshold was 68 mA at 6 V, external quantum efficiency was 69% and maximum light output per pulse was 150 mW. Under CW operation, the laser lifetime was only 1 minute. Although this is short, the research team's Matthias Klude is confident that lifetime, operating voltage and threshold current can be improved. "These devices are made in the most rudimentary way. To be honest we were surprised to see them operating. Improvements would come from facet coating, top-down mounting and ridge waveguide processing," Klude told our sister publication *Opto & Laser Europe* magazine.

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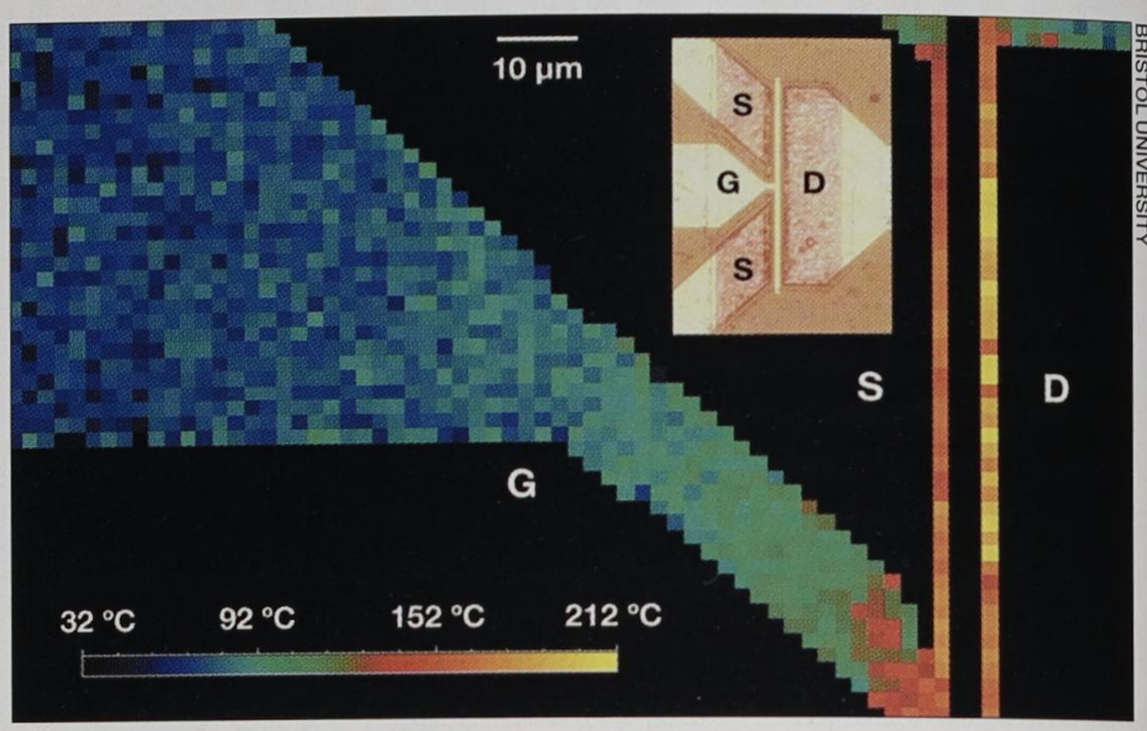
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Temperature mapping reveals hot spots



BRISTOL UNIVERSITY

Temperature map of an AlGaN/GaN FET on sapphire recorded at I_{DS} = 32.5 mA and V_{DS} = 20 V. Lateral resolution is 2 µm. Half of the device is shown, with the full device layout shown in the inset.

The performance of high-power, high-frequency AlGaN/GaN HFETs is limited by self-heating effects. The use of high thermal conductivity substrates and flip-chip bonding has improved power management and helped achieve power densities of over 10 W/mm for X-band operation. Knowledge of the temperature distribution in the active area of AlGaN/GaN HFETs would enable the optimization of device design and improve reliability and performance. The infrared techniques often employed to measure the temperature of an active device require extensive calibration and have limited spatial resolution when compared with the micron-size source-drain opening in high-power AlGaN/GaN HFETs.

In work to be published in *Electron Device Letters* in January 2002, M Kuball *et al.* from Bristol University and QinetiQ, UK, have reported using micro-Raman spectroscopy to measure changes in the phonon frequency of GaN with temperature. This can be done on active devices with around 1 µm spatial resolution and better than 10 °C temperature accuracy. The devices were scanned in 0.2–2 µm steps using a computer-controlled XY-stage to obtain temperature maps. A temperature map obtained by micro-Raman mapping of an AlGaN/GaN HFET on sapphire is shown in the figure above. The device was operated at a drain bias voltage of 20 V (I_{DS} = 32.5 mA), corresponding to a power dissipation of 0.65 W. A maximum temperature of about 180 °C is visible in the source-drain opening, where heat is generated in a line source next to the gate contact.

To improve the method's accuracy, phonon frequencies measured at zero bias were subtracted from those measured on active devices. This removes the effects on the measurement of scattered laser light leaving at oblique angles near the contacts. 3D thermal simulation of the structure gave good agreement with the measured temperature map. Temperature mapping was also demonstrated for AlGaN/GaN HFETs grown on SiC substrates. Whilst power dissipation was higher at 1.75 W, the device temperature was lower due to the high thermal conductivity of SiC. This allowed more efficient heat extraction through the substrate and a factor of five difference was seen in thermal resistance between devices on SiC and sapphire. At a drain-source voltage of 2 V, the maximum temperature measured for an HFET on SiC was 120 °C.

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Cautious optimism for 2002 mobile-phone market rebound

The inventory problem seems to have been solved, but will new technologies and applications provide the key to resuming growth in 2002? **Marie Meyer** reports.

Executives at the companies that make mobile phones or components used in phones no doubt indulge in the occasional daydream wherein there is a huge buying frenzy this Christmas that instantly solves all the industry's excess inventory and overcapacity problems.

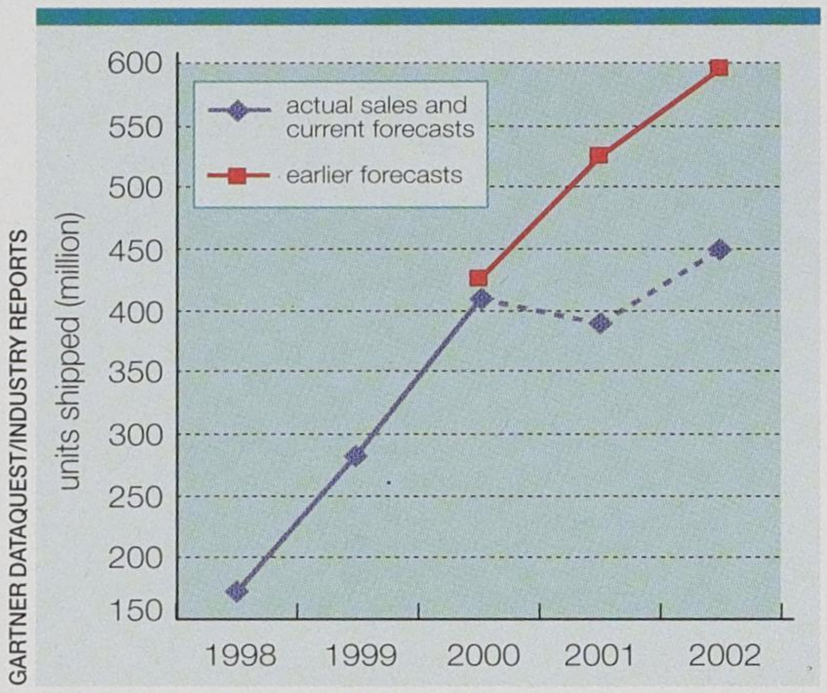
Barring this result, there are four major issues in the mobile-handset market as we move into 2002. How many units are being sold? Who will the top manufacturers be? When will the manufacturers start buying RF components again? And what is the outlook for the much-discussed new technologies and services?

Unit demand

The outlook for mobile-handset sales in 2002 remains remarkably uncertain. In fact, with just one month to go, top analysts are still unsure of the number of units that will be shipped this year.

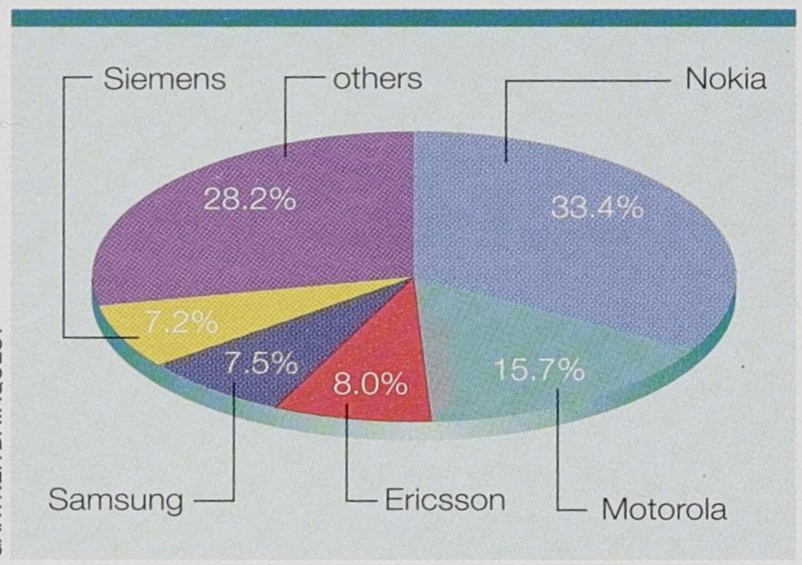
Nokia executives recently predicted a big fourth-quarter rally that would push industry-wide sales up 17.5% over the third quarter. If so, worldwide shipments for 2001 would total 390 million units. This represents a decrease of 6% compared with 2000, and is also a huge climb down from the original forecasts for 2001 that looked for shipments of more than 500 million units (figure 1).

Even achieving the lowered mark will require some help from Christmas shoppers – for example, Nokia is looking to increase its fourth-quarter sales by 25% over the third quarter. Statements made by Nokia CEO Jorma Ollila at the COMDEX meeting in mid-November indicated that company performance was on track, and management was therefore standing by its prediction. Nevertheless, there are also many analysts who say



GARTNER DATAQUEST/INDUSTRY REPORTS

Fig. 1. Current forecasts for handset shipments are considerably more conservative than those issued in 2000.



GARTNER DATAQUEST

Fig. 2. Market shares for the major mobile-phone makers for the third quarter of 2001.

that Nokia's outlook is simply too aggressive.

Among the critics is Sofia Ghachem of UBS Warburg, who is predicting that Nokia will at best increase its sales by 18%. "Given the negative data points coming from Europe with respect to slowing subscriber growth and replacement demand, in conjunction with an uncertain outlook for the US and China, we believe this to be a more prudent position at this time," she said. Analysts from Bear Stearns Equity Research have expressed concern that while Nokia might meet its targets for shipments, the "sell-through" to consumers at the retail level may not keep pace. This scenario raises the unpleasant prospect of a repeat of 2001, when the industry entered the new year with a backlog of many millions of unsold units in the pipeline. While many commentators are suggesting 450 million units as a target for 2002 sales, it is unlikely that any firm predictions will be made before the results for the December quarter are fully understood.

Market share

Nokia remains the number one supplier of handsets by a healthy margin. The most recent data, covering handset sales in the third quarter of 2001, shows that Nokia controls 33.4% of the market, followed by Motorola with 15.7%.

The relative positions of the five companies shown in figure 2 will be watched with great interest in 2002. For component manufacturers it is almost as important a question as the total number of units shipped, because most of the suppliers are strongly identified with just one or two of the major manufacturers – for example, RF MicroDevices and Nokia, Alpha Industries and Motorola.

Some analysts believe that Nokia has revealed some weakness this year. "Nokia, for the first time, has one of the older product portfolios among leading manufacturers," says Bryan Prohm, a senior analyst with Gartner Dataquest. He believes that Nokia has lost some GSM market share to competitors with more "contemporary" designs.

While Nokia's market share has slipped a few points each quarter this year, Motorola's

has increased by one point per quarter. Gartner Dataquest analysts say that Motorola's resurgence is no longer limited to a few products or just North America – rather it has become a global phenomenon, encompassing all of the major air interfaces.

Ericsson's traditional position as the number three supplier has been challenged this year by both Siemens and Samsung, the latter being widely considered as a "rising star" on the strength of its CDMA business. But Prohm expects Ericsson to fight back. "Ericsson has introduced a range of novel handsets, many of which have received positive reviews and seem eagerly anticipated by consumers," he said. Prohm also believes that the launch of the Sony–Ericsson mobile communications joint venture in the fourth quarter of 2001 will generate the momentum needed to propel Ericsson "back into double-digit market share and firmly into the coveted third-place position worldwide".

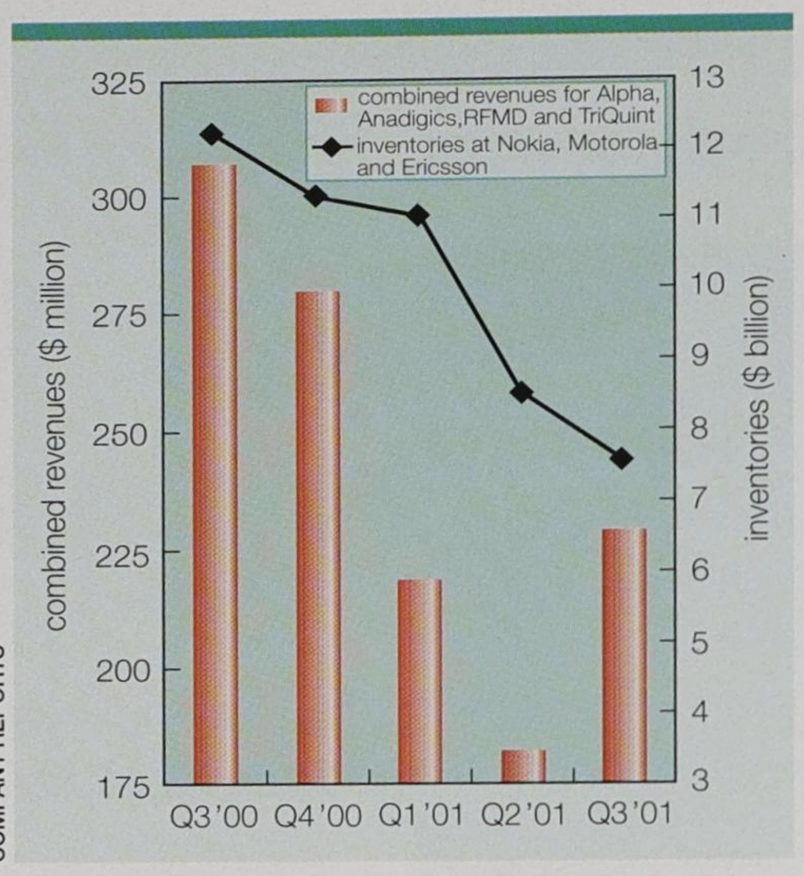
Inventories

When the handset manufacturers sneezed in 2001, the component suppliers caught pneumonia. The decline in RFIC shipments was much sharper than the drop-off in cellphone shipments, because the handset manufacturers were sitting on large stockpiles of parts that needed to be consumed or written off before new buying could begin.

The relationship between inventories at the three largest cellphone manufacturers and the revenues of four of the top suppliers of GaAs RFICs is shown in figure 3. After several months of belt tightening, inventories dipped below $3 billion for each phone manufacturer in the second quarter, which led to shipments of RFICs picking up sharply in the following quarter. This, ultimately, is what lies behind the oft-repeated message that the bottom has been reached in the RFIC market. RFMD saw its sales increase 40% between the second and third quarter; Anadigics is predicting that its wireless sales might increase by as much as 80% in the December quarter. Of course, whether or not these trends can be turned into profits is another story, as all of the fabs are suffering from expensive overcapacity problems (see Portfolio, p59).

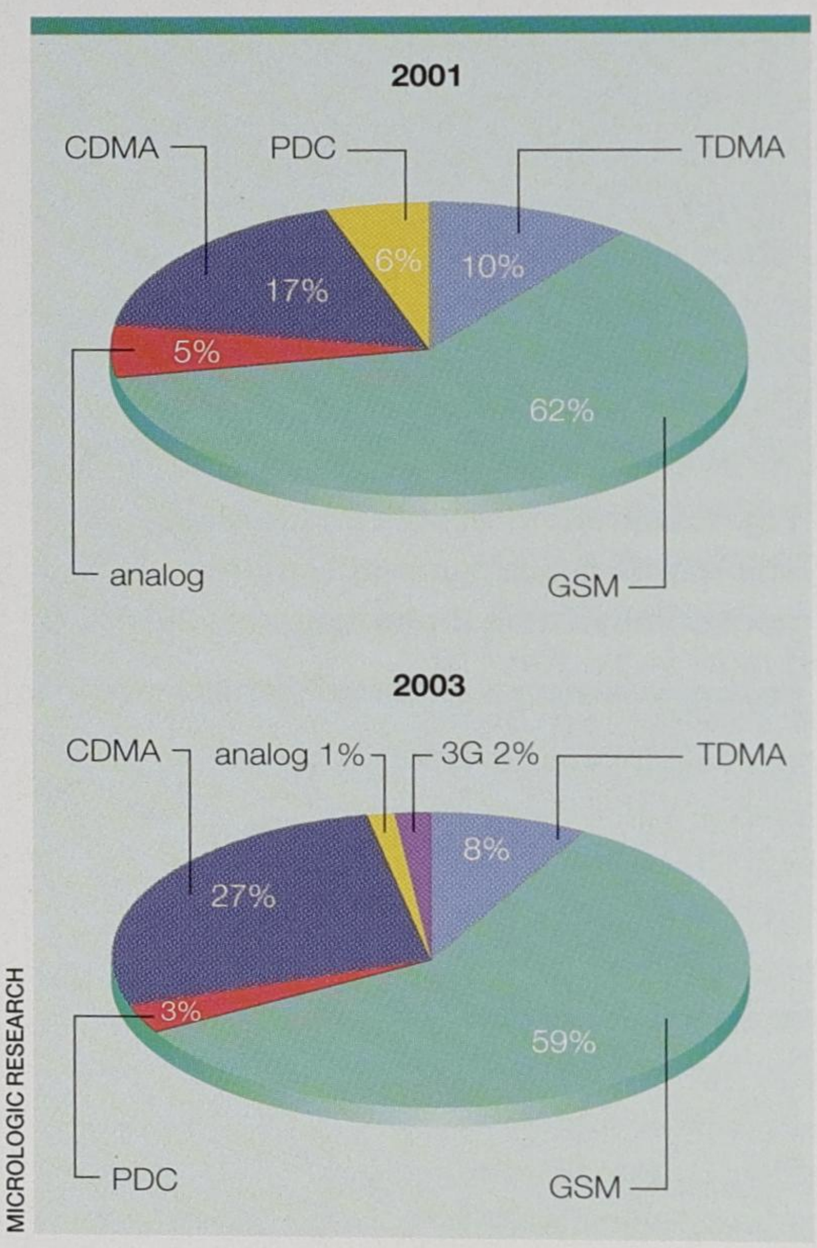
Technologies

Many of the hopes for the future of the mobile-handset industry are being pinned on the new technologies that are intended to revitalize consumer interest. Unfortunately, it has yet to be seen whether consumers really are interested in these new features and services. While it all looks good on paper, there is a distinct possibility that the entire movement to 3G phones is being moved along too fast by the higher-end phone manufacturers who see it as their best defense against a loss of market share to manufacturers of low-end generic handsets.



COMPANY REPORTS

Fig. 3. The reduction of inventories at the major cellphone manufacturers was a prerequisite for the resumption of growth in the RFIC market.



MICROLOGIC RESEARCH

Fig. 4. A comparison of the projected market share for the major air-interface standards in 2001 and 2003.

Few new phones were launched in 2001 because the manufacturers simply couldn't afford it. Instead, the emphasis was on improving the profit margins on existing models. It is no accident that Nokia's aging product line is the most profitable in the industry.

So does this mean that the formerly exciting cellphone market might turn dreary, like the PC market? Analysts say it depends on the ability of phone manufactures and network operators to develop new applications that appeal to consumers. "We need new applications," says Jeffrey Sclesinger of UBS Warburg. "GPRS is a technology, but people don't buy technology, they buy applications."

Several US carriers are rolling out enhanced services, while in Europe carriers have finally received shipments of Nokia GPRS phones and have begun to pitch "2.5G" services. The latter is an interesting opportunity to judge consumer sentiment, given the extremely high penetration rates of the older technologies throughout the continent. If the Europeans start buying phones again, it is a sure sign that the market is being driven by the new technologies, as there are no untapped pockets of first-time subscribers to be found.

Asian carriers are serving as the test-bed for 3G phones and services, and are currently busy working out the kinks in the system. DoCoMo launched the world's first fully-operational 3G service in Japan in October, with handsets supplied by Matsushita and NEC. Nokia announced in November that it would deliver 3G phones in Europe in the third quarter of 2002, with volume production to begin in 2003. Kyocera is the first company sampling 3G handsets among North American wireless carriers.

3G may prove to be the best opportunity for the Japanese manufacturers to fight their way back into the handset market. Nokia is believed to be the only non-Japanese company that is capable of delivering 3G units without an alliance with another manufacturer.

The whole 3G field is dogged by question marks and uncertainties, and is so far making only a token appearance in the forecasts for market share by air-interface standards (see figure 4). However, London's *Financial Times* quotes Chris Gent, CEO of the world's leading mobile operator, Vodafone, as saying that he was sticking to his commitment for a formal launch of 3G services in the second half of the next calendar year. However, a shortage of handsets, Gent cautioned, could delay the widespread availability of 3G services until mid-2003.



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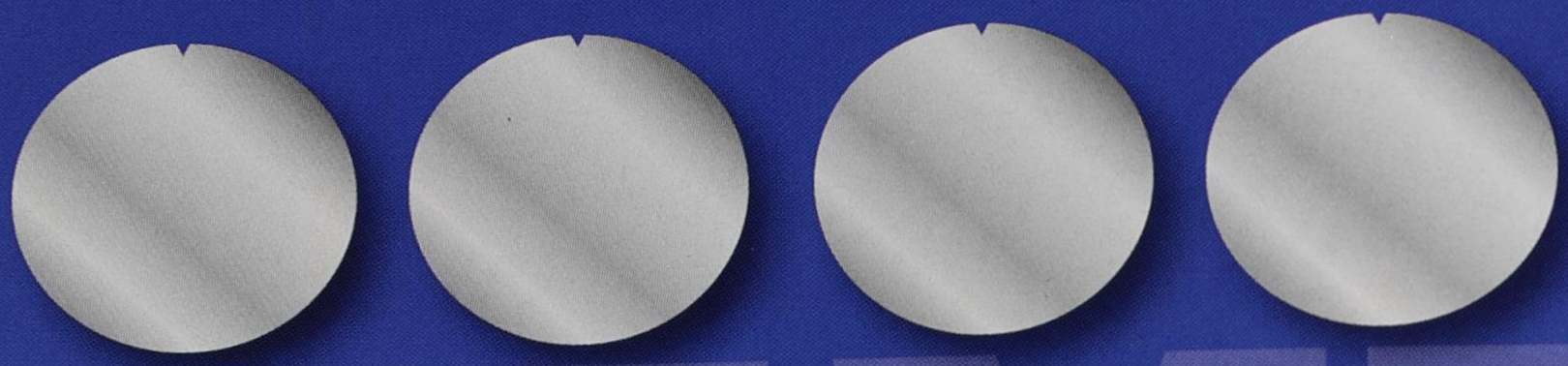
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Automation and integration will aid component recovery

Automation, outsourcing and integration are all key areas for fiber-optic component manufacturers as they struggle to cope with the current market slump, writes **Tim Whitaker.**

Optical component funding during 2001

Quarter	*Company*	*Amount ($ million)*	*Products*
Q1	nLight Photonics	44.0	pump laser modules
	VSK Photonics	18.0	40 Gbit/s InP components
	Qusion Technologies	9.3	integrated InP components
Q2	Multiplex	105.0	transmitters, transponders, EMLs and pump lasers
	Intense Photonics	11.0	planar waveguides
	Comlase AB	3.5	pump laser chips and modules
Q3	Agility Communications	83.0	tunable lasers
	Princeton Optronics	25.0	tunable lasers
	Applied Optoelectronics	10.0	tunable VCSELs
Q4	ThreeFive Photonics	6.4	integrated InP components
	Lytek	3.8	long-wavelength VCSELs

Despite the bleak fiber-optic market, component makers continued to win investment funding during 2001. A solid business plan is vital for a start-up looking for venture capital.

The market for fiber-optic components was badly hit during 2001. After several years of very rapid growth the bubble burst. According to RHK's John Lively, the overall market for optical components in fiber-optic networks fell by 30–35% in 2001 to $4.63 billion, compared with $6.85 billion in 2000 (see p35). The reason is relatively straightforward, although it wasn't obvious enough for anyone to predict it. During 1999 and 2000, carriers built fiber-optic networks at an unsustainable rate. In the first part of 2001, when reality hit home, carriers massively reduced their spending, and equipment orders dried up. At the same time, equipment vendors decided to burn through their component inventory, which had become excessive during the period of over-inflated growth.

It appears that most of this excess inventory has now been used or rendered obsolete. "Excess inventory has mostly been burnt off," says Jeff Montgomery, chairman and founder of ElectroniCast, "so a renewed flow of components is required to maintain even a depressed level of equipment production." Even so, recovery will be gradual and the bottom may not yet have been reached.

Many companies have had to reassess their strategies. In particular, component makers are addressing areas such as automation, integration and outsourcing to streamline their manufacturing. According to Dan DiLeo, executive VP of the Optoelectronics division of Agere, the demand for optoelectronic devices for optical networks is still growing, and this technology will only flourish if the costs are not a barrier to implementation. "The solution is to continue with innovation, automation and integration at both the module and the optoelectronic IC levels."

All set for recovery?

Despite the industry's troubles, there is still an underlying demand for bandwidth. "The Internet has continued to grow very significantly, even in the last 10 months," says Vivienne Hudson, VP of optical networking at Nortel Networks. "Every carrier in North America or Europe has told us that their traffic is growing at 100% per year. The fundamental problem is that although it is growing very fast it is not very profitable, and all the profits are still due to voice services. So the challenge is to create new services that will allow those profits to be generated."

William Shreve, director of Agilent's Systems and Solutions Lab, says that component makers have a role to play in helping carriers achieve profits from data traffic. "Carriers are seeking to add services and are looking to the component manufacturers to help them reduce costs by providing more and more component integration and automation."

Whatever happens, recovery at the component level will occur slowly. RHK predicts that the combination of price declines for components with flat or slightly declining shipment volumes is likely to result in a fall in revenues during 2002. The most likely scenario is an 8% drop to $4.25 billion next year, with double-digit growth returning in 2003. ElectroniCast is more optimistic after talking with its clients. "In the past couple of months, we've seen very positive signs in the shape of equipment vendors receiving quotation requests," says Jeff Montgomery. "Growth will return slowly, and will accelerate in the second half of 2002. Growth in component shipments could return to 25–30% in 2003."

Others continue to urge caution. Analysts at Morgan Stanley Dean Witter have released a report suggesting it is too early to predict a recovery for the optical components industry. The problem is that although inventories are being reduced, it does not necessarily follow that demand will pick up again. The analysts argue that a much more likely scenario is a flattening of both component supply and system demand, with gradual recovery taking place. Morgan Stanley is advising investors to take care when buying optical component stocks. "We would recommend investors look for companies with critical mass, sophisticated manufacturing methods, strong intellectual property and attractive valuation," say the analysts, citing Agere Systems as an example of a company fitting all of these criteria.

An even less positive view comes from Bear Stearns, which looked at capital expen-



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Integration: benefits will take time to be realized

Based on the experiences of the microelectronics industry, integration is a key next step for optical components, and is expected to lead to reduced cost, power consumption and size, plus greater reliability and functionality. Microelectronics moved from mounting discrete components onto a board and wiring them together to integrating millions of transistors onto the same piece of silicon.

Although the comparison is useful, it can easily be pushed too far. The mainstream silicon industry uses a single material, while optoelectronics lacks an obvious platform. The silica-on-silicon approach is being used by a number of companies, notably Bookham and Kymata/Alcatel, while InP offers lots of material advantages and is being investigated by established manufacturers, as well as start-ups such as ThreeFive Photonics, Intense Photonics and MetroPhotonics. "InP is the only material with the required level of 'integratability'," says Lawrence Gasman, president of market research firm Communications Industry Researchers (CIR). "In theory it allows the integration of actives and passives, and electronic and optical devices. However, InP suffers from problems such as small wafer sizes, and is much less mature than silicon."

The primary reason for integrating components is to reduce costs. "At the moment, integration has very little to offer in terms of direct cost reduction," says Gasman. "Because there are no standards, integrated components are not 'plug-and-play' substitutes for discretes, so an equipment vendor must take into account the cost of designing the integrated product into the system." CIR has estimated that integration might reasonably be expected to lead to a 12.6% reduction in capital costs by 2005 – not quite the improvement that some might hope for, but nevertheless significant.

Integration is also expected to have a large impact on operational costs and to improve the performance:cost ratio of equipment to a level that will open up high-volume markets, although there are no signs of this at present. Integration has the potential to reduce power requirements and insertion losses, but current products struggle to achieve the performance available using discretes.

A more compelling incentive at present appears to be the reduced footprint of integrated components. However, Gasman believes that integration will start to become more commonplace, for a number of reasons. Yields, which are now often extremely low, should improve rapidly as the industry adopts automated manufacturing techniques, and prices will decline as yields and volumes increase. More functionality per chip will reduce the cost per function and also the footprint, although equipment vendors are skeptical about the reliability of multi-functional chips, and have concerns about how to design them into their products. Big equipment companies such as Alcatel, Nortel and Lucent have all begun to think through what integration is going to mean for them, says Gasman – Alcatel's purchase of Kymata earlier this year is evidence of this interest. "We should start to see next-generation equipment containing integrated optics by the end of next year," he says. "What you're not going to see is the optical equivalent of a microcomputer. They'll use some integrated optics together with conventional technology. The industry is on a fairly slow path towards integrated optics – unless there's some major breakthrough, but I'm not sure what that would be."

diture (capex) estimates for US service providers. For these companies, capex spending has dropped significantly since the start of 2001 and could be down by as much as 20–25% in 2002. The Bear Stearns analysts believe that the bottom for equipment vendors will only be seen when the carriers' revenue growth stabilizes, and that it could be an extended period – perhaps 2 years – before renewed growth in the equipment sector.

Automation and new strategies

The current downturn has created an opportunity for component makers to streamline their manufacturing operations. Nortel has sold off huge quantities of fab equipment and consolidated its operations (see p4) while JDS Uniphase has closed plants and turned to outsourcing. These and many other companies have shed thousands of staff hired during periods of huge component demand, when it was necessary to focus on time-to-market and time-to-volume rather than cost-efficient, high-yield manufacturing techniques. Now companies are being forced to rethink, and the automation of assembly, test and packaging functions is becoming a key area (see p47).

"Companies are reducing their reliance on manual operations in two ways, either by introducing automation or outsourcing some of their production," says ElectroniCast's Montgomery. "Major manufacturers have the resources to be able to adapt while start-ups can select one route or another from the outset – for medium-sized companies, the problems are more significant."

Many larger companies such as Agere, Alcatel, Nortel and JDS Uniphase have invested heavily in automation. JDSU recently signed a development alliance for optical component and module manufacturing with Adept Technology, which makes factory automation systems (see p13). However, fully automated processes are still not in place. "We've seen automation in the manufacture of laser diodes and some in fiber attachment," says Agilent's Shreve. "However, automation tends to follow standardization, and companies won't build large automation systems unless there is a significant customer base. Many manufacturing systems are semi-automated and still require a lot of human operators. What we want to avoid in future is the philosophy of hiring more people to ramp up component production volumes."

Ironically, new start-ups that have focused from inception on automation and creating a common product platform may actually be in a stronger position than their larger, more established counterparts. Even so, some emerging component manufacturers have been forced to switch their development resources away from next-generation products in order to focus on making products that customers want right now. Tunable laser manufacturer Bandwidth9 is currently focusing on tunable spares rather than network provisioning equipment, because carriers believe the former application can make their networks more cost-efficient. Similarly, Novalux recently introduced new lower-power, low-cost pump lasers for metro networks because there was limited demand for the high-power devices that the company had previously commercialized (see *Compound Semiconductor*

November 2001, p41). According to ElectroniCast, New Focus is concentrating on integrating multiple functions into one package and reducing its R&D spending on new technologies since its customers have narrowed the areas they are interested in discussing.

Outsourcing

Along with automation, component manufacturers can seek to reduce costs by moving to low-wage regions or by outsourcing production. Contract manufacturing through electronics manufacturing services (EMS) providers is a mature feature of the electronics industry, but in the optoelectronic field the EMS providers are on a steep learning curve. However, outsourcing is becoming more prevalent; for example, Celestica has a contract to provide JDSU with optical subassembly services for optical amplifiers. Also, WL Gore is outsourcing production of its nLighten family of VCSEL-based modules to Flextronics, a Singaporean contract manufacturer that also makes mobile handsets for Ericsson and Siemens.

Integration

Integration is a key method to reduce the cost of optical components (see box, p33) and takes two forms. One is the monolithic or hybrid integration of multiple functions onto the same chip, while the other involves squeezing more components into the same module. The monolithic vs hybrid debate continues to rage. "Wafer-level processing of active components is the best way forward, and this is becoming more prevalent," says Agilent's Shreve. "However, many of the optical functions cannot be performed with the same materials. In the manufacturing area, I think we'll see hybrid integration of electronics and optics in the near term, followed by a push towards an all-optical solution in the long term, featuring electronics and optics integrated on the same substrate. We will also see more use of standardized packaging."

Venture capital funding

Another feature of the downturn is a reduction in venture capital funding. However, the optical components sector has suffered much less than the VC market in general, and many companies were funded during 2001 (see table, p31). "The venture community still has money to spend," says Melanie Swan, director of financial services at RHK. "Now VCs have more time to evaluate and scrutinize potential investments." A solid, rational business plan is now key to raising cash, and for second- or third-round funding a list of customers and a reasonable, sustainable demand for products are essential.

According to Swan three types of company are more likely to receive investment funding. The first is companies with real products that have already gained a foothold in the marketplace, while very young companies may have enough cash to survive until their products hit the market in 18–24 months. Finally there are the "walking wounded" – the candidates for merger or acquisition.

Although it is hard to gain a consensus on when conditions will improve in the fiber-optic component market, everyone at least agrees that next year there will be a lot fewer optical component makers in the industry.

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FIBER-OPTIC COMPONENTS

Component manufacturers must reassess their priorities

After four years of "hypergrowth", the optical components industry is now in the middle of a major slump. Component price declines coupled with flat-to-declining volumes are likely to result in negative growth in revenues in 2002. As RHK's **John Lively** explains, a period of restructuring and consolidation will demand a leaner, more manufacturing-savvy approach to component production.

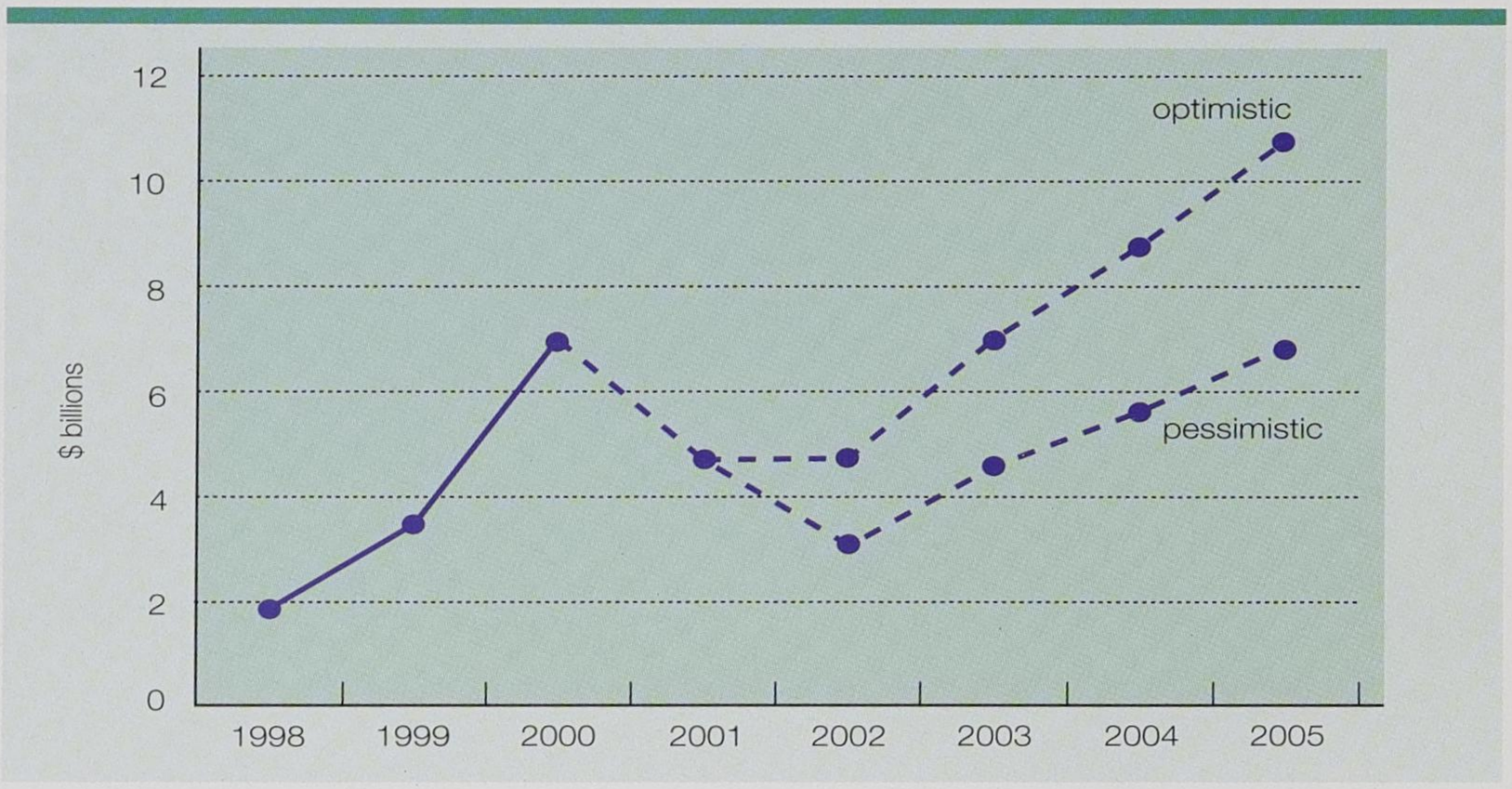


Fig. 1. RHK's current estimated range of global market revenues for optical components.

The latest research by analysts here at RHK indicates that the worldwide market for optical components used in fiber-optic networks will decline some 30–35% in 2001, compared with last year's record sales level of $6.85 billion. That steep decline follows four years of growth exceeding 100% per annum. The question is: why has demand fallen so sharply?

Excess inventory is one of the main reasons for the slowdown. Over the past four years, new-entrant long-haul carriers in North America built out networks at an unprecedented rate, often leaving systems suppliers surprised by the size and timing of equipment orders. What's more, the order patterns tended to be "lumpy", with only limited visibility into carriers' ongoing deployment plans.

When existing forecasting and materials management systems proved inadequate, some vendors turned to "evangelical forecasting". In this scenario, the CEO sets a growth objective based on "market intuition" or "gut feel", and then becomes an evangelist of growth, mobilizing the organization to meet its goals. In one case, in late 1999, a major systems vendor simply stopped providing forecasts to its optical components suppliers. Instead, the CEO in question told suppliers to quadruple their capacity in 12 months, and to simultaneously build higher levels of inventory. If they didn't, they'd be replaced – as simple as that.

On the supply side of the equation, the "hypergrowth" market environment of 1997–2000 forced business managers in optical transport and optical components companies to make maintaining, or even building, market share their top priority. In turn, the focus shifted towards shipping "on-demand" – though having adequate products to ship was particularly challenging in optical systems and components, owing to acute shortages in many key product areas.

At the same time, the carriers' desire to deploy the most advanced optical transport technologies meant that systems houses pulled novel components out of the lab ahead of schedule, with less and less emphasis on the traditional product development cycle. "Time to market" soon became a common thread in suppliers' mission statements, strategic visions and critical success factors. Consequently, many cutting-edge components – 100 GHz thin-film filters, high-power pump lasers and 10 Gbit/s sources, for example – went into production with poorly developed, low-yield manufacturing processes. Inevitably, suppliers found it difficult to keep up with demand.

The resultant supply shortages led to a pattern of predictable behavior across the industry. Systems and subsystems manufacturers began double-ordering, or ordering more than their order book indicated. In parallel, component suppliers demanded large order quantities and volume purchase agreements, sometimes tying customers to volumes in excess of their known demand. On both sides of the supplier–customer relationship, the response to hypergrowth led to a build up of inventory well above what is considered healthy in a "normal" market.

Blame it on the financial markets

The other major reason for the optical communications slowdown is the fact that North American long-haul carriers have slashed their capital and operational expenditures. It was these same carriers, of course, who helped to create the conditions for hypergrowth in the first place. Funded by $200 billion in bonds and an IPO-eager stock market, start-up carriers like Global Crossing, Broadwing, Williams and 360networks raced each other to deploy state-of-the-art nationwide networks.

The business case for this fiber-laying frenzy was simple enough: so-called "next-generation" networks would allow newer carriers to achieve significantly lower operating

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costs (frequently expressed as "lowest cost per bit"), opening the way to lower prices and, in turn, stimulating further bandwidth demand. Advocates of this business model argued that incumbent carriers – many of them locked into older, less-efficient and higher-cost network technologies – would quickly lose market share as the newer networks came on line.

But the argument was flawed. It became apparent in late 2000 that there were simply too many new carriers competing for a slice of the same bandwidth pie. And the "lower cost per bit" calculations supporting the new carriers' business models assumed fully loaded equipment (i.e. that a 40-channel DWDM system would have 40 lit channels, all carrying traffic).

With hindsight, it is now all too apparent that some carriers failed to achieve the required utilization of installed channels, and costs therefore outpaced revenues. In fact, some of the more speculative carriers installed entire networks in advance of committed customers.

Aggregate network traffic growth, though fuelled by Internet traffic growth of 100% per year, was simply outpaced by the total growth in industry capacity. Combined with heavy payments on bonds issued to pay for the new networks, this created cashflow problems for some of the newer carriers, sending 360networks into bankruptcy and causing several others to make drastic cuts in their network budgets.

Concerns about the liquidity of these and other companies spread to the entire carrier segment, and soon everyone was playing the game of seeing who could make the biggest cuts to their capital expenditure. The result was a dramatic reduction in carrier spending on transport equipment, a process that intensified during the first six months of this year.

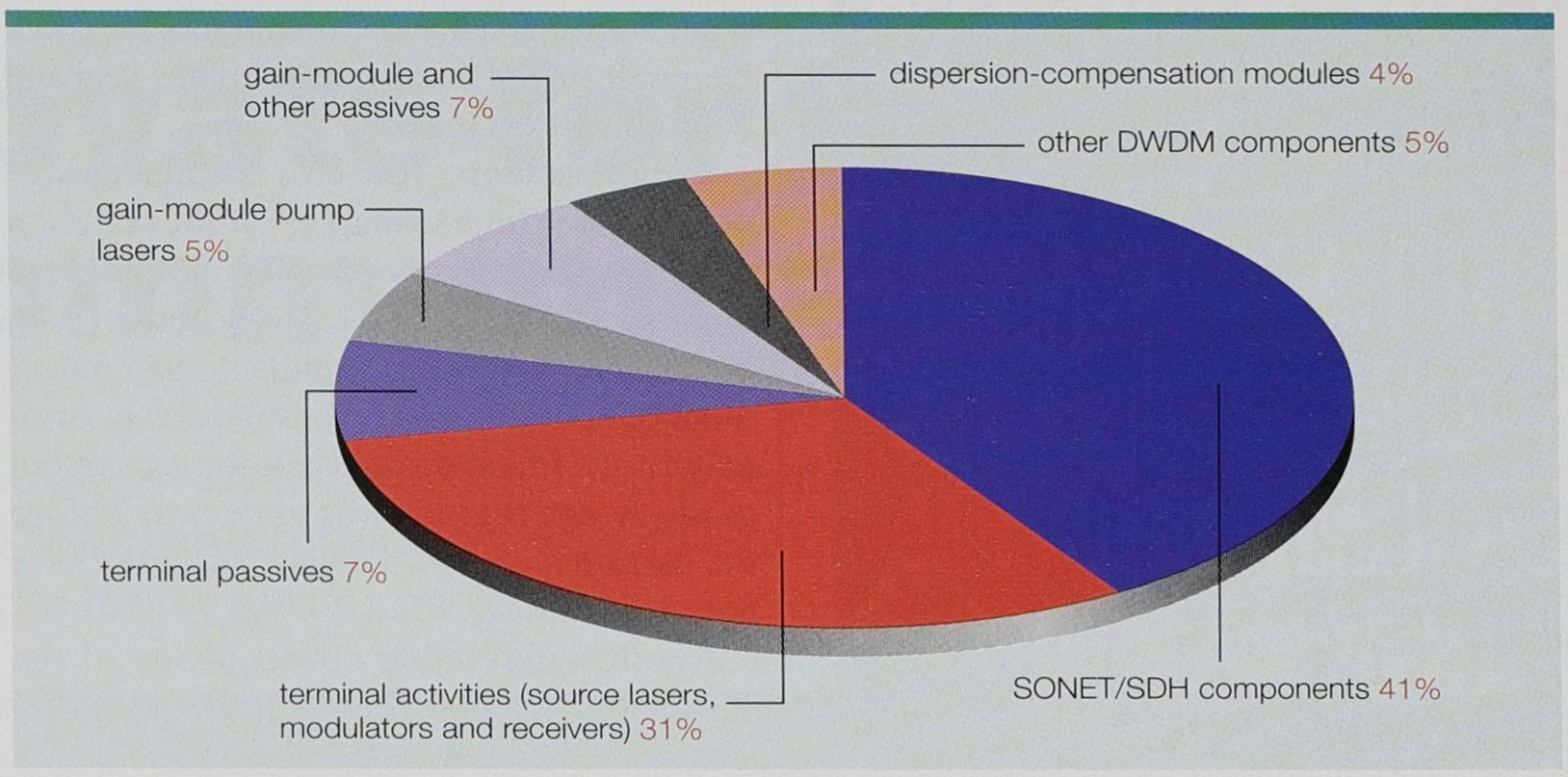


Fig. 2. Breakdown of optical component demand into product groups for 2002. The total projected market value is $4.25 billion.

From hypergrowth to zero growth

In most product areas, progress has been made in working down the excess inventory. RHK's spring 2001 forecast estimated that there was some $1.8 billion in excess optical components inventory across the industry. Beginning in the second quarter of 2001, and continuing into the third, more than $2.9 billion in optical components and optical transport equipment has been written off. However, RHK's latest channel checks suggest that significant inventory remains in some product areas, and excess inventory will likely roll-over into 2002, depressing sales of new products next year as well.

To make matters worse, carrier spending on optical transport will exhibit negative growth in 2002. In North America, the newer long-haul carriers have ditched their "build it and they will come" deployment strategies. And while estimates for overall carrier capital expenditure for next year vary from flat to negative, RHK believes a further decrease after 2001 is likely.

The available data suggests that appreciable growth will not return to the components market until 2003. Systems sales will start to pick up some time in the latter half of 2002, and optical components sales will follow. It is likely, though, that component price declines coupled with flat-to-declining volumes will result in negative growth in revenues in 2002. Stronger volume growth, combined with more stable pricing, should result in double-digit growth in the optical components market starting in 2003 (figure 1).

One thing is certain: the era of hypergrowth is over for good. When growth resumes, it will not be at rates of 100% per annum. Hypergrowth was fuelled by easy capital and a "gold rush" reaction to a new, disruptive technology – the Internet. While RHK expects North American Internet traffic to continue to grow at some 100% per year, the research suggests that existing network providers will be able to keep up with traffic increases through judicious addition of capacity to their existing networks for the next several years.

Sales of line cards, and the components that go into them, will outstrip all else for several years. New research by RHK analysts shows that in North America many carrier routes are now equipped with 40- and 80-channel DWDM systems, with only a handful of those wavelengths being lit. Consequently, carriers trying to conserve capital and improve cashflow will first increase network capacity by adding line cards to fill channels on their equipped fibers; they will only equip additional fibers with mux/demux and optical amplifiers as a last resort. To sum up: in the next two to three years, many more line cards will be sold than mux/demux filters, optical amplifiers, pump lasers and gain-module passives (figure 2).

A new-look industry

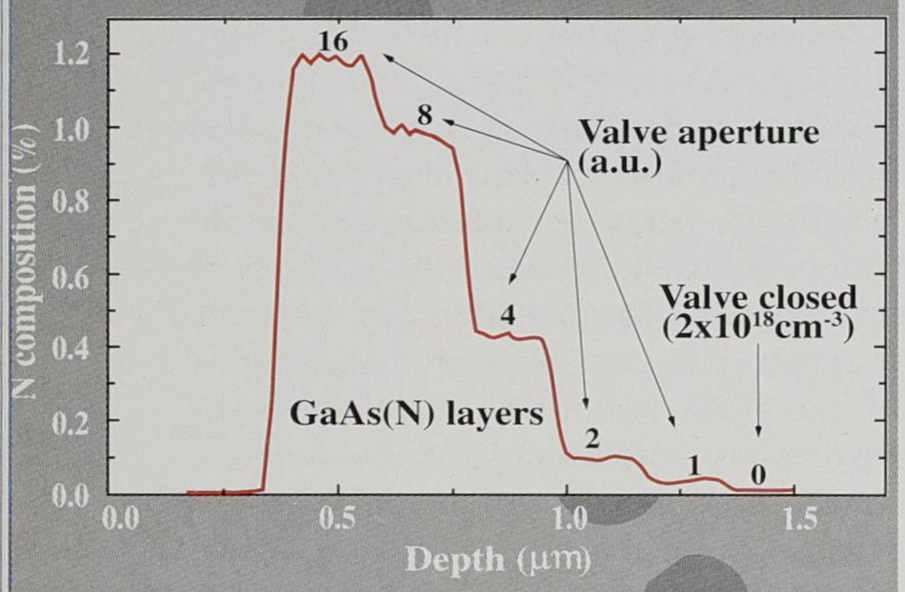
The protracted slowdown in market demand means that significant consolidation is now under way across all levels of the optical communications business. The bankruptcy of 360networks could well be the first of many at the top of the supply chain. At the system OEM level, meanwhile, established DWDM equipment vendors are likely to gain as spending shifts from new upstart carriers to older incumbent carriers. Conversely, a number of ultra-long-haul and metro systems start-ups are expected to go to the wall over the next 12–18 months, as companies exhaust their cash before significant order volumes return.

Hardest hit, though, will be the 200 or so optical components start-ups, who will be forced to fight it out over a much-reduced market opportunity. Admittedly, most components start-ups today are well funded, and can survive for 12 months or more by living off their existing bank accounts. But the psychological adjustment of the founders and venture capitalists, who have to accept greatly reduced valuations of their companies, will take some months. The brutal truth is this: even with layoffs and tough austerity measures, it is likely that many optical compo-

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FIBER-OPTIC COMPONENTS

nents start-ups will close their doors for good, beginning in the fourth quarter of this year and continuing well into 2002.

In the near term, "low-cost manufacturing" will replace "time to market" as the common strategic imperative of optical components makers. Vendors are pursuing three basic approaches to low-cost manufacturing: movement of operations to low-wage areas, automation and integration. While the movement to low-wage regions was underway before the market slowdown began, the process is now accelerating.

Another inevitable consequence of the slowdown is a delay in the adoption of new network technologies. While systems OEMs are compelled to offer the latest "bells and whistles" on their platforms – 40 Gbit/s transmission speeds, Raman amplification and L-band operation – carriers are unlikely to embrace these technologies as readily as they bought into 10 Gbit/s systems just a few years ago. In short, the carriers have shifted decisively towards improved cashflow and minimizing capital expenditures; paying a premium for the latest technology is no longer on the agenda. So, while some new networking technologies will be deployed in 2002, RHK believes that wide-scale adoption will be delayed by 12–24 months because of the market slowdown.

Component price declines coupled with flat-to-declining volumes will result in negative growth in revenues in 2002. Stronger volume growth, combined with more stable pricing, should result in double-digit growth in the optical components market starting in 2003.

A change in the old order

Meanwhile, conditions are now such that new market leaders may well emerge when the upswing eventually kicks in. After the personal computer industry's first serious slowdown in 1985–1986, for example, technological innovation no longer played a dominant role in achieving market leadership. Instead, efficient, low-cost manufacturing and direct-to-consumer distribution channels proved to be more important, with Dell and Gateway replacing Apple and IBM as market leaders. The current slowdown in optical components certainly sets the stage for a similar remaking of the competitive landscape.

The overall market leader, JDS Uniphase, is currently addressing the challenge of turning its collection of disparate acquisitions into an integrated, low-cost manufacturing company. Corning, the historic market leader in optical gain modules, finds itself focused on the two product lines most vulnerable to a reduction in new network construction – gain modules and passive mux/demux filters. Nortel HPOCS faces the challenge of somehow making up for the 70% reduction in business of its largest customer, Nortel Networks.

Paradoxically, Alcatel Optronics of France stands to benefit from what were formerly perceived to be its weaknesses – market strength weighted toward Europe, Asia and submarine networks, and a product portfolio heavily weighted toward source lasers and receivers. Agere Systems, with a similar product portfolio, is also positioned somewhat more favorably in the current market environment.

Elsewhere, though components start-ups face revenue challenges in the near term, in many cases they bring radically different skills and experience to the industry. Populated in some cases with veterans of the disk-drive and DRAM chip wars of the 1980s and 1990s, these companies have alternative takes on process discipline and manufacturing, an outlook that may be especially relevant in a market facing sluggish demand and intensified price pressures. Because of this, it would not be all that surprising to see one or more of these start-ups on the list of top-tier optical components suppliers within the next two or three years.

Longer term, after the current period of industry consolidation and restructuring ends, a leaner, more manufacturing-savvy components industry will emerge. Supply and demand will once again come into balance, and the industry will enter an era of renewed health.

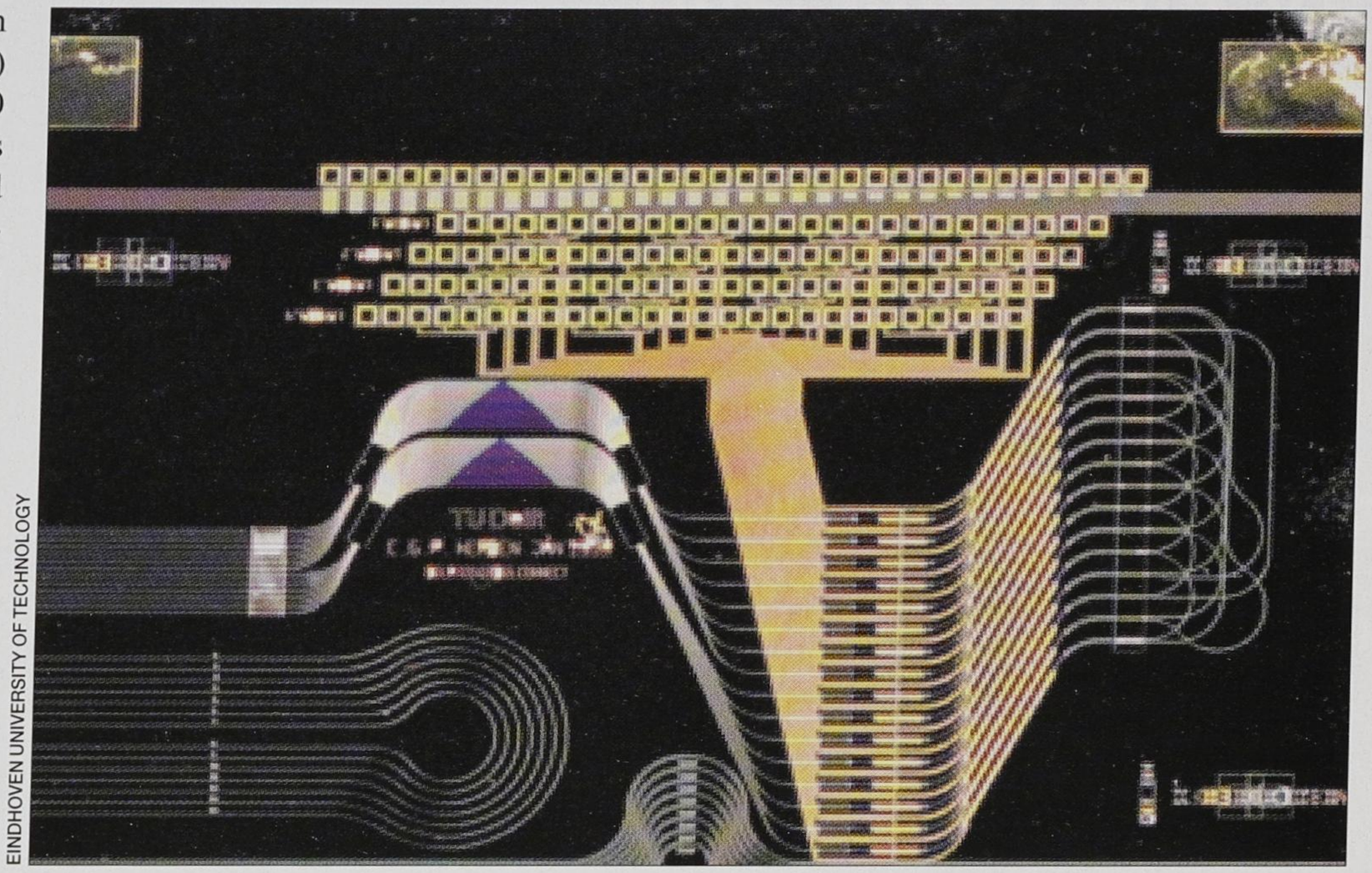
John Lively is director of the optical components practice at RHK Inc, South San Francisco, CA. E-mail John_Lively@RHK.com. Web www.rhk.com. This article was originally published in FibreSystems Europe *magazine.*

III-Vs innovate for future optical communications

Compound semiconductor devices are a key technology for the continued development of optical communications. **Jessica Maclean** reports from ECOC on the latest advances that are helping to make optical networks faster and more flexible.

The 27th European Conference on Optical Communication (ECOC '01) took place in Amsterdam from 30 September to 4 October. The 1800 attendees (23% of whom were from the US) benefited from a rich variety of topics relating to communications networks that were covered during technical sessions, plenaries, short courses and tutorials. Subjects included optical network architectures, optical regeneration and polarization mode dispersion, as well as both fiber-based and III-V-based components. There were also 350 exhibiting companies, filling two large exhibition halls, who had a wealth of new products on display (see *Compound Semiconductor* November 2001, p41).

The current economic downturn in the optical communications industry has seen manufacturers scale back production as excess fiber capacity is utilized and large component inventories work through the system. Spending on research and development, however, is seen as crucial in ensuring that companies emerge from the recession in a good position to compete for a share of the market in next-generation products. The number of impressive results across a wide range of device types is evidence that this is exactly what is happening behind the gloomy headlines.



EINDHOVEN UNIVERSITY OF TECHNOLOGY

Fig. 1. Photograph of an InP-based WDM cross-connect with switches.

Planar lightwave circuits

A plenary talk given by Kristian Stubkjaer from the Technical University of Denmark set the scene for the conference. The optical communications industry has grown over the last 20 years as a result of the ability to mass-produce single-mode fiber, long-wavelength laser diodes and the fiber amplifier. The development of wavelength- and time-division multiplexing (WDM and TDM) technologies and related components has allowed the same fundamental infrastructure to transmit and receive more information. The main issues in implementing these technologies are component non-linearities and compatibility with amplifier technology, together with fiber dispersion losses. The resulting solutions are showing a general trend towards further integration of components. Since WDM and TDM techniques are suited for steady-state traffic, a need for an all-optical packet-switching layer, at the edge of the optical to electronic conversion domain, has also developed. This packet-switching layer would consist of all-optical gates, such as semiconductor optical amplifiers (SOAs), combined with interferometers, and requires some form of all-optical random access memory. Such an optical-switching layer is therefore a source of inspiration (and perspiration) for work on planar lightwave circuits.

Arrayed waveguide gratings

M Smit from Eindhoven University of Technology described developments in monolithically integrated InP arrayed waveguide grating (AWG) circuit functionality. The AWG consists of two multiport couplers interconnected by an array of waveguides, and is used as a mux/demux in WDM systems or as a static router (figure 1). Most of the key components for WDM applications can be realized from a combination of AWGs, SOAs and optical switches. Rival silica-on-silicon AWGs currently have lower crosstalk than InP AWGs, but the ability to integrate active optoelectronic functionality in InP will potentially lower overall module losses and manufacturing costs. The smaller InP AWG size (100 times smaller) results in greater switching speeds than silica-on-silicon devices, making InP AWGs suitable for packet-switching applications.

An example of a zero insertion loss, monolithically integrated, 64-channel selector was presented by N Kikuchi of NTT Photonics Laboratories. Using the novel architecture of

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a front 1 × 8 AWG, followed by a rear 8 × 8 AWG, only 16 SOA gates were needed to switch all 64 channels.

Edge-emitting lasers

A four wavelength (400 GHz spacing) 1550 nm InGaAsP ridge-waveguide laser array based on a DFB grating design with excellent single-mode operation and >10 mW output power was reported by J Kreissl of the Heinrich-Hertz Institute (HHI) in Berlin. A 60% array yield was achieved by using precision control of the phase-shifted index gratings.

Buried heterostructure InP laser diode devices for high-speed 1550 nm applications were reported by S Bouchoule of CNRS in France. The devices were grown using selective-area MOVPE, and incorporated a low capacitance InAlAs diffusion-blocking layer. The device gave performance parameters identical to those of unburied structures; the lasing threshold current was 450 A/cm^2 and the internal efficiency was 65%.

A record CW power output of 450 mW at 1310 nm was reported by R Menna of Princeton Lightwave for an InGaAsP/InP ridge-waveguide laser. This performance was achieved through the optimization of the grating coupling coefficient, the mirror reflectivities, and the position of the laser gain peak. The power output is similar to that achieved for the Fabry–Perot lasers incorporating fiber Bragg gratings that are deployed as Raman pump lasers.

VCSELs and optical interconnects

From a manufacturing viewpoint, the main attractions of VCSELs include the ability to perform on-wafer testing before dicing and packaging, and the possibility of hybrid integration with silicon ICs. As manufacturing techniques develop to enable the reduction of series resistance, VCSEL power consumption is steadily decreasing. Avalon Photonics of Zurich quoted an absolute maximum power rating of 30 mW per laser in a 1 × 10 array of 850 nm VCSELs. Very high array reliability was predicted after a post-processing burn-in for 20 hours at 100 °C.

F Mederer presented the results of collaborative work between the University of Ulm and Infineon Technologies on the transmission characteristics of 1300 nm dilute nitride VCSELs on GaAs substrates. The device active region consisted of two 6.5 nm InGaNAs quantum wells with 35% indium and 1.8% nitrogen, separated by 20 nm GaAs barriers. The GaAs/AlGaAs mirrors were undoped and

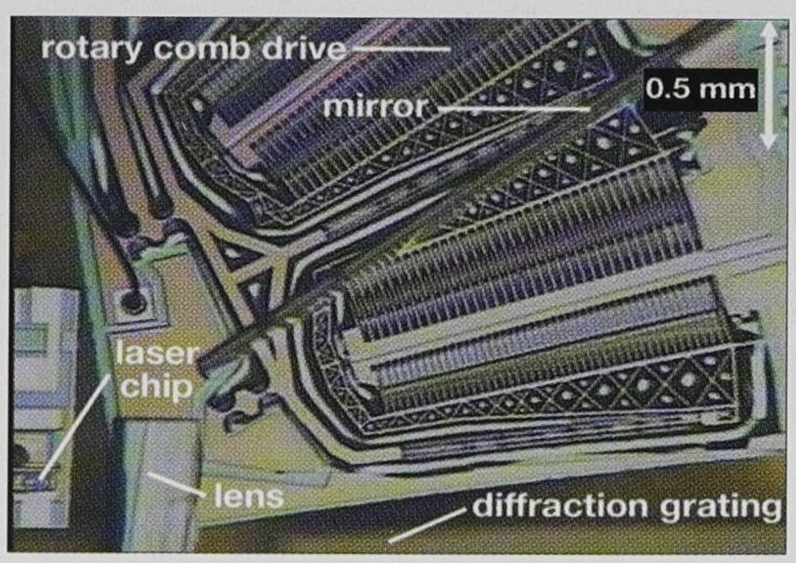


Fig. 2. Photograph of Iolon's laser, which can be tuned over a 40 nm range by moving the mirror on a comb drive.

there were two intracavity contact layers for current supply. Driven at 6 mA, 1 Vpp, the devices demonstrated error-free transmission over 20.5 km of single-mode fiber at 2.5 Gbit/s.

Connie Chang-Hasnain gave a talk on Bandwidth9's electrically pumped, top-emitting VCSEL which is tunable from 1530–1620 nm. This was achieved by the monolithic integration of a MEMS device (a cantilever) with the VCSEL (see *Compound Semiconductor* June 2001, p49). The device consists of the usual lower n-type distributed Bragg reflector (DBR) mirror, a cavity with the active region and an upper DBR mirror. The upper mirror consists of two parts separated by an air gap; the lower part is a p-DBR and the upper part is an n-DBR supported by a cantilever. The application of a reverse voltage between the top n-DBR and the p-DBR across the airgap, electrostatically attracts the cantilever downwards, thus tuning the laser to a shorter wavelength. The eye diagram for 2.5 Gbit/s operation showed error-free operation and the wavelength could be locked within 2.5 GHz accuracy to a new channel wavelength within 200 μs.

Tunable lasers

Tunable lasers are in high demand for wavelength-switching applications where a dynamic response to network routing requirements is needed, and also for optical packet-switching applications. Two contrasting approaches to tunable external cavity laser (ECL) diodes were reported. Jill Berger of Iolon described a high-power (+10 dBm) device tuned using an electrostatic actuator 85 μm thick, fabricated by deep reactive ion etching from single crystal silicon. The mirror is mounted on a rotary comb drive and the application of ±140 V rotates this element of the cavity by ±1.4°, enabling a wavelength tuning range of 40 nm (figure 2). The laser's linewidth at 3 dBm was only 1 MHz, less than a typical tunable DFB laser where it usually exceeds 20 MHz.

The second approach, presented by G Souhaite of NetTest, used an original design for the ECL. This featured a 16-stripe laser diode and a fixed external grating to switch between different wavelengths with no moving parts or tuning current. The emitted output power is +7 dBm and the wavelength is determined by whichever laser diode is powered. The switching time is limited by the typical response time of a directly modulated laser.

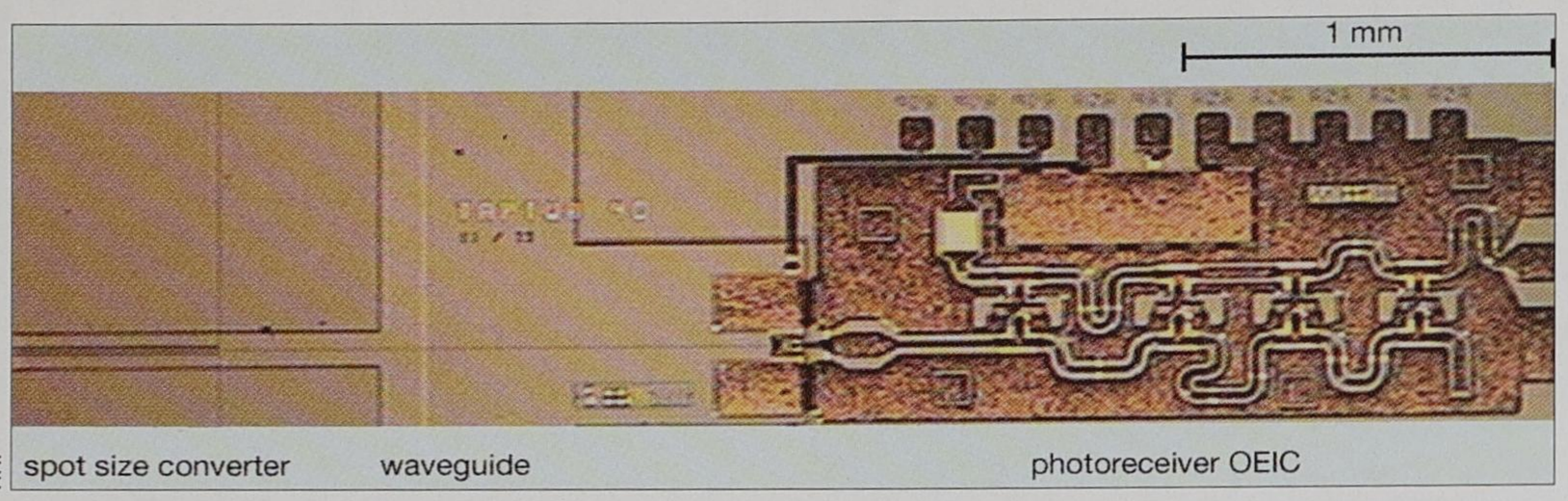
Photodetectors

The photodetector component in a photoreceiver may be one of a number of types depending on the application. Side-illuminated photodiodes are suitable for hybrid integrated modules, whereas high sensitivity photoreceivers frequently use photodiodes in a vertical geometry. The electrical output of the photodetector is amplified by a front-end amplifier which may be monolithically integrated with the detector.

Some of the component designs presented at ECOC were specifically for surface hybrid integration on a silicon optical bench. For example, side-illuminated InGaAs-on-InP photodiodes designed for 2.5 Gbit/s applications at 1300–1550 nm were reported by M Achouche of Opto+, France. On-wafer yields of 96% were achieved and very low dark currents (20 pA at –10 V) and high responsivities of 0.9 A/W were obtained. By using evanescent coupling from a waveguide beneath the device, the vertical alignment tolerance was 5 μm without the need for additional lenses or mirrors. This is well within the usual specification for silicon platform technology.

InP/InGaAs-based avalanche photodiodes (APDs) with a large gain bandwidth product of 100 GHz and high efficiency (0.88 A/W) were reported by E Ishimura of Mitsubishi Electric. By incorporating an n-InP/InGaAs DBR structure as the bottom mirror of the top-illuminated device, the quantum efficiency was increased by 20%, as compared with a similar 20 μm diameter device without the DBR mirror. At 0.9 V bias the dark current was 30 nA and the capacitance was 0.19 pF.

An integrated photodiode with spot size converter, low polarization dependence and a high efficiency of 0.80 A/W for 1550 nm wavelength operation, was reported by N Yasuoka of Fujitsu Laboratories. The detector and tapered waveguide were buried in semi-insulating InP using selective-area



HHI

Fig. 3. A fabricated InP-based photoreceiver optoelectronic integrated circuit (OEIC), comprising a spot size converter, a waveguide-integrated photodiode and a HEMT-based travelling wave amplifier. The chip measures 4 mm x 1 mm.

epitaxy, thus allowing horizontal access of light from a fiber. The low parasitic capacitance achieved through the use of an air-bridge top contact and a thin InGaAs absorption layer allowed the high-frequency performance suitable for 40 Gbit/s systems.

H Bach of the HHI reported on a collaborative effort (with Lucent Technologies and HHI spin-out u^{2}t Innovative Optoelectronic Components) to enhance the performance of a monolithically integrated photoreceiver for 1550 nm, 50 GHz operation. The original InP-based chip (figure 3) consists of a mode size converter, a waveguide-integrated photodiode and a HEMT-based travelling-wave amplifier. The chip's optical to electronic conversion efficiency was 1.1 A/W, and with a single bias voltage of 2 V the total power consumption was only 90 mW. In order to increase the transimpedance further, the group applied a cascode-type scheme for the travelling wave amplifier, using 8 HEMTs and requiring two bias voltages, 2V and 4V. This increased the conversion efficiency of the optoelectronic integrated circuit to 1.7 A/W and gave a bandwidth of 35 GHz.

T Nakata of NEC described an InP-based APD with separate p-InGaAs absorption and InAlAs multiplication regions which had both low capacitance and low series resistance allowing a high gain bandwidth product of 180 GHz. This receiver front-end achieved a 30 GHz bandwidth when combined with a GaAs-based HBT pre-amplifier. This is the first demonstration of an integrated APD receiver with such high bandwidth.

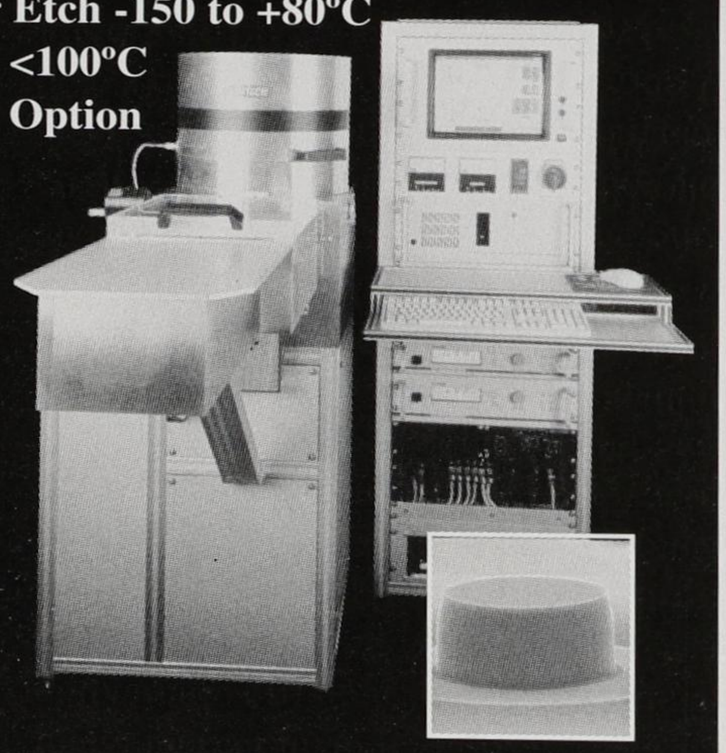
Entrepreneurship

There was plenty of advice for budding photonics entrepreneurs both during a workshop devoted to the subject and in the plenary given by Milton Chang of iNCUBiC.

The workshop brought together speakers with different experiences of the technology business world. Claes Rickeby, now with Proximion Fiber Optics, described his experience of being part of a company that was acquired by Cisco Systems. The company, called Qeyton Systems, was founded in 1998 by a small group of dedicated people who saw clear applications for their products. Qeyton Systems' main products were directed at the metro market, which has recently undergone great expansion. After only two years, during which time Qeyton's valuation increased by a factor of 1000, negotiations began with Cisco Systems who were interested in acquiring Qeyton. A deal was signed in June 2000, and within one month the company had been fully integrated with Cisco, just as 61 other companies before them had been. Much work was needed to finish Qeyton's products and comply with Cisco's business and technical procedures. However, the benefit to the fledgling products was a ready-made distribution channel to the world's biggest network market for products which, at that time, had an unknown market impact.

Milton Chang analyzed the recent market conditions that generated much investment and created many start-up companies in the optical communications sector. The subsequent decline of many of these start-ups was attributed to a number of causes including an underestimation of the effort required to transfer a product to larger scale manufacture, and the lack of in-house production and business expertise. He viewed the more somber investment environment of recent months as more realistic but still abundant in opportunities for innovation.

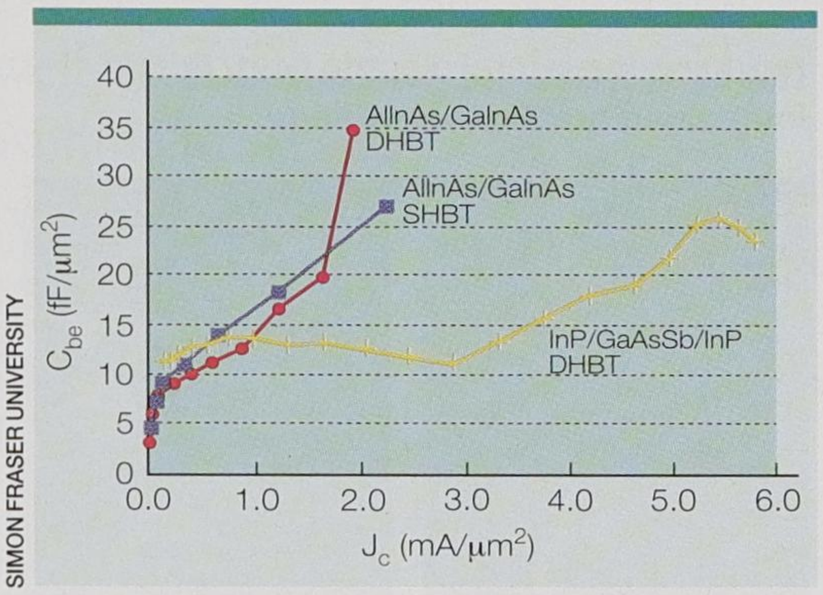
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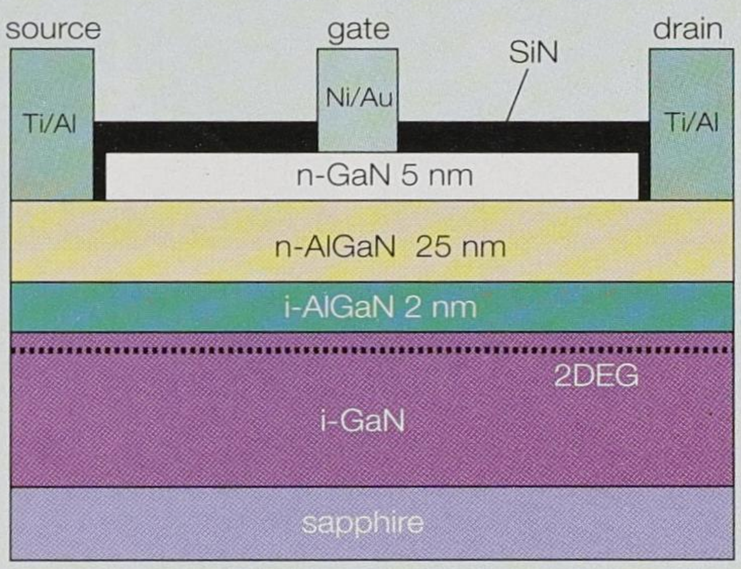
Though dominated by silicon microelectronics, there was plenty to report on state-of-the-art III-nitrides and other compound semiconductor devices at this year's IEDM, writes **Jon Newey**.

The annual International Electron Devices Meeting (IEDM) is the leading event for the discussion of research into electron devices and their applications. The 2001 meeting was held in Washington DC on 3–5 December and featured 204 papers across 41 sessions. These covered a broad range of topics including RF power devices, SiGe bipolar technology, device modelling and processing, and MEMS sensors. As one would expect, most of the papers discussed advances in silicon-based technology, but the compound semiconductor world was also well represented with papers covering research into nitrides, high-speed devices and optoelectronics. The adherence to a policy of only accepting papers with previously unreported results ensured that there were many claims and counter claims for new records in device performance. While it is difficult to make comparisons between these performance figures without knowing how other parameters are affected (see *Compound Semiconductor* November 2001, p35), they represent a benchmark for progress and encourage healthy competition between laboratories around the world.



SIMON FRASER UNIVERSITY

Fig. 1. The InP/GaAsSb DHBT shows very different behavior at high currents. The alloy blocking effect causes C_{be} to increase sharply with current in AlInAs/GaInAs HBTs. The minimum in C_{be} for the InP/GaAsSb DHBT corresponds to a maximum in f_t.



FUJITSU

Fig. 2. A schematic of the Fujitsu recessed ohmic power FET structure.

DHBTs set new records

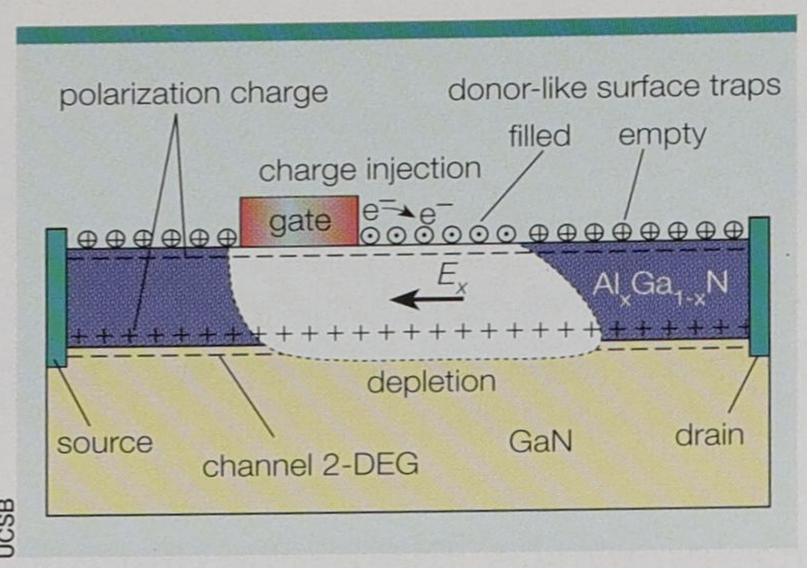
Bolognesi *et al.* of Simon Fraser University (SFU), Canada, presented the findings of an investigation into the effects of high currents in InP/GaAsSb/InP DHBTs, in particular the roll off in f_t at high current density. These DHBTs feature a type-II band line-up where the difference in conduction or valence band energies of the two materials is greater than that in the bandgaps. This band structure enables operation at high current densities – perfect for digital circuits at 40 Gbit/s and above. Their operation is facilitated by the conduction band of the GaAsSb base lying above that of the InP layer, meaning that electrons in the DHBT do not encounter the potential barrier at the base-collector interface that limits DHBTs with a type-I band line-up.

While studying RF characteristics as a function of temperature, the SFU group recorded what it believes to be the highest f_t for a bipolar transistor prior to the meeting; 320 GHz measured at –40 °C (305 GHz at room temperature). The peak in f_t comes as the base-collector electric field collapses due to the travelling electron space charge. This collapse occurs at lower currents, and f_t roll-off is less sharp as the temperature increases. The base/emitter capacitance (C_{be}) is directly related to transistor operation. The InP/GaAsSb/InP DHBT showed very different behavior to that of a type-I AlInAs/GaInAs DHBT where C_{be} rapidly increased at higher currents due to the blocking effect of the potential barrier (figure1). C_{be} decreased in the type-II DHBT as current density increased, reaching a minimum as f_t peaked. At this point current density was 3 mA/μm². Above this figure, f_t begins to fall as C_{be} rises due to increasing carrier storage in the base. C_{be} remains low below 3 mA/μm² because the absence of the alloy blocking effect means no excessive charge is stored in the base.

The announcements of record f_t figures continued as Ida *et al.* from NTT reported an InP/InGaAs DHBT with an f_t of 341 GHz at room temperature and a current density of 800 kA/cm². The NTT group believes its f_t to be the highest reported for a bipolar transistor. The high current density was achieved by decreasing the layer thicknesses, although this caused some problems by reducing the breakdown voltage and increasing the collector capacitance. The NTT group used a collector layer that was 150 nm thick to boost current density and to keep a useful breakdown voltage. The collector was compositionally graded and contained a 20 nm InGaAsP layer to suppress the collector current blocking effect. The sub-collector and emitter InP layers were designed with thicknesses to minimize the series resistance.

When the current density was 850 kA/cm², breakdown voltage was over 2 V, a figure adequate for ECL circuits. The peak f_t of 341 GHz was achieved at a current density of 833 kA/cm². Figures for f_t exceeding 300 GHz were achievable with current densities of around 500–1000 kA/cm².

So, who is right in claiming the f_t crown? While the NTT figure for f_t is clearly higher, this is achieved at the expense of other parameters of operation. Various figures of merit can be used to analyze the results. Taking breakdown voltage into account by multiplying it by the f_t figure puts SFU ahead. Fujihara *et al.* from NEC showed data using an alternative figure of merit, the product of f_t and f_{max} divided by the sum of f_t and f_{max}. Applying data presented at the meeting to this formula puts the NTT devices at about 130 GHz with the SFU devices at about 160 GHz thanks to a high f_{max}. "In any case, the NTT 341 GHz result is quite exciting. Very nice work," said SFU's Colombo Bolognesi.

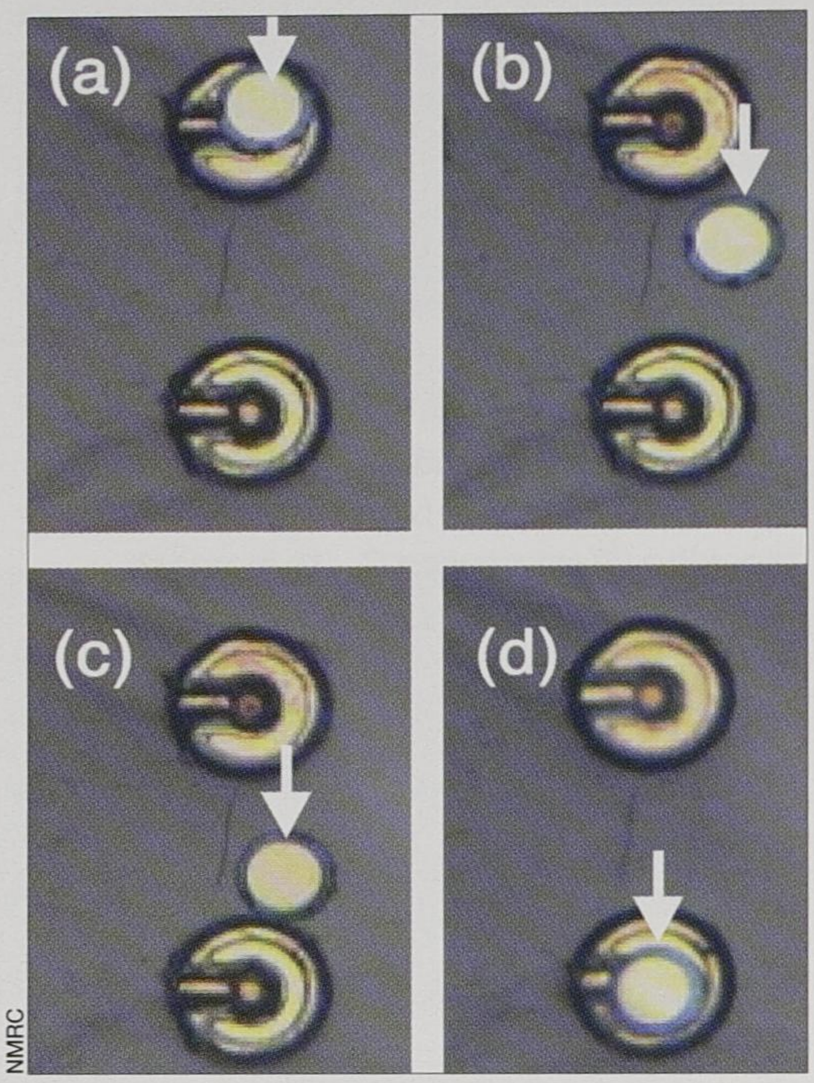


UCSB

Fig. 3. AlGaN/GaN HEMT under positive drain bias and pinch off. Electrons injected from the gate contact fill surface traps, vertically depleting the channel charge and reducing the lateral electric field, thus increasing breakdown voltage.

New structures for nitrides

Low gate leakage current and high breakdown voltage are required for high output power AlGaN/GaN HFETs. The integrity of the gate oxide is an important factor in achieving this. Inoue *et al.* from Matsushita, have proposed an alternative to the deposited oxide, reporting that thermal oxides provide better device performance figures. They fabricated devices with drain currents up to 700 mA/mm, drain breakdown voltages of 130 V and gate leakage currents of less than 1 μA at a drain voltage of 100 V. The AlGaN/GaN HFET structures were grown by MOVPE onto SiC. Device isolation was done by selective area oxidation of the epilayer at 900 °C in an O_2 ambient. The gate oxide was formed after the contact regions had been protected from oxidation by silicon. The exposed areas were oxidized at 900 °C in an O_2 ambient for 27 minutes. The silicon was then removed and ohmic contacts and electrodes were deposited in the unoxidized areas. Though the quality of the gate oxide resulted in enhanced device performance compared with deposited oxides, the thermal oxide formation time adds significantly to the processing time. The device isolation step took 4 hours for devices with undoped GaN channel layers and 12 hours for those with doped channels.



NMRC

Fig. 4. Sequential frames from a video demonstrating the transport and localization of two 80 μm diameter LEDs to two different receptor electrodes. The electrodes are 100 μm in diameter, and are spaced at 250 μm.

High power densities in AlGaN/GaN HEMTs require high sheet charge density and electron mobilities. Increasing the aluminum content gives a larger charge density, but reduces mobility because of alloy scattering and imperfections in the crystal lattice. Shen *et al.* from the University of California, Santa Barbara (UCSB), used an AlGaN/GaN structure that incorporates a 1 nm AlN layer between the GaN and AlGaN. Electron penetration into the AlGaN channel layer from the GaN is reduced due to the different conduction band energies between the GaN and the AlN, and because the binary AlN at the interface does not cause alloy scattering. This decrease in alloy disorder scattering improves mobility, and the larger difference in conduction band energies increases two dimensional electron gas density. Devices fabricated from this structure gave peak currents of 1 A/mm at a V_{gs} of 2 V and an output power density of 8.4 W/mm with a PAE of 28% at 8 GHz.

The best GaN power FET technologies have been based on the use of SiC substrates. Though sapphire is cheaper and easily available in large diameters, its poor thermal conductance compared with SiC has meant that devices on sapphire have yielded much lower power performance figures. Ando *et al.* of NEC reported GaN devices on thinned sapphire substrates with performances comparable to those on SiC substrates. The AlGaN/GaN heterostructure was grown by MOCVD on 300 μm thick sapphire substrates. The HFET devices were fabricated and the sapphire substrate thinned by mechanical polishing to 50 μm to aid thermal management. Power measurements at L-band frequencies were performed with the devices packaged in ceramic carriers. An 8 mm wide device gave 11.9 W CW output power, 13.3 dB linear gain and 49.7% PAE at 26 V drain bias. At 16 mm and 32 mm the devices' output power increased to 22.6 and 113 W, respectively, while gain dropped to 9.4 and 6.8 dB.

Wu *et al.* from Cree presented the findings of a study into the bias dependent performance of AlGaN/GaN HEMTs grown on SiC substrates. The devices had gates 300 μm wide and 0.6 μm long, and achieved a power density of 10.3 W/mm, the highest for any FET of the same dimensions. A promising aspect of the devices was their ability to generate a flat PAE plateau of 56–62% at 8 GHz across a wide bias voltage span (10–40 V), ensuring the devices' suitability for use across a range of power-supply requirements.

The role of surface states

Control of surface traps in AlGaN/GaN devices has been recognized as a critical issue for improving device performance (see *Compound Semiconductor* August 2001, p58). The use of a SiN passivation layer has been shown to markedly reduce surface trapping and hence current collapse in the channel at large bias voltages. Kikkawa *et al.* from Fujitsu and UCSB demonstrated the combination of a thin n-type GaN cap layer combined with SiN passivation and a recessed ohmic structure (figure 2). The GaN cap layer controlled the polarization-induced surface charge, while the SiN layer stabilized the GaN surface between the source and drain electrodes. Recessing and isolation prevents leakage currents propagating through the surface region to the source and drain electrodes, resulting in an increase of the on-state breakdown voltage from 50 to 70 V.

Conversely, while many researchers attempt to reduce surface states for RF power

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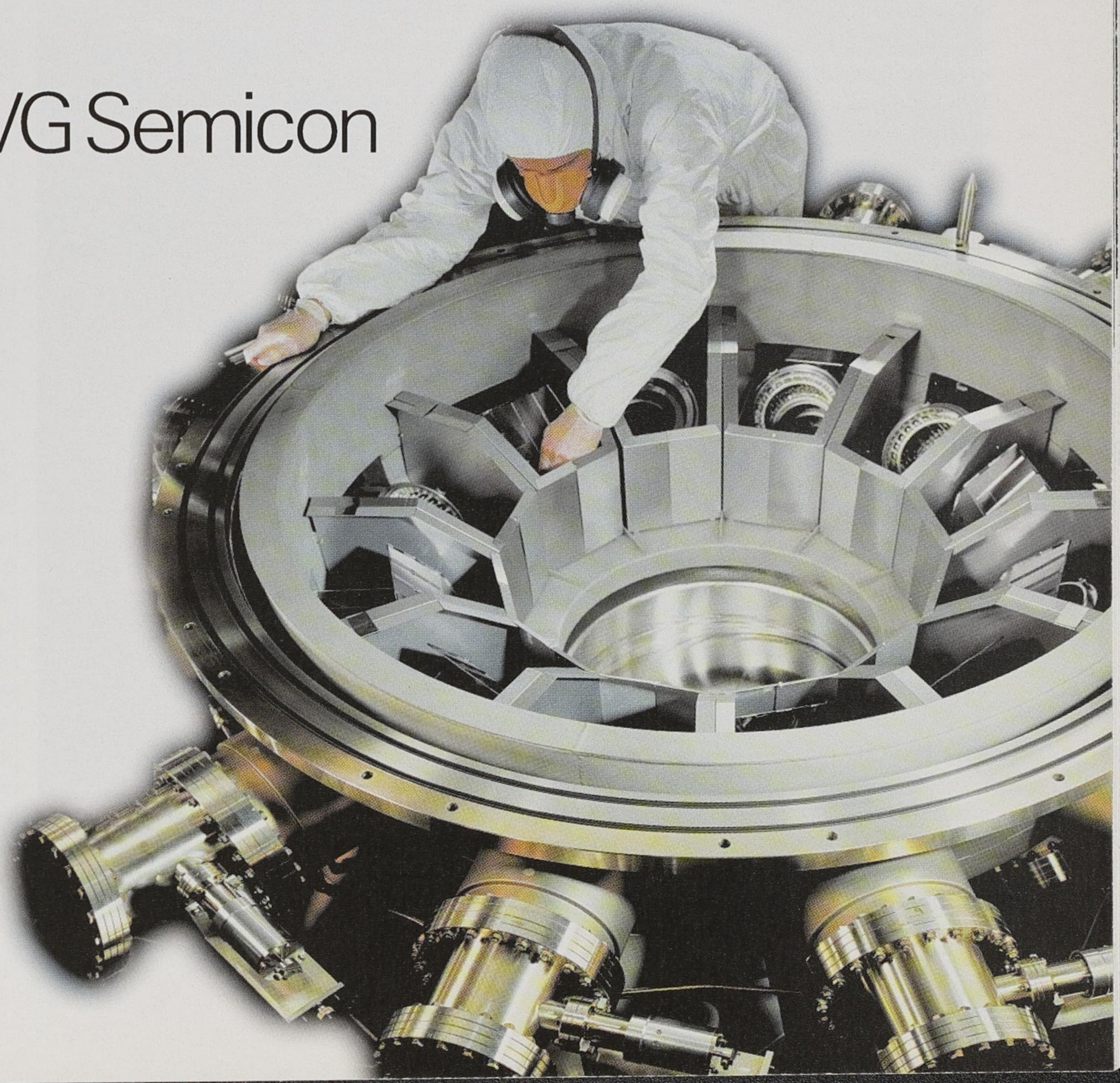
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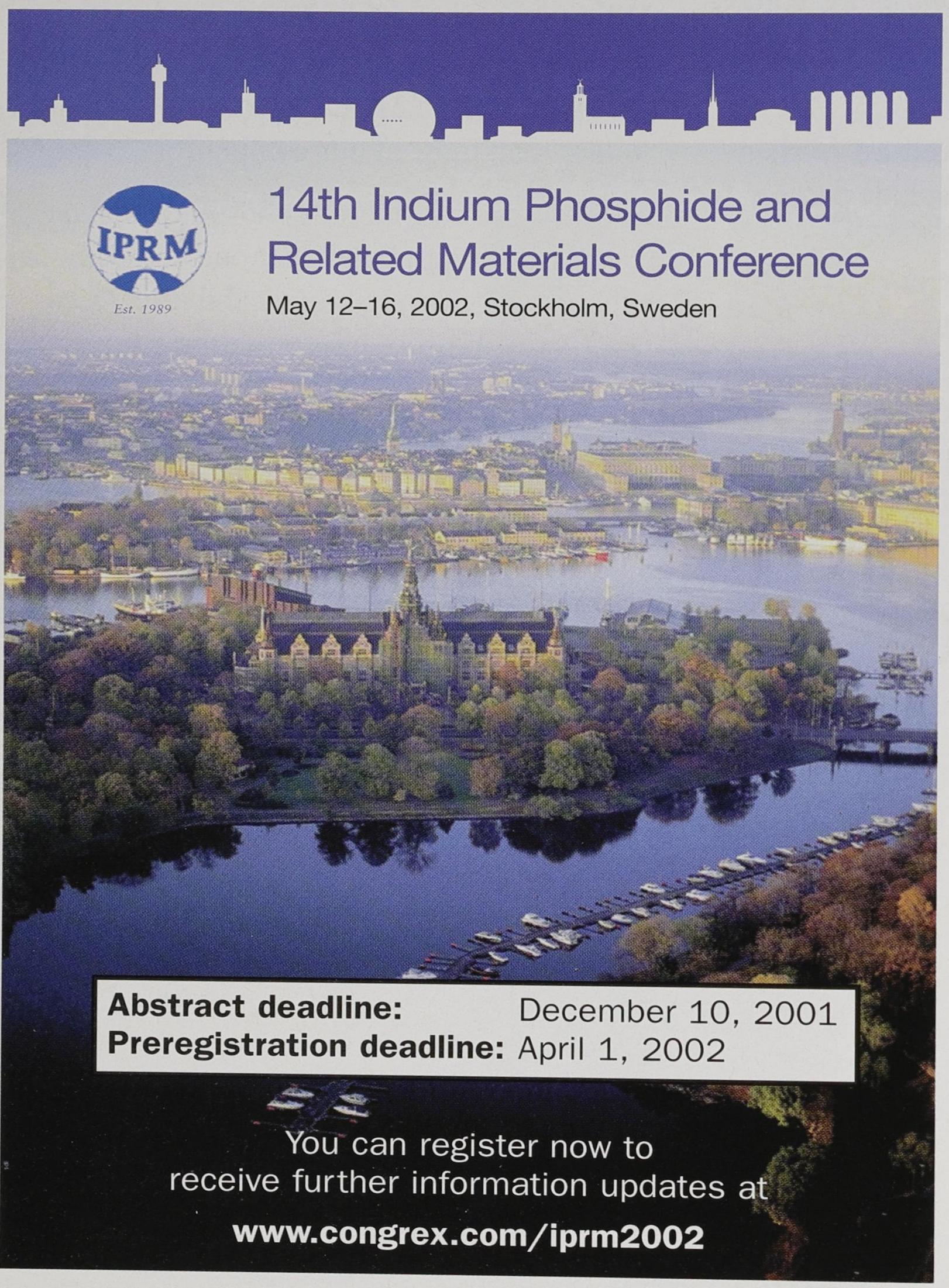
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devices, a team from UCSB and Yale University has investigated the effects of surface traps on the breakdown voltage for GaN power switching HEMTs. Showing that the presence of surface traps increases breakdown voltage, the team fabricated a HEMT with a breakdown voltage of 1050 V. The proposed mechanism for this increase is the filling of positive surface traps with electrons injected from the gate electrode during pinch-off (figure 3). With surface traps filled with electrons, the channel charge is vertically, instead of laterally, depleted by the drain bias. With no lateral depletion, the lateral electric field (E_x) at the drain side of the gate electrode is reduced, giving a higher breakdown voltage.

The team fabricated an insulated gate HEMT using an SiO_2 film deposited by jet vapor deposition. The film formed deep surface traps on the AlGaN to capture electrons on the surface near the gate electrode. This gave a large breakdown voltage at the expense of slower switching speed.



Heterogeneous integration

There were a number of presentations that were focused on schemes to integrate devices constructed from dissimilar materials. Brown *et al.* from Georgia Institute of Technology and the University of Wisconsin, discussed the growth of GaN on $LiGaO_2$ (see *Compound Semiconductor* November 2001, p38), and the subsequent integration of photodiodes with silicon circuitry.

Egawa *et al.* from Nagoya Institute of Technology, Japan, presented work on the development of reliable InGaN MQW green LEDs grown on silicon substrates. Though blue LEDs have been fabricated with some success on large-area silicon substrates (see *Compound Semiconductor* November 2001, p63), as yet little progress has been made with green LEDs on silicon. The Nagoya group reported an output power of 20 μW at 505 nm for 20 mA drive current at 7 V. This compares with 40 μW at 20 mA drive current at 4.5 V for green LEDs on sapphire. Lifetime tests showed that the power output dropped by 2% after 500 hours of operation at room temperature. Further improvements in buffer layer and MQW quality are expected to improve performance levels towards those seen on sapphire.

The results of work to integrate GaAs-based optoelectronic devices with a silicon platform by DC electric-field-assisted transport was presented by O'Riordan *et al.* of the NMRC in Ireland. Device transport and localization is performed by the application of DC fields between arrays of individually addressable Au or Pt receptor and counter electrodes, defined on the silicon and coated with Sn/Au solder. Using this method LEDs as small as 50 μm in diameter, suspended in a non-aqueous solvent, could be successfully transported and placed at selected locations. The group demonstrated the method in action by showing a video of two 80 μm diameter LEDs being transported on to two separate electrodes (figure 4). The use of a non-aqueous solvent enables the placement of devices without damage to layers sensitive to aqueous solutions. Following assembly, the devices were bonded to the substrate by solder reflow in air and electrically tested. The group has also extended the technique to the parallel integration of two dissimilar devices, 80 and 50 μm diameter LEDs emitting at 650 nm.

Component makers move towards automated processes

Optoelectronic component manufacturers are currently experiencing considerable downward cost pressure. **Bruce Hueners** of Palomar Technologies looks at how the component makers are moving towards improved high-accuracy, high-yield automated methods of testing, assembly and packaging.

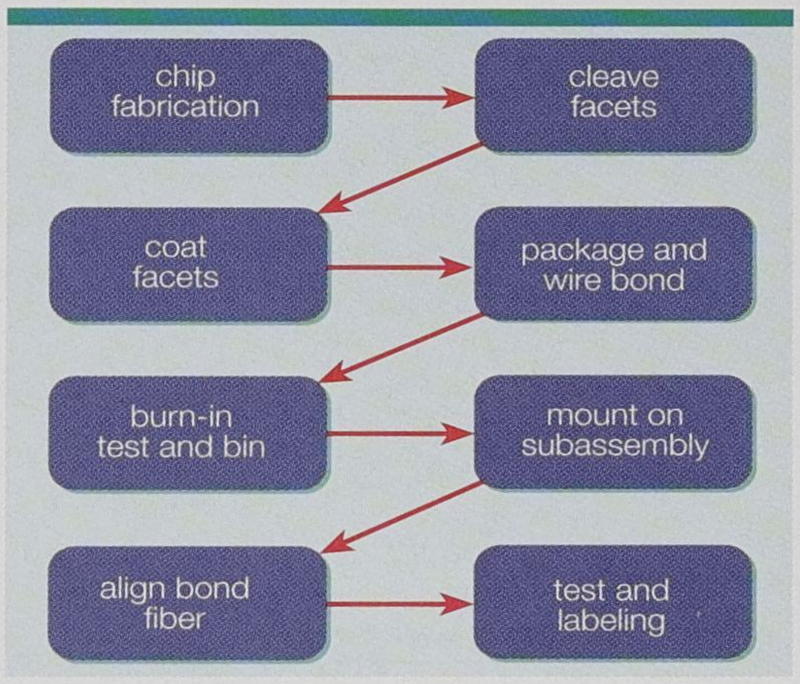


Fig. 1. Schematic of a generic fiber-optic device assembly process.

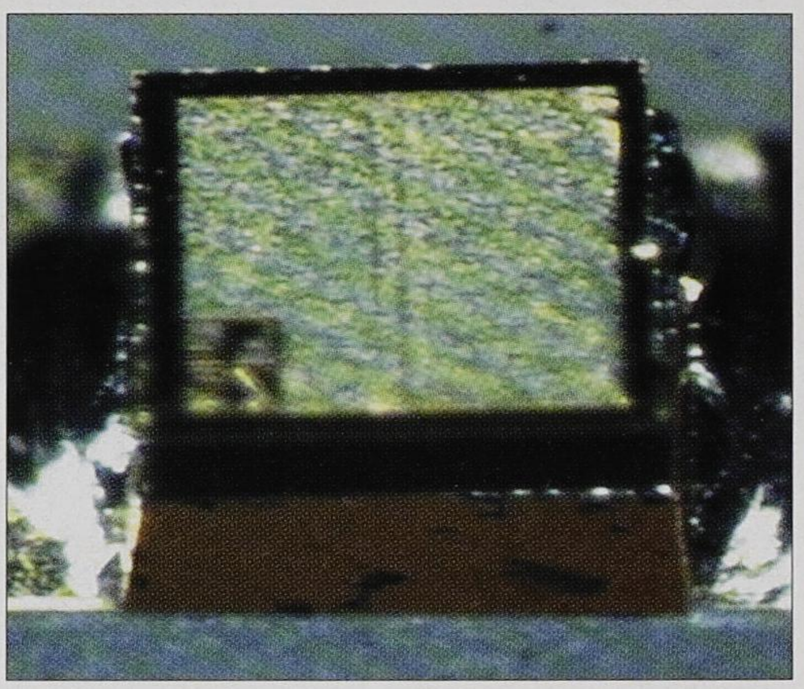


Fig. 2. An InP laser diode (shown p-side up) mounted with a gold-tin preform.

Even with moderated growth projections, the downward pressure on optical component costs is forcing significant improvements in the processing, packaging and testing of these devices. For key active components such as source and pump lasers, an understanding of the factors that influence yield, performance and reliability are essential to provide lower cost packaging and test solutions.

Fabrication and packaging

Today, fiber-optic component manufacturing is predominantly a manual process of handling and assembly. These methods include custom wafer processing, thin-film processing, device and subassembly packaging (including eutectic and epoxy component attach and wire bonding), fiber handling and alignment, and the finish steps of tuning, adjusting and testing. Multiple fabrication techniques and processes are common, coupled with a lack of package and material handling standards. A generic process in fiber-optic device assembly is shown in figure 1, and explained below.

Chip fabrication A substrate crystal orientation of (001) is essential for fabricating lasers since parallel mirrors should be made by cleaving the wafer in the (110) plane that is normal to the (001) crystal plane. Grooves 50 μm deep are fabricated by photolithography, with spacing of about 200–300 μm in the wafer to provide scoring lines for chip singulation. Wafers are normally polished from the back-side down to about 100 μm.

Facet cleaving Next, the wafer is cleaved along the direction normal to the grooves in the wafer. At this point in the procedure, special care must be taken to prevent surface damage of the laser, which can introduce dislocation defects that propagate inwards from the chip edges. At this stage, each diode is tested under pulsed operation, and good devices are selected.

Facet coating After cleaving the wafer into diode arrays or bars, both mirror facets are protected by a dielectric film such as SiO_2, Al_2O_3 or Si_3N_4, which is usually deposited by RF sputtering or CVD. There are two reasons for protecting the mirror surface from exposure to the atmosphere; to suppress oxidation of the facet, which causes long-term degradation, and to reduce surface recombination velocity. This latter parameter is important for catastrophic failure, since a higher surface recombination velocity lowers the critical degradation level.

Die separation The diode arrays are divided into chips by applying stress along the grooves. Only good diodes are selected.

Mount on subassembly This operation includes both die bonding and wire bonding of singulated diodes (see table "Processes for optoelectronic assembly"). Special care must be taken not to introduce thermal or mechanical stress during this procedure. During the device fabrication process, external stress may be applied to the diodes. When cleaving processed wafers into diode arrays, mechanical damage can be induced from the cleaved edge of the crystal. In some cases, dislocations are generated from such regions. During die attach or wire bonding, thermal or mechanical stress is applied to the diode chips, which may accumulate elastic strain in the diode or generate mechanical damage or scratches in the crystal. To minimize stress, this assembly process should be automated and recipe-driven for extremely repeatable and consistent results (figure 2).

Critical considerations

Several critical process considerations affect performance and reliability, such as the introduction of stress or mechanical damage during the fabrication and assembly process, and the onset of catastrophic optical damage.

Stress and strain Elastic strain can result from the difference in the thermal expansion coefficient between the epitaxial layers and the electrodes, and insulating films in the chip fabrication process. External stress can also be induced during cleaving of the wafer into diode arrays or during cleaving of the diode arrays in chips. External stress can also be induced during the die-bonding and wire-bonding processes. This stress can be managed with an automated, recipe-driven process.

Mechanical damage Scratches and cracks

Processes for optoelectronic assembly

process	*details*
eutectic component attach	• *in situ* pulse heat • gold-tin preform
epoxy component attach	• conductive and non-conductive adhesives
Wire bond	• gold wire (25 µm diameter) • gold ribbon (25 x 75 µm)
fiber alignment	• passive • active
active component alignment	• lens-to-lens • lens-to-fiber

Laser diode measurement categories

electrical	measurement of voltage drop, photodetector monitor current and light output
spatial	output light intensity profile in the far and near field and pointing angle of the radiation pattern
spectral	spectral data acquired to calculate center wavelength, spectral width and observe mode structure
optical	measurement of astigmatism and other wavefront errors
dynamic	measurement of rise time, fall time, chirping, noise and intermodulation distortion

often arise during the handling of the chips and/or cleaving of the diode arrays. Since mechanical damage and cracks involve a high density of dislocations, they can be origins for rapid degradations and thus should be eliminated. For this reason, manual handling should be minimized and replaced with consistent and predictable mechanized handling. For example, AlGaAs/GaAs high-power lasers degrade rapidly through the generation of DLDs (dark line defects). DLDs propagate from cracks or from regions of mechanical damage that exist in the active layer far away from the active region where weaker light emission is generated.

Catastrophic optical damage (COD) This defect is normally detected at the subassembly level when the laser chip is tested under power. In extreme cases, facets in degraded diodes are scorched during the lasing because critical optical power density has been exceeded. Failure mechanisms include DLDs and dislocations. The mechanism of catastrophic failure typically proceeds as follows:

- During pulsed lasing operation, rapid nonradiative recombination occurs at the mirror surface, causing a decrease in the bandgap of the active layer.
- Strong optical absorption occurs at the mirror, causing a local temperature rise and a further decrease in the bandgap.
- Above certain COD power levels, this positive feedback gives rise to thermal runaway up to the melting point.
- After the pulse, the molten region at the facet cools rapidly and is recrystallized, and a large number of dislocation loops and microdefects are quenched into this region to compensate for the volume change from liquid to the solid phase. The highly defective region terminates in the form of dark areas, which are likely to be non-crystalline, amorphous regions.
- When the next current pulse is applied, the same phenomenon occurs and the molten region propagates from the mirror surface to deep into the inner crystal region of the active layer until the optical power drops below the critical value (Ueda).

Most manufacturers have recognized that a paradigm shift in assembly methods will have to take place to drive down component costs and accelerate time-to-volume.

Higher reliability, lower costs

The packaging process for an optoelectronic device challenges efforts to reduce costs. Because the purpose of an optical component is to manipulate light, the design rules for packaging are significantly more complex than those found in the semiconductor industry. With semiconductors, advances in wafer processing drive technology, and packaging is very automated and planar. With optical components, the front-end process is significant, as we have seen, but equally important for photonic devices are package design, controlled assembly processes and meeting critical assembly tolerances.

The importance of recipe-driven process control for optoelectronic assembly can be illustrated by considering the case of attachment of a laser diode within a source or pump laser. This is an extremely temperature-sensitive device that requires careful process control during assembly. Laser operating temperature is a key factor in device reliability as threshold current tends to rise with temperature, increasing the amount of waste heat generated. Furthermore, laser lifetime decreases as temperature increases. Given these device requirements, it is clear that recipe-driven process control is essential in the fabrication of laser diodes.

Laser diodes are attached via a low-ohmic, high-thermal conductivity metalization in a precisely controlled place and eutectic reflow process (figure 3). The reflow profile during an automated *in situ* eutectic die attach process is engineered to provide consistent melting and a void-free attach interface. This results in smooth heat transfer from the diode and contributes significantly to temperature stabilization during laser operation (figure 4).

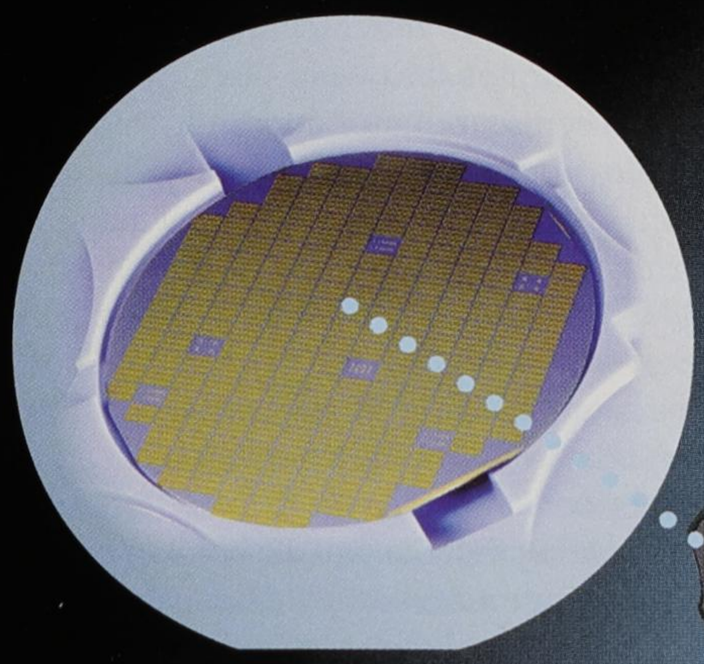
Programmable pulse heating coupled with automated component attach provides the recipe-driven process control essential to producing high-yield, high-performance laser diode assemblies. During the *in situ* reflow process, temperature slopes for heating and cooling, overshoot and dwell times are programmable to enable process optimization and repeatability. Tightly coupled temperature control ensures profiles are tracked repeatably in production.

Laser diode characteristics

Laser diode characterization can be broken down into five categories (see table "Laser diode measurement categories"). The most common form of characterization is the L/I curve, which plots drive current against output light intensity. This curve is used to determine the laser's operating point (i.e. drive current required to provide rated optical power) and the threshold current (current at

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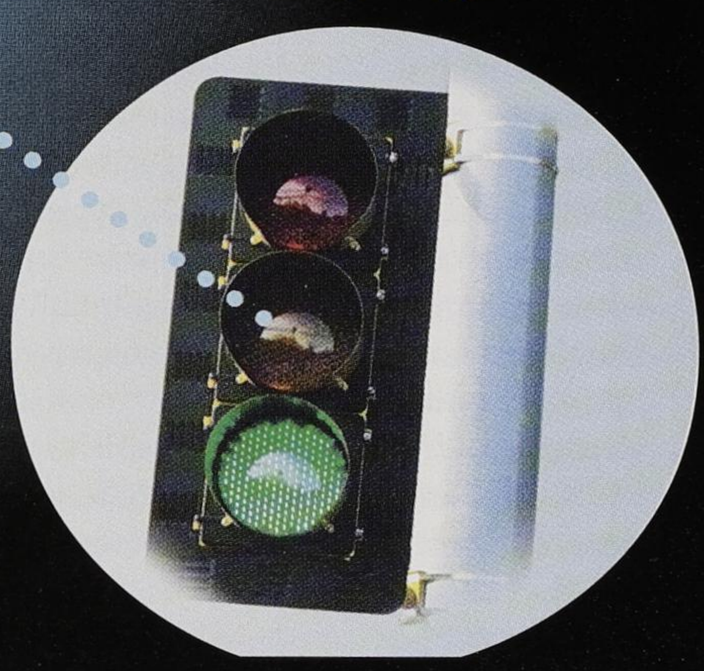




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which lasing begins). The threshold of the laser is strongly affected by its temperature. Typically, laser threshold will increase exponentially with temperature in proportion to exp (T/T_0), where T is the laser temperature and T_0 is the characteristic temperature of the laser (typically 60–150 K).

The efficiency of a laser diode is also derived from the L/I curve. It is commonly expressed as slope efficiency and measured in units of mW/mA. Although not as apparent as threshold shift, laser efficiency falls off with increasing temperature. Efficiencies are typically about 0.3 mW/mA at 25 °C, and drop about 0.01 mW/mA for every 10 °C increase in temperature.

The L/I characteristics may also be acquired in a low-duty-cycle pulsed mode. The increase in threshold and decrease in slope efficiency observed in CW operation, as compared with pulsed operation, stem from the rise in junction temperature. This rise, due to the thermal resistance of the device, is typically 40–80 °C/W. Typically, pulse widths used in this type of measurement are 100–500 ns, with a duty cycle of less than 1%.

Unusually large differences between the CW and pulsed L/I curves may suggest poor die attachment or a leaky junction, and are often an indicator of poor laser quality. As a rough estimate, lifetime is reduced by an order of magnitude for every 30 °C rise in case temperature. It is usually desirable to operate the laser at as low a temperature as possible, depending on the laser type (Hertsens).

Summary

Currently, the optoelectronic component manufacturing industry is under considerable downward cost pressure. Most manufacturers have recognized that a paradigm shift in assembly methods will have to take place for them to drive down component costs and accelerate time-to-volume. That shift is emerging as a move from the manual assembly processes that have characterized the industry for decades, to high-accuracy, high-yield automated manufacturing and testing.

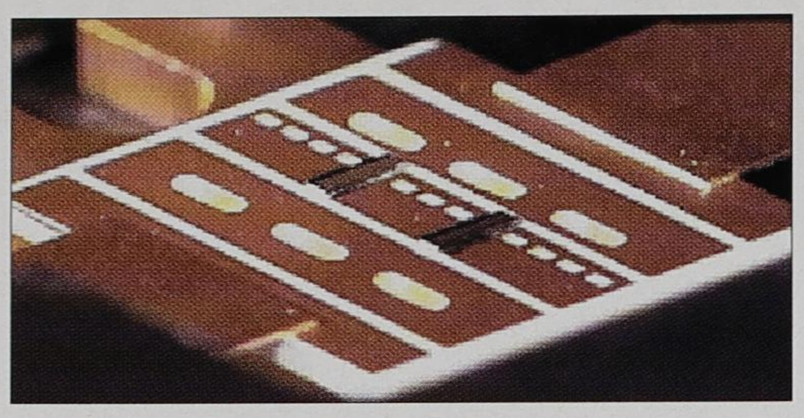


Fig. 3. Multichip eutectic component attach on a gold-plated substrate.

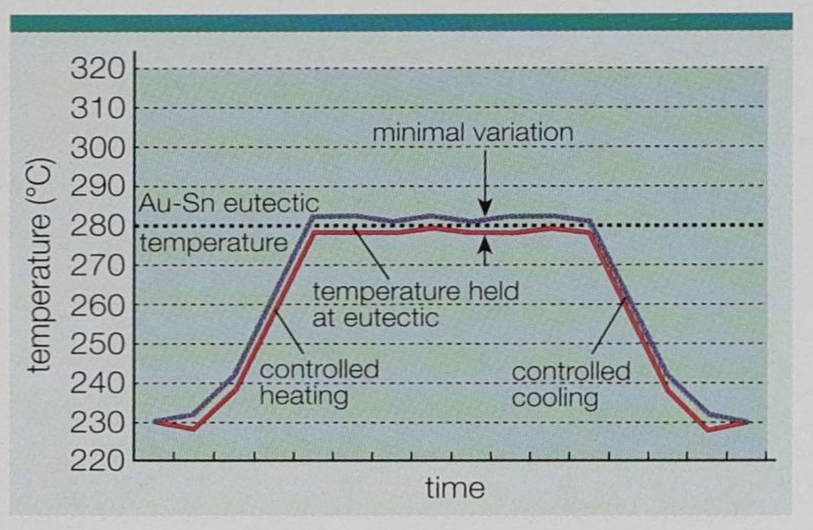


Fig. 4. A programmable reflow profile for laser diodes, which achieves consistent melting and heat transfer, and a void-free attach interface.

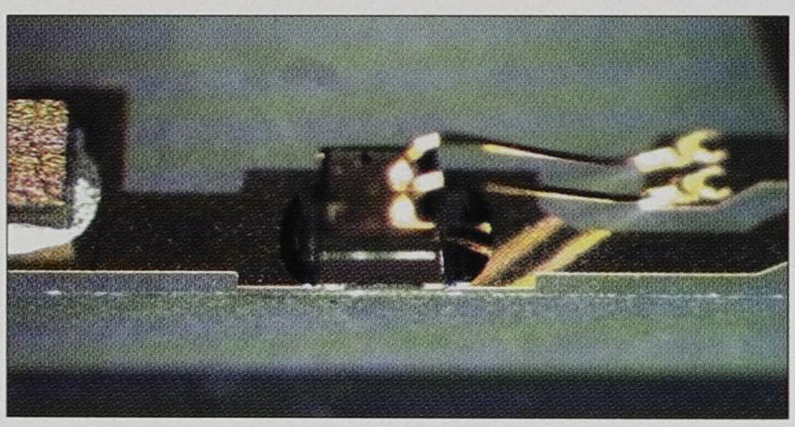


Fig. 5. An example of gold wire bonding to an InP laser chip.

While automation will eventually be able to provide complete process solutions for the optical component assembly industry, there are currently significant challenges to automation. The combination of extreme accuracy and process requirements, significant variations in height, unusual form factors, unusual materials and the inherent difficulties arising from the requirement to guide light, have prevented most equipment available today from being utilized in optical component packaging.

Fortunately, there are a few available systems that have the flexibility to support these difficult tolerances and process requirements. Specifically, die attachment and wire bonding techniques that were developed in the hybrid semiconductor and high-frequency wireless industries are now being incorporated into the optical component manufacturing industry. So far, the early results from the implementation of this equipment have been very encouraging. In actual case histories companies have experienced a 50% increase in yielded throughput and a 67% reduction in required cleanroom floor space by replacing four manual die bonding stations with a single automatic die bonder. Furthermore, automated wire bonders are facilitating the move to higher frequency devices, as they have superior control of wire length and loop profiles when compared with manual processes (figure 5).

We are now seeing the emergence of an equipment supplier base that is able to support the stringent tolerances of the optoelectronic component assembly industry. The equipment that these suppliers are designing today will not only facilitate the efficient manufacture of optical components, but will enable the component designers to continue to push the envelope of communications technology into the foreseeable future. ●

Further reading

T Hertsens *Measuring Diode Laser Characteristics* ILX Lightwave Application Note No. 5.

O Ueda 1996 *Reliability and Degradation of III-V Optical Devices* Artech House.

Bruce Hueners is with Palomar Technologies of Vista, CA, a supplier of automated equipment for the production of optoelectronic and high-frequency wireless components. Tel. +1 800 854 3467. Web www.palomartechnologies.com.

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Gas purifiers earn their place in MOCVD material growth

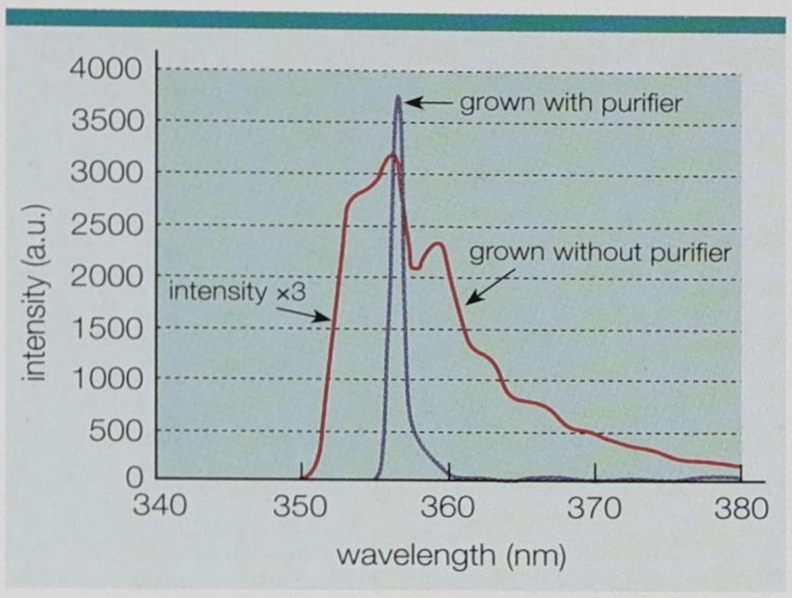
The industry's battle for ever-purer gases in semiconductor manufacturing is being fought on many fronts, including their point of use. **Jon Newey** takes an in-depth look at all the options that are available in the MOCVD process to ensure purer gases during semiconductor growth.

Cleanliness is everything in any semiconductor manufacturing process. The link between unwanted impurities and poor material and device quality is well established. There are many potential sources of impurities and one area to which particular attention has been paid is the use of gases. These are used in almost every stage of device production including bulk crystal growth, epitaxy and dry etching. Where compound semiconductor processes are concerned, impurities will affect the electrical characteristics through compensation of dopants or unintentional doping, shift the intended emission wavelength in lasers or LEDs, and reduce device lifetime by degrading the interface and introducing imperfections in the crystal lattice (figure 1).

Epitaxy, in particular MOCVD, makes use of a variety of gases including arsine, phosphine and ammonia as source materials for growth and doping, as well as hydrogen as a carrier gas for metalorganic (MO) precursors. The purification of MO sources is a subject to which much attention has been paid over the past few years, and considerable progress has been reported (*Compound Semiconductor* February 2001, p84). However, the end user has no control over the quality of MOs beyond carefully changing bubblers and maintaining the pipework between the bubbler and reactor. This is not true of the various gases employed for MOCVD.

Point of use (POU) gas purifiers are an option available to the gas user. As the range of gases in use has expanded over the years and purity requirements have become increasingly stringent, the variety and performance of POU purification methods have improved. These purifiers can be divided into three main types: palladium membrane cells, catalytic purifiers and getters.

Palladium membrane cells are used to purify hydrogen by allowing only hydrogen to diffuse through a Pd membrane, which



SAES GETTERS

Fig. 1. An example of the low-temperature photoluminescence spectrum from GaN which has been grown both with and without an ammonia purifier.

leaves all the impurities behind. Catalytic purifiers rely on a number of processes to separate impurities from a gas. They are mostly regenerable and operate at ambient temperature. Getter purifiers contain a heated metal alloy that reacts with impurities to bind them at the surface then diffuse them into the bulk.

Why install POU purifiers?

For the end user gas impurities can arise from a number of sources. As well as being present in the gas that is supplied from the manufacturer, impurities can arise from unclean or leaking gas distribution pipework, or as a result of improperly changed gas cylinders. Therefore, the most common impurities that need to be dealt with are those originating from the atmosphere such as oxygen and water vapor. A POU purifier gives the user a measure of insurance against inconsistency in the quality of gas from a manufacturer and a buffer against problems with the gas-distribution network. But it should be noted that fitting a POU purifier itself introduces another possible source of contamination. Attention must be paid to the way such purifiers are used, and to replacement and/or regeneration schedules to ensure the purifier does not reintroduce the impurities that have already been extracted.

Palladium cells and hydrogen

The commonest POU purifiers and the ones that have been used the longest are palladium membrane purifiers, often referred to as Pd-cell purifiers. These may be used in MOCVD systems where hydrogen acts as a carrier gas. Any impurities in the hydrogen may react with the MO, possibly contaminating an entire batch of expensive precursor. Impurities could also be incorporated into the growing epilayer.

The Pd-cell contains tubes made from Pd membranes and is operated at 300–400 °C. Hydrogen, at a pressure of about 250 psi, is usually fed into the cell in such a way that it arrives at the outside of the Pd tube membrane. The H_2 molecule dissociates into protons and electrons which diffuse across the membrane to the inside of the tube where they recombine and are fed out of the cell (figure 2). Typical impurities such as H_2O, CO and O_2 are inefficient at dissociation and migration, so they do not migrate into the tube.

Cell throughput can be varied from 1 to 1000 l/h depending on the pressure drop across the membrane and its thickness. Pd-cells typically last 3–5 years, though their failure is very unpredictable, and is usually the result of the membrane cracking or developing pinholes. These failure modes can be caused by sudden exposure to high impurity levels (for example, more than 50 ppm of oxygen) or rapid thermal cycling. Power loss can cause sudden and uneven cooling of the membrane resulting in cracking. The Pd membrane is also damaged if it cools in the presence of hydrogen. For this reason when power is lost the cell needs to be immediately purged with nitrogen. Despite the undoubted ability of the membrane to purify hydrogen to a high level, the sudden failures have been a source of frustration to users and have prompted the development of competing techniques. As Eric

Armour of Emcore's electronic materials division points out, "Pretty much everyone using [Pd-cells] has experienced the sudden failures. If they could make them highly reliable they would be the ultimate hydrogen purifier."

Solving the Pd-cell problems

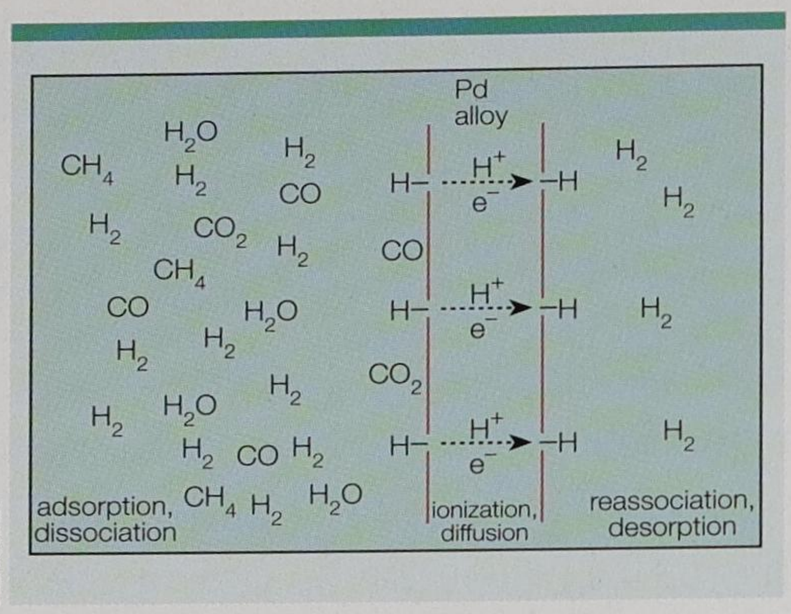
In an effort to improve the reliability of Pd-cells Matheson Tri-Gas, in collaboration with hydrogen purification specialists Power and Energy (Ivyland, PA), has made some design changes to reduce the impact of power loss on the cells. Conventional Pd membrane tubes have diameters of about 1.5 mm. Slight imperfections in the tubing can cause crushing under the high pressure of the hydrogen feed. The new cell, PerfectH2, feeds the hydrogen from the inside of the tube so that it diffuses outwards. The tube is thus under tension rather than compression and will not crush. The tubes can therefore be made with a larger diameter improving the flow of both the hydrogen and the nitrogen purge gas. When power is lost the hydrogen flow is automatically stopped and a small nitrogen flow at about 75 psi is fed into the cell. The ability to purge using a smaller nitrogen flow reduces the thermal load on the membrane.

Conventional designs using small-diameter tubes often contain steel internal strengthening wires to limit crushing under high-pressure operation. It is harder to clean these tubes after manufacture than the larger ones without the need for wire reinforcement. As a result of this the cell may introduce hydrocarbon contamination to the purified hydrogen. As the PerfectH2 uses an internal feed, any contamination from the manufacturing process is kept inside the tube so it is not exposed to the purified hydrogen that has passed to the tube exterior.

Hydrogen delivery

Hydrogen can be delivered from the manufacturer as a pressurized gas or in liquid form. Small facilities with low demands for hydrogen usually opt for pressurized gas. Though hydrogen is less pure as a pressurized gas than it is as a liquid (99.995% compared with 99.9995%), it is cheaper to handle. Ironically liquid hydrogen is cheaper to manufacture as well as purer. Larger facilities running multiple MOCVD systems on a 24 hour working day can benefit from liquid hydrogen's greater purity while spreading its increased handling cost over a wider production base.

The use of liquid hydrogen causes problems for Pd-cell purifiers, as the low delivery pressure (approximately 100 psi) makes diffusion across the Pd membrane very slow. Therefore multiple Pd-cells running in parallel are required to maintain the necessary hydrogen volumes, making the use of Pd-cells expensive as multiple cells must be purchased and heated. This is another reason for the development of alternatives to Pd-cells.



AERONEX

Fig. 2. Hydrogen ionization and diffusion through a Pd alloy membrane.

Catalytic purifiers

Purifiers that use catalytic media to remove impurities from a gas stream rely on a number of processes including adsorption, chemisorbtion and oxidative addition. The composition of a catalyst and the reaction chemistry depend on the gas being purified and the impurities being removed. Catalysts manufactured for the purification of hydride gases such as ammonia, phosphine and arsine, for example, contain a medium tailored for the gas to be purified. While arsine and phosphine are troubled by similar impurity species arsine is more prone to decomposition, so the gases have different purification techniques.

Typically, a catalyst will be a silicate-based zeolite with a porous structure giving it a very large surface area. There are a wide variety of zeolites with porous structures of different sizes. Chemically active species (usually metals) may be dispersed onto the zeolite which acts as an inert support. The metal chosen will depend on the process gas and impurities to be removed. The metal will react directly with the impurity or by first adsorbing the gas to form a surface that is highly reactive to contaminant species. SAES manufactures a range of ambient-temperature purifiers that utilize metals dispersed on a large-area zeolite. A Mn/Fe alloy is used for its ammonia purifier, while boron is used for the etchant gas HCl.

A catalytic POU purifier often contains more than one type of active site and impurities will be removed by a combination of mechanisms. For example Aeronex manufactures a range of catalytic purifiers, with the version for hydrogen purification containing nickel dispersed on a high surface area silicate. This reacts to remove impurities including O_2, CO and CO_2, but has limited ability to deal with moisture levels below 100 ppm. To deal with moisture more effectively, a second titania catalyst is added to the purifier.

Matheson Tri-Gas also makes catalytic purifiers that operate using a range of zeolite-based media or a porous organometallic resin. The resin is black in its unreacted form and gradually turns brown as it reacts with impurities. This provides an indicator of the remaining useful life of the purifier. These purifiers must be preconditioned by the manufacturer with the process gas, and the reactions with impurities are irreversible. Once the resin is preconditioned and packaged it must be kept sealed as exposure to the air will render it useless. Also there are environmental issues associated with these resins as they are toxic and must be disposed of carefully once they reach the end of their useful life.

The great attraction of catalytic purifiers is that they operate at ambient temperature. Since they do not require heating, they can't be damaged by a sudden power loss. Also they do not require large pressure gradients across the purifier so are compatible with low-pressure liquid-hydrogen delivery systems. Most catalytic reactions are reversible by heating, which means the purifier can be regenerated, though it may need to be returned to the manufacturer. In cases where the purifier can be safely regenerated by the user, it is common for two purifiers to be installed; while one is in use, the second can be heated and purged.

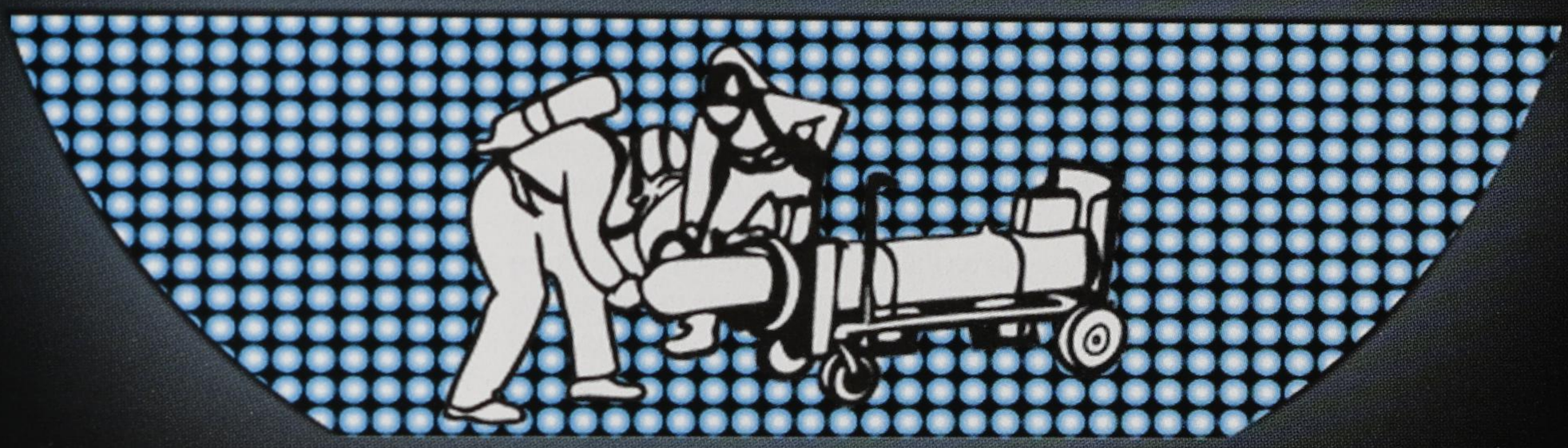
Getter purifiers

Many of the impurities commonly found in the gases used in MOCVD and other processes will react readily with certain materials known as getters. Gettering processes have been used in the removal of residual gases in vacuum systems and in gas purification. In gas purifiers the getter material will typically be a zirconium-based alloy that readily forms nitrides, oxides and carbides. However, not all getter reactions take place at ambient temperatures so getter purifiers are operated at about 450 °C. The high temperature also speeds up the diffusion of gettered impurities into the bulk of the getter material, making surface sites free once more for adsorption.

Unlike many of the ambient-temperature purifiers, the reactions are irreversible so



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replacement rather than regeneration is necessary once the purifying medium is saturated. However, the lifetime of a getter can be up to 40 times that of the ambient-temperature purifiers depending on gas-flow rates (up to 2000 l/h) and contamination levels. As the zirconium-based alloy absorbs impurities its electrical resistance changes, giving an indicator of its useful lifetime. As with catalytic purifiers, getters do not require large pressure gradients to operate and are less affected than Pd-cells by sudden cooling caused by power loss. Indeed, getters have found use in MOCVD systems between Pd-cells and MO bubblers to provide a back-up in case of sudden Pd-cell failure that could otherwise result in the contamination of an MO source.

Ammonia

The development and commercialization of nitride-based LEDs have seen the use of ammonia in MOCVD undergo a steep rise. With GaN-based lasers and HEMTs approaching commercialization, this situation looks set to continue. However, it is not just demand for GaN-based devices that makes ammonia a gas used in large volumes. The nitride growth process is relatively inefficient because the ammonia does not readily decompose on the growth surface. A higher group V:group III ratio is required in comparison with arsenide or phosphide growth, so high ammonia flow rates are necessary.

Ammonia has shown itself to be one of the more complex gases. The main impurity of concern is water because it is particularly soluble in liquid ammonia. Matheson Tri-Gas has shown that the partition coefficient for water between the liquid and gas phases of ammonia is 200:1, so measuring 1 ppm of water in the gas phase means that 200 ppm is present in the liquid source (Funke *et al.*). This was established under quasi-equilibrium conditions. When drawing vapor during growth, conditions are far from equilibrium and the partition coefficient changes significantly. In typical flow conditions during growth, a 1 ppm specification ammonia actually delivers about 7 ppm moisture.

In addition it has been demonstrated that because water is so soluble in ammonia, and also because of the high partition coefficient between liquid and gas-phase ammonia, the water concentration will rise exponentially as the ammonia container is emptied, as shown in figure 3 (Torres *et al.*). Because of this effect an MOCVD grower typically replaces an ammonia cylinder once it is 70% consumed.

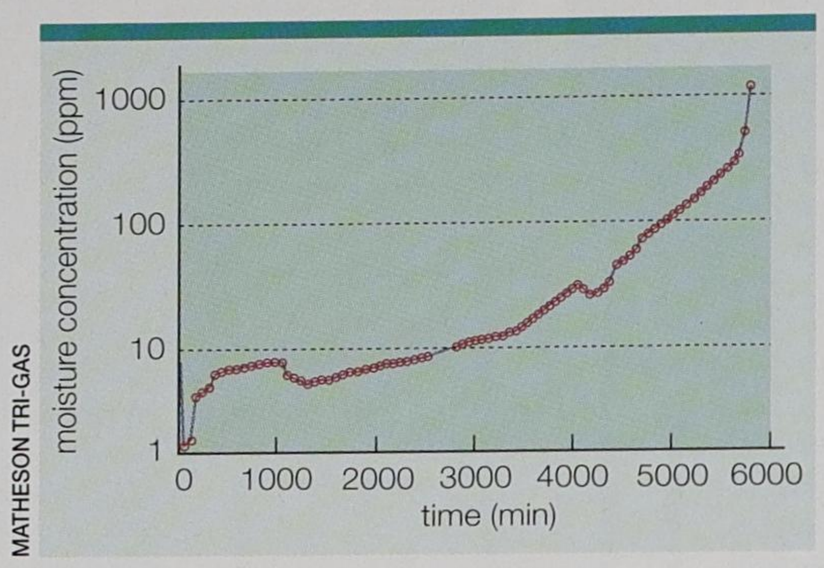


Fig. 3. Moisture concentration in a cylinder of ammonia as the cylinder is emptied.

Uniroyal's Eric Bretschneider: "We are in this business to make money. The economics will almost always point you towards using lower-grade ammonia with a purifier."

These complicated issues with ammonia purity make POU purifiers important but also difficult to use. A POU purifier's useful life depends on the impurity levels in the gas to be cleaned. Since impurity levels in the ammonia vapor will depend on the flow rates and the amount of ammonia left in the container, careful monitoring and conservative estimates are needed to decide when a purifier should be replaced to avoid poor material. As Eric Bretschneider of Uniroyal Optoelectronics points out, "At Uniroyal we have found empirically that there is no good endpoint detection for the ammonia purifier. We will get bad material first." Unfortunately the degradation in epitaxial growth is not necessarily an accurate indicator of the endpoint of a purifer. "Purifier failure in terms of what happens to the epi growth can be mimicked by a lot of other things," says Bretschneider.

The business case for purification

Users of ammonia in low volumes, such as small research labs, may dispense with a purifier and simply use the highest-grade ammonia available such as Solkatronic's Blue Ammonia or Praxair's 99.99995% (6.5 nines) grade ammonia. Carefully monitoring usage and the quality of the epi material will determine when the source should be changed. Deciding whether to use a purifier comes down to a cost-benefit analysis. There is a large difference in price between 5 and 6 nines grade ammonia. For the user of low ammonia volumes, relying on expensive high-grade ammonia without POU purification may well be the route to adopt. But the math will be somewhat different for the bulk user. As Bretschneider explains, "We are in this business to make money so we need to maintain low operating costs through balancing the selection of raw materials, purifiers and acceptable epi yields. The economics will almost always point you towards using lower-grade ammonia with a purifier."

Cost reduction

As researchers in the compound semiconductor industry have made progress in understanding the links between device performance and impurities in gases and other starting materials, suppliers have been forced to improve their products. "The compound semiconductor industry has far more documented evidence that impurities are important than even the silicon industry," says Stuart Bestrom, director of North American sales and marketing at SAES Pure Gas. Also an economic driver for gas suppliers to improve purity levels has emerged in recent years as compound semiconductors have begun to take a larger slice of the total semiconductor market. "All the suppliers are starting to realize that the compound semiconductor industry is fairly large now, and are really starting to pay attention to us," says Emcore's Armour.

Some of the gases used by MOCVD growers have improved so much that POU purifiers are routinely left out of the gas-delivery system. Arsine and phosphine are not plagued with the same complex issues that affect ammonia purity. The availability of these gases at 6 nines purity has enabled users to omit POU purification where they are confident in their suppliers' guarantees of purity. However, the move towards this standard of purity for other gases does not spell the end of POU purification. The selection of gases and purifiers must be based on a rigorous cost-benefit analysis since compound semiconductor processes compete with CMOS and SiGe in many applications. This analysis will often conclude that purifiers are still needed.

Further reading

Funke *et al.* 2001 *Journal of Electronic Materials* **30(11)** 1438
Torres *et al.* (in press) *2001 CS-MAX Conference Proceedings*

Announcing Purification for MOCVD Production Tools

Aeronex Infinity Gas Purification Systems provide a continuous supply of pure gas at ambient temperature

Purification Enables Process

In MOCVD and MBE films, atomic oxygen shifts the emitted wavelength, increases the bandwidth for optical devices, reduces device life through lattice instability, and decreases the carrier mobility in the film, thereby reducing the speed of the device. Aeronex purification technology improves the performance and lifetime of compound semiconductor optoelectronic and wireless devices by removing oxygen and other contaminants.

Without Interruption

As the process moves from R&D to Production, demand increases for purified nitrogen, hydrogen, and ammonia. Previous purification technologies required halting the process to replace the purifier bed. Today's process engineers require a high flow of pure gas and continuous up-time to maximize return. To meet these challenges Aeronex has developed the Infinity GPS™, which delivers a continuous supply of ultra pure gas without interruption.

Performance

Aeronex purifier technology sets the standard for pure gas. The patented media removes contaminants such as moisture, oxygen, CO, CO_2, and hydrocarbons from gas or liquid sources. This unique inorganic media operates at room temperature and handles high flows at very low pressure, a requirement for next generation MOCVD equipment.

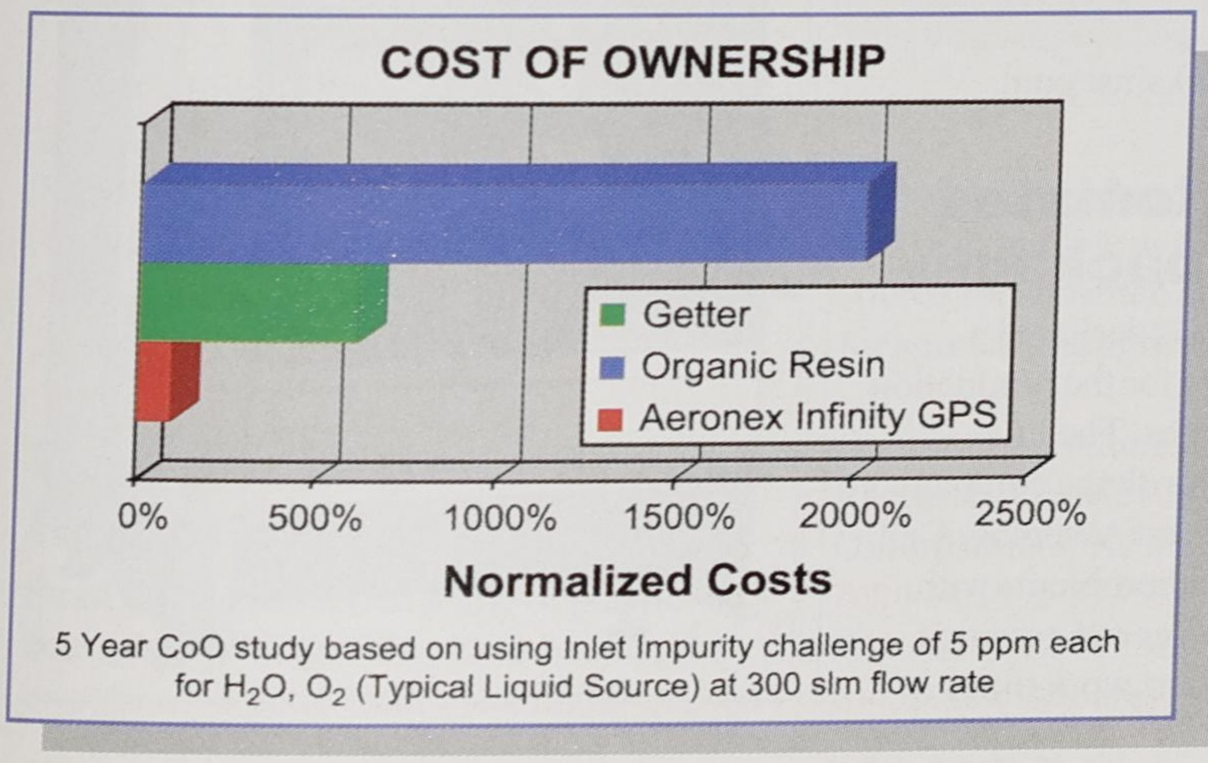
To provide a continuous supply of pure gas, the Infinity is designed with two purifier beds in parallel. While one bed is on-line, the second is automatically regenerating. Preconditioning time is eliminated, as is running on a spent or cracked purifier. No special gas blends are needed for start-up and hydrocarbons are never outgassed.



Value

The Aeronex purifier delivers the lowest cost of ownership. The Infinity GPS provides continuous savings through reduced labor and continuous uptime (see graph below). Competitive purifiers become a hazardous waste once spent, generating high costs in time, money, and liability. All related downtime and disposal costs are eliminated.

The Infinity accommodates different gas grades from either liquid or gas sources to significantly reduce your total tool operating costs through reduced cylinder change-out and lower gas costs. The purifier is hydrocarbon free, removing the possibility of expensive tool repair or chamber clean-up from system upsets. The result: reduced liability, lower operating costs, and increased product throughput.



5 Year CoO study based on using Inlet Impurity challenge of 5 ppm each for H_2O, O_2 (Typical Liquid Source) at 300 slm flow rate

Safety

Safety is a major concern at Aeronex. By enabling gas purification at ambient temperature and low pressure, safety is increased. The Infinity GPS regenerates in-situ, so technicians are no longer routinely exposed to process gas during purifier change-out. Automated monitoring minimizes potential loss that could occur from system upsets. There are no disposal or hazardous waste issues as in competitive technologies.

Total Purification Solution

Aeronex Purifiers are the only total purification solutions that provide improved performance, value, and safety. Contact Aeronex for more information on GateKeeper® and Infinity products for hydrogen, nitrogen, or specialty gases such as ammonia.

Aeronex purifiers are the choice for the leaders in III/V semiconductor films.

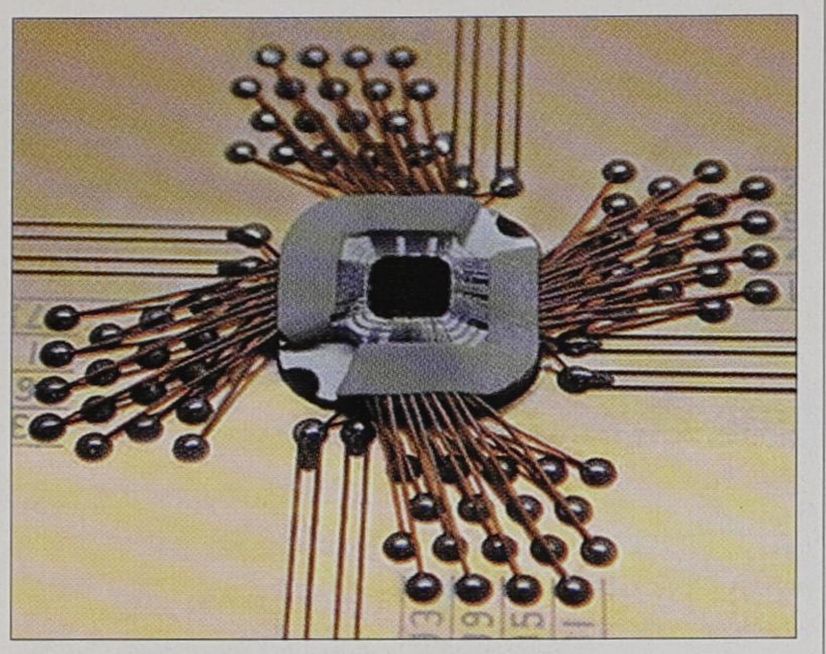
Call Aeronex to find out why.

AERONEX
The Source for Gas Purification

www.gaspurifier.com

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Tel (858)452-0124 • Fax (858)452-0229
6975 Flanders Drive • San Diego, CA 92121

Kulicke & Soffa's new SpeedTip RF tester



Probe cards consist of a complex multi-layer PCB that uses a number of probes to separately contact a series of electrical contact points or pads on the IC in wafer form. Kulicke & Soffa's new SpeedTip RF tester is a cantilever-based probe card that accommodates test rates from 1.2 to 2.5 Gbit/s on 2 to 16 RF lines. Contributing to this performance is the total probe length of less than 0.25 inches, and a metal ring that extends the ground plane over all probes to maintain isolation.

Contact Henry Parys, Kulicke & Soffa Industries Inc, 2101 Blair Mill Road, Willow Grove, PA 19090, USA
Tel. +1 215 784 6818
Fax +1 215 784 6284
E-mail parys@kns.com

RF-microwave probe provides flexibility

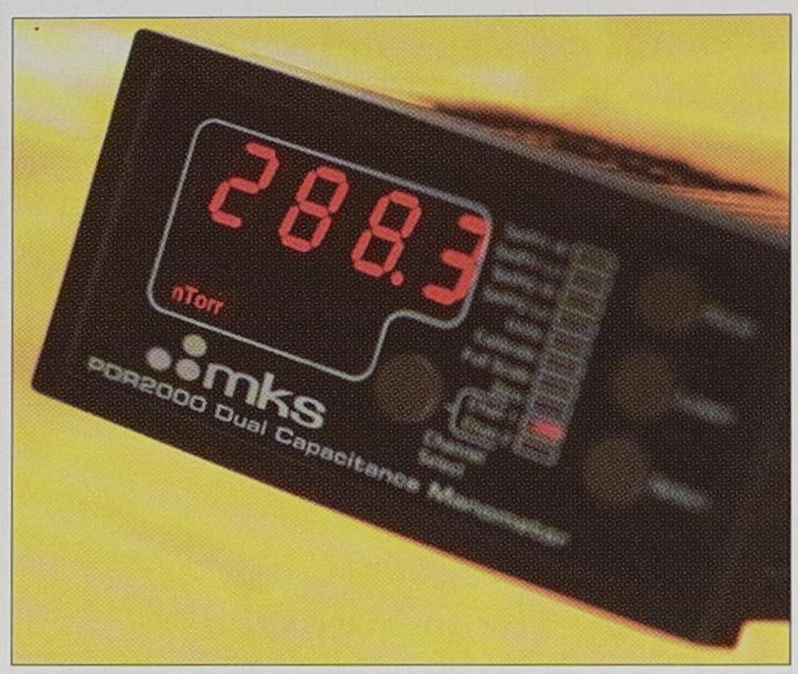
The Micromanipulator Company, a manufacturer of semiconductor test stations and probes, has introduced an RF-microwave probe, complete with manipulators which have been engineered to allow testing with five degrees of freedom: up/down, forward/backward, side to side, planarity and theta. A choice of three mounting bases, including vacuum mounts, magnetic mounts and mechanical lock, are also available.

The company's manipulators feature an 81 × 60 mm base that provides a secure foundation for the (semi) rigid cables used in RF test applications. The new 5-axis manipulator is currently available with delivery times ranging from 10 to 14 weeks, depending upon configuration.

Contact Karen Schanhals, The Micromanipulator Co Inc, 1555 Forrest Way, Carson City, NV 89706, USA
Tel. +1 775 882 2400
Fax +1 775 882 7694
E-mail info@micromanipulator.com

Low-cost pressure read-out units

MKS Instruments has designed a low-cost power supply and read-out unit to power and display its range of pressure measurement gauges, including Baratron heated transducers (45 °C) and single high-temperature (100 °C) Baratron pressure transducers. Intended for laboratories,



government research facilities and OEMs, the PDR2000 provides dual-channel display and digital output and includes units in torr, bar and Pa. Also included are two relay trip points, an LED readout and RS-232 interface. The unit is housed in a 3.8 × 1.85 × 7.0 inch package.

Contact Lisa Robillard, MKS Instruments Inc, 6 Shattuck Road, Andover, MA 01810-2449, USA
Tel. +1 978 975 2350
Fax +1 978 975 0093
E-mail lisa_robillard@mksinst.com

Complete automated line for opto packages

Palomar Technologies has designed a complete automated line for the production of optoelectronic packages. The line integrates wire bonders with the company's new *in situ* UV Component Assembly Cell, which addresses inherent problems with snap cure methods, such as out gassing, small batch sizes and short work times.

The hands-free recipe-driven process assembles the components in the package and performs the first level interconnect necessary to provide the component's electrical connection. The line is then integrated with a high-volume fluid dispenser, reflow oven, plasma cleaner, and inspection machines, with automatic handling between process stations. Processes include high accuracy component assembly with eutectic solder or epoxy, precision ball bonding, and wedge bonding for fine pitch devices.

Contact Bruce Hueners, Palomar Technologies, 2230 Oak Ridge Way, Vista, CA 92083, USA
Tel. +1 760 931 3600
Fax +1 760 931 5191
E-mail sales@bonders.com

Vitronics' selective soldering system

Vitronics Soltec's new selective soldering unit is an automated system that delivers high throughput and quality in batch or inline production.

The soldering unit consists of two stations to allow different requirements: the MultiWave module, which is designed to reduce cycle time, and the SelectWave unit, which provides high soldering accuracy. The SelectWave is equipped with a single solder nozzle blanketed by a constant flow of nitrogen, which ensures a stable, clean solder wave. The system operates at temperatures up to 400 °C, which allows for lead-free soldering.



Contact André Myny, Vitronics Soltec BV, Karolusstraat 20, 4903 RJ Oosterhout, The Netherlands
Tel. +31 162 483000
Fax +31 162 483253
Web www.vitronics-soltec.com

Closed loop ultrasonic cleaning system

Closed-loop recycling in cleaning systems is cost-effective for medium to high volume production. JNJ Industries' AquaSonic AQS-7500 ultrasonic cleaner features



closed-loop recycling which replaces evaporation processes, and leads to energy, water and cleaning chemistry savings. The AQS-7500 uses a three-stage filtration system to cleanse the waste water for re-use.

With closed-loop recycling, the bath life of both the wash and rinse tank fluids in the AQS-7500 can be extended by up to six months in certain circumstances. Other features include a 5 μm wash tank filter and a 4000 W heated wash tank.

Contact Bob Enterkin, JNJ Industries Inc, 290 Beaver Street, Franklin, MA 02038, USA
Tel. +1 508 553 0529
Fax +1 508 553 9973
Web www.jnj-industries.com

New packages improve RF performance

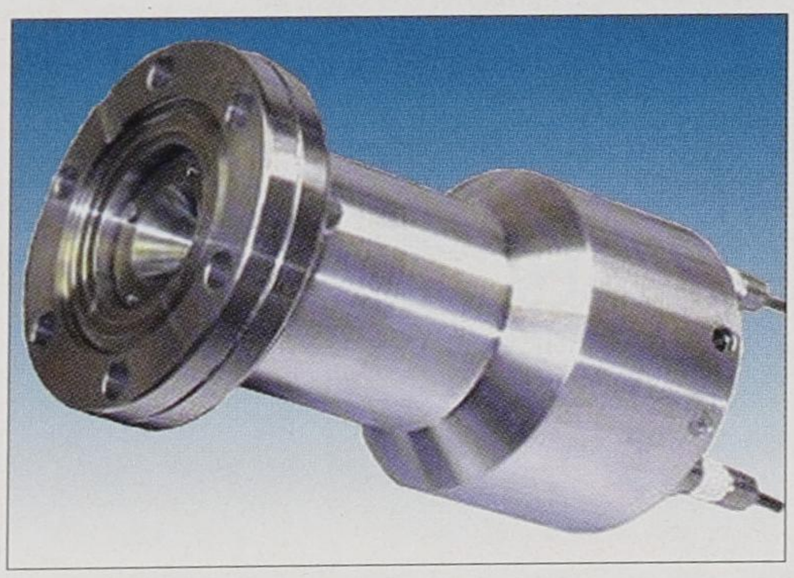
StratEdge has unveiled a line of plastic equivalent packages that have been based on a glass-ceramic composite material used for the body. Because such packages precisely match the outlines of the standard plastic packages, they are readily assembled and tested using standard tooling, equipment, and processes, and are ideal for testing prototype die or for low volume production runs.

The ceramic body is combined with a gold-plated Kovar lead frame for the conductors and metal die attach pads. At frequencies above 2 GHz, the packages provide an improved electrical performance in comparison with traditional plastic housings, and they can also be hermetically sealed. Potential future applications include Bluetooth ICs, C-band VSAT amplifiers, cellular base station amplifiers and wireless networking components.

Contact Tim Going, StratEdge, 4393 Viewridge Avenue, San Diego, CA 92123, USA
Tel. +1 858 569 5000
Fax +1 858 560 6877
E-mail t.going@stratedge.com

OAR offers a new cold-cathode ion source

Oxford Applied Research (OAR) has added the MIG5 to its family of ion sources. Based on a filament less cold-cathode design, the compact ion source operates at very low gas flows and can beam currents up to 80 μA.

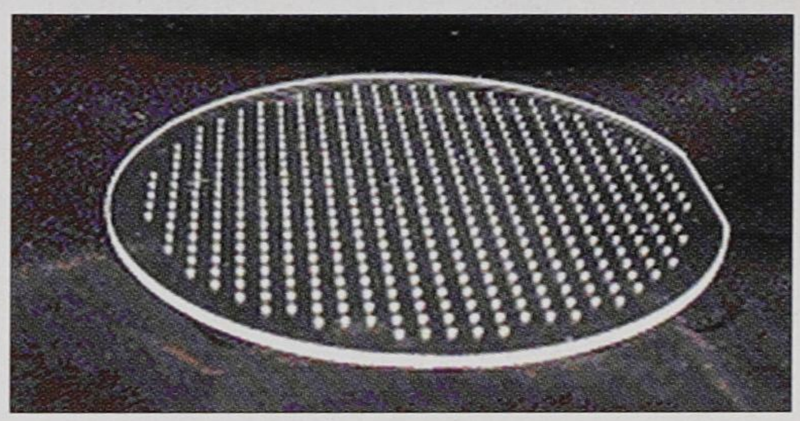


Covering the 0.2 to 5 keV range, the new MIG5 is suitable as a low-cost ion gun source for substrate cleaning, as well as for sputtering applications.

Contact Lars Allers, Oxford Applied Research, Crawley Mill, Witney, Oxfordshire, OX29 9SP, UK
Tel. +44 1993 773575
Fax +44 1993 702326
E-mail sales@oaresearch.co.uk

Durable sapphire wafer carriers from Maintech

Maintech is offering sapphire wafer carriers for GaAs and other types of semiconductors. The new wafer carriers feature high chip-resistance and have been



designed to be chemically resistant. Maintech is offering the carriers in sizes from 2 to 6 inches with or without perforations, and the supports are scratch resistant, transparent and durable.

Contact Michael Skiffington, Maintech, Inc, 860 Welsh Road, Huntingdon Valley, PA 19006, USA
Tel. +1 215 938 9111
Fax +1 215 938 9112
E-mail mskiffington@maintechinc.com

Qualiflow introduces solid-state sensor

Thermal mass flow controllers are used in the epitaxy, ion implantation, CVD, RTP, plasma etch and clean stages to deliver accurate gas compositions and concentrations to the processing chamber. Qualiflow has introduced a solid-state sensor designed to provide a non-drifting sensing unit for its AFC 90MD digital mass flow controller.

Drift on a mass flow controller typically leads to a drop in the quality of processed wafers. The new unit offers a faster response time and reduces the amount of drift and re-calibration required by conventional sensors which, during testing, exhibited no measurable drift over a period of three years.

Contact Pascale Garnier, Qualiflow Montpellier, 350 rue A Nobel, BP7-34935 Montpellier, CEDEX 9, France
Tel. +33 4 6 7 99 47 47
Fax +33 4 67 99 47 48
E-mail pgarnier@qualiflow.com

20–25 January 2002
Photonics West
San Jose, CA, USA
Web: spie.org/app/conferences

7–8 February
Strategies in Light (LED conference organized by Strategies Unlimited)
San Francisco, CA, USA
Web: www.strategies-u.com

11–15 March
Int'l Symposium on Blue Lasers and LEDs (ISBLLED 2002)
Cordoba, Spain
Web: www.die.upm.es/research/

17–21 March
Optical Fiber Communication (OFC) Conference
Anaheim, CA, USA
Web: www.osa.org/mtg_conf/

1–5 April
MRS Spring Meeting
San Francisco, CA, USA
Web: www.mrs.org/meetings/

8–11 April
GaAs Mantech
San Diego, CA, USA
Web: www.gaasmantech.com

12–16 May
Indium Phosphide and Related Materials (IPRM)
Stockholm, Sweden
Web: www.congrex.com/iprm2002

19–24 May
CLEO/QELS
Long Beach, CA, USA
Web: www.cleo-online.org/

20–24 May
29th IEEE Photovoltaics Specialists Conference (PVSC)
New Orleans, LA, USA
Web: www.ewh.ieee.org/soc/pvsc

3–7 June
IEEE MTT-S International Microwave Symposium
Seattle, WA, USA
Web: www.ims2002.org

3–7 June
International Conference on MOVPE
Berlin, Germany
Web: icmovpe.physik.tu-berlin.de

17–21 June
European MRS Meeting
Strasbourg, France
Abstract deadline: 14 January
Web: www-emrs.c-strasbourg.fr

24–26 June
Device Research Conference (DRC)
Santa Barbara, CA, USA
Web: www.tms.org/Meetings/Specialty/DRC/2002/DRC-2002-Home.html

26–28 June
Electronic Materials Conference (EMC)
Santa Barbara, CA, USA
Web: www.tms.org/Meetings/Specialty/EMC02/EMC02.html

22–25 July
International Workshop on Nitride Semiconductors (IWNS)
Aachen, Germany
Abstract deadline: 10 March
Web: www.fz-juelich.de/iwn2002

4–8 August
14th American Conference on Crystal Growth and Epitaxy (ACCGE)
Seattle, WA, USA
Abstract deadline: 3 May
Web: www.crystalgrowth.org/conferences/accge14

6–8 August
IEEE Lester Eastman Conference on High Performance Devices
Newark, DE, USA
Abstract deadline: 14 April
Web: nina.ecse.rpi.edu/shur/EastmanConference

1–5 September
European Conf on Silicon Carbide and Related Materials (ECSCRM–2002)
Linköping, Sweden
Abstract deadline: 15 May
Web: www.ifm.liu.se/ecscrm2002

8–12 September
European Conference on Optical Communications (ECOC)
Copenhagen, Denmark
Abstract deadline: 15 April
Web: www.ecoc.dk

15–19 September
National Fiber-Optic Engineers Conference (NFOEC)
Dallas, TX, USA
Abstract deadline: 18 January
Web: www.nfoec.com

15–20 September
International MBE Conference
San Francisco, CA, USA
E-mail: harris@snowmass.stanford.edu

23–27 September
GAAS/European Microwave Week
Milan, Italy
Abstract deadline: 8 March
Web: www.eumw.com

29 September – 1 October
Semiconductor Laser Conference
Garmisch, Germany
Abstract deadline: 1 May
Web: www.ileos.org/info/calendar2002.html

7–10 October
29th International Symposium on Compound Semiconductors (ISCS)
Lausanne, Switzerland
Abstract deadline: 15 May
Web: www.iscs2002.epfl.ch

21–23 October
GaAs IC Symposium
Monterrey, CA, USA
Web: www.gaasic.org

11–13 November
Compound Semiconductor Manufacturing Expo (CS-MAX)
San Jose, CA, USA
Web: www.cs-max.com

2–6 December
MRS Fall Meeting
Boston, MA, USA
Abstract deadline: 15 June
Web: www.mrs.org/meetings

3–6 December
International Electron Devices Meeting
Web: www.his.com/~iedm

For links to event Web sites, visit the Calendar section of our Web site at www.compoundsemiconductor.*net*.

GaAs fabs begin recovery

Wireless orders are beginning to pick up as cellphone makers finish clearing out their inventories, but comparisons of the "Big Four" GaAs RFIC makers show that the outlook is still mixed.



Two of the four most prominent GaAs RFIC makers returned to profitability in the last quarter, with TriQuint reporting a net income of $6.6 million on sales of $80.8 million, and RF MicroDevices earning $1.5 million on sales of $98.3 million. Alpha Industries reported a loss of $2.6 million on $33.0 million in revenues. Anadigics trailed the rest of the group, reporting a net loss of $22.4 million on revenues of $16.3 million.

All four companies reported that their shipments for wireless handsets improved in the September quarter. Even so, the outlook remains mixed. Anadigics executives predict that wireless sales might increase in the December quarter by as much as 80% compared with the September quarter, with shipments of InGaP-based PA modules for CDMA handsets tripling. However, that alone will not be enough to return the company to profitability – more on this later.

Alpha's management predicts that their results for the fourth quarter will be roughly similar to those of the third, but they hold out the prospect of returning to profitability in March. RFMD executives also advised that their results for this quarter would be in line with the previous one. Since then, however, analysts who follow the company have been telling their clients that RFMD has landed some important new contracts. Merrill Lynch analyst Christopher Danely says RFMD is benefiting from the fact that its biggest customer, Nokia, is gaining market share, while at the same time the company is winning new business from new customers, such as Korean manufacturers of next-generation CDMA phones. Samuel May of US Bancorp Piper Jaffray said that RFMD is "gaining traction" with Ericsson, Motorola, Samsung and Siemens, with design wins in four new GPRS handsets.

On 20 November TriQuint announced that its December-quarter revenues would be within the range of its prior estimates, although at the low end of its forecast of $75–80 million. While initially this might seem like a harmless statement, it sparked off a 15% drop in the company's share price. Several analysts seem to have read between the lines and detected something they do not like. Soundview's John Lau suggests that TriQuint is being hurt as a result of not being incorporated into certain Nokia handsets that have been gaining in market share; others have suggested that the company is suffering from a general lack of penetration into GSM markets.

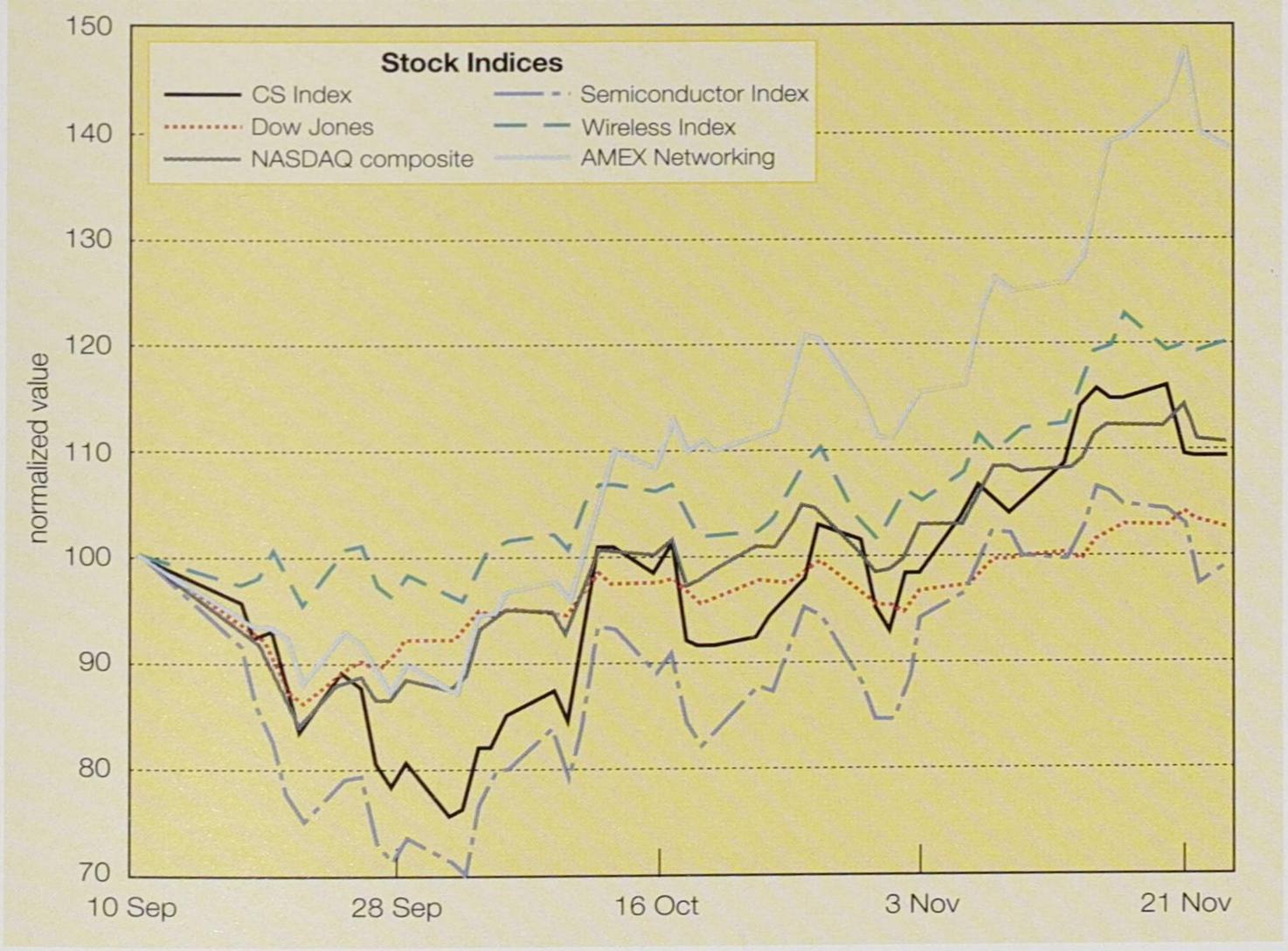
A quarter-by-quarter comparison of the four GaAs RFIC makers shows that TriQuint has suffered the least thus far (see table). In the first nine months of this year the company recorded a cumulative profit of $21.6 million, while the others are all in the red for this period (Alpha –$3.1 million, RFMD –$38.85 million and Anadigics –$82.40 million).

However, all that will change in the December quarter when TriQuint takes a very large – perhaps $100 million – special charge to write off excess fab capacity. This will push the company into the red for both the quarter and the calendar year. "While it is unpleasant to report such a large loss, we believe TriQuint will emerge much stronger," CEO Steve Sharp said.

Results for GaAs RFIC fabs ($ million)

		Q3 '01	Q2 '01	Q1 '01	Q4 '00	Q3 '00
Alpha	sales	33.00	32.20	53.00	78.70	73.20
	income	–2.60	–3.90	3.40	11.60	10.60
Anadigics	sales	16.30	18.90	28.50	30.70	51.00
	income	–22.40	–55.40	–4.60	–0.30	7.00
RFMD	sales	98.30	70.00	55.00	79.90	102.20
	income	1.50	–33.50	–6.85	7.84	17.70
TriQuint	sales	80.80	60.70	80.80	90.20	80.60
	income	6.60	2.30	12.70	23.10	20.90

Industry indices



STRATEGIES IN LIGHT 2002

Charting New Directions in High-Brightness LEDs

February 6-8, 2002 – Hyatt Regency San Francisco Airport

Strategies Unlimited will host its third annual executive-level conference on high-brightness LEDs on February 6-8, 2002 at the Hyatt Regency San Francisco Airport in Burlingame, California. This international event is considered to be the premier forum for addressing commercial developments in high-brightness LEDs. STRATEGIES IN LIGHT 2002 will provide insight into rapidly growing markets and applications, and will focus particular attention on the outlook for solid-state lighting.

STRATEGIES IN LIGHT 2002 will include:

UPDATED MARKET TRENDS AND FORECASTS directly from Strategies Unlimited, the world's premier market research firm in LEDs.

EXECUTIVE-LEVEL PRESENTATIONS on applications, technology and market potential from international suppliers and users of HB-LEDs. Topics will include:

- Signs and signals
- Automotive lighting
- Illumination & displays
- National solid-state lighting initiatives
- Regional perspectives
- Standards & measurement

TECHNOLOGY ISSUES and timeframes related to HB-LED development, including an exploration of solid-state lighting and the role of optical technology.

BUSINESS AND FINANCIAL ISSUES associated with the emerging HB-LED industry.

CONFERENCE HIGHLIGHTS include:

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- 1-1/2 day focused agenda
- Unique access to industry executives
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Check www.strategies-u.com for conference updates and registration materials.

Strategies Unlimited

201 San Antonio Circle, Suite 205
Mountain View, CA 94040
www.strategies-u.com

PennWell

Just to reach the break-even point, Anadigics needs to almost double its current sales volume and raise its gross margins to around 25%.

Market overview

Company	Symbol	Closing price on 23 Nov	52-week low–high	Market cap*	P/E ratio**
GaAs IC companies					
Alpha Industries	AHAA	25.65	13.0625–55.3750	1.132B	135
Anadigics	ANAD	16.75	10.2200–25.3800	508.5M	N/A
Celeritek	CLTK	13.44	9.8125–50.0625	161.7M	N/A
Conexant	CNXT	13.93	6.5700–33.0000	3.514B	N/A
Endwave	ENWV	1.35	0.6000–12.5938	47.7M	N/A
Multilink	MLTC	7.38	3.2000–18.4000	505.6M	N/A
RF Microdevices	RFMD	26.14	8.7500–37.5000	4.356B	N/A
Sirenza Microdevices	SMDI	5.32	2.9800–42.2500	156.4M	N/A
TriQuint	TQNT	17.35	10.2500–61.5625	2.260B	42.32
Vitesse	VTSS	12.07	6.6500–77.2500	2.299B	N/A
Opto companies					
Agilent	A	25.10	18.0000–68.0000	11.571B	N/A
Agere	AGRa	5.75	3.1000–9.5000	9.402B	N/A
Alcatel Optronics	ALAO	8.50	4.0400–62.9375	140.2M	7.46
Coherent	COHR	29.30	25.0500–53.7500	829.0M	30.84
Cree	CREE	24.12	12.2100–47.0625	1.745B	83.75
JDS Uniphase	JDSU	11.71	5.1200–76.6250	15.547B	N/A
Stratos Lightwave	STLW	6.25	3.1800–24.8125	400.6M	N/A
Uniroyal Technology	UTCI	4.14	2.0800–10.1100	116.0M	N/A
Semiconductor materials and equipment companies					
ATMI	ATMI	21.20	14.3750–32.7300	643.6M	116.48
AXT	AXTI	14.20	9.9000–46.4375	317.5M	12.14
Emcore	EMKR	9.99	7.6700–55.3750	344.8M	N/A
Kopin	KOPN	15.58	4.0000–16.9375	1.019B	N/A
Tegal	TGAL	1.29	1.0000–4.5000	16.3M	N/A
Trikon	TRKN	9.40	6.9600–16.7200	120.5M	5.93
Veeco	VECO	30.80	19.9000–66.5000	885.2M	25.67
European companies (currency data in €)					
Aixtron	AIXG.F	28.95	13.50–59.85	1.87B	N/A
Bede	BED.L	3.06	1.93–3.52	88.65M	N/A
Filtronic	FTC.L	6.81	1.37–8.52	501.95M	N/A
IQE	IQE.L	3.28	1.38–4.50	537.85M	158.06
Picogiga	PGIG.LN	4.58	2.60–34.00	29.60M	N/A
Riber	RIBE.LN	4.85	2.51–23.00	90.79M	11.46
ST Systems	SRTS.L	2.62	1.61–4.10	82.09M	23.56

*Market capitalization = # shares × current share price.; **Price/Earnings ratio = current share price ÷ (income for the last four quarters ÷ # shares).

The outlook for Anadigics

Despite the recent rebound in its wireless business, Anadigics continues to struggle. Its share price has dropped 17.5% since 16 November when the company announced that it planned to raise $75 million through a convertible debt note offering. This plan gives the creditors the right to convert the notes to shares under certain circumstances, and therefore could have the effect of diluting the stock by about 10%.

While offerings of this type are often unpopular with the existing shareholders, it could be argued that Anadigics had little choice. The company's liquid resources – cash, cash equivalents and marketable short-term investments – have dwindled from $148.3 million in December 2000 to $54.4 million at the end of September 2001. Company executives do not think Anadigics will return to profitability before the second half of 2002. In fact, just to reach the break-even point Anadigics needs to almost double its current sales volume and raise its gross margins to around 25% – but in the September quarter the company reported a negative gross margin of $1.9 million, and a similar result is expected in the December quarter. Dale Pfau of CIBC World Markets believes it will be at least another year before they reach the break-even point.

The debt offering will allow the company to operate for the next several quarters, but it alone can't solve all Anadigics' problems. Company executives say that they are "on track" with initiatives aimed at reducing manufacturing costs and operating expenses by 30% in the first quarter of 2002. As part of this effort, Anadigics plans to partially outsource its test operations, and

Aixtron's ability to continue to increase its sales is an encouraging sign for the long-term health of the industry.

Pleasant surprise from Aixtron

On 8 November MOCVD equipment maker Aixtron reported third-quarter revenues of €61.9 million ($54.58 million) and earnings of €10.6 million ($9.35 million). Compared with the year-ago period, sales increased by more than 100% and profits increased by more than 300%. Its growth has slowed more recently – sales were up just 5% over the second quarter. But in light of the industry-wide slowdown, Aixtron's ability to continue to increase its sales is an encouraging sign for the long-term health of the industry. CFO Claus Ehrenbeck says that the break-down of reactor sales by end-use was 40% LEDs, 34% communications, 24% consumer products and 2% other, which is consistent with previous periods.

Aixtron will not issue a formal forecast for 2002 until mid-March. However, Ehrenbeck did say that Aixtron has a "comfortable order backlog to lead us into 2002". As of 30 September the backlog was 16% higher than it was in the year-ago period.

is also "evaluating strategic alternatives" for its fiber-optics product line, which could include a possible sale.

This latter announcement should probably be seen as a tacit admission by Anadigics' management that its fiber products – mostly low-end products such as TIAs for OC-48 and OC-192 – are no longer viable in an increasingly competitive market. Sales for the fiber product line have dropped from $6.8 million a year ago to just $2.4 million in the last quarter, and they will be less than 5% of sales in the December quarter.

Would it be possible to sell this product line? Pfau says maybe, if Anadigics can find a buyer which can blend these products in with an existing product line. But he also notes that there are hurdles to be overcome, not least the fact that the manufacturing is intimately tied to the processing steps unique to Anadigics' fab.

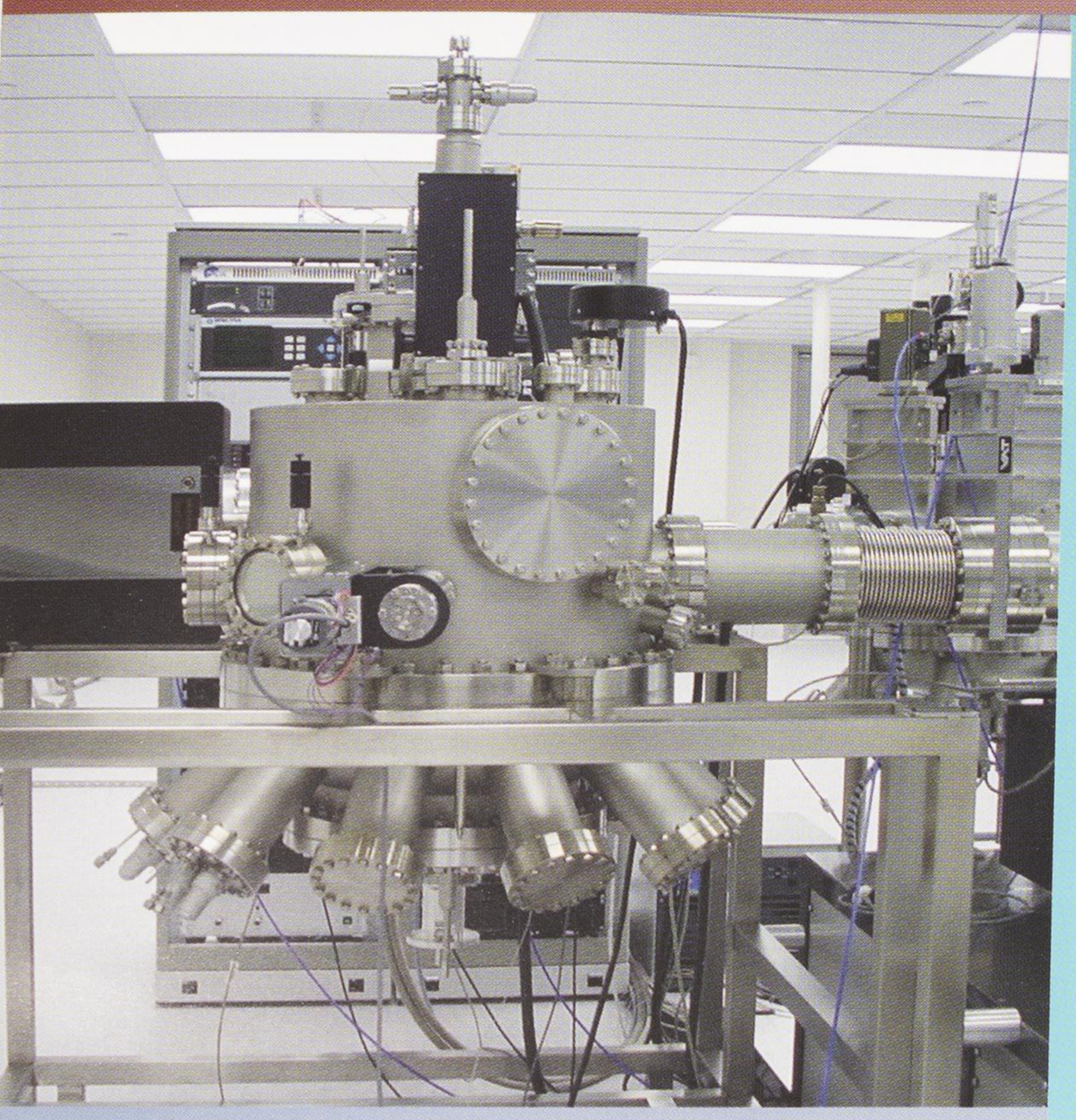
Anadigics has been forced into this position in part because its current fiscal squeeze makes it impossible for it to invest in expanding its fiber-optic product offerings. For the September quarter Anadigics spent $9.5 million on R&D. In comparison, RFMD spent $17 million, TriQuint spent $13.2 million and Alpha spent $9.9 million. Of the four companies, Anadigics is the only one that is currently spending less on R&D than it did last year.

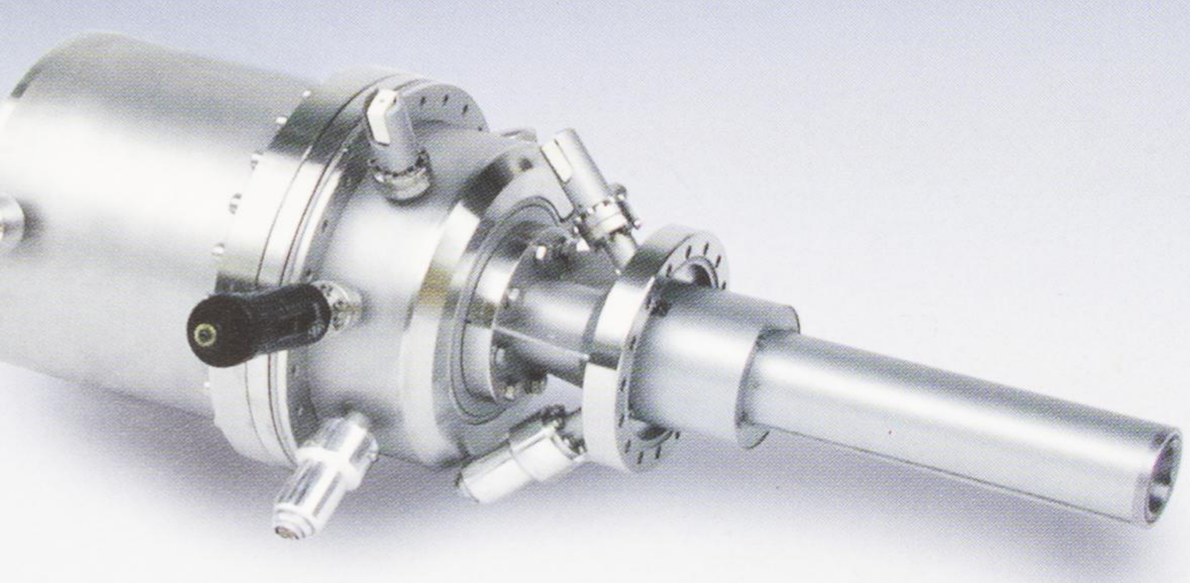
Exiting the fiber-optic market will allow Anadigics to focus all of its efforts on the wireless market, where it does appear to be gaining some traction. For example, the company recently landed a large contract from Kyocera for cellphone PAs. However, analysts believe it will take two or three more deals of a similar size to help the company get back to the break-even point. ●

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Seokyo Commerce Company
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seokyo@netsgo.com

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Fax: 03-594-7479
chuton7@iris.seed.net.tw