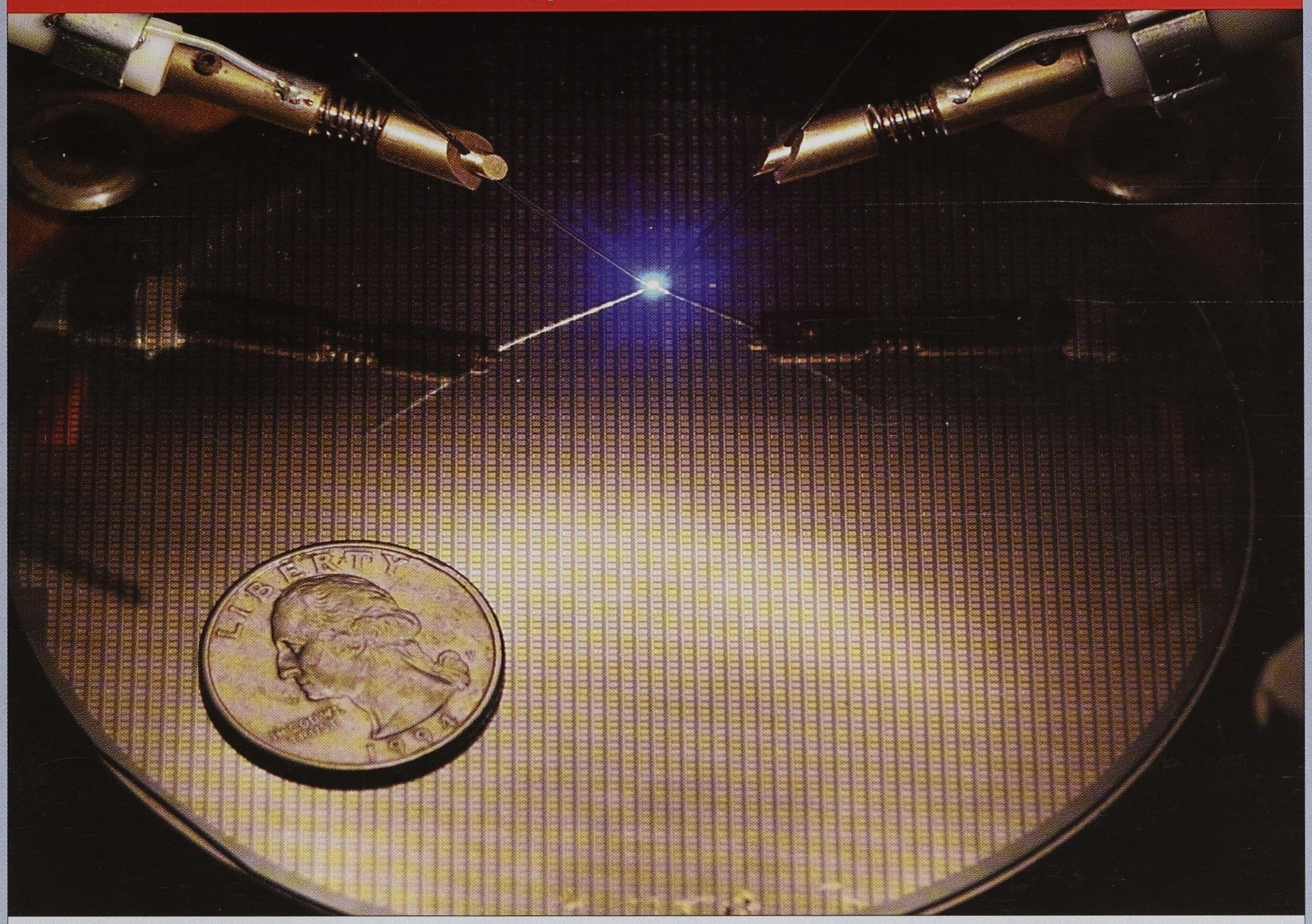
COMPOUND SEMICONDUCTOR

November 2001 Volume 7 Number 10

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NITRIDES

LEDs, power devices and GaN-on-silicon

ALSO INSIDE

RF Micro Devices buys RF Nitro	**Reports from GAAS and ECOC**	**MCT infrared focal plane arrays**

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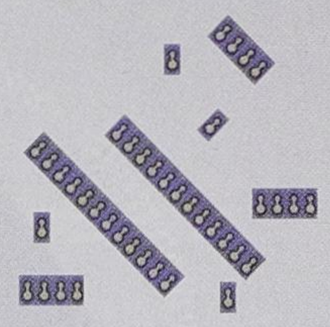
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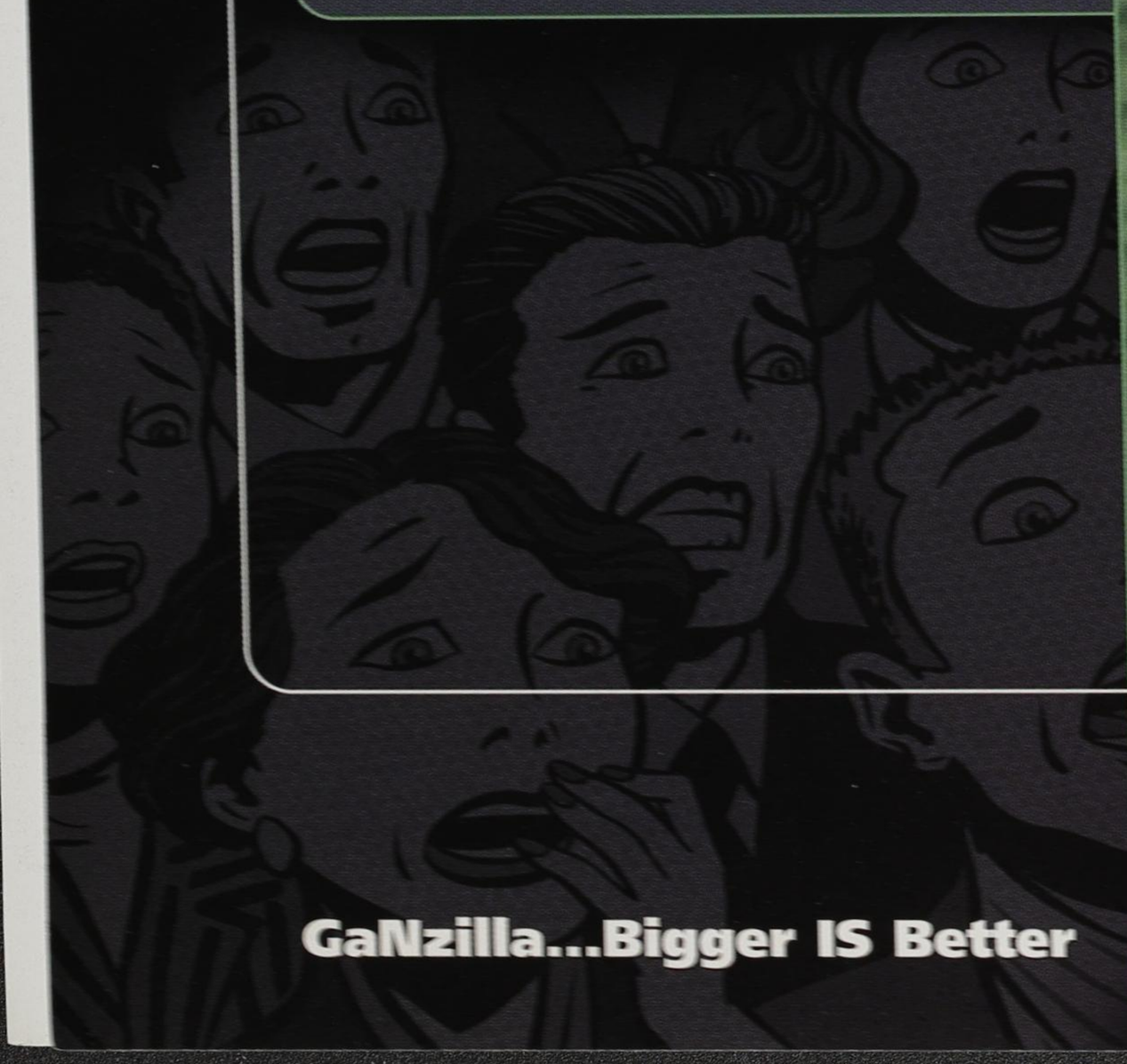
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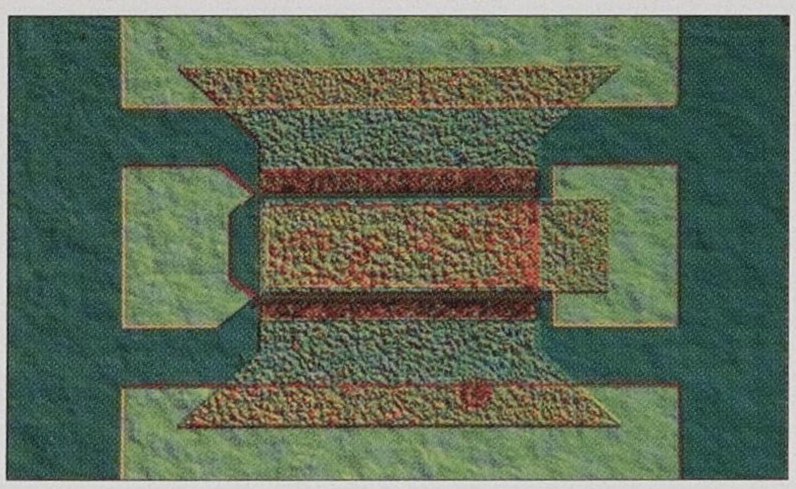


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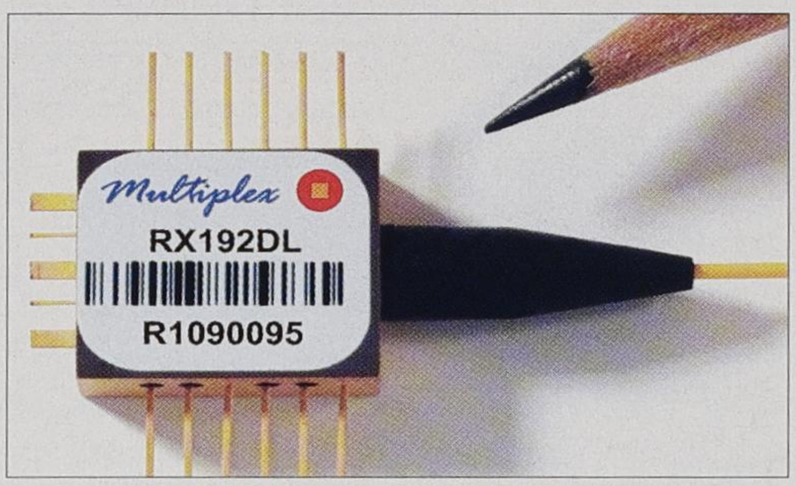
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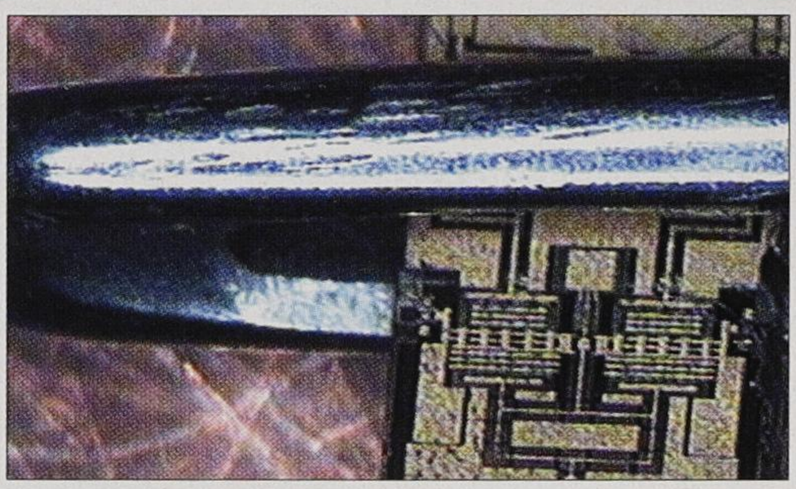
NOVEMBER 2001 VOLUME 7 NUMBER 10



RF Micro Devices has bought RF Nitro, which manufactures GaN-based devices **p3**



Multiplex was one of the companies that introduced new products at ECOC **p41**



Cornell is raising the performance of GaN-based power devices to new levels **p69**

NEWS

3 **Headline News:** RFMD buys RF Nitro...Airtron first victim of GaAs slump...GaAs show suffers

9 **LED News:** Cree and Osram renew contract...LED patent battles update...Microsemi's blue LEDs

11 **Nitride News:** II-VI Inc buys Litton SiC business...4 inch SiC wafers from Nippon Steel

15 **Fiber News:** Acelo leverages Rockwell license...50 Gbit/s InP circuits from Inphi

19 **GaAs News:** Modules gain status...UMS and Atmel join forces...GCS focuses on InGaP, InP HBTs

25 **Opto News**

27 **Market News**

29 **Materials & Equipment**

31 **New Devices**

FEATURES

41 **Components on show at ECOC**
Despite market conditions, Tim Whitaker found that component vendors had plenty to say at ECOC.

45 **GaAs is still the material of choice for many applications**
A mixture of technical papers and discussion sessions covered an impressive variety of topics at GAAS2001. Tim Whitaker and Jon Newey report on the highlights.

53 **MCT moves into the next generation of thermal imaging**
MCT dominates the high-performance infrared sensing market. Jon Newey looks at the current activity in material growth and device fabrication.

75 **Caldus raises temperature of silicon carbide contacts**
A small Oregon company has developed the technology to form contacts to SiC that are stable up to temperatures over 1000°C, writes Donald Hagge.

COVER STORY: NITRIDES

59 **High-volume production of AlInGaN-based LEDs**
III-nitride-based LED technology has many problems to grapple with before it will yield truly low-cost, high-volume products, write Heng Liu and colleagues from AXT's LED Division.

63 **Silicon substrates provide a disruptive technology for GaN**
Substrates for GaN growth are generally small and expensive. Nitronex's Warren Weeks and Ricardo Borges discuss the GaN-on-silicon alternative.

69 **GaN reaches new power levels**
Lester Eastman writes about the latest high-power GaN-based devices from Cornell University and gives an insight into what we can expect in the future.

73 **BU's Wide Bandgap Lab grows better GaN for novel devices**
GaN research at Boston University covers a wide range of areas, writes Yvonne Carts-Powell.

DEPARTMENTS

Index 2 **Silicon Update** 35 **Research Review** 37
Product Showcase 76 **Portfolio** 79
Advertising Index 82 **Calendar** 82

On the cover: *Nitronex is growing device-quality GaN on 4 inch silicon substrates for a wide variety of applications including blue LEDs – see page 63.*

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Organization Index

Acelo	15
Aeronex	29, 77
Agere	42, 79
Agilent	43 79
Agility	16, 32
AIFOtec Fiberoptics	41
Aixtron	30, 79
Alcatel Optronics	41, 79
Alcatel Space	45
Alpha Industries	19, 79
American Xtal Tech.	4, 59, 79
Anadigics	22, 32, 79
Applied Microcircuits	31
Army Research Laboratories	54
Atmel	22
ATMI	79
Avalon Photonics	43
B/E Aerospace	9
BAE Systems	54, 55, 57
Bandwidth9	16
Bede	29, 79
Boeing	57
Boston University	73
Caldus	75
Cascade Microtech	76
Celeritek	79
Centre National de la Recherche Scientifique	39
Cermet	12
Ciena	16
Coherent	25, 79
Conexant	36, 79
Cornell Univ.	48, 50, 69
Cree	9,10, 12, 79
CyOptics	31, 42
Daimler Chrysler	48
DCA	30
DRS Technologies	57
Eblana Photonics	42
Emcore	15, 29, 30, 79
Endwave	20, 79
Ericsson	42, 19
Exelight	42
EXFO	76
Fairchild Semiconductor	31
Filtronic	79
Fraunhofer IAF	11
Freiberger	7
Furukawa	30, 41
GCS	3, 16, 20
GCT	3
Georgia Tech	38
Giga Epitaxy	22
Hitachi	35
HRL Labs	53, 54, 57
Hughes Electronics	57
IBM	29, 35
IEM Technologies	76
IEMN (France)	48
II-VI Inc	11
Infineon	32, 36
Inphi	16
IQE	3, 45, 50, 79
Isonics	12
JDS Uniphase	15, 41, 79
JX Crystals	26
Kamelian	41
Karl Suss	29, 77
Keithley	76
Kopin	45, 79
Kymata	41
LG Cable	42
Lite-on Electronics	31
Litton Airtron	3, 4, 11
LKF Advanced Optics	17
Lockheed Martin	57
LumiLeds Lighting	30
LuxNet	15
M/A-COM	7
Marconi Applied Technology	50
Marconi Optical Components	43, 50
Matsushita	25
Microsemi	9, 12
Mindready	76
Mitsubishi	42
MKS Instruments	76
Modulight	17
Motorola	3, 30, 45
Movaz	16
Multilink	79
Multiplex	43
NASA	26
NEC	38, 42
NEL	42
Neoptec	42
Nichia Chemical	25, 38, 64
Night Vision and Electronic Systems Directorate (NVESD)	54
Nippon Steel	11
Nitronex	9, 48, 63
NLight	16
Nokia	48, 50
Nortel Networks	41
Northrup Grumman	4, 11
Novalux	41
NTT	37, 39
Oki Electric	31
OMMIC	48
OpNext	42
Opto+	50
Osram Opto	9, 10
Oxford Applied Research	29, 76
Philips	29
Picogiga	39, 79
Powdec	12
QinetiQ	48
Raytheon	32, 53, 54, 57
RF Micro Devices	3, 19, 79
RF Nitro	3
Riber	29, 79
Rockwell	15, 57
Rohm	25
Sofradir	58
Sony	12
Spectra-Physics	31
Sterling Semiconductor	11, 12
Strategy Analytics	7, 50
Stratos Lightwave	79
Sumitomo Electric	7
Suntek	3
Tampere Univ.	37
TDI	13
Tecstar	26
Tegal	30, 79
Tellabs	16
Temescal	30
Texas Instruments	57
Thales	45
Three-Five Photonics	17, 41
Toshiba	32
Toyoda Gosei	10
Trikon	79
TriQuint	57, 79
U2T	17
UMS	22, 32, 50
Uniroyal Technology	12, 79
Univ. of Braunschweig	11
Univ. of Cantabria	48
Univ. of Michigan	48
Univ. of Salamanca	48
Univ. of Stuttgart	11
Univ. of Ulm	11, 22
VEECO Digital Inst.	79
Vitesse	42, 79
Wafer Technology	7
WIN Semiconductors	3
Yokogawa	16

GaAs show suffers from low numbers

By Tim Whitaker

The first major US compound semiconductor conference to be held since the events of 11 September suffered somewhat from the dual effects of economic restrictions and a general reluctance to travel. The GaAs IC Symposium, held on 21–24 October in Baltimore, attracted around 300 attendees, fewer than expected, but still put together a technical program of the usual high standard, including several interesting panel discussions. Over 50 companies participated in the exhibit, although there were some notable absentees, particularly Litton Airtron, which has now shut down its GaAs substrate business (see p4).

On the positive side, no fewer than four foundry companies were exhibiting at the show, three of which were from Taiwan (the fourth was Global Communication Semiconductors). Along with WIN Semiconductors and Suntek, who both attended the GAAS show in London, Global Communication Technology (GCT) announced its commercial readiness.

Global Communication Technology

Founded in July 2000, GCT built a 6 inch GaAs wafer fabrication facility in Hsinchu, Taiwan, which was completed in January of this year. The fab has 5200 sq. ft of class 1 processing space, 1200 sq. ft of class 100 space and 15 000 sq. ft of class 1000 space for backside processing and testing. The company has entered production with its power and digital InGaP/GaAs HBT processes, and is also developing 0.5 μm and 0.35 μm AlGaAs/InGaAs PHEMT processes for late 4Q01 release. An InGaP/InGaAs PHEMT process will be available in 3Q02.

According to John Parsey of GCT, the foundry is also using materials other than GaAs to manufacture SAW filters and other products. "Ultimately, GaAs ICs will make up approximately 70% of the company's product mix," says Parsey, "SAW filters will make up about 20% with the remainder being MEMS products."

When fully equipped, GCT's fab has a maximum capacity of 5000 6-inch wafers per month, although Parsey says that the current equipment level provides about 3000 wafers per month. "We plan to ramp our capacity in line with market demand," he says. "On the other hand, large long-term customers need the reassurance that we have a large potential total volume." In fact, GCT has already signed a lease on land to build another fab with a capacity of up to 15 000 6-inch wafers per month. The current schedule calls for this facility to come on line during late 2003.

One of the points raised when discussing GaAs foundries in Taiwan is whether there will be sufficient demand for the huge levels of capacity that these companies intend to bring on line. At present, the integrated device manufacturers (IDMs) are running well below full capacity, and seem unlikely to require foundry services in the short term. However, GCT's Huan-Chun Yen believes that the foundries will offer IDMs new opportunities when business picks up. "Previously, during periods of expansion, the IDMs had no real choice but to build more capacity themselves," said Yen. "Now, when the market returns, they will have the option to use foundries instead."

Device results for GaAs-on-silicon

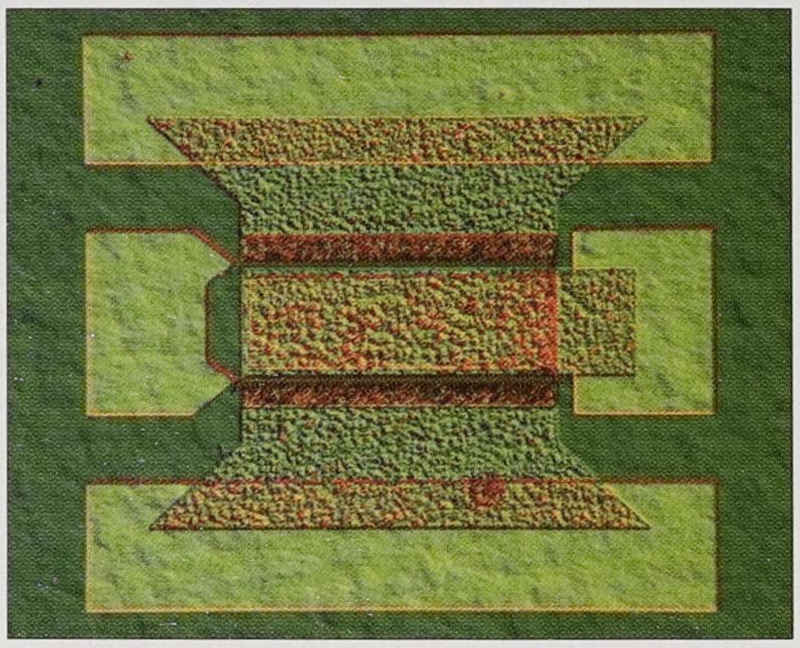
The Motorola/IQE work on GaAs-on-silicon attracted a great deal of attention, and the team revealed their initial device results. GaAs layers with a thickness of 2 μm and a defect density of less than $1 \times 10^5/cm^2$ were grown on the GaAs/STO/Si wafers. A MESFET structure with a 150 nm channel (doped at $8 \times 10^{17}/cm^3$) and a 50 nm contact layer (doped at $5 \times 10^{18}/cm^3$) were grown on the buffer. Devices with a gate length of 0.7 μm showed a saturation current at 0.5 V forward gate bias of 367 mA/mm, and a maximum transconductance of 223 mS/mm. These values were only slightly below control devices grown on GaAs substrates. Other DC, RF and lifetime test data also showed good promise, said the authors.

RF Micro Devices buys RF Nitro Communications

By Richard Dixon and Tim Whitaker

RF Micro Devices is to acquire RF Nitro Communications, a start-up company whose products include GaAs PHEMT and InGaP HBT ICs, as well as GaN epiwafers and devices. The transaction will be completed by the end of the year subject to customary closing conditions, and RF Nitro will operate under the name RF Micro Devices Charlotte. The terms of the deal were not disclosed, but company executives have indicated that they anticipate charges of approximately $8.2 million, spread over the next two years.

RFMD is one of the largest manufacturers of RFICs, primarily for the wireless handset market. The company operates a AlGaAs/GaAs HBT fab in Greensboro, NC, and is planning to bring its second fab on line by the end of the year. RFMD also has access to a number of other technologies including GaAs MESFET, SiGe HBT and Si CMOS through a range of foundry arrangements, and is developing InP HBT technology. The acquisition provides RFMD with access to InGaP/GaAs HBT and GaN technologies, and will expand its product offerings in the wireless infrastructure sector, a relatively new market sector for the company.



RFMD CHARLOTTE

RFMD Charlotte's NGN-125 AlGaN/GaN transistor on a sapphire substrate. The gate geometry is 0.20 x 250 μm.

The power of GaN

"Through RF Nitro, we will gain instant access to advanced compound semiconductor processes such as GaN, as well as additional resources to conduct advanced research on this and other technologies," said William Pratt, RFMD's chairman and CTO.

Since July, RF Nitro has sold prototype quantities of GaN power transistors that exhibit a power density approximately 10 times that of conventional GaAs power transistor processes, and approximately 100 times that of silicon. "Using this technology, base-station

PAs may be built to operate at very high voltages and at higher efficiency and better linearity than existing designs using LDMOS technology," said Pratt. In fact, RFMD expects GaN to ultimately displace silicon in high-power applications such as base-station PAs.

RF Nitro's product portfolio

RF Nitro manufactures GaAs PHEMT-based ICs, in addition to GaN HEMTs on both SiC and sapphire substrates. Recent AlGaN/GaN HEMT products include VCOs operating at 3 GHz with a power output of 2.7 W, and prototype 10 GHz transistors with a power density of 6 W/mm and a breakdown voltage of 100 V. While these circuits are currently produced externally, the company recently announced that it is building a new 4 inch wafer line at its fabrication facility, scheduled for completion later this year (*Compound Semiconductor* September 2001, p23). This facility will be used both for production and as a technology incubator. RF Nitro also has design, assembly and test capabilities, all of

The acquisition provides RFMD with access to InGaP/GaAs HBT and GaN technologies, and will expand its product offerings in the wireless infrastructure sector.

which are located at the site in Charlotte, North Carolina.

InGaP HBT technology

RF Nitro will also provide InGaP HBT technology for power amplifiers; the company currently offers InGaP-based MMIC PAs operating up to 17 GHz. While RFMD manufactures AlGaAs HBTs, many of its competitors use InGaP processes, citing the higher performance and reliability. The lack of an InGaP process has not prevented RFMD from continuing to gain important design wins. However, the company has started to investigate InGaP circuits, and has sampled MOVPE-grown InGaP epiwafers. "We expect RF Nitro's expertise in InGaP HBT PAs to accelerate our previously announced initiatives to introduce InGaP circuits for wireless applications," said Pratt.

GaN technology development

RF Nitro's GaN technology was developed over the last six years by Cornell University through a government-sponsored ONR-MURI program. During the program, Cornell demonstrated a world-record power density of 11.2 W/mm at 10 GHz and 45 V operation (see p69). In addition, Cornell has successfully built GaN devices on silicon. Under the terms of the transaction, Cornell Research Foundation will provide RFMD with an exclusive license for all electronic and optoelectronic applications, including power switching and RF amplification, as well as solid-state lighting.

Airtron becomes first victim of GaAs recession

By Marie Meyer

In a development that would have seemed inconceivable 12 months ago, the Airtron Division of Northrop Grumman – formerly Litton Airtron – has ceased operations. The semi-insulating GaAs substrate production facility in Morris Plains, NJ has been shut down, its three-ton gallium stockpile has been sold to former rivals, and its remaining assets will be put up for auction after the first of the year. Around 100 workers have also lost their jobs. Furthermore, the assets relating to Litton Airtron's nascent silicon carbide substrate operation have been sold to II-VI Incorporated (see p11).

The decision to pull out of the substrate business was apparently made several months ago, shortly after Northrop Grumman completed its acquisition of Litton. Former Airtron employees say that attempts were made to sell Airtron as a going concern, but a buyer for the GaAs business could not be found, and Northrop Grumman rejected an offer for a management buy out because it was against company policy.

In the mid-1990s Airtron was one of the world's leading suppliers of semi-insulating GaAs substrates, and at one point claimed to control 25% of the market. They were also the first company to launch volume production of 6 inch GaAs substrates, becoming the primary supplier to Vitesse's 6 inch fab in 1998.

Bob Ochrym, who served as the sales manager for Airtron for several years, said that the division was performing very well until

In the mid-1990s Airtron was one of the world's leading suppliers of semi-insulating GaAs substrates, and at one point claimed to control 25% of the market.

March of this year. "From October 2000 to March 2001 we were shipping 10 000 6-inch wafers per month and booking $4–4.5 million in revenue every quarter," said Ochrym. "But then we were hit by major cancellations." Unfortunately for all concerned, this was happening at almost exactly the same time that Northrop Grumman was reviewing its plans for rationalizing the myriad of different businesses they acquired via the Litton deal. "Within four weeks of closing the merger, Northrop Grumman decided to divest the Airtron business," explained Ochrym. "Perhaps we were too honest, but we told them that we had seen 90% of our business cancelled, and that we did not see it coming back for at least a year."

Relying on low-pressure growth

Industry insiders say that Airtron depended almost entirely on high-volume business from a relatively small number of customers – perhaps less than 10. In recent months Vitesse's fab utilization has dropped dramatically, and TriQuint Semiconductor, one of Airtron's other big customers, has let it be known that they believe their current inventory of GaAs substrates will last them until September 2002.

Moreover, Airtron was also presenting the company's new owners with a request for a significant increase in R&D spending and capital investment which would allow them to implement a bulk GaAs growth technology based on a vertical process. Production at Airtron was based on the low-pressure liquid-encapsulated Czochralski (LP-LEC) method; this has long been favored in implant processes because of its low cost, but is less competitive in epi markets because of its higher

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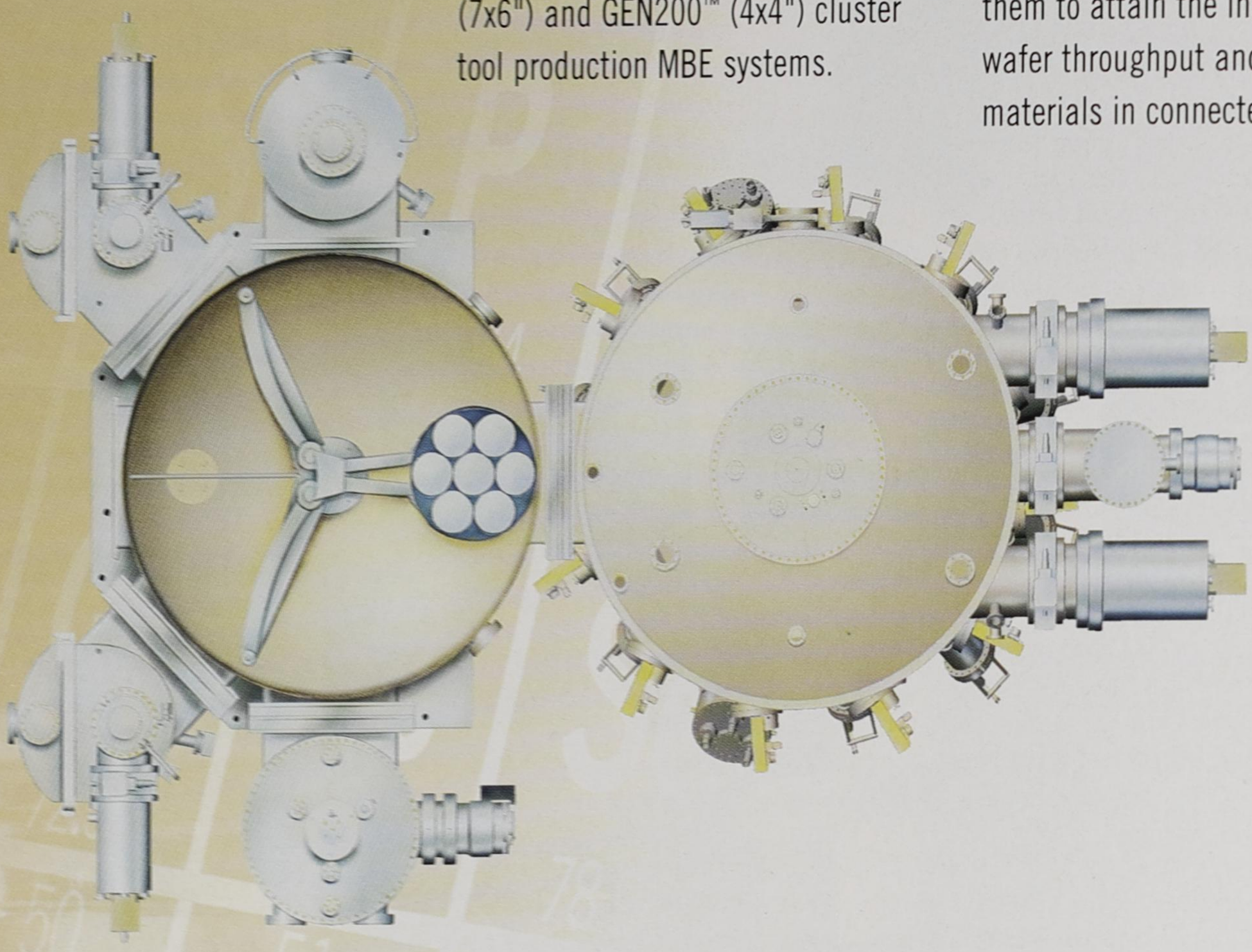
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defect densities. Ochrym reports that Airtron's management believed that implant would eventually dwindle to less than 10% of the total SI GaAs market, making the operation's position untenable unless a new growth technology could be added.

"There is no question that Airtron was the world's number one supplier at one time," says Asif Anwar, an analyst who tracks the GaAs industry for Strategy Analytics. "However, they failed to reinvest in more up-to-date facilities." Even so, Anwar believes that Northrop Grumman's inability to find a buyer can be attributed to the current slowdown in the GaAs business. His firm believes that demand for semi-insulating substrates will be down by 40% or more this year compared to last year. "Surely someone would have bought Airtron if the market was still like it was in 2000. Instead, in the current climate, everyone is happy to have one less competitor to deal with."

"Surely someone would have bought Airtron if the market was still like it was in 2000. Instead, in the current climate, everyone is happy to have one less competitor to deal with."

Victory for vertical?

Airtron's demise could be seen as a vindication of the viewpoint that vertical growth techniques are the way of the future for the GaAs industry. AXT, Wafer Technology, Sumitomo Electric and others already use vertical techniques (sometimes side-by-side with LEC). Freiberger, who in the past was, like Airtron, an all-LEC company, is known to be bringing a vertical production method on line.

However, representatives of M/A-COM say that this turn of events is also an endorsement of their use of high-pressure LEC (HP-LEC). The primary advantage of LP-LEC is that it is relatively easy to set up and requires fairly low levels of up-front capital investment. However, the downside of this convenience is that the LP-LEC provides much shorter boules than other techniques.

Whereas LP-LEC pullers can be "home-made", HP-LEC pullers are available from a limited number of sources, and have lead times of 12–18 months. However, they have been shown to yield boules that are up to five times longer and that yield a greater number of quality wafers with lower defect levels. Sources within the industry estimate that Airtron was using as many as 50 LP-LEC pullers during its heyday, leading to a cost structure that proved unworkable as soon as the current slowdown hit.

Free market rules

From 1994 to 1998, Airtron, M/A-COM and AXT all participated in a US Government program that was designed to ensure a secure domestic supply of semi-insulating GaAs wafers for the US market. Airtron received $7 million in government funding under the "Title III Program" to increase its production capacity and improve its yields over the four-year course of the program.

In its day, the Title III Program was considered to be a great success. The three participants increased their output by five times, and from 1994 to 1998 US suppliers increased their share of the world market for semi-insulating GaAs from 25% to 60%.

But in the US system, where the continuing subsidy of manufacturing businesses is frowned upon, the participants were free to go their own way once the program was over. Inevitably, Airtron's exit from the GaAs business will tarnish the program's legacy. Moreover, AXT has moved some stages of its substrate manufacturing operation to China, a move that is not sympathetic to the program's original intentions. M/A-COM now stands as the only remaining unambiguous positive result.

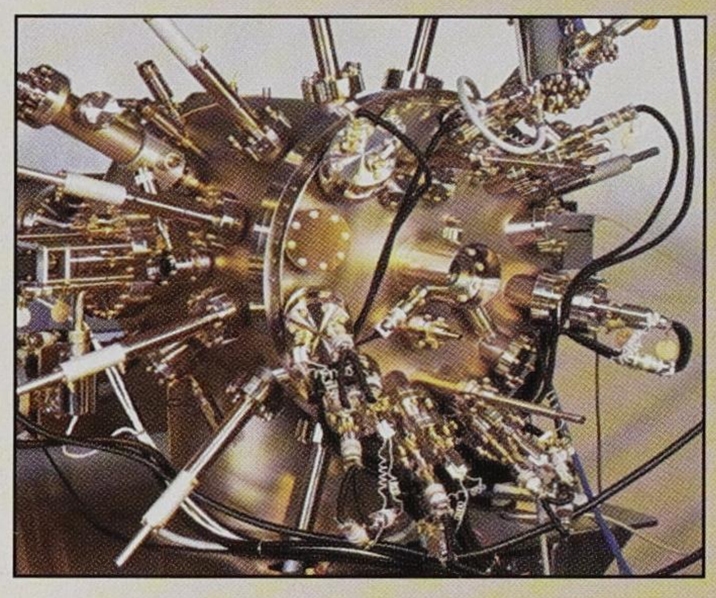
Gallium production

Ukrainian gallium output to increase to 10 tonnes

According to a recent report from Reuters, a Ukrainian company is planning a more than five-fold increase in its output of gallium metal. Mykola Serbin, head of Ukrainsky Aluminium, said that his company plans to build a new aluminum smelter in Ukraine, and would also set up new smelter facilities to increase production of gallium to 10 tonnes a year, from the current annual level of 1.8 tonnes.

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Cree renews lucrative LED contract with Osram

Cree has renewed a one-year purchase agreement with its largest customer, Osram Opto Semiconductors, for standard, high-brightness, Ultra Bright and Mega Bright LEDs and wafer products. The new agreement represents a 30% increase in LED volume compared with Osram's previous commitment, and is the largest contract in Cree's history. Osram accounted for 25% of Cree's business in the third quarter of 2001.

According to Cree, sales of its 470 nm blue Mega Bright InGaN-on-SiC LED, which offers 10 mW at 30 mA, now account for around 16% of LED revenues. The company also provides 405 and 395 nm UV LEDs with an output of 12 mW, and says it is pushing ahead with the development of 505 and 525 nm green Mega Bright devices intended for signage and traffic applications.

"The Cree and Osram relationship continues to grow as we are able to build on the benefits of SiC and GaN-based LEDs in the marketplace," said Chuck Swoboda, Cree's president and CEO. "As we continue to develop our LED technology and introduce increased brightness levels while improving price and performance, we believe that we will be able to continue to penetrate new and emerging applications." Cree's LED products are all grown on 2 inch SiC wafers, but the company may make the transition to 3 inch wafers next year. Due mainly to improvements in yield, average selling prices decreased by 6% in the September quarter.

White LEDs and blue lasers

In its recent conference call, Cree revealed that the automotive market accounted for half of its LED revenues, with handsets (20%) and signs (15%) major areas too. The "other" category (15%) included a small but profitable business for UV LEDs in counterfeit detection systems. Cree is developing two approaches to white LEDs – blue chips with a yellow phosphor for general use, and UV chips with RGB phosphors for applications requiring better color rendering – and believes the two markets will grow in parallel. Finally, the company stated that it has reduced the threshold currents of blue lasers to the range of commercial applications, and plans to begin sampling in the fourth quarter of the year.

White LEDs make their appearance in lighting systems for commercial aircraft

B/E Aerospace, a manufacturer of aircraft cabin interior products based in Wellington, FL, has launched LED-based interior lighting systems for business and commercial aircraft.

Two types of lamp are used to provide directed light for reading or "wash" lighting for general illumination. Mounted on a passenger seat, flexible light stems allow passengers to direct white LED light for reading, and can be retrofitted in the same footprint as traditional incandescent or halogen lamps. The company says that it purchases phosphor-coated blue LEDs and blue/yellow complementary LED mixing fixtures to achieve the white output required.

"Our new integrated system provides the same high-quality, natural white light as traditional B/E lighting systems," said Mark Krosney, general manager of B/E's Business Jet group. "The benefits associated with our patented LED technology include 10 to 12 times' longer life than existing products, 50% less power consumption, reduced cabin heat and no electromagnetic interference with other systems in the aircraft."



B/E AEROSPACE

B/E Aerospace employs white LEDs in its new general- and directed-illumination lamps for the interior of aircraft.

Microsemi samples blue LED products

Microsemi has made significant progress in the development of blue LEDs, and is now providing samples. The Irvine, CA-based manufacturer of RFICs and GaAs-based optoelectronic devices, transient protection products and power-management packages has developed two different blue LEDs which incorporate GaN-based die supplied by Cree and Nitronex.

Specifically, Microsemi is developing packages that enable LEDs to be driven at much higher currents than the typical 30 mA rating. The company employs Cree's 10 mW Mega Bright blue chip in its Optomite LED package, which supports drive currents up to 100 mA without overheating or the device lifetime being adversely affected.

"We are pleased with the first results from our Optomite-based LEDs," commented Steve Litchfield, Microsemi's director of business development. "We are confident that these first products are the right combination of performance and cost, enabling us to position ourselves as a leading US supplier of high-brightness LEDs."

Team-up with Nitronex

The company is developing a second product with Nitronex, which uses either blue or UV LEDs grown using Nitronex's GaN-on-silicon process (see p63). The aim is to encapsulate Nitronex's chips using spin-on glass developed by Microsemi (see *Compound Semiconductor* August 2001, p19). The glass package increases the brightness of the device and lowers the forward voltage, in addition to eliminating the epoxy packaging that tends to discolor under UV exposure. Microsemi expects to ship samples of the new design to customers in December.

"Microsemi has solved key technical issues and we are now seeing bright blue emission from devices grown on 4 inch wafers, which is not seen anywhere else in the industry," claimed Litchfield. "This product provides a distinctive set of features that will help introduce LEDs as a viable solid-state lighting solution," he added.

This month's cover story on nitrides begins on page 59.

More bad news for Nichia in patent disputes

Two recent trial decisions have gone in favor of Toyoda Gosei in its long-running battle with Nichia over blue LED patents. In September, the Supreme Court in Japan rejected an appeal by Nichia against a decision in the Tokyo High Court dating from March 2001. The case concerns Japanese patent no. 2 737 053, which is owned by Toyoda Gosei and refers to the basic composition of an LED device with a double heterostructure with an undoped active layer. The March decision rendered the patent valid, overturning a previous ruling.

In October the same court effectively invalidated Nichia's Japanese patent no. 2 778 405, describing double heterostructure LEDs with an Mg-doped p-type GaN contact layer above an Mg-doped p-type AlGaN cladding layer.

On the grounds that the patent lacks an inventive step, the court overturned a ruling by the Japanese Patent Office, which in December 1999 had rejected a demand from Toyoda Gosei to invalidate the patent. Unless the decision is reversed on appeal, it makes it likely that Nichia will be forced to drop its infringement lawsuit based on this patent.

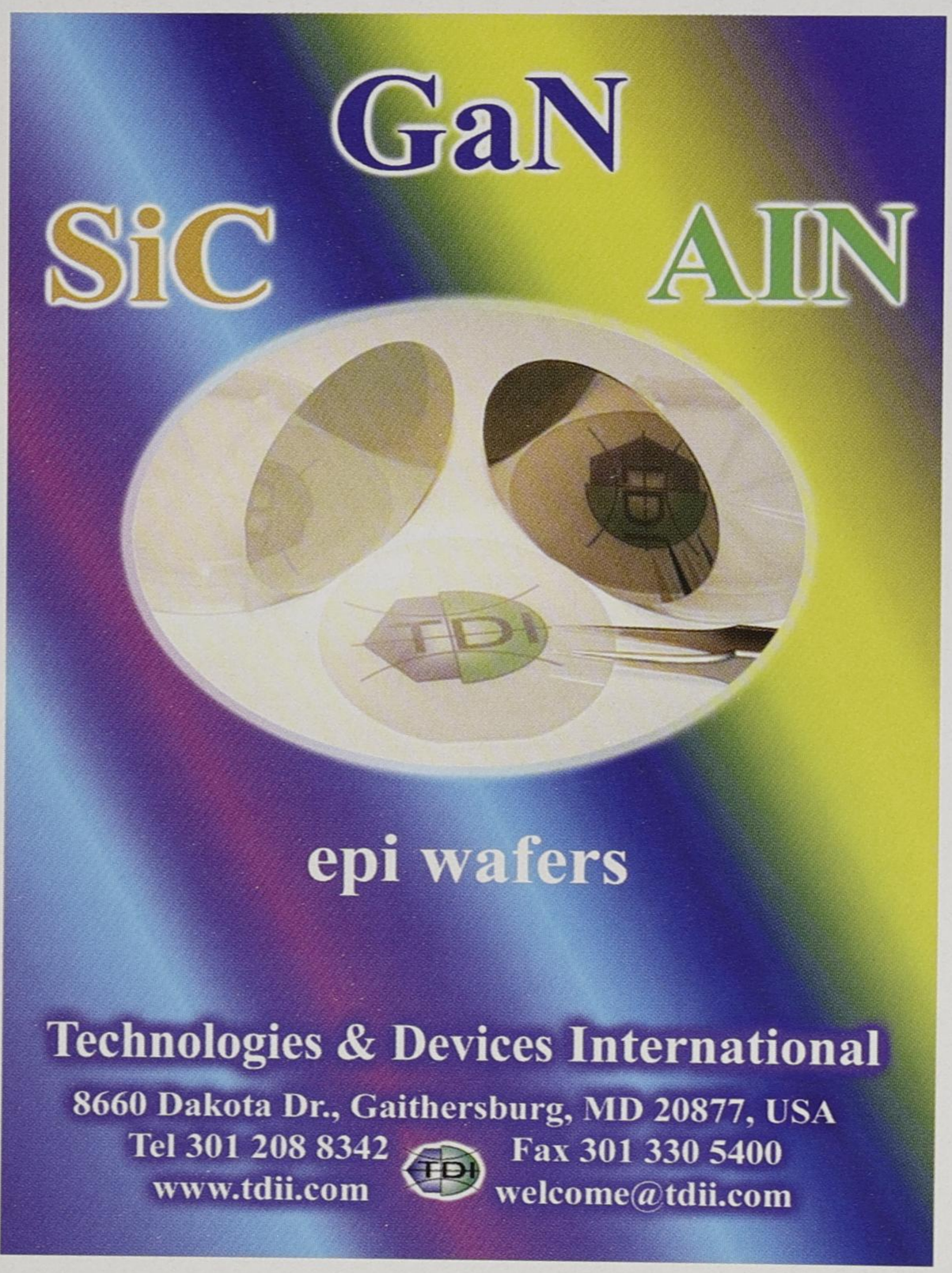
Osram vs Nichia

In late September Osram Opto Semiconductors filed two lawsuits in the US and Germany seeking to prevent Nichia from importing and selling white LEDs. The lawsuits are based on US patents 6 066 861 and 6 245 259, and cover basic technologies to manufacture devices using a single LED chip to create mixed-color light. According to Osram, the technology was developed by its employees between 1995 and 1997.

"We intend to prevent the illegal use of our technology by a company which neither holds nor has applied for a license to use it," said Rüdiger Müller, chief executive officer of Osram Opto Semiconductors. The lawsuits follow a decision in July of this year to dismiss a complaint from Nichia against Osram, which claimed that the German company's white LEDs infringe the Japanese patent no. 2 927 279 (see *Compound Semiconductor* August 2001, p26).

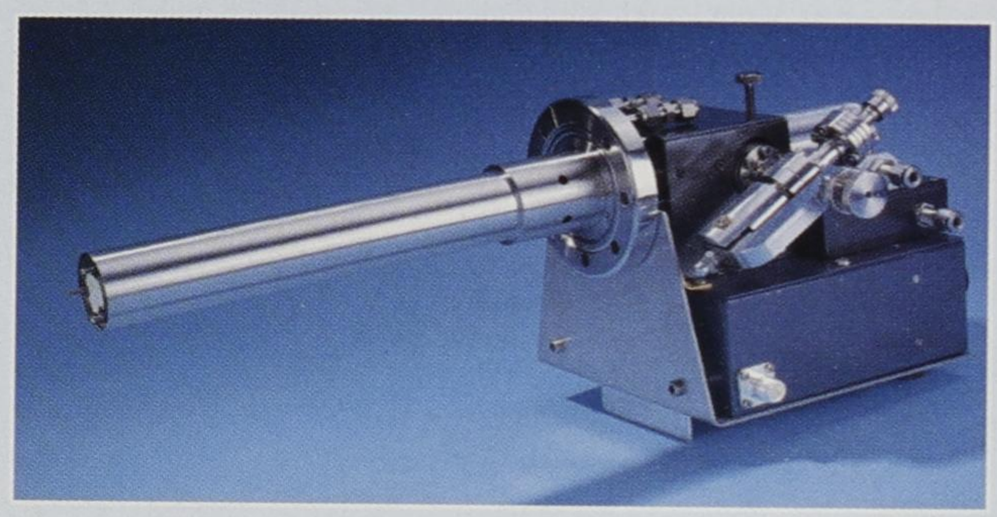
Cree vs Nichia

Cree was also affected by the trial decision concerning Nichia's patent number 2 778 405 (see above). This patent is the subject of an infringement lawsuit against Cree's products filed in Japan in June 2000. A statement from Cree said, "Unless reversed or modified on appeal, the decision in effect requires that the Japanese Patent Office invalidate at least the major claim of the patent and may provide an additional ground on which to seek dismissal of Nichia's complaints based on the patent." In May 2001, a lawsuit filed by Nichia against Cree and concerning Japanese patent no. 2 918 139 was dismissed (see *Compound Semiconductor* June 2001, p11).



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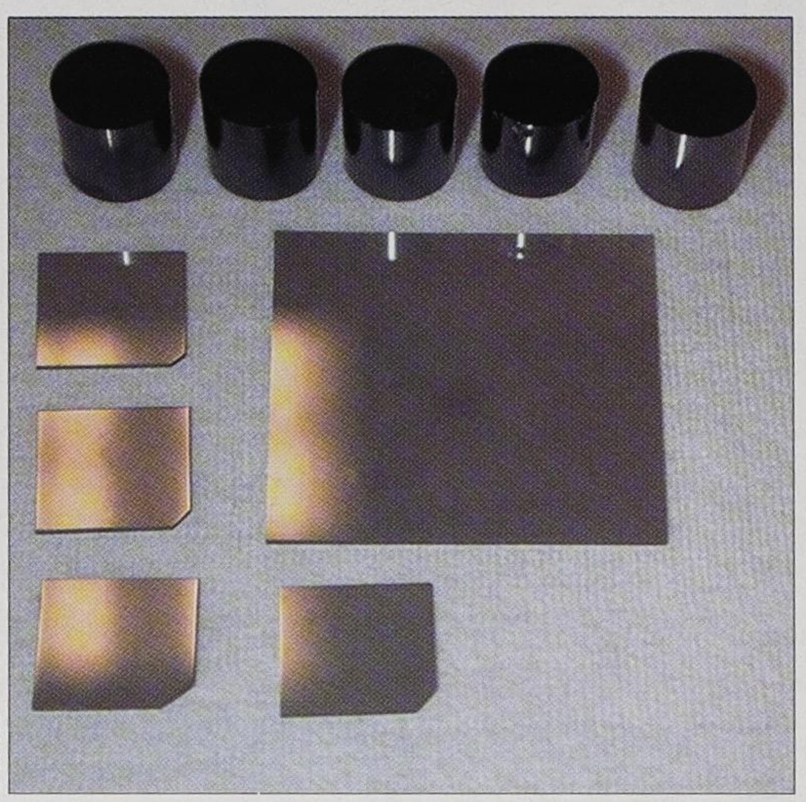
II-VI Inc buys Litton's SiC business

By Richard Dixon

II-VI Incorporated of Saxonburg, PA has bought the SiC substrate activity of Litton Systems Corporation, a subsidiary of Northrop Grumman, for an undisclosed sum. Litton's SiC development and manufacturing operations were part of the Electronic Materials Group of Litton Airtron, which was included in the $5.1 billion sale of parent company Litton Industries to Northrop Grumman at the beginning of the year (see *Compound Semiconductor* February 2001, p6).

II-VI Incorporated is a materials company with vertical manufacturing operations in infrared products, primarily for high-power CO_2 lasers. The company also supplies CdTe, ZnSe and ZnS substrates and owns eV Products, a manufacturer of CdZnTe materials and focal plane array detectors used in medical applications. Since 1998, II-VI's R&D program has led to commercially available 6H SiC wafers up to 2 inches in diameter, with 4H SiC in development.

"Combining II-VI and Litton's resources will more than double our SiC capability and should accelerate both the pace of product development and reduce time to market," said Carl Johnson, chairman and CEO of II-VI Inc. "While this strategic acquisition will increase our research and development investment in the near term, we believe it will make a significant contribution to our long-term success," he added.



II-VI INC

II-VI Inc, which makes cadmium zinc telluride materials and devices, has acquired the former Litton Airtron's SiC group.

The right fit

Until recently, Litton Airtron also manufactured GaAs wafers up to 6 inches in diameter, and was at one time the world's largest producer. However, Airtron recently closed down its GaAs substrate business due to unfavorable market conditions after failing to find a buyer (see p4). Litton's SiC activity has since continued as part of Northrop Grumman's Components Sector at the former Litton Airtron facility in Morris Plains, New Jersey; the company is a commercial supplier of 2 inch diameter SiC wafers.

According to vice-president of R&D, Tom Anderson, Litton Airtron had been looking for a buyer for its SiC program for several months. "I think II-VI is the right choice for our SiC activity because it's a materials company with a materials focus," said Anderson, who will head up the New Jersey operations. "We'll get the right level of investment needed to make SiC substrates a viable business."

"Northrop Grumman was looking for a buyer with a track record in SiC substrate development," said Craig Creaturo, treasurer of II-VI Inc. "The deal also allowed us to obtain non-exclusive access to Northrop Grumman's SiC substrate growth and fabrication patents."

According to Linda Self, director of communications for Northrop Grumman's Component Technology sector, the deal should allow the SiC business to develop. "We had treated the SiC activity as an R&D program, but with our decision to stop the GaAs initiative, the infrastructure was no longer there to grow the SiC business in the way it deserved," she said. "II-VI seemed an appropriate organization to do that."

- The eV Products division of II-VI Inc recently completed delivery of the last of 40 000 cadmium zinc telluride (CdZnTe) radiation detectors for the NASA Swift program. The detectors will be placed on the burst alert telescope to detect gamma rays; the mission is scheduled for launch in 2003.

Silicon carbide substrates

Sterling Semiconductor samples 3 inch SiC

Sterling Semiconductor has begun customer sampling of its new 3 inch diameter SiC substrates. The current samples are conducting 6H polytype material, and Sterling also plans to develop 3 inch diameter 4H polytype conducting and semi-insulating substrates. At present, most commercial device fabrication still uses 2 inch diameter wafers, and the move to 3 inch substrates will provide increased yields and greater cost efficiencies for electronic device manufacturers.

"Larger substrate size is key to reducing SiC device costs and gaining acceptance in the mainstream semiconductor marketplace," said Robert Soran, Uniroyal Technology's president and COO. "Our technical team has made excellent progress in expanding wafer size and we're continuing this effort."

Nippon Steel develops 4 inch SiC substrates

Using a high-temperature sublimation technique, Nippon Steel has successfully demonstrated a 4 inch SiC substrate. Shipments of samples are set to begin next year, with mass production scheduled for 2005. The company has developed proprietary technology to provide temperature control up to 2500°C, which is needed to grow monocrystalline material.

- Cree displayed a 4 inch SiC wafer at the ICSCRM conference in 1999, although the company still only sells 2 and 3 inch wafers.

First CW nitride laser in Europe

A German collaborative team claims to have demonstrated Europe's first nitride-based laser operating in continuous-wave mode at room temperature. The 420 nm InGaN-on-SiC device showed an output power of more than 20 mW and a threshold current of 110 mA. However, the lifetime was no more than "several minutes", according to a report in *Opto & Laser Europe*, a sister publication of *Compound Semiconductor* (see *OLE* November 2001, p5). The team, which consists of Osram Opto Semiconductors, Fraunhofer IAF and the universities of Ulm, Stuttgart and Braunschweig, demonstrated a pulsed laser in July 1999, and first made the breakthrough to continuous-wave operation in March of this year.

Sony spin-off Powdec develops GaN epiwafers

Former employees of Sony have launched a start-up company to mass-produce GaN-based epiwafers for microelectronic applications. The company plans to start shipping 4 inch epiwafers next summer; the large wafer size is expected to sharply cut production costs for GaN chips. The new company, Powdec KK, was set up in May of this year by former Sony researcher Hiroji Kawai and others from Sony and NTT. "We will produce AlGaN device structures on sapphire using newly-developed MOCVD technology," said Kawai. The production technique, which produces highly uniform layers, was developed at the Sony Research Center in Yokohama, Japan. Sony has applied for a patent for the technology; if the application is approved, Sony has agreed to license the patent to the start-up. Powdec aims for annual sales of ¥1 billion ($8.5 million) in three years.

Sterling receives Phase II SBIR award

Sterling Semiconductor has been awarded a $746 000 R&D contract from the US Army. The funds will be used to develop a method to grow epitaxial thin films on SiC substrates, primarily to develop SiC device technology for military and commercial electronic applications. The contract is a phase II SBIR award that follows the successful completion of a phase I contract. Sterling now has seven active contracts with the Army, Navy, and Air Force related to advances in SiC technology. "In each contract, the program also parallels our path to market for commercial products and can help accelerate the time-to-market of advanced SiC epitaxy and devices," said Robert Soran, president and COO of Sterling's parent company Uniroyal Technology Corporation. "The fact that the Army is relying on Sterling to fulfill this contract requirement is another indication of the quality of Sterling's technology."

Isotopically-pure ZnO investigated

Isonics Corporation and Cermet have entered into a joint development program to evaluate isotopically pure zinc-64 oxide. The partnership will evaluate whether improved thermal behavior can be bestowed on ZnO by removing isotopes from the material. As a direct band gap semiconductor, ZnO emits in the blue and ultraviolet portion of the spectrum, and is also a potential substrate for the growth of GaN-based epitaxial structures.

The use of isotopically pure materials improves thermal conductivity as the crystal lattice is made more perfect. Cermet will employ Isonics' purified ZnO powder and convert it into single crystal wafers using a proprietary process, after which the thermal conductivity and other properties will be measured. Isonics will also supply the modified zinc in the form of diethyl zinc for fabrication into various devices using MOCVD. The program is expected to last 12–18 months.

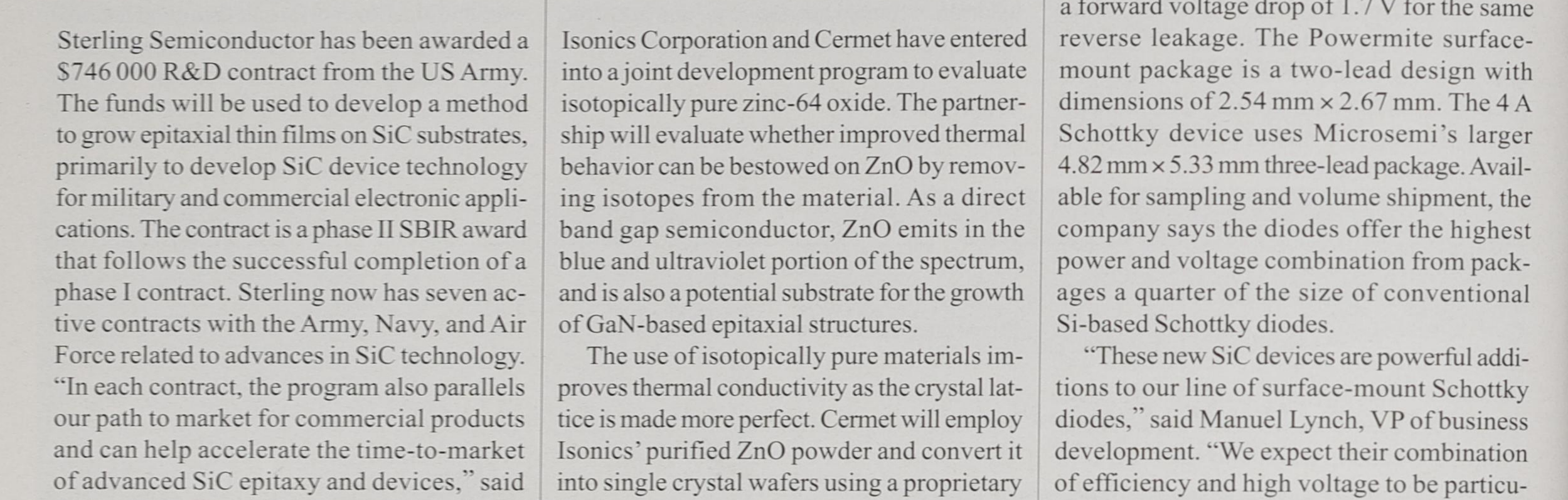
Cree and Microsemi release 600 V SiC Schottky diodes

Microsemi and Cree have unveiled the first in a series of compact SiC Schottky diodes operating up to 600 V for use in high-voltage applications such as telecommunication switching equipment and military aircraft. The products use Cree's SiC Schottky diodes in Microsemi's Powermite surface-mount packages, and were developed as part of the alliance formed in May (see *Compound Semiconductor* July 2001, p8).

The UPSC series offers 200, 400 and 600 V devices that feature a maximum current rating of 1 A, typical forward voltage drop of 1.6 V and reverse leakage of 20 μA. The UPSC4600 offers a maximum current rating of 4 A, and a forward voltage drop of 1.7 V for the same reverse leakage. The Powermite surface-mount package is a two-lead design with dimensions of 2.54 mm × 2.67 mm. The 4 A Schottky device uses Microsemi's larger 4.82 mm × 5.33 mm three-lead package. Available for sampling and volume shipment, the company says the diodes offer the highest power and voltage combination from packages a quarter of the size of conventional Si-based Schottky diodes.

"These new SiC devices are powerful additions to our line of surface-mount Schottky diodes," said Manuel Lynch, VP of business development. "We expect their combination of efficiency and high voltage to be particularly valuable in cardioverter defibrillator applications, military aircraft and telecommunication switching equipment."

- Cree is migrating its Schottky process to 3 inch SiC wafers, and is developing 1900 V, 4 A and 1400 V, 20 A devices.

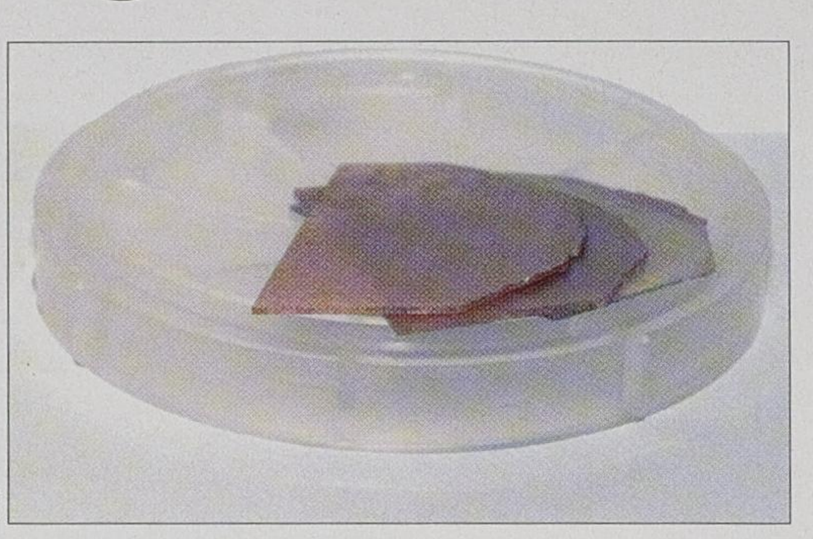


TDI makes large bulk GaN wafers

Technologies and Devices International (TDI) has made a major step forward in the development of bulk GaN substrates with the announcement of polished GaN wafers with a maximum diameter of 1.5 inches (35 mm). Bulk GaN is notoriously difficult to grow, and commercial GaN-based LEDs, lasers and microelectronic devices are all grown on sapphire or SiC substrates.

According to TDI's president and CEO Vladimir Dmitriev, sample boules currently yield "several" slices, and are composed of single crystal material of high quality. While exact details of the growth process are being kept under wraps, Dmitriev says the crystals are grown using a 1.5 inch GaN seed crystal, and are expected to be scalable to 3 and 4 inches in future. GaN bulk growth typically employs very high temperatures and pressures.

GaN templates suitable for device growth have typically been grown by HVPE on a sapphire or SiC substrate, which can be subsequently removed to leave a free-standing GaN substrate. However, these free-standing



TDI

TDI has successfully produced bulk GaN substrates up to 1.5 inches across using a 1.5 inch GaN seed crystal.

wafers contain a high density of dislocations produced during relaxation of stresses caused by thermal and lattice mismatch, which can adversely affect device reliability. According to Dmitriev, independent measurements of the bulk wafers have revealed a reduction in dislocation density of several orders of magnitude compared with epitaxially-grown templates.

"The performance and lifetimes of all GaN-based device designs will be significantly improved using bulk GaN versus GaN layers grown epitaxially on non-native substrates such as SiC or sapphire. To date, those have been the wide bandgap industry's only alternatives," said Dmitriev. "In addition, the bulk form allows control of the crystal orientation, and of the crystallographic planes required in the growth of certain devices."

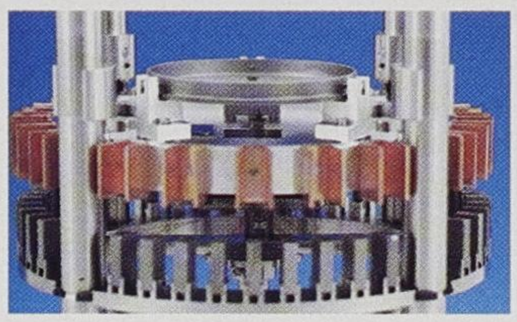
Commercialization soon?

TDI, which is based in Gaithersburg, MD, says it is developing proprietary, patent-pending crystal growth and wafer-fabrication technology to commercialize the new low defect-density GaN substrates, and is in active discussions with potential commercial development and manufacturing partners for volume production. The company says it expects to sample pilot quantities of the wafers in around six months' time.

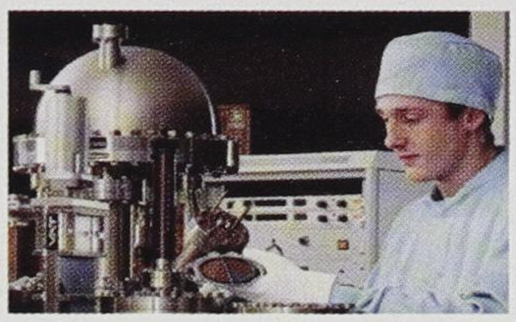
"With the right commercial development partners, within one year TDI's bulk GaN could act as the basis of next-generation commercial devices," said Dmitriev.

MBE and Surface Analysis

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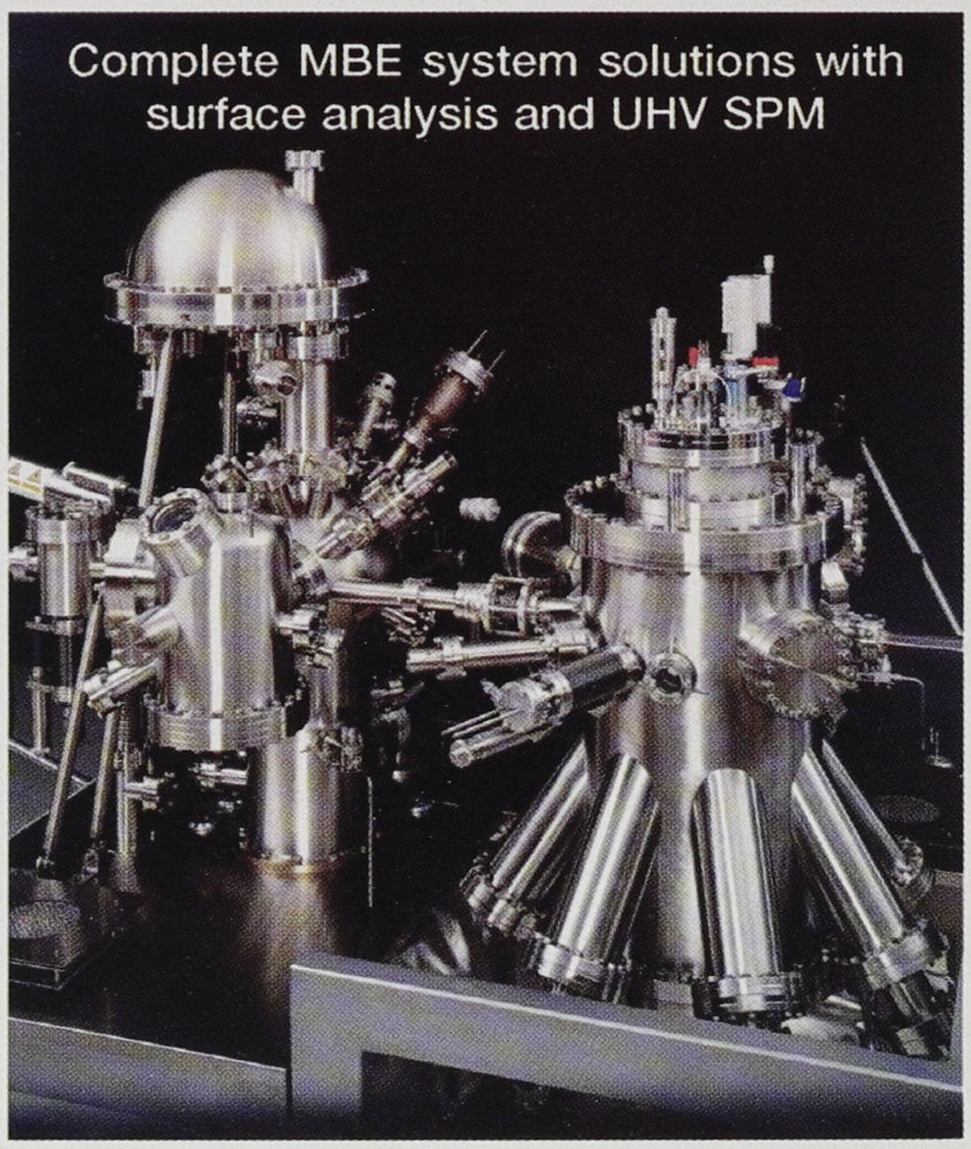


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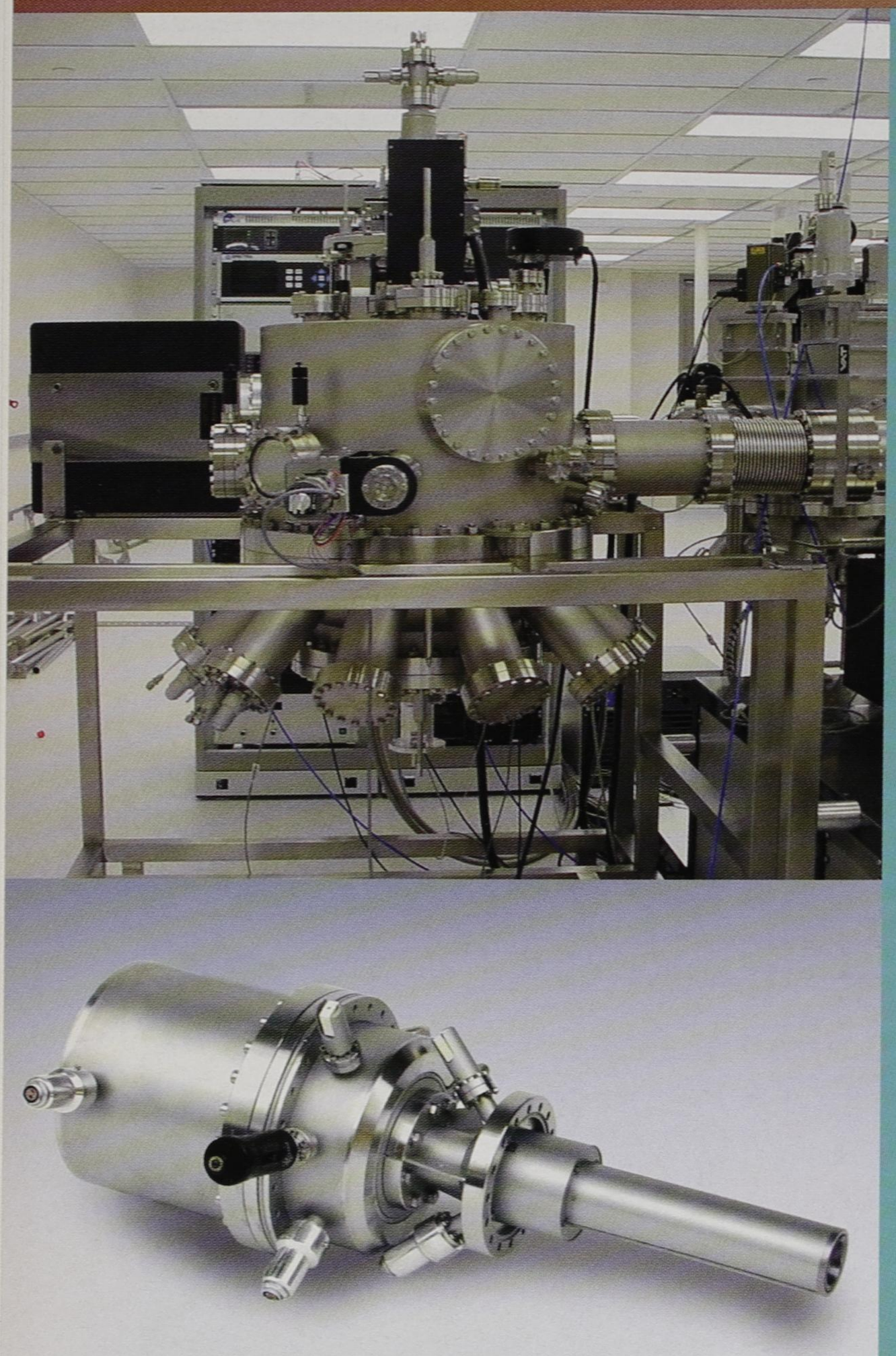
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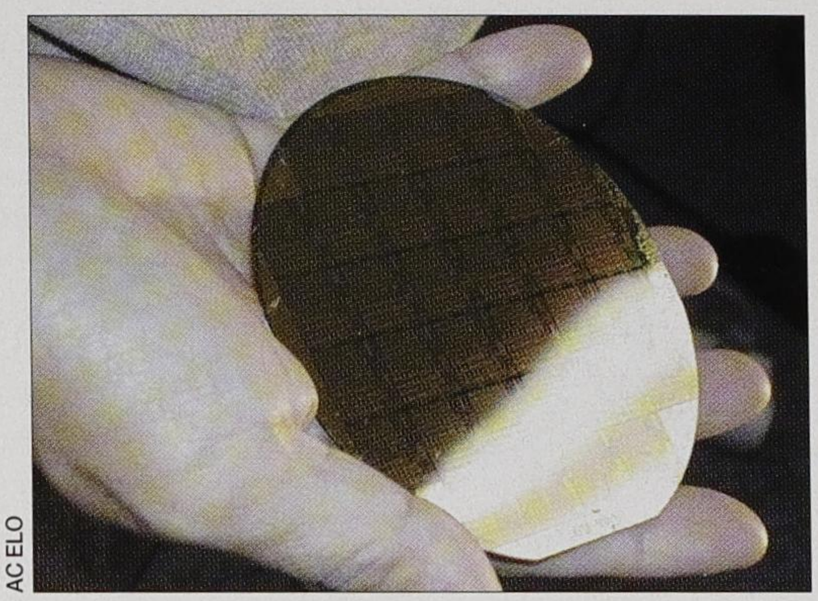
DCA INSTRUMENTS

Acelo leverages Rockwell license

Acelo Semiconductor, a recently launched company that designs and manufactures analog ICs, has unveiled GaAs modulator/laser drivers and transimpedance amplifiers for systems operating at 10 and 40 Gbit/s. Founded in mid-2000, Acelo leverages an exclusive license covering GaAs PHEMT and InP technology from Rockwell Scientific, which ranks alongside Cisco as one of its major investors.

Although Acelo does not produce its own epiwafers, it manufactures unpackaged chips at its plant in Oxnard, CA, which includes 4 inch front- and back-end processing lines and RF test facilities. The company also employs 10 people at a design center in Korea.

"Having all design and fabrication in house for 10 and 40 Gbit/s modulator drivers and transimpedance amplifiers, including wafer processing, allows us to apply a customized approach and deliver immediate solutions to telecommunications equipment makers," said John Hong, Acelo's chief executive officer. Acelo is using a 0.18 μm PHEMT process giving intrinsic f_t and f_{max} values of 80–100 and 240 GHz, and will be migrating some of its products to 0.15 μm designs in the future.



ACELO

Acelo is manufacturing high-speed ICs for the fiber-optic market, which are based on GaAs PHEMTs and InP HBTs.

First products

Acelo's 10 Gbit/s laser driver dissipates just 800–900 mW of power at full-drive current from a chip measuring 1.0 × 1.1 mm. An OC-768 (40 Gbit/s) modulator driver has an output voltage of 8 Vpp and 17 dB gain with a power dissipation of 800 mW, and is the only single-chip configuration that is capable of driving lithium niobate modulators. For the broadband wireless market, Acelo is developing PA and LNA circuits for point-to-point and point-to-multipoint distribution systems operating above 30 GHz.

Acelo is sampling the OC-192 modulator driver with an output voltage of 7.5 Vpp and 26 dB gain, for a power dissipation of 1.4 W. It is also developing mixed-signal devices, such as mux and demux ICs, to complete its chipset offering for OC-768 transponders, which will be available in early 2002.

"We decided on a medium-risk approach using a GaAs-based technology," said Hong. "In the 10 Gbit/s arena, SiGe is definitely a good solution, but at 40 Gbit/s, the reliability of these components at these very high clock rates comes into question. In the next few months, we will therefore be announcing novel InP-based HBTs that address the reliability concerns at these high data rates."

Emcore to sell VCSEL-based transceivers and transponders

Emcore is to sell its 12 × 1.25 Gbit/s VCSEL-based fiber-optic transmitter and receiver modules and very-short-reach (VSR) 10 Gbit/s transponders, having assumed direct sales and marketing responsibilities for these products from JDS Uniphase. Under a combined development, manufacturing and marketing agreement between the two companies dating back to last year, Emcore manufactured VCSEL-based modules for sale under the JDS Uniphase brand. The agreement with JDS Uniphase has now been amended to allow Emcore to sell its own branded modules. (In addition to the module business, Emcore makes VCSEL chips and arrays at its Albuquerque, NM facility and sells these products under its own name.)

JDS Uniphase will provide transitional marketing and sales services, and will designate Emcore its primary vendor of VCSEL-based products. A supply agreement between the companies will also be set up, subject to certain terms and conditions. The companies stated that the amended relationship allows them to "better achieve their respective economic objectives". It is thought that JDS Uniphase was unable to continue to support the previous arrangement due to its current financial malaise.

As part of the new arrangement, several personnel have transferred from JDS Uniphase to Emcore, including Matt Louis, who is now director of sales and marketing for Emcore's Fiber-Optic Division. While at JDS Uniphase, Louis was responsible for the overall marketing and sales efforts of JDS Uniphase products manufactured by Emcore, as well as JDS Uniphase's other high-speed optical products.

- Emcore recently announced a new 300 pin MSA (multi-source agreement) compliant transponder module to provide very-short-reach interconnections over parallel fiber links at SONET OC-192 data rates. The MTR8500 is the initial product offering from a family of Emcore transponder products and will soon be followed by a small-form-factor version. The transponder contains 1 × 12 arrays of 850 nm oxide-confined VCSELs manufactured by Emcore.

LuxNet targets low-cost manufacturing

Optical component manufacturer LuxNet has received a total of $18 million from investors, including Acer Technology Ventures and Citigroup, in its latest round of venture capital funding. LuxNet says that the investment funding follows on from the recent establishment of both its MOVPE epitaxial growth facility in Fremont, CA, and a 15 000 sq. ft manufacturing subsidiary which is situated in Lung-Tan, Taiwan.

LuxNet will use the injection of funds to speed development and ramp production of a range of products, which include VCSEL chips and arrays, PIN photodiodes, and Fabry Perot and DFB lasers. These products are primarily targeted at storage, local and metropolitan-area networks.

"Our samples have consistently shown themselves to be some of the best performing in the optical networking industry," said LuxNet's chairman and chief executive officer Hsing Kung. "Through proprietary device design and fabrication processes, LuxNet has the ability to provide both superior product performance and in-house, high-volume low-cost manufacturing."

Inphi uses GCS foundry for InP ICs

Inphi, an optical components company in Westlake Village, CA, has developed and tested what it describes as the first commercial 50 Gbit/s InP circuits. Inphi is sampling 4:1 mux and 1:4 demux prototypes. The extra bandwidth gives network providers the ability to offer super forward-error correction (FEC) and to extend the range of future long- and ultra-long-haul networks, says Inphi.

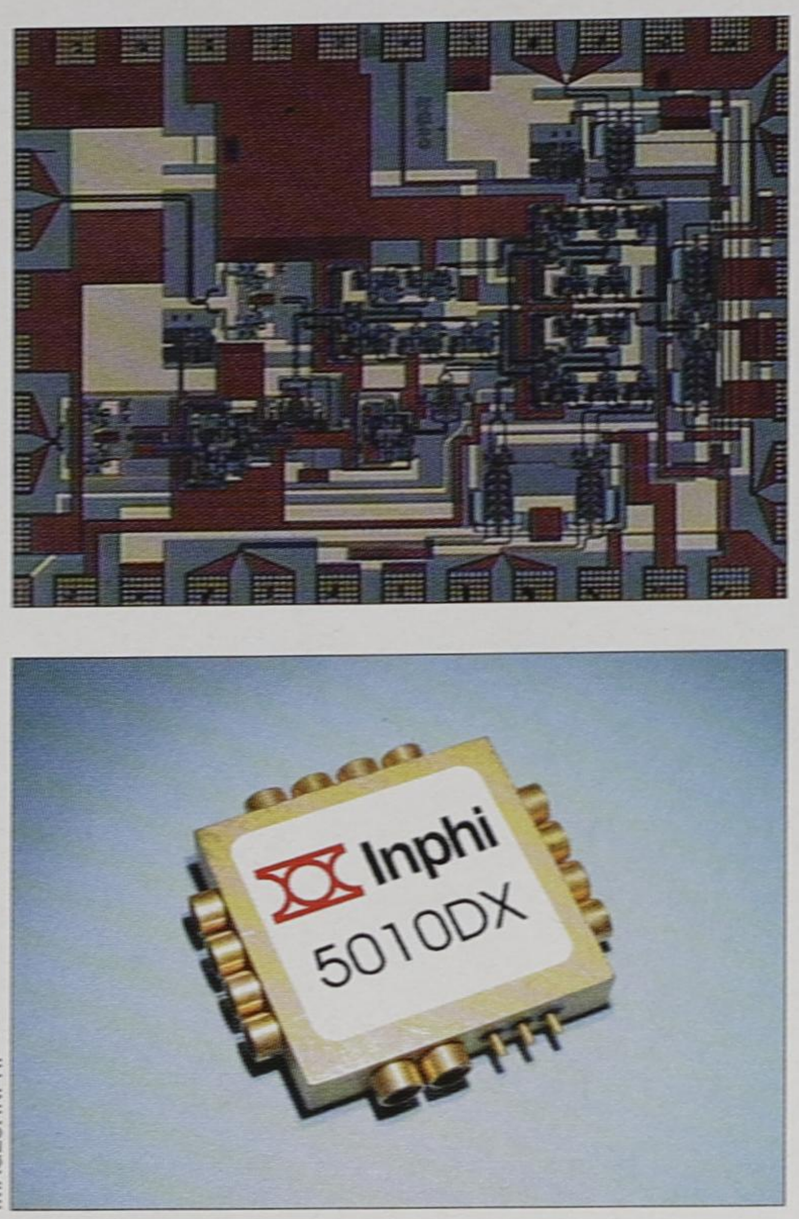
The company also says that its new mixed signal circuits offer this data-rate specification at around 900 mW, or one-quarter of the power consumption required by existing SiGe or GaAs devices currently operating at data rates of 10 Gbit/s. This development enables optical equipment vendors to build transponder modules, high-end routers and DWDM transport systems with OC-768 interfaces at power levels comparable to those of current OC-192 ports.

Following the fabless model

Founded at the end of 2000, Inphi is a fabless company with a staff of 30 undertaking design, packaging and high-frequency testing, and reliability studies. The company is currently using GCS's 4 inch InP single HBT process, which features a carbon-doped InGaAs base, an emitter width of 1 μm and f_t and f_{max} above 160 GHz. Inphi is led by former fab operations manager for HRL's InP high-speed-circuit laboratory, Loi Nguyen.

Inphi sees its key differentiator as the ability to offer circuit designs that combine high-speed operation with low power consumption. "GaAs and SiGe are having a difficult time reaching 40 Gbit/s, and consume a lot of power – up to 3 W for SiGe at the same level of functionality as our InP circuits," said Nguyen. "OEMs would like components with four times the bit rate for the same power consumption, with the net effect that the network carriers they supply can deploy further revenue-generating services. Our 50 Gbit/s ICs, which are unique to the market, offer less than 1 W of power consumption and are clearly a step in that direction."

Inphi is currently sampling mux/demux ICs and intends to introduce several InP analog and mixed-signal circuits in the future, including electroabsorption modulators and a Mach Zender driver by the fourth quarter. Physical layer chipsets for clock and data recovery and clock multiplication functions will be available in 2002, along with front-end modulator drivers and transimpedance amplifiers.



IMAGES: INPHI

Fabless design house Inphi has launched its operations with 50 Gbit/s InP mux/demux ICs, shown here in their (top) bare and (bottom) packaged form.

In brief...

Movaz and Bandwidth9 to develop laser subsystems

Bandwidth9 is working with Movaz Networks to develop tunable laser subsystems for the remote tuning of wavelengths in optical networks. Movaz will use Bandwidth9's MetroFlex VCSEL-based module, which is able to lock to a specific wavelength in less than 200 μs across a continuous tuning range in the C-band.

Yokogawa launches new 40 Gbit/s HBT modules

Yokogawa Electric has released new GaAs HBT modules for use in 40 Gbit/s optical networking systems and measuring instruments. A driver module for $LiNbO_3$ modulators provides an output of 5 Vpp and gain of 23 dB, while another module designed for electroabsorption modulators supplies 4 Vpp and 15 dB gain.

nLight opens laser diode plant

nLight Photonics, a supplier of pump lasers headquartered in Seattle, WA, has opened a laser diode manufacturing plant in nearby Vancouver. Completed just over a year after the company's foundation and including a 22 000 sq. ft class 1000 clean room, the plant recently began producing pump lasers for use in Raman amplifiers. The location provides access to local chip manufacturing infrastructure and skilled labor, says the company, which has received $60 million in funding.

"Our product and process technologies allow us to improve the performance significantly while reducing the cost of active optical components," said president Scott Keeney. "This new facility will give us increased control of product reliability and shortened design cycle times. Even with the current downturn in optical component markets, we strongly believe that continued investment in our capabilities and proprietary technology positions us well for the industry turnaround."

Agility funding round reaches $83 million

Tunable laser manufacturer Agility has received $83 million in a third round of funding led by General Motors Investment Management. The new round brings the total received by the company to more than $186 million. Existing investors Morgenthaler Ventures and US Venture Partners were joined this time round by optical networking manufacturers Ciena and Tellabs. Agility says it is currently shipping its sample-grating DBR tunable device in production quantities to several customers and sampling to more than 35 companies. "With the significant financial support demonstrated in this large funding round, we can fulfill our mission of taking the lion's share of the widely tunable laser market," said Ron Nelson, president and chief executive officer.

European start-ups secure funding

Two European start-ups have recently secured first-round funding, while two more companies have opened new facilities. ThreeFive Photonics and Hymite have been awarded $6.4 million and $5.3 million respectively by different groups of venture capitalists. ThreeFive Photonics, which is based in Delft, The Netherlands, is developing InP-based components for optical communications networks. It aims to use monolithic integration to add complexity and functionality to components with the goal of producing complete network subsystems on a single chip.

"This funding will enable us to complete the development of our first chip, codenamed Argo, and prepare it for production," said Wouter Deelman, CEO and co-founder of ThreeFive Photonics. "We will have a working prototype of Argo by the end of the year. Production will start in 2002."

Based at the Danish Technical University in Copenhagen, Hymite aims to provide multichip modules for fiber-optic networks. The company has component manufacturing facilities, and is concentrating on hybrid integration techniques. "Linking several components such as lasers and arrayed-waveguide gratings into a single optical module will revolutionize the manufacturing of optical components," said Jochen Kuhmann, founder and CEO of Hymite, "in the same way printed circuit boards have changed the way electronics systems are built."

u²t expands facilities and buys LKF

u²t Innovative Optoelectronic Components has opened a new facility in Berlin for the assembly and testing of InP-based products. These include 40 Gbit/s photodetectors and optical modulators. u²t has been occupying rented space at the Heinrich-Hertz-Institut für Nachrichtentechnik (HHI) from which it was spun out in 1998. The new facility gives the company 400 m² of class 10 000 clean-room space close to HHI. u²t will continue to use HHI's InP processing facilities, but plans to set up its own process line in the future. u²t has also bought another HHI spin-out, LKF Advanced Optics. LKF's products include pulsed lasers operating at up to 40 GHz and the firm is developing optical switches based on semiconductor optical amplifiers.

Modulight opens new plant

Modulight, based in Tampere, Finland, has opened a new production facility. The products include InP- and GaAs-based lasers and receivers for metro, access and enterprise networks (see *Compound Semiconductor* May 2001 p70). The new 32 000 sq. ft plant consolidates all Modulight's production in one place. "The new fab gives us the possibility to respond quickly to increased customer demand. Our plot allows us to easily quadruple the manufacturing space," said Petteri Uusimaa, president and CEO.



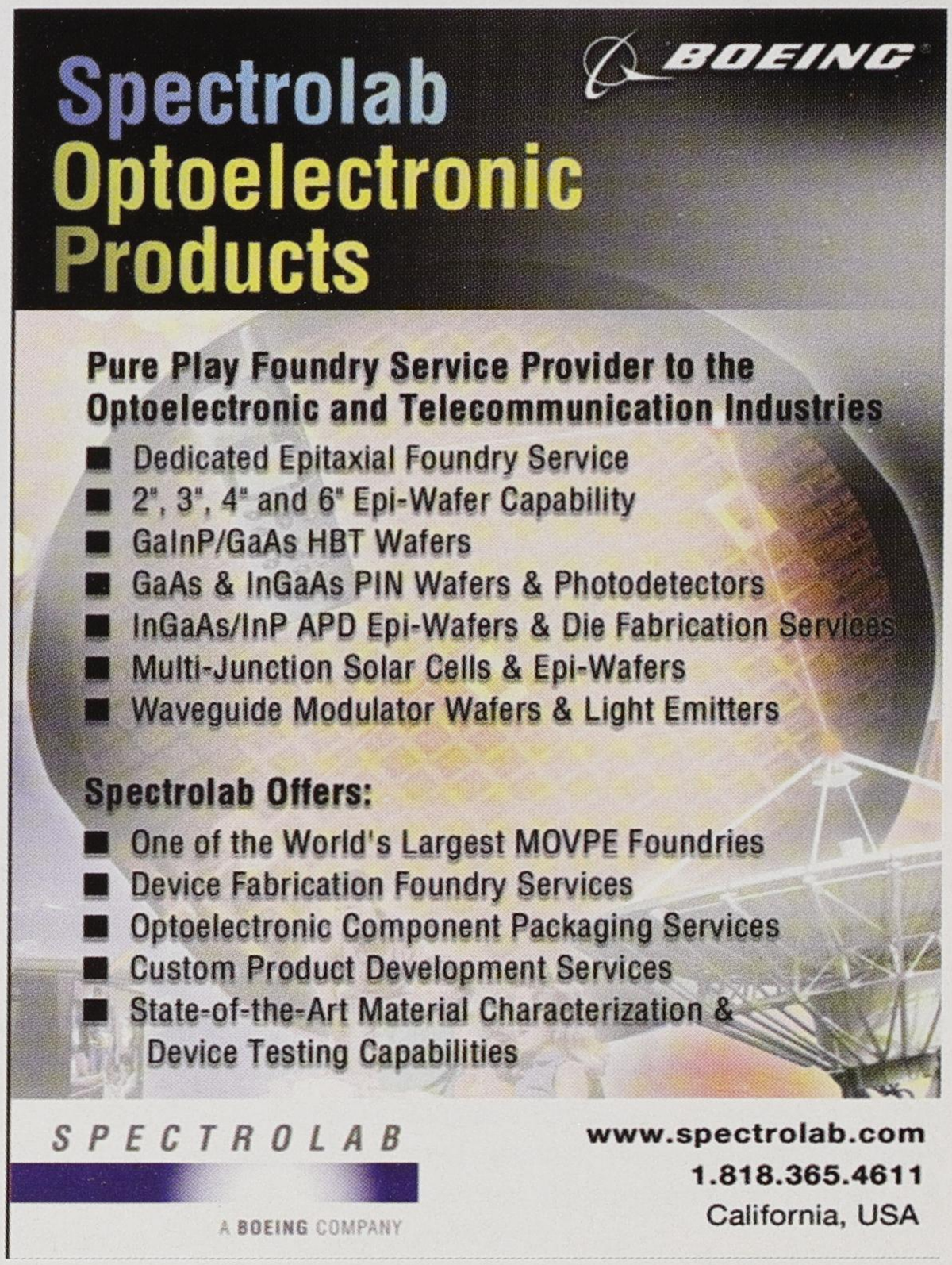
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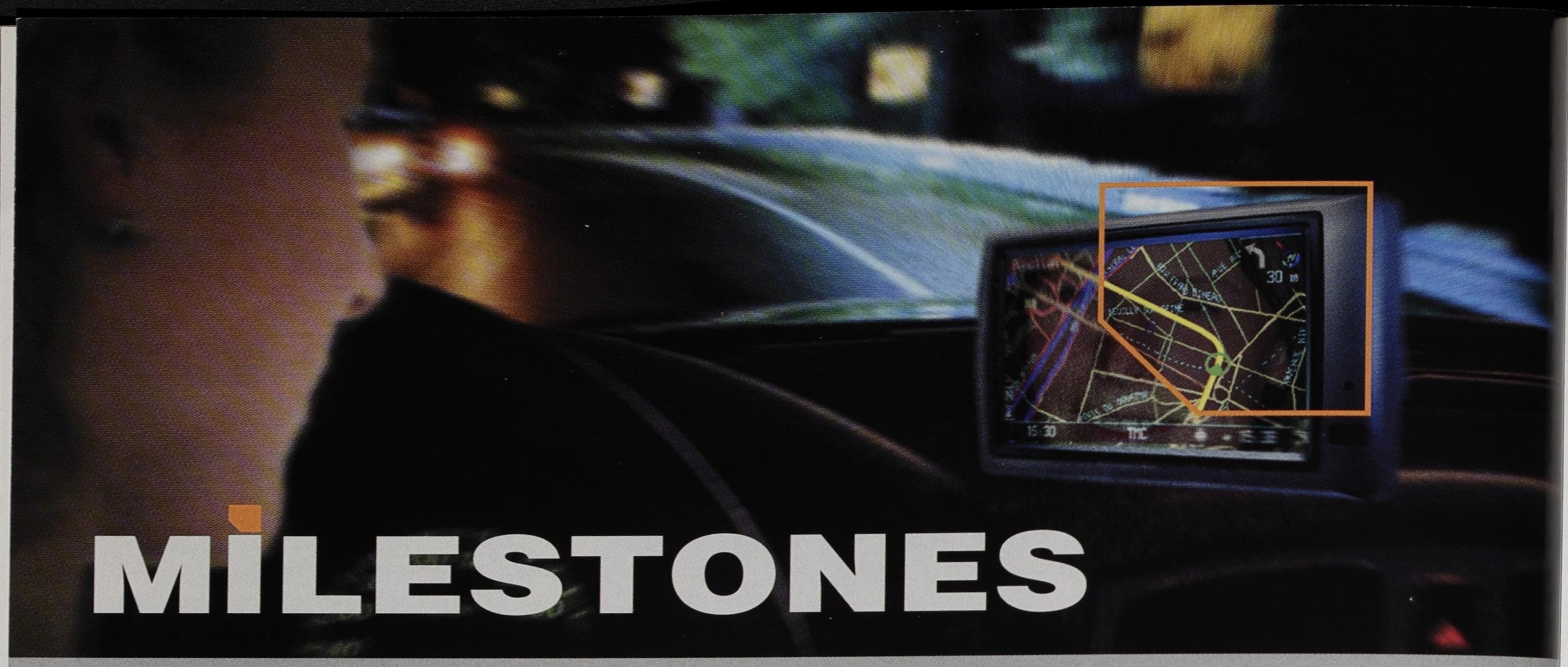
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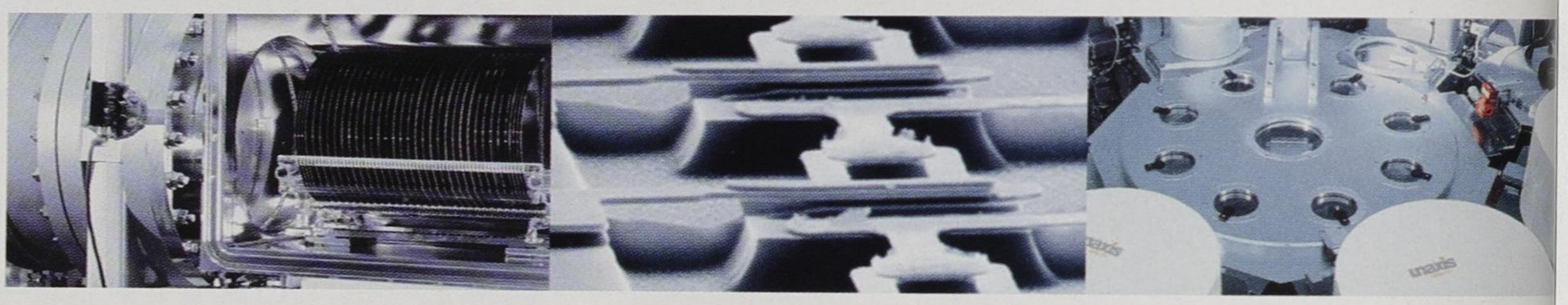
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RF modules ramping up at US GaAs fabs

By Marie Meyer

Power amplifier modules for wireless handsets now account for more than 43% of revenue at RF MicroDevices and may rise to as much as 75% in the near future, according to company executives. RFMD's module shipments have ramped up from less than $3 million per quarter in mid-2000 to more than $40 million in the September quarter (see chart). This trend supports the opinion of many industry analysts who believe that manufacturing integrated modules instead of individual MMICs is the best strategy for manufacturers of RFICs to increase their market share in the highly competitive wireless handset market.

RFMD has been shipping dual-band GSM PA modules for several quarters now, and has launched TDMA and GSM GPRS modules in volume production. According to chief financial officer Dean Priddy, RFMD is increasing its profit margins on modules and has reduced its cycle time to eight weeks, down from 16 weeks a year ago. Gross margins are currently around 40% on the module products, but Priddy commented that as production continues to ramp up, that figure should move closer to 50%.

Among the other GaAs fabs, Alpha is expected to launch volume shipments of PA modules for GPRS phones in the December quarter, and the company already has a triband PA module in production. Front-end switch modules are also being planned. Alpha's chief executive officer Dave Aldrich describes these as multi-throw switches, logic, and low-pass filters, "wrapped around an LTCC platform".

"It's an easy migration path for the customers that are buying MMICs from us today because they're already using multi-throw highly integrated InGaP switches," said Aldrich. But he also said that it does take a bit of time for the handset designers to come around. "They have to change their mindset away from lots of discrete semiconductors, filters and ceramics towards this module. So it's a difficult application support process. But the performance is great, and when they get used to it, they love it."

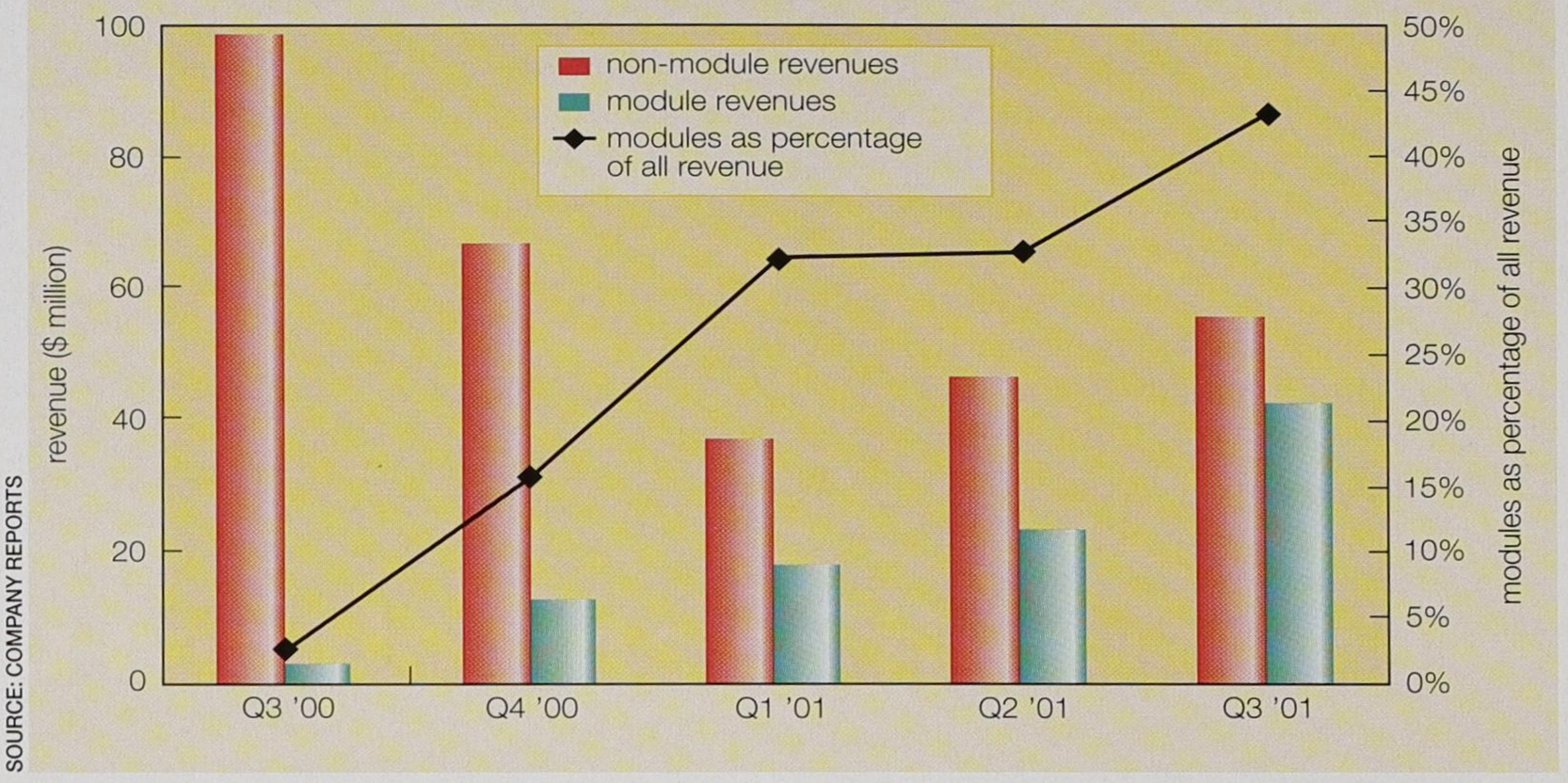
Future directions

RFMD president and CEO David Norbury said that future generations of modules will be even more centered on the power amplifier than current models. "As we move from one generation to the next, the PA itself will contribute more of the added value. Today we have got an awful lot of discrete components – capacitors, resistors, inductors, etc – typically one or two active devices and more than a dozen or so passives. A year from now you are probably going to see somewhat larger GaAs or active PA chips with maybe just one or two passives."

Alpha has developed a roadmap for combining amplifier and switch filter modules into an integrated front-end. Aldrich says this is an exciting but challenging prospect because it revolutionizes the architectural approach currently used by handset designers, by turning the entire RF front-end of the phone into a single component – one that Aldrich says would have to be sole-sourced to Alpha, "because there isn't anybody else today that can make it".

Aldrich predicts that Alpha may land orders for the proposed fully integrated front-end in the early part of next year. But RFMD predicts that the next development will be modules for receive functions, instead of adding more functions into the PA module. The company is currently sampling receiver modules with integrated SAW filters. TriQuint's acquisition of filter manufacturer Sawtek earlier this year was intended to address this same market. In late October TriQuint announced its first transmitter module products, handling all the transmit functions from the analog base-band output to the power amplifier input. However, the RF portions are executed in SiGe, not GaAs.

Modules manufacturing grows in importance at RFMD



SOURCE: COMPANY REPORTS

In the September quarter, modules accounted for 43% of RFMD's total revenues.

GaAs fab plans

In its recent conference call with investors, RFMD executives confirmed that the company was proceeding with plans to begin volume production in its second HBT fab in the December quarter of this year. In the past year RFMD has branched out beyond its strong relationship with Nokia, and now counts Motorola as its second largest customer and is also shipping to Ericsson. Alpha Industries CFO Paul Vincent indicated that his company would delay implementing its 6 inch conversion until the spring of 2003. Motorola remains Alpha's largest customer, with Ericsson emerging as their second largest account.

RFMD predicts that the next development will be modules for receive functions, instead of adding more functions into the PA module.

GCS focuses on InGaP and InP HBTs

As a result of recent advances in its HBT technology, Global Communication Semiconductors (GCS) says it has reorganized its work-force and technical teams to focus on the increasing demand for InGaP/GaAs and InP HBT foundry processes. "In the past, GCS has provided advanced compound semiconductor foundry services in a wide variety of technologies," said CEO and president Owen Wu. "However, with our recent achievements in InGaP HBT reliability and InP HBT performance, it became evident that our future is in HBT technology."

As well as demonstrating high reliability with its InGaP HBT process (see below), GCS has seen growing demand for its proprietary InP HBT process, notably from Inphi (see p16). Another publicly announced InP customer, GTRAN, is using its own process.

GCS utilizes a low-loss interconnect (for high-speed circuits) and a carbon-doped base (ensuring long-term reliability). "Although circuit performance is equally dependent upon design," said Chanh Nguyen, CTO, "GCS's InP HBT technology meets the most demanding performance needs for those designing into OC-768 applications and future needs for high-performance PAs."

GCS has seen growing demand for its proprietary InP HBT process, notably from Inphi.

GCS also intends to hire additional specialist staff to support InGaP and InP HBT production, and will also address the integration of HBTs with optoelectronics for future optoelectronic IC applications.

GCS reveals InGaP reliability results

GCS recently announced new reliability data obtained from test devices manufactured using its proprietary InGaP HBT process. The process is used in handset power amplifier circuits and devices such as transimpedance amplifiers and laser drivers employed in optical networks operating at 10 Gbit/s.

"Over two years ago, GCS chose a robust InGaP HBT power process for the manufacture of ICs," said Wu. "Since then we have accumulated over 5 million device-hours of accelerated life test data and established the reliability of our InGaP HBT process." Wu says that devices manufactured this way exhibit an activation energy of 1.2 eV and mean-time-to-failure (MTTF) of 10 million hours at 125°C, with fewer than 15 failures in time (FITs) in 10 years. "This level of reliability meets even the most stringent requirements of our customers," said Wu.

WIN receives quality certificates in first year of operation

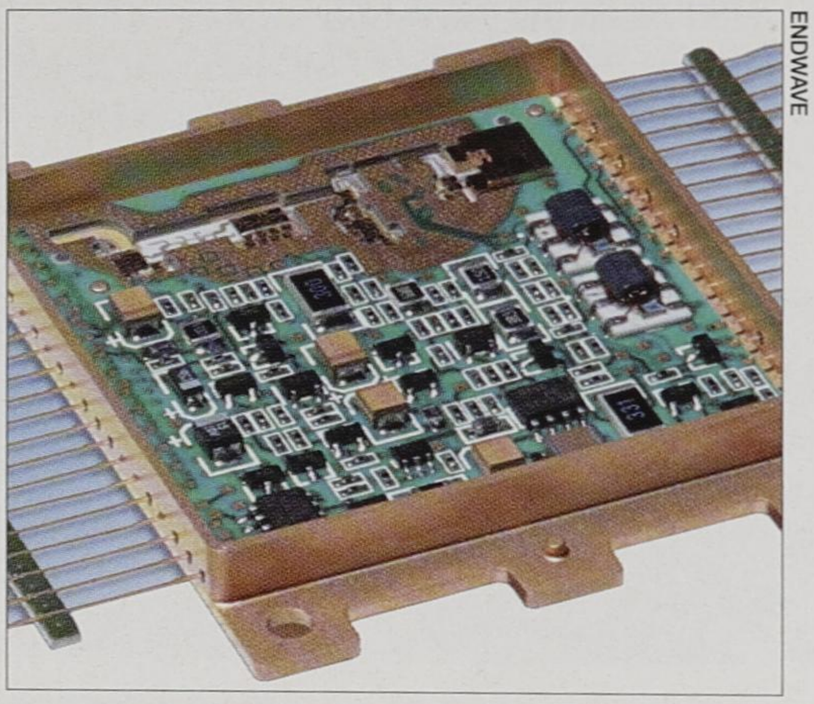
WIN Semiconductors in Taipei, Taiwan, has obtained QS-9000 and ISO-9001 quality management certificates less than a year after beginning foundry operations at its 6 inch GaAs fab. These underscore WIN's aim of becoming a high-volume foundry source of HBT and PHEMT MMIC wafers.

Based on ISO-9000 with additional requirements specific to the automobile and semiconductor industries, the QS-9000 certification adds more than 100 requirements in areas such as defect prevention and reduction of waste in the supply chain.

"The development of a quality management system and the dual certification is a milestone in the short history of WIN," said the CEO C S Wu. "It provides proof of the company's dedication to providing its customers with the highest possible quality in both products and services."

Our report from the GAAS2001 show begins on page 45.

Endwave accelerates 60 GHz broadband transceiver program



ENDWAVE

Endwave's Access60 transceiver unit contains transmit, receive and IF functions in a single compact package. The module has been designed for the self-regulating 57–64 GHz frequency band.

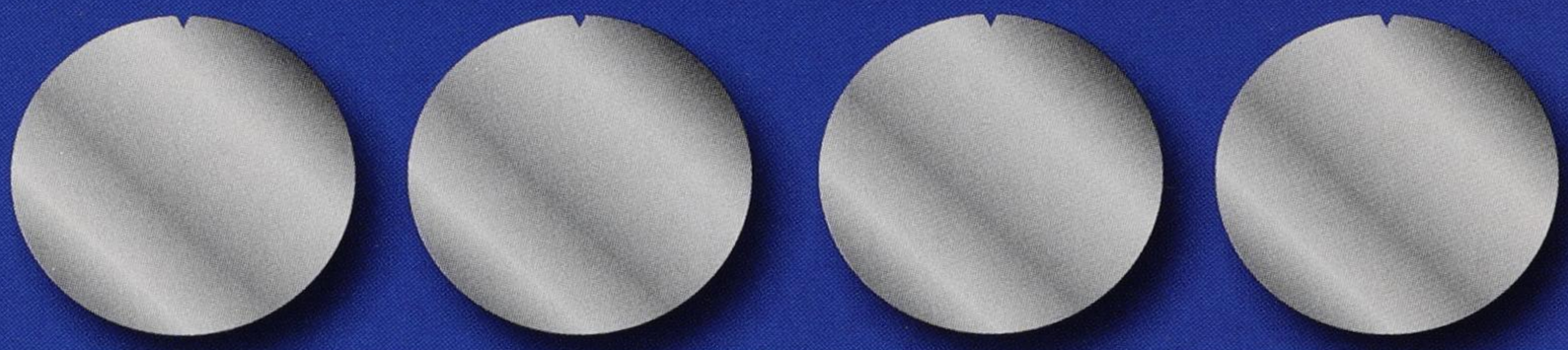
Endwave has unveiled a new program to accelerate development of broadband wireless transceivers in the 57–64 GHz frequency band. The Access60 program features 60 GHz chipsets that combine transmit, receive and IF functions into a single compact package. The devices, which include TRW's GaAs MMIC technology, are produced at the company's high-volume automated production, assembly and RF test facility in Sunnyvale, CA.

Broadband wireless transceivers are used to provide Gbit/s radio links which connect cellular phone base stations to a central switching point, to link LANs in corporate campuses and office parks, as back-haul links for 3G base stations and to provide access to WANs and MANs.

The 57–64 GHz spectrum includes the as yet relatively untapped 60 GHz frequency. This is a self-regulating band which is exempt from licensing requirements. Endwave says that the 60 GHz band enables low-order data modulation schemes, which makes high data-rate radios easier to design. The company has already qualified its first Access60 transceivers, which operate at 58 GHz, in Nokia's MetroHopper broadband wireless infrastructure system, which is currently operational in Europe.

"The Endwave Access60 program was an important part of Nokia Networks' MetroHopper 58 GHz radio solution," said Risto Valtonen, general manager of Nokia Networks. "This allowed our customers to avoid delays caused by frequency license applications or waiting for leased lines."

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UMS joins Atmel in new R&D alliance

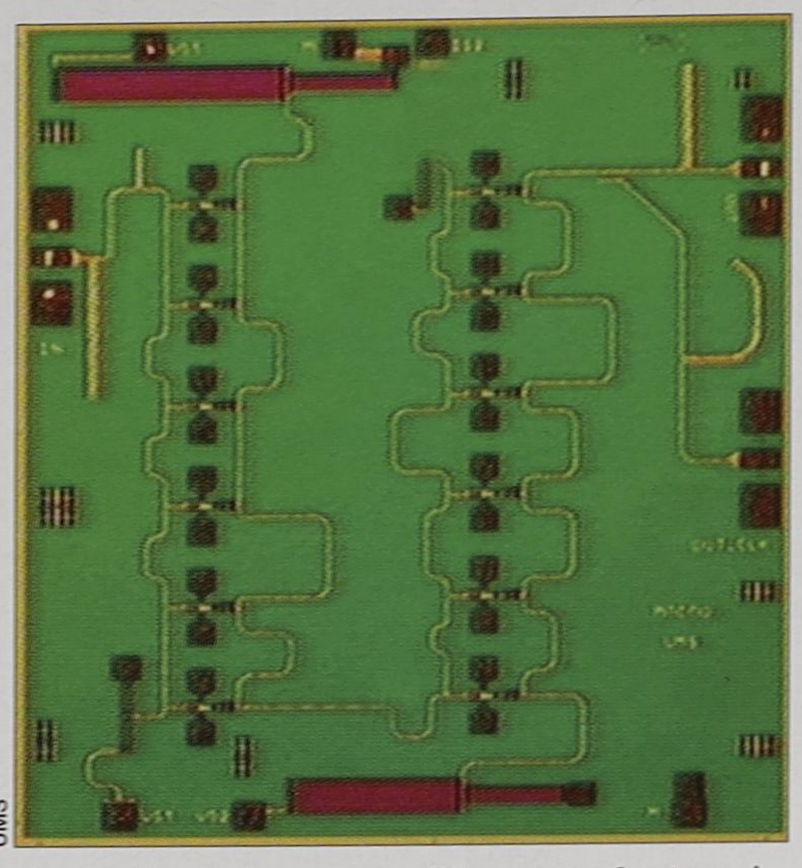
By Richard Dixon

United Monolithic Semiconductors (UMS) is teaming with Multilink, Atmel and the University of Ulm to create an industry-academia R&D group. To be located at the University of Ulm's campus in south Germany, the new Competence Center for Integrated Circuits in Communications will develop ICs for analog functions in wireless and high-speed optoelectronic systems.

The University of Ulm, which maintains a 7500 sq. ft clean room at the core of its microelectronics activities, has previously played host to several projects with Atmel and UMS. The latter company makes high-frequency communications devices in Orsay, France, and Ulm, where it operates a 4 inch GaAs line. Based in Heilbronn, Germany, Atmel offers silicon technology and a high-frequency SiGe process that operates at up to 82 GHz. Multilink is a fabless supplier of GaAs digital and mixed-signal ICs for fiber-optic networks based in Somerset, NJ.

In addition to circuit design, the new center will undertake device modeling and characterization. The industrial partners will use the center to generate new ideas relating to device design topologies and applications, which if successful will be commercialized.

"One of the aims of the alliance is to take a longer-term view that looks past current circuit developments," said Matthias Bopp, Atmel's director of R&D for communication ICs. "Synergies are also expected to result from discussions of the kind of pre-development circuit design work that needs to be undertaken for particular applications."



UMS

A transimpedance amplifier manufactured by UMS using a 0.15 μm PHEMT process.

According to the director of the center Hermann Schumacher, the joint activity will afford the University of Ulm access to commercial SiGe and III-V technologies and allow the realization of new circuit ideas. In addition, it will provide a continuous industrial focus for research, including acting as a potential future pool of specialized personnel. "Examples of the typical projects we will undertake include high-linearity amplifiers for CDMA systems and front-end ICs for long-haul fiber-optic systems operating at 40 GHz and beyond," said Schumacher.

Common problems

Schumacher explained that the alliance would also address the problems that beset both analog electronic front-end portions of fiber-optic systems and broadband microwave circuit designs. "At wireless frequencies above 5 GHz, very similar problems are encountered in the treatment of interconnect parasitics, both on- and off-chip," said Schumacher. "Also, the lessons we have learned in producing compact 24 GHz circuit layouts that are intended primarily for wireless applications will prove to be helpful in optimizing circuits for wide-band fiber-optic communications systems."

"On the other hand, the bandwidth requirements of near DC to over 20 GHz in fiber-optic front-end circuits present interesting challenges," said Schumacher. "They should aid the design of wide-band ICs for wireless applications, where the bandwidth requirements are not quite as excessive."

The center will be supported by payments from the industrial partners, and the University of Ulm will provide offices, laboratories, and computational and characterization infrastructure. Start-up funding for the center has been made available at state level and by a leading German scientific funding organization, as part of a larger grant program which has been designed to explore new ways of industry-academic co-operation. The center will also participate in publicly funded R&D projects, and solicit collaboration with additional industrial partners.

Anadigics receives second GaAs patent

Anadigics has been awarded a second patent (no. 6 242 986) for a new GaAs multi-band amplifier. The circuit is designed to provide the optimum gain and input/output impedance at either the 800 MHz (AMPS, GSM) and 1900 MHz (PCS) bands.

According to Anadigics, switching impedance networks are used at the input and output of the amplifier to provide matching input impedance and the desired output impedance for multi-band operation. Similar networks are used between stages of the amplifier to provide the correct inter-stage impedance. The amplifier is easily switched between the modes by applying a control signal.

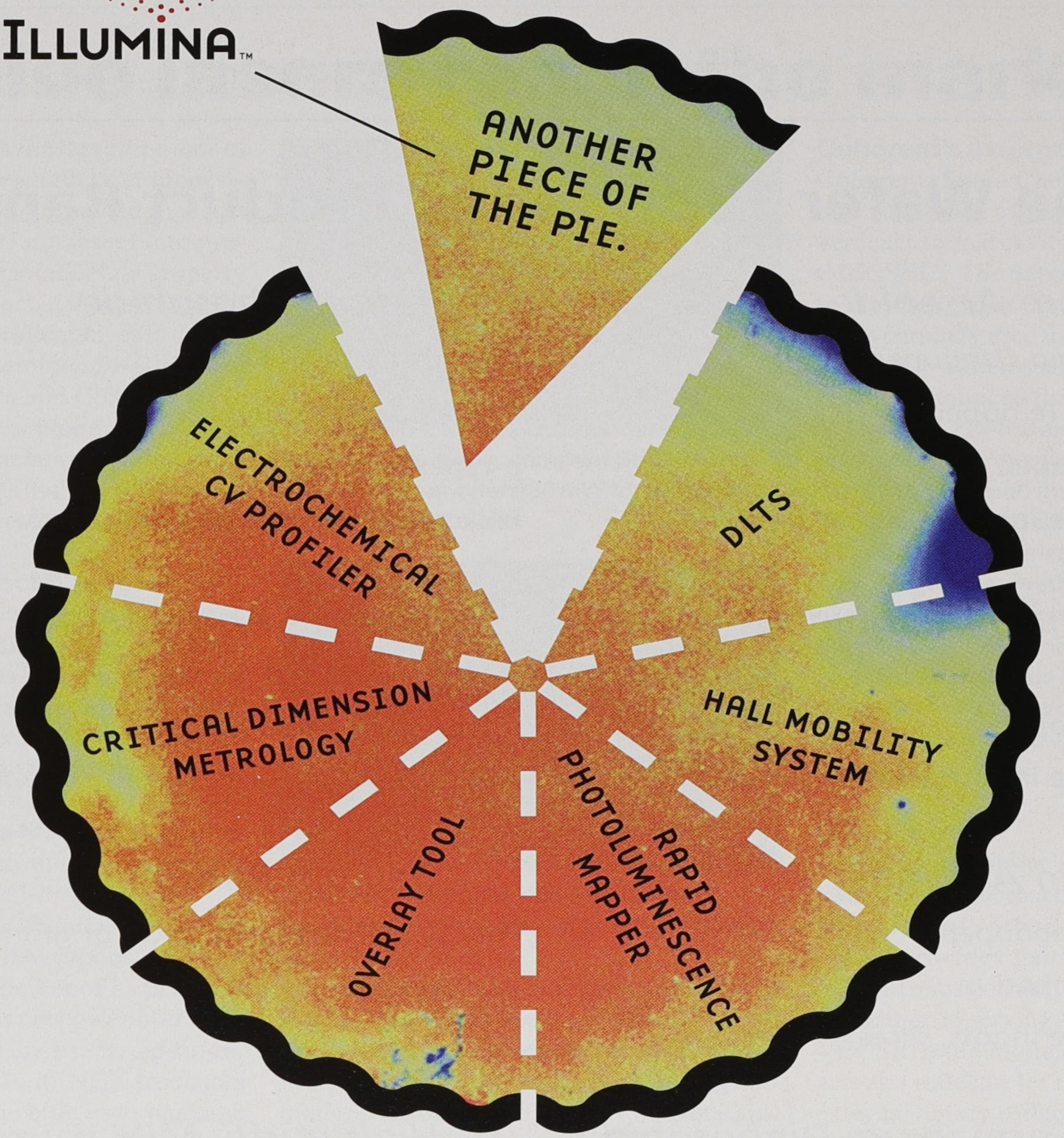
Giga Epitaxy completes 6 inch GaAs epiwafer facility in Taiwan

Giga Epitaxy Technology has completed the construction of a new facility in Taiwan for the production of 6 inch GaAs epiwafers. Hitachi Cable, itself a leading epiwafer and substrate manufacturer, spent more than $14 million to acquire a 51% stake in the company earlier this year. Hitachi Cable signed technology transfer and OEM agreements with Giga for the growth of MESFET, HEMT and HBT epiwafers by MOVPE. Giga is targeting components for handset and base stations used for the new 3G wireless standard, which began services in Japan in October.

Construction of Giga's facility in Yangmei, Taoyuan County in Taiwan began at the end of last year and was completed in September 2001. The building contains more than 23 000 sq. ft of cleanroom space, with the option to expand to more than 40 000 sq. ft in future. Qualification samples are expected to leave the facility in the fourth quarter of 2001.

Giga will initially ramp production up to around 2000 GaAs HBT epiwafers per month in the first quarter of 2002, increasing this to 3000 epiwafers per month in the second quarter. The company says the total capacity could be increased to about 12 000 6-inch wafers per month, depending on demand.

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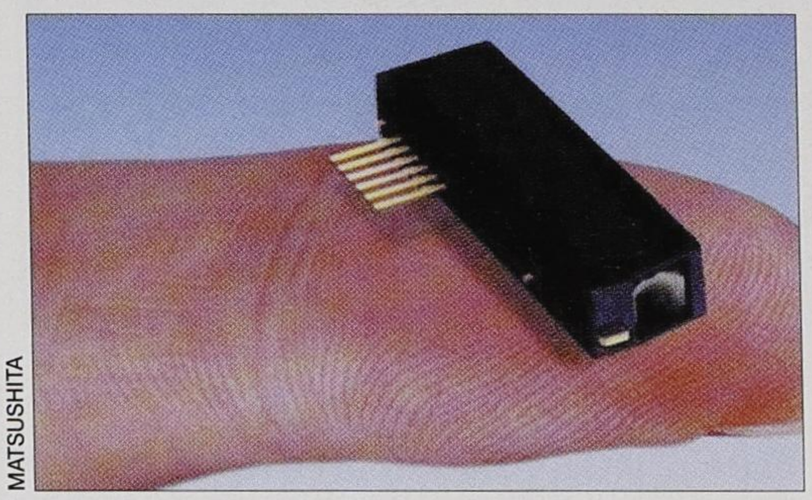
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SHG blue lasers reach the market

Nichia currently leads the development of GaN-based short-wavelength laser diodes – the company recently announced that it is moving its 30 mW, 405 nm lasers into production. The wealth of intellectual property held by Nichia and others in this area has led some companies to seek alternatives to the III-nitrides approach to semiconductor-based blue lasers. Matsushita and Coherent have now launched high-power blue emitters based on second harmonic generation (SHG), which could be used in markets as diverse as optical storage media and fluorescence spectroscopy.



MATSUSHITA

Matsushita's highly compact SHG 410 nm blue SHG laser offers 30 mW for recording data on optical disks.

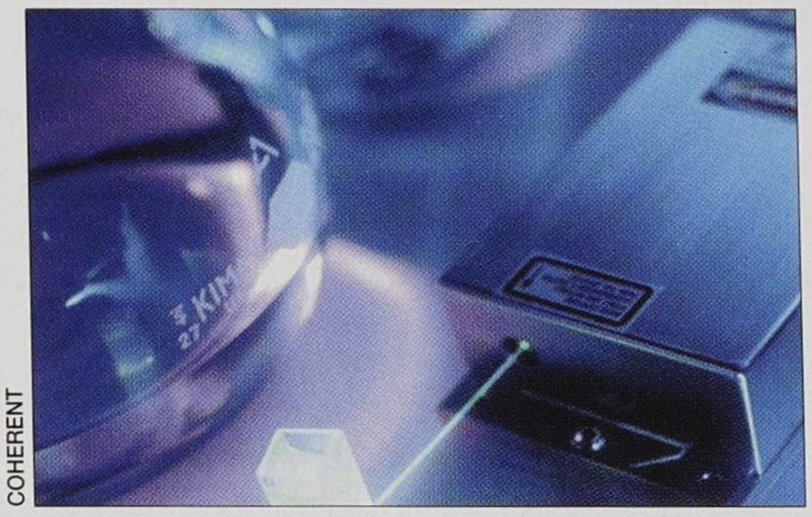
Matsushita's compact blue laser

Matsushita (Osaka, Japan) has developed what it describes as the first high-power, high-efficiency SHG blue laser diode suitable for high-density optical-disk recording systems. Matsushita's device operates at 410 nm, which is achieved by halving the emission wavelength of an infrared laser diode. The wavelength is shorter than in Matsushita's earlier 425 nm devices, which the company says were not suited to optical-disk systems.

Matsushita's first SHG blue laser appeared as early as 1999, but its new product provides 30 mW – 15 times the power of its previous 2 mW device, which was not powerful enough for recording optical disks. In addition, Matsushita collaborated with NGK Insulators to reduce the size of the blue laser package to 0.3 cm^3, one quarter of the size of previous packages, which also makes it more suitable for optical-disk recording systems.

Novel optical storage devices

Matsushita has incorporated the new laser into a rewritable dual-layer optical disk for recording digital high-definition video. While single-sided 4.7 Gb and doubled-sided 9.4 Gb DVD-RAM disks have been commercialized, Matsushita's new optical system fits an enormous 50 Gb of rewrite capacity onto one side of a CD-size dual-layer disk. The company attributes this to the ultra-thin GeSbTe recording film used as the phase layer of the first and second recording regions. The new system features fast record and playback, making it possible to record more than 4 hours of digital high-definition video at 25 Mbit/s.



COHERENT

Coherent's Sapphire 460-10 blue laser provides 10 mW at a wavelength of 460 nm.

Coherent's external cavity VCSEL

Coherent (Santa Clara, CA) has unveiled a blue laser diode based on an optically pumped vertical external cavity surface-emitting laser (VECSEL). The Sapphire range is designed to compete with the air-cooled argon-ion lasers currently used in digital imaging, wafer-inspection systems and bio-instrumentation (e.g. laser-induced fluorescence).

Operating at 460 nm, the Sapphire 460-10 provides 10 mW power output and is intended for graphic arts and display applications. The 488-20, launched in May 2001, produces 20 mW of output power at 488 nm, which is a wavelength commonly used in fluorescence excitation. Initial shipments have included the Sapphire 980 nm device, which is an optically pumped laser for the telecom market-place, while the 488 nm blue laser is making headway in the bio-instrumentation and wafer-inspection markets.

How it works

The device exploits an 808 nm diode pump laser. The CW output of this device is focused onto an MBE-grown GaAs QW structure, which provides gain for the fundamental infrared emission at either 976 nm or 920 nm. In addition to serving as the gain medium, the VECSEL chip includes a Bragg mirror that acts as a reflector for the resonator. A second external highly reflective mirror completes the linear infrared cavity of the VECSEL.

A non-linear crystal is inserted into the cavity to convert the infrared radiation to the blue via SHG, in a manner similar to that used in Matsushita's device. The output beam is characterized by both single transverse mode and longitudinal modes.

Rohm upgrades its range of CD/DVD laser diodes

Rohm has upgraded its range of laser diodes with a new 180 mW infrared laser intended for optical pickups in high-speed 32× CD-RW drives. Rohm says that it has optimized the low-loss waveguide and low-density active layer of its existing 150 mW device to achieve this high output power. However, the new chip has the same radiation angle and output characteristics as its existing products, so optical pickups will need only minimal changes.

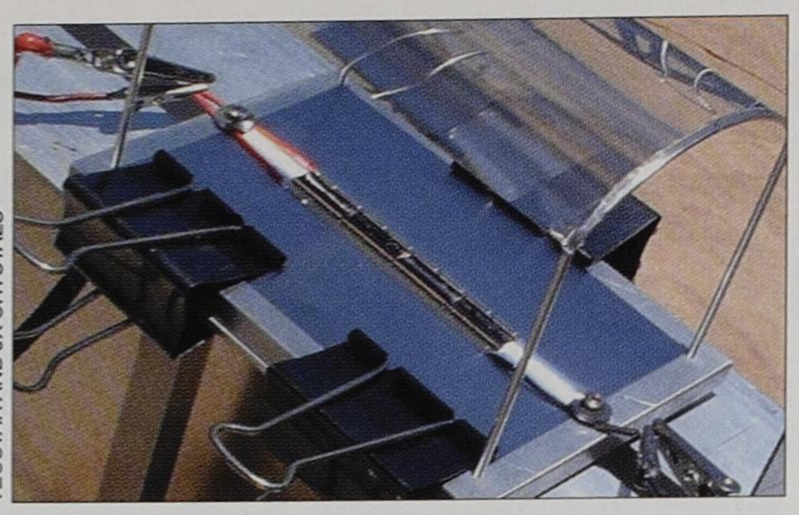
The laser offers a high catastrophic optical damage threshold of 315 mW (pulsed), a 779–789 nm wavelength range and a differential efficiency of 0.9 mW/mA (CW). The device is packaged in a 5.6 mm forged stem structure. Samples of the RLD78PZW2 are now shipping and production runs should reach 500 000 units per month by December.

Rohm is also beginning the mass production of new infrared laser diodes for CD-RW applications and a red laser diode for DVD-ROM devices in special thin packages. The RLD78MQW1 and RLD65MQT1 chips will be housed in a new 3.5 mm diameter package designed for thin pickups, replacing the 5.6 mm version. The new package reduces footprint by 60% and volume by 25%. The company believes these reductions will provide more room for optical adjustments when assembling pickups, especially for the low-profile styling used in the optical disk drives required for CD-ROM, CD-R/RW and DVD-ROM drives in notebook PCs. Rohm is already shipping samples of these two products and the mass production of 500 000 units per month is now expected.

New solar cells have efficiency of 33.4%

JX Crystals (Issaquah, WA) and Tecstar (City of Industry, CA) have demonstrated solar cells for space-based applications that are 33.4% efficient, measured at 15 suns under air mass zero (15 AM0). The new cells are part of an ongoing NASA Small Business Innovation Research phase II collaboration on mechanically stacked solar cells for aerospace applications. It is one of the aims of phase II to achieve cell efficiencies exceeding 30%; this has been accomplished by stacking Tecstar's InGaP/GaAs dual-junction front cell with JX Crystal's GaSb bottom cell.

Tecstar's front cell now provides 27% efficiency compared with 24% previously. Three factors are responsible for the gain: the 15 times' concentration of sunlight onto the cell under AM0 conditions, compared with previous measurements at 1 AM0; operation at the higher voltage of 2.61 V (compared with 2.4 V); and a fill factor – a measure of how closely the cell follows an idealized solar-cell I-V operating curve – of 87% (an improvement of around 3.6%).



TECSTAR AND JX CRYSTALS

Mechanically stacked solar cells made by JX Crystals, including Tecstar's 27% efficient InGaP/GaAs front cell and a solar concentrator lens from Entech. The lens is 8 cm long and mounted on arches.

The InGaP/GaAs top cell is grown on a transparent GaAs substrate that allows impinging near-infrared light to be absorbed by JX Crystals' bottom cell. The collection efficiency of the company's GaSb cell is 6.4%. Tecstar has also embarked on a different NASA project involving the California Institute of Technology (Caltech) and the National Renewable Energy Laboratory (NREL) targeting 40% efficient solar cells using a four-junction design (see *Compound Semiconductor* August 2001, p29).

JX Crystals has developed a simple two-terminal voltage-matched circuit for the new stack that mounts into a line-focus array from Entech, a manufacturer of lightweight solar concentrator lenses based in Keller, TX. Four InGaP/GaAs dual-junction cells from Tecstar are stacked on top of eight GaSb cells, producing a circuit 8 cm long with an active illumination target width of 6 mm. This compares with its previous 2:7 top:bottom mechanical-stack ratio (see *Compound Semiconductor* September/October 2000, p25).

The four top cells are wired in parallel while the eight bottom cells are wired in series, producing a two-terminal voltage-matched circuit. The circuit outputs of these cell-interconnected circuits range from 3.07 to 3.25 W, and result in a measured best efficiency of 33.4% at 15 AM0.



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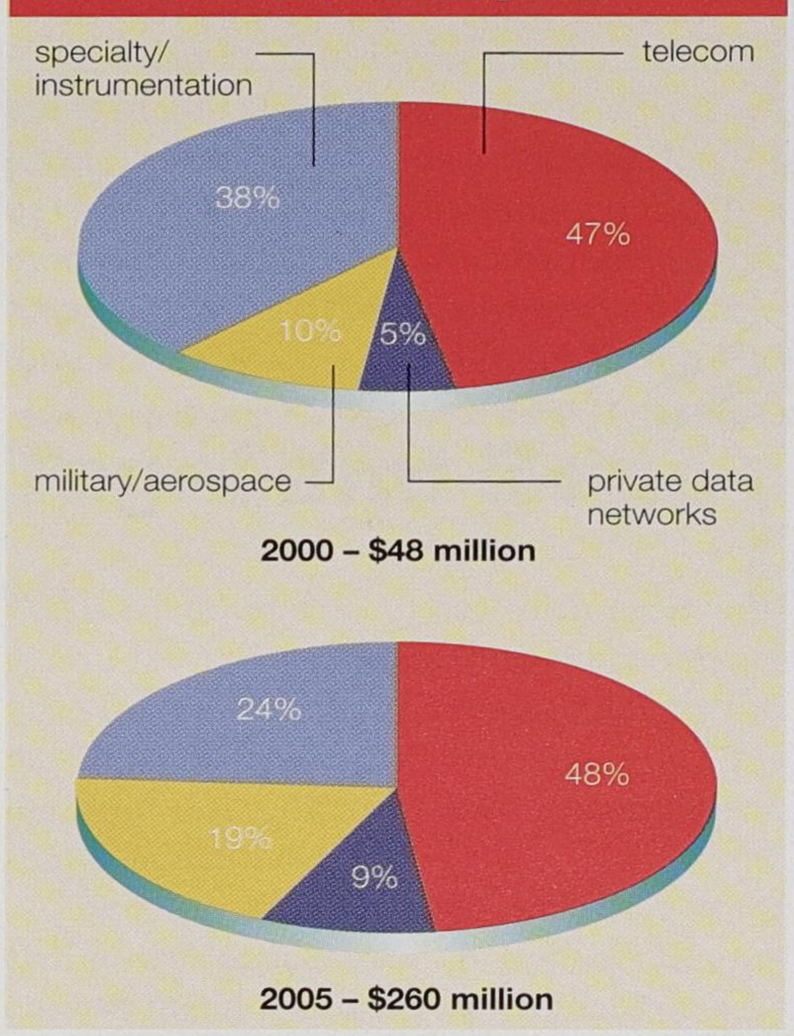
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SOA market to hit $260 million by 2005

The global consumption of semiconductor optical amplifiers (SOAs) is set to expand five-fold, from $48 million in 2000 to $260 million by 2005. According to a new report by ElectroniCast, the primary near-term use of such devices, which are usually InP-based, will be as optical switches used in telecommunication photonic switch units for optical cross-connects and WDM links, in addition to optical amplification in fiber-optic transmission networks.

The largest sector, telecommunications, will account for 48% of the market for SOAs, or $122 million, by 2005 (see figure below).

Global SOA consumption



ELECTRONICAST

A second major application will be for laboratory and field test equipment and built-in instrumentation. These markets comprised a 38% share in 2000, but will decline to 24% or $62.4 million by 2005.

In North America, which is currently the biggest market for telecommunication components, SOA consumption will rise steeply from $31.3 million in 2000 to $147.1 million in 2005. By the end of the decade, the leading application will be within photonic switch matrices.

"*Semiconductor Optical Amplifiers Global Market Forecast*" is available from ElectroniCast – see www.electronicast.com for further information.

KMI update predicts 14% decline in global DWDM market in 2001

KMI has updated its 2001 predictions for global DWDM markets, which it says were quickly invalidated by the substantial softening of the market outlook during the early part of 2001. KMI now believes that the worldwide market for DWDM transport equipment will decline 14% in 2001, to $7.1 billion. The market will resume its growth in 2002, but at rates that vary sharply by geographic region and by application.

In its analysis, KMI notes the strong growth in DWDM spending between 1998 and 2000, and the subsequent decline in 2001, and places it within the perspective of network building cycles. Internet adoption almost doubled the DWDM systems market in two years, from $2.3 billion in 1998 to $4.2 billion in 1999, and then to $8.3 billion in 2000. But with most long-distance network build-outs complete by the end of 2000, and with the capacity sufficient to meet growing demand, equipment deployments have slowed dramatically during 2001.

Metro market still booming

For long-haul DWDM applications, the worldwide market will fall by 23%, but the short-distance market – primarily for metro applications – will grow by 63%. Markets in North America and Europe will fall 23% from $7.8 billion in 2000 to $6 billion, whilst emerging markets in Asia and the rest of the world will double.

Using moderate bandwidth demand assumptions, estimates based on average DWDM systems deployed in 1999 and 2000 show that usage will rise to 60–70% of capacity at staggered rates through 2002 and early 2003. According to KMI, carriers usually plan new system deployments before the existing systems are at 70% capacity. Forecasts therefore show a slow rise in DWDM revenues in most markets beginning in 2002, with acceleration into 2003.

More information on "*2001 Update to Worldwide Markets for DWDM*" can be obtained from www.kmicorp.com.

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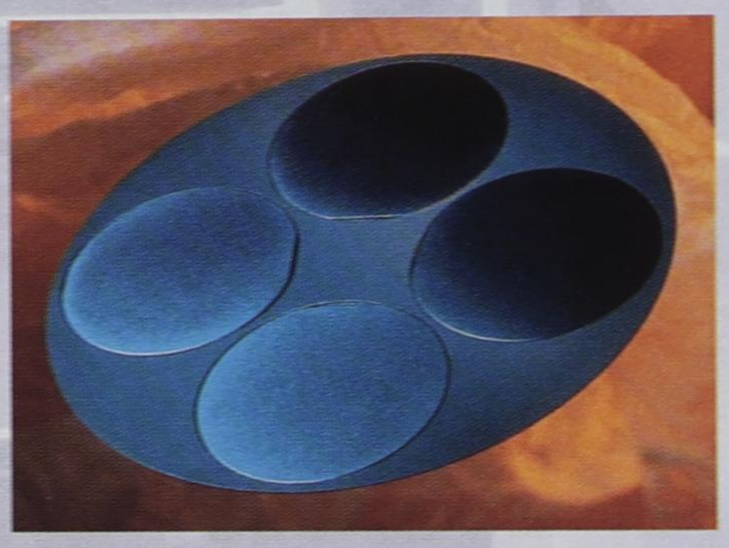
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Demand forces Suss to expand flip-chip capacity

Karl Suss France, a subsidiary of Suss MicroTec, has completed an expansion of its flip-chip bonder manufacturing facility in France that more than doubles the company's capacity. With a total space of around 13 000 sq. ft, including a 7500 sq.ft cleanroom, Suss says the expansion will accommodate the growing demand for these bonders.

A leading supplier of these systems to the optoelectronics and MEMS markets, Suss invested FFr 12 million (around $1.7 million) in the facility, which is situated next to the existing production plant at Saint-Jeoire in the French Alps.

Suss's two flip-chip bonding systems, the FC250 and FC150, accommodate bonding loads of 200 and 100 kg respectively. Each levels, aligns and bonds a wide variety of devices automatically, including multichip modules, laser diodes, focal-plane arrays, chip-on-glass, and flat-panel displays. Depending on the process technology, the FC250 can perform 300 bonds per hour.



KARL SUSS FRANCE

Karl Suss's FC250 flip-chip bonding system.

"Despite the economic situation, demand for our high-precision flip-chip bonders continues to grow," said Gael Schmidt, president of Karl Suss France. "This expansion was critical to supporting our customer base."

Aeronex will supply purifiers to Emcore

Aeronex (San Diego, CA) has signed a five-year agreement to supply Emcore with specialty purifiers for atmospheric and specialty gases. The gas purifiers will be used in the production of GaN and GaAs devices such as LEDs, which typically require the highest purity gases, especially the ammonia used in nitride growth. The purifiers will be used in Emcore's in-house production MOCVD tools, in addition to being recommended for tools sold by Emcore. Emcore will also act as the exclusive worldwide distributor and reseller of these purifiers.

"We are excited to have a partnership with such a technically competent company in the purification industry," said Frank LoBrace, Emcore's director of materials and corporate supply management. "Aeronex's performance has met or exceeded competing technologies at a lower total cost of ownership."

Aeronex manufactures a range of purifiers based on a proprietary titanium catalyst and a nickel silica catalyst. The purifiers are regenerable and operate at ambient temperature.

Tegal and Bede receive patents

Tegal (Petaluma, CA) has been granted a patent for an etching method that controls growth in the width of a feature during the manufacture of sub-0.13 μm circuits, including gold interconnects used in compound semiconductor devices.

The company's approach exploits its 6500 etch system, and relies on controlling the reactions of metal masks, known as hard masks, with plasmas to inhibit a change in the mask dimensions. This change is caused by compounds – formed from the etch gases, the lithographic mask itself or the material being etched – which tend to coat the sides of the feature and alter its size.

US patent number 6 287 975 describes methods that include altering the plasma composition and using masks made from materials such as Ti, Ta, W and Al to slow erosion. The patent also covers masks that have been treated with oxidizing gases or ions to form oxides, nitrides and carbides to promote etch selectivity with respect to the mask.

"By using the method described in the patent, our customers can develop the robust next-generation processes required for a broad array of next-generation devices," said the company's chief technology officer and vice-president Steve DeOrnellas.

Bede's new X-ray source

Bede's recently granted US patent (number 6 282 263) relates to the development of a compact, high-brightness X-ray source designed for diffraction tools used in the semiconductor industry, and for sale to other makers of analytical instruments.

The Microsource generator is based on an X-ray source that is much smaller than usual, and efficiently collects with micro-mirrors the smaller number of X-rays that are generated. While the source achieves the same 0.5 mm diameter spot as standard systems using rotating anode sources, the new generator has a smaller system footprint overall.

Bede says that with a typical set-up using an X-ray target spot size of 40 μm, the system operates at only 80 W, compared with several kilowatts for conventional sources. The generator features in Bede's QC200 analyser, which characterizes composition and layer uniformity for GaN and other III-V materials.

European project researches MBE for single-crystal oxides

A project funded by the European Commission's fifth framework program on Information Society Technologies is looking at introducing MBE into mainstream silicon CMOS device manufacturing. The three-year project called Integration of Very High-k Dielectrics with Silicon CMOS Technology (INVEST) started in July 2001 and is researching new materials with high dielectric constants to replace SiO_2 as the gate oxide in CMOS devices.

Current industry efforts focus on dielectric growth by CVD. Single-crystal oxides are now being researched as a possible high-k replacement for SiO_2 (see *Compound Semiconductor* September 2001, p35). The INVEST project will focus on single-crystal oxide layers grown by MBE, with the goal of integrating an MBE step into an 8 inch silicon processing line. Industrial partners include IBM, Philips, MBE reactor manufacturer Riber and Oxford Applied Research, a manufacturer of MBE accessories.

Equipment sales

● **DCA Instruments** has delivered a P600 MBE system (3 × 2 inch or 1 × 4 inch) to the **National Tsing Hua University** in Hsinchu, Taiwan (see photo). The reactor is being used to grow GaN and related materials. DCA has also received an order for its 450 MBE system from **Motorola** in Tempe, AZ for delivery early next year. The 450 system is a 3 inch R&D system available with a single-wafer load lock or a cassette-loading system.



DCA

DCA Instruments has received an order for its P600 MBE system.

● **Furukawa Electric** (Yokohama, Japan) has placed a repeat order for an **Aixtron** AIX 2400 Planetary Reactor. Furukawa's FITEL Products Division will use the system, which is configured for 8 × 2 or 8 × 3 inch wafers, to produce high-quality lasers with wavelengths of 980–1550 nm.

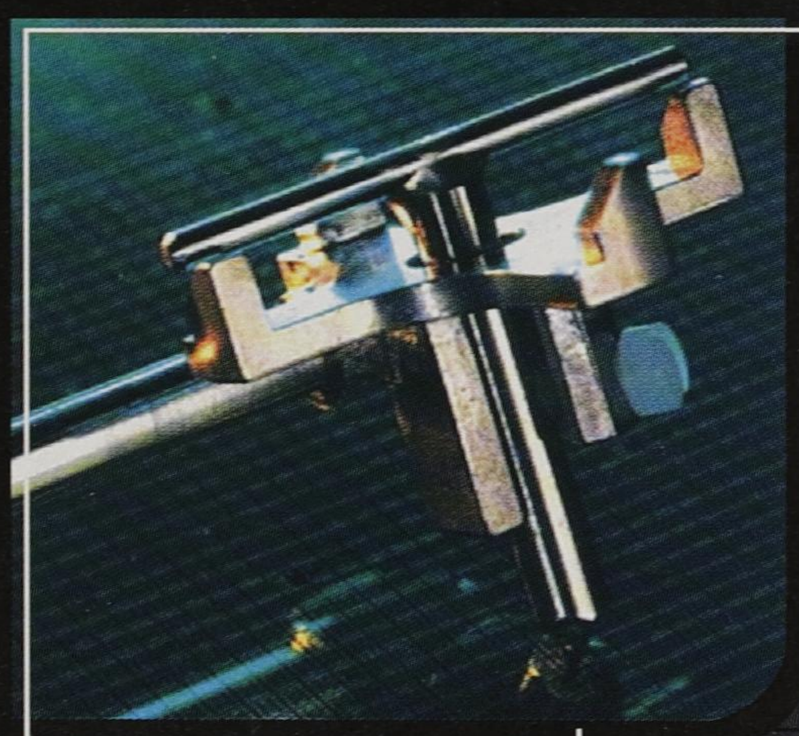
● **Tegal** has received an order for its 903 diode plasma-etch tool from a leading North American manufacturer of RFICs. Due for installation later this year, the system will be used for etching oxide films for new high-performance RFIC communications products.

● The optoelectronics business of **PerkinElmer** (Fairfield, CA) has selected **Temescal**'s FC-1800 evaporator for use in manufacturing its optical network components. The FC-1800 provides fast-cycle load-locked processing using a substrate fixture design that allows the system to convert quickly between lift-off and step-coverage processes.

● **LumiLeds** has signed an agreement to purchase MOCVD reactors from **Emcore** for the production of GaN-based LEDs. The initial phase of the agreement has seen LumiLeds purchase a number of reactors as it ramps up its production of blue, green, cyan and white LEDs.

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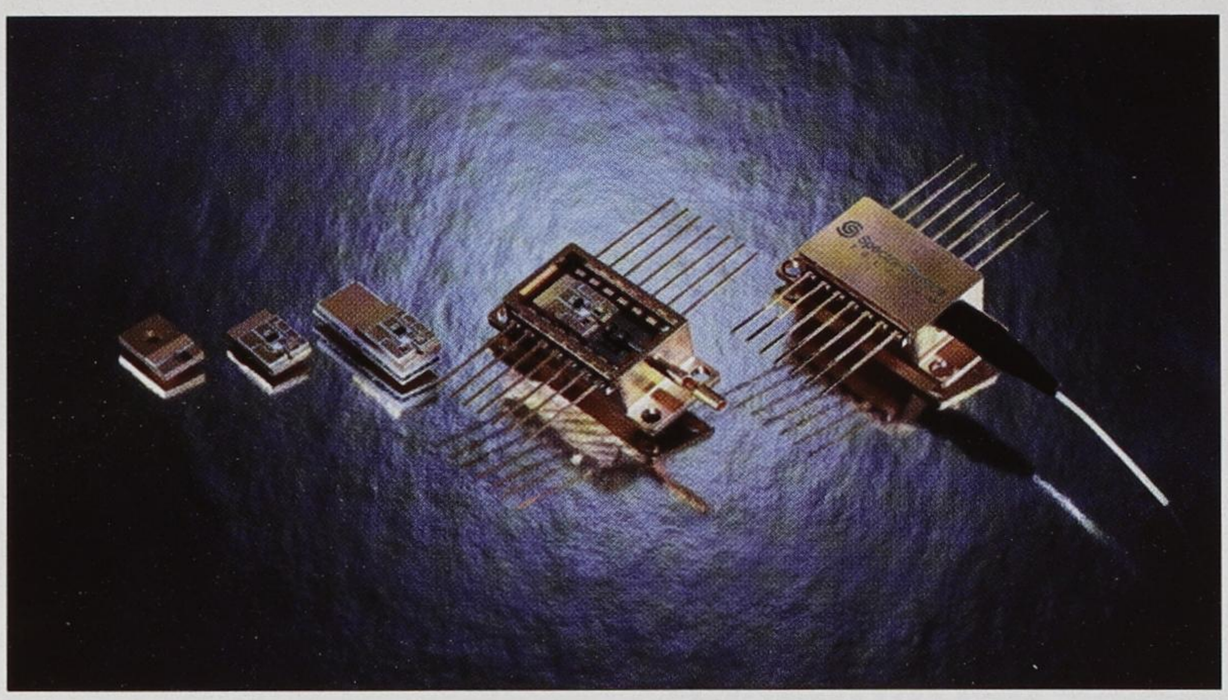
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OPTO PRODUCTS



Spectra-Physics unveils 2.5 W lasers

Mountain View, CA. Spectra-Physics' new series of multi-mode GaAs-based pump lasers deliver up to 2.5 W of power – twice the power level of previously available lasers. Two wavelengths are available: 915 nm for pumping Raman fiber lasers and 975 nm for co-doped EDFA pumping. The lasers are offered in standard packages, in addition to chips on sub-mount and lensed chips on sub-mount, and hermetically sealed, fiber-coupled 14-pin butterfly packages.

Fiber-coupled versions employ a 105 μm core and 0.15 NA fiber, and deliver 2 W of output. Both thermoelectrically cooled and uncooled versions are available. Telcordia-qualified, these high-power pump lasers are now available for volume delivery.
www.spectra-physics.com

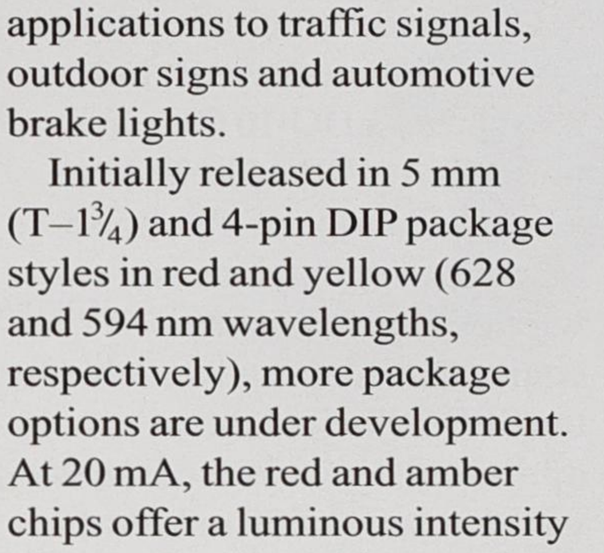
AlInGaP/GaP LED lamps from Lite-On

Milpitas, CA. Lite-On has added transparent-substrate AlInGaP/GaP LED-based lamps to its range of absorbing substrate AlInGaP emitters. The high-efficiency LEDs allow more light to escape from the device and improves brightness, extending the range of applications to traffic signals, outdoor signs and automotive brake lights.

Initially released in 5 mm (T–1¾) and 4-pin DIP package styles in red and yellow (628 and 594 nm wavelengths, respectively), more package options are under development. At 20 mA, the red and amber chips offer a luminous intensity of 4.2 cd and 2.5 cd in 5 mm packages. The 4-pin DIP packaged red and amber devices operate at a total flux of either 3.75 lm or 2 lm at 70 mA, with a viewing angle of 90°.
www.liteon.com

Optocoupler mixes error with isolation

Rosemont, IL. New from the R&D laboratories of Fairchild



Semiconductor comes the FOD2712 – an optically isolated error amplifier that combines the amplifier, reference voltage and an optocoupler, and is designed for use in isolated AC to DC power supplies and DC to DC converters. The use of integrated components and an 8-pin small outline package leads to fewer components and subsequent space savings in tightly packaged designs.

The basis of the optocoupler is a GaAs LED optically coupled to a silicon phototransistor, with an isolation of 2500 V RMS. The reference voltage is 1.24 V with a ±1% tolerance, the transfer ratio range is 100–200%, and the operating temperature ranges from –40 to +85° C.
www.fairchildsemi.com

FIBER PRODUCTS

OC-768 driver IC achieved in SiGe

San Diego, CA. Applied MicroCircuits Corporation has released an OC-768 SiGe modulator driver designed for use in electroabsorption and differential lithium niobate modulators. The S76803 operates at 48 Gbit/s and is intended for short- and long-reach SONET data links used in MAN and WAN applications.

The device's core is a distributed limiting amplifier with high single-ended output swings up to 3.5 V (or differential output swings up to 7 V peak-to-peak) and low output reflection coefficient and power dissipation. Operating from a single –5.2 V supply, the driver's output cross point can be adjusted between 30% and 70% of peak signals.
www.amcc.com

New duo of 1480 nm pump laser modules

Sunnyvale, CA. Oki Semiconductor has released two new high-power 1480 nm pump laser diode modules designed for EDFAs used in long-haul fiber-optic systems.

The OL4128N-160 and OL4128N-180 offer 160 and 180 mW of output power, respectively, and both incorporate TEC cooling for lower current operation and improved temperature stability. Samples of the two pump modules are now available.
www.okisemi.com

Error-free detectors and modulators

Waltham, MA. CyOptics has introduced an InP-based 10 Gbit/s electroabsorption modulator (EAM), in addition to 10 and 40 Gbit/s photodetectors. Based on InP, the EAM is housed in a compact,



hermetically-sealed 0.75 × 0.63 inch package, and offers reduced power consumption in comparison to the lithium niobate modulators which are used in metro and long-reach applications. This provides error-free operation on uncompensated fiber spans over 100 km, which translates to transmissions of over 500 km in long-reach WDM applications (which include chromatic dispersion compensation).

The company's 40 Gbit/s photodetector complements CyOptics' optical transmission modulators and is also based on InP. The device is an edge-illuminated waveguide PIN photodiode that offers a bandwidth which exceeds 50 GHz and has a responsivity of 0.7 A/W, plus an overload

tolerance of 7 dBm.

The edge-illuminated design provides a longer absorption length in which to capture light and boost the response at OC-768 bandwidths.

www.cyoptics.com

Tunable lasers reduce costs of test

Palo Alto, CA. Agilent Technologies' new tunable laser source modules allow the configuration of multi-channel test setups in both the C- and L-bands. The 81689B module covers the 1525–1575 nm range of the C-band, providing an adjustable power output of up to +10 dBm across this range. The module lowers test costs that result from spares. The 81649A supplements the L-band (1570–1620 nm) with a maximum output of +6 dBm.

www.agilent.com

WIRELESS PRODUCTS

Much to gain from block amplifiers

Warren, NJ. Anadigics has launched the first device in a new line of GaAs gain block amplifiers destined for applications requiring high linearity, low noise and low distortion. The AGB3301 is intended for transmit and receive paths in 50 ohm wireless applications such as cellular base stations, WLL and MMDS.

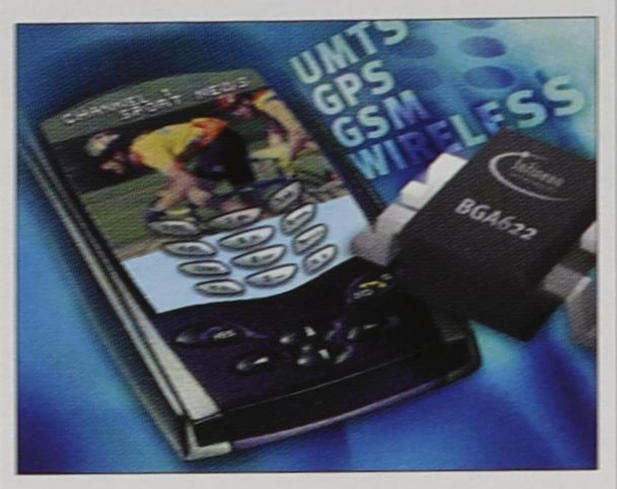
Consuming less than 1 W, the AGB3301 provides an output IP3 of +45 dBm, while the gain attains 14 dB and noise is kept to 2.4 dB. The device operates over a frequency range of 250 to 3000 MHz at supply voltages between 5 and 10 V, and at temperatures from –40 to +85°C. Housed in a SOT-89 surface-mount package, the AGB3301 is currently sampling.

www.anadigics.com

Infineon designs LNAs with SiGe

Munich, Germany. Infineon's BGA622 LNA is an integrated amplifier designed especially for GSM, GPS, UMTS and wireless LAN applications in the 0.9–6 GHz range.

Based on Infineon's B7HF



SiGe bipolar process, the company's MMIC features a gain of 15 dB and a low noise figure of 1.1 dB at 2.1 GHz. The device also offers cut-off frequencies (f_t) up to 75 GHz, and matched input/outputs that require no additional external components. A low supply current and an integrated on/off feature reduce power consumption and increase standby time for 3G handsets.

The BGA622 is available in sample quantities in an SOT343 package, with mass production expected in November.

www.infineon.com

Toshiba launches SiGe HBT RFICs

Irvine, CA. Toshiba America Electronic Components Inc has introduced a new family of SiGe HBT RFICs. The MT4S100U is a high-frequency transistor and the MT4S101U is a high-power gain transistor. Suitable for cellular phones and other portable wireless devices with wide-band CDMA and wireless LAN functionality, Toshiba's 2 GHz circuit employs the company's SiGe bipolar transistor process, which features an on-wafer cut-off frequency of 60 GHz and maintains a V_{CEO} of 3.5 V and a noise figure of 0.7 dB.

Toshiba also offers the MT4S101U high-power gain transistor with an insertion gain of 17.5 dB at a current of 20 mA. Both devices are encased in a 4-pin surface-mount small package, and will be available in December initially at a monthly volume of five million units.

www.chips.taec.com

PHEMT offers low-noise performance

Sunnyvale, CA. Sirenza Microdevices (until recently Stanford Microdevices) has introduced a DC-10 GHz low-noise GaAs PHEMT circuit suited to a range of low-noise amplifier applications in wireless-infrastructure equipment. Options available for the SPF-3043 include an optimized device biased at 3 V with a current of 20 mA. At 1 and 2 GHz operation, this configuration features a noise figure of 0.25 dB and 0.5 dB with gains of 25 dB and 22 dB. At 5 V and 40 mA, the circuit delivers an IP3 of 32 dBm.

Housed in an SOT-343 surface-mount package, the product will be shipped from Sirenza's (fabless) facility for $0.99 each in batches of 10 000.

www.sirenza.com

Surface-mount format lowers costs

Orsay, France. United Monolithic Semiconductors (UMS) is offering surface-mount device-packaged millimeter-wave MMICs. Surface-mount assembly lines reduce manufacturing bottlenecks due to pick-and-place and bonding processes. This allows pre-testing and replacement of single surface-mount type packages to improve RF module production yields.

The company's first such products employ MMICs designed for applications in the 26–32 GHz range. Based on the existing CHA2069, CHA2093, CHA3092, CHA2098 and CHT3091 PHEMT-based MMICs, the additional insertion loss is typically 1.0 dB.

www.ums.com

Power management adds to battery life

Andover, MA. Raytheon's RF Components Division has unveiled a new line of GaAs HBT power amplifiers that use power management to increase battery charge time by up to 20% in CDMA and W-CDMA wireless terminals.

Conventional power amplifiers typically operate at a constant power setting, but Raytheon says its management scheme automatically adjusts the amplifier bias in accordance



with signal requirements, while maintaining linearity across the operating range.

The RMPA0951-102 targets domestic cellular CDMA applications, while the RMPA1751-102 and RMPA1951-102 are intended for PCS/WLL applications in Korea. In the low-power operating range where most transmission occurs, the amplifier maintains 4.0 dBm output at 1.7 V setting. As more power is needed, the voltage is increased to a maximum of 2.7 V, which corresponds to as much as 28.0 dBm.

www.raytheon.com

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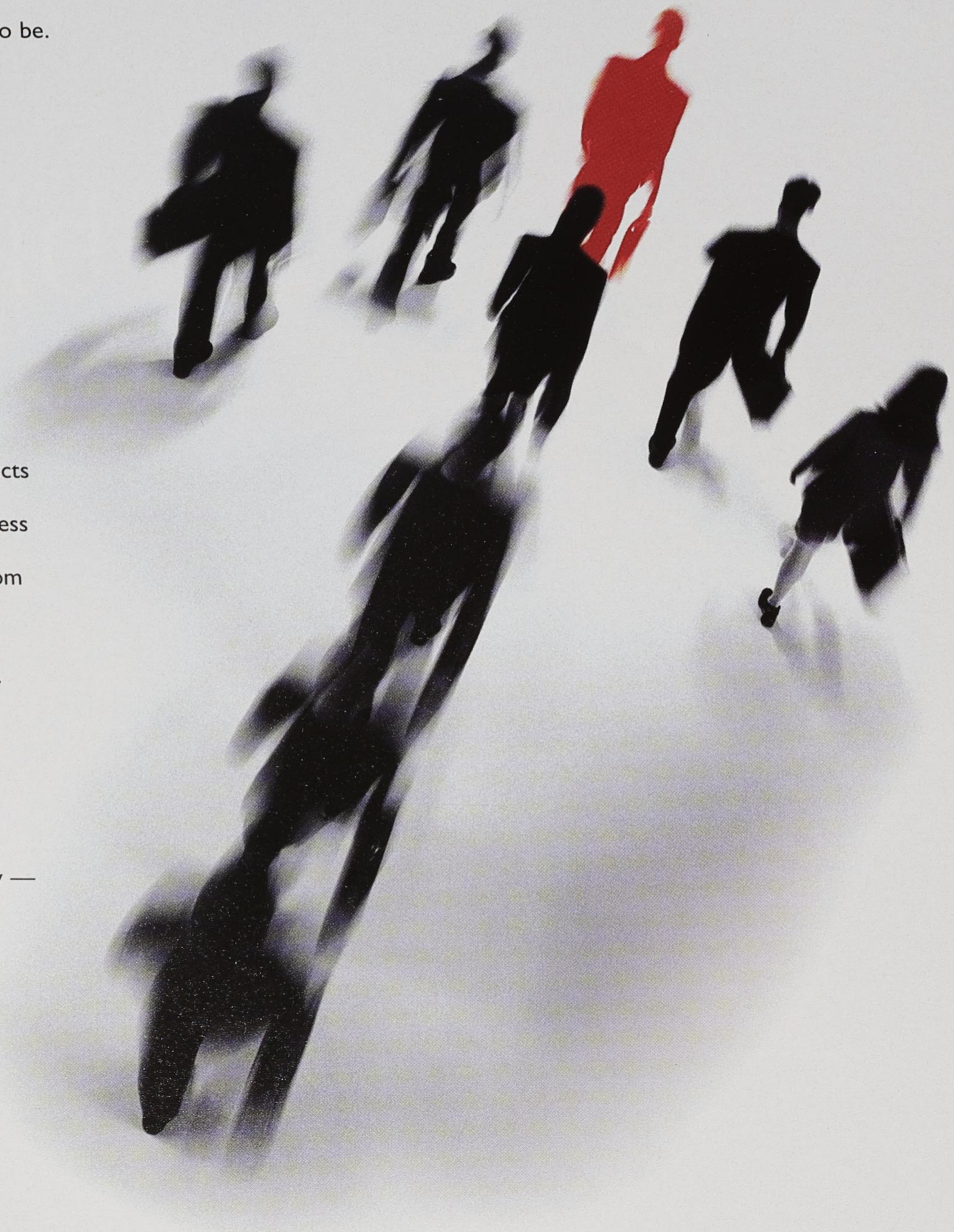
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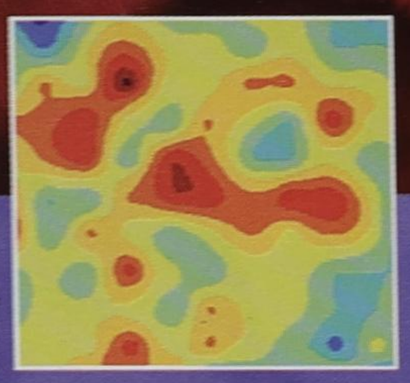


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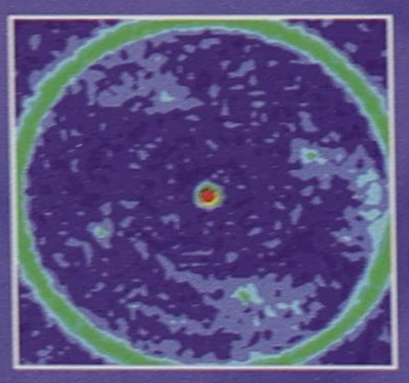
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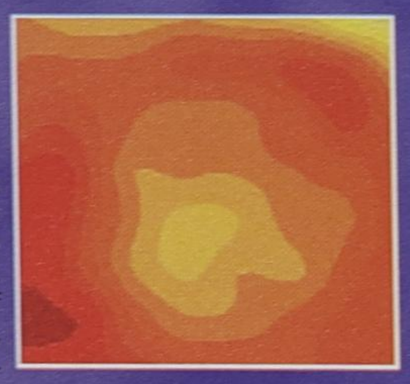




SiGe Wafer Map; data collected on a Bede QC200™. Data courtesy of Dr Peter Zaumseil, IHP, Germany.



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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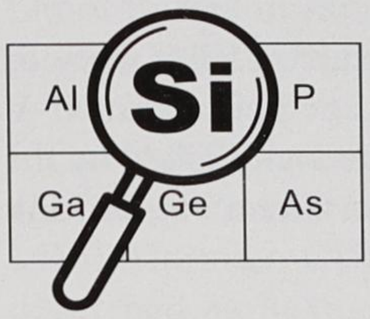
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WITH BOB METZGER

Competing performance figures cause confusion

Companies are publishing ever higher performance figures for SiGe HBTs. But careful analysis is required when making comparisons between different technologies.

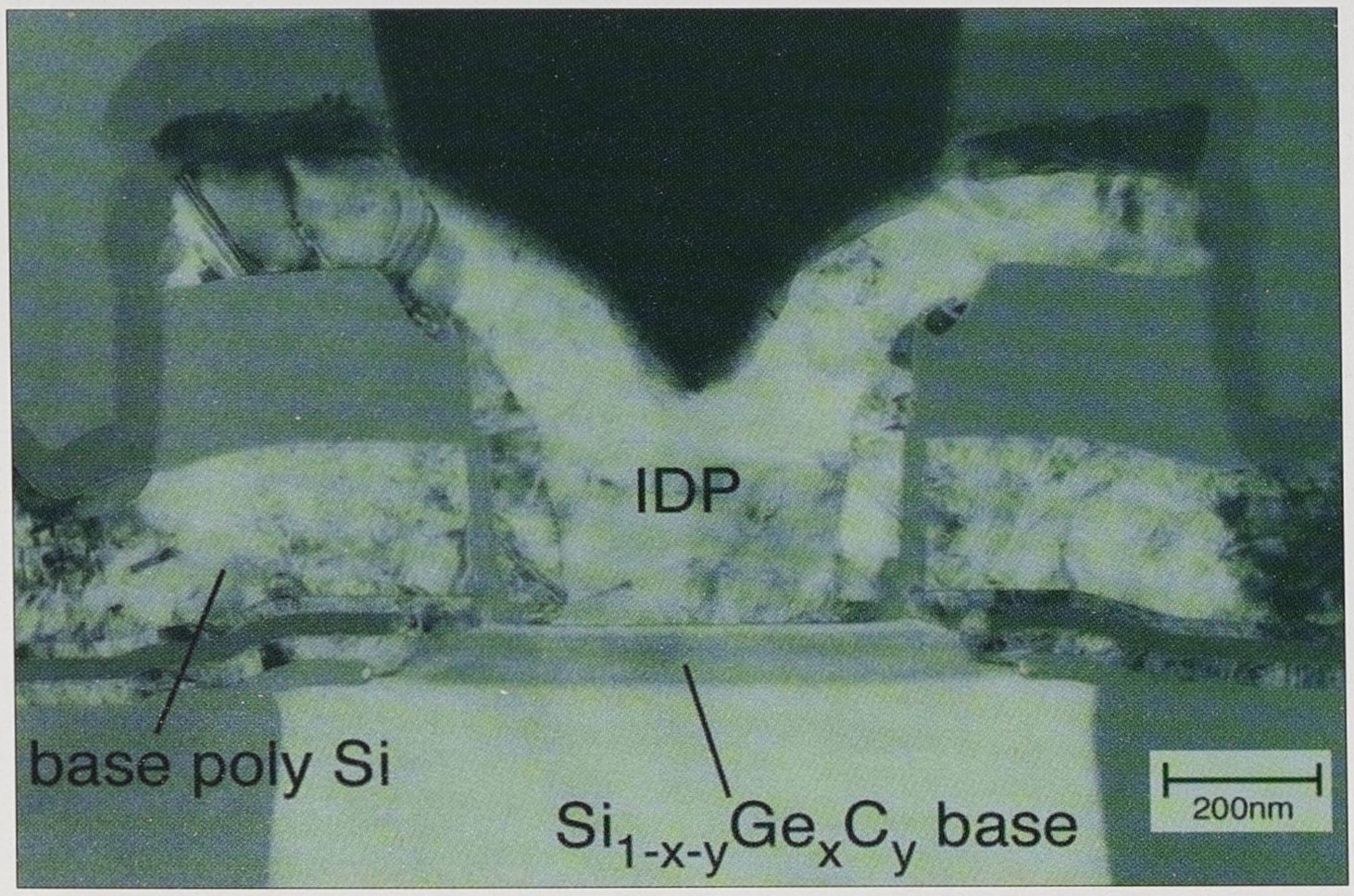


Be sure to take a look beyond the headlines before giving up on III-V devices.

At one time or another many of us have been involved in the f_t and f_{max} race. These two benchmarks, the cutoff frequency (f_t) and the maximum frequency of oscillation (f_{max}), are probably used more than any others to compare technologies or benchmark improvements in a given technology. Nowhere is this more evident than in the case of SiGe HBTs. This technology is often presented as combining the best of two worlds – the high yield, low cost and high transistor count of Si, coupled with the RF performance of GaAs. But the values of f_t and f_{max} can be totally meaningless when evaluating and comparing different technologies.

Many SiGe HBT processes are benchmarked against the IBM production process, and for good reason. The process has existed for much longer than any other and its foundry services are used by many manufacturers that are putting SiGe chips in commercial products. In terms of f_t and f_{max}, the process can be characterized as possessing values of 48 and 70 GHz respectively. Someone recently mentioned to me that Hitachi is running a SiGe process that is twice as fast as IBM's, representing a real threat to IBM's dominance in the area. When I pressed for details on what "twice as fast" meant, I was told that Hitachi's process has RF characteristics of better than 100 GHz.

That sounded impressive. Not only does it beat IBM – it's better than almost all the GaAs MESFET and GaAs HBTs used in production. Such capabilities appear to represent a real threat not only to existing SiGe processes, but also to many III-V processes.



TEM cross-section of the Hitachi SiGe:C HBT, showing the *in situ* doped poly (IDP) silicon emitter electrode. The base region is grown by selective area epitaxy and incorporates 0.4% carbon to suppress outdiffusion of the boron doping, resulting in an f_{max} of 174 GHz.

Hitachi takes on IBM

I was referred to the just published Hitachi results in the *IEEE Transactions on Electron Devices* (Washio *et al.*). They reported on a 0.2 μm SiGe HBT process with a complex SiGe base profile consisting of a 15 nm thick dual-graded Ge-profile (graded from 0 to 10% and from 10 to 15%) $Si_{1-x}Ge_x$ layer, a 45 nm thick $Si_{0.85}Ge_{0.15}$ layer and a 10 nm thick Ge-retrograded (from 15 to 0%) $Si_{1-x}Ge_x$ layer. The resulting devices exhibited f_t and f_{max} values of 90 and 107 GHz, respectively. The process was implemented on a 200 mm wafer line with a transistor yield of 99.9993%, that utilized four layers of metal, dual deep trench isolation and Ti silicide contacts, and exhibited an ECL-gate delay of only 6.7 ps.

This sounds more than capable of beating IBM's process. The only problems are that the values of f_t and f_{max} for the two processes were measured at different biases, and the devices exhibited markedly different BV_{CEO} values. The Hitachi RF measurements were made at a V_{CE} of 2.0 V, while the IBM measurements were made at V_{CB} of 1.0 V. Operating at a higher bias can greatly improve RF characteristics.

But the real difference is in the breakdown voltage of the devices. The Hitachi devices have a BV_{CEO} of 2.0 V, which not only means that the RF values were obtained under operating conditions very near breakdown (where a device used in a commercial product could never operate), but that this low breakdown precludes their use in many RF applications. The IBM device exhibited a BV_{CEO} of 3.3 V, a value well in excess of where the RF measurements were taken.

So which is the better process? It is impossible to tell, because the answer will vary depending on the specific requirements of a given application. So is the Hitachi

Someone mentioned to me that Hitachi is running a SiGe process that is twice as fast as IBM's.

process twice as good as the IBM process as I was told, based on a headline RF value? Most likely not, especially when you consider that the IBM devices with a standard f_t value of 48 GHz can be pushed up to 120 GHz under maximum biasing conditions – a value 33% higher than the best reported by Hitachi.

Amazing SiGe HBTs

One reason why I'm discussing this is to bring to your attention the need to dig down into the data in order to compare processes (and even then it might not be possible). But this is also by way of a warning, because around the time you read this the 2001 International Electron Devices Meeting (IEDM) will be taking place, and 2001 represents a banner year for the announcement of impressive SiGe RF results. You will undoubtedly hear of some amazing SiGe HBTs.

Hitachi will present its latest results (the figures I've discussed above, although just appearing in the *IEEE Transactions on Electron Devices*, are actually several years old, since they were first presented at the 1999 IEDM). The new Hitachi process incorporates carbon in the base that suppresses boron diffusion, resulting in a device with an f_{max} of 174 GHz. Conexant Systems will report on its 163 GHz f_t and 148 GHz f_{max} SiGe process for devices that exhibit a BV_{CEO} of 2.0 V, which is incorporated in a BiCMOS process utilizing six layers of metal. Also Infineon Technologies will discuss its process exhibiting f_t and f_{max} values of 106 and 145 GHz respectively, with a BV_{CEO} of 2.3 V.

IBM will announce the most impressive headline numbers of all. Using a conventional Si substrate (SOI and high-resistivity substrates can improve RF performance still further by reducing capacitive coupling to the substrate), IBM has developed a 0.18 μm process that exhibits an f_t in excess of 200 GHz and an f_{max} of 150 GHz. Just remember that these figures are all headline numbers (although they are nonetheless all extremely impressive).

But before you decide to give up on III-V devices altogether, taking these results as evidence that III-V commercial products will soon be vanquished by the might of SiGe HBTs, be sure to take a closer look beyond the headlines.

Further reading

K Washio *et al.* 2001 A 0.2 μm self-aligned selective-epitaxial-growth SiGe HBT featuring 107 GHz f_{max} and 6.7 ps ECL *IEEE Transactions on Electron Devices* **48(9)** 1989



NTT researchers grow GaN mirror facets on InGaN-on-SiC lasers

Mirror facets formed in III-nitride lasers are typically fabricated by cleaving or dry etching. The latter approach is promising but usually leads to facets that are rough and not vertical to the substrate. Researchers at NTT's Basic Research Laboratories in Japan have employed selective-area MOVPE to fabricate GaN mirror facets on InGaN MQW lasers (T Akasaka *et al.*, *App. Phys. Lett.* 2001 **79(10)** 1414). The micron-sized lasers are described as hexagonal microfacet lasers, because they comprise six facets defined by etched trenches. NTT employed electron cyclotron resonance dry etching to form the planar InGaN MQW-based devices by etching back to the SiC substrate. This step was followed by regrowth of *p*-GaN to form atomically flat, vertical $(11\bar{2}0)$ facets that acted as high-quality mirrors (see figure 1).

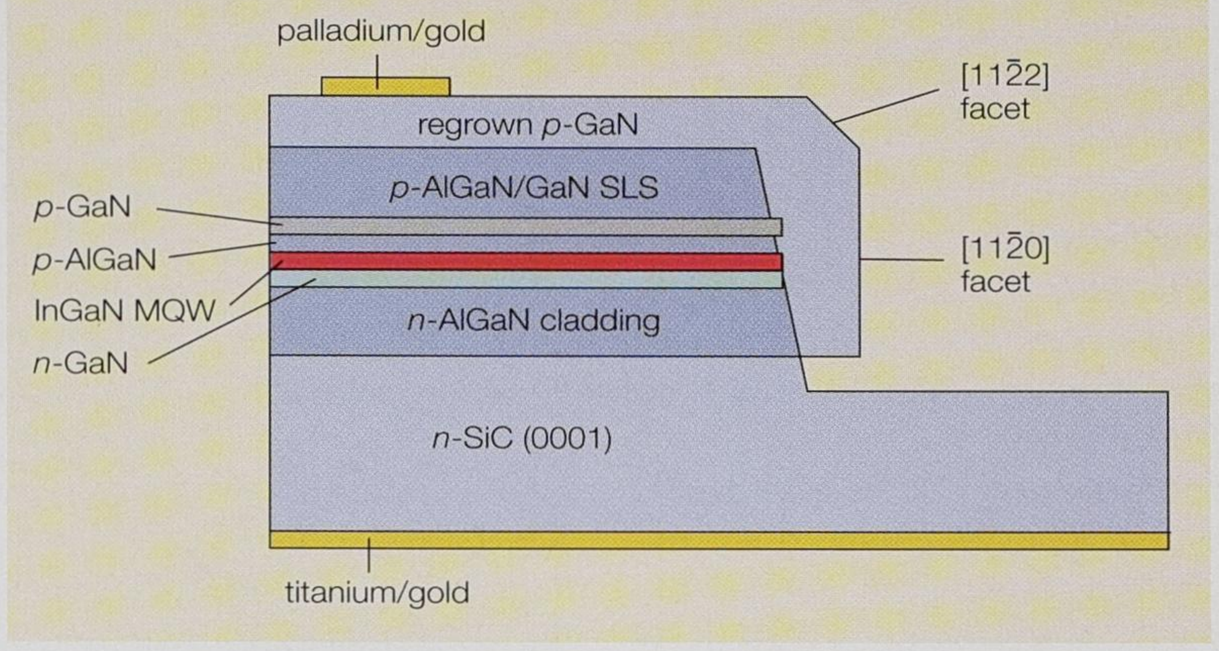


Fig. 1. The NTT InGaN laser showing the GaN regrowth layer used to form the mirror facets. A modified dry-etch technique is used to etch the InGaN device profile down to the SiC prior to MOVPE regrowth.

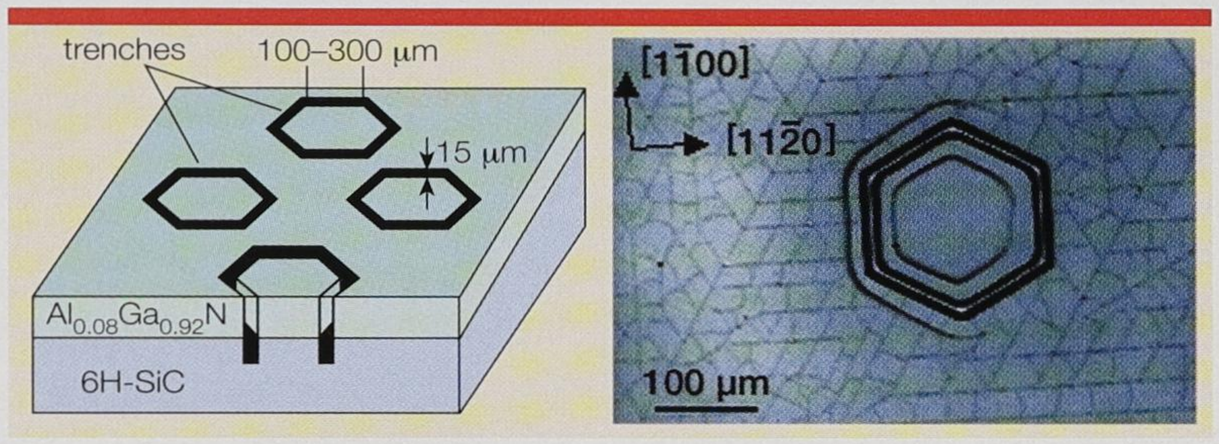


Fig. 2. Etched hexagonal microstructures in AlGaN/SiC (left), and an optical micrograph of a 7.2 μm thick crack-free GaN layer inside a hexagon, formed by etching down to the SiC substrate and subsequent MOVPE regrowth of GaN (right). The etched trenches, which stop lateral crack propagation, define the hexagonal microfacet lasers.

Devices consisted of a 500 nm *n*-$Al_{0.08}Ga_{0.92}N$ cladding layer grown directly on the SiC substrate, followed by a 100 nm *n*-GaN optical guiding layer and an InGaN MQW active layer consisting of three pairs of 2.5 nm undoped $In_{0.15}Ga_{0.85}N$ wells and 5 nm *n*-$In_{0.02}Ga_{0.98}N$ barrier layers. A *p*-$Al_{0.2}Ga_{0.8}N$ layer was added to prevent dissociation of the InGaN layers, followed by a 100 nm *p*-GaN optical guiding layer and a 90 period *p*-AlGaN/GaN strained layer superlattice (SLS) to act as a cladding layer.

The mirrors are formed by selective MOVPE regrowth of a 900 nm *p*-GaN layer on both the top (0001) surface of the SLS layer and the dry-etched side walls of the III-nitride layers. The regrowth did not occur on the SiC surface at the bottom of the trenches.

Devices operated at 401 nm in pulsed mode at room temperature, and exhibited threshold currents and densities of around 0.9 A and 26 kA/cm^2, respectively. The cavity length had no effect on threshold current density, say the authors, suggesting that the facets act as total reflectors.

Akasaka and co-workers have also used the etched trench and regrowth techniques to extend the thickness of GaN films up to 11 μm without inducing the cracks that limit the performance of LEDs and laser diodes (*App. Phys. Lett.* 2001 **79(9)** 1261).

Typically, GaN/SiC layers develop cracks after 1 μm, but the etched trenches act to suppress the lateral motion of cracks, and the mismatch strain in the layers is relaxed at the edges of the small areas of hexagonal GaN.

The trenches were formed into hexagonal shapes (see figure 2). The side lengths of the inner hexagons were varied up to 300 μm, and two sides were parallel to the $(1\bar{1}00)$ direction of the AlGaN layer. The width of the trenches was fixed at 15 μm.

A 0.5 μm thick $Al_{0.08}Ga_{0.92}N$ layer was directly grown on the SiC substrate at a temperature of 1010°C. Trenches were etched down to expose the SiC using electron cyclotron resonance dry etching and conventional photolithography, and this was followed by MOVPE regrowth of GaN layers at 1060°C. The GaN layers were selectively grown on both the top (0001) surfaces and the dry-etched side walls of the thick AlGaN layer. The regrowth layer provides a crack-free GaN surface, potentially suitable for further device growth.

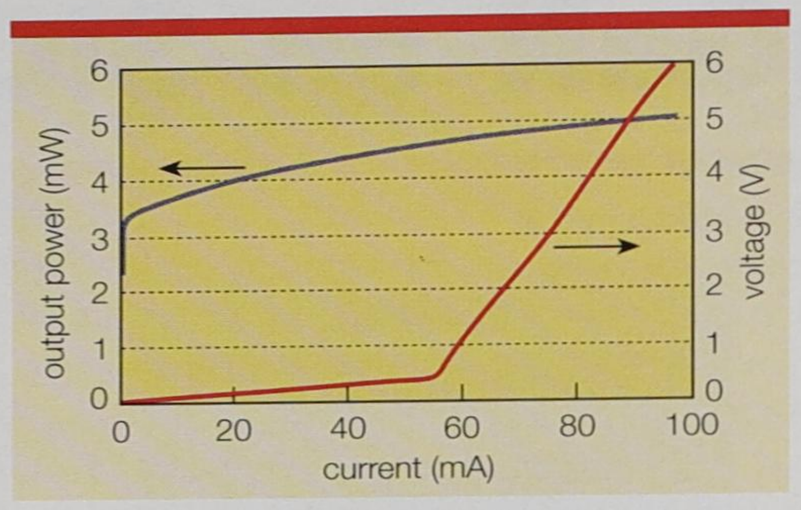
Record-breaking 1.32 μm GaInNAs/GaAs SQW laser

Wei Li and colleagues from the Optoelectronics Research Center at Tampere University of Technology, Finland have reported a GaInNAs/GaAs single quantum well (SQW) laser operating at 1.32 μm (*App. Phys. Lett.* 2001 **79(20)**). The laser has shown a threshold current density of 546 A/cm^2, a record for an uncoated, broad area oxide stripe Fabry–Perot device. The cavity length was 1600 μm, and an optical output of up to 40 mW per uncoated facet under continuous-wave operation at room temperature was achieved. The active region of the MBE-grown device comprised a 6 nm $Ga_{0.66}In_{0.34}N_{0.02}As_{0.98}$ SQW layer with $GaN_{0.02}As_{0.98}$ barriers. The waveguide and cladding layers were GaAs and $Al_{0.3}Ga_{0.7}As$, respectively.

For a 20 μm wide stripe laser with a cavity length of 1000 μm, slope efficiency was 0.28 W/A per facet. The maximum thermally saturated continuous-wave output power of 40 mW was achieved with a threshold current density of 756 A/cm^2. Lasing wavelength at this power was 1320 nm.

Ultraviolet GaN SQW laser diodes

The development of blue and violet GaN-based laser diodes has been progressing at a rapid pace in recent years, with reliability and device characteristics improving to the point where commercialization is now beginning. Typically the laser structures are grown on epitaxially laterally overgrown (ELOG) GaN substrates, with the active regions consisting of ternary InGaN layers. Shin-ichi Nagahama and colleagues at Nichia, Japan, have reported the first stimulated ultraviolet (UV) emission from binary GaN single quantum well (SQW) layers by current injection (*Jap. J. Appl. Phys.* 2001 **40(Pt. 2, 8A)** L785). The structure was grown on an ELOG substrate and included an $Al_{0.1}Ga_{0.9}N/Al_{0.05}Ga_{0.95}N$ modulation-doped strained layer superlattice cladding layer with a total thickness of 0.5 μm, both above and below the 100 Å undoped GaN SQW layer. A ridge geometry laser stripe was etched into the structure with an area of 25 μm × 600 μm. The laser facet coating consisted of three pairs of quarter wavelength ZrO_2/SiO_2 dielectric multilayers.



L-I and V-I characteristics of GaN SQW laser diodes under 25°C continuous-wave operation.

Above the threshold current, strong lasing emissions were observed at 366.9 nm using pulsed conditions with 2 μs pulses at 2 ms intervals. This emission wavelength is believed to be the shortest reported for III-N-based lasers by current injection. Under continuous-wave (CW) operation at room temperature, multimode emission at 369 nm was observed. The shift to longer wavelength during CW operation is as a result of heating. At room temperature the threshold voltage and current was 4.6 V and 53 mA, respectively, corresponding to a current density of 3.5 kA/cm^2. The low current density is a result of the low dislocation density in the ELOG material, and is expected to decrease further as the ELOG material growth, and the crystalline quality of the GaN SQW is improved. Lifetime tests at room-temperature operation, with output powers of 2 mW per facet, gave an estimated lifetime of 2000 hours.

High-quality GaN on $LiGaO_2$ substrates holds promise for photodetector fabrication

Recent research into GaN has focused on achieving device quality epitaxial material and integrating GaN films onto alternative substrates. Epitaxial quality is strongly associated with the formation of dislocations produced by lattice mismatched growth. Typically, GaN epilayers are grown on either sapphire or SiC substrates with lattice mismatches of 16% and 3.1%, respectively. In contrast, hexagonal GaN has lattice mismatch of only –0.19% to the *b* axis of lithium gallate ($LiGaO_2$), offering the potential for lower defect densities. Added to this is the ease of substrate removal by wet etching with HF:H_2O. This allows heterogeneous integration of GaN devices to alternative substrates.

A paper by S Seo and co-workers from the School of Electrical and Computer Engineering at Georgia Institute of Technology (*App. Phys. Lett.* 2001 **79(9)** 1372) describes the growth, fabrication and characterization of UV metal–semiconductor–metal GaN photodetectors grown on (001) $LiGaO_2$ by RF plasma-assisted MBE. The resulting GaN/$LiGaO_2$ material is of high quality, exhibiting dislocation densities of around 10^8 cm^{-2} (compared with 10^9–10^{11} cm^{-2} for GaN-on-sapphire).

The devices consist of a five-period superlattice of (0001) $Al_{0.4}Ga_{0.6}N$/GaN deposited as part of the nucleation layer, followed by a 1 μm thick unintentionally doped GaN epitaxial layer. Standard photolithography was used to pattern photoresist for subsequent metalization and lift-off used to define metal Schottky contacts on the GaN. Contacts were formed as interdigitated fingers 47 μm long and 2 μm wide, with a finger spacing of 10 μm. The total detector area was 50 × 50 μm^2.

The fabricated GaN/$LiGaO_2$ photodetectors exhibited a high responsivity of 0.105 A/W at a reverse bias voltage of 20 V at 308 nm, in addition to a dark current of 7.88 pA at 60 V reverse bias. Given the excellent etch selectivity of $LiGaO_2$ with respect to GaN and the performance of the devices, subsequent GaN device integration onto alternative substrates appears promising.

Selective regrowth for blue laser production

The ridge structure in AlGaInN-based lasers is usually formed by dry etching. However, it is difficult to control ridge dimensions by this method, and to obtain lasers with reproducible operating characteristics while maintaining a good quality, damage-free etched surface. Masaru Kuramoto and colleagues from NEC in Japan have demonstrated the use of selective area epitaxial regrowth for the formation of the ridge (*Jpn. J. Appl. Phys.* 2001 **40(Pt. 2, 9A/B)** L925). This is being investigated as a viable route to reliable mass production, as the ridge dimensions can be precisely controlled by photolithography and varying epitaxial growth time.

The laser structure was grown in two stages by MOVPE onto an ELO n-GaN substrate. In the first stage, a 1 μm AlGaN cladding layer and 0.1 μm n-GaN optical guiding layer are grown. These are followed by the InGaN multiple quantum well (MQW) active region that consists of three pairs of 3 nm $In_{0.15}Ga_{0.85}N$ well layers separated by 5 nm Si-doped $In_{0.05}Ga_{0.95}N$ barrier layers. The MQW region is capped with a p-AlGaN layer and a 0.1 μm n-GaN optical guiding layer. After this first step, a 300 nm SiO_2 layer is deposited and window stripes patterned and opened by photolithography and etching.

In the second growth stage, a 0.5 μm p-AlGaN cladding layer followed by a 20 nm p-GaN contact layer were epitaxially regrown into the openings in the SiO_2. Metal contacts were evaporated onto the GaN contact layer and the underside of the ELO GaN substrate. TEM studies did not show any dislocations originating at the regrowth interface. The transverse mode of ridge-type lasers is very sensitive to the ridge width and thickness. Lasers with ridges of different dimensions were fabricated and the criteria for transverse mode stability obtained. The laser showed stable fundamental transverse mode up to 40 mW of output power over a wide range of dimensions. Within these dimensions it is possible to obtain beams with aspect ratios suitable for use in applications such as DVD systems.

Energy-efficient high-power AlGaN ultraviolet LEDs grown on bulk GaN substrates

AlGaN-based LEDs offer considerable potential as energy-efficient solid-state replacements for mercury lamps as UV light sources. T Nishida and colleagues from NTT Basic Research Laboratories in Japan have produced an AlGaN device using a bulk GaN substrate (*Appl. Phys. Lett.* 2001 **79(6)** 711). This substrate is lattice matched to GaN alloys, giving fewer dislocations compared to GaN epilayer growth on SiC or sapphire substrates. The 500 μm thick GaN substrate was grown by Sumitomo Electric using hydride vapor-phase epitaxy.

Low-pressure MOVPE was used to grow an $Al_{0.18}Ga_{0.82}N$ buffer prior to a 2.5 nm thick $Al_{0.04}Ga_{0.96}N$ SQW layer surrounded by $Al_{0.1}Ga_{0.9}N$ barriers. Cladding was provided by an AlGaN superlattice with a period of 3 nm. 20 nm *n*- and *p*-type $Al_{0.3}Ga_{0.7}N$ layers were introduced on both sides of the SQW for carrier confinement, followed by top and bottom contacts. The testing of unpackaged devices showed emission centered on 352 nm with an output power of 0.55 mW at an injection current of 20 mA, increasing to 3 mW at 100 mA. The maximum output power was 10 mW at 400 mA.

The internal and external quantum efficiencies were measured and found to be ~80% and 1%, respectively; the latter was an order of magnitude greater than similar devices grown on SiC, which the authors attributed to the much lower defect density in the bulk GaN-based emitter. Further improvements in the substrate and the packaging technology hold great promise for future compact efficient UV emitters.

Poor efficiency limits monolithic white LEDs

The replacement of incandescent bulbs with LEDs requires the development of highly efficient white LEDs. The most efficient of these to date have been based on InGaN/GaN blue LEDs that pump polymer or YAG phosphors which in turn emit white light. The addition of the phosphor adds a step to the LED production, making white LEDs by this route relatively expensive. Damilano and co-workers from the Centre National de la Recherche Scientifique, and Picogiga, France, have proposed a white LED using a stack of InGaN/GaN quantum wells (QWs) emitting at different wavelengths inside a GaN p-n junction (*Jpn. J. Appl. Phys.* 2001 **40(Pt. 2, 9A/B)** L918).

The LED structures are grown by MBE onto sapphire substrates. A thick (few microns) GaN:Si buffer layer is deposited before the multiple (M) QW active region is grown. The active region is capped with a 0.2 μm GaN:Mg contact layer. The researchers varied the number and composition of the QWs, and the position within the structure, to see how the emission spectrum was affected. An LED with two thin QWs (2.3 nm) on the n-GaN side, and four thick QWs (4.5 nm) on the p-GaN side was fabricated. Dual emission at 470 and 550 nm gave light from this LED that was white to the naked eye. The efficiency of these monolithic white LEDs is limited by the poor efficiency of yellow emission. Improving yellow emission requires an increase in In composition of the InGaN QWs. This has proved to be difficult due to the low In-N binding energy and lattice mismatch between InN and GaN.

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ECOC

Components on show at ECOC

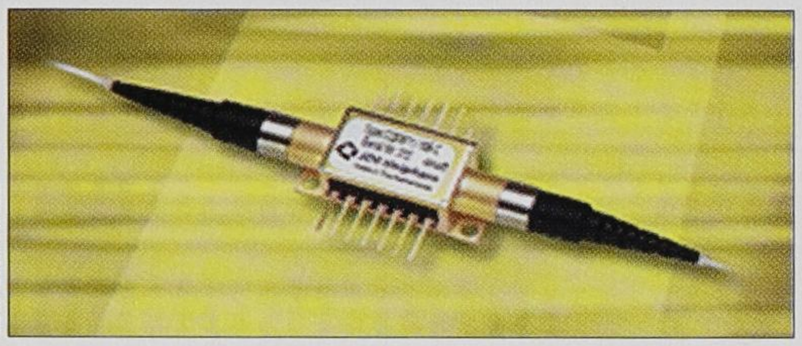
Despite the difficult market conditions, component vendors had plenty to talk about at the European Conference on Optical Communication (ECOC), writes **Tim Whitaker**.

Component vendors at this year's ECOC show, held on 1–3 October in Amsterdam, The Netherlands, displayed a range of emotions. Some are confident that their technologies will put them in a healthy position when the current slump ends, and others have reassessed their strategies to cope with the dire market conditions. Nevertheless, times are tough and no-one knows when things will pick up, although Milton Chang, chairman of New Focus and plenary speaker, predicted that inventory stockpiles will be largely depleted by the fourth quarter of this year.

Around 2500 people attended the ECOC exhibition, most of whom also registered to attend the technical sessions. This represented an increase on last year's figures, but the timing of ECOC ensured that it missed out on the boom experienced by OFC in March this year. At times, the exhibit hall and its tented annex looked a little empty.

It will be interesting to see how many of this year's exhibitors survive until next year's show, or even until next year's OFC. Most observers agree that consolidation is coming soon; Alcatel's recent purchase of high-profile start-up Kymata could set the trend. Other companies will undoubtedly go out of business in the coming months.

One noticeable absentee was Nortel Networks, who didn't have a booth despite advertising on the back of the exhibit program. The news from Nortel continues to get worse; the company is auctioning off a huge amount of processing, assembly and test equipment from its fabs in Ottawa, Zurich, Paignton (UK), and Boston.



JDS UNIPHASE

Fig. 1. JDS Uniphase's low-cost SOA module is targeted at the metro market.



AGILENT

Fig. 2. Agilent's 1310 nm serial 10 Gigabit Ethernet transceivers, which conform to the XENPAK multi-source agreement.

Integration

Fresh from receiving its latest round of funding (see p17), ThreeFive Photonics demonstrated the type of monolithic optoelectronic chip that the company plans to manufacture in future. The chip was a 4-channel, 2 × 2 WDM cross-connect consisting of four arrayed waveguides and four Mach–Zehnder electro-optic cross-bar switches. "The device is all InP and measures 1.5 × 3.3 mm, making it, to our knowledge, the smallest WDM cross-connect in the world," said ThreeFive Photonics' Chretien Herben. "It can cross-connect any of the four wavelengths on both multi-wavelength inputs individually to the multi-wavelength outputs."

The hybrid integration technology (HIT) platform demonstrated at ECOC by AIFOtec Fiberoptics combines a fiber grating laser (FGL) with a silicon optical bench. The FGL consists of a Fabry–Perot laser chip combined with an external fiber grating. AIFOtec's devices incorporate an integrated spot-size converter, which greatly reduces coupling losses into the fiber. The HIT platform utilizes v-grooves in the silicon bench to hold the fibers and flip-chip bonding to mount the active components. For example, a multi-wavelength array can be assembled by mounting several lasers onto the platform and attaching fibers with different gratings. AIFOtec uses passive alignment techniques and is focusing on automated manufacturing. Although Fabry–Perot laser chips can be manufactured with much higher yield than DFB lasers, one disadvantage of FGLs has been wavelength drift and deteriorating performance over time. AIFOtec has developed a control feedback IC that stabilizes the emission wavelength of the device without using additional optics.

Pump lasers

Furukawa displayed several high-power 14xx nm pumps, including a 400 mW module, a 600 mW version containing two pump lasers, and a 300 mW Rainbow pump with an integrated fiber Bragg grating. The company has also developed a 980 nm laser in combination with Mitsui, and was showing additional products such as source lasers, VCSELs and transponders.

Low power, low cost from Novalux

Novalux announced its second suite of products – 980 nm pump lasers with powers of 100 and 200 mW, which are intended for EDFAs in metro optical networks. Products introduced at OFC in March emphasized high power, while the new lasers reflect a shift in market emphasis. Novalux claims that its surface-emitting NECSEL design offers cost-saving features over edge-emitting technology, such as the ability to perform on-wafer testing. The company plan to start shipping beta samples in late October.

SOAs hit the mainstream

Semiconductor optical amplifiers (SOAs), touted as alternatives to EDFAs in short-reach applications, were much in evidence at ECOC. JDS Uniphase introduced an SOA module targeted at the metro market, with a price of under $2000 in volume. Most amplifiers are designed to deliver the performance needed for long-haul applications, whereas metro does not require as much performance and therefore can use a less costly solution. The modules (figure 1) operate over the entire C-band, with a typical gain of 16–20 dB (depending on type) and a saturated output power of 10 dBm.

New names on the component vendor list

Despite the difficult market situation, several new component vendors emerged at ECOC this year. **Eblana Photonics**, a newly established laser manufacturer based in Dublin, Ireland, announced plans to introduce transmission and pump lasers based on a proprietary technology platform that allows high-volume manufacturing of lasers in a cost-effective manner. The company evolved from Trinity College Dublin in conjunction with the Irish National Microelectronic Research Center, and is currently based in the Trinity Enterprise Center, Dublin.

The fiber-optic component industry in Taiwan is gathering momentum. **Copax Photonics**, based in Tao-yuan, develops and manufactures high-performance optical active components and modules, including high-speed Fabry–Perot lasers, uncooled DFB lasers and single-transverse-mode VCSELs. **Optoway**, which has a fab in the Hsinchu Industrial Park, manufactures a complete line of Fabry–Perot and DFB lasers, photodiodes, PIN-TIA modules and LEDs, in a range of packages including single and multimode transceivers.

Two companies from Korea were also present. **Opto*on** a subsidiary of Knowledge*on, formerly known as Optel, manufactures chips and modules for data rates from 155 Mbit/s to 2.5 Gbit/s at its facility in Iksan. Lastly, **Neoptek** is a spin-off from LG Cable, which has been manufacturing components such as source lasers and detectors for about eight years. According to marketing manager Ian Yun, Neoptek will focus on low-speed components for the metro and fiber-to-the-home markets. "There are many companies working on high-speed products for long-haul networks," said Yun. "Neoptek will use its production expertise to concentrate on high-volume, low-cost products."

Kamelian's optical linear amplifier

Kamelian added another acronym to the industry with its variable-gain optical linear amplifier (OLA). The structure of the InP-based device is similar to an SOA, except it has a DBR section at each end. The design permits linear amplification of multiple wavelengths – conversely, SOAs can only amplify single wavelengths – and also allows variable gain. This latter feature is not available with other linear optical amplifiers, such as the device announced earlier this year by Genoa (see *Compound Semiconductor* May 2001, p49) – this device is optically pumped by an integrated VCSEL-like structure. According to Kamelian, the OLA offers a cost-effective alternative to EDFAs, particularly in the metro market. "Traditionally, SOAs have been most effective in single-wavelength applications," said Paul May, Kamelian's chief executive officer. "The OLA offers the prospect of multi-channel in-line amplification at a cost which will be very attractive for metro networks, where the use of EDFAs cannot easily be justified." Kamelian's new InP fabrication facility near Oxford, UK, which will manufacture and package SOAs in both single package and multi-channel (OLA) formats, is "close to completion," said staff.

40 Gbit/s products

NEL was exhibiting examples of 50 Gbit/s parts manufactured using InP HEMTs, including a d-type flip-flop, a toggle flip-flop, a 2-1 selectro and a 1-2 DEMUX. Samples are expected to be available by the end of the year. Furthermore, the booth also displayed a processed 6 inch GaAs wafer fabricated at the company's new factory near Tokyo, which was completed in July.

OpNext demos 40 Gbit/s system

A live 2 km transmission experiment using fully functional 40 Gbit/s transmitter and receiver modules was performed by OpNext. The transmitter module contained a 40 Gbit/s semiconductor modulator driven by an InP HBT driver IC, together with a SiGe 4-to-1 multiplexer IC. The receiver contained a photodiode and TIA, an InP post-amplifier, a 40 GHz clock recovery circuit, and a SiGe 1-to-4 demultiplexer IC. "Our customers want our 40 Gbit/s products as soon as possible," said OpNext president and chief executive officer, Harry Bosco. "We are planning to deliver fully integrated samples by Q4 2002."

40 Gbit/s transponder MSA

A number of optical component manufacturers – Agere, Agilent, Alcatel Optronics, Ericsson, ExceLight, JDS Uniphase, Mitsubishi Electric, NEC and OpNext – announced a multi-source agreement (MSA) for 40 Gbit/s transponder modules. The design features integrated clock and data recovery and a serializer/deserializer supporting 16 electrical input and output channels in parallel at 2.5 Gbit/s. MSA members believe the fully integrated solution will afford network system suppliers shorter design cycles and allow a significant increase in network capacity. Transponder products are expected on the market in 2003–2005.

New recruits for 10 GbE MSA

Seven new companies joined the XENPAK MSA group, which also announced revised specs for 10 Gigabit Ethernet (10 GbE) transceivers. The XENPAK MSA covers all four 10 GbE transceiver types, i.e. serial solutions at 850, 1310 and 1550 nm, together with coarse WDM at 1310 nm. Size is defined as 36 × 121 × 17.4 mm (1.5 × 4.8 × 0.7 inches), which enables eight devices to be mounted on typical line cards. Agilent, a founder member of the MSA group, introduced the 10 GBASE-LR XENPAK transceiver with XAUI interface (figure 2). The 1310 nm transceiver has a range of 10 km and utilizes uncooled, directly modulated lasers. Agilent will ship production volumes in Q3 2002, and expects pricing to fall below $1000 when the 10 GbE market reaches high volume in 2003.

Vitesse and CyOptics join forces

CyOptics and Vitesse demonstrated interoperability of their 10 Gbit/s components using the Vitesse VSC7991 modulator driver and the CyOptics electro-absorption modulator (EAM). The latter is an InP device priced at $1500 in quantities of 1000. The VSC7991 is a single chip 10 Gbit/s EAM driver with a 3 Vpp drive voltage and is available in die form or in a low-cost 32-pin package, priced at $126 and $151, respectively, in quantities of 1000. "This combination is significantly superior to lithium niobate alternatives in terms of size, price, and ease of system design," said Hava Volterra of CyOptics.

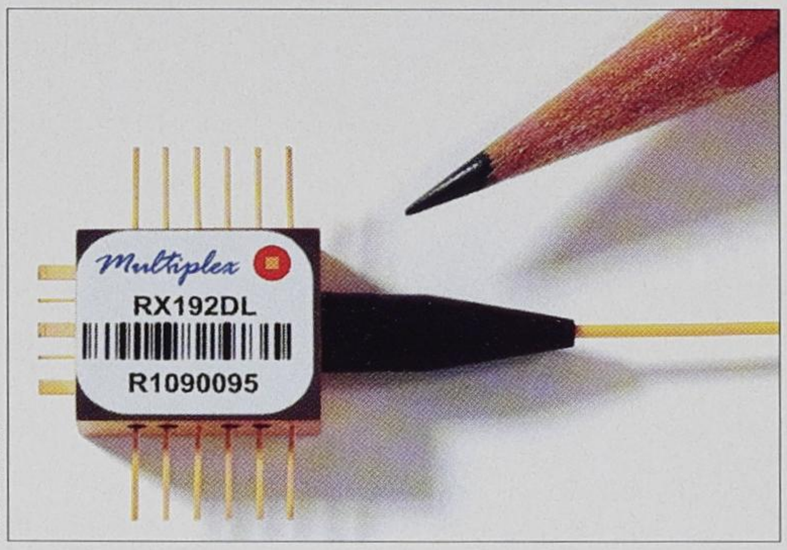
VCSELs

John Humphries, one of the founders of Swiss VCSEL-maker Avalon Photonics, described the company's focus on developing wafer-level burn-in processes for VCSELs. Reliability is a key feature for oxide VCSELs, as is develop-

ing a suitable package for 10 Gbit/s operation. Avalon is looking at flip-chip processes and through-wafer transmission at 960 nm, as well as developing telecom wavelength devices.

Source laser modules

The E2581-series electroabsorption modulated laser (EML) module, launched by Agere, was claimed to be the industry's first to combine a single-chip InP EML with a GaAs driver IC at 10 Gbit/s, and to provide a reach of 80 km. Integrating the laser driver IC with the EML gives the device optimum RF performance by shortening the distance between the driver chip and the modulator. The EML's compact size and integrated architecture offer significant benefits over external modulators and drivers, which are often bulkier and more expensive. The package also contains a thermoelectric cooler, thermistor, rear facet monitor photodiode and optical isolator. The EML uses pulse compression to compensate for the dispersion limitations of singlemode fiber (SMF) at distances up to 80 km, and features a 10 dB-or-greater RF extinction ratio, as well as a dispersion penalty of less than 2.0 dB over 80 km of standard SMF.



MULTIPLEX

Fig. 3. Multiplex's new 10 Gbit/s "postage stamp" photoreceiver measures only 0.5 x 0.595 x 0.235 inches.

Receivers

Multiplex introduced a new small-form 10 Gbit/s "postage stamp" photoreceiver measuring only 0.5 × 0.595 × 0.235 inches (figure 3). The product features coplanar differential outputs, and a larger first-generation receiver with a single output is also still available. Multiplex says it was the first company to integrate a limiting amplifier into its receiver package, and the new small-form product is also available with this feature, which results in sensitivity of better than –19 dBm. Standard and small-form receiver variants are available for 10 and 12.5 Gbit/s. An APD receiver is anticipated to be available early in 2002.

Marconi goes for GaAs

Marconi Optical Components (MOC), the independent business unit of Marconi launched in March 2001, revealed a series of products based around its GaAs modulator technology. Marconi has built a 6 inch processing line for GaAs modulators and ICs at its Caswell facility in the UK. In addition to scalability, MOC feels that GaAs offers excellent modulator performance at 40 Gbit/s and above, as well as the prospect of integrating other optoelectronic devices and analog ICs. MOC also has InP manufacturing technology, which is used to build multi-section tunable DBR lasers and fixed wavelength source lasers. Several 10 Gbit/s transmitters (tunable and fixed wavelengths) combining InP lasers with GaAs Mach–Zehnder modulators and wavelength lockers were on show. MOC has also developed RZ and NRZ 40 Gbit/s transmitters, and demonstrated a 40 Gbit/s NRZ transmitter with a drive voltage of 5 V provided by a GaAs PHEMT IC, also fabricated in-house.

QUALITY QUESTIONS?

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GaAs is still the material of choice for many applications

A mixture of technical papers and discussion sessions covered an impressive variety of topics at GAAS2001. **Tim Whitaker** and **Jon Newey** report on the highlights.

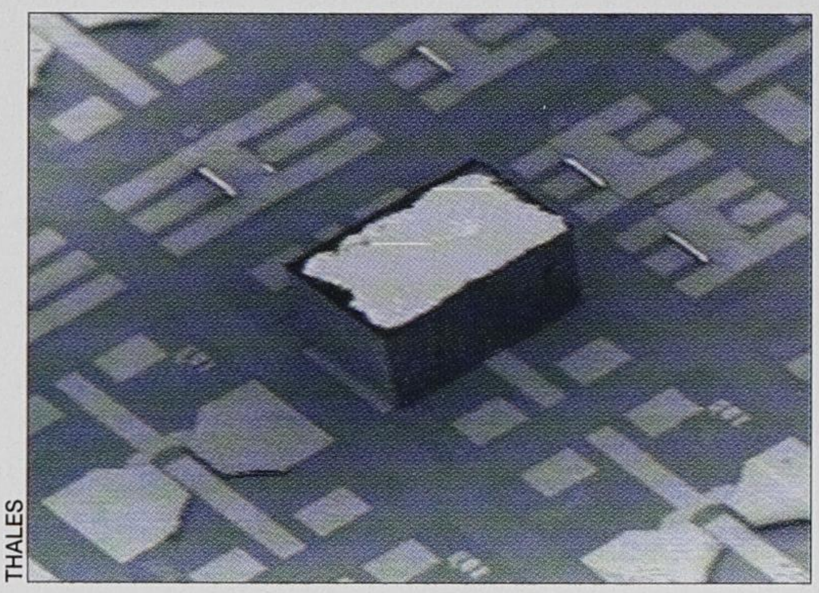


Fig. 1. SEM image showing a 300 μm thick diamond thermal sponge mounted on a multifinger InGaP power HBT.

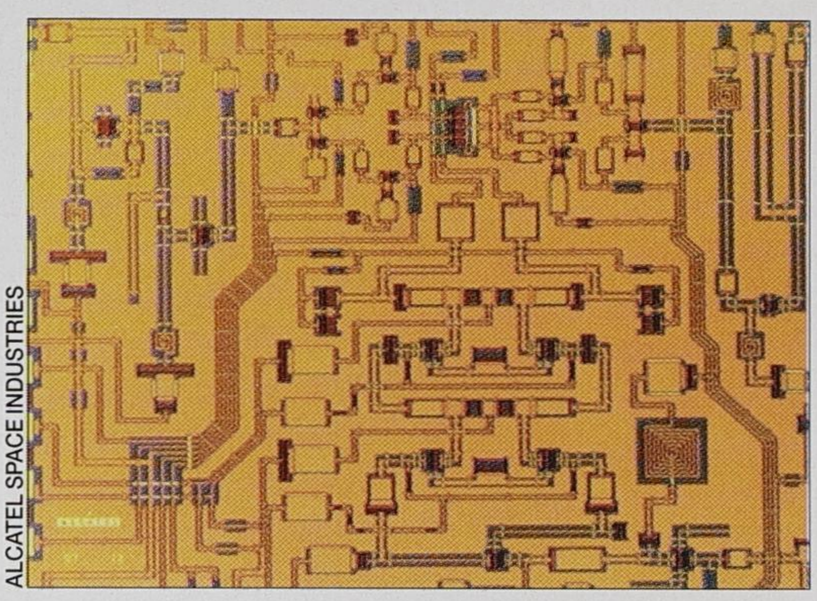


Fig. 2. Alcatel's 3.7 x 4.2 mm MMIC receiver combines four functions on a single chip which contains 24 PHEMTs.

The GaAs Application Symposium (GAAS2001), which was held on 24–25 September, covered the first two days of European Microwave Week in London, UK. Sessions covered all aspects of GaAs-based materials and devices, including device modeling, power devices, material and device characterization, packaging, and optoelectronic devices. The meeting also included work on related materials, such as the III- nitrides. There were papers on the latest developments in SiC and GaN-based electronics, as well as work on silicon devices in areas where they compete with GaAs. Many of the GAAS2001 sessions were run jointly with the European Microwave Conference, another meeting forming part of the week's events. As would be expected, these joint sessions focused much more on areas such as the development and packaging of MMICs for particular microwave applications.

The conference opening session included two invited talks. The first of these was a late change to the program, with Tom Hierl of IQE using the opportunity to present the work done with Motorola on the now much reported GaAs growth on large-area silicon wafers (*Compound Semiconductor* October 2001, p47). Lester Eastman of Cornell University presented record-breaking data for AlGaN/GaN HEMTs on SiC substrates. Continuous-wave operation of a 1.5 mm periphery device operating in the 8–10 GHz range gave a power density of 7 W/mm and is expected to reach 10 W/mm with design improvements (p69).

HBT developments

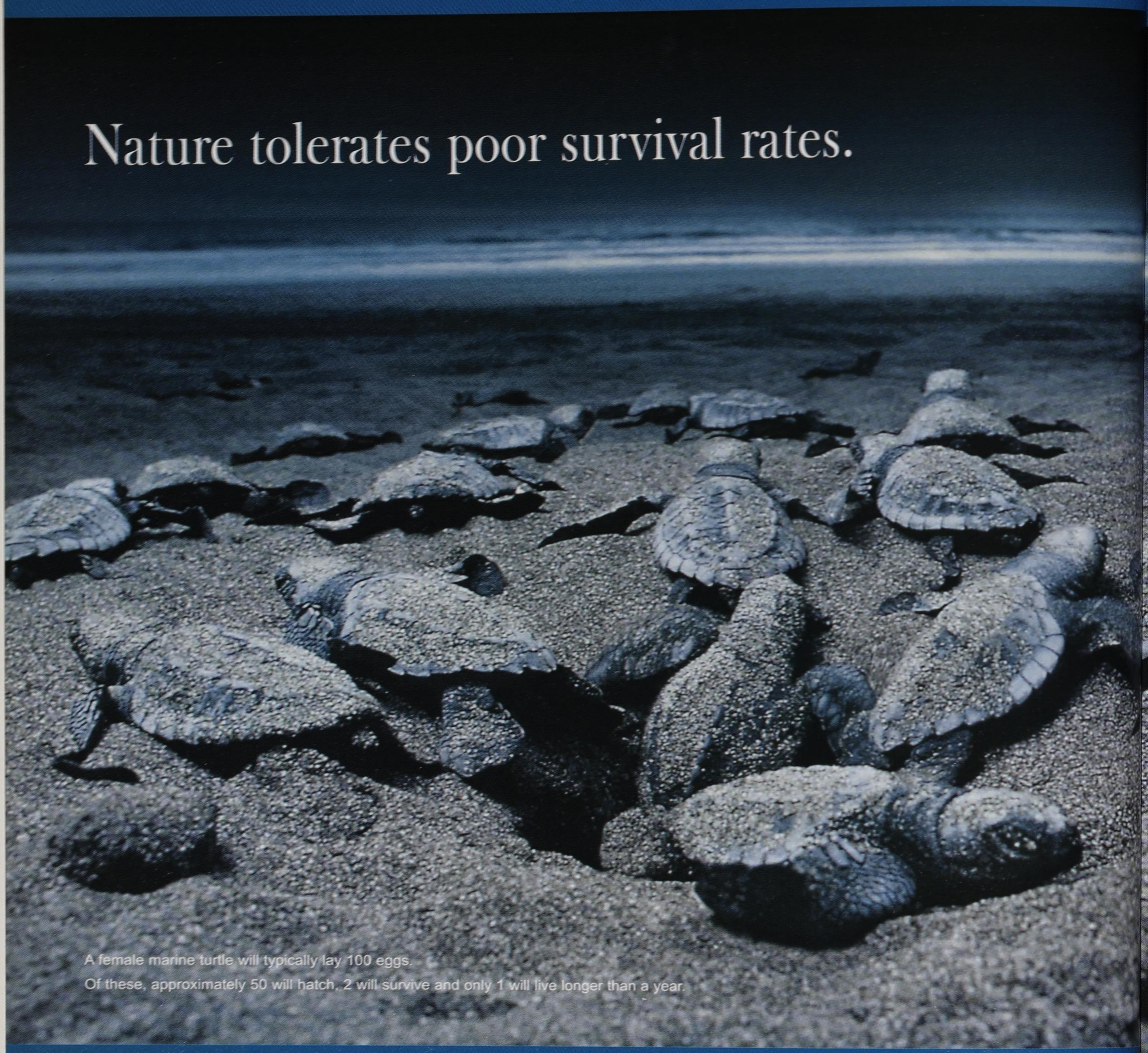
D Floriot *et al.* from Thales and UMS discussed the current status of the GaAs HBT as a power technology and the future performance challenges. In particular, improved thermal management was seen as a crucial factor in raising HBT performance levels. The use of a gold layer on emitter fingers has helped to reduce thermal resistance and improve cooling and temperature uniformity across devices. The move towards single and double HBTs operating at 40 GHz is placing a heavy burden on present thermal management techniques. One solution discussed was the use of bump bonding, leading to a 30% improvement in thermal resistance and an enhancement in the reliability of HBTs. This approach introduces a new level of complexity to manufacturing and impacts on yield. Increasing the thickness of the gold layer on emitter fingers introduces problems during back-end processing. A solution to this has been the use of material with high thermal conductivity and diffusive properties to stabilize and limit heating. This approach is based on the use of thick copper or diamond materials on top of the emitter finger to act as a thermal sponge (figure 1). The thin gold layer is retained because it aids bonding of the thermal sponge to the finger.

K Stevens *et al.* from HBT epiwafer vendor Kopin described a promising material technology for enhancing GaAs-based HBT performance. This was based on Kopin's InGaP/GaAs HBT, but with In and N introduced into the GaAs base layer to lower its energy gap. Device performance improvements, such as lower operating voltages, improved gain stability and higher PAE, can be met by manipulating the relative magnitudes of collector and base current components in GaAs-based HBTs. These current component changes can be made by lowering the base-layer energy gap. Substituting GaInNAs for GaAs in the base layer does this while maintaining a cost-effective GaAs platform. Using this approach over the conventional InGaP/GaAs HBT has lowered operating voltage by 115 mV and given superior temperature stability. This has been achieved while maintaining the standard 500 Å base thickness and 4×10^{19} base doping level. The epitaxial growth is still at an early stage of development and, as this is refined, further HBT performance improvements are expected.

GaAs in space

Space-based applications place stringent demands on electronics because of the harsh operating environment and the necessity to keep the mass and volume as low as possible in payloads. Several papers were presented that considered device design and packaging for satellite applications. J Villemazet *et al.* from Alcatel Space Industries, Toulouse, France, described a new design for a coplanar mixer for integration into a satellite repeater. Compared with the current generation of 12/14 GHz satellite mixers, the Alcatel team's design gave a device about 65% smaller at 1.8 mm^2 and provided 2 dB of gain instead of the 10 dB loss that is generally seen in such

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mixers. The mixer has been successfully integrated into a single MMIC receiver chip. Other functions on the chip include a two-stage IF amplifier, a four-stage local oscillator (LO) differential amplifier and an LO voltage controlled attenuator. The MMIC was fabricated on OMMIC's 0.2 µm PHEMT process, contains 24 PHEMTs and measures 3.7 × 4.2 mm (figure 2).

Equipment used in scientific experiments is another demanding area for electronics. Combine this with space-based radio astronomy, and performance specifications get very tight. The Plank Low Frequency Instrument is a satellite-mounted device to measure variations in the cosmic microwave background radiation. This covers the 30–100 GHz range. B Aja *et al.* from the University of Cantabria, Santander, Spain, described the development of a Ka-band low-noise amplifier for this application. The noise figure for the amplifier was the critical parameter because the end application was for background noise measurement. The LNA design was fabricated on OMMIC's 0.2 µm depletion-mode PHEMT process with gate widths of 6 × 15 µm. The four-stage design consisted of a low-noise input stage and three gain-flatness stages. The three gain-flatness stages used parallel feedback to reduce gain roll-off with frequency and provide flat gain over a wide bandwidth without impacting on the noise figure. The result was an average noise of 2.3 dB from 28–36 GHz with a gain of more than 20 dB. A minimum noise of 1.2 dB was achieved at 29.5 GHz. Changing the amplifier bias point for increased gain gave 29 dB at 30–31 GHz with an increase in noise to 2.5 dB.

Nitrides

A number of papers touched on the role of surface passivation in AlGaN/GaN HEMTs. The current slump in the drain when operating at high drain bias is caused by the trapping of electrons by empty surface states. The build-up of charge depletes the channel and limits the available RF current amplitude. Surface passivation using SiN has been found to alleviate this problem.

H Leier *et al.* from DaimlerChrysler, EADS and QinetiQ compared the RF performance of passivated and non-passivated AlGaN/GaN HFETs grown on SiC and sapphire. Though passivation made no significant difference to carrier concentration and mobility, RF performance was markedly improved. RF power measurements were made on devices grown on sapphire with 2 × 100 µm gates and operated

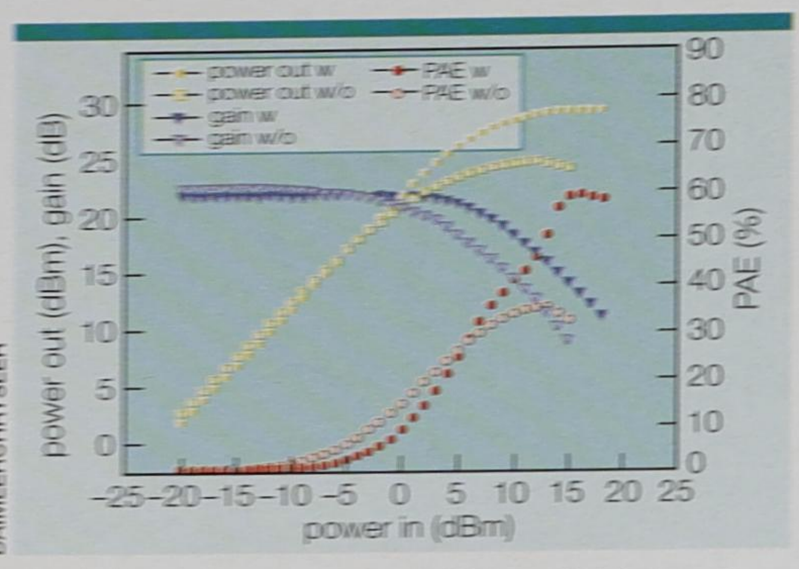
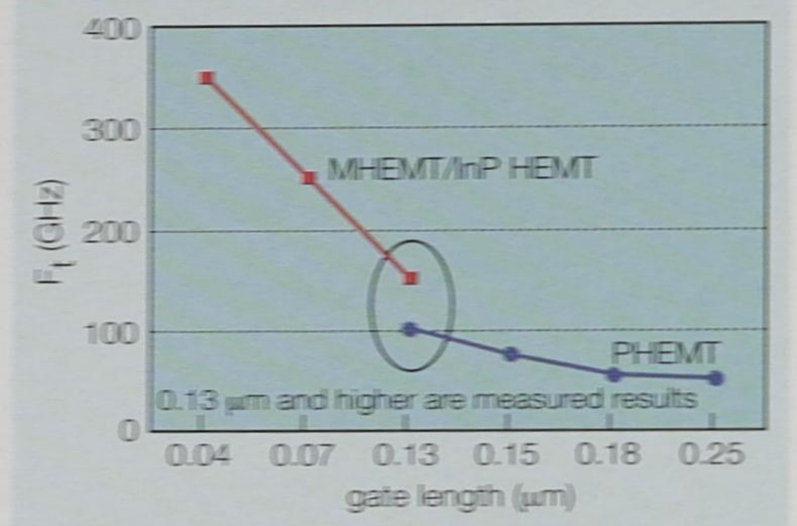


Fig. 3. Performance at 2 GHz with (w) and without (w/o) SiN passivation for a 2 x 100 µm gate HEMT grown on SiC.

MHEMT processes revealed



OMMIC used European Microwave Week to launch its MHEMT process (*Compound Semiconductor* October 2001, p11). MHEMTs with 0.13 µm gate lengths give an improved f_t over PHEMTS with 0.13 µm gates. Further reductions in gate length for the MHEMT process are expected to yield considerable advances in f_t.

OMMIC

Stephen Entwistle of Strategy Analytics said that the GaAs industry's growth had only been "blunted" by the current period of slowdown.

with a V_{ds} of 25 V. At 2.5 GHz the unpassivated device gave a saturated output power density of 1.7 W/mm and PAE of 41%. Surface passivation improved these figures to 3.1 W/mm and 55%. Similar improvements were observed for devices on SiC with RF power rising from 24.8 to 29.1 dBm when passivated and PAE improving from 35% to 59% (figure 3).

While the best AlGaN/GaN HEMTs have so far been grown on SiC substrates, these are prohibitively expensive compared with silicon or sapphire and are not available as large-diameter wafers. The SIGANTIC process developed by Nitronex allows the growth of thick, high-quality GaN and AlGaN layers on cheap, large area silicon substrates. W Sutton *et al.* from the University of Michigan and Nitronex reported the first fabrication of AlGaN/GaN HEMTs with 1 µm gate lengths on SIGANTIC substrates. A 2 × 75 µm periphery HEMT gave a maximum current density of 0.4 A/mm and a maximum breakdown voltage, BV_{ds}, of 35 V. Curiously, maximum values for transconductance for all of the devices occurred at positive gate bias as opposed to the negative bias values usually reported for GaN HEMTs. An f_{max} of 12 GHz was obtained at a V_{ds} of 15 V and the maximum f_t value observed was 5.8 GHz. Significant improvements are expected on these figures as ohmic contacts are improved and gate lengths drop below 1 µm.

Transferred substrate HEMTs

S Bollaert *et al.* from the IEMN, Lille, France, CEA-LETI, Grenoble, France, and the University of Salamanca, Spain, presented the results of a transferred substrate InAlAs/InGaAs HEMT structure with a 0.12 µm T-gate. As gate lengths shrink, the short-channel effect is becoming the limiting factor to improvements in f_{max}, and the injection of carriers into the substrate degrades the output conductance of the device. One way round this is to use an insulating substrate. This can be achieved by a transferred-substrate technique as used in SOI-MOS device fabrication. The IEMN-led group has extended this concept to III-V-based devices by transferring an InAlAs/InGaAs HEMT to a SiO_2/Si substrate.

The FET structure was grown by MBE on an InP substrate and then coated with SiO_2. The oxidized Si wafer and the FET structure are then bonded together by annealing at 200°C for 60 min. The InP substrate and the InGaAs and InAlAs etch stop layers are then removed by wet etching. The formation of the 0.12 µm T-gate HEMT device can then be started. An f_t of 185 GHz was achieved, comparable with the figures reported for lattice-matched (LM) HEMTs on InP, and f_{max} was 290 GHz, with the InAlAs buffer layer still in place. This figure is expected to improve with the removal of the buffer layer.

Power amplifiers

Fazal Ali of Nokia gave a personal view of challenges that formats such as W-CDMA will

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Silicon
28.086

Ga
Gallium

As
Arsenic
74.922

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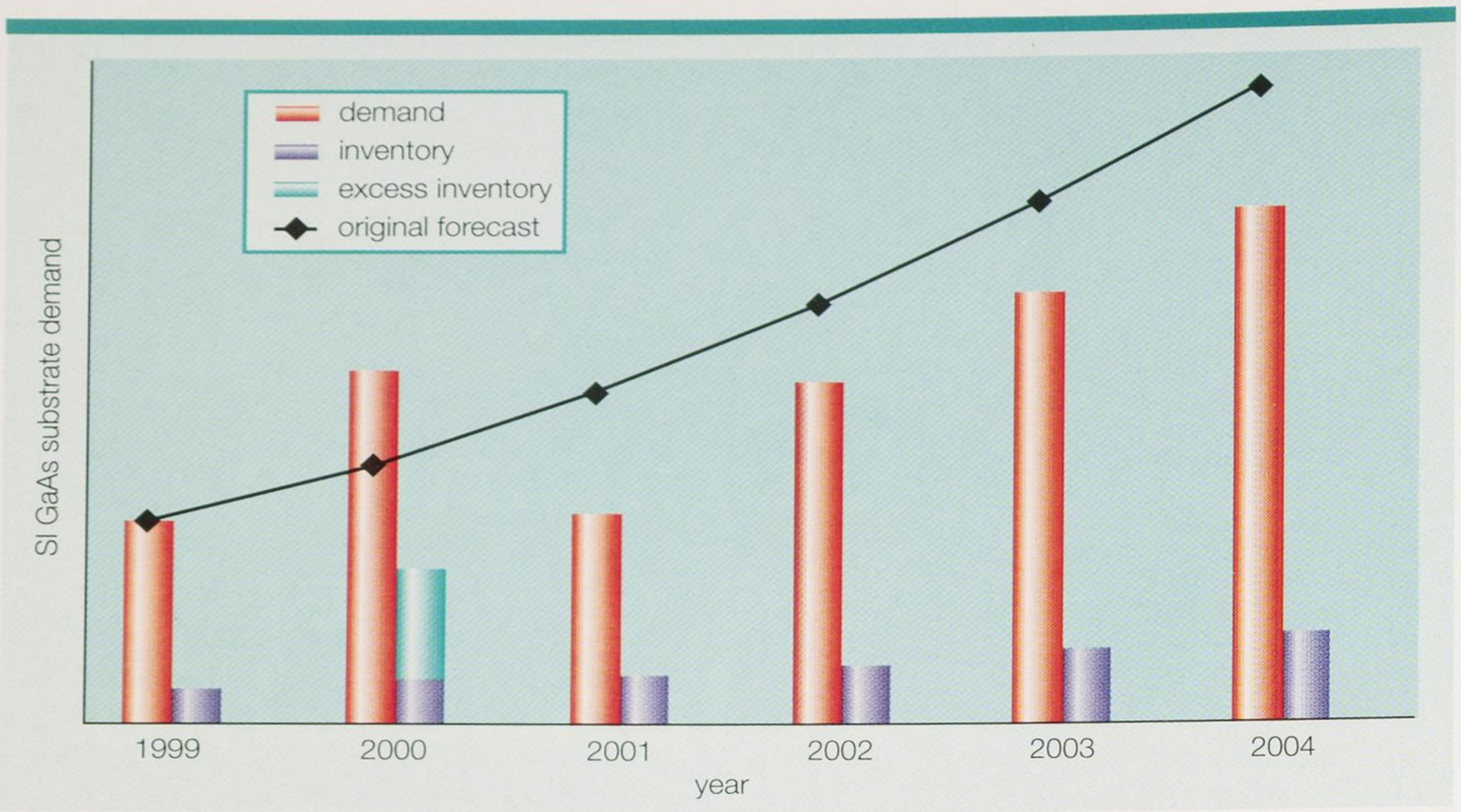


Fig. 4. Demand for semi-insulating GaAs substrates. In 2000, over-exaggerated market forecasts and industry fears of gallium shortages resulted in the build-up of excess inventory, which in turn reduced the demand for GaAs substrates during 2001.

present to power amplifier manufacturers. In terms of technology, Ali felt that InGaP/GaAs HBTs have many advantages over AlGaAs/GaAs HBTs, offering better temperature performance and higher power density per unit area. E-mode PHEMTs offer good low-voltage performance and the prospect of integrating PAs with switches and other components. Ali described the performance of SiGe HBTs as "nothing to write home about", the main issue being low breakdown voltage. However, flip-chip technologies such as those being developed by companies like Maxim could be advantageous. Ali commented that "indium phosphide is inherently not profitable". Later he elaborated that there was very little, if any, benefit in using InP for PAs in the 900–2000 MHz range.

Ali also described several options for smart PAs, which can improve the PA efficiency at low power levels while maintaining a high maximum linear power. This is necessary because CDMA field tests showed an average power of 11 dBm in urban environments, compared with a maximum power of 24 dBm. Techniques include power mode control (PMC), adaptive bias control (ABC) and dynamic supply voltage (DSV). PMC switches to a different mode at a fixed low-power level, while ABC uses a bias circuit to reduce the bias current when power drops. This approach was used in RFMD's new PA module which was announced at the European Microwave Week (*Compound Semiconductor* October 2001, p11). Ali concluded with the observation that technologies have to provide a "PCS" solution (i.e. meeting the requirements of performance, cost and size) and he warned against believing in the performance of suppliers' "golden samples", as described in press releases.

Indium phosphide

Andre Scavennec of Optoplus, the joint R&D center of Alcatel and France Telecom, stated that 40 Gbit/s solutions would hit the market "when they are cost-effective, and when they are required". There are several technology options – SiGe effectively adds frequency performance to a well established technology, and performance metrics such as static frequency divider speed are getting close to those achieved by InP. The latter material has advantageous transport properties, but scaling is needed. Typical dimensions are 1.0 μm for InP HBTs, compared with just 0.2 μm for SiGe. Although GaAs may struggle to compete for 40 Gbit/s applications, GaAs PHEMT technology is still best for high-voltage drivers.

Scavennec felt that there was room for improvement with InP, from scaled devices through new material combinations (e.g. the use of antimonides) to new device structures (e.g. resonant tunneling diodes). As the bit rate increases, there is also scope for innovations to improve areas such as characterization, packaging, modeling and reliability. The target will be to reduce the cost of 40 Gbit/s ICs to the current level of 10 Gbit/s parts.

Markets and forecasts

Stephen Entwistle of Strategy Analytics presented his view of the GaAs market, expressing the opinion that the industry's growth has only been "blunted" by the current period of slowdown and inventory correction. Furthermore, he added that the underlying metrics remain sound. "Shipments will grow or, at worst, remain flat, while penetration of GaAs into its target markets will also increase," said Entwistle. "The big question is: will average selling prices stay level or will we see price wars?" The answer appears to be that ASPs will hold up, because there are many single-source, proprietary products in the industry, so there is little scope for cost competition.

After explaining why problems occurred in the bulk substrate side of the industry during 2001 (figure 4), Entwistle presented figures putting the GaAs market at $3.15 billion in 2000. The market was dominated by communications, with wireless taking a 58% share and fiber optics accounting for 24%. During 2001, the market will be flat, or may even show a slight decline over 2000, due to the "inventory burn" that has taken place. However, Entwistle sees conservative growth in 2002, followed by sustained increases in the next few years. Modules are becoming increasingly important and will have a "profound effect" on the market-place, with many IC companies moving towards supplying module-based solutions. The window of opportunity may be closing for LMDS applications, but prospects for automotive radar are looking more promising. Finally, Entwistle suggested that only a small number of the many current foundry ventures will be successful, and that the industry will have to wait 5–6 years before GaAs-on-silicon has a significant impact.

Panel session

Entwistle's numbers and a range of other issues facing the GaAs industry were discussed by a panel chaired by Massimo Comparini of Alenia Aerospazio. Participants included Tom Hierl of IQE, Andrew Phillips of Marconi Optical Components, Heinrich Daembkes of UMS, Nigel Priestly of Marconi Applied Technologies, Fazal Ali of Nokia and Lester Eastman of Cornell University.

Daembkes talked about the high-frequency market and his company's new packaging approach that enables MMICs to be surface-mounted by module assemblers (see New Devices, p31). This removes one of the production bottlenecks for such customers – namely the requirement to purchase lots of wire-bonding tools to attach bare MMIC die. UMS is also looking to reduce costs by

continually seeking ways to reduce the size of devices through improved designs. This prompted Priestly to point out that, even with all of the effort put into reducing MMIC costs for high-frequency applications, Gunn diodes were still the device of choice for those now designing second-generation automotive radar products at 77 GHz. The reason behind this choice was the low price and robustness of the diodes. He also said that Marconi was expecting continued demand for its Gunn diodes as third-generation automotive radar systems are developed. Designers are looking to use deep-implant stacked Gunn diodes in the future. Priestly saw the future for this as being the integration of MMIC and discrete devices. This would combine the performance benefits of MMICs with the protection afforded by discretes against power surges that might damage the MMICs.

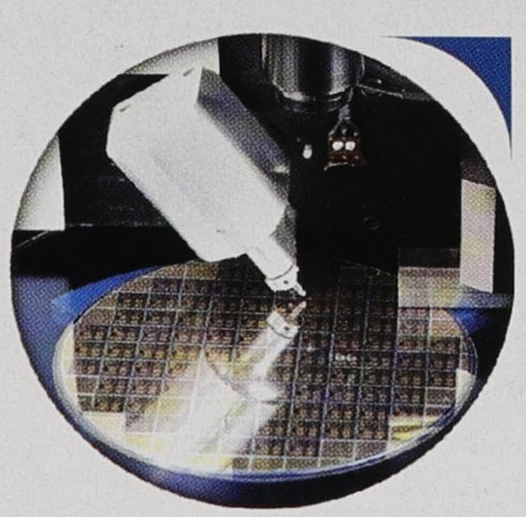
Fazal Ali of Nokia made a short contribution to suggest that, aside from the mobile handset market, GaAs will probably see limited applications below 5 GHz, having proved itself too expensive for the HyperLan and wireless LAN markets. Tom Hierl commented on the impact of the current recession on IQE's business, indicating that, while production orders have slowed down, many companies were maintaining their R&D efforts. Also, he said that customers were coming to IQE for epitaxy R&D rather than to make investments in their own capabilities during a severe market downturn.

Concerning the Motorola/IQE development of GaAs on large-area silicon substrates, the question was asked: where are the high volume markets that need large-area wafers? Silicon has plenty of very large-volume markets, such as DRAM, to make the move to 12 inch substrates a viable proposition. Daembkes said that although UMS would consider using GaAs-on-silicon substrates (provided that the GaAs material was of sufficient quality), it would only require 4 inch wafers to fit its current process lines, and perhaps 6 inch wafers in the future. He pointed out that the markets that UMS concentrates on are relatively low-volume ones at present, and that moving to 8 or 12 inch wafers would mean that the company's entire annual output could be processed on a small batch of wafers. The immense cost of tooling up to process these wafers would never be recouped.

Next year's GAAS Applications Symposium will be held on 23–24 September in Milan, Italy. Web www.eumw.com.

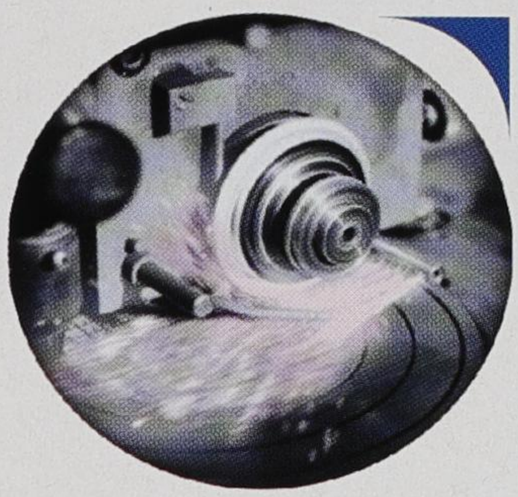
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MCT moves into the next generation of thermal imaging

MCT-based infrared systems dominate the high-performance thermal camera and sensor market. **Jon Newey** investigates current developments in material design, growth and manufacture.

The desire to be able to see in the dark or sense differences in temperature during the day or night for military purposes has been the main driver pushing thermal imaging technology. Though thermal cameras and sensors made from a variety of non-semiconducting materials are commonplace today, the highest-performance thermal imagers are used in military systems (and to a lesser degree in astronomy) and are fabricated from the II-VI semiconductor $Hg_{1-x}Cd_xTe$ (MCT). By tuning the value of x, it is possible to make MCT responsive across the infrared spectrum, especially in the windows of interest where infrared radiation is not absorbed by atmospheric gases. To obtain the highest performance, the devices must be cooled (usually to 77 K) to remove thermally generated background current, though advances in material technology and device design are pushing operating temperatures up.

Most of the devices in military systems are referred to as second-generation thermal imagers. These rely on small arrays (e.g. 4 × 288 pixels) that are scanned across a scene. The need for mechanical devices to scan the detector and the slow build-up of a thermal scene has required the development of a different kind of array. Large-area two-dimensional infrared focal-plane arrays (IRFPAs) stare at a scene, removing the need for mechanical scanning, which reduces power consumption and system size. MCT IRFPAs are now beginning to form the third generation of high-performance infrared imagers.

Most of the companies developing IRFPAs are large defense contractors, such as Rockwell and Raytheon. What follows is a look at the technologies that such companies are developing to increase the size and performance and decrease the cost of MCT IRFPAs.

The move to growth on silicon

The growth of MCT IRFPAs has largely been carried out on bulk CdZnTe (CZT) substrates using a CdTe buffer layer. This places a constraint on the maximum size of the FPA that can subsequently be fabricated because bulk CZT wafers are not available in large sizes, unlike other semiconductors such as silicon. This is one of the main reasons why the growth of MCT onto silicon wafers has become a hot topic of research and development. Array sizes are being pushed ever upwards by the demand for greater image resolution. Little progress seems to have been made in increasing CZT wafer areas above 30 cm^2 (4.7 $inch^2$), making the ability to grow MCT on other materials of prime importance.

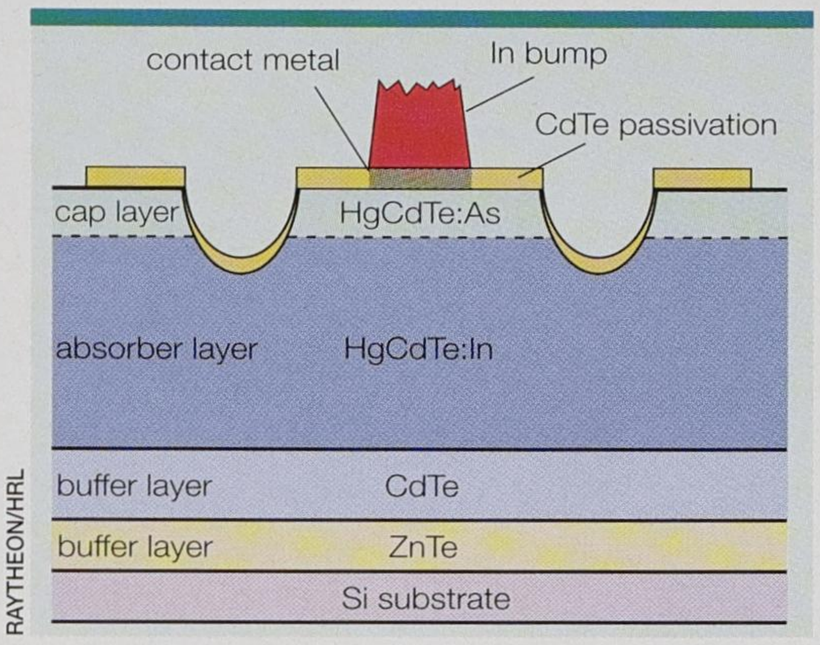


Fig. 1. Cross-section of an MCT/Si detector structure (after Varesi *et al.*).

Silicon seems the obvious choice for several reasons. Si wafers are readily and cheaply available in a range of diameters. Costs are driven down by using the cheaper material, but also the larger area means that more FPAs of a given size can be processed on a single wafer. A 4 inch Si wafer gives three times the area of a standard CZT substrate, and moving to 6 inch Si would give seven times the area. Si wafers with diameters at or above 4 inches are also compatible with standard semiconductor processing tools, as developed and used in the Si microelectronics industry, meaning that FPA production can be more easily scaled and automated. The use of Si offers another attraction. The processed FPA must be flip-chip-bonded to Si read-out circuitry. Growing the FPA on Si removes a source of thermal stress as the substrate and read-out circuitry have the same thermal properties.

Growth on Si has its problems. CZT has traditionally been used as a substrate because it provides a good lattice match to CdTe and MCT. The growth of MCT onto Si results in a large dislocation density because of the 19% lattice mismatch. Work to reduce this has focused on using thick CdTe/CZT buffers, allowing strain relaxation before MCT growth commences. State-of-the-art dislocation densities for MCT on Si are now around 10^6 /cm^2. This is still an order of magnitude more than that found when growing on CZT, but, despite this, MCT array performances have been on a par with those achieved through growth by MBE or LPE on CZT.

Currently, MCT growth on CZT substrates is done by liquid-phase epitaxy (LPE). This technique does not lend itself to growth on Si for a variety of reasons. The preparation of the Si substrate requires it to be heated to a high temperature in the reactor to desorb the surface oxide, leaving a clean Si surface that is highly reactive. Unlike MBE, LPE is not a UHV technique making it relatively "unclean". The reactive, oxide-free Si surface will be exposed to impurities that will affect subsequent epitaxial growth. Detector structures are also becoming more complicated, requiring the increased use of thinner layers to improve array performance and flexibility. LPE is not suited to the growth of such layers.

Current state of growth on silicon

A group from Raytheon Infrared Operations and HRL Laboratories (Varesi *et al.*) has reported work on large-format MWIR FPAs fabricated from MCT grown by MBE on 4 inch Si substrates. The defect etch pit density of the MCT was 1–7 × 10^6/cm^2, with fewer than 1000 voids per square centimeter. The variation in x value from the center of the wafer to the edge was found to be 1–4%. Although an order of magnitude more than

LPE growth on CZT, this defect density was found to be acceptable for high-performance mid-wave infrared (MWIR) device fabrication. The structure used was based on standard LPE-grown structures with a ZnTe/CdTe buffer layer to prevent defects propagating into the active region (figure 1).

128 × 128 pixel arrays were fabricated, each pixel being 40 × 40 μm. Cd x values were varied in different growth runs from 0.23 to 0.3 to give a MWIR cut-off from 4.8 to 6.4 μm at 140 K. Spectral response curves were found to have a typical shape, regardless of cut-off wavelength, giving a uniform response across wavelengths below the cut-off point. Quantum efficiency, measured at 140 K at 4.0 μm for an active layer with an x value 0.3, was found to be 69%. The maximum reported value for MCT on CZT is 79%. It is thought to be lower on Si because Si reflects a larger portion of the incident MWIR radiation than CZT. Though 1/f noise was found to be higher than in LPE material as a result of higher defect density, the observed 1/f noise is not the dominant contributor to overall FPA noise and so is not having a large detrimental effect on the array performance.

Overall FPA performance was tested on both 128 × 128 and 640 × 480 (20 μm unit cell) arrays and compared with arrays fabricated in InSb MWIR detector technology. Despite operation at higher temperatures and without an antireflection coating, the MCT/Si arrays gave comparable performance.

Buffer layers for growth on silicon

Efforts to reduce the dislocation density in MCT grown on Si are concentrated on the all-important buffer layer. Scientists at Army Research Laboratories and the Night Vision and Electronic Systems Directorate (NVESD) are claiming significant progress in this area through a systematic study of buffer layer growth parameters (Almeida *et al.*).

Growth by MBE on Si is typically done by growing a thin ZnTe layer followed by a thin CdTe layer and annealing at about 380°C under a Te_2 flux. CZT growth then proceeds by introducing a flux from a ZnTe cell to the flux from the CdTe cell. This produces surfaces with faceted pit defects with a density of 10^5–10^7 /cm^2, which become replicated in the subsequent MCT layer. It was found that lowering the growth temperature and raising the CdTe flux reduced the defect density, which points to the faceted pit formation being the result of excessive evaporation from the CZT surface at elevated temperatures.

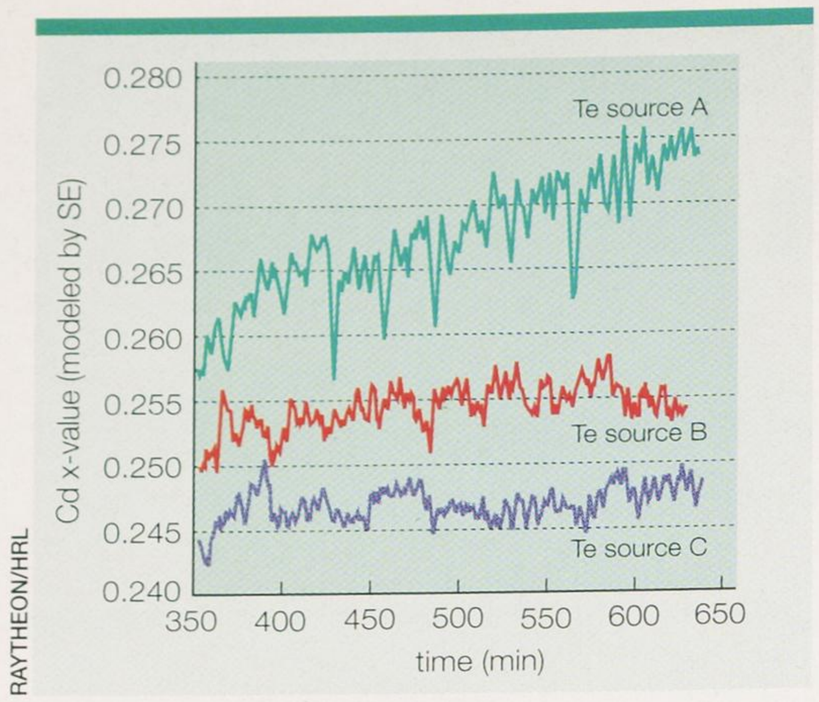


Fig. 2. Variation in cadmium x value, measured by SE, for different tellurium source designs (after Maranowski *et al.*).

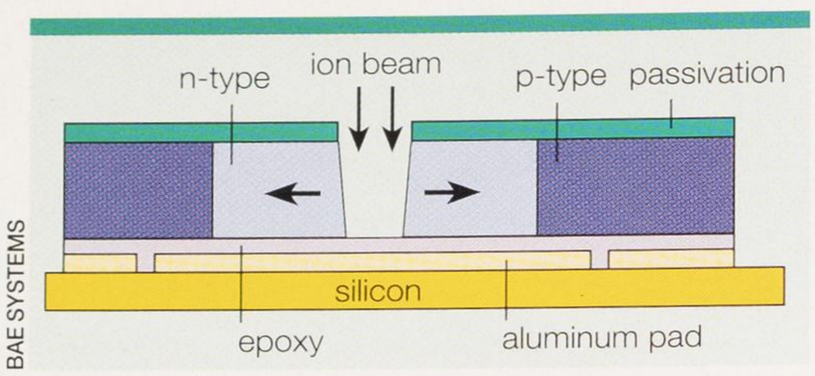


Fig. 3. Ion-beam milling simultaneously forms the via holes and p-n junctions (after Baker *et al.*).

Optimization of the growth rate and temperature gave pit densities lower than 200 /cm^2. A growth rate of about 1 μm/h and temperature less than 290°C were required to maintain good morphology. Crystalline quality was improved by using a cyclical thermal anneal. Because of the high temperature involved (about 380°C), a Te_2 overpressure of 2×10^{-6} mbar was used to suppress the formation of pits by evaporation of the CZT. Using this anneal reduced the pit density from $1–3 \times 10^7$/cm^2 to $2–8 \times 10^6$/cm^2 for a buffer layer 12 μm thick. The lowest density observed was 8×10^5/cm^2 for a 20 μm buffer.

MBE growth

A second group from Raytheon Infrared Operations and HRL Laboratories (Maranowski *et al.*) reported the first growth of a p-on-n MCT detector structure on a 4 inch Si substrate. To date, much of the work has concentrated on 3 inch substrates. As the need to reduce costs and increase array sizes drives the move to 4 inch substrates, a move to larger MBE reactors is also necessary. A thorough understanding of how growth parameters affect uniformity and defect density is critical to the further scaling of MBE to accommodate larger substrates.

The group has investigated this in the course of refining its p-on-n structure. The buffer was formed by depositing 1 μm of ZnTe (to preserve substrate orientation before CdTe deposition) followed by a 6–9 μm CdTe layer. The MCT junction layers are grown on the buffer and consist of a 10 μm MCT:In n-type layer, followed by a 2 μm MCT:As n-type layer. The value of x for all layers grown was 0.3 to give detection in the MWIR region. When growing this structure over a 4 inch diameter area, void defects increased in size and number towards the wafer edge. This was linked to insufficient Hg coverage at the wafer edge, so the void number was lowered simply by increasing Hg flux from the liquid source during growth. Defect etch pit density across the wafer was comparable with state-of-the-art values for growth on 3 inch Si.

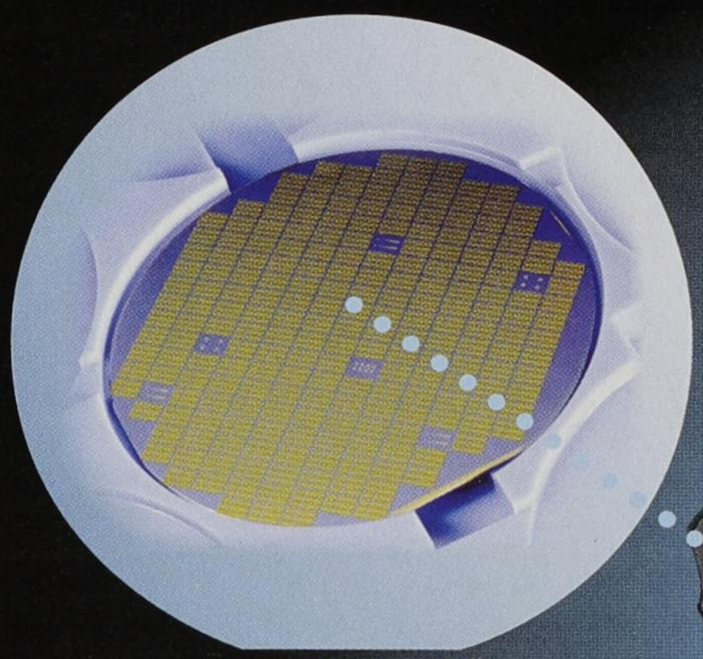
The study also showed how the Te cell design impacts the stability of the value of x with both layer thickness and distance from the wafer center. Three Te source configurations were used to grow MCT layers, keeping the CdTe cell the same in each instance. Spectroscopic ellipsometry (SE) was used to monitor the Cd x value as layer growth progressed (figure 2). Cell designs B and C gave uniform x-values with time (i.e. thickness), with cell A giving a drift in x of about 0.015 over around 11 hours. *Ex situ* FTIR measurements of the MWIR layers grown with the different cell designs showed the variation in x-value from the wafer center to the edge. While cells B and C gave uniform x-values with depth, only cell C gave good spatial uniformity also. This shows that MBE source design is crucial to gaining long- and short-term flux stability as well as spatial uniformity. By optimizing Te source design, the x value uniformity on 4 inch substrates was comparable to that from 3 inch substrates.

Loophole technology

BAE Systems Infrared, UK, has a different approach to two-dimensional MCT arrays from those that have been described so far (Baker *et al.*). It uses a via hole technology (called loophole technology by the company) as opposed to indium bump bonding for diode read-out. The drivers for developing this approach were noise reduction and the minimization of defective elements. The MCT is grown by LPE on CZT substrates. The loophole process differs because the substrate is removed to allow front surface illumination, which means, therefore, that infrared transmission through the substrate and the

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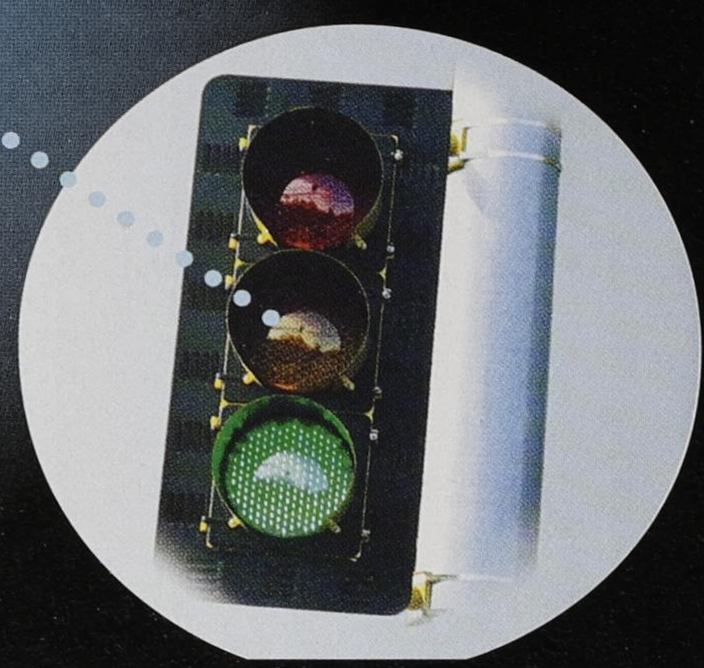




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A guide to the main players in the thermal imaging industry

It is not just military technology that is constantly changing. Throughout its history, the defense industry has been evolving, with divestments and mergers seeing business units pass from one contractor to another and some companies disappearing altogether. Here is a brief guide to the situation today among the key players in the infrared imaging business.

Raytheon
In July 1997 Raytheon bought Texas Instruments' defense electronics business, which became Raytheon TI Systems. In December 1997 it merged with Hughes Aircraft Company. The authorities deemed the company to be too powerful and anti-trust legislation led to the sale of the IRFPA business (acquired through TI) to DRS Technologies. The company was allowed to keep the IRFPA activity acquired through the merger with Hughes. Raytheon Infra Red Operations is based in Goleta, CA. The anti-trust legislation also meant selling the GaAs MMIC capability (acquired through TI) to TriQuint.

HRL Laboratories
Hughes was bought by General Motors in 1985. Hughes Research Laboratories became jointly owned by Hughes Electronics and Raytheon in 1997. In January 2000 Boeing acquired Hughes' space communications business, so now Boeing, General Motors and Raytheon own HRL jointly. HRL Laboratories is in Malibu, CA.

Rockwell Scientific
Previously known as Rockwell Science Center, Rockwell Scientific has a long history in infrared imaging. Rockwell sold its aerospace and defense unit to Boeing in 1996. Boeing remains a customer of Rockwell Scientific's services. Rockwell is based in Thousand Oaks, CA, and plans to open a new R&D and manufacturing facility in Camarillo in 2001.

BAE Systems Infrared and Lockheed Martin
BAE Systems came into existence in 1999 when British Aerospace (BAE) purchased the defense electronics division of GEC Marconi. This included GEC Marconi Infrared in Southampton, UK, which was renamed BAE Systems Infrared Limited. Lockheed Martin acquired Sanders in 1996 and formed Lockheed Martin Aerospace Electronic Systems. This was sold to BAE Systems in 2000, giving BAE Systems a variety of new activities in defense electronics, including the infrared imaging business based in Lexington, MA. Lockheed Martin retains activity in infrared sensing through its Missiles and Fire Control division.

DRS Infrared Technologies
DRS Technologies, Texas, acquired Raytheon TI Systems' IRFPA business in 1998 (see Raytheon, left). DRS has recently signed an agreement to acquire the Sensors and Electronic Systems business of Boeing, based in Aneheim, CA. This appears to be part of a move by Boeing away from components and modules to enable it to concentrate on complete systems surveillance and targeting.

quality of the substrate/MCT interface are not issues. Effort can instead be concentrated on producing a very-high-quality MCT region in the center of the wafer. Thermal mismatch between the MCT and silicon read-out circuitry is dealt with by bonding a thin (typically 9 μm) MCT monolith to the silicon circuitry, with the strain arising from thermal expansion is taken up elastically.

One photolithography stage is used to define the mask through which the via holes are etched. This is done by ion beam lithography to expose the aluminum contact pads on the Si read-out circuit beneath. The device is coated with metal and the photoresist removed to leave metal only in the via holes to form a contact between the MCT and aluminum circuit contact below. The process of ion beam milling also crates a junction around the via hole by converting the p-type MCT to n-type by injecting Hg atoms into the lattice, thereby eliminating acceptor-like Hg vacancies (figure 3). A disordered n^+ layer 0.5–1.0 μm thick is created with an n-type doping region that decreases exponentially away from the surface for 2–3 μm.

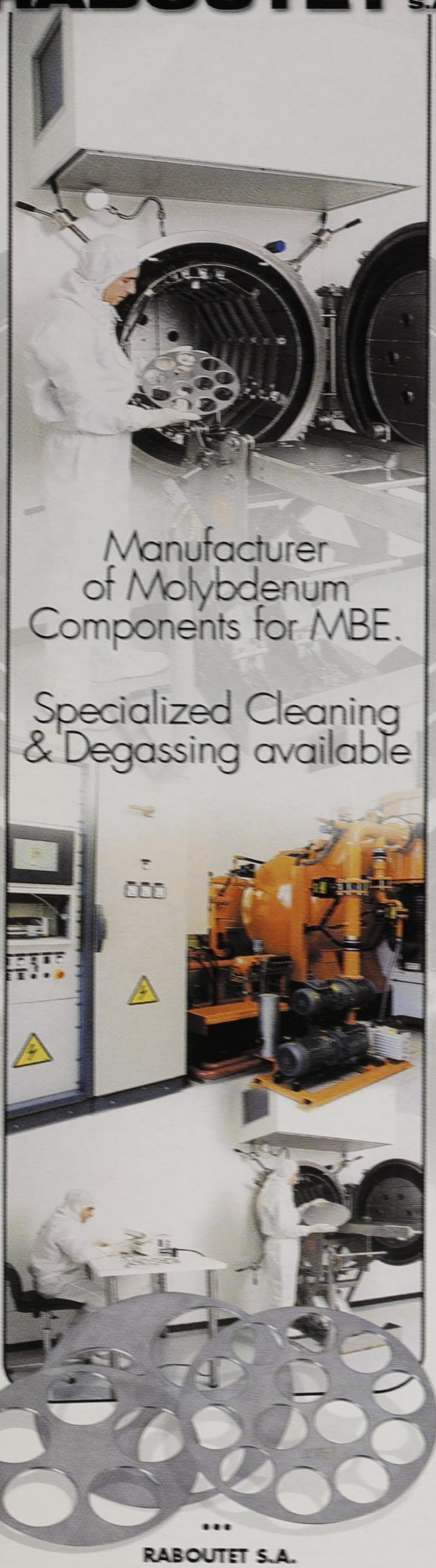
Two-color detection

The ability to detect in multispectral bands using the same pixel array enables more information to be rapidly extracted from a scene. For example, objects of interest can be better distinguished by subtracting background clutter or sun glare. The effective signal-to-noise ratio of a two-color IRFPA is far superior to a single-color array. A research group led by Rockwell Scientific and Boeing Electronic Systems and Missile Defense has adapted a single-color pixel design to give a two-color device (Tennant *et al.*). The design is based on Rockwell and Boeing's simultaneous unipolar multispectral integrated technology (SUMIT) architecture.

SUMIT is an extension of Rockwell's double-layer planar heterostructure (DLPH) architecture. Both DLPH and SUMIT structures are shown in figure 4. The SUMIT approach retains the DLPH MBE-grown n-type MCT:In absorber layer with the wider bandgap cap layer, an arsenic implanted p-type region, a passivation layer and a metal contact. The two-color SUMIT extends the DLPH architecture by adding an extra absorber layer for the second color of interest. The shorter wavelength (band 1) absorber is grown first on the substrate, followed by the longer-wavelength band 2 absorber. A wide-bandgap barrier layer is grown between them to prevent carrier diffusion from one band to the other. A thin wide-bandgap capping layer is used to reduce surface recombination.

As in the DLPH process, arsenic implantation forms the p-type doped regions. However, to implant into the band 1 layer, it must first be exposed through the band 2 layer by wet chemical etching. A second etch step (dry etching) is required to isolate the pixels, because the lateral diffusion lengths of the carriers are larger than the pixel pitch for MWIR detectors. Metal contacts are made to the diodes and indium bumps deposited for bonding to the Si read-out circuitry. The SUMIT design gives each pixel two independent p-on-n diodes, making signal read-out a simple extension of the single-color design. Band 1 and 2 signals can be integrated and processed simultaneously, making the analysis of a thermal scene rapid – crucial in military threat warning systems.

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Two-color MWIR/MWIR 128 × 128 arrays of 40 μm pitch have been fabricated using the SUMIT approach. The performance reported is comparable to that of single-color detectors and it is expected that the SUMIT approach will also work in other spectral regions, such as in MWIR/LWIR detectors. The challenge for SUMIT lies not in accessing different spectral regions or moving to three-color detection, but in moving the process to larger array sizes with smaller pixel formats.

Volume manufacturing

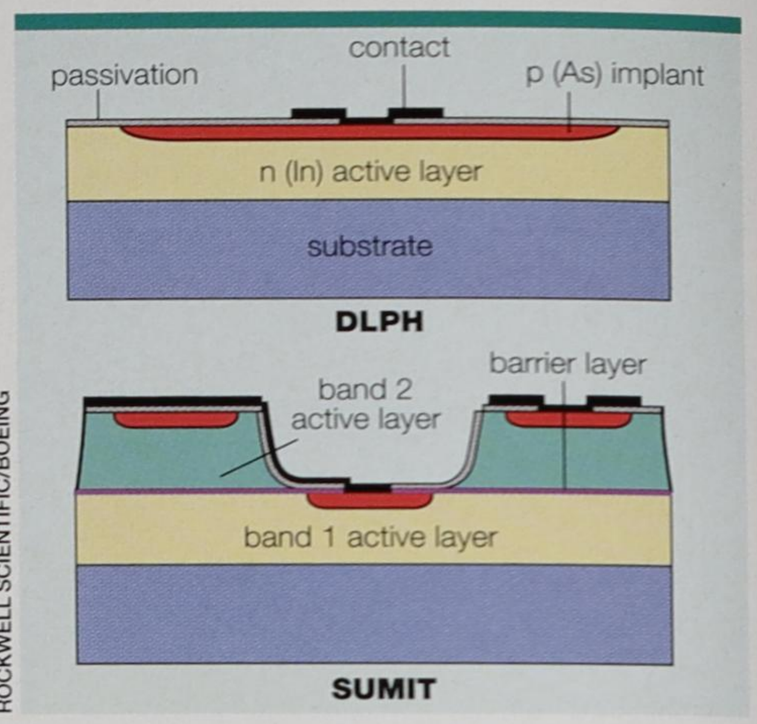
To get devices from the development stage into fieldable systems requires a move to volume manufacturing (Tribolet *et al.*). MCT has proved problematic over the years because of difficulties in achieving reproducible device performance. One organization that has set about doing this is Sofradir (Chatenay-Malabry, France). By increasing the wafer size, device yield, equipment capacity and process speed, Sofradir has seen capacity rise exponentially over 10 years, with more than 250 IRFPAs made per month.

IRFPA production at Sofradir is based on MCT grown by LPE on CZT substrates. This is the most mature technology and so far it yields the best-quality material and the best device performance. Using a high-quality 46 × 46 mm^2 CZT substrate and a well controlled LPE process, a variation in cut-off wavelength of less than 0.15 μm at 300 K is achieved for material designed to give a cut-off at 10.3 μm. Material quality (both substrate and epilayer) is the key to high device yields, reproducibility and cost-effective production.

Though Sofradir and its partners are working on other growth technologies, it sees its LPE on CZT method as a benchmark. The company's planar process for manufacturing the photovoltaic diodes also contributes to the achievement of high array and pixel yields. The process does not involve complicated mesa etching because diode junctions are formed by ion implantation, giving well defined pixels. The pixel yield per wafer was monitored over a five year period for 10–10.5 μm spectral cut-off MCT, and the average was found to be more than 95% with no wafer falling below 90%. Each production step is continuously monitored to detect any deterioration and instigate corrective action or improvements.

Beyond the military

The applications for MCT-based arrays have to date been almost entirely military. As with other technologies, the military will accept higher costs in exchange for performance benefits. In most civil applications for thermal imaging and sensing, this rationale does not apply. There is no doubt that the commercial demand for infrared imaging and detection is strong, but it is being adequately met by the relatively cheap uncooled lower-performance systems. There are some niches outside the military where this is not the case. The world's largest MCT arrays (2048 × 2048 pixels) were developed by Rockwell Scientific for infrared deep-space astronomy (*Compound Semiconductor* March 2000, p12). However, an example such as this is very rare and represents a small market, even when compared with sales to the military. Developments in MCT device design will undoubtedly push operating temperatures towards ambient in the coming years and in doing so provide better performance than current uncooled technologies. The possible uptake of MCT-based systems by larger volume, non-military applications would also mean higher manufacturing throughput, thereby effectively lowering production costs and helping MCT arrays to compete on cost as well as performance.



ROCKWELL SCIENTIFIC/BOEING

Fig. 4. Single color (DLPH) and two color (SUMIT) structures. The band 2 implanted area is a concentric ring around the band 1 contact depression (after Tennant *et al.*)

Further reading

Almeida *et al.* 2000 "Special Issue on the 2000 Workshop on the Physics and Chemistry of II-VI Materials" *J. Elec. Mater.* **30(6)** 608.
Baker *et al.* 2000 *ibid.* 682.
Maranowski *et al.* 2000 *ibid.* 619.
Tennant *et al.* 2000 *ibid.* 590.
Tribolet *et al.* 2000 *ibid.* 574.
Varesi *et al.* 2000 *ibid.* 566.

CONTENTS

High-volume AlInGaN LED manufacturing at AXT p59
Nitronex describes growth of nitrides on silicon p63
Cornell's recent progress in high-power devices p69
Nitrides materials research at Boston University p73

High-volume production of AlInGaN-based LEDs

A number of challenges need to be overcome before AlInGaN-based LED production becomes a truly high-volume, low-cost process, write **Heng Liu and colleagues** from AXT's LED Division.

High-efficiency AlInGaN-based LEDs are becoming increasingly important due to the wide wavelength range offered by this material system. Although the bandgap of the AlInGaN system can address applications from the deep UV to the whole visible spectrum, the current useful range is between 380 and 540 nm. Blue, green and white LEDs are used in a variety of applications including indoor/outdoor full-color video displays, traffic management signage, auto interior lighting, and backlights for cell phone and personal digital assistants. The development of backlights for PC monitors is also under investigation, and UV LEDs have recently been drawing a great deal of attention due to their potential for applications in biological sensing, counterfeit detection, dental curing and white-light generation by down-conversion etc.

During the last seven years the market for AlInGaN-based LEDs has grown from almost zero to about $600 million in 2000. It is predicted that the market will grow at a compound annual growth rate of about 20% until the end of the decade (Strategies Unlimited). However, this forecast does not take into account the general lighting market as it is expected that LEDs will not be able to compete with conventional lighting until the next decade due to cost and performance. General lighting is considered the holy grail of the high-brightness LED industry since it represents a much larger market size of many billions of dollars. With such tremendous market opportunity in both the near and long terms, a huge investment has been made in building up the manufacturing capacity for these devices.

Compared to other existing LED growth technologies such as LPE, VPE of GaP-based LEDs, and MOCVD of AlInGaP-based LEDs, the nitride LED manufacturing process is much less mature and the cost of making blue and green LEDs is much higher. As with any other technology in the early stages of its evolution, there are issues which need to be addressed before cost-effective manufacturing can be realized.

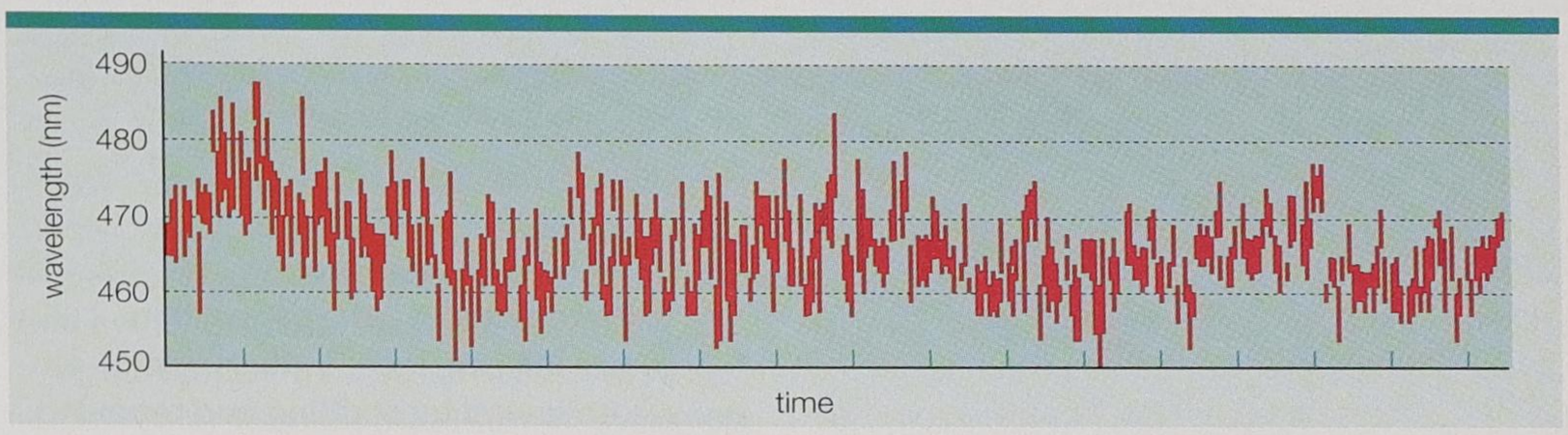


Fig. 1. Wavelength uniformity across a wafer and reproducibility over a three-month production period for AlInGaN-based LEDs. The target wavelength is 470 nm.

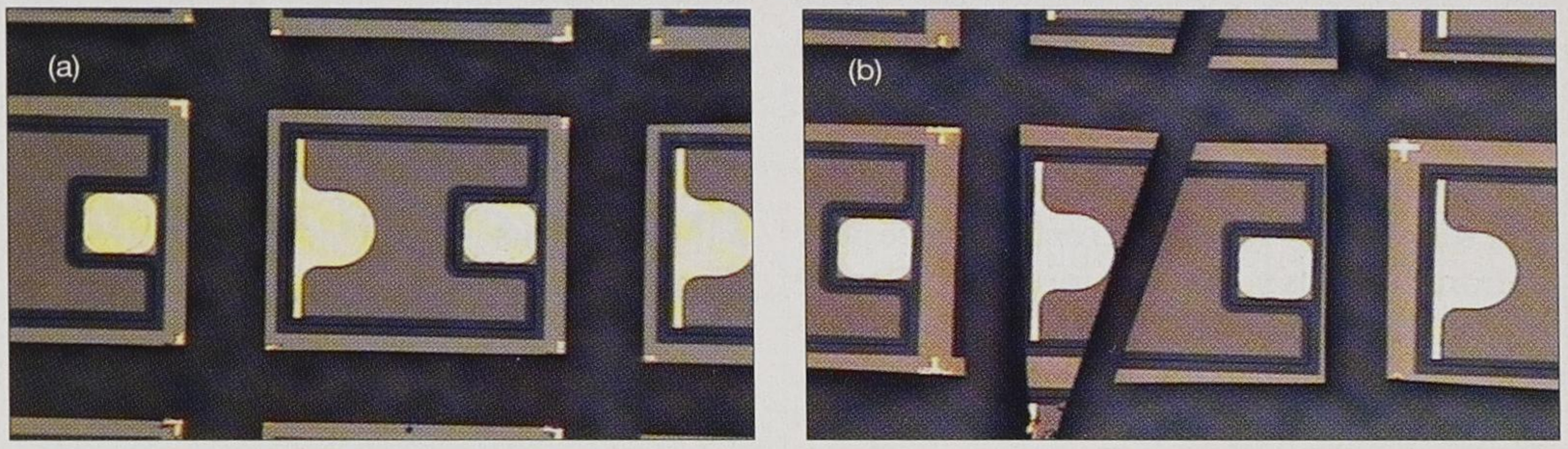


Fig. 2. Typical die fabricated using a scribe-and-break technique. Figure (a) shows a good die, and figure (b) shows an unwanted breakage.

Manufacturing issues

LEDs are a so-called penny business. Conventional LEDs sell at sub-penny levels per packaged lamp, high-end AlInGaN-based LEDs can sell at more than 50 cents. Compared to laser diodes, which usually sell in the few dollars range, LEDs are much more cost-sensitive components to fabricate. The overall yield for conventional types of LEDs (e.g. AlGaAs-based) is normally better than 80%, and the throughput in the manufacturing process is much greater than those utilizing MOCVD processes. In recent years, however, high-throughput MOCVD reactors (more than 35 × 2 inch wafers per run) for the production of AlInGaP-based high-brightness LEDs (HB-LEDs) are gaining acceptance in the industry. It took about a decade for the low-cost manufacturing process to be developed for AlInGaP-based HB-LEDs. Many of the challenges that have been resolved are

related to MOCVD processes such as epilayer structure, uniformity and defect control. Nevertheless, the production of AlInGaP-based HB-LEDs is still more expensive than that of conventional devices.

The general consensus is that AlInGaN-based LEDs will follow a similar evolutionary path to that of AlInGaP-based HB-LEDs. One example of this is that since the introduction of AlInGaN-based HB-LEDs in 1994 by Nichia, the production MOCVD process has evolved from using single wafers to being a multi-wafer batch process. Whether this analogy will continue in the next few years, however, will depend on how some specific issues are resolved. In our view, there are two major issues specific to the AlInGaN material system that have a major impact on the manufacturing cost. One is the color uniformity control in the MOCVD process, and the other is the dicing of AlInGaN-on-sapphire wafers, which is much harder than the dicing of AlInGaP-on-GaAs wafers.

The manufacturing of AlInGaN-based LED chips involves three steps: MOCVD growth, wafer fabrication and die separation. The level of LED chip performance and consistency is usually dictated by the applications in which the devices are used. For example, in outdoor full-color video LED displays, both brightness and uniformity are important characteristics in achieving good picture quality. The required color uniformity is very tight, roughly 5 nm for blue and 2 nm for green. This is a challenge for low-cost manufacturing due to the fact that current MOCVD processes can only achieve poor uniformity. This is also true for cyan LEDs for traffic lights, and blue LEDs for phosphor down-conversion to create white light.

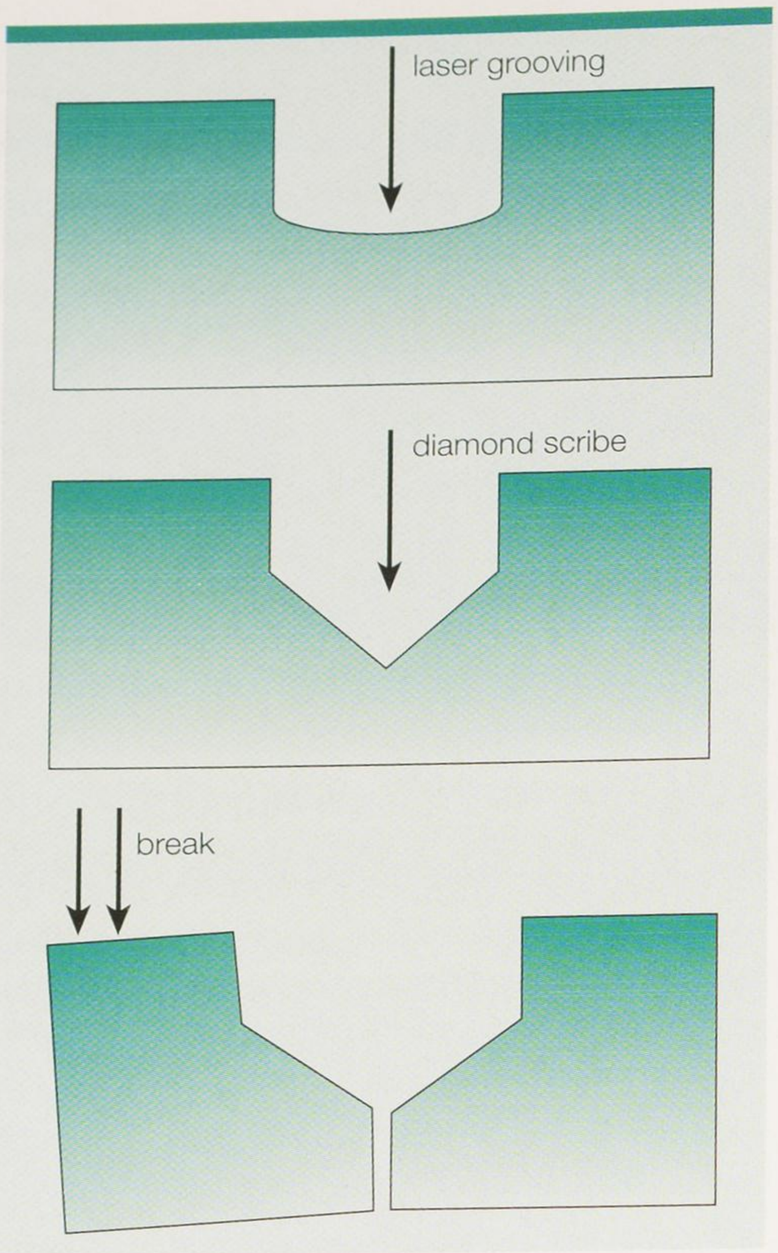


Fig. 3. Schematic of a die separation technique utilizing laser cutting to etch a groove, followed by scribing and breaking.

There are two major issues specific to the AlInGaN material system that have a major impact on the manufacturing cost. One is the color uniformity control in the MOCVD process, and the other is the dicing of AlInGaN-on-sapphire wafers.

MOCVD epitaxial process uniformity

In the growth of AlInGaN thin films on sapphire by MOCVD, ammonia (NH_3) is the most commonly used nitrogen source. Due to the low decomposition efficiency of NH_3 at growth temperatures, the required partial pressure of NH_3 in the reaction chamber is much higher than that required for AsH_3 or PH_3 during the growth of As- or P-based compounds. The required NH_3 flow rate is therefore so high that the gas properties of NH_3 have to be considered in the overall flow dynamics during the growth process. This is not the case for processes using AsH_3 or PH_3, in which the concentration of hydride is much lower, and where the overall flow dynamics are determined solely by the property of the main carrier gas, such as hydrogen or nitrogen. Since NH_3 is a relatively viscous gas, it is difficult to maintain a good laminar flow. Usually a very high total flow rate and a small reactor geometry are used. One example is the two-flow reactor developed by Nichia (Nakamura *et al.*). On the other hand, to achieve good uniformity in a large area, a low growth pressure has to be used to avoid the need for unrealistically high gas flow rates. However, as mentioned previously in the MOCVD growth of AlInGaN compounds, a large NH_3 partial pressure is required due to the low decomposition efficiency of NH_3. The total growth pressure therefore cannot be too low in order to maintain sufficient NH_3 partial pressure, and this in turn requires a trade-off for the flow dynamics, a low-pressure condition to achieve a high degree of laminar flow. Figure 1 shows a trend chart of color uniformity for a production period of three months; samples were grown in a multi-wafer commercial reactor. The target wavelength is 470 nm. Each bar represents the variation within a wafer and is about 10 nm. We also calculated the variation of the average wavelength from each wafer, which was about 15 nm. This means the overall maximum variation could be as high as 25 nm.

Compared to the MOCVD production of AlInGaP-based LEDs, the wavelength control in this case is much worse. Aside from flow dynamics, it is believed that the other cause of variation is indium segregation (Narukawa *et al.*). The mechanism is even more severe at longer wavelengths as more indium is required. How the process parameters in the MOCVD process correlate to the indium segregation mechanism is not clear. However, we do know that temperature and pressure are usually critical factors in determining the chemistry and kinetics of the indium complex on the surface. More research is needed to further understand the mechanism and to develop engineering techniques to control this segregation process.

Die separation

The second issue in manufacturing AlInGaN-based LEDs is the difficulty of die separation. Usually a scribe-and-break technique is used for this process, but the scribing tool does not last long because of the hardness of the sapphire, and therefore the cost of the dicing tool is high. It is also very difficult to cleave perpendicular facets in order to make rectangular die; if one scribe is on a cleavage plane, the other would not be, due to the six-fold symmetry of the sapphire crystal. A typical die fabricated using this approach is shown in figure 2a. As it is hard to control how the wafer breaks the non-cleaved direction, unwanted breakages happen and many die could be destroyed, resulting in yield loss. A typical broken die is shown in figure 2b.

One of the ways to address this problem is to use laser cutting, a commonly used technique in many cutting applications due to its versatility, reproducibility and cleanliness. In the case of sapphire, the advantage of using laser cutting is that the direction of the cutting does not depend on the cleaved planes. One of the laser cutting processes for this specific

use is depicted in figure 3. After the laser sputters a groove into the substrate, a diamond scribe is used inside the groove. The wafer is finally separated by applying pressure on one side of the cut groove. An experimental piece of LED wafer with a device pattern and two laser-cut grooves is shown in figure 4. The width of the groove is much smaller than the street size (i.e. the width between devices), indicating the feasibility of the technique. The depth of the groove is about 14 μm.

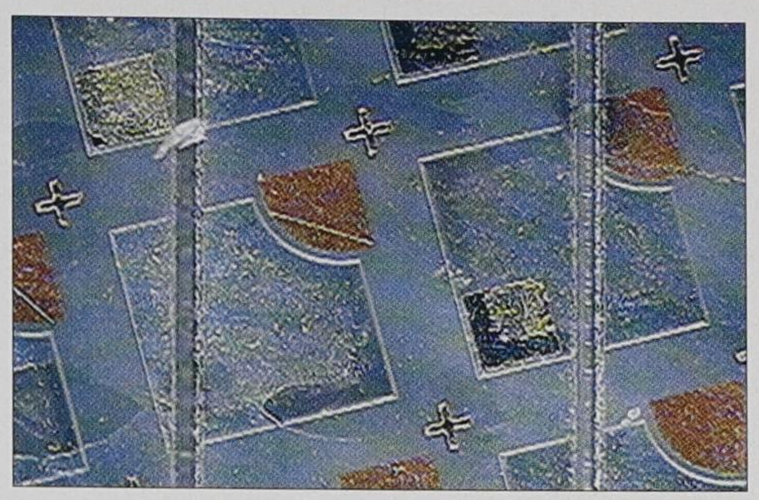


Fig. 4. An example of laser cutting of a nitride epitaxial layer on sapphire. The width of the groove is much smaller than the width between devices.

Other issues

There are of course other issues facing the high-volume production of AlInGaN-based LEDs. These may not have as much impact as the two previously mentioned issues, but their collective effect is also significant. Compared with conventional GaAs-based or AlInGaP-based LEDs, which are vertical devices with n- and p-electrodes on opposite sides of the wafer, the fabrication process for AlInGaN-on-sapphire LEDs is much more complex. Because sapphire is insulating, both n- and p-electrodes have to be made on the same side of the wafers, and mesa etching is therefore required. Also, in order to prevent shorting during the wire-bonding step in the lamp packaging process, a passivation layer is usually preferred. Because more steps are involved, the yield is generally lower.

Furthermore, there are more possibilities for the process to deviate. Usually the first step after the die are made is to perform visual inspection to screen the visually bad die. The second step is die sorting which requires 100% testing. In a high-volume environment the number of die produced per day is at the level of tens of millions, and 100% testing is very time consuming. In order to improve this shortcoming, automated machinery can be employed for both visual inspection and die sorting. Unfortunately, the capability of current visual inspection systems is not sufficient to identify the complex variety of defects in die; these include bond-pad peeling, scratching, broken passivation, contamination and badly cut or broken die. Because of the current lack of suitable equipment, production has to rely on a massive amount of manual labor to separate good and bad die. This adds to the cost, and throughput is also limited. It is clear that more development is needed to obtain the right manufacturing tools to address these issues.

Summary

There are several important issues in the manufacturing of AlInGaN-based high-brightness LEDs. Wavelength control during MOCVD epitaxial growth is the most challenging for cost-effective production. The causes of the wavelength variation in MOCVD need to be explored further, in particular by the tool manufacturers. Furthermore, the throughput of MOCVD tools currently available for AlInGaN-based LED production is limited. Larger reactors need to be developed in the near future in order to speed up the cost reduction cycle. In die fabrication, new tools need to be developed to address effective die separation, visual inspection and sorting processes.

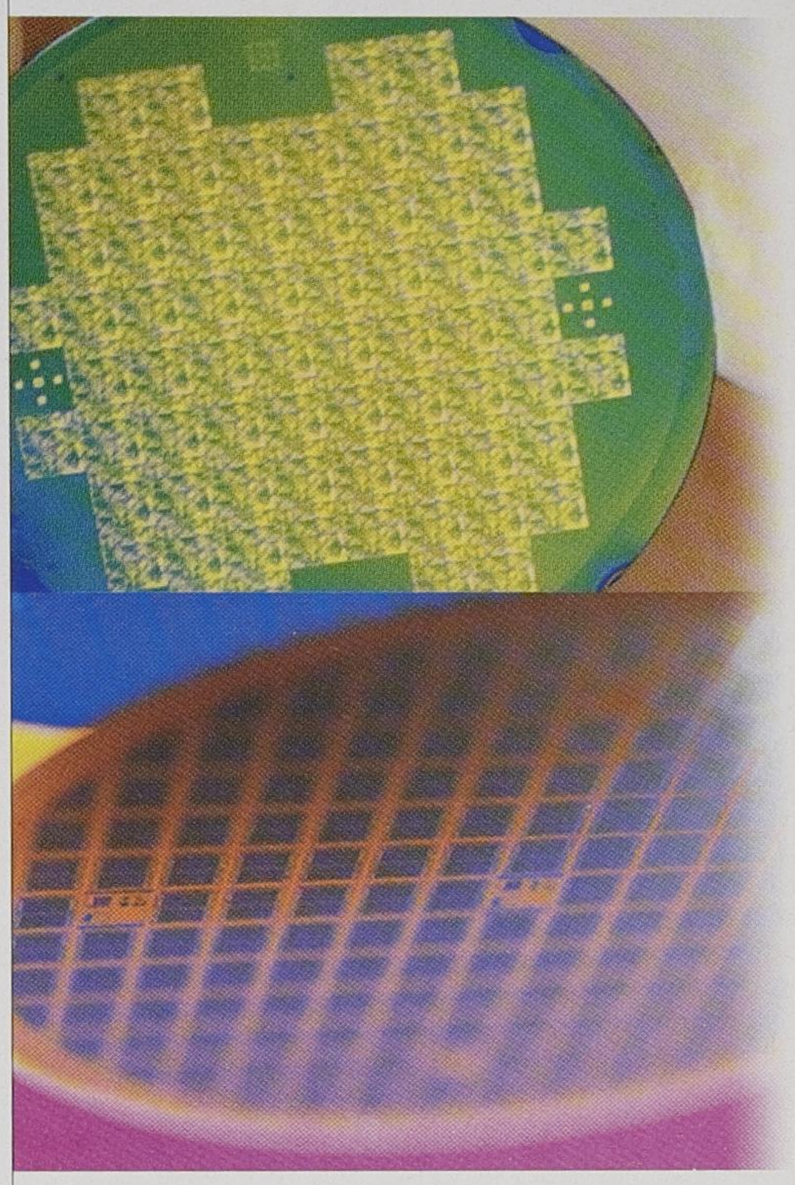
In addition, we have not mentioned the reliability aspects of AlInGaN-based LEDs, a vital area which needs further improvement. The soft reverse breakdown characteristics of AlInGaN-based LEDs results in higher leakage current compared with conventional GaAs-based LEDs. This introduces some limitation in the circuit design where sophisticated control systems are required. Due to the insulating nature of the sapphire substrate, and the defects within the GaN material, the AlInGaN-based LEDs are sensitive to electrostatic discharge. The details of the failure mechanism are not yet fully understood. With these material issues in mind, it is obvious that more research is needed to study the fundamental characteristics surrounding this material system.

Further reading

Strategies Unlimited, May 2000, Report SC-23 *Gallium Nitride 2000 – Technology Status, Applications, and Market Forecasts*.
S Nakamura *et al.* 1991 *Appl. Phys. Lett.* **58(18)** 2021.
Y Narukawa *et al.* 1997 *Phys. Rev. B* **55** 1938.

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Silicon substrates provide a disruptive technology for GaN

Substrates for gallium nitride growth are generally small, expensive and difficult to work with, but GaN-on-silicon offers a viable alternative, according to **Warren Weeks** and **Ricardo Borges**.

Performance advantages and cost benefits are the driving forces behind the adoption of any newly maturing technology. Although the performance benefits of gallium nitride are well documented, the manufacturability and cost benefits of GaN are less certain. GaN-on-silicon is an enabling, disruptive technology that addresses both issues and could help accelerate the acceptance of GaN for microelectronic and optoelectronic applications.

Since the 1960s, III-V nitride researchers have attempted to advance GaN technology from university and government laboratories to commercial production lines. Researchers were partially successful during the 1990s through significant advances in the sophistication of growth techniques, source purity improvements, and controlled introduction and activation of selected dopants – all of which fuelled the rapid commercialization of GaN-based LEDs.

Researchers have also sought to capitalize on characteristics that are unique to III-V nitrides, including their considerable physical hardness, good thermal conductivity, direct wide bandgaps and high melting temperatures. Along with such exceptional semiconductor characteristics, these materials also possess large saturated electron drift velocities, high junction temperatures, large band discontinuities and breakdown fields, and advantageous piezoelectric behavior. Together, these properties form the basis behind the long awaited promise of high-power, high-frequency and high-temperature microelectronics and blue, green and ultraviolet optoelectronic devices.

The major roadblock in the development of technology based on the III-V nitrides, particularly GaN-based devices, has been the lack of indigenous substrates on which to grow device-quality epitaxial films. This scarcity results in the high per-unit costs associated with custom manufacturing of small wafers, thereby continuing to inhibit the true commercialization of GaN technology.

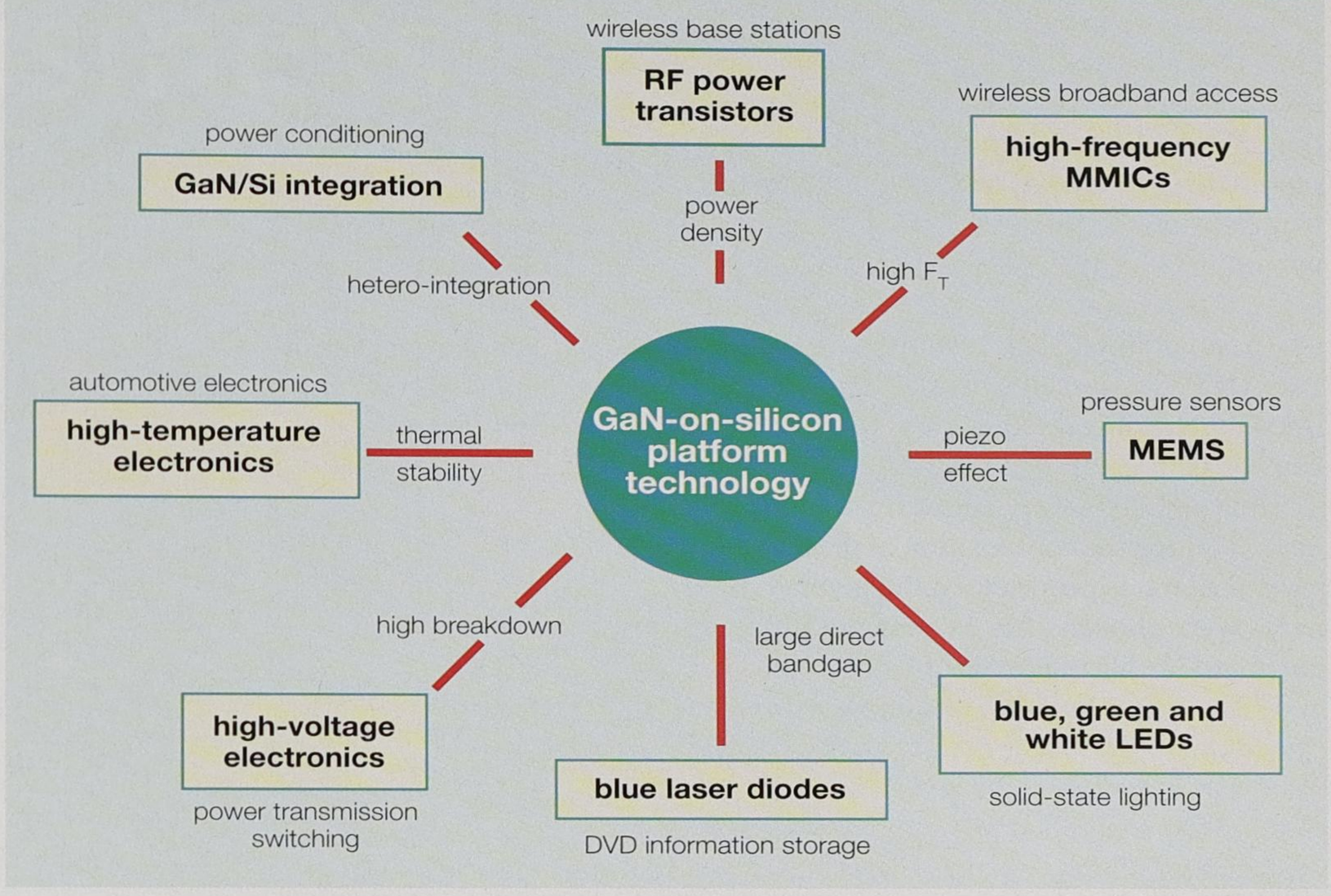


Fig. 1. GaN-on-silicon platform technology offers a broad range of applications, including microelectronic and optoelectronic products, optical sensors and high-voltage rectifiers.

GaN-on-silicon is a disruptive platform that enables a major technological shift. As a wide bandgap semiconductor platform, GaN-on-silicon offers a broad range of product applications. Some of these are shown in figure 1 and include opportunities in optoelectronics, microwave and millimeter-wave high-power electronics, optical and mechanical sensors, high-temperature and radiation-tolerant electronics, and high-voltage rectifiers.

Materials issues

Impeded by the absence of commercially viable "bulk" GaN boules, efforts have focused on methods that allow the use of substrates with significant mismatches in lattice parameters and thermal expansion coefficients (TECs) for heteroepitaxial growth of this and other III-V nitrides (table 1). Currently, the two substrates most commonly employed for GaN growth are sapphire and silicon carbide.

Although both of these substrates are readily available in 50 mm diameters, substrates with much larger diameters ($\geq$ 100 mm) are needed to enable and promote the high-volume commercialization of GaN, particularly for microelectronic applications. Although a good deal of research into GaN on ordinary silicon substrates was attempted prior to the 1990s, the published GaN successes using sapphire substrates overshadowed this research and led to the abandonment of silicon as a viable substrate.

Due to the large lattice mismatch between GaN and sapphire (~13%), amorphous low-temperature ($\approx$ 500–600°C) aluminum nitride or GaN buffer layers approximately 25 nm thick are used to nucleate subsequent GaN device layers. The negative differences in

TECs place the resulting GaN films under a compressive stress.

This differs from the growth of GaN-on-SiC, where high-temperature (≈ 1100°C) monocrystalline AlN buffer layers exceeding 100 nm in thickness are typically employed; these are facilitated by the relatively small lattice mismatch (~1%) between SiC and AlN. GaN films deposited on HT-AlN/SiC substrates are under positive tensile stress.

For the growth of crack-free, device-quality GaN-on-silicon, both the large lattice mismatch and gross positive TEC difference must be overcome. Many research groups have attempted, with limited success, to achieve this by using various buffer layers between GaN and silicon, including GaAs, AlAs, ZnO, $LiGaO_2$, SiO_2, Si_3N_4, sputtered AlN, LT-GaN, LT-AlN, and deposited and converted SiC films. The SIGANTIC epitaxial growth platform developed by Nitronex Corporation for depositing GaN on large-area silicon wafers resolves these thermal expansion and lattice mismatch problems. Though the composition of the transition layer scheme is proprietary, the layer components were chosen after examining and comparing their thermal expansions versus GaN and silicon as a function of temperature. Precise temperature, composition and film thickness control must be obtained to eliminate radial stress gradients. The room-temperature mobility of GaN-based HEMT structures grown using this technique routinely exceeds 1600 cm^2/Vs (see *Compound Semiconductor* March 2001, p17).

GaN vs common substrates

	lattice mismatch	*TEC mismatch*
AlN	2.4%	+26%
SiC	3.4%	+25%
sapphire	13%	–34%
silicon	17%	+100%

Table 1. Mismatches in lattice constants and thermal expansion coefficients (TECs) between GaN and the substrates commonly used to grow GaN. AlN is shown since it is often used as a buffer layer for GaN growth on sapphire and SiC.

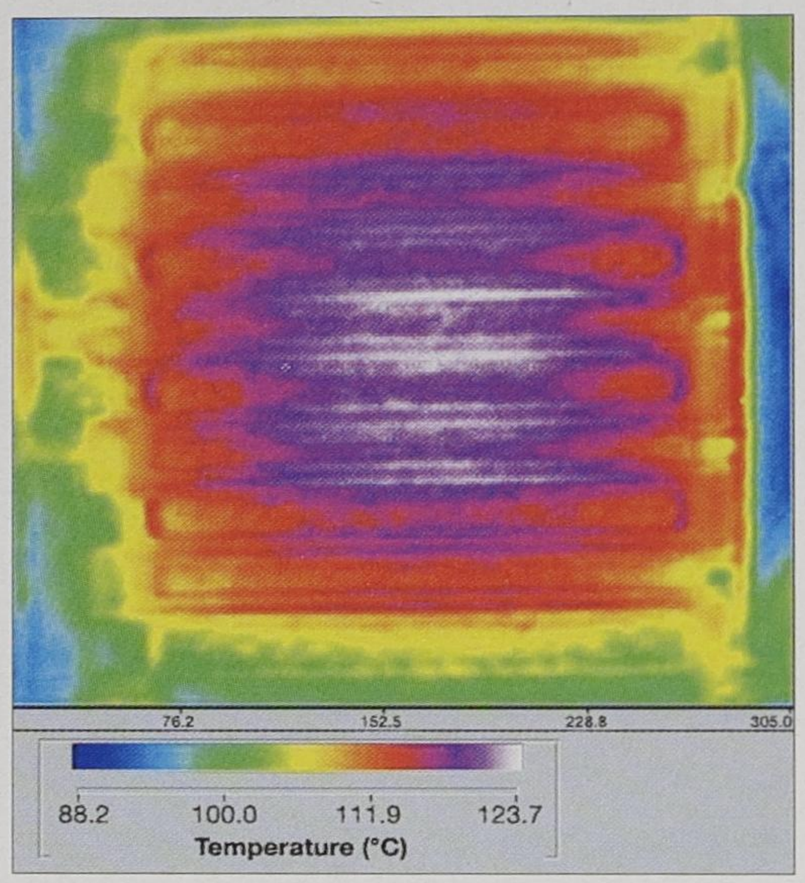


Fig. 2. Infrared image of a GaN-on-silicon HEMT under bias. The thermal impedance is very close to that of a silicon device and is superior to that of a GaAs device.

Microelectronic applications

To date, the principal application of GaN in electronic devices has been in microwave power generation – typically in the form of MESFET and HEMT devices. The results from industry research groups, government laboratories and universities have been very encouraging, particularly with respect to HEMT power density at X band (8–12 GHz) and above. With power densities typically exceeding 2 W per mm of device periphery, AlGaN/GaN HEMTs have shown clear advantages over microwave power devices like GaAs MESFETs, InP HEMTs, GaAs HBTs and silicon BJT and LDMOS devices.

The reason behind this performance boost stems from the superior electronic material properties of GaN. Since it is a wide bandgap semiconductor, the breakdown field is quite high, at approximately five times that of GaAs and silicon, enabling high-voltage operation. The AlGaN/GaN heterostructure system enables a high charge (~$1.0 \times 10^{13}/cm^2$) and a good, low-field mobility (~1500 cm^2/Vs) 2DEG films, which boosts the current-handling capability. At high fields, the electron velocity saturates at 2.5×10^7 cm/s, which is close to the GaAs value and a key contributor to the high-frequency performance of GaN in power applications when the internal device electric fields are large.

For growth of crack-free, device-quality GaN-on-silicon, the large lattice mismatch and gross positive TEC difference must be overcome.

Given these desirable electronic material properties and impressive device demonstrations, it is fair to ask when one might expect to see GaN electronic devices inserted into commercial applications. Notwithstanding the technological challenges of optimizing fabrication process flows and packaging, the main barrier to commercialization is the unavailability of a single crystal substrate. Though there is ongoing work in bulk GaN growth, any near-term electronic applications will have to rely on heteroepitaxy using one of three substrates: SiC, silicon or sapphire.

Due to its low thermal conductivity, sapphire severely limits thermal dissipation in microwave power applications. Silicon carbide has excellent thermal conductivity and can address very-high-power applications, particularly when the device is operated in saturated mode when raw power is the primary concern and signal purity is relatively unimportant. However, it also comes at a high cost, in limited availability and size, and has relatively poor crystal quality and surface finish compared with conventional silicon substrates.

GaN devices can address medium-power ranges using silicon as a substrate. Figure 2 shows an infrared-imaging thermal scan of a GaN-on-silicon HEMT under bias. The interdigitated multifinger device layout exhibits typical thermal profiles with a hot spot in the center of the fingers. The thermal impedance is, as expected, very close to that of a silicon device and therefore superior to that of a GaAs device. Depending on the application, the gate finger pitch can be adjusted to maintain a particular operating junction temperature.

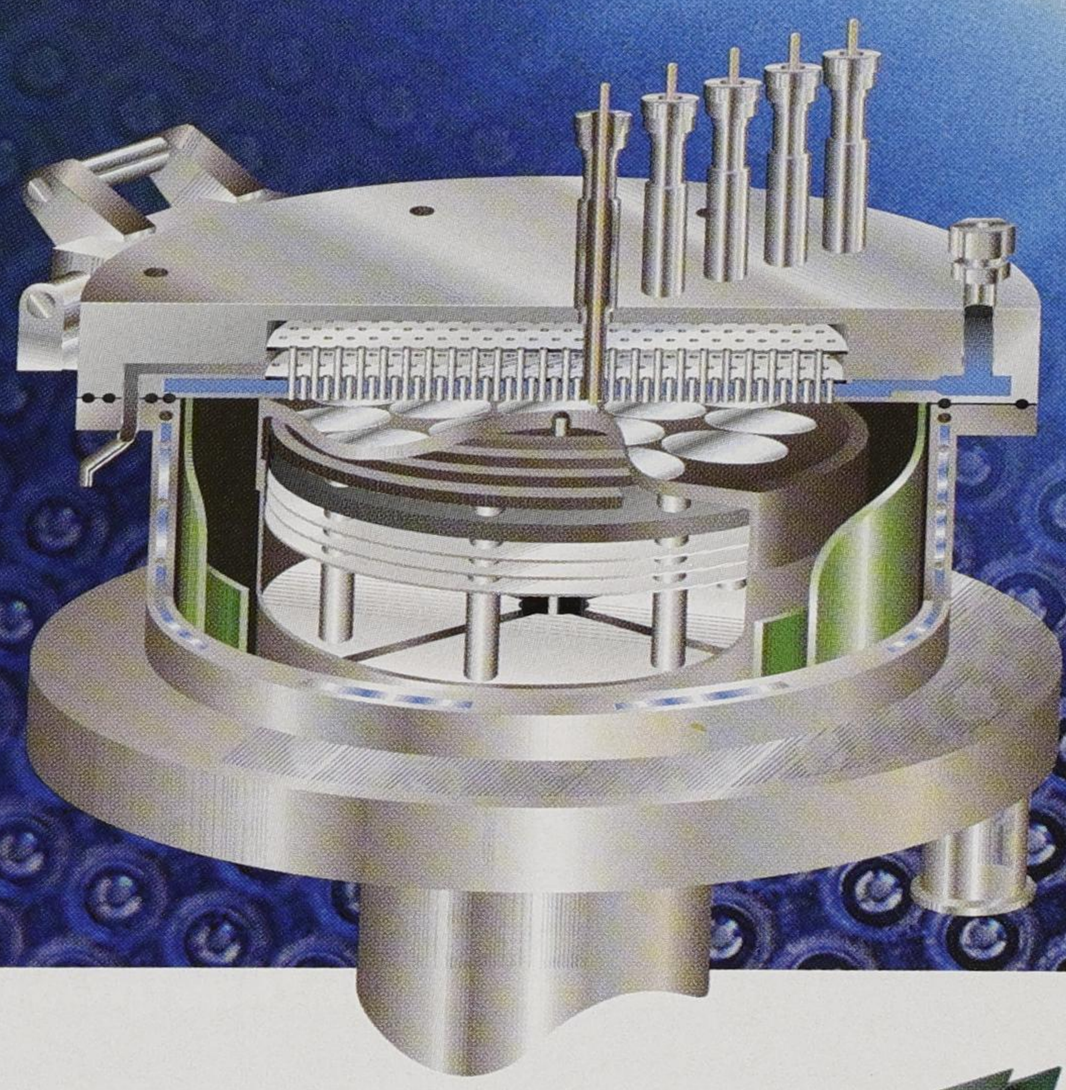
When comparing a GaN HEMT with a silicon LDMOS device, the power density in the HEMT is four times greater than that of the LDMOS device while still providing additional benefits in linearity and efficiency. The higher power density is important when designing very-high-power devices because it leads to higher device impedances when power cells are combined in parallel. This is a common practice that eases the impedance transformation that circuit designers must undertake when matching a 50 Ω system to low device impedances.

What are some of the applications in the foreseeable future? The cellular phone industry is undergoing a fundamental transformation from voice-centric to data-centric applications, as evidenced by the rollout of 2.5-generation and third-generation (3G) air interfaces. Whether it is a GPRS, EDGE, CDMA-2000 or W-CDMA protocol, these systems demand greater signal purity from the power amplification stages to minimize co-channel inter-

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ference, which is particularly deleterious in data transmission. Although silicon LDMOS has a strong foothold in this application, its performance is marginal with respect to frequency response (or gain), efficiency and linearity. GaN HEMTs are projected to offer substantial performance advantages for the reasons stated above. However, the cost must be comparable to LDMOS, therefore confining the substrate of choice to silicon.

Longer term, specialized markets include military radar, higher frequency point-to-point and point-to-multipoint distribution systems, and cellular backhaul. In these cases, the competing technologies are other III-V compounds. GaAs MESFETs still find widespread use in applications up to about 20 GHz, while InP-based HEMTs dominate at higher frequencies. Clearly these markets will take longer to penetrate since an integrated circuit process for GaN needs to be able to overcome the traditional problems associated with silicon substrate losses at high frequencies.

Optoelectronic applications

Double-heterostructure, co-doped blue LEDs were the first III-V nitride products to be introduced to the commercial marketplace. Though more sophisticated, quantum-well-based blue, green and white LEDs are now available, these products are still produced on 2 inch diameter sapphire or SiC wafers.

Product binning by wavelength, brightness and operating voltage is commonplace, even on small-diameter wafers. Uniform, large-area, GaN-based LEDs on silicon offer a revolutionary new approach.

A blue LED on a 4 inch silicon wafer is shown being probed in figure 3. This wafer will eventually be glass encapsulated at the wafer level. The devices will be bump-contacted and diced for subsequent flip-chip attachment, which will eliminate wire bonding and epoxy packaging (see *Compound Semiconductor* August 2001, p19).

A typical two topside-contacted blue LED measures 300 μm × 300 μm, which yields approximately 20 000 die per 2 inch wafer. The same-sized die on a 4 inch silicon substrate would create over 80 000 die. The additional space on 4 inch diameter and larger wafers enables larger junction-area LEDs for use in portable lighting, emergency signaling and decorative lighting applications.

For example, as white LEDs become viable alternatives for general illumination, the resulting price pressures will only be eased by using large-area silicon wafers. Vertically conducting, top- and bottom-contacted LEDs and laser diodes can also be made using GaN-on-silicon technology. Vertical device designs allow for reduced die sizes, less complicated processing, decreased processing costs and increased numbers of die per wafer.

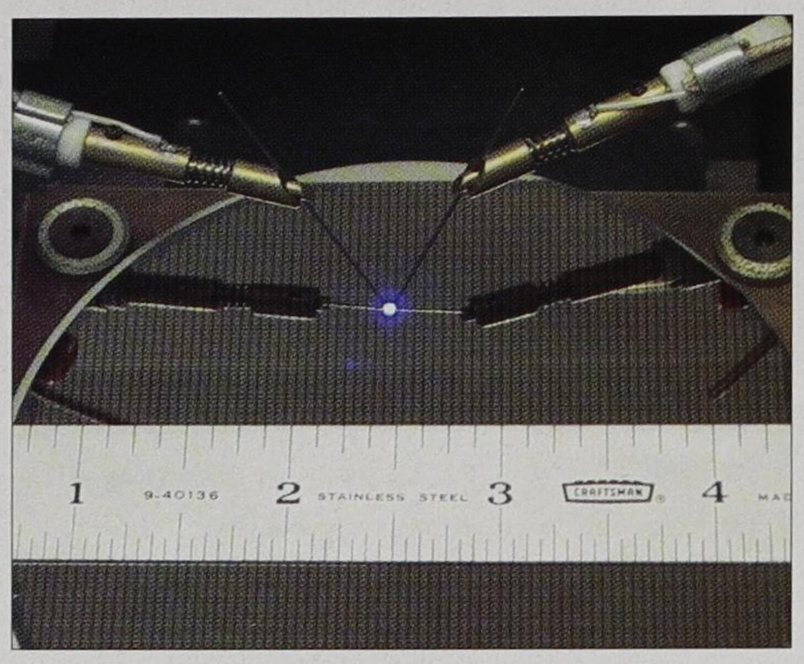


Fig. 3. On-wafer probing of blue GaN-based LEDs on a 4 inch silicon wafer. Because of on-wafer absorption losses, brightness is substantially improved once the LEDs have been diced into chips.

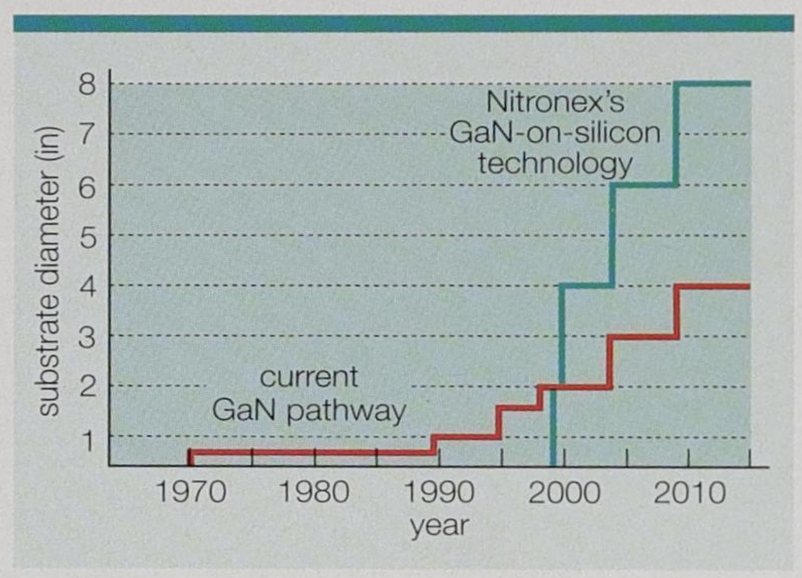


Fig. 4. A comparison of Nitronex's GaN-on-silicon technology with the current GaN development pathway.

As white LEDs become viable alternatives for general illumination, the resulting pricing pressures will only be eased by using large-area silicon wafers.

An obvious concern with silicon is that it absorbs the blue, green and ultraviolet light generated by GaN-based LEDs. Unlike SiC and sapphire substrates, both of which are extremely hard, impervious to wet chemical etchants and difficult to process, silicon processing is commonplace. The maturity of silicon technology allows for novel process routes to improve the extraction efficiency of silicon-based LEDs. Ultimately, following the pathway of transparent substrate AlInGaP LED technology, replacing the absorbent silicon substrate with an optically transparent substrate using compound wafer bonding, may be a suitable approach.

Manufacturability

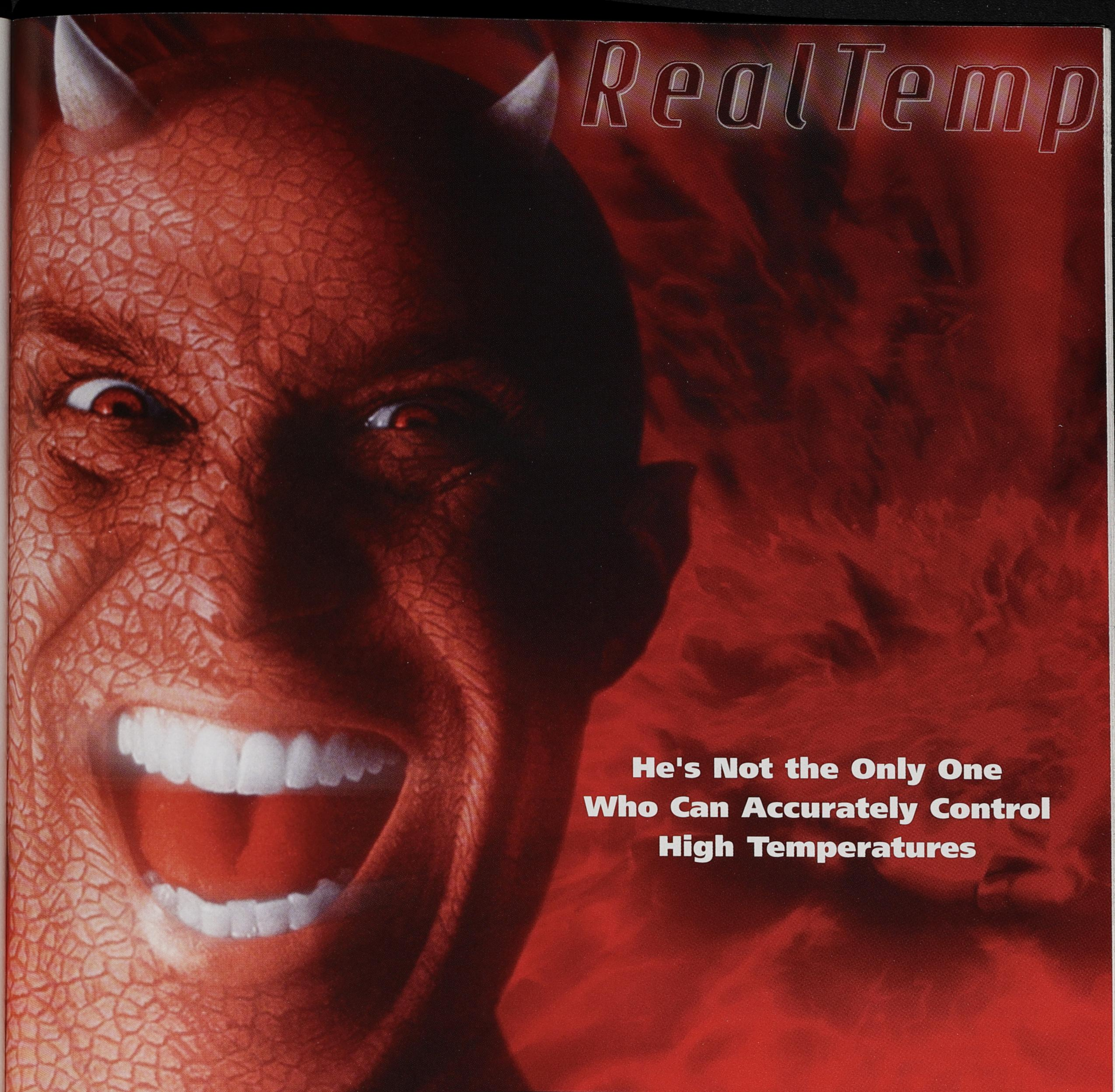
Many of the new applications of GaN in sensors and wireless applications, for example, require large-area devices and stable manufacturing processes. Economies of scale are achieved with larger diameter wafers, higher throughput and optimal equipment utilization, as well as the compatibility with current semiconductor fabrication tools and wafer-handling systems. Because many tool sets and process routes are similar, GaN-on-4 inch silicon benefits by leveraging the similar advances made in GaAs technology.

Performance-per-unit cost is a critical factor in the technological acceptance of GaN in commercial applications. As shown in figure 4, GaN-on-silicon is a platform technology which is superior to the current GaN pathway. We therefore believe that the economics of continuing to employ GaN-on-small-area sapphire and SiC are questionable.

Conclusions

As many companies retool for 6 inch diameter GaAs, 4 inch processing lines and related equipment are either under capacity or being decommissioned. GaN-on-silicon can help to fill this void. Gallium nitride's potential is limited by the current methodologies, which are based on smaller wafer sizes using difficult and expensive substrates. Until an alternative technology is adopted, GaN will continue to be used only in high-brightness LEDs, laser diodes, military electronics and other applications that are less sensitive to the unit-area cost of wafers. When looking for an alternative and considering the cost, size, quantity, crystal quality, processing flexibility and integration, silicon is the ideal platform for commercializing gallium nitride device technology.

The authors work for Nitronex Corporation, Raleigh, NC. Warren Weeks is general manager of the optoelectronics division, commercializing GaN-on-silicon LEDs and lasers, and Ricardo Borges is director of device engineering, developing GaN-based power transistors. Tel. +1 919 807 9100; Fax +1 919 807 9200; Web www.nitronex.com.



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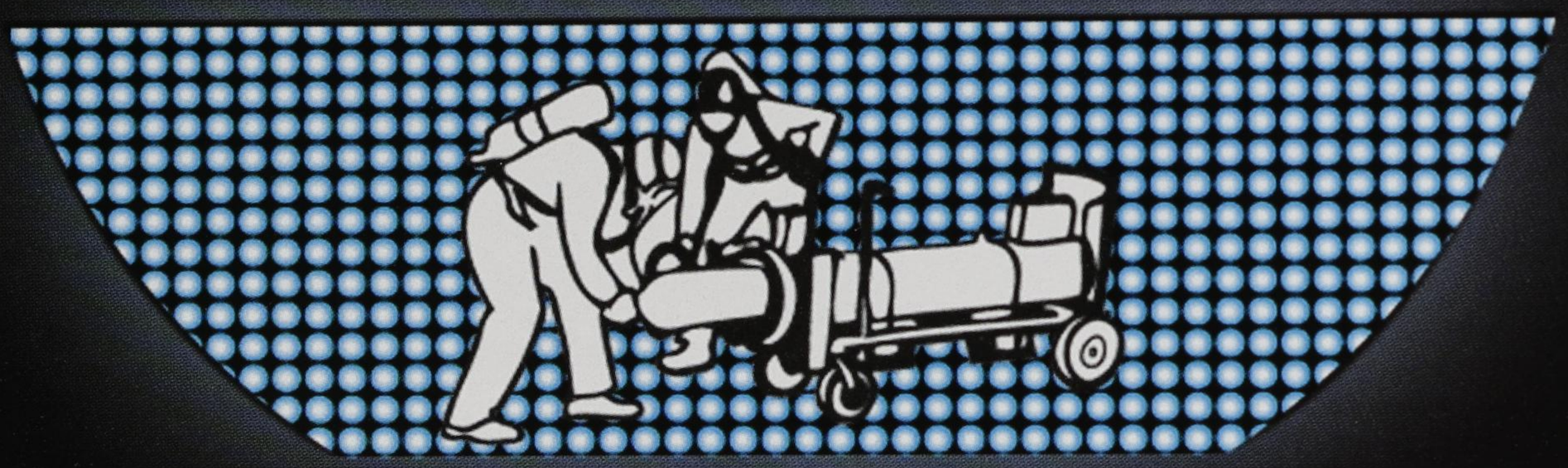
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GaN reaches new power levels

The ability of GaN to withstand high power densities has made it a hot research topic. **Lester Eastman** provides an insight into what we can expect from GaN-based devices.

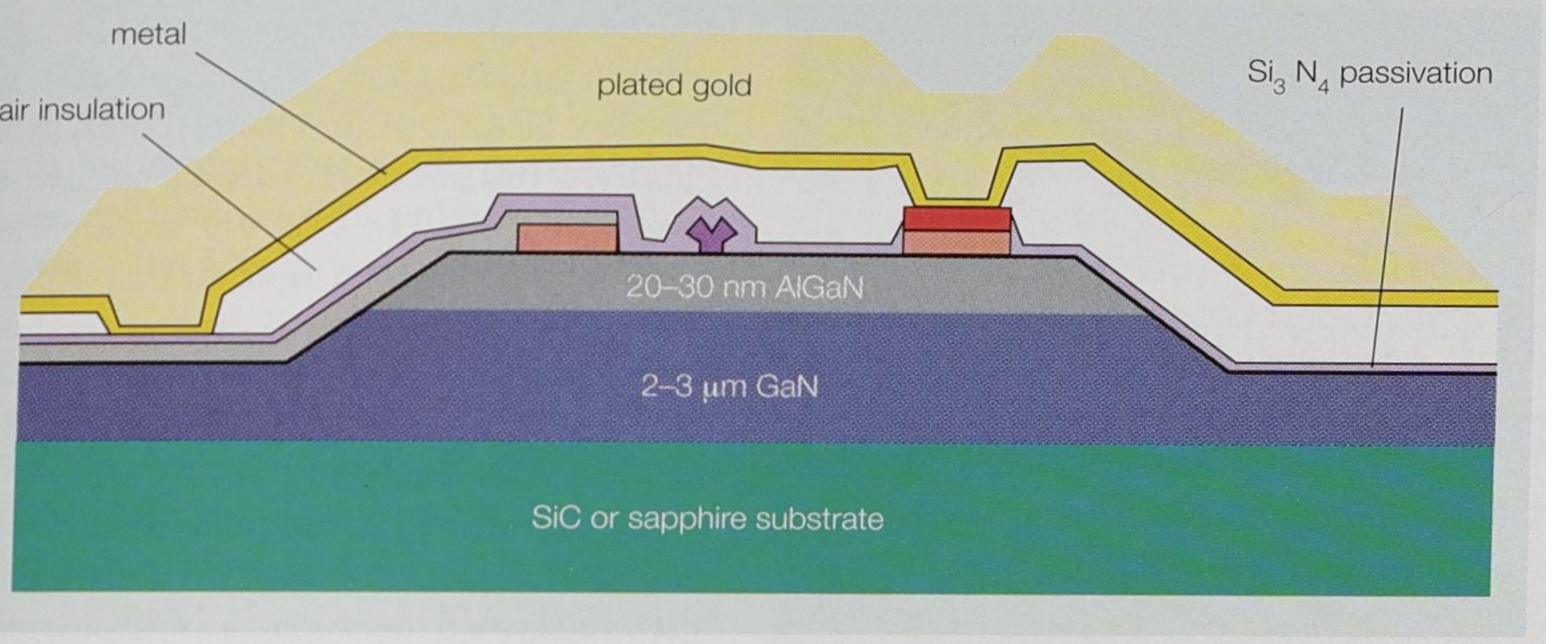


Fig. 1. A typical layer structure used for the fabrication of AlGaN/GaN HEMTs.

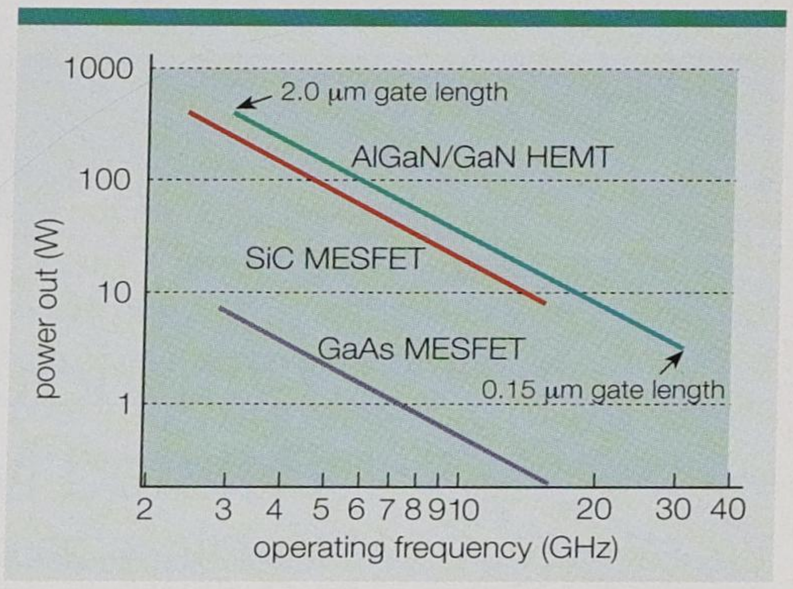


Fig. 2. Comparison of the potential power delivered by HEMTs that have been fabricated in GaAs, SiC and GaN.

The drive for ever-higher levels of RF power has been instrumental in the rapid development of GaN power HEMTs. Its 3.4 eV bandgap means that GaN can withstand 7.5 times the electric field that GaAs can before avalanche breakdown occurs. This in turn allows a proportionately higher operating voltage and current for the same load impedance. When voltage and current are taken together, a power delivery greater than 50 times that of GaAs devices is possible using GaN-based FETs, providing that heat removal is made possible by larger periphery designs and low thermal resistance substrates. It is this potential 50 times increase in power performance that acts as a great motivator for pursuing GaN-based devices and circuits.

2DEG formation

In GaAs- or InP-based HEMTs, a doped donor layer is required to form the two dimensional electron gas (2DEG) at the heterojunction. No doped donor layer is required in GaN HEMTs in order to supply charge. When grown on the Ga-face, along the C axis of the wurtzite crystal, a positive polarization charge is generated. This is approximately equal to 5.5×10^{13} cm^{-2} times the electronic charge multiplied by the Al fractional content in the $Al_xGa_{1-x}N$ top barrier layer. With a surface conduction band potential of about (1.0 + 1.9x) volts, which puts it 1.6 eV above the Fermi energy for the 30% Al concentration typically used in these devices, a 2DEG of about 1×10^{13} cm^{-2} is induced in the GaN near the heterojunction. This charge is lower by 20–30% than that predicted by theory, and this is due to surface depletion effects and the charge effects created by the high level of dislocations present in GaN. HEMT devices fabricated with undoped AlGaN barriers typically exhibit electron mobility values in the 1200–1700 cm^2/Vs range, and average electron transit velocities of $1.2–1.3 \times 10^7$ cm/s.

GaN epitaxy

While GaAs and InP substrates can be used to grow lattice-matched alloys, there is no suitable lattice-matched substrate for GaN growth. SiC is generally used for HEMT applications, particularly for high-power devices where its heat conductivity of 3.3 Wcm^{-1} K^{-1} (10 times higher than sapphire, another possible substrate) means heat is readily removed. However, the lattice mismatch between GaN and SiC typically results in the GaN HEMT exhibiting $2–5 \times 10^8$ cm^{-2} threading dislocations. These generate 4×10^7 cm^{-1} charged states that act to decrease the polarization-induced charge. Other than a slight decrease in channel charge, these dislocations do not negatively impact HEMT performance.

MOVPE or MBE can be used to grow AlGaN/GaN HEMTs, though most reported results are on MOVPE-grown material. To obtain device-quality material, it is critical that growth be done on a Ga-face surface. MOVPE growth exhibits a Ga-face surface during typical growth conditions. For MBE growth, a N- or Ga-face may occur when growth is initiated on sapphire substrates. A combination of a thin (7 nm) AlN nucleation layer and an Al-rich sapphire surface is required for Ga-polarity surfaces in MBE. N is supplied during MBE growth by an RF plasma source producing atomic nitrogen. Sapphire substrates are heated using a coating of tungsten to act as a radiation absorber. GaN growth by MBE is typically done at 800°C and at a rate of 0.5 μm/h. Under these conditions, significant Ga desorption takes place. The Ga/N ratio is carefully optimized so that within the substrate temperature non-uniformity, the cooler edge of the wafer is Ga-rich and the hotter center of the wafer is N-rich.

MOVPE growth performed at Cornell is done using flow-modulation techniques in a custom-built, cold-wall, multi-wafer quartz reactor, at a pressure of 76 torr and a substrate temperature of 1040°C. The precursors used are triethylgallium, trimethylaluminum and ammonia with V/III ratios set at 1800 for GaN and 900–1800 for AlGaN. A single-step, high-temperature nucleation process is utilized that produces atomically smooth, planar films within the first several hundred Angstroms

of growth on both sapphire and SiC substrates. It has been found that establishing a 2-D growth front as early as possible is crucial in achieving the insulating GaN films critical for HEMT device operation.

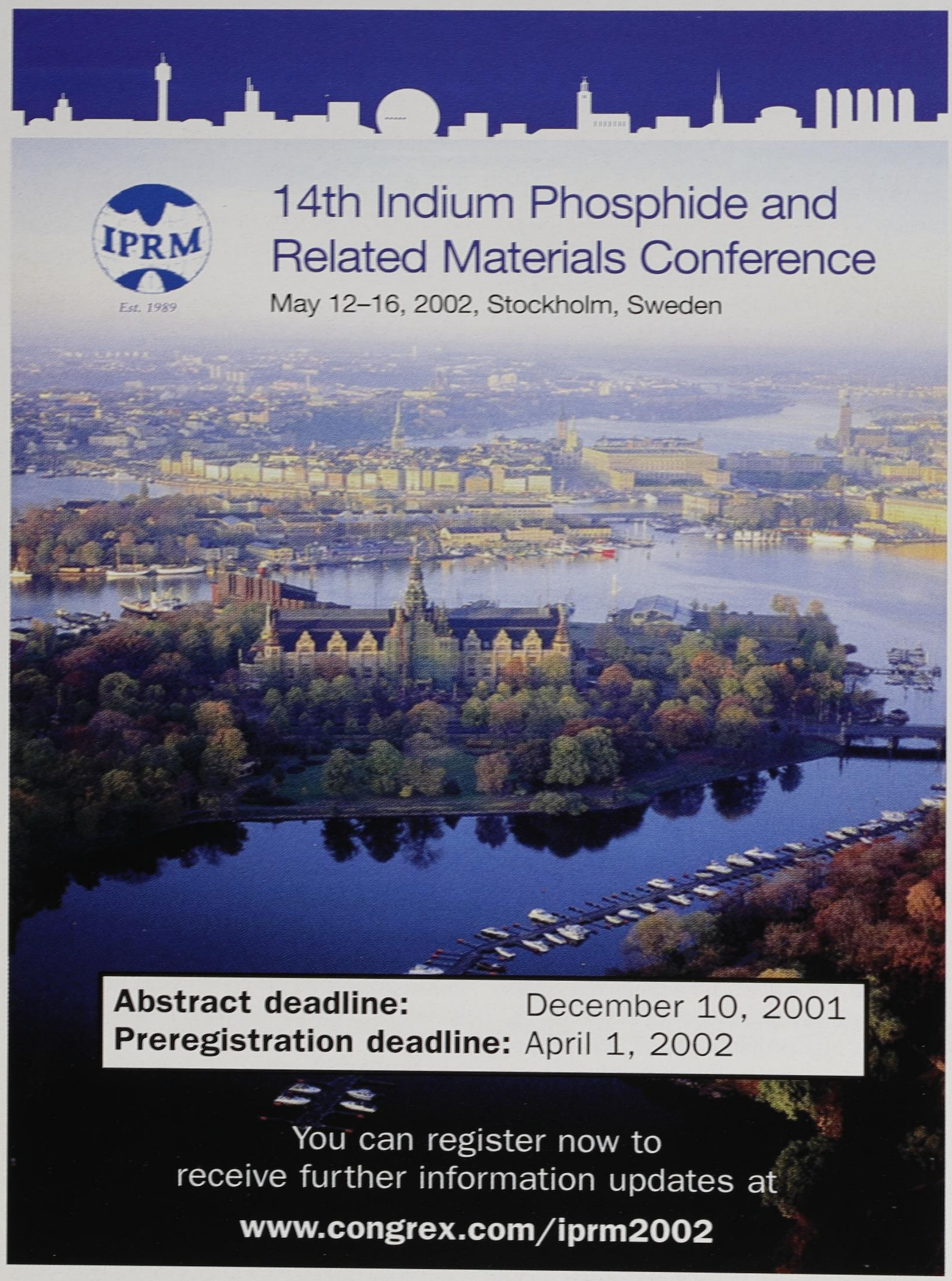
HEMT fabrication

A typical layer structure used for the fabrication of AlGaN/GaN HEMTs has a 5–20 nm AlN or AlGaN nucleation layer, a 2–3 µm unintentionally doped (UID) GaN buffer and a 25 nm UID $Al_{0.3}Ga_{0.7}N$ barrier. A GaN cap of 2–3 nm can also be grown to increase the effective Schottky barrier, which improves breakdown characteristics and decreases the gate leakage. A Cl_2-based electron cyclotron resonance process is used to define isolated mesas, which typically have a final height of 200 nm. E-beam lithography is used to define the ohmic contacts. This avoids the loss of 2DEG charge during optical lithography, which can occur when using hydroxyl-based optical developers. These chemicals attack the GaN surface and dislocations, reducing charge. A two-layer resist lift-off process and E-beam evaporation is used for ohmic metallization that consists of a Ti/Al/Ti/Au (20 nm/100 nm/45 nm/55 nm) composite, followed by a 30–60 s anneal at 800°C. Typical contact resistances for this process range from 0.3 to 0.5 Ωmm. Ni/Au (20 nm/360 nm) E-beam defined mushroom gates with gate lengths ranging from 0.15 to 0.6 µm are used, followed by Ti/Au (20 nm/360 nm) contact pads. Finally, a 100 nm Si_3N_4 surface passivation layer is deposited by PECVD, a critical step that can double or even triple the output power of the device. The finished structure is shown in figure 1. For a 0.35 µm gate length, the HEMT exhibits a breakdown voltage of 70 V, an f_t of 35 GHz and an I_{ds} of 1 A/mm.

In structures with such large 2DEG concentrations ($1–2 \times 10^{13}$ cm^{-2}) it is critical that attention is paid to the gate's ability to pinch-off this charge. For GaAs and InP, the ability to pinch-off the 2DEG can be enhanced by increasing the height of the barrier layer. However, for GaN-based HEMTs, an increase in the barrier height (by increasing Al content in the AlGaN barrier material) also increases the piezoelectric-induced charge, thereby making pinch-off harder to achieve. Because thermally assisted tunneling is a predominant component of the leakage current at high temperatures, and for power applications the gate region will typically operate at about 300°C, leakage needs to be determined at this temperature. Leakage current increases as Al content increases, with a typical value of 10^{-7} A/mm, a figure sufficiently low for power applications. However, this value can be significantly larger if the material and surface properties of the GaN are not optimized.

Device performance

Improvements in material and device fabrication have led to new performance limits for GaN HEMTs. For 0.15 µm gate-length devices using 25 nm barrier layers, the f_t values of HEMTs fabricated on sapphire and SiC substrates are 74 and 106 GHz, respectively. Optimizing for power added efficiency results in a value of 78% for a 1.5 mm periphery device on sapphire operating at 1.8 W/mm. The gate-drain breakdown voltage depends almost linearly on the gate length, with gate-drain separation as another parameter. A breakdown voltage of 72 V was obtained for a HEMT with



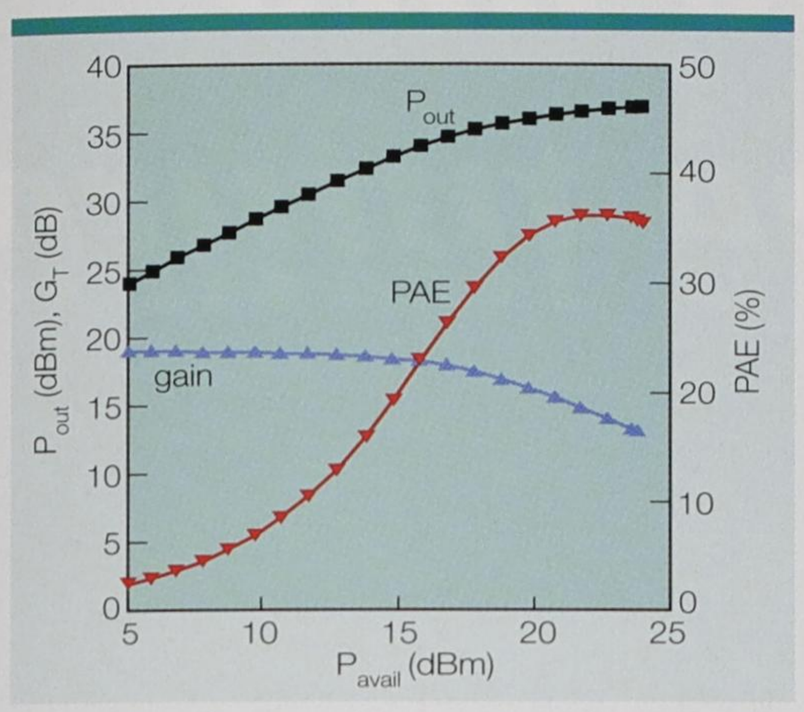


Fig. 3. Performance of a high-gain cascode power cell using two 0.3 µm gate-length HEMTs, each with gate widths of 1 mm.

a gate length of 0.3 µm and a gate-to-drain spacing of 2.0 µm. The present normalized CW power density at 10 GHz is 11.2 W/mm for a 100 µm periphery device on SiC. In terms of noise performance, for a 0.3 µm device on SiC with a V_{ds} of 8.1 V and a V_{gs} of –3.22 V, 1.4 dB was obtained at 10 GHz operation. In general, these limits have been obtained by trading off against another performance metric.

When these operating limits are combined with thermal conductivity simulations the operating limits of power HEMTs can be compared for several different material systems. This is shown in figure 2, where it can be seen that a GaN HEMT has the potential to deliver 56 times more power than a GaAs MESFET and 1.8 times more power than a SiC HEMT.

Circuits

Material growth, device processing and discrete HEMT performance are all necessary steps in the development of a technology that can be applied to high-power RF applications. However, it is still necessary to transfer this experience into the fabrication of circuits required for power generation – GaN-based circuitry is now entering into that phase, with power cells and amplifiers being demonstrated. Figure 3 shows the performance of a high gain cascode power cell using two 0.3 µm gate length HEMTs, each with gate widths of 1 mm. Operating in the cascode configuration provides approximately 7 dB of additional gain, enhanced small signal gain, and around 10 V of additional drain voltage swing. Using the cascode power cell as a building block, two

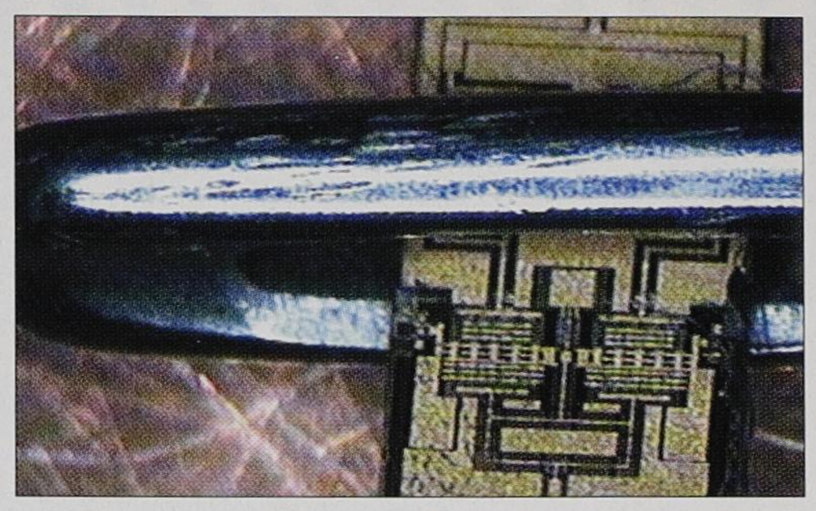
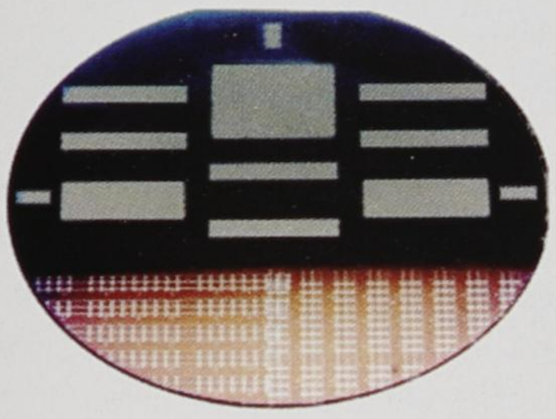


Fig. 4. The 5 mm² broadband amplifier uses two cascode power cells.

such cells are used in the fabrication of the broadband amplifier in figure 4. With a die size of only 5 mm², the amplifier exhibits a bandwidth of 9.5 GHz, and greater than 14 dB small signal gain. With these results it is clear that the potential offered by the GaN material system for power applications is becoming a reality.

Lester Eastman is Professor of Engineering at the School of Electrical and Computer Engineering, Cornell University, Ithaca, New York. This article is based on a presentation at the 2001 Key Conference, held 5–6 March in Key West, Florida.

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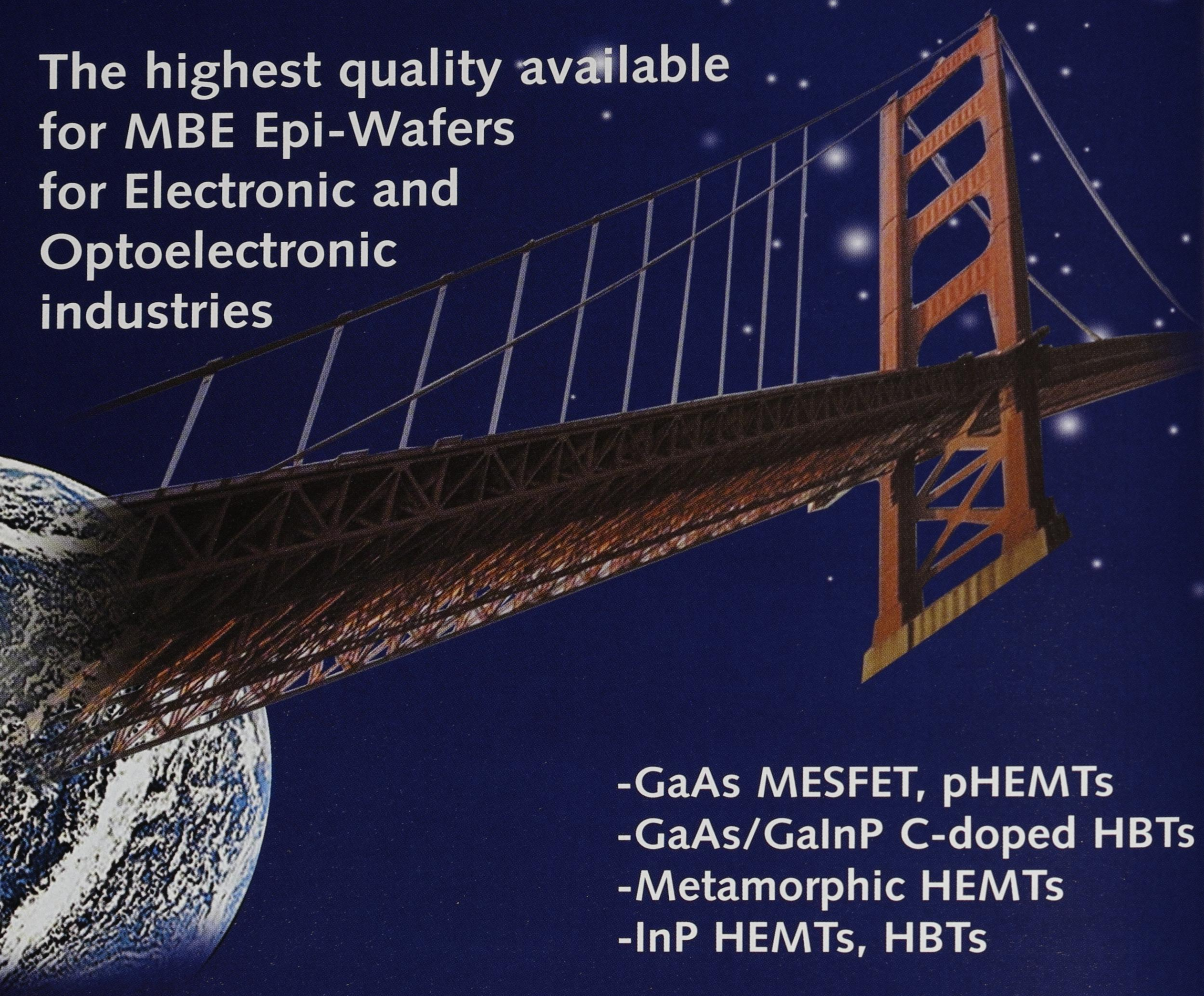
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BU's Wide Bandgap Lab grows better GaN for novel devices

Gallium nitride research at Boston University covers a wide spectrum of fields from basic materials research to advanced device development, writes **Yvonne Carts-Powell**.

At the Boston University Photonics Center, much of the work at the Wide Bandgap Lab focuses on gallium nitride research. Professor Ted Moustakas (figure 1) leads a group which is researching better ways of growing GaN as well as developing the material for sensors, electronics and optical applications. Moustakas' group has contributed a number of important innovations in nitride development. In the early 1990s, they were the first to describe the nucleation steps necessary to grow good-quality GaN on substrates, including the addition of a GaN buffer layer (Moustakas *et al.* 1993). The group also described how to p-dope GaN using MBE without postgrowth treatments (Moustakas and Molnar); and how to choose an appropriate metal for making ohmic contacts to nitrides (Foresi and Moustakas). All these advances are in common use today.

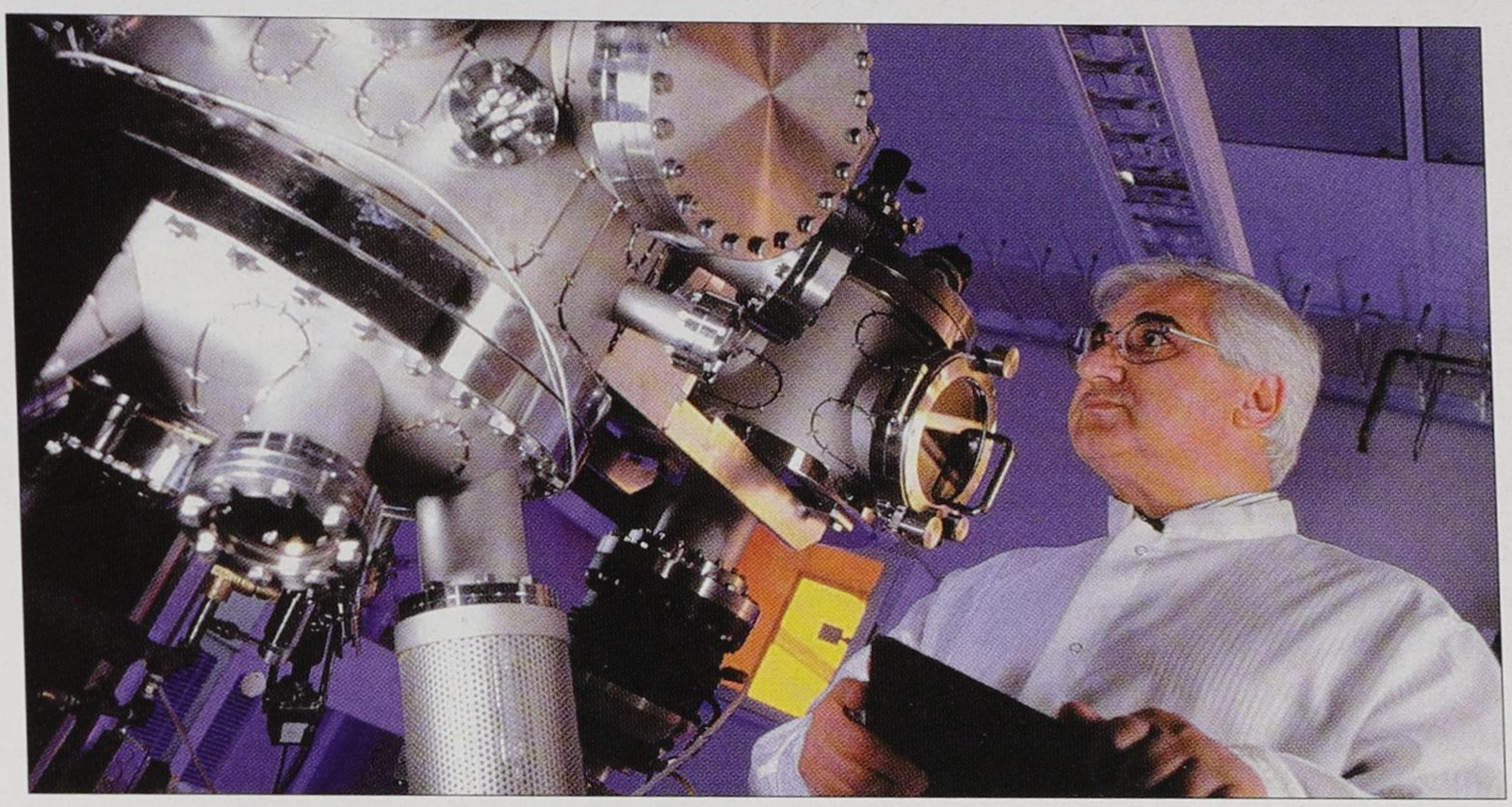


Fig. 1. Professor Ted Moustakas next to an MBE machine used to grow AlGaN by depositing GaN/AlN superlattices at Boston University .

Self-ordered alloys

Moustakas believes that his group's current work on growing self-ordering alloys of gallium, aluminum and nitrogen may be another far-reaching contribution. (See box "Alternative deposition methods" for other growth research.) At first glance, one might expect deposited alloys of Al, In, Ga, and N to be a random homogeneous mixture of atoms. Growth kinetics, however, encourage separation and organization of AlN, InN and GaN layers under certain conditions.

Moustakas' group has done a number of studies on InGaN, and discovered both phase separation and long-range ordering in this material. The group is also investigating AlGaN. Because the lattice parameters for GaN and AlN are different by about 4%, organized layers of GaN and AlN would be thermodynamically more stable. If the growth conditions allow such self-organization, the alloys will form superlattices. Instead of a random alloy, superlattices contain alternating layers of compounds (e.g. GaN and AlN),

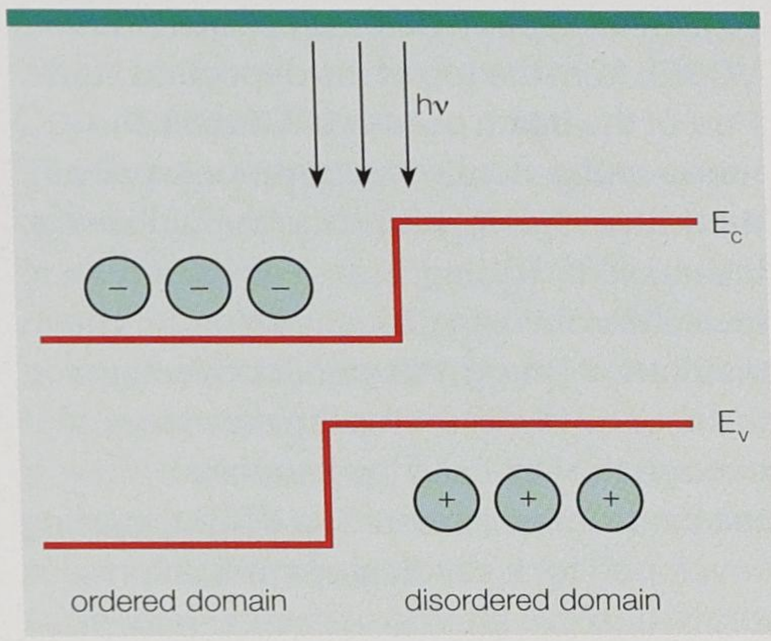


Fig. 2. When light shines on a partially ordered AlGaN alloy, it generates electron-hole pairs. The carriers migrate to either the ordered (for electrons) or disordered (for holes) domains to achieve the lowest potential. Researchers suspect that this separation is why charge carriers in such partially ordered alloys have notably longer lifetimes.

which are expected to provide higher transport coefficients and different optical properties than bulk alloys. The new materials are exciting prospects for developing novel and exotic devices.

Elefterios Iliopoulos and others at the Lab used MBE to grow AlGaN alloys and influence the way that gallium and aluminum are incorporated into the film (Iliopoulos *et al.*). They discovered that three types of long-range order structures (2, 7 or 12 monolayer superlattices) spontaneously formed during deposition.

Detectors and other devices

The Boston University (BU) group has started applying the alloy research to growing better GaN VCSELs and detectors. Mira Misra (now at LumiLeds) and others at the Lab reported growing photoconductive detectors made from partially ordered AlGaN alloys grown by MBE (Misra *et al.*). Their research showed that detectors based on partially ordered AlGaN alloy films have significantly higher photoconductive gain than detectors based on pure GaN. They also found that the mobility-lifetime product varies by over five orders of magnitude as the composition of the film is changed.

Alternative deposition methods

The Wide Bandgap Lab at BU is investigating two alternative deposition methods for GaN, besides MBE. One project aims at better quality crystals, while the other focuses on fast-rate growth of GaN for use as substrates. To provide better quality GaN, Moustakas' group is focusing on low-temperature deposition using clusters of nitrogen ions, rather than the typical atomic nitrogen. The Lab has acquired a tool that forms clusters of 2000 to 3000 nitrogen atoms. Such clusters react with a beam of Ga (or Al or In) atoms to form nitride layers. "What is novel about this approach," says Moustakas, "is that we see evidence of better nucleation and more efficient doping, and evidence of growing good material (with large domain sizes) at low temperatures."

For substrate growth, Moustakas' group (along with many others around the globe) is working on hydride vapor phase epitaxy, which provides fast growth of GaN on top of a substrate of another material. The method, originally developed by Jacques Pankove in the 1970s, uses gaseous hydrochloric acid and ammonia as the precursors. Moustakas says the method has provided a growth rate as high as 100 μm per hour, together with very low dislocation density.

Although the band structure of the material has not been fully described, the researchers have some experimental evidence that ordering reduces the magnitude of the energy gap. They believe that the longer lifetimes are due to the separation of electrons and holes in the ordered and disordered domains, which lead to indirect recombination (figure 2). Longer lifetimes result in higher photoconductivity and a more sensitive photodetector material.

In general, GaN is an attractive material for robust sensors because such sensors can operate at much higher temperatures than silicon and are resistant to acids and bases. As such, GaN can be used in hostile environments, including in engine blocks, in space, or down drilling holes. GaN is also piezoelectric and has a large bulk modulus, which makes it suitable for electromechanical and acoustic sensors, respectively.

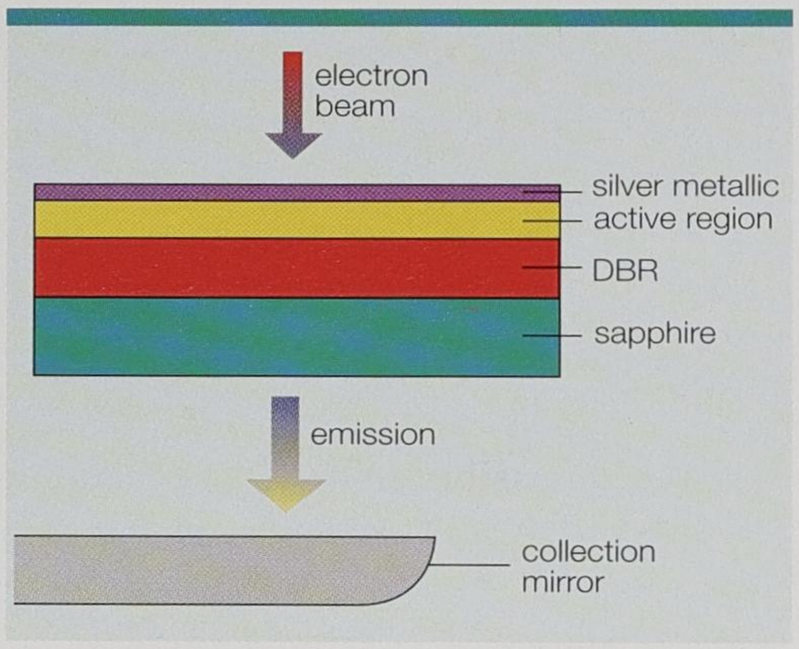


Fig. 3. An electron beam pumps a nitride VCSEL from the top of the deposited stack. Part of the beam penetrates the silver mirror and generates electron-hole pairs in the active region, driving the population inversion and lasing. The silver mirror facilitates draining of excess charge. The distributed Bragg reflector (DBR) acts as the second cavity mirror. Light passes through the DBR and the sapphire substrate for collection. The VCSEL is being developed for laser display applications.

Electronic applications

Imagine such a robust sensor measuring combustion efficiency in a car engine, and combine that sensor with electronics that can also operate at high temperatures. Car engines typically run at about 600°C, at which temperature silicon is no longer a semiconductor. GaN, on the other hand, has an energy gap about three times as large as silicon, and is still a semiconductor at 1000°C.

Moustakas collaborates with Professor Jacques Pankove of Astralux (Boulder, CO) and the University of Colorado on research to develop high-power GaN transistors. Pankove was a pioneer in developing GaN during the 1970s, and together the groups have tested a GaN transistor operating at 500°C. By depositing n-doped GaN on top of p-type SiC (part of a SiC pn junction), they created a HBT with remarkably high gain; at room temperature the device has a gain of 100 000.

BU graduate student Anand Sampath, in collaboration with Pankove's group, is working on developing a GaN thyristor (a device that switches between an insulating and a conducting state). These could be used in electrical power generation and transport of electricity, as well as in neural networking. The BU group is also working on other exotic transistors.

Vertical emitters

GaN VCSELs are currently a hot research topic because future optical recording is expected to use the wavelengths that GaN provides. Moustakas says, "VCSELs would allow parallel processing rather than direct-write processing; in other words, you could write an entire CD at once using a 2-D array of lasers."

Another major potential application of these devices is for projection displays. Moustakas explains, "Along with BU, there are only a few groups working on GaN VCSELs in the world: the University of Tokyo, Sandia National Laboratories, and a collaboration of Brown University and Hewlett-Packard." Within the BU group, Hock Min Ng (now at Bell Labs) worked on developing electron-beam-pumped VCSELs (figure 3) (H M Ng *et al.*).

For VCSELs, one typically wants integrated high-reflectivity distributed Bragg reflector (DBR) gratings as mirrors. Creating nitride DBRs with high reflectance has been challenging, but in the past year both Arakawa's group at the University of Tokyo and BU researchers have reported high-reflectivity DBRs. The BU researchers recently described nitride alloy DBRs with reflectance of more than 99% from 300 to 550 nm.

Attention to materials and devices

Nitride semiconductors have a great future in optics, electronics, and perhaps in MEMS applications as well. In order for GaN materials to achieve their potential, both materials research and device development need to continue (Moustakas 1999, Moustakas *et al.* 2001). At BU's Wide Bandgap Lab, both aspects are progressing hand in hand.

Further reading

T Moustakas *et al.* 1993 *Physica B* **185** 36.
T Moustakas and R Molnar 1993 *Mat. Res. Soc. Symp. Proc.* **281** 753.
J Foresi and T Moustakas 1993 *Appl. Phys. Lett.* **62** 2859.
E Iliopoulos *et al.* 2001 *App. Phys. Lett.* **78(4)** 463.
M Misra *et al.* 1999 *Appl. Phys. Lett.* **74(15)** 2203.
H M Ng and T Moustakas 2000 *Proc. SPIE* **3944** 22.
T Moustakas 1999 *Semiconductors and Semimetals 58* ch. 2 (Academic Press) 33.
T Moustakas *et al.* 2001 *J. Crystal Growth* **227–228** 13.

Yvonne Carts-Powell is a freelance technology writer based in Boston, MA.

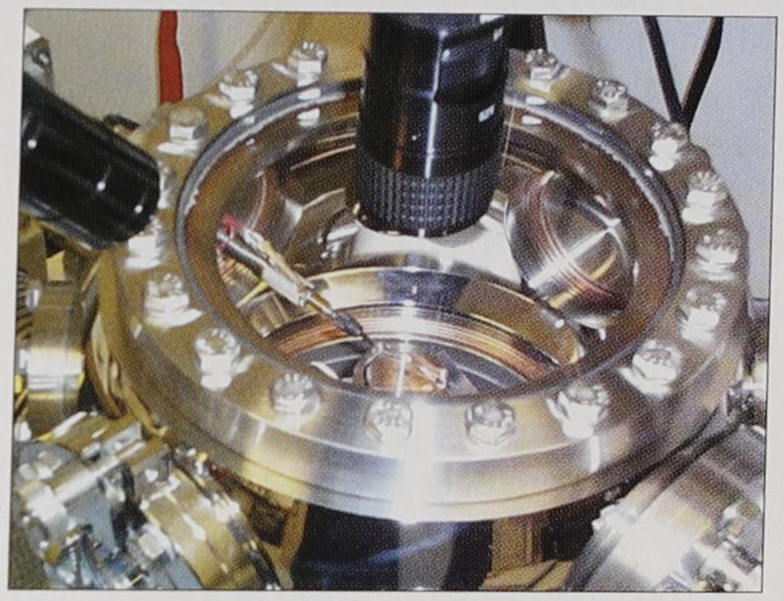
Caldus raises temperature of silicon carbide contacts

A small Oregon company has developed the technology to form contacts to SiC that are chemically and electrically stable up to temperatures exceeding 1000°C, writes **Donald Hagge**.

It has been recognized for several years that SiC possesses several fundamental advantages over silicon as a semiconductor material for devices in high-temperature and high-power solid-state electronics. In addition, SiC devices offer potential advantages for high frequency and logic circuit applications, power conversion (mixer diodes, MESFETs), single chip computers (n-MOS, CMOS, bipolar transistors), and non-volatile random access memory. The potential maximum average power, maximum operating temperature and thermal stability of SiC solid-state devices and circuits far exceeds Si- or GaAs-based devices.

Technology barriers for commercial products have existed both in the availability of quality SiC material and for the formation of stable metallized contacts. Caldus Semiconductor Inc, a small company based in Beaverton, Oregon, has developed the technology to form metallized rectifying Schottky junctions and ohmic contacts to SiC that are chemically and electrically stable up to temperatures in the 1000°C range.

Innovative high-temperature packaging is also being developed. Specific to sensor technology, SiC substrate and refractory metal contact structures enable entirely new regimes of thermal processing that were not previously accessible. There are whole sets of materials and compounds that could never be used in conventional semiconductor processing because of the high temperatures involved. Semiconductor substrate and contact materials would migrate or melt. Piezoelectric and magnetic materials with Curie points between 300 and 900 K can now be processed on SiC sensor platforms. Ceramic gas sensing materials can be applied directly to the substrate as the active gate for an entirely new technology with corresponding improved sensitivity and the possibility of detector regeneration. A wide range of inert and consumable catalysis materials can be applied to the sensor platform for tunable catalyst technology, which offers new possibilities for smart thermal sensors in safety-critical devices. MEMS fuel cells are also now possible using wide bandgap SiC material and contact technology that can function at 1000°C.



CALDUS

A test chamber at Caldus Semiconductor is used to evaluate silicon carbide devices at temperatures exceeding 1000°C in a controlled environment.

Commercial devices

The first commercial products under development by Caldus are devices for temperature, pressure and gas sensing in the 200–1000°C range. Since the company's metal-SiC technology has been demonstrated to be stable at temperatures as high as 1100°C it will be possible to develop SiC sensors that are stable, durable, chemically inert, small and relatively inexpensive.

Several issues are driving demand for the SiC products. Among them are energy conservation, national security, automotive and engine emission requirements, and wireless and space communications. However, Caldus plans to focus solely on sensing devices in the early stages of its growth, and will consider other products and markets once this initial strategy is successful.

Currently, a large suite of electronic systems used in commercial, industrial, and military applications (including, but not limited to aerospace, automotive, electric power, nuclear power and space) would benefit significantly from components and packaging designed and optimized for higher temperatures under generally harsh environmental conditions. These types of electronic systems are positioned away from the source of heat or they require the use of cooling systems. This design philosophy forces the use of costly cabling, connectors, tubing and/or cooling systems and creates excess weight, excess volume and decreased reliability. Furthermore, these factors increase maintenance requirements and consequently have higher costs.

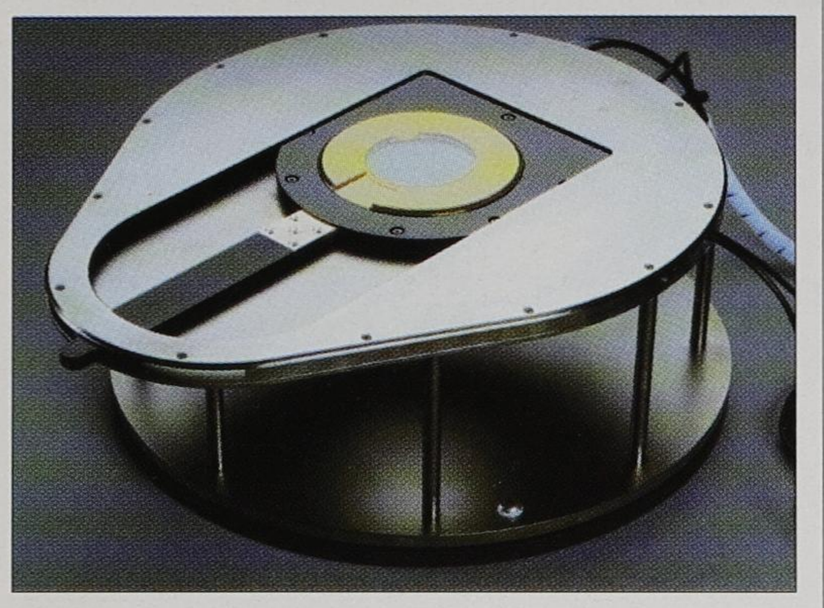
About Caldus

Caldus Semiconductor Inc was founded as 3C Semiconductor Corporation at the Oregon Graduate Institute of Science and Technology (OGI) to develop and market unique SiC devices. Caldus has created proprietary technology in response to a growing demand for semiconductor devices that operate reliably at much higher frequencies, power levels and temperatures than existing silicon devices. Three patents have been issued to the company and three more applications have been filed. Caldus believes that its technology will create products with significant performance and cost advantages relative to competitive products for some high-temperature applications. This market is the focus of the International High Temperature Electronics Conferences held in Albuquerque, NM every two years.

The Oregon Research and Technology Development Fund (ORTDF) and OGI supported the SiC technology program within OGI. Additional venture-capital financing has been committed to Caldus, which has also won SBIR Phase I and II contracts from the Ballistic Missile Defense Organization.

Donald Hagge is the chief executive officer of Caldus Semiconductor.
E-mail donpdx@home.com.

Probe station allows backside wafer testing



Cascade Microtech's new optical probe station incorporates a novel transparent chuck allowing optical access to both sides of the wafer. This enables optical signal coupling to photodiodes and emitters from all directions, which is essential for flip-chip photonic device testing. The chuck window can be coated with a transparent conductive layer of indium tin oxide for backside ground or bias connections.

Device handling is also simplified with a pullout tray for loading and quick sample alignment. The chuck, which is available as an upgrade to some Cascade probe stations, has a method to reduce stray capacitance to a value below 2 pF, and current measurement in the femtoamp range.

Contact Ellen Payne, Cascade Microtech, 2430 NW 206th Avenue, Beaverton, OR 97006, USA
Tel. +1 503 601 1181
Fax +1 503 601 1002
E-mail ellen_payne@cmicro.com

Haleos system aids electro-optic assembly

Current manufacturing and packaging of laser die, VCSELs and silicon optical benches for transceiver modules all require precision tolerances. Haleos has responded to the demand with its new fluxless sub-micron alignment and bonding system for high-volume electro-optic assembly and manufacturing.

Achieving alignment tolerances considerably lower than the 5 μm currently available, the system improves coupling efficiencies between lasers and fibers. In many applications the system eliminates the need for active alignment, and the company claims that its short cycle time allows for high-volume processing.

Contact Tom Zuckerwar, Haleos Inc, 3150 State Street, Blacksburg, VA 24060, USA
Tel. +1 540 552 4610
Fax +1 540 553 3732
E-mail tzuckerwar@haleos.com

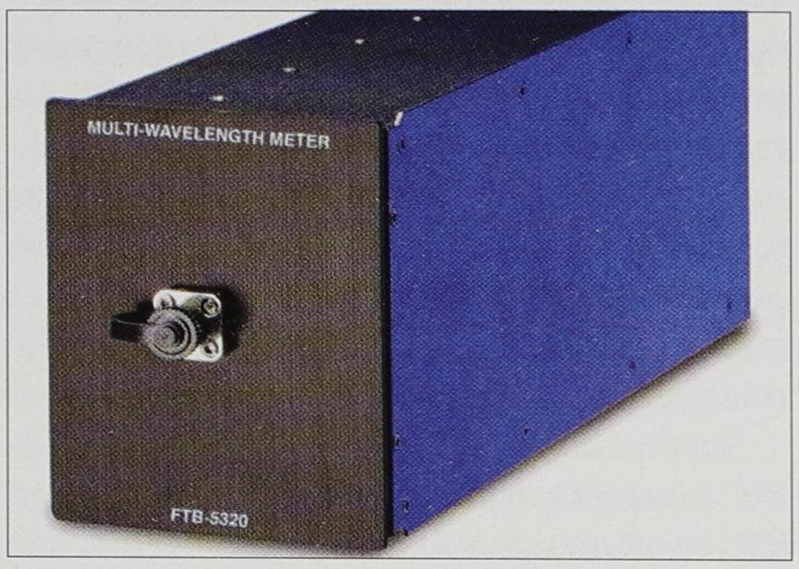
Mindready introduces alignment platforms

Mindready Solutions has introduced an active alignment automation system for the assembly of optical components that reduces overall test and automation costs. Combining the company's PXI nano-positioning, robot handling and artificial vision platforms with its hardware and software integration capabilities, Mindready's alignment platform allows automatic precision alignment of lenses and fibers.

Contact Tom Poitras, Mindready Solutions Inc, 2800 Avenue Marie-Curie, St-Laurent, Quebec, H4S 2C2, Canada
Tel. +1 514 339 1394
Fax +1 514 339 1376
E-mail tom.poitras@mindready.com

Multi-wavelength meters from EXFO

EXFO Electro-Optical Engineering has increased the dynamic range of its field-ready and manufacturing plant multi-



wavelength meters to 55 dB (from –45 to +10 dBm) to allow detection of low-power peaks on long-haul DWDM networks.

EXFO has also improved the wavelength accuracy and signal-to-noise ratio of its meters used in optical test instruments, which target telecommunications carriers and systems manufacturers. The FTB-5320 and IQ-5320 testers are housed in separate modular test platforms and can be combined with other test modules, such as an optical spectrum analyzer, to fully characterize an optical network and its related components.

Contact Glenna Malleau, EXFO, 465 Avenue Godin, Vanier, Quebec, GUM 3G7, Canada
Tel. +1 418 683 0211
Fax +1 418 683 2170
E-mail glenna.malleau@exfo.com

New monitors for CVD and etch processes

Two new *in situ* process-monitoring systems designed to improve component productivity using residual gas analysis have been unveiled by MKS Instruments. The Spectra Vision 1000-C tracks gas species during chamber clean, passivation sequences and deposition steps during



various CVD processes, including growth of titanium nitride and tantalum oxide, in addition to atomic layer epitaxy and MOCVD. The Vision 1000-E monitors plasma and high-density plasma etching, RIE and microwave etching.

Both systems offer detection limits below 200 ppb (for non-interfering species), and combine a closed ion-source analyzer with a close-coupled automated inlet to monitor the complete CVD or etch process cycle.

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

Keithley upgrades C-V measurement system

Keithley has added new capacitance software to its 4200-SCS characterization system. The upgraded collection of

instrument drivers and test libraries enables simultaneous high frequency and quasi-static C-V measurements on wafer devices with a single voltage sweep – half the sweep time required for sequential measurements – and increases productivity.

The technique also reduces the voltage stress on the devices under test and eliminates the need for theoretical curves and doping profile assumptions. Supporting Keithley's model 590 and 595 C-V meters, and those from other vendors, the 4200-SCS also provides built-in prober control.

Contact Ellen Modock, Keithley Instruments Inc, 28775 Aurora Road, Cleveland, OH 44139-1891, USA
Tel. +1 440 498 2746
Fax +1 440 248 6168
E-mail modock_ellen@keithley.com

Karl Suss develops on-wafer prober

Karl Suss has developed the |Z| Probe tip for on-wafer testing of transistors, diodes, filters, amplifiers, high clock rate data circuits and RF circuits up to 65 GHz.

Developed in co-operation with Rosenberger, the impedance-controlled probe tip differs from probes that make the transition from coax to planar at the tip, which causes measurement interference requiring balancing out of the result. The new design makes the transition from coax to planar within the probe body and completely isolates it with air to ensure minimal insertion loss.

Contact Fiona Kemp, Karl Suss Dresden, Strasse 1, D-01561 Sacka B, Dresden, Germany
Tel. +49 35240 73 349
Fax +49 35240 73 750
E-mail fkemp@sussdd.de

Polisher removes electronic circuits

The Multipol 8FA precision polisher from Ultra Tec offers the ability to de-layer electronic circuitry from the front side of die with sub-micron accuracy. A higher degree of surface flatness can be obtained – in comparison with existing 'off the lap' machinery – as a result of the true flat lapping technology, which relies on the system's precision polishing jig that holds



the sample and rides on the surface of the polishing plate.

Furthermore, the Multipol 8 offers improved control and precision in cross-sectioning, electron microscopy and backside sample preparation.

Contact Tim Hazeldine, Ultra Tec Mfg Inc, 1025 E Chestnut Ave, Santa Ana, CA 9270, USA
Tel. +1 714 542 0608
Fax +1 714 542 0627
E-mail tim@ultratecusa.com

Retrofit gas purifiers suit GaN and GaAs

Aeronex is offering a gas purifier retrofit package for GaN and GaAs MOCVD tools used in the manufacture of device circuits, LEDs and optoelectronics. These packages allow users to upgrade the performance without modifying existing plumbing.

The GaN package purifies nitrogen, hydrogen and ammonia gases, while the GaAs package purifies nitrogen, hydrogen, phosphine and arsine. Based on the company's GateKeeper purifiers, these systems operate at ambient temperature, and require no heat or external power.

Contact Jeff Spiegelman, Aeronex, 6975 Flanders Drive, San Diego, CA 92121, USA
Tel. +1 858 452 0124
Fax +1 858 452 0229
E-mail info@aeronex.com

IEM liquid scrubber comes in handy size

IEM Technologies has introduced a compact version of its Gemini Mark 2 liquid scrubbing system. The Gemini waste management range treats hazardous, toxic and pyrophoric gases during epitaxial growth (e.g. MOVPE and CVD) of microelectronics and optoelectronics devices, LEDs and solar cell manufacture.

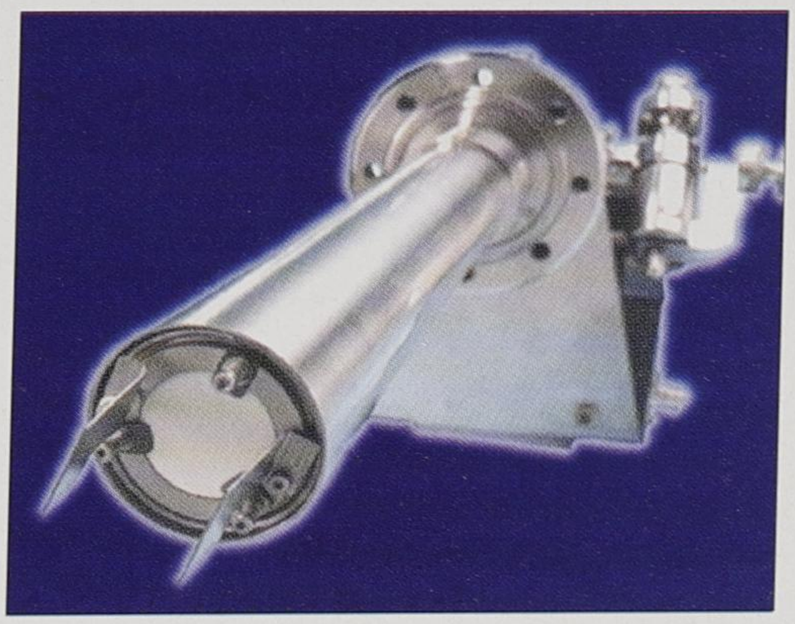
Designed for the needs of smaller operations running one or two compound semiconductor growth reactors, the system delivers the same continuous operation as the full-sized Gemini but with low volume production economics.

Handling up to two liters per minute of hydride gases, the Gemini Compact is available in either fully or partially automated models. The fully automated option provides automatic dosing, draining and water fill, while the partially automated scrubber provides automatic dosing only.

Contact Sally Kavanagh, IEM Technologies Ltd, Unit 6, Fothergill House, Colley Lane Industrial Estate, Bridgewater, Somerset TA5 5JJ, UK
Tel. +44 1983 761004
E-mail sally@masthead-publicity.co.uk

N and O atom sources include beam shaping

Oxford Applied Research (OAR) has announced a new range of RF atom sources for zero-damage oxide and nitride film growth over large areas. The new design encompasses beam shaping of the atomic flux to allow high uniformity to be achieved over substrate platens of up to 12 inches in diameter. OAR sources have been



employed in applications such as GaInNAs, GaN, ZnO and ultra-thin Al_2O_3 and deposition of high-k dielectric oxide layers.

Contact Lars Allers, OAR, Crawley Mill, Witney, Oxfordshire OX29 9SP, UK
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Mixed signals on recovery

As the war with Afghanistan gets under way there is not much good news in the quarterly earnings reports – but have the analysts on Wall Street already factored that into their calculations?



The downward spiral of share prices seems to have stopped, and even partially reversed.

Unsurprisingly, there hasn't been much good news reported thus far in the third-quarter earnings "season". There are a few isolated bright spots, but for the most part revenues are down, profits are scarce and the outlook remains murky as no-one is really sure when the communications market will recover and what the long-term impact of the military campaign in Afghanistan will be.

Nevertheless the downward spiral of share prices seems to have stopped, and even partially reversed. Wall Street likes to credit itself with thinking six months ahead, so perhaps analysts have already factored in all the bad news in advance, and are now looking to start placing their bets again.

The Compound Semiconductor Index

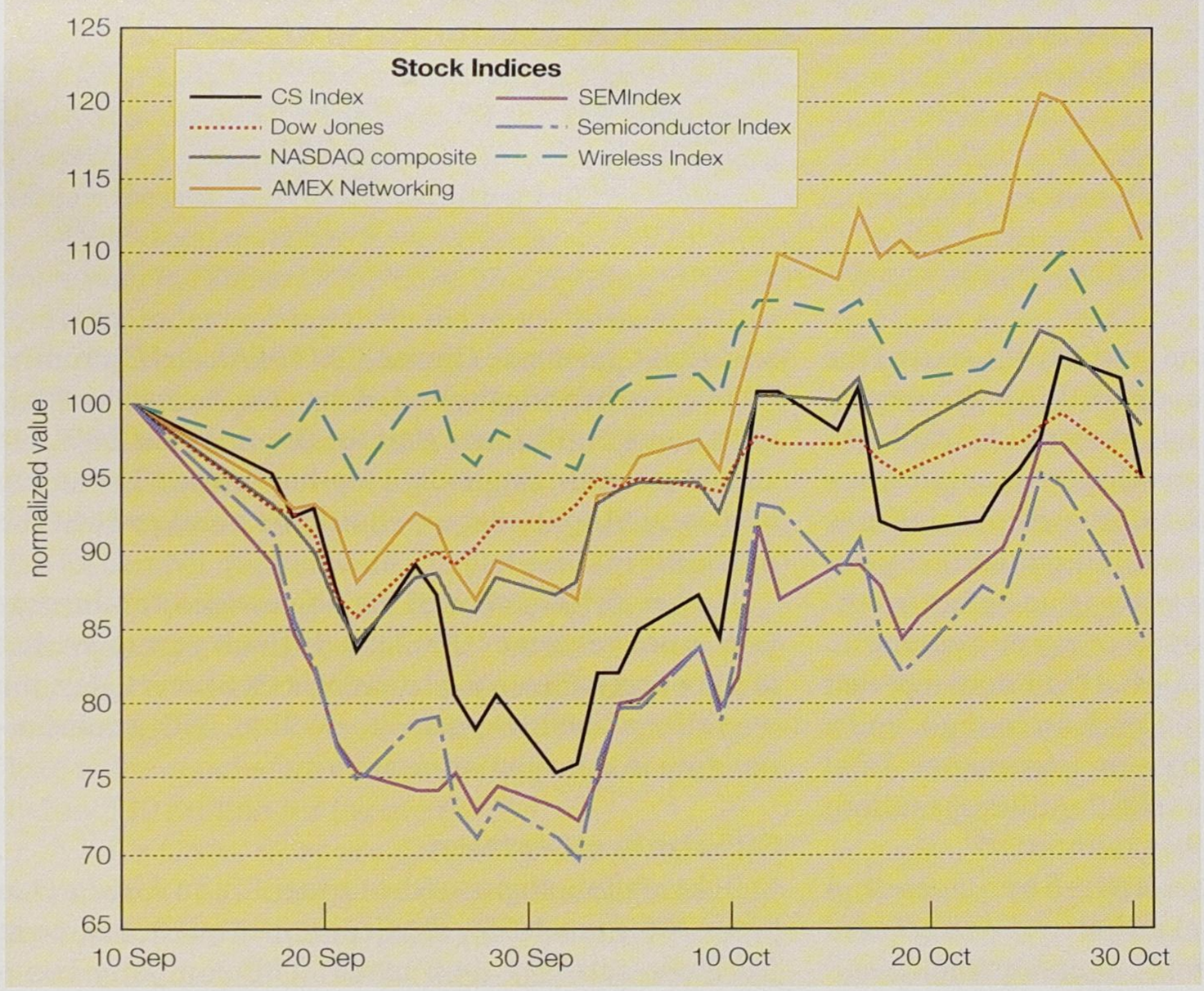
The chart below continues the project that was launched in our previous issue – creating a simple Compound Semiconductor Index that can be compared with major indices to illustrate how the companies in our industry are faring relative to larger markets. The index comprises the US companies listed in the table on the following page. (We hope to add the European companies next month.)

This "CS Index" showed a 17% drop in our last issue, falling with the rest of the market after 11 September, and it fell another 15% in the following weeks. However, it has now rebounded to within 5% of its 10 September level. It is holding up significantly better than both the Philadelphia Semiconductor Sector Index, which comprises 16 of the most widely held semiconductor-related stocks (down 16%), and the SEMIndex, which is made up of 65 semiconductor equipment and materials companies (down 11%).

But the real news for this month is the surge in enthusiasm for networking stocks, as represented by the 11% increase in the AMEX Networking Index, which includes 15 of the largest network equipment-makers like Nortel, Alcatel Lucent, 3Com, Cisco and Ciena. Unfortunately it is still too early to tell whether this is the infamous "dead cat bounce", or whether it is a sign of renewed confidence in the sector.

In our previous issue we noted that it was the companies with significant exposure to the wireless and military markets that were keeping the CS Index afloat. Examples included Alpha, TriQuint and Anadigics. Since then the pendulum has swung over to the companies most active in the fiber communications field, including Alcatel Optronics (up 36% since 1 October), JDS Uniphase (up 20%), Vitesse (up 17%), Stratos Lightwave (up 15%) and Emcore (up 35%).

Semiconductor indices



Opto results

One company not benefiting from the mini-opto rally is JDS Uniphase, whose shares dropped more than 11% on 26 October after the company posted another steep loss and said it expects sales to drop further. For the third quarter JDSU posted a loss of $1.2 billion on revenues of just $329 million, which is less than half the revenues reported a year ago. The company needs to achieve revenues of $350 million per quarter just to break even.

Shares fell by $1.19 to close at $8.77; the company was the third most active stock on NASDAQ for the day, with more than 60.8 million shares changing hands.

Company executives warned that the continued weak demand for optical components would depress sales a further 10–15% in the December quarter as it completes a massive restructuring program. JDSU has reduced its payroll by more than half to 13 000 and closed 17 sites at a total cost so far of about $778 million.

Recovery is not expected until at least the end of

Recovery is not expected until at least the end of the second quarter of 2002 and possibly the start of the third, according to JDS Uniphase executives.

Market overview

Company	Symbol	Closing price on 30 Oct	52-week low–high	Market cap*	P/E ratio**
GaAs IC companies					
Alpha Industries	AHAA	23.34	13.0625–55.3750	1.026B	118
Anadigics	ANAD	14.90	10.2200–25.7500	452.3M	N/A
Celeritek	CLTK	12.31	9.8125–50.0625	148.1M	N/A
Conexant	CNXT	10.15	6.5700–33.5000	2.561B	N/A
Endwave	ENWV	0.83	0.6000–17.6250	29.3M	N/A
Multilink	MLTC	4.57	3.2000–18.4000	427.4M	N/A
RF Microdevices	RFMD	20.44	8.7500–37.5000	3.370B	N/A
Sirenza Microdevices	SMDI	3.56	2.9800–42.2500	104.7M	N/A
TriQuint	TQNT	17.69	10.2500–61.5625	2.294B	40.29
Vitesse	VTSS	9.44	6.6500–81.9375	1.798B	N/A
Opto companies					
Agilent	A	22.27	18.0000–68.0000	10.258B	23.37
Agere	AGRa	4.60	3.1000–9.5000	7.521B	N/A
Alcatel Optronics	ALAO	7.99	4.0400–68.0000	131.8M	5.96
Coherent	COHR	26.51	25.0500–53.7500	750.1M	29.21
Cree	CREE	17.95	12.2100–64.1250	1.309B	59.13
JDS Uniphase	JDSU	8.09	5.1200–83.0000	10.713B	N/A
Stratos Lightwave	STLW	4.10	3.1800–27.6250	262.8M	N/A
Uniroyal Technology	UTCI	3.02	2.0800–10.3750	84.6M	N/A
Semiconductor materials and equipment companies					
ATMI	ATMI	19.19	14.3750–32.7300	582.6M	100.82
AXT	AXTI	10.92	9.9000–46.4375	243.8M	9.19
Emcore	EMKR	11.16	7.6700–55.3750	385.2M	N/A
Kopin	KOPN	12.56	4.0000–17.7500	817.4M	N/A
Tegal	TGAL	1.35	1.0000–4.5000	17.0M	16.5
Trikon	TRKN	8.51	6.9600–17.6875	109.1M	3.99
Veeco	VECO	25.48	19.9000–72.0000	632.1M	20.96
European companies (currency data in €)					
Aixtron	AIXG.F	20.90	13.50–59.85	1.35B	N/A
Bede	BED.L	2.59	1.93–3.53	75.03M	N/A
Filtronic	FTC.L	3.42	1.37–8.54	252.08M	N/A
IQE	IQE.L	2.25	1.39–4.51	368.95M	112.7
Picogiga	PGIG.LN	4.09	2.60–34.00	26.43M	N/A
Riber	RIBE.LN	3.70	2.51–23.00	69.26M	9.02
ST Systems	SRTS.L	1.95	1.61–4.11	61.10M	18.39

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

the second quarter of 2002 and possibly the start of the third, said executives. "We are still in a downturn, although the rate of descent has moderated," said JDS chief financial officer Anthony Muller in a conference call with investors. "The sales levels we are seeing now are depressed because of inventory liquidation by our customers. Sales can begin to grow again before inventory liquidation is complete at all of our customers."

For the September quarter Alcatel Optronics reported a 24% drop in sales compared with a year ago, and a 37% decline compared with the previous quarter. Total revenues were €95.0 million ($86.1 million) resulting in a loss of €10.1 million ($9.15 million).

"The third quarter was characterized by a steep drop in our revenues. Our 'breakeven barrier' was crossed and our margins were therefore adversely impacted," said Jean-Christophe Giroux, CEO of Alcatel Optronics. "As we are nearing the end of the year, we can now say with some confidence that for the full year 2001 we should see mid-, single-digit top-line growth. Excluding non-recurring items, we should be breakeven at the operating income level."

However, he cautioned that the outlook for the next year is not yet clear. "2002 is a difficult year to predict in its entirety. Given the situation as we see it today, the overall top line is expected to decline, with a substantial drop in our submarine activity."

Substrate slowdown

In light of the collapse of the former Litton Airtron (see p4), AXT's results for the September quarter came in for more scrutiny than usual. The company has a

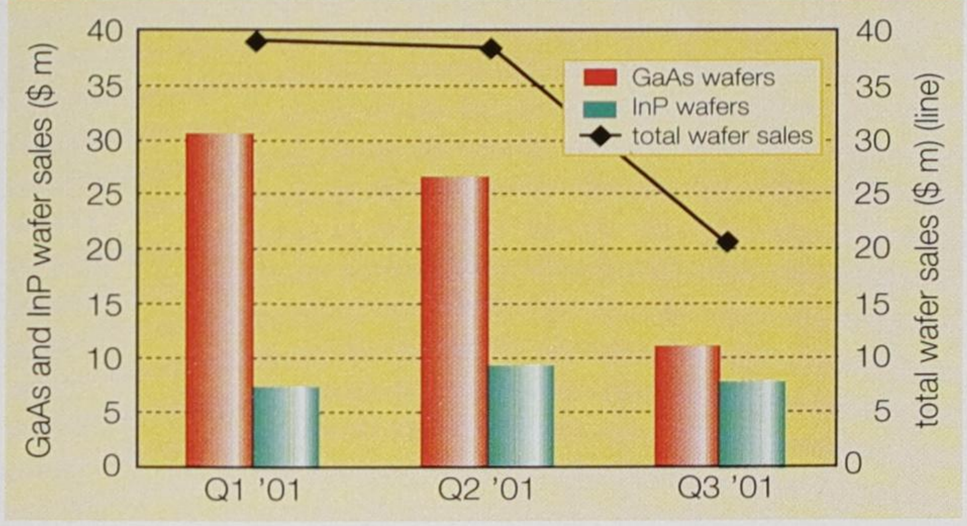
New entries in the Portfolio table

Four companies have been added to the Compound Semiconductor Portfolio:

- Multilink Technology of Somerset, NJ, a fabless designer of digital and mixed-signal semiconductors for optical networks. Multilink outsources production to foundries such as TRW for III-Vs and IBM for SiGe.
- Stratos Lightwave of Chicago, IL, a manufacturer of optical components and sub-systems for the data communications market. Its compound semiconductor operation, known as Bandwidth Semiconductor, was acquired from Spire in 1999 and is located in Bedford, MA.
- Veeco Instruments of Woodbury, NY, a manufacturer of semiconductor equipment. Veeco recently acquired MBE equipment manufacturer Applied Epi; it also supplies PVD systems for GaAs fabs.
- ST Systems of Newport, Wales. Another addition to our growing list of European companies, ST Systems manufactures etching and deposition equipment.

There is yet another new name in the table – Sirenza Microdevices. But Sirenza is not a new company, just the new identity of Stanford Microdevices, which lost its legal fight with Stanford University to keep using its original name. The ticker symbol remains the same.

Wafer sales at AXT



comparably good balance sheet and is not in any danger, but nonetheless its results could not have cheered its investors.

Substrate sales showed a sharp decline, with GaAs shipments down nearly 60% and InP sales down 17% compared with the previous quarter (see chart). Sales of large diameter (5 and 6 inch) GaAs substrates were hit particularly hard, dropping from $8.5 million in the June quarter to $1.6 million. Of the InP shipments, roughly 65% were destined for optoelectronic operations – the rest went to the fledgling InP IC market.

AXT's total revenues for the quarter were $22.8 million, with the substrate division contributing 90% and the remainder coming from the optoelectronics division. Optoelectronic shipments consisted primarily of LEDs. The company posted a net loss for the quarter of $1.4 million, compared with a profit of $5.2 million for the second quarter.

AXT executives said that results would worsen in the December quarter, with sales of both GaAs and InP substrates continuing to decline. Sales of Ge substrates are expected to increase and the optoelectronics division, driven by LED orders, should reach record levels, accounting for 21–29% of revenues. These comments lead to the conclusion that total substrate sales may dip below $10 million for the quarter.

AXT's GaAs sales are declining sharply at a time when signs of a recovery are visible, at least in the wireless area. This is traditionally AXT's largest market, accounting for 40% of GaAs sales. CEO Morris Young said that while the company is seeing new orders from some of its wireless customers, many are still working through "substantial" inventory levels, which is delaying the onset of recovery in this area.

As noted previously (see *Compound Semiconductor* July 2001, p94), analysts had predicted that AXT's GaAs business would lag the market both on the downside and the upside because of its use of long-term fixed-priced supplier agreements.

Young also said that while AXT remains committed to the plan for outsourcing portions of its production to China (to take advantage of lower labor costs), the company has recently scaled back its production ramp there in light of the general slowdown.

Kopin rebounds

Revenues at Kopin have picked up somewhat, following a disastrous second quarter that saw GaAs epiwafer shipments drop to $3.8 million, compared with $19.5 million in the same quarter last year. In fact the company exceeded even its own expectations by posting a total revenue of $12.3 million and a net loss of $9.9 million, compared with a net loss of $15.2 million for the previous quarter.

Revenue from III-V products was $5.6 million, down considerably from the $17.9 million reported in the year-ago quarter, but up 47% over the previous quarter. "The wireless handset market began to rebound in the third quarter, fueling sequential revenue growth of 47% in our III-V business," said John C C Fan, Kopin's chairman and chief executive officer. He indicated that the company is receiving orders from new customers as well as a resumption of shipments to long-time accounts, including, presumably, Conexant (traditionally Kopin's largest customer).

"Our third-quarter results indicate that handset OEMs have worked through the excess inventory of the past several quarters," said Fan. "They are now focused on ordering components for new models being introduced in early 2002, so we again look for sequential top-line growth in the fourth quarter." He predicted that the III-V business would show double-digit growth again in the December quarter.

The wireless handset market began to rebound in the third quarter, fueling a 47% sequential increase in Kopin's III-V business.

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MRS Fall Meeting
Boston, MA, US
Web: www.mrs.org/meetings

2–5 December
International Electron Devices Meeting (IEDM)
Washington, DC, US
Web: www.his.com/~iedm

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

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

7–8 March
Key Conference 2002: Compound Semiconductors in Communications
Key West, FL, US
Web: www.keyconference.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, US
Web: www.osa.org/mtg_conf/

18–20 March
International Symposium on Quality Electronic Design (ISQED)
San Jose, CA, US
Web: www.isqed.org

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

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

16–18 April
Semicon Europa
Munich, Germany
Web: www.semi.org/web/wexpositions.nsf

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

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

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

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

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

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Advertisers' Index

Accent Optical Technologies	23	Logitech	61
Aixtron	5	Loomis	30
Applied Epi	6,7	Omicron	13
AXIC	27	Oxford Applied Research	10
AXT	IBC	Philips Analytical	52
Bede Scientific Instruments	34	Picogiga	72
BOC Edwards	33	QinetiQ	71
Bruker AXS	43	Raboutet	58
CS Clean Systems	39	RF Nitro	17
Cutting Edge Optronics	36	Riber	28
DCA Instruments	14	Rohm & Haas	55
Dynatex International	51	Solkatronic Chemicals	68
Emcore	ii, 21,67	Spectrolab	17
Epichem	44	Sterling Semiconductor	62
Epitaxial Technologies	71	Strategies in Light conference	78
EpiWorks	40	TDI	10
Hitachi Cable	26	Thermo VG Semicon	OBC
IEM	12	Thomas Swan Scientific Equipment	65
Indium Phosphide conference	70	Trikon Technologies	46,47
Insaco	26	Unaxis	18
IQE	8	Veeco	49
Knowledge*on	56	Wafer Technology	24

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