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SEMICONDUCTOR

Winter 1 - February, 1998

Volume 4 Number 1

THINGS to WATCH in 1998

- 6" GaAs
- High Data Rate Fiber
- Silicon Germanium
- Catching up with Nichia

New & Improved
for 1998 - see page 4

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GaAs

AlGaAs

InGaAlP

InP

InGaAsP

InAlAs

GaN

InGaAlN

GaP

InSb

SiC

CdZnTe

ZnMgSSe

ZnO

BaSrTiO

PbZrTiO

SrBaTi(N)

SrTiO

YBaCuO

Si

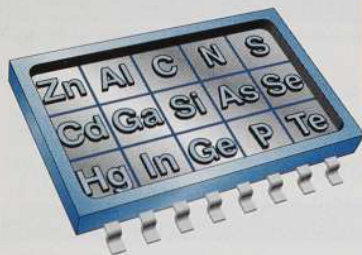
SiGe

Cu

W

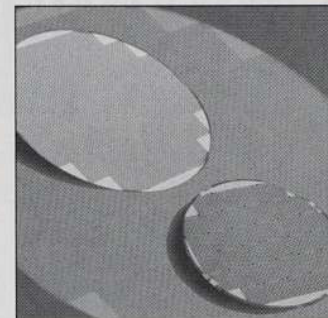
Pd

TiN



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26 Dense wavelength Division Multiplexing

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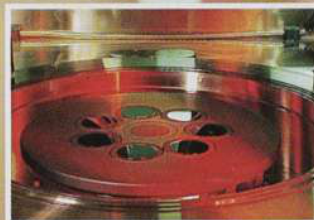
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Welcome to Our First Issue in 1998!

We are introducing some improvements to our publication in 1998 that I would like to tell you about.

The biggest change is that we are increasing our frequency of publication to 9 times a year. This will allow us to bring you more news and information, in a more timely fashion.

We are also introducing some new sections to the magazine in this issue. On page 21 you will find the "Silicon Update", a new feature from our Microelectronics Editor Bob Metzger. It will highlight the latest IC and device results from the Si field, with special emphasis on those technical and market areas which are in direct competition with compound semiconductors.

Also new in this issue is our "New Products/New Literature" section, which begins on page 40. Here you will find information about the latest offerings from companies and organizations which support the compound semiconductor industry.

Most importantly, this issue marks the debut of our new Assistant Editor, Tim Whitaker. Tim received his Ph.D. in semiconductor epitaxy and precursor synthesis from Oxford University. More recently he was with the Electronics Department of the Defense Evaluation and Research Agency (the former Royal Signals and Radar Establishment, or RSRE) in Malvern, England. While at DERA, Tim worked first in III-V epi growth, and more recently in business development.

We think Tim will be an excellent addition to our staff, and we are very pleased to have him on board.

Best wishes to all of our readers for a happy and prosperous new year!

Marie Meyer

Marie Meyer
Editor

NEWS BRIEFS

TriQuint Acquires TI GaAs Operation

On January 13 TriQuint Semiconductor closed a deal to acquire the MMIC operations of the former Texas Instruments' Defense Systems & Electronics Group from Raytheon Co. for about \$39 million. The purchase price will be paid half in cash and half in TriQuint stock.

Raytheon acquired the Dallas-based GaAs fab last year as part of its \$3 billion acquisition of the entire TI defense systems business. However, it was forced to sell the operation by the U.S. Justice Department, due to concerns over Raytheon building up a monopolistic position in the supply of GaAs MMICs for millimeter wave radar transmit-receive modules by combining the TI GaAs operation with its own GaAs fab in Andover, MA.

According to TriQuint, sales from the former TI fab were around \$35 - \$40 million in 1997 - though some analysts suggest \$25 - \$30 million is more likely. The operation employs 300 people, including 50 RF and microwave circuit designers. It will remain on the TI campus in Dallas, though it will be consolidated from the two current locations into one 100,000 sq. ft. area leased from TI.

The acquisition will roughly double TriQuint's size, and will also give the company access to a new range of technology. Until now TriQuint has produced only GaAs MESFETs, with a roughly

75%/25% split between analog and digital applications. Their primary area of specialization has been receiver ICs for wireless applications at <5 GHz. TI has been a major provider of foundry and custom high frequency MMIC design services, as well as offering standard MMIC products such as PAs, gain blocks, switches, and control products. Processes at the TI fab include HFET, 0.25 μ m low noise MESFET and HEMT, 0.5 μ m power MESFET and HEMT, and low noise and power HBT.

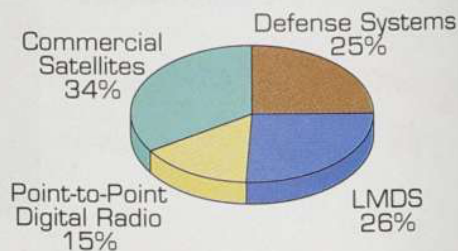
"This acquisition will provide TriQuint with the strategic capabilities to be the leader in the emerging and potentially enormous markets for very high performance GaAs integrated circuits" said TriQuint President Steve Sharp. "It will provide us with a two year head start over our competition in the emerging high end commercial markets. Companies are rarely presented with this type of opportunity and we are extremely pleased with our ability to forge a win-win situation for both TriQuint and Raytheon. In fact, TriQuint will have immediate revenue flow by continuing to be a major supplier to Raytheon and to the existing customer base for advanced defense systems and high performance commercial applications. Going forward, our intention is to continue to support these applications while intensifying the focus on the emerging commercial markets."

Con't on page 6

TriQuint's new Fab at a Glance

- 1997 Sales: \$35 Million (est.)
- 2000 Sales: \$100 Million (projected)
- Major Customers: Raytheon
Hughes
Alcatel
Bosch
Lockheed-Martin
- Capacity: ~12,500 4" wafers/year
- Processes: MESFET, HFET, HEMT, HBT
- Capacity Utilization:
40% military/60% commercial
- Employees: 300
- Location: Dallas, TX

The Market for MillimeterWave GaAs ICs in Year 2000



Total Value = \$400 Million

TriQuint's assessment of the market for millimeter wave (>10 GHz) GaAs ICs in the year 2000.

EPI

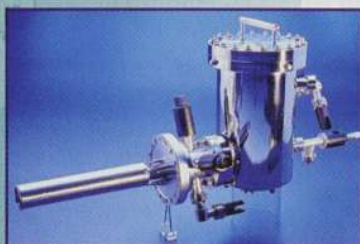
**MBE Products
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SUMO™ Cells
Patent Pending



UNI-Bulb™ RF Plasma Source
Patent Pending



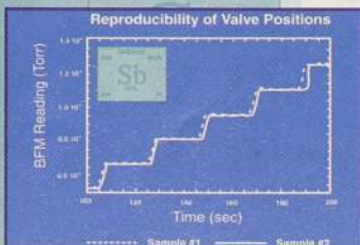
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**Mark IV Valved Cracker
for Phosphorus**
Patent Pending



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New Markets for TriQuint

TriQuint forecasts a \$400 million market for millimeter wave GaAs ICs by the year 2000, broken down into four major application areas: defense systems, point-to-point radio, multi-point distribution systems (also called LMDS), and commercial satellites. See chart, page 4. Commenting on the defense business - a traditional strength of the TI GaAs operation, accounting for 40% of its 1997 sales - TriQuint CEO Steve Sharp said "TriQuint expects to enjoy excellent business from this sector and attract more business from the other defense system companies who would, prior to this acquisition, not consider using a competitor, i.e. Raytheon or TI Systems, as a supplier. There should be no doubt TriQuint plans to continue to support the DOD programs and be an aggressive competitor." TriQuint believes it will be one of the two top suppliers in the defense market, with Raytheon as their main competitor. Raytheon will also be an important customer, because they now own all of the other parts of TI's defense business.

In addition to defense electronics, TriQuint has also acquired some ready-made business in the newly emerging LMDS field, which will use a recently-allocated frequency band around 28 GHz to supply bandwidth to homes and offices for applications such as high speed Internet or video telephony. Last year Bosch Telecom bought the entire Texas Instruments LMDS operation, and has since been developing equipment based on MMICs from the TI GaAs fab. Sharp indicated that he expects volume business with Bosch and possibly other LMDS vendors to begin in the first half of this year.

Sharp also said that he expects demand for "tens of millions of millimeter wave GaAs ICs" from commercial satellite vendors over the next 10 years. "These customers are already major TriQuint customers and have been urging us for years to develop higher performance technology", Sharp said. "The new Texas operation complements our Oregon foundry and positions us as the largest foundry service serving the entire communications spectrum."

All This for \$39 Million?

Possibly the most surprising aspect of this transaction is the purchase price - \$39 million, which is less than 2x current sales. Other companies which had looked at the TI operation say they were concerned about the low level of revenue per employee (~\$100,000). In addition, some investment analysts have expressed concerns over whether the operation is in fact currently profitable and capable of making a contribution to TriQuint's bottom line in the near future. TriQuint officials, however, say that they believe the operation to be currently profitable.

Watkins-Johnson to Acquire Samsung Microwave Semiconductor

In the other big GaAs transaction of the month, on January 5 Watkins-Johnson Company (Palo Alto, CA) announced plans to purchase the assets of Samsung Microwave Semiconductor (SMS), Inc. (Milpitas, CA). The terms of the acquisition were not disclosed, although the purchase price has been variously reported as between \$5 - \$10 million.

The SMS operation will become part of WJ's Wireless Products Group, currently based in Palo Alto. The company says it plans to gradually transfer its Palo Alto semiconductor manufacturing operations to the Milpitas facility where SMS is located.

The SMS fab includes a 3" and a 4" processing line, with capacity for around 20,000 wafers/year. It is equipped for 0.5 micron MESFETs and PHEMTs.

"Our acquisition of SMS moves WJ toward the strategic objective of expanding our gallium-arsenide and thin-film manufacturing capability to enhance our position as a supplier of advanced radio-frequency devices to the wireless communications industry," said Malcolm J. Caraballo, president of Watkins-Johnson's Wireless Products Group.

WJ has traditionally used its semiconductor operation as a captive supply for its military and space electronic business, but in 1997 it began an active effort to transform itself into a merchant semiconductor company for the wireless industry. In October the company sold-off its defense electronics business, but opted to hang on to its GaAs fab (CS 3(6), p. 30). The addition of the Milpitas fab facility is intended to allow WJ greater access to high volume wireless markets.

Samsung bought SMS from Harris Semiconductor in 1993. After spending three years and \$20 million to re-orient the company from military to commercial markets, SMS introduced its first RF products, a low-noise amplifier and two voltage-variable attenuators, last year.

Although Samsung, like virtually all other Korean companies, is current-

Application Update

In the late 1980s, when Anadigics first switched from military to commercial applications, GaAs ICs for DBS were their first product line. Their current offerings include downconverter ICs for the Ku-Band low noise block in the dish, plus a tuner IC in the set-top converter box.

DBS accounted for 23% of Anadigics sales in 1996. But what will happen as this market segment matures? According to Tom DeNigris, DBS Sales Manager, growth has begun to slow, but is still 10 - 15% per year. See Chart. In addition, competition is heating up, forcing the company to focus on cost, especially by using plastic instead of metal packaging. Eventually, he foresees DBS moving to higher frequencies to enable interactive satellite and digital radio. Which should be good news not just for Anadigics, but for other GaAs suppliers as well.



ly strapped for cash, most observers think that the timing of the deal and the small value of the transaction suggest that the fab was not sold because of the Asian financial crisis. A company spokesperson said that Samsung had decided that the GaAs market was too small to justify any further investment.

WJ had 1996 sales of \$438 million, of which \$349 million represents continuing operations after the divestiture of the defense electronics unit.

MCI Sends 80Gbit/s Down A Single Optical Fiber

MCI recently became the first service provider to carry live commercial voice and data traffic on an 80Gbit/s optical link through a single fiber. This was achieved by using dense wavelength division multiplexing (D-WDM) to combine 8 wavelength channels each operating at 10Gbit/s (the SONET OC-192 standard). The link, which was opened on a 170-mile section of MCI's network between Los Angeles and Rialto, CA, is enabled by components supplied by Nortel, based on their 10Gbit/s S/DMS Transport Node OC-192 system.

Although this is the first use of an 8-channel D-WDM system at OC-192, systems with up to 16 channels are widely deployed elsewhere at lower data rates. MCI claim that over 70% of their network now incorporates WDM, with tremendous cost savings. Installing new fiber starts at around \$70,000 per mile and is much more expensive in densely populated areas, whereas D-WDM now offers an alternative to laying cable. As Fred Briggs, MCI's Chief Engineering Officer, described, "Using WDM and other technologies, we've been able to put 70 times the capacity on our fiber plant at one-seventh the cost of adding new fiber".

A further advantage of D-WDM systems is that capacity can be turned on when required. Once the fiber is in place, the number of channels can be increased using D-WDM to meet demand, so there is neither a glut nor a shortage of capacity. MCI say that they will eventually reach Terabit per second data rates down a single fiber sometime in the next century, using 32 channel D-WDM operating at 40Gbit/s.

Nortel System Supports 160Gbit/s

The Nortel S/DMS Transport Node OC-192 system, which enables the MCI link, is actually capable of supporting 16 channels, equivalent to 160Gbit/s. The systems utilize 1530-1560nm GaInAsP DFB lasers and III-V Mach-Zehnder modulators in the transmitters, 980nm AlGaAs pump lasers in the EDFAs, and PIN diodes in the receiver. The optical components are manufactured in Ottawa, and packaged in Paignton, UK. Nortel claim to have a market share of upwards of 90% for OC-192 systems deployed in 1998. In addition to MCI, their systems have been utilized by Touch America, Qwest Communications (see CS3(5), p.20), IXC Communications, Electric LightWave Inc. and Norlight Communications. The quoted 10^{-15} Bit Error Rate of their OC-192 systems provides the highest performance in the industry and the 'least cost per bit' operation.

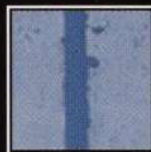
For more on D-WDM, see page 26.

Dry Process III-V Dicing

SCRIBE AND BREAK TECHNOLOGY

SPEED
CONTROL
VERSATILITY
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YIELD

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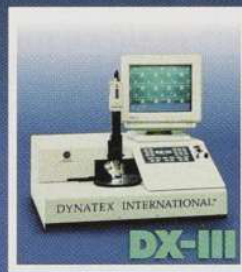
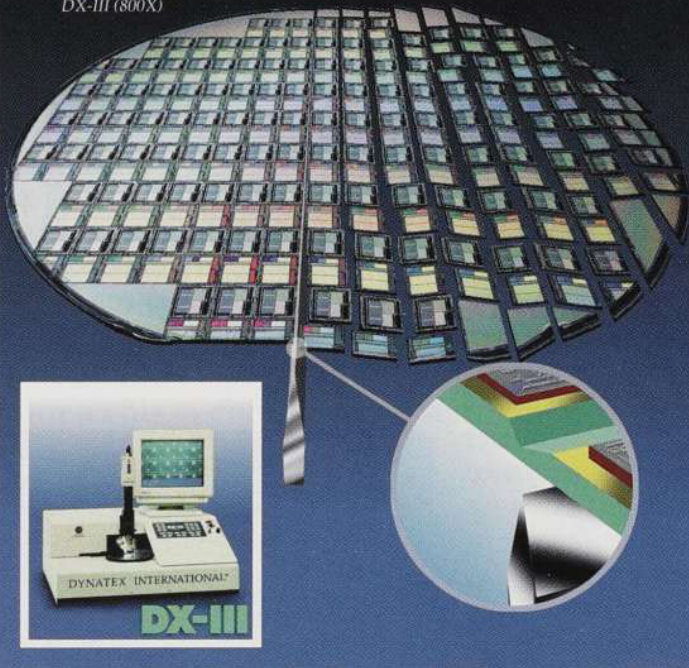
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New Telecom Laser Company

A new laser diode manufacturer, Spectracom, Inc., has been established in White Bear Lake, MN (a suburb of Minneapolis/Saint Paul). The new venture is owned by the same interests which own MBE equipment maker EPI. Spectracom President Andy Quinn says the new company will focus on telecommunication laser diodes, particularly pump lasers for EDFAs (Er-Doped Fiber Amplifiers) for WDM and D-WDM. The first products will be 975 - 985 nm GaAs/AlGaAs diodes, grown by MBE. The primary emphasis will be thermoelectric cooled lasers for terrestrial applications, but Quinn says the company is also setting up a subdivision to produce products using diamond heat sinks, intended for the submarine market.

Quinn says Spectracom will provide fully packaged devices, as well as chips and chips-on-submounts. Plans call for shipping samples in early Spring, and the delivery of fully qualified devices by June, 1998. The company, whose facility includes over 6,000 sq ft of clean room space, plans to employ 40 - 50 people by year end.

Eagle-Picher Expands Solar Cell Substrate Production

Eagle-Picher Industries (Joplin, MO) has completed an expansion in their Germanium Solar Cell Substrate Department, increasing capacity for polished Ge substrates to 3,000 m² per year - the equivalent to 60,000, 6 x 7 cm rectangles, or 30,000, 100 mm dia. wafers. With the building expansion came the procurement of 15 additional Czochralski crystal growth furnaces, several saws, and seven dual arm polishers. The expansion also includes a separate Class 100 final clean and inspection area which allows substrates to be offered in "epi-ready" condition.

Ge substrates are commonly used as a less expensive alternative to GaAs substrates for the production of compound semiconductor solar cells. (See CS 2(6), p.22) Eagle-Picher has been in the solar cell substrate business for over 10 years, in the germanium industry for over 50 years, and the company itself is 150+ years old.



Eagle-Picher

Compound Semiconductor Researchers on 1998 IEEE Fellows List

Several compound semiconductor researchers were among the 235 new IEEE fellows for 1998. The list includes:

- **Rajaram Bhat**, Bellcore, Red Bank, N.J., for contributions to optoelectronic materials and devices through the advancement of organometallic chemical vapor deposition of III-V semiconductors.
- **April Susan Brown**, Georgia Institute of Technology, Atlanta, GA., for contributions to the development of lattice-matched and pseudomorphic high electron mobility field effect transistors.
- **Constance J. Chang-Hasnain**, University of California, Berkeley, Calif., for contributions to electro-optics in the area of monolithic semiconductor laser arrays.
- **Richard Alexander Chapman**, Texas Instruments, Dallas Texas, for the development of HgCdTe imaging devices and contributions to CMOS technology.
- **Young-Kai Chen**, Lucent Technologies, Murray Hill, N.J., for contributions to ultra-short pulse generation using semiconductor laser, integrated laser-modulators, and high frequency InP HBTs.
- **Michael C. Driver**, II-VI Inc., Saxonburg, Pa., for contributions to broadband gallium arsenide power circuits.
- **Barry K. Gilbert**, Mayo Foundation/Mayo Clinic, Rochester, Minn., for developments of improved electronic packaging for high performance gallium arsenide integrated circuits.
- **Khalid Ezz El-Din Ismail**, IBM T.J. Watson Research Center, Yorktown Heights, N.Y., for development of Si/SiGe materials for high performance microwave devices.
- **Richard Arthur Kiehl**, Stanford University, Stanford, Calif., for contributions to heterostructure field-effect transistors and circuits.
- **Conilee G. Kirkpatrick**, Hughes Research Laboratories, Malibu, Calif., for leadership in the development and manufacturing of III-V electronic materials and devices and their application to military and commercial systems.
- **Mohammad Madihian**, NEC, Kawasaki, Japan, for contribution to the design and development of microwave as well as millimeter-wave solid state monolithic integrated circuits for personal computing and wireless networking systems.
- **Hiroiyuki Sakaki**, University of Tokyo, Tokyo, Japan, for seminal contributions to quantum effects in semiconductor nanostructures and devices.
- **Hirobumi Takanashi**, Fujitsu Laboratories, Ltd., Kawasaki, Japan, for leadership and contributions in the development of optical semiconductor devices and transmission systems.
- **Shih-Yuan Wang**, Hewlett-Packard Company, Palo Alto, Calif., for research in and development of photonic high speed detectors and surface emitting lasers.

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Aixtron Conducts IPO

Aachen, Germany. On November 6, 1997, Aixtron AG joined the ranks of the publicly traded compound semiconductor related companies. The company, which is now listed on the Frankfurt stock exchange, raised around 50 Million DM / US\$27.5 million. One million shares, approximately 40% of the company, were offered. Aixtron reports that the offering was more than 30 times oversubscribed. After opening at DM 142, the company was trading at around DM 210 at year end.

In 1996, the last year for which figures are available, Aixtron and arch-rival Emcore were virtually tied for leadership in MOCVD equipment sales. See chart. Aixtron was formed in 1983. The company says it has been profitable in each year of its existence, and it has been growing at around 30% per year for the past few years. The majority of its revenue is derived from the sale of production-scale MOVPE reactors, primarily to large industrial clients such as Ericsson, Hewlett-Packard, Hughes, Kopin, Lucent,

Motorola, Philips, Rockwell, Samsung, Siemens and "numerous Japanese corporations". About 30% of system sales are to research institutions. Over 80% of Aixtron's sales come from outside Europe.

Production capacity has been quadrupled over the last 3 years and staff numbers have increased from 67 in 1994 to around 140 in 1997 with a further increase expected in 1998. In 1996 revenues rose to DM 47.7 million / US\$25 million - an increase of over 70% on 1995. In the same period earnings tripled from DM 1.7 million / US\$0.95 million to almost DM 5.3 million / US\$2.92 million.

Aixtron says it expects to achieve total revenues of around DM 75.5 million / US\$42 million for 1997, and they are forecasting a turnover of DM 100 million / US\$55.5 million for 1998.

The proceeds of the IPO will be used to increase production capacity and to explore new application areas, such as ferroelectrics and dielectrics.

Air Products to Acquire Solkatronic Chemicals

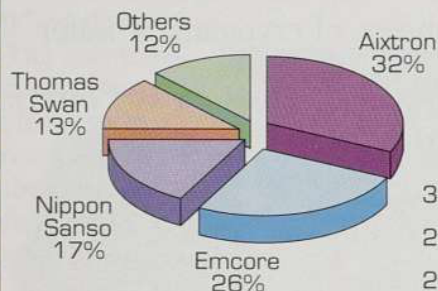
Fairfield, NJ. On November 6, 1997 Air Products and Chemicals, Inc. and Solvay America, Inc. announced they had entered into an agreement for the sale of Solkatronic Chemicals, Inc. to Air Products. Solkatronic manufactures high purity semiconductor-grade gases, including arsine and phosphine, as well as 99.99994% pure ammonia used in GaN processes. The company's headquarters are in Fairfield, NJ, and it operates a specialty gas manufacturing plant in Morrisville, PA and is in the process of starting-up a second production facility in Catoosa, OK. Solkatronic has enjoyed double-digit sales growth for the last 10 years.

E.P.I. to Expand, Offer HBT Wafers

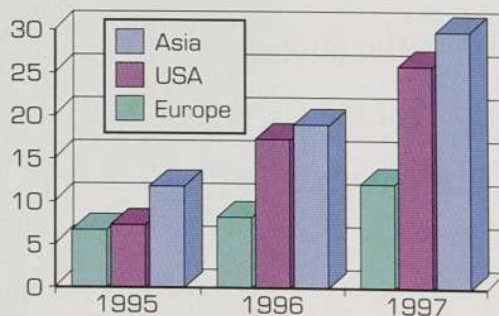
Cardiff, UK. Epitaxial Products International (E.P.I.) has announced plans to expand their MOVPE epi wafer manufacturing capacity. Work is currently in progress to expand their facilities from the current 15,000 sq. ft. to approximately 37,000 sq. ft., which will include more than doubling the clean room production space. According to Drew Nelson, Managing Director at E.P.I., the expansion will allow the company to add on up to eight more MOVPE reactors 'to accommodate increasing demand for our epiwafer products'.

E.P.I.'s traditional strengths lie in the optoelectronics area, and the company claims to be the largest merchant supplier of epiwafers for visible lasers, and the only merchant supplier of epiwafers for VCSELs. But E.P.I. also recently announced that it has begun sampling 3" and 4" C-doped GaInP HBT wafers to key customers. The technology for producing the wafers has been developed, in part, under the European Community ESPRIT project GAMMA (GaAs Materials for Microwave Applications); a project which included, among others, GEC-Marconi, Philips, Siemens, Thomson, and

Who is selling...



...and who is buying



Segmentation of the MOCVD equipment market. Figures for production (left) are for 1996; figures for destination (right) are based on Aixtron's shipments only. Source: Aixtron Prospectus.

United Monolithic Semiconductors. According to the company, consistently high current gains in the region of 100 to 200 have been demonstrated over a range of base sheet resistances from around 200 to 400 ohms/sq. The GaAs base layer is doped using carbon with typical levels between 2×10^{19} and $4 \times 10^{19} \text{ cm}^{-3}$. Hydrogen contamination of the base, a typical problem for MOVPE grown material, has been limited to below the detection limit of SIMS ($<1 \times 10^{18} \text{ cm}^{-3}$). E.P.I. will also offer AlGaAs emitter HBTs.

E.P.I. currently employs 95 people. In 1997, E.P.I. recorded total revenues of \$11 million. According to Nelson, both revenue and profit in 1997 were the best ever for the company.

Epichem Opens New Facility

Haverhill, MA. On December 6, 1997, Epichem officially opened their new \$4.5 million facility for the production of metal-organic precursors in Haverhill, MA. The new plant serves as a duplicate for Epichem's main factory in Bromborough, England. Epichem will also continue to utilize The Air Products facility in Hometown, PA for the production of TBA and TBP.

In other news, Epichem also recently announced that it has established a precursor research facility at the University of Salford, UK. The research will be directed by Prof. Tony Jones, which is the Principal Scientific Consultant to Epichem. Major objectives include the development of new routes to low oxygen precursors, the investigation of second-generation adduct purification techniques, and the use of "designed" precursors to influence MOCVD process.

Epichem was founded in 1983. Its sales have risen from \$7 million in 1992 to \$17 million last year and are expected to reach \$20 million this year. Staffing has increased 50% in the past year to 90.

Acquisition, Alliance for Emcore

Somerset, NJ. December 5 was big day at Emcore, as the company closed an acquisition and a new strategic alliance with a major supplier to the electronics industry.

In the first transaction, Emcore purchased privately-held MicroOptical Devices, Inc. (MODE), which is based in Albuquerque, NM. The all-stock transaction was valued at \$30 million.

MODE, which was founded by scientists and engineers from near-by Sandia National Laboratories and the University of New Mexico, specializes in VCSEL development, pursuing applications such as Internet access, Gigabit Ethernet, LANs, DVD and fiber optic switching. Customers are said to include AMP, IBM, Samsung, Fuji Xerox, Boeing and Northrop Grumman.

"By joining forces, Emcore and MODE are in a strong position to shape both the future of VCSEL technology and the optical communications markets," said Reuben Richards, President and Chief Executive Officer of Emcore. "MODE is a recognized leader in the development of VCSEL technology. We believe VCSEL technology will solve a number of technical bandwidth challenges applicable to the high-speed computing and communications markets, allowing optoelectronic applications to perform their functions at higher speeds with lower costs over traditional optoelectronic systems. We believe that with the acquisition of MODE, Emcore will establish itself at the forefront of the next-generation development of the optoelectronic laser market, which is estimated to grow to one billion dollars by 2000."

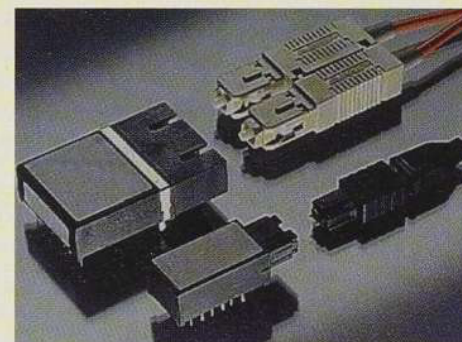
Under the terms of the agreement, Emcore Corporation will issue 1.547 million shares of common stock in exchange for 100% of the outstanding capital stock of MODE. The transaction is valued at approximately \$30 million based on Emcore's recent stock price. A significant portion of the purchase price will be taken as a one-time charge by Emcore related to the write-off of in-process research and development costs.

The proposed transaction is expected to begin adding to Emcore's bottom line within the first twelve months. MODE will operate as a subsidiary, led by the current MODE management team of Thomas M. Brennan and Robert P. Bryan.

And Emcore has already put their new subsidiary to work. That same day Emcore announced an agreement with AMP Incorporated to initiate a long-term strategic alliance to develop and produce MODE's VCSELs for the AMP line of fiber optic communication products. The alliance is intended to accelerate the introduction of new products through joint developments of key VCSEL components. Among the first fruits of the deal will be the use of MODE's GigaLase™ VCSEL devices in a line of recently announced fiber optic products for Gigabit applications.

"We are very excited by this alliance," stated Dr. Terry Unter, vice president of Global Optoelectronics at AMP. "It will combine the market presence of AMP and our competence in the field of communications transceivers with Emcore's semiconductor materials, device design and manufacturing expertise. By putting our teams together to focus on key issues, we anticipate cutting development cycle times and costs significantly."

AMP is the world's largest supplier of electronic interconnection systems, with annual sales in excess of \$5.5 billion, and more than 45,000 employees in 50 countries.



AMP serial and parallel interconnects, which use MODE VCSEL arrays as the light sources.

Japan's Materials Shipments On The Rebound

Manufacturers report a return to health after a slow 1996

The leading Japanese manufacturers of compound semiconductor materials enjoyed brisk business in the first half of fiscal 1997, according to figures compiled by Japan Manufacturers' Society of Compound Semiconductor Materials (JAMS-CS). For the six months ending in September, 1997, shipments totaled ¥23.2 billion (\$173.2 million) - the highest ever reported, and a 23% increase over the comparable period in 1996. Shipments of GaAs wafers totaled ¥11.5 billion (\$86 million), up 19% from 1996. Even bigger gains were recorded for GaP (up 27%) and InP (up 39%) - see table, below.

The increase in GaAs shipments is said to be due to greater demand in both the electronic and optoelectronic areas. The JAMS-CS says that GaP shipments were boosted by the thriving liquid crystal display backlight and display panel market. The growth in InP shipments is attributed to growth in the optical communications market.

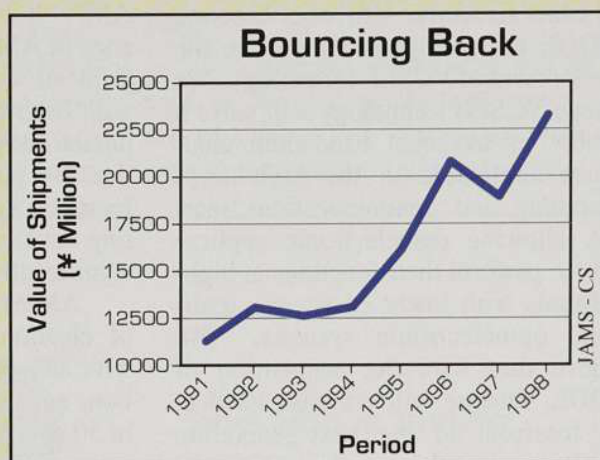
All of this comes as good news in light of the generally disappointing results reported for fiscal 1996. After enjoying three consecutive years of double digit growth, the JAMS-CS

members saw their business decline by 5.2% last year. (CS 3(4), p. 13). Much of the disruption was the result of large inventories of GaP and semiconducting GaAs piling up at LED manufacturers - a situation which now seems to be resolved.

Exports accounted for 38% of shipments for the first half of 1997, which is a few percentage points higher than previous periods.

The JAMS-CS reports that shipments for all of fiscal 1997 will likely reach ¥45 billion (\$335.8 million), which would be a new record.

The nine members of the JAMS-CS are: Dowa Mining, Furukawa Electric, Hitachi Cable, Japan Energy, Mitsubishi Chemical, Shin-Etsu Handotai, Showa Denko, Sumitomo Electric Industries, and Sumitomo Metal Mining.



JAMS-CS Statistics for 1st Half of Fiscal 1997

Shipments of compound semiconductor wafers by Japanese manufacturers

Material	Value		% of Total	Change*	Destination	
	¥M	US\$M			Japan	ROW
GaAs	11,533	86.06	50%	+19%	68%	32%
GaP	9,517	71.02	41%	+27%	52%	48%
InP	1,707	12.74	7%	+39%	65%	35%
Other	447	3.34	2%	-2%	78%	22%
Total	23,204	173.2	100%	+23%	62%	38%

*Change in value of shipments since 1st half of fiscal year 1996

Japan News Briefs

Even Brighter LEDs from Nichia

In November Nichia Chemical reported that it has developed a new structure for blue and green LEDs which are nearly twice as bright as its current models. At 20mA, the blue and green LEDs can generate 3 and 9cd, respectively. In comparison, the units which are currently available are specified at 2 and 6 cd. (see page 26). The new models will be commercialized for outdoor display applications.

High Temperature Telecom Laser from NEC

NEC Optoelectronics and High Frequency Device Research Laboratories report that they have developed a heat-resistant telecommunications laser diode. The 1.3 µm laser is made of InAsP / InAlGaAs, instead of InGaAsP, which is more commonly used in telecom lasers. Standard lasers operate inefficiently at high temperatures, but NEC says that its new laser can operate at 85°C with just a 50% increase over room temperature operating current. In contrast, the company says conventional telecom lasers require around 3x the normal current to operate at such high temperatures.

NEC plans to use the new device in indoor and outdoor locations subject to high temperatures. The company is heralding this development as another step toward making "fiber-to-the-home" economically feasible, as it will obviate the need for thermoelectric cooled units in harsh environments.

Digital GaAs from OKI

Oki Electric has announced plans to commercialize 18 GaAs digital ICs for use in high-speed optical communications devices such as multiplexers and demultiplexers. Prototype production was scheduled to begin in December, with plans to launch volume production in 1999. The company reports that will initially use the ICs in-house, but will later target the merchant market.

The release of some new digital GaAs ICs for the U.S. market is expected this spring. In 1997, digital circuits comprised roughly 10% of all GaAs IC sales.

LED Business Booming. Showa Denko K.K. recently revealed more details of its plans to expand its compound semiconductor business. Last year the company announced it planned to double sales of III-V substrates and epiwafers to ¥20 billion (\$167 million) by the year 2000. (CS 3(4) p. 12). The company recently completed a ¥3 billion (\$25 million) expansion at its Chichibu plant which increased capacity by 15 - 20%. The main focus of the investment has been LPE and other epitaxial process for GaP. Showa Denko says it is also branching out into MOCVD, in order to produce epiwafers for high brightness LEDs.

The company reports that the LED business has improved considerably since the spring of 1997. The market had been beset by inventory build-ups and production cutbacks, but now demand has recovered sharply, due in part to new applications for LEDs in wireless handsets and large area displays. Showa Denko says it expects this market to continue to grow for some time to come.

High Frequency FET from Murata. In January Murata Manufacturing released details of a prototype millimeter wave GaAs FET which it plans to commercialize by 2000. The prototype achieves $f_t = 110\text{GHz}$ and $f_{\text{max}} = 200\text{GHz}$. The FET, which uses a $0.2\text{ }\mu\text{m}$ gate created with photo lithography, is described as being based on an insulating gate-doped channel structure which has a silicon-doped InGaAs channel layer over a GaAs buffer layer, and has a non-doped GaAs insulation layer over the channel layer. The company says the resistance from the parasitic capacity under the gate and parasitic resistance under the source and drain electrodes were reduced.

Murata says potential applications include automotive radar and large bandwidth wireless telecommunications.

New Record for InGaP/GaAs solar cells. A two-terminal, monolithic $\text{In}_{0.5}\text{Ga}_{0.5}\text{P}/\text{GaAs}$ tandem solar cell has been developed with a world-record efficiency of 30.28%, which is approaching the theoretical limit (34%) for this device heterostructure. The work was performed at Japan Energy Corp., Japan Energy Research Center, and Toyota Technological Institute.

In addition to being highly efficient, this is also a large area device at 4cm^2 , which should lead to significant cost reduction. The heterostructure was grown by low pressure MOCVD on a p-type GaAs substrate and features a GaAs bottom cell and InGaP top cell connected optically and electrically by an InAlP/InGaP/InAlP tunnel junction. The use of an InAlP barrier prevents Zn diffusion from the tunnel junction and preserves the high efficiency of the top cell, while the tunnel junction is also very effective in obtaining a high tunneling current. The device features a high open circuit voltage of nearly 2.5V.

Esaki Wins Japan Prize. On December 22, 1997 the Tokyo-based Science and Technology Foundation of Japan announced that Leo Esaki has been awarded the 1998 Japan Prize. Leo Esaki, 72, a Nobel laureate and president of the University of Tsukuba, was awarded the prize for invention the semiconductor superlattice. Esaki, who worked at the IBM Thomas J. Watson Research Center from 1960 - 1993, was awarded a Nobel Prize in 1973 for his discovery of quantum tunneling in junction diodes. In 1993, Esaki retired from IBM and accepted an appointment as president of the University of Tsukuba.

He will be presented with the award at a ceremony scheduled for April 28, 1998, at the National Theater in Tokyo.

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Plenty of Room for Everyone

"The Market and Business Outlook for GaAs & Other Compound Semiconductors"
November 12-14, 1997, San Diego, CA

TIM WHITAKER

This conference, organized by Gorham/Intertech Consulting, broke new ground in bringing together over 20 high-profile speakers from throughout the compound semiconductor industry to discuss business and market-related issues. Although many different sets of figures and forecasts were presented, a clear message came across that the industry prognosis is extremely healthy at present, with strong demand for high performance devices and components, and an ever-increasing range of applications. According to Earl Lum, representing Dataquest, 'there will be plenty of room in the marketplace for all the numerous technologies to find their application niches... however, in around 5 years time, the industry will face a shake-down, with winners emerging from a wide-ranging consolidation of technology options.'

Supply and Demand

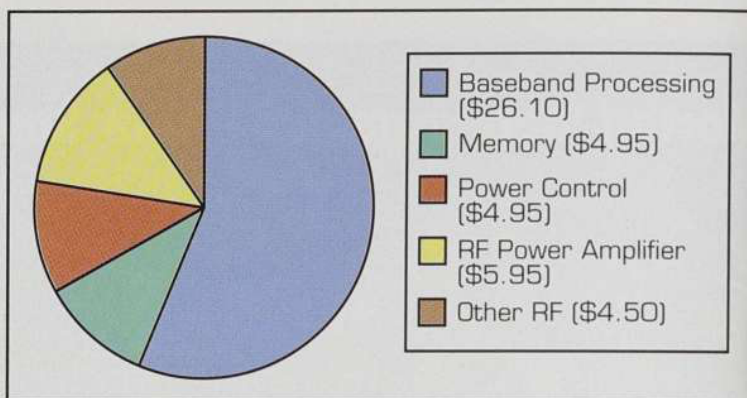
A problem of more immediate concern is the issue of supply, which is struggling to keep up with demand. Several speakers noted that their companies were working at or very near to full capacity, whilst Julio Costa of Motorola described the difficulty of finding alternative suppliers. Although Motorola normally requires at least two suppliers, said Costa, performance is so closely tuned to the application that it becomes increasingly difficult to find components providing identical performance.

Broadband Communications

The consumer communications market for compound semiconductor devices continues to grow. Philips described the expansion of the Broadband Wireless Service (BWS) applications, including LMDS (Local Multichannel Digital Service) at 27-31GHz and MVDS (Multipoint Video Distribution Service), a European standard using 40.5-42.5 GHz. Next generation components are likely to be GaAs MMICs for the upconverter and power amplifier in the transmitter, and also for the low-noise amplifier and double balanced mixer in the receiver. Clifford Vaughan of Oki pointed out that while recent FCC and court rulings allow new phone and cable companies to compete to provide local services, the incumbent provider does not have to allow use of existing phone cables. So-called 'Wireless Cable' solutions such as LMDS offer an attractive alternative to laying new fiber-optic cable.

Power Amplifiers for Mobile Phones

According to Julio Costa, the rapid shift from 6V to 3.5V power supplies in mobile phone handsets will result in an increased demand for GaAs-based components, which have a clear advantage in both low voltage requirements and digital mode operation. Due to a large existing AMPS infrastructure and a lack of a unified US digital standard, American handsets will be dual-mode for a good part of the next decade. Epi-based technologies, particularly GaAs HEMTs, are already winning most of the advanced dual-mode PA sockets due to their superior power density and efficiency characteristics.

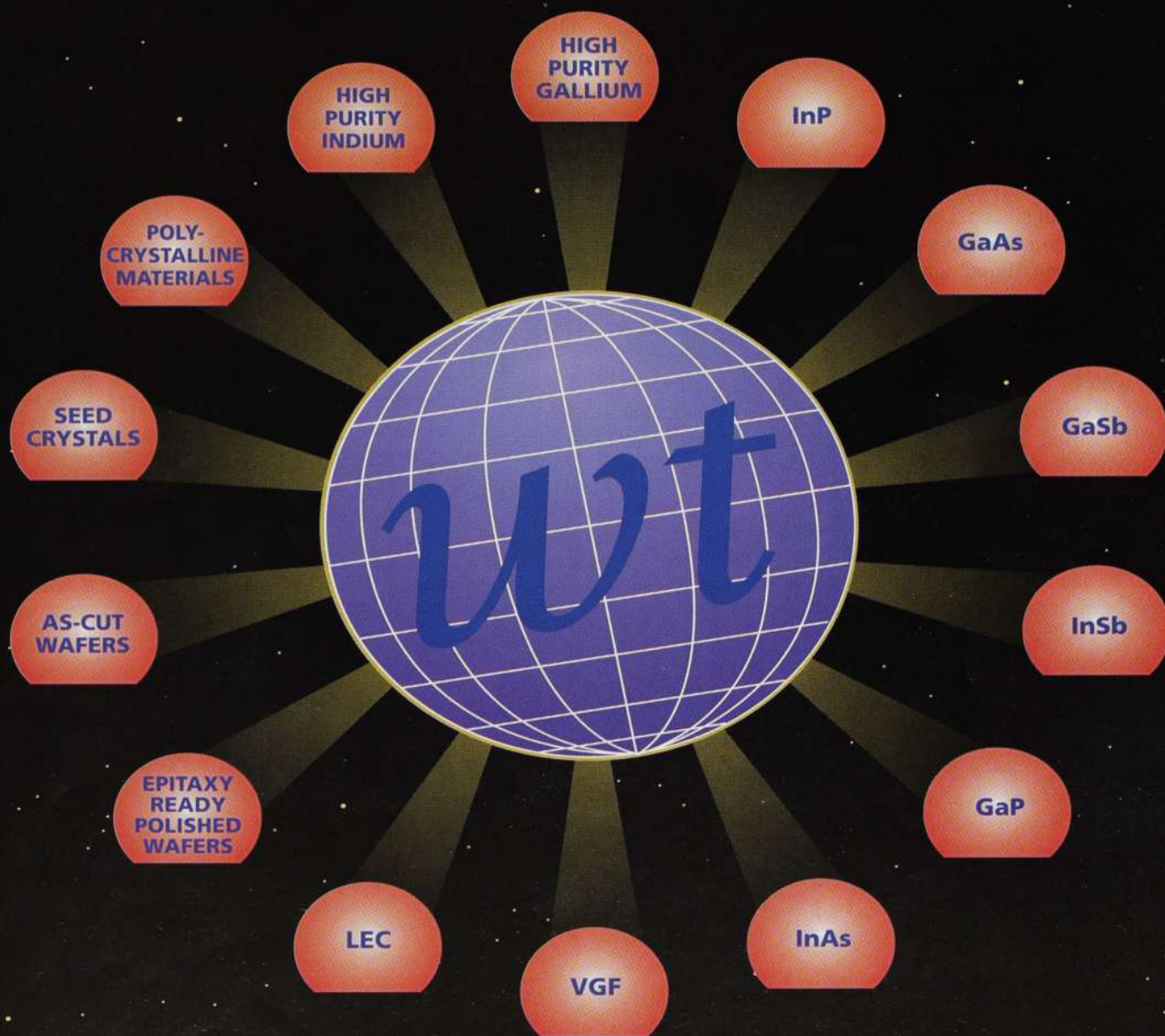


Semiconductor Bill of Material (BOM) for digital cellular handsets. Total = \$46.45. GaAs competes for the RF portions, which total \$10.45. The BOM for 6V analog handsets is much lower, at ~\$30.

Optical Communications

Shoji Horiguchi of NTT Electronics Corp. described the continued drive in Japan towards Terabit/second transmission capacity, which he predicted 'will become a reality early in the next century'. The solution is unlikely to be the TDM approach due to the extremely high speed required of the semiconductor IC components. The most promising solution, said Horiguchi, was to pursue optical WDM systems at speeds around 40Gbit/s, requiring in excess of 25 channels.

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Significant progress will be required in opto-electronic components, and the status of InP-based devices was described by Nisa Khan of Lucent. InP materials are particularly suited to high speed integrated electroabsorption-modulated lasers, stand-alone modulators and guided-wave optical switches. If InP is to win out against other technology platforms such as LiNbO_3 , silica and polymers, there are a number of major challenges, particularly in the areas of packaging, and interconnects, and in reducing the size of components to overcome propagation losses and material non-uniformity.

Substrate Issues

The move to 6" substrates is inevitable if GaAs is to compete effectively with silicon. David Miller of Litton Airtron stated that the cost per die of GaAs devices can be reduced by up to 40% by moving from 4" to 6", and that state of the art device production equipment is now designed for the larger size. Miller proposed that, as high volume processes reach maturity and manufacturing yields increase, 6" GaAs will be able to compete on a cost basis with 8" Si processes. Although GaAs substrates will remain more expensive, the cost will fall as true volume manufacturing is realised, but will also require users to adopt a 'no frills' spec which is adequate for device requirements. (For more on 6" GaAs, see page 24.)

Although GaAs is unlikely to be replaced in the foreseeable future, the difficulties associated with use of other substrates may be avoided by the realisation of compliant universal (CU) substrates. (CS 3(2), page 27). These will be chemically and mechanically compatible with any compound semiconductor having a lattice constant between 4 and 7 Å, according to Yu-Hwa Lo of Cornell University.

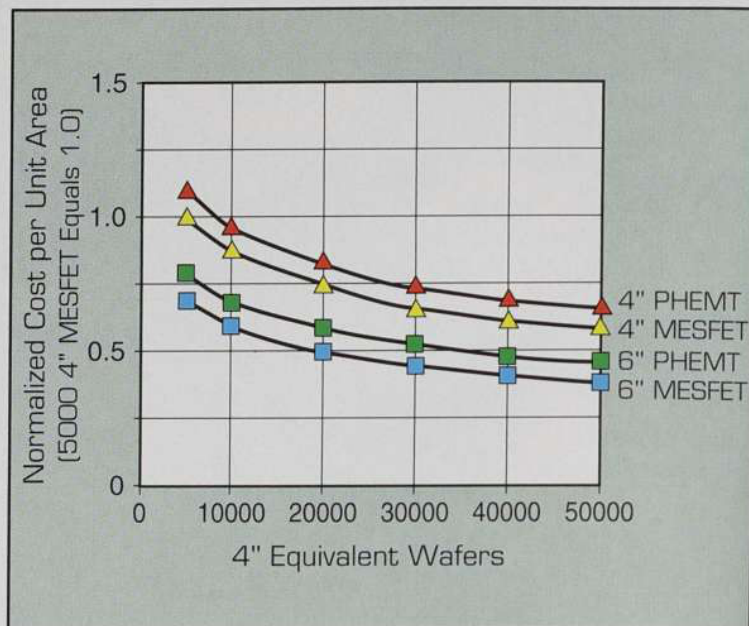
Merchant Epiwafer Vendors

Epiwafer vendors, including both MBE and MOVPE growers, continue to expand their roles, offering an increased range of services as exemplified by Kopin's Wafer Engineering Group and Emcore's E²M and Pegasus divisions, which are now selling devices as well as epiwafers. As such companies work increasingly closely with their customers at all stages, the use of merchant epi supply is likely to grow still further. In the opinion of Timothy Murray of Epitronics, 'new captive epi facilities are unlikely to be funded, since the cost of entry does not yield sufficient business advantage'. James DiLorenzo of Raytheon partially confirmed this view when he stated that 'Raytheon established its epi capability with great reluctance, due to the inability of vendors to meet our requirements'. 40% of Raytheon's epi-wafer supply is from external sources, while the rest comes from their captive epi facility.

Epi v. Ion Implantation

This debate, along with MBE v. MOVPE, was one of the undercurrents of the conference. Ron Ruebusch of TriQuint, predictably held the view that 'PHEMT is not necessarily the answer

(for high performance GaAs ICs) due to the high cost of epi'. However, Julio Costa predicted a bright future for epi-based devices (GaAs HEMTs and HBTs) in cellular phone power amplifiers, and James DiLorenzo stated that 'the higher cost of epi is offset by the superior RF performance achieved by epi-grown GaAs-based devices'. Raytheon's comparison of PHEMT and MESFET (see below) shows a price difference of ~15%, and also indicates the advantages of moving to 6" wafers.



Cost comparison of MESFET and PHEMT for 4 and 6 inch wafers, showing the normalized cost per unit area against volume per year by type.

Heat and Electricity Co-generators

GaSb infrared thermophotovoltaic (TPV) cells have been incorporated into co-generators which burn a fuel such as propane to produce heat whilst the TPV cell utilises IR radiation to generate electricity. Lewis Frass of JX Crystals Inc. described the units, which generate 40W electricity and 2kW of heat, as being 200x more efficient than solar cells and lacking the dependence on time of day or location. Initial markets in cabins, recreational vehicles such as yachts and for the military could reach \$285million, with twice that being available from servicing remote homes across the US and Canada.

Establishing New Materials

The factors involved in bringing new materials such as SiC and GaN to market discussed by Tim Murray. Even for these materials which have very clear and sought-after device applications, the process is arduous; based on historical examples, this could require \$60million and 15 years' worth of patience. Materials technology and understanding should be shared, and developed in parallel with device technology, through partnerships with companies who know how to get these technologies into designs and products.

Highlights of the Nitride Symposium at the Fall MRS Meeting

Boston, MA
December 1-5, 1997

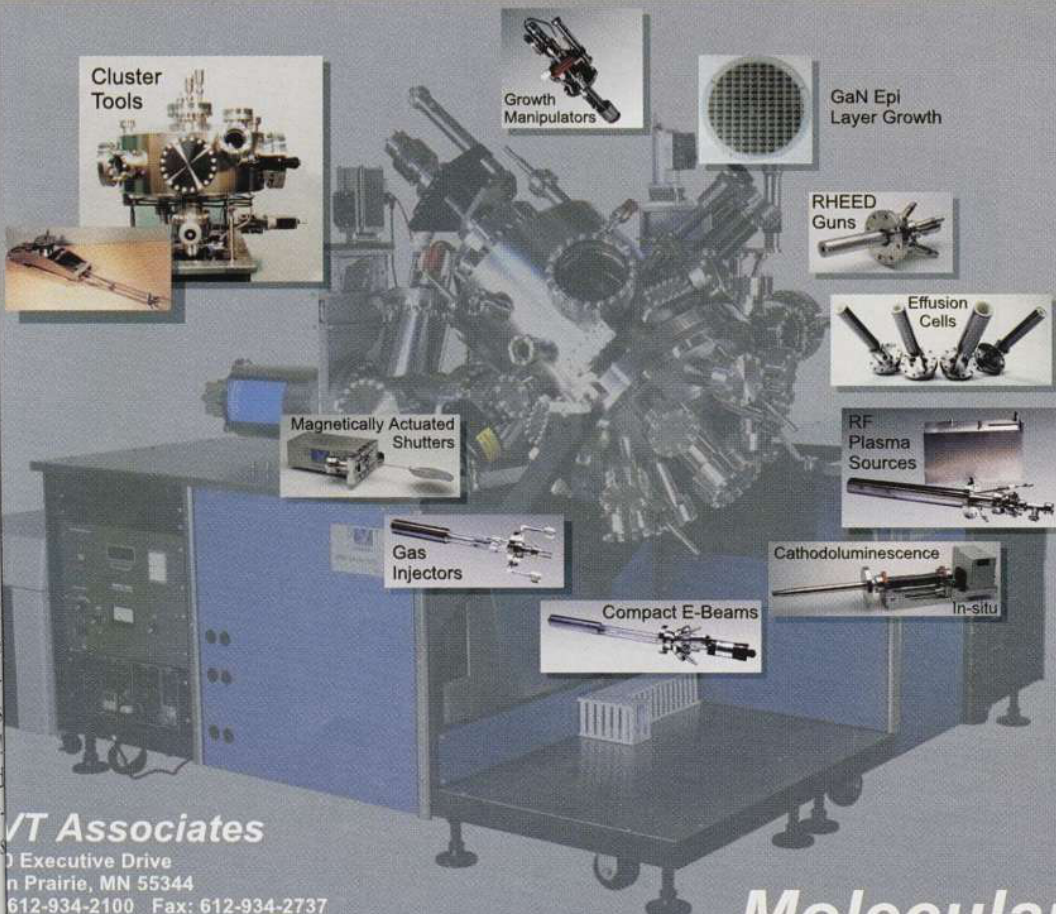
GARY WICKS

A large portion of the international Group III-Nitride research community gathered in Boston in December for the Symposium on GaN and Related Materials that was held in conjunction with the Fall Meeting of the Materials Research Society. This was the biggest event in the GaN field to be held in the United States in 1997, with estimated attendance over 500 throughout the course of the five-day program, which included over 80 talks and 160 poster presentations.

Epitaxial Lateral Overgrowth and Selective Area Growth

Epitaxial lateral overgrowth (ELO or ELOG) was a topic that evoked quite a bit of interest. It may be the solution to the number one problem in nitrides: high dislocation densities resulting from the lack of a practical lattice-matched substrate. ELO of nitrides is typically carried out on a crystalline substrate, usually sapphire, which has been patterned with amorphous (SiO_2 or SiN_x) stripes and windows.

MOCVD growth on such a substrate will initiate only on the exposed crystalline substrate, growing up through the windows and then laterally over the SiO_2 stripes. Reports from North Carolina State University (NCSU), Mie and Nagoya Universities, and Nichia indicate that the nitride material overgrown across the mask has lower dislocation densities, by up to several orders of magnitude, than that grown above the windows. The NCSU group went one step further; double ELO. In double ELO, the windows



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and stripes of the first ELO layer are offset with respect to a second ELO layer that is grown on top of the first. This insures that none of the surface region has a direct line of sight through nitride material to the substrate, thereby producing low dislocation densities over the whole surface. Indeed the biggest news in nitride devices, Nichia's recent announcement of blue lasers with projected room temperature lifetimes of 10,000 hours (see below), was achieved through the use of ELO.

The discovery of the benefits of ELO was an outgrowth of efforts on selective area growth (SAG) of GaN. SAG, like ELO, is carried out on crystalline substrates that have patterned SiO_2 on it. Epitaxial growth (typically MOCVD) will be catalyzed on the exposed crystalline substrate, but will not initiate on the amorphous SiO_2 mask. SAG has been used in recent years by a few groups for specific applications such as growth of arrays of pyramids of GaN for field emitters. An invited talk by Prof. Kazumasa Hiramatsu of Mie University and his collaborators at Nagoya University reviewed recent developments in selective area growth by MOCVD and HVPE. By selecting the correct growth parameters, SAG of GaN can be very selective, but AlGaIn SAG has not been very successful. Growth up through windows and over masks is characterized by the ratio of vertical to lateral growth rates. This ratio is very dependent on the crystal orientation of the mask, and can range from less than 0.5 to more than 20.

Bulk Growth and Thick Epi

While ELO is raising new hopes for a solution to the high dislocation densities in heteroepitaxial GaN, the traditional approach to the problem, homoepitaxy, is still active. The GaN substrate that is required for homoepitaxial GaN growth can be made by bulk growth of GaN crystals or by thick heteroepitaxial GaN growth by HVPE. The bulk growth method would be preferable — if it could be accomplished in practical sizes. It is not an easy process, however, requiring temperatures up to 2000 K and nitrogen pressures of 20 kbar. The leader in the growth of bulk GaN substrates, the Polish Academy of Sciences, is now up to centimeter-sized GaN substrates. An alternative to bulk growth, which is available with present day technology, is high

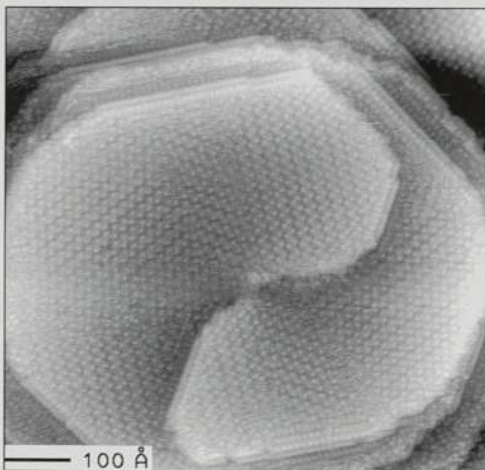
growth rate epitaxy done by HVPE. GaN growth rates in excess of 100 $\mu\text{m/hr}$ were reported by NEC. Both NEC and Lincoln Labs have used thick HVPE GaN layers as substrates for subsequent MOCVD or MBE growth of GaN devices.

Surface Studies

The complex nature of the surface structures of epitaxial GaN was explored in a paper by Carnegie Mellon researchers and their collaborators. Epitaxial growers, especially those using MBE, are familiar with (1 x 1) and (2 x 2) RHEED patterns of GaN. The Carnegie Mellon paper found several higher (mainly 3rd and 6th) order RHEED patterns, which are associated with partial gallium surface coverages at lower temperatures. Striking STM images clearly display these surface reconstructions to be (3 x 3), (6 x 6) and $c(6 \times 12)$. At temperatures above 300°C, increased gallium surface mobility causes these highly structured surfaces to give way a less ordered surfaces, producing the (1 x 1) RHEED pattern.

Optical Emitters

As is usually the case in nitride meetings, there was tremendous interest in Shuji Nakamura's presentation of Nichia's latest result in blue lasers and LED's.



"Scanning tunneling microscope image of the GaN (0001) surface, showing a $c(6 \times 12)$ arrangement of Ga atoms on the surface. A growth spiral, produced by a dislocation intersecting the surface near the center of the image is apparent. The image extends over an area of 75 nm x 75 nm. Courtesy of A. R. Smith, R. M. Feenstra, and D. W. Greve, Carnegie Mellon University.

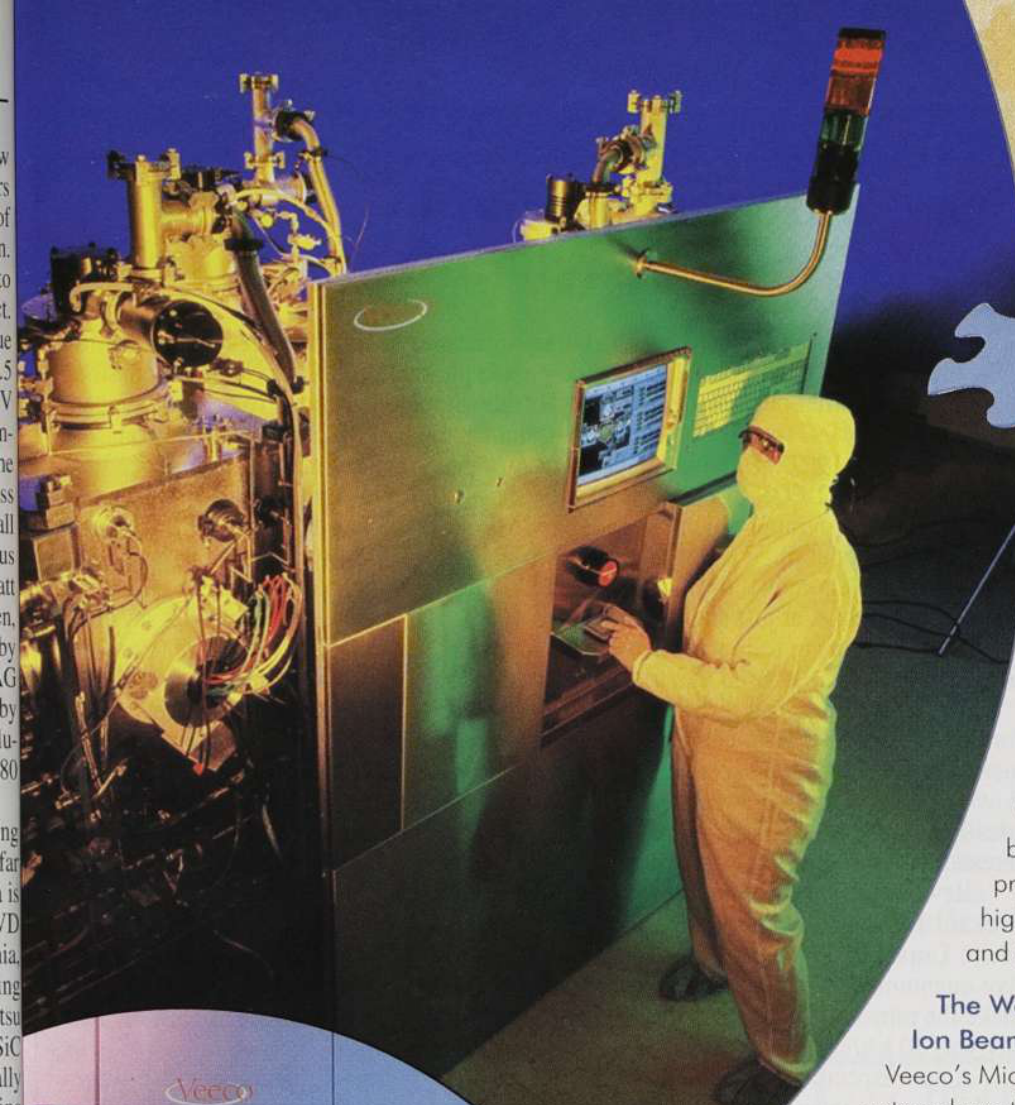
Through the use of ELO, Nichia has now improved the lifetime of their blue lasers to a projected value of 10,000 hours of room temperature continuous operation. This is sufficient lifetime for Nichia to consider the blue laser as a viable product. The present numbers on the Nichia blue lasers are: 50 mW output power, 1.5 kA/cm^2 threshold current density, 4-5V operating voltages — all with room temperature continuous operation. On the LED front, Nichia reviewed its progress obtaining red through UV wavelengths, all from GaN-based materials. Luminous efficiencies of 5 and 30 lumens per watt have been achieved in the blue and green, respectively. A white LED operates by using a blue LED to excite a yellow YAG phosphor. A large market targeted by Nichia is the replacement of standard fluorescent lights, which produce around 80 lumens per watt.

Many other institutions are working on InGaIn laser diodes, but all are far behind Nichia in performance. Toshiba is growing blue lasers with an MOCVD ambient of nitrogen rather than ammonia, and forming the laser mirrors by cleaving instead of dry etching. Cree and Fujitsu are working on nitride laser growth on SiC substrates rather than the conventionally used sapphire. Electrically conducting substrates and ease of cleaving are the advantages of SiC. University of California at Santa Barbara, Xerox and Sony also announced new blue laser results reported the first GaN pn junction LED grown by HVPE.

Applications

The final regular session in the symposium was a tutorial on applications of blue diode lasers. Ross Bringham of Xerox discussed blue laser diodes for laser printing. The laser printing market is projected to be \$100 billion in the year 2000. Advantage of blue diode lasers for laser printing and photocopying are that they allow high resolution printing, while keeping engineering tolerances down and maintaining smaller sizes for optical elements. He outlined a preliminary specification for a blue laser that could be used for laser printing: 6 mW output power, wavelength longer than 420 nm, switching times of 1 nsec, and single transverse mode operation.

Akito Iwamoto of Toshiba discussed



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DVD applications of blue lasers. Conventional CDs use 780 nm diode lasers and contain 0.65 Gbyte; available soon are DVDs using 635 or 650 nm diode lasers that contain 4.7 Gbytes (ROM) or 2.6 Gbytes (RAM). By the year 2000 high density DVDs will use blue diode lasers and contain 15 Gbytes. Laser diode requirements for these future high density DVDs: 3-5 mW for ROM, 30-40 mW for RAM, beam aspect ratio of less than 4; operating temperature = 60°C.

R.L. Melcher of IBM discussed the possibilities of lasers for displays. From a technical standpoint, lasers are ideal for displays due to their extreme brightness and near perfect color saturation. The result of the application of lasers to displays would be improved display performance, and positive effects on the system design and the remainder of the display components. From a financial standpoint, however, lasers are still not competitive with incoherent, broadband sources such as arc lamps.

Nitrides: A Rapidly Growing Field

In the talk that opened the symposium, Prof. Akasaki of Meijo University, an early pioneer and long-standing leader in the field of nitrides, showed data on the rapid growth of publications in the field of GaN-based materials and devices. Over the past decade, the GaN publication rate is increasing by more than 200% each year. The great prosperity in nitrides made for a spirited, enthusiastic meeting. Optimism reigns.

The 1998 Fall MRS Meeting will be held in Boston November 30 - December 4.

Upcoming major conferences in the GaN field include the 3rd European GaN Workshop, to be held June 22-24, 1998 in Warsaw, Poland, and the 2nd International Symposium on Blue Laser and Light Emitting Diodes (ISBLLED), to be held September 29 - October 2, 1998 in Chiba, Japan. See the "Calendar" section, beginning on page 44, for more information.

Sony & Hewlett-Packard Report Blue Lasers

Sony and Hewlett-Packard are the latest companies to report success in fabricating blue lasers in their research labs. Sony made their report in Late News submissions to the International conference on Nitride Semiconductors (Tokushima, Japan, October 27-31, 1997) and the Nitride Symposium at the Fall MRS Meeting (Boston, MA December 1-5, 1997). Hewlett-Packard made their announcement in a post-deadline paper at the 1997 LEOS Conference (San Francisco, CA November 10 - 13, 1997).

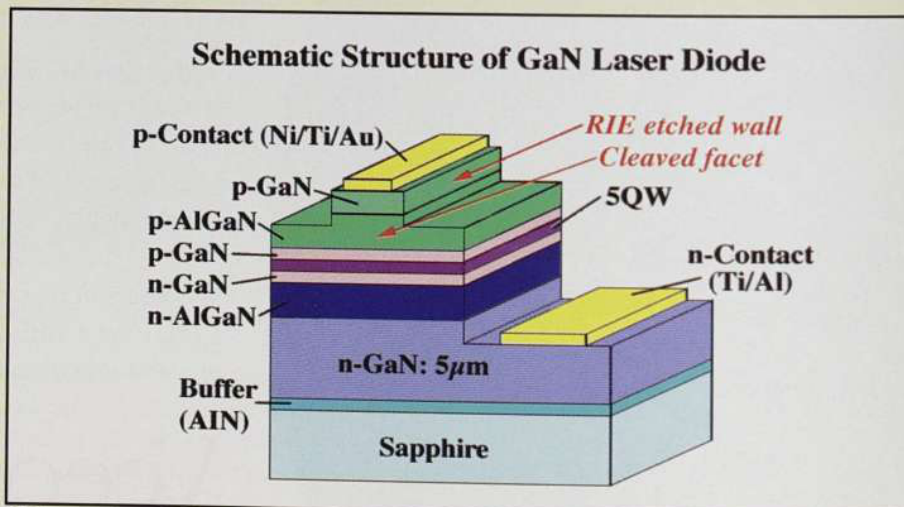
The Sony program, which is headed by Masao Ikeda and Hiroshi Ooki, has been underway for about three and a half years. In the area of short wavelength laser diodes, Sony is more well known for its work in ZnSe. In fact, they hold the current record for ZnSe laser lifetime, at just slightly more than 100 hours. A Sony spokesperson says that the company plans to follow a "dual-track" approach, and that "Sony's efforts to make a blue laser from ZnSe-based materials will continue in parallel with the GaN program".

The Sony laser was grown by MOCVD on C-face sapphire, with facets being formed by cleaving. Optical pumping was used to analyze the effect of the number of quantum wells used, and five was determined to be the optimized number. Thresholds down to 33 kW/cm² were reported for optical pumping at room temperature. For electrically pumped lasers under pulsed operation at room temperature, the key figures were: threshold current density = 9.5 kA/cm², threshold voltage = 18 V; lifetime = 5 hours.

Hewlett-Packard's breakthrough was achieved by a collaboration between Hewlett-Packard Laboratories Japan, led by Norihide Yamada, and Isamu Akasaki's group at Meijo University (Nagoya, Japan). Like Sony, the Hewlett-Packard researchers used a five quantum well structure grown on C-face sapphire substrate which were cleaved to make the mirrors. Under pulsed room temperature operation, the threshold current density was 30 kA/cm², and the threshold voltage was 22 V.

A new aspect found in the Hewlett-Packard work is the fabrication of ridge waveguide, which is intended to allow the laser to operate in a single lateral mode. (Previous nitride lasers operate in modes other than the fundamental mode, and as a result can not be focussed down to a single small spot, as would be required for most applications such as the next generation DVD). A 5 µm wide index-guiding ridge was formed by chlorine-based RIE. The etching was timed to leave about 100nm of the top AlGaIn layer. The laser facets were then formed by cleaving along the (1100)-plane of sapphire after the substrate was polished down to 150 micron. HP reported that the roughness of the facet, as measured by AFM, was less than 1nm.

Marie Meyer



Schematic of the HP laser diode. The active layer is a 5 QW structure, using $Ga_{0.03}In_{0.97}N$ barriers and $Ga_{0.15}In_{0.85}N$ for the wells.

Silicon Stands Out at the 1997 IEDM

ROBERT A. METZGER



The International Electron Device Meeting (IEDM) is the traditional forum for presenting state-of-the-art silicon ICs results. The 1997 IEDM, which was held in Washington, DC December 7-10, continued this trend. The program included two standout papers discussing MOS-based technology which can compete head to head with most commercial GaAs MESFET-based technologies in several major market areas.

It is often debated just how far up the performance curve CMOS can be pushed before it finally runs into some fundamental limit. Each year those "fundamental limits" seem to be pushed further and further back. An excellent example of this was shown in work performed by Fari Assaderaghi and coworkers from IBM Semiconductor Research and Development Center in Hopewell Junction, NY. They described an SOI CMOS process utilizing non-fully depleted SIMOX wafers. The process includes shallow trench isolation, deep source/drain junctions with ultra-shallow extensions, and a self aligned silicide process. The gate oxide thickness is only 35 Å, and the NMOS and PMOS gate lengths are 0.07 and 0.09 µm, respectively.

Using this technology, the IBM researchers fabricated an 83 stage CMOS inverter ring oscillator, along with an 1024 divider and output buffer to simplify measurements. At a supply voltage of 2.1 V, the inverter delay is 7.9 ps at room temperature, and 5.5 ps at liquid nitrogen temperature, while decreasing the supply voltage to 1.2 V only increases these delay times to only 11.4 and 8.2 ps at room temperature and liquid nitrogen temperature, respectively. These values rival the best seen in any III-V technology, and amply demonstrate just how much more performance may be squeezed out of silicon CMOS.

Another result was presented by Isao Yoshida from the Semiconductor Technology Development Center of Hitachi in Tokyo, Japan. Aiming directly for the 1.8-2.4 GHz power amplifier market, Hitachi has developed a MOSFET structure which uses a composite 0.4 µm metal-silicide/Si gate structure which is shunted to an Al line running directly above it in order to decrease gate resistance and improve RF performance.

At 2 GHz operation with a 3.6 V bias this device delivers an impressive 50% PAE and 1.0 W output power, making this device a strong performance contender with GaAs MESFETs at this frequency and power supply range. Additionally, the Hitachi result appears to be much closer to a manufacturable process than the one described by IBM, as it does not require the sub 0.1 µm gates.

Robert Metzger is a member of the technical staff at the Georgia Institute of Technology, and the Microelectronics Editor for this magazine

Know your competition.

That's what "Silicon Update", a new feature we are introducing in this issue, is all about. It is based on the premise that the semiconductor industry is virtually synonymous with silicon ICs, and that the III-V community can not afford to forget this fact if it wishes to continue to prosper and grow. It will highlight the latest IC and device results from silicon field, with special emphasis on those technical and market areas which are in direct competition with compound semiconductors.

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Things to Watch in 1998

TIM WHITAKER & MARIE MEYER

What will the big news in the compound semiconductor industry be in the coming year? Here are our four top candidates.

1 The 6" Era Begins

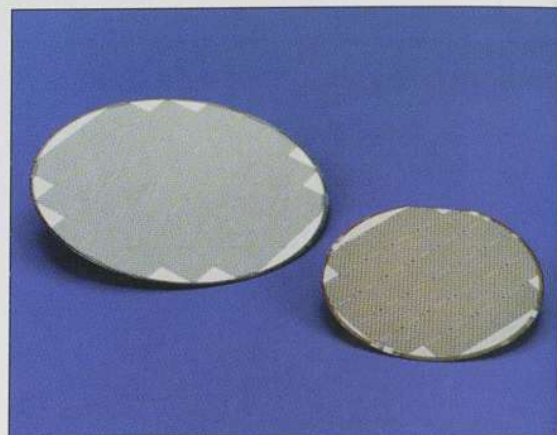
A new era for the GaAs industry will begin later this year when Vitesse becomes the first company to commission a 6" GaAs processing line. The final phases of construction of Vitesse's new 6" fab in Colorado Springs, CO are currently underway. According to Lou Tomasetta, Vitesse's President and CEO, several wafer lots have already been run through the fab on a test basis, and work has begun on final qualification for standard parts. If all goes well, the first ICs from the new facility will ship in April, which is three months ahead of the original schedule. Vitesse hopes to be running 300 - 400 wafers/week by early summer. Full capacity for the fab as it is currently equipped is around 750 wafers, but provisions have been made to allow expansion to around 1500 wafers/week. The company will also continue to operate its existing 4" GaAs fab in Camarillo, CA.

Litton Airtron was the first vendor to offer 6" GaAs, all the way back in 1996, and they will be the primary supplier for Vitesse. Other producers of semi-insulating GaAs, including Freiburger, M/A-COM, Sumitomo Electric, Hitachi Cable, and AXT, report that they are sampling 6" wafers to various customers. Prices on a per-square-inch basis are generally higher than for 4", but all of the vendors are predicting that parity will be achieved as volumes increase, with target prices of ~\$500 per wafer for the first production runs, and perhaps decreasing to ~\$400 per wafer in 3 - 4 year's time.

Who's Next?

Conversion to 6" wafers is the obvious path forward for GaAs fabs which are nearing full capacity. But it will likely be one or two years before any other companies make the leap. Fab managers candidly report they fear that the new technology might be a minefield, and they are happy to hang back and let Vitesse clear the way for them. And this isn't the first time this has happened: Vitesse was also the first company to complete a full 3" to 4" conversion.

So why is Vitesse so eager to serve as the industry's sapper? They have little choice, given the rapid rise in demand for their products (see Chart). Vitesse, which concentrates on digital GaAs ICs, contends with more extreme die size pressures than other GaAs fabs, almost all of which produce analog/mixed signal circuits exclusively. Switching to larger wafers will not only solve the tiling problems, but will also make state-of-the-art processing equipment available, as many semiconductor tools are no longer available in 4" models.



Later this year Vitesse Semiconductor will become the first company to launch a high volume 6" GaAs process. Shown is a wafer from one of their test runs, next to a 4" wafer for comparison



Growth in revenue per quarter at Vitesse from 1995 through the first quarter of fiscal year 1998.

But the greatest benefit of 6" processing, for Vitesse or any other company, is the reduction in cost per die. Figures compiled by Litton Airtron from various published sources indicate that for a MESFET process, the die from 6" wafers should cost 40% less than those from 4" wafers. See Table. The cost reduction for an epitaxial process could be even greater, although it will likely be a few years before any epi-based processes are converted.

All-in-all, the advent of 6" GaAs processing will likely deserve to be remembered not only as the major event in the compound semiconductor industry in 1998, but also a major milestone in the history of GaAs. The cost reductions and general modernization that it allows should help GaAs retain the competitive edge and respectability it has won over the past five years.

We look forward to the day when 4" wafers look as quaint as 2" wafers do today.

How Does 150mm GaAs Stack Up?

	GaAs 0.5 μ m E/D*	Silicon Bipolar	0.5 μ m BiCMOS
Ft, GHz	35	16	25
Steps	24-30	70	100
Masks	4-6	15	30
Cost @ \$100/Mask	\$500	\$1,500	\$3,000

Size	GaAs	Si	Die/wafer @ 270 x 270 mil**	Cost/die
100mm	\$190		141	\$4.894
150mm	\$500	\$70	336	\$2.976
200mm		\$150	615	\$2.683
300mm		\$500	1415	\$5.122
				\$2.473

* Enhancement/Depletion Mode MESFET

** Roughly equal to 6.85 x 6.85 mm, or 47 mm²

Materials cost comparison among GaAs MESFET and Si bipolar and BiCMOS processes. Cost/die is calculated by adding mask and wafer costs, and dividing by die/wafer. Based on cost data compiled by Litton Airtron from various published sources.

2 Blue LEDs: Who Will Be #2?

Last year's most interesting topic in the GaN field was the race to achieve a working blue laser. Nichia won the prize last fall when it announced that it had a diode with a lifetime in excess of 10,000 hours, and that it planned to start shipping commercial samples in late 1998.

Nichia is generally considered to be three to five years ahead of everyone else in all areas of GaN technology. Given that they began production of blue LEDs in earnest in 1994, it seems time for another big player to emerge.

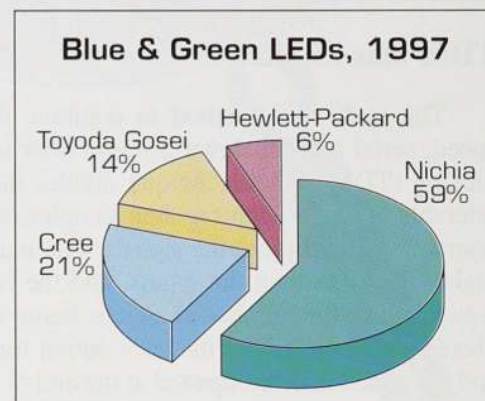
Cree Research currently holds the second spot in the LED market. A BCC market study¹ reports that in 1997 Cree had 21% market share, compared to 59% for Nichia. See Chart. Cree is expanding their production capacity, and announced on January 15 that it is beginning volume production of a new LED process which uses a conductive buffer layer. This change allows Cree to capitalize on their conductive SiC wafer by using a vertical device structure, with top and bottom contacts. This means that each die can be smaller, which results in bigger yields from each wafer.

But Cree also suffers from some disadvantages. Firstly, the performance of their LEDs simply isn't as good as the competition. See Table, page 26. At present that is not a problem, according to BCC's Marc Favreau, because demand for blue LEDs outstrips supply by a large margin. "Someday the performance of Cree's LEDs might hold them back" he says, "but right now they are bright enough for outdoor use, so they should be able to sell all they can make."

Cost is another issue for Cree, as they are the only producer to use a SiC-based process. The scale of Cree's operations is also a potential problem: Cree is a small company, and while their main rival, Nichia, is not huge, some of the newer entrants in the blue LED business are much, much bigger.



Hewlett-Packard's first blue LED products.



Leading producers of blue and green LEDs in 1997, based on unit volume. Total value: \$189.5 million.

¹ "Markets for Blue Semiconductor Light Emitting Devices and Materials", published by Business Communications Company, 25 Van Zant Street, Norwalk, CT 06855 USA, TEL [1] 203 853 4266; FAX [1] 203 853 0348, Email rrandydw@aol.com, Web Site <http://www.buscom.com>.

Which brings us to the company which seems most likely to take over the #2 spot: Hewlett-Packard. HP began shipping blue LEDs just last fall, and its first products were based on epiwafers obtained from Toyoda Gosei. But the company reports that it is now shipping products produced entirely in-house. Their LEDs are not as bright as Nichia's (see Table), but they are investing heavily in R&D aimed at bridging the gap. And by 1999 HP should have a production capacity equal to Nichia's.

In addition to their very deep pockets, HP occupies a leadership position in other segments of the high brightness LED market (though a true, non-GaP green LED is noticeably lacking from their palette). But they won't be unique for long. Nichia's Shuji Nakamura talks of someday being able to produce GaN-based LEDs at longer wavelengths. But before that, we will probably see other LED manufacturers enter the market. Favreau thinks that Stanley, a leading Japanese LED maker, will be producing blue LEDs by 1999, as will Rohm. He says both companies have had demonstration units for a few years.

And what about Toyoda Gosei? They are the third largest supplier at present, but little is known about their GaN plans. They are currently involved in a patent dispute with Nichia, which has the prospect of turning ugly and expensive.

One advantage that all the Japanese companies enjoy is the

weak yen, which should help to boost exports. The strong dollar may slow down HP this year, but nonetheless, they look likely to become a major factor in this segment of the compound semiconductor industry in a relatively short time.

	Nichia	Nichia	Cree	H-P
Material	InGaN on Sapphire	InGaN on Sapphire	InGaN on SiC	InGaN on Sapphire
Peak Wavelength	470nm	525nm	430 nm	473 nm
Luminous Intensity	2 cd	6 cd	n.a.	1.1 cd
Radiant Flux	3.0 mW	2.0 mW	0.75 mW	3.0 mW
Spectrum Half Width	30nm	40nm	65nm	35nm

Comparison of standard LEDs offered by Nichia, Cree, and Hewlett-Packard. Luminous intensity is not available for Cree LEDs because they are supplied in die form only. The specifications for Cree's products are not expected to change significantly when their new conductive buffer layer product is introduced later this year.

3 Dense Wavelength Division Multiplexing

The ever increasing demands for visual, audio and data communications, including services such as Internet and Intranet and videoconferencing, are placing strain on existing optical fiber networks. There are three main solutions to increasing the capacity and relieving the congestion; install more fiber, increase the data rate for optical transmission, or use techniques such as dense wavelength division multiplexing (D-WDM). The latter option has taken off in the last year or so, and D-WDM will increasingly be deployed both in long haul and metro networks.

TDM Has Limits

The traditional method to combine data streams for high speed, serial transfer down a single fiber is time division multiplexing (TDM). This technique divides the inputs into discrete intervals of equal duration, then samples each channel in turn to interweave (multiplex) the signals. The multiplexed signal has a higher data rate than the inputs, and the increase is by a factor equivalent to the number of signals being combined. The multiplexed signal modulates the laser output for optical transmission, and the signal is demultiplexed at the end of the route. Most of the long haul network operates on the SONET standard of OC-48, or 2.5Gbit/s, with several vendors offering OC-192 (10Gbit/s).

To support higher and higher bit rates through TDM alone, the operating speed of the drive ICs and the mux/demux must also rise. Although GaAs and InP-based ICs operating well in excess of 10Gbit/s are relatively common, and Siemens have recently developed a SiGe-based mux/demux operating at 60Gbit/s (see page 36), a widescale move beyond OC-192 is by no means certain. At higher data rates, signal dispersion in single-mode fiber, in particular polarization mode dispersion (PMD), becomes a significant problem. However, widespread testing of different fiber types by various companies and organizations seems to indicate that PMD is less of a problem at OC-192 than was originally thought.

Getting the Most From Your Fiber

Installing new fiber obviously creates more capacity, but is frequently difficult and always costly, particularly in urban areas. Point-to-point transmission usually requires two working fibers, one for each direction of transmission, and also two protection fibers, to provide backup capacity in case of damage.

D-WDM technology provides network operators with a solution to getting the greatest capacity possible from existing fiber networks. Rather than sending signals down separate fibers, DWDM assigns each signal a separate wavelength, then multi-

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Anatomy of a D-WDM System

A highly simplified, schematic diagram of a unidirectional D-WDM system, capable of supporting 8 wavelengths, is shown below. The outputs from the 8 laser sources are modulated then passively multiplexed. The signal is amplified using an Er-doped fiber amplifier (EDFA) before transmission, then amplified again at intervals which depend on many factors including fiber type, number of channels, bandwidth etc. Beyond a certain distance, the signal must be regenerated, which involves conversion back to electronic form. Some method is also included to compensate for the effects of dispersion. At the receiver, the signal may be amplified again before being demultiplexed. The individual wavelengths are detected by separate PIN diodes or avalanche photodiodes, before passing to the electronic retiming and signal recovery circuitry.

The separation of the laser wavelengths within the 1530-1560nm band usually conforms to one of the ITU (International Telecommunications Union) grids at either 100GHz or 200GHz. 16 channels are possible with a separation of 200GHz, whereas the 100GHz grid allows more channels, but places more stringent requirements on the filters to keep the channels separate. The laser output can be modulated directly, or by using an external III-V or lithium niobate device. Direct modulation at high speeds leads to frequency chirping, which limits the transmission distance. The Nortel D-WDM systems use very stable, temperature-controlled DFB GaInAsP lasers co-packaged with III-V Mach-Zehnder modulators, while Lucent have previously reported a laser integrated with an InP electro-absorption modulator (see CS 3(1), p.23). Future systems may incorporate tunable lasers and possibly even VCSELs.

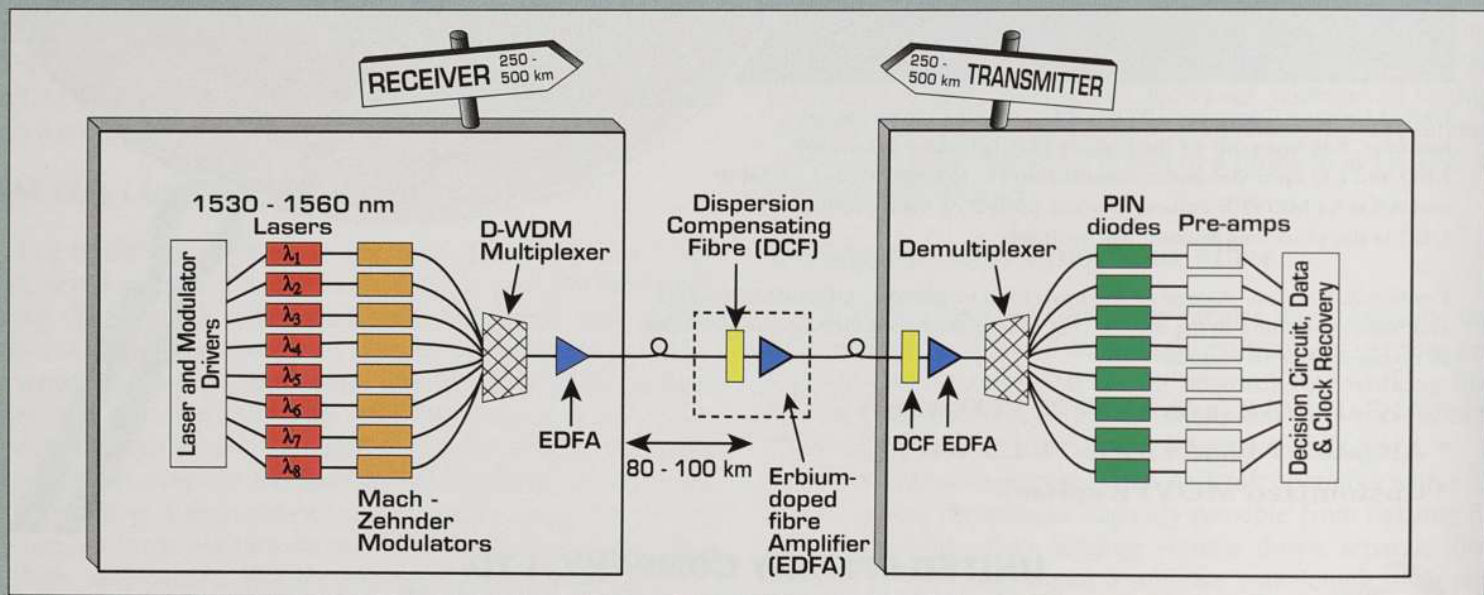
Multiplexing the wavelength channels requires a wavelength-selective filter. Nortel uses a thin film dielectric deposited on glass, which offers low insertion losses and low

crosstalk, and is favored for small numbers of wavelengths. Other options for D-WDM are planar waveguide technology, based on silicon, or fibre Bragg gratings, in which the refractive index of a section of the fibre core is altered. The choice of technology depends on the number of channels and other specific user requirements.

The signal is boosted by an EDFA, which works by using a 980nm AlGaAs pump laser to excite Er^{3+} ions within a section of doped fiber. The resulting Er^{3+} lasing transitions amplify the whole of the 1530-1560nm wavelength band as it passes through the EDFA. Dispersion of the signal along the fiber is a major problem in optical transmission systems, and increases dramatically at high data rates. Compensation for dispersion can be achieved using non-zero dispersion-shifted fiber (NZDSF), which is up to 50% more expensive than ordinary single-mode fiber. Alternatively, a passive dispersion compensating fiber (DCF) or grating can be included at either end of the optical fiber, or with one of the amplifiers.

Along the route, optical filters acting as add/drop multiplexers can be incorporated. These allow certain wavelengths to pass through uninterrupted whilst diverting other wavelengths along different routes, or adding new wavelengths. At the end of its fiber journey, the optical signal is demultiplexed and detected.

The Nortel system used on the MCI LA-Rialto 80Gbit/s corridor (see page 7) is actually bidirectional, which means that a single fiber supports 4 wavelengths co-propagating in each direction simultaneously. The system is capable of handling 16 wavelengths (8 in each direction) per fiber, whereas using unidirectional components would require two sets of the equipment shown above, and two fibers. The Nortel system obviously requires that the optical amplifiers and mux/demux components operate in both directions.



plexes these wavelengths before sending them down the same fiber. As systems which support 32 channels or more become available, the benefits in terms of fiber usage are obvious.

What does this mean for the compound semiconductor manufacturer? The news is good, since many laser sources are required to provide the separate wavelength channels. The systems can also incorporate III-V detectors and modulators (see section below), and of course high speed ICs are still required to sustain the high data rate operation.

Many companies are already involved. As reported in the News section of this issue, Nortel have supplied MCI with a system which can transmit 80Gbit/s down a single fiber, and which will actual-

ly support 16 wavelengths. Although Nortel claim upwards of 90% of the world market in OC-192 products, other major players offer multi-channel capability at these data rates and below, including Lucent, Alcatel, Pirelli and Hitachi. NEC and Fujitsu both have 32 channel systems in the pipeline.

Future Developments

One interesting aspect to watch will be the migration of this technology from long-haul applications, where it is generally more cost-effective, to metro and local networks. At present, for very short distances it is often cheaper to install new fiber. The choice to upgrade OC-48 by installing a 16-channel D-WDM, or by moving to OC-192 with 4 channels (both

giving 40Gbit/s capacity) is a complex trade-off involving the type of fiber, PMD, transmission distance and spacing of amplifiers, bandwidth, network type and of course, cost.

The next stage of developing the optical layer from point-to-point applications to true optical networking will create systems capable of managing and routing signals without converting them back to electronic form. Some of the companies named above are working on configurable optical components; Lucent recently exhibited a 16 x 16 optical cross-connect switch, and Alcatel expects to have fiber-switched optical cross-connects by the end of 1998. This should, in the longer term, make multi-wavelength D-WDM systems even more attractive.

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After a few false starts, it looks as though 1998 will be the year that silicon germanium semiconductors finally reach the market.

Temic will offer both standard products in SiGe as well as a foundry service "for big telecommunication customers", according to a company spokesperson. Production is being done on a upgraded 6" bipolar line. Temic uses the SiGe process developed at the Daimler-Benz Research Center in Ulm, Germany, which uses MBE to grow the SiGe-base and the n-emitter on top of a CVD-grown collector. The process is said to yield $f_t = 50$ GHz in production, but >110 GHz in research.

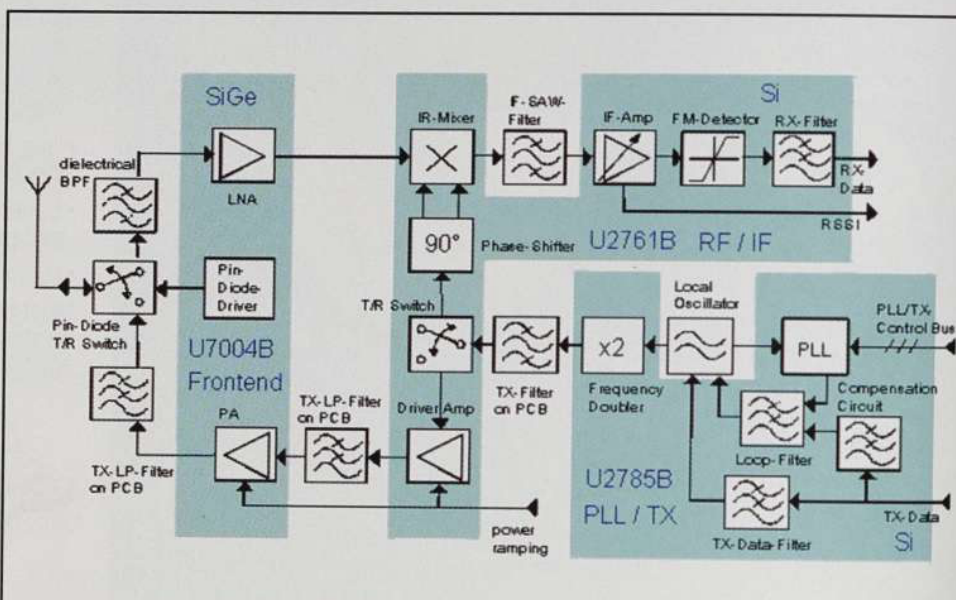
The Sky is Not Falling

making much headway in the pure analog RF and microwave area."

Of course, one can also find a lot of commentators who will offer opinions about why the roll-out of SiGe circuits signals the end of boom times for the GaAs industry. Which is why it is somewhat of a relief to see that companies are at last beginning to offer SiGe circuits.

A collage featuring a SiGe chip, a TEMIC calculator, and a CD-ROM, symbolizing the integration of silicon and germanium technology. The SiGe chip is prominently displayed in the center, with its intricate circuitry and gold wire bonds visible. The TEMIC calculator is positioned at the bottom right, showing its keypad and display. A CD-ROM is partially visible in the background, adding to the technological theme. The overall composition is set against a dark, textured background with a grid pattern.

Now the whole GaAs vs. SiGe debate can move off paper and into the marketplace. May the best technology win.



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Research Review

The following is a sampling of recent papers from a variety of international journals, compiled by the staff of Compound Semiconductor.

Topics in this issue —

Optoelectronic Devices

- VCSELs operating in the 2-3 μ m range
- GaAs/AlGaAs unipolar lasers
- GaN photodetectors
- Strained QW lasers on ternary substrates

Microelectronic Devices and Circuits

- New Silicon Carbide devices
- SiGe demultiplexers at 60Gbit/s
- HBTs with reduced power dissipation
- Split-gate transistors

Compound Semiconductor Materials

- Dislocation densities in laterally overgrown GaN
- Low defect density ZnSSe

Optoelectronic Devices

Antimonide-based 2-3 μ m VCSELs

The key advantages of VCSELs compared to edge-emitting lasers have not yet been fully realised at longer wavelengths, due in part to the thickness of the Bragg mirror required to define the optical cavity. However, two groups have recently reported VCSELs with antimonide-based structures operating in the mid-infrared region. Workers at the Naval Research Lab in collaboration with Hughes report an optically pumped, type-II VCSEL operating at 2.9 μ m, whilst Montpellier University, France, report a room temperature, electrically pumped VCSEL at 2.2 μ m.

The NRL/Hughes 2.9 μ m device has a pulsed threshold intensity at 86K of 1.2kW/cm² for a large spot size, with a threshold power of 22mW observed for a 30 μ m spot. Lasing was observed up to 280K, and the peak output power exceeded 2W from a 600 μ m spot up to 260K. The laser structure, grown by MBE, features an 11-period GaSb/AlAs_{0.08}Sb_{0.92} Bragg mirror stack, overgrown with 1.5 additional mirror periods and a 78- or 79-period InAs/GaSb/InAs/AlSb active region. The layer thicknesses, which were slightly different (19.5Å/28Å/19.5Å/40Å for the 78-period structure), were chosen to produce a gain maximum at ~3.0 μ m at different operating temperatures. The active regions were capped with 160Å AlSb (to block the escape of holes), followed by GaSb [C. Felix et al, Appl. Phys. Lett., 1997, 71(24), 3483].

The Montpellier laser operates at near 2.2 μ m at room temperature, with a threshold current density as low as 2.2kAcm² measured for a 200 μ m-diameter device. A pulsed optical output power of 20mW was achieved. This structure was also grown by MBE and features GaSb/AlAs_{0.07}Sb_{0.93} Bragg mirrors, with 17.5 periods for the bottom mirror (Te-doped) and 15 periods for the top (Be-doped). The active region consists of six 6.5nm Ga_{0.65}In_{0.35}Sb_{0.9}As_{0.1} strained quantum wells with 22nm GaSb barriers, surrounded by 225nm GaSb to form one-wavelength long optical cavity. [A. Baranov et al, Electronics Lett., accepted for publication].

Strained QW lasers grown on ternary substrates with T₀ of 140K

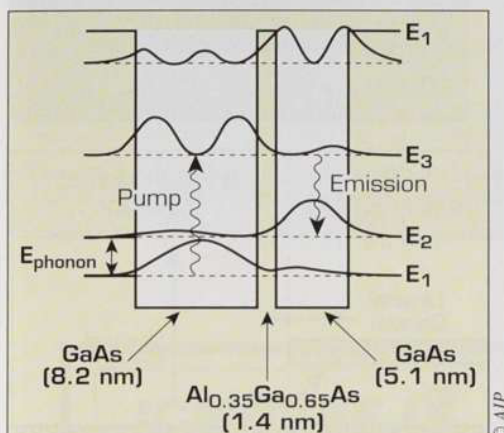
K. Otsubo et al, Electronics Lett., 1997, 33(21), 1795

To improve both threshold currents and characteristic temperatures (T₀) of lasers operating at 1.3 μ m, a key step is to achieve larger optical gain and stronger optical confinement by making the quantum well potential much deeper than in conventional InGaAs/InP systems. One approach, used here by workers from Fujitsu, is through the use of ternary substrates. Using the Bridgman method, In_{0.22}Ga_{0.78}As substrates suitable for epitaxial growth were prepared, although the FWHM measured by X-ray diffraction was 20x larger than for GaAs substrates. The laser structure grown by MOVPE features a QW region with two 7nm thick In_{0.41}Ga_{0.59}As 1.32% compressively strained wells separated by a 10nm InAlGaAs barrier, with InGaP cladding layers. The maximum gain of the well layers was designed to be in the 1.2 μ m region, because the In content of the substrate is not large enough for 1.3 μ m lasers. The composition of the InAlGaAs layer was adjusted to provide a bandgap of 0.9eV and a deeper potential well than in previous structures. Under pulsed conditions, a 600 μ m laser with high reflective coatings on both faces had a very low threshold current density of 176A/cm². The T₀ of 140K is exceptionally high for this wavelength. By improving the quality of the ternary substrates and increasing the In content to 0.25-0.3, it should be possible to realize 1.3 μ m lasers with improved T₀.

GaAs/AlGaAs unipolar lasers operate at 15.5 μ m

O. Gauthier-Lafaye et al, Appl. Phys. Lett., 1997, 71(25), 3619

Mid-infrared lasers are increasingly sought for high sensitivity, tunable detection of trace gases for environmental control, pollution monitoring and remote chemical sensing. Traditional compound semiconductor lasers in the 3-5 μ m band (narrow gap III-V materials) and above 8 μ m (II-VI or IV-VI lead-salt materials) rely on optical transitions between conduction and valence bands, and at longer wavelengths the various non-radiative mechanisms become increasingly more efficient, limiting the output power of these devices. In contrast, lasing transitions in unipolar QW lasers (also known as quantum cascade lasers) occur between subbands of the conduction band of quantum wells. Previously, unipolar lasers between 4 and 11 μ m have been reported in the InGaAs/InAlAs material system. Researchers at CNRS, France, have recently reported a novel type of quantum cascade laser based on the GaAs/AlGaAs system, operating at very long wavelengths (~15.5 μ m). The structure is carefully engineered so that the subbands in the two coupled GaAs QWs have certain specific energy levels (see Figure). When optically pumped with a CO₂



Conduction band profile of the coupled GaAs quantum wells, along with the moduli squared of the electron envelope wavefunctions. The wavy lines indicate the pump and emission intersubband transitions.

laser, electrons are excited to the upper subband (labelled E₃). The transition between the first excited state and the ground state (E₂-E₁) is closely matched to the optical phonon energy in GaAs, so the lifetime of E₂ is very short compared to E₃. This creates the population inversion necessary for stimulated (laser) emission from the E₃-E₂ transition. The laser has been operated at up to 110K in the pulsed regime, with peak output powers at 30K of 0.6W. The use of optical pumping greatly simplifies the device design and fabrication, although the requirement for a CO₂ laser is far from ideal. The absence of doped layers for electron inversion minimizes free-carrier absorption losses and allows longer wavelength operation.

GaN-based UV photodetectors with ~50% efficiency

J. Carrano et al, Electronics Lett., 1997, 33(22), 1980

In addition to providing light sources in the blue visible region of the spectrum, the wide bandgap Al_xGa_{1-x}N system is also being used to fabricate solar-blind UV photodetectors. This work from the University of Texas at Austin describes a straightforward metal-semiconductor-metal (MSM) structure, which has a high quantum efficiency of ~50% and a very low dark current of ~800fA. Since there is no discernible photoconductive gain, the high quantum efficiency indicates that the photodetector material is highly efficient in converting photons to electrons. The single 4.0 μ m epitaxial layer grown by MOCVD was unintentionally doped n-type, with $n \sim 6.0 \times 10^{16} \text{ cm}^{-3}$. The Schottky barriers at both interfaces were formed with Pt metal contacts, and the devices had a finger width of 2 μ m, with 2.5 and 10 μ m gap spacings. The spectral response of the device indicates flat responsivity with a sharp bandedge transition and no discernible responsivity below the bandgap (i.e. longer than ~380nm), which is an important property for solar-blind detectors. This technology could provide simple, practical low cost UV photodetectors for a variety of applications.

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Compound Semiconductor Materials

Defect Density Studies of Laterally Overgrown GaN

Since Shuji Nakamura of Nichia Chemical announced it as part of his 10,000 hour GaN laser structure, epitaxial lateral overgrowth (ELO, or ELOG, or variations thereof) has attracted considerable attention. Several papers from North Carolina State University, from both before and after Nakamura's announcement, describe TEM and other studies which provide a great deal of insight into why ELO is successful in significantly reducing dislocation densities in GaN epilayers. Lateral overgrowth takes place when a GaN epilayer has a patterned SiO_2 mask deposited upon it. During subsequent selective growth on the patterned surface, GaN initially grows in the window areas defined by the SiO_2 mask, but does not deposit on the mask itself. Further deposition results in both vertical growth above the window region, and lateral growth over the mask. The gallium precursor flow rate affects the growth rates of the top and sidewall facets, and thus controls lateral growth, whilst surface diffusion towards the window region of Ga and N adatoms which land on the SiO_2 mask plays only a minor role.

The TEM cross-section and its schematic representation in Figure 1 show a GaN ELO layer grown by MOVPE on a 6H-SiC substrate, using an AlN buffer. Clearly, there is a high density of dislocations ($\sim 10^8$ - 10^9 cm^{-2}) in the initial GaN layer. These originate at the SiC/AlN and AlN/GaN interfaces, and following mask deposition, these dislocations extend into region A, directly above the window. However, dislocations in the laterally overgrown region B are few in number, and are limited to short dislocations parallel to the interface plane, where vertical threading dislocations are transposed through 90° , and a small number of stacking faults. The coalescence of laterally growing volumes results in nearly defect-free GaN, although a subsurface void is often seen where the lateral growth fronts combine.

As reported in this issue's Nitride News, NCSU have also studied stacking two ELO layers, one on top of the other. A TEM cross-section from such a layer is shown in Figure 2. Precise alignment of the two SiO_2 masks and control of the growth parameters should allow the growth of very low defect density GaN epilayers.

[see T. Zheleva et al, *Appl. Phys. Lett.*, 1997, 71(17), 2472; O. Nam et al, *MRS Symp. Proc.*, 1997 (to be published)]

Low defect density ZnSSe epilayers

J. Leem et al, *Semicond. Sci. Technol.*, 1997, 12, 767

Low defect densities are crucial to avoid degradation of short wavelength laser diodes fabricated from ZnSe-based compounds grown on GaAs(100) substrates. Eliminating defects originating from the II-VI/GaAs heterointerface has previously been achieved by adding a small amount of S into the ZnSe, or by using a Zn treatment on an As-rich GaAs surface. This report, from the Korean Institute of Standards and Science and Samsung, describes a method to improve crystalline quality by reducing the unintentional variation in growth temperature which often occurs during MBE growth of Zn(S,Se) layers. The incorporation of S species is very sensitive to the surface temperature, which can vary due to effusion cell heating effects, and as a result of the change in surface emissivity as the epilayer thickness increases. An optimized temperature control profile was developed, by experimentally minimizing the FWHM of the double-crystal x-ray rocking curves. Using this technique, $\text{Zn}_{0.06}\text{Se}_{0.94}$ epilayers were grown with an etch pit density of around $5 \times 10^3 \text{ cm}^{-2}$.

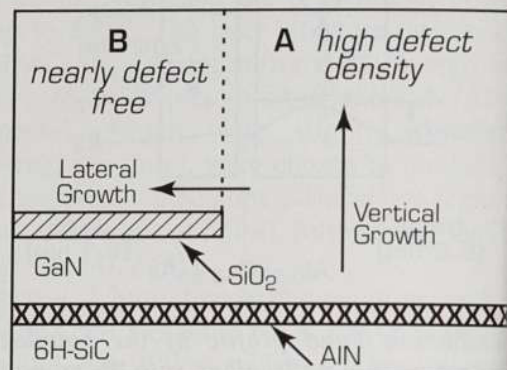
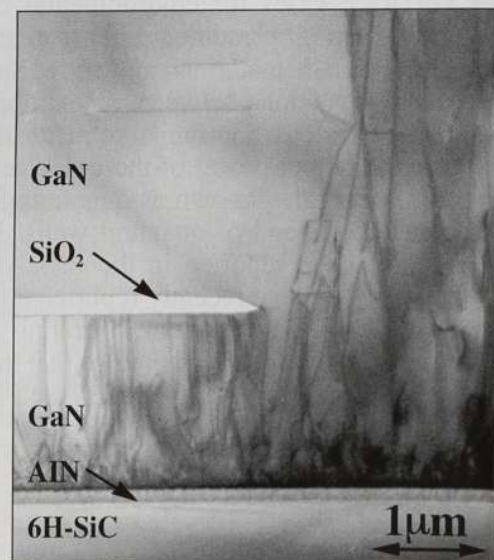


Fig 1. TEM micrograph and schematic of a section of GaN laterally overgrown on an SiO_2 mask. Region A shows a high density of dislocations, while the lateral growth region B is nearly defect-free.

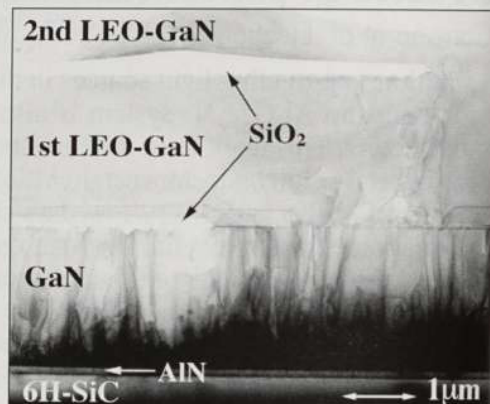


Fig 2. TEM micrograph showing first and second LEO (Lateral Epitaxial Overgrowth) layers.

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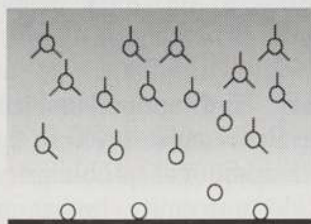
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Microelectronic Devices and Circuits

Superfast SiGe for 60Gbit/s Demultiplexing

A. Felder et al, *Electron. Lett.*, 1997, 33, 679

Although Wavelength Division Multiplexing (WDM) appears to have the lead in deployment of high speed optical transmission systems, components which enable high data rate Time Division Multiplexing (TDM) at 40Gbit/s or more continue to appear. TDM prepares signals for serial transfer by dividing the signals into discrete intervals of equal duration, and then sampling each channel in turn at a higher rate to interweave (multiplex) the signals. At the other end of the transfer route, the signals are separated (demultiplexed). The speed of the multiplexed signal is increased by the same factor as the number of channels to be combined, so that the data rate of a TDM system is determined in part by the operating speeds of the multiplexer/demultiplexer (MUX/DEMUX) functions.

Workers at Siemens AG and Ruhr-University Bochum have developed MUX and DEMUX SiGe-based components capable of operating at 60Gbit/s, which is a record value for ICs in any technology. The DEMUX [1] separates the 60Gbit/s into two 30Gbit/s outputs and feature excellent re-timing capability. The DEMUX circuit consists of several building blocks; two master-slave D-flipflops (MS-D-FFs) operating in parallel in the DEMUX core, the data and clock input stages, and two output buffers. The speed improvement compared to conventional bipolar technology has been achieved by moving to SiGe HBT technology. Using a Ge gradient in the base, a drift field is generated which increases f_T to ~68GHz. The intended application of this technology is as the decision circuit with DEMUX function in the receiver of a 40Gbit/s TDM transmission system. The authors believe that a single MS-D-FF function (ie without DEMUX) at 40Gbit/s is not yet available.

Lightly-doped Emitters Reduce HBT Power Dissipation

C. Chang et al, *IEEE Microwave and Guided Wave Lett.*, 1997, 7(11), 377

Although high speed operation of HBTs typically requires high collector current densities, which means high power dissipation, the maximum device speed is not always required throughout the entire device design. Rockwell, UCSD and TRW report HBTs based on TRW's baseline devices, modified by the inclusion of a lightly doped emitter (LDE) layer between the base and the emitter, and by introducing a Si δ -doped region at around $6 \times 10^{11} \text{cm}^{-2}$. The utility of the LDE HBT devices was demonstrated by their inclusion in a digital 128/129 programmable prescaler circuit, using TRW's MMIC HBT foundry design rules to yield high levels of integration. The prescaler chip featured 223 HBTs and several TRW 20GHz MMICs. Use of the LDE HBT resulted in a reduction of power dissipation by up to 50%, and improved bandwidth, without any circuit modifications.

Split-gate Transistors

N.J. Collier and J.R.A. Cleaver, *Appl. Phys. Lett.*, 1997, 71 (20), 2958

By combining split-gate and dual-gate GaAs/AlGaAs HEMTs, a novel gating action has been achieved which is not observed with normal dual-gate devices, allowing the threshold of either gate to be controlled by altering the bias at which the other gate is held. In a single split-gate transistor, a negative potential between gate and source depletes electrons from the 2DEG region and defines a narrow channel between the split-gate electrodes. Increasing the bias further reduces the channel width, while a second independent electrode placed adjacent to the gap gives additional control over the carrier density in the channel, particularly when a protrusion from the continuous gate extends into the center of the split-gate gap. Possible applications of this device include a dual-gate mixer with the RF signal applied to the split-gate and the local oscillator signal applied to the continuous gate, with the output taken from the drain. (Work carried out at the University of Cambridge, UK).

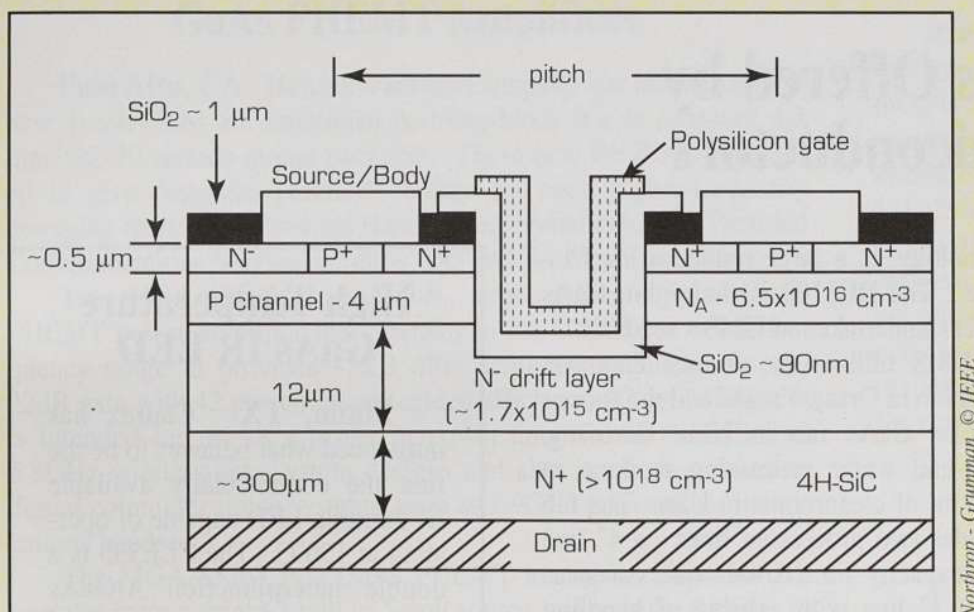
New Silicon Carbide Devices

The material advantages of SiC compared to GaAs and Si (higher thermal conductivity, higher breakdown field, wider bandgap, higher saturated electron drift velocity) continue to be exploited for high-power switching applications. SiC power devices include pn junction and Schottky diodes, thyristors, U-groove MOSFETs and JFETs. Here we review some of the recent reports of SiC research devices with enhanced performance.

Power MOSFETs

SiC power MOSFET devices are expected to have a very low specific on-resistance and fast switching compared to Si, and to outperform Si IGBTs in the 600-2000V range. Although double-implanted MOS transistors have been reported with a blocking voltage of 760V, such devices are very difficult to fabricate due to low diffusion coefficients. Vertical UMOS structures are preferred but suffer serious problems which can limit the maximum operating voltage to 100-200V, despite the use of thick drift regions with theoretical breakdown voltages of a kilovolt or more. High temperature and high electric fields cause stress in the gate oxide, and additional problems include poor oxide uniformity, higher interface state densities in the sidewall, electric field crowding at the trench corners and Fowler-Nordheim carrier injection (see below).

Northrop-Grumman and Lehigh University [1] report UMOS device structures (see Figure 1) with room temperature blocking voltages ranging from 1.0kV to 1.2kV. The specific on resistance was measured as $74 \text{m}\Omega \text{cm}^{-2}$ with an applied gate bias of 2.9MV/cm. The structure was grown by VPE on a heavily doped n-type, 4H-SiC substrate. The gate oxide uniformity was improved by reducing the growth rate differences between the trench walls and bottom, using a combination of thermal SiO_2 fol-



Schematic device cross-section of 4H-SiC vertical U-groove MOSFET, grown by vapor phase epitaxy [1].

lowed by a thicker CVD layer. Other improvements included using boron-doped polysilicon for the gate contact and reducing the finger pitch of the 40-finger UMOS cell to increase charge sharing between the fingers, allowing for higher breakdown voltages.

The same group at Northrop-Grumman have also studied [2] the temperature dependence of Fowler-Nordheim (F-N) carrier injection from SiC into the gate oxide in UMOS structures similar to Figure 1. The large bandgap of SiC should, in theory, result in negligible leakage currents even at temperatures as high as 400°C. Study of Si MOS devices shows that high temperatures combined with high electric fields leads to F-N carrier injection-induced dielectric breakdown of the gate oxide. The larger bandgap of SiC compared to Si reduces the barrier height for carrier injection, and the effect is even more pronounced for the 4H-SiC system, which has a wider bandgap (3.26eV) than the 6H- system (2.85eV). This is unfortunate as 4H-SiC has ~5x higher electron mobility in the c-direction compared to 6H-SiC. As the temperature is increased, the statistical spreading of the carrier energy increases the level of tunneling through the barrier,

and this effect raises serious questions about the long-term reliability of SiC MOS devices.

Alternatives to U-groove FETs

Some of the problems of SiC MOS structures can be addressed through alternative device structures. The Power Semiconductor Research Center, NCSU, describes the introduction of a buried p⁺ layer into a vertical MOSFET structure. This effectively shields the channel region, forming a high mobility accumulation layer. The fabricated 6H-SiC devices had a blocking voltage of 350V and a specific on resistance of only 18mΩcm², measured at room temperature with a gate bias of 5V. This value of specific on resistance is much lower than previously reported for 50V UMOSFETs.

Although UMOSFETs offer potentially superior performance due to their vertical design, planar-type devices such as buried-gate (BG) JFETs are also being investigated [4]. The device was fabricated using CVD of n and n⁺ layers on a p⁺ (8x10¹⁷cm⁻³) 6H-SiC substrate, which acts as the buried gate in the device. The channel grooves (~0.72mm wide) were formed by reactive ion etching leaving a 1μm thick

channel. The devices demonstrated a blocking voltage of up to 700V and on-state currents of 60mA. The channel pinch-off voltage is below 40V. Although the BG JFET is somewhat more stable to breakdown than other high voltage SiC devices, surface effects still result in a considerable decrease in operating voltage, showing the importance of developing appropriate passivation techniques for these devices. (Work carried out at ABB, the Ioffe Institute of St. Petersburg, and the Industrial Microelectronics Center, Sweden).

Thyristors

Northrop Grumman has also developed an asymmetrical gate turn-off (GTO) thyristor in which current densities of 1000Acm⁻² were easily obtained [5]. The forward blocking voltage ranged from 600-800V at room temperature, while a forward voltage drop of 4.8V was obtained at a 350°C operating temperature and a current density of 500Acm⁻². Due to the difficulty of obtaining highly conductive, p-type SiC substrates, the structure was inverted and was grown on a heavily doped p-type (p=1x10¹⁹cm⁻²) 4H-SiC substrate. Following an n⁺ buffer layer, a heavily doped p-type layer was grown to form a punch-through structure, while the blocking voltage was supported across a lightly doped 6.0μm thick p-type base layer. The GTO device has excellent turn-off and turn-on times of less than 1μs. Also, 4 GTO cells were connected in parallel to demonstrate 600V, 1.4A (800Acm⁻²) performance.

References

- [1] A. Argwal et al, IEEE Electron Dev. Lett., 1997, 18 (12), 586
- [2] A. Argwal et al, *ibid.*, 1997, 18 (12), 592
- [3] P. Shenoy et al, *ibid.*, 1997, 18 (12), 589
- [4] A. Konstantinov et al, IEEE Electron Dev. Lett., 1997, 18 (11), 521
- [5] A. Argwal et al, *ibid.*, 518

New Product & Process Offered by United Monolithic Semiconductors

Orsay, France. In December United Monolithic Semiconductors released a new 0.15 μm PHEMT low noise transistor. The company also announced the availability of new foundry service for extremely high-frequency diode technology based on an epitaxial 1.0 μm Schottky Diode Process. UMS is an independent joint venture of Thomson-CSF and Daimler-Benz Aerospace.

The new PHEMT, the EC2612, is designed for low noise applications up to 40GHz. Typical noise is 0.5dB at 12GHz and 1.5dB at 40GHz with respectively 14dB and 9.5dNB associated gain. It is already available in chip form (dimensions 0.63 x 0.37 mm). Plans call for availability in micro package form for use in K/Ka band in early 1998.

The new Schottky diode foundry process, BES100, is intended for the production of mixer and switch circuits for high-performance applications up to W band operating frequencies. It includes spiral inductors, MIM capacitors, TaN resistors and via-holes, and offers cut-off frequency > 3 THz. UMS says that its major advantage, compared to HFET

technology, is a large reduction in 1/f - noise. The BES100 is the eighth GaAs process undertaken at UMS - see chart.

UMS utilizes the former Thomson GaAs fab in Orsay, France and the former Daimler GaAs fab in Ulm, Germany. Front-end wafer processing is done in 1400 m² of cleanrooms in Ulm. The fab includes two processing lines: a 4" line with capacity for 10,000 wafers a year; and a 3" line with capable of handling 5000 wafers a year. The back-end processing is in Orsay, including wafer back side processing, on-wafer measurements, dicing and visual inspection of the components and the delivery to the customers. The facilities include more than 10 automatic test stations, including high volume handler/tester enable the full characterization of components in the 0.1 to 100 GHz range.

The GaAs products offered by UMS include a variety of broadband amplifiers operating at frequencies from 0.5-18 GHz; variable gain amplifiers operating at 8-12 and 20-40 GHz; several low noise and power amplifiers operating from 2.7 to 40 GHz; as well as mixers, modulators, and other types of circuits.

UMS GaAs Technologies

Name	Application	Transition Frequency	Max. Usable Freq.	Noise Figure	Associated Gain	Power at -1dB Comp	Active Layers*	Status
LN05	Low Noise	30 GHz	20 GHz	1.8 dB at 12 GHz	8.5 dB at 12 GHz	0.15 W/mm	I	Production
HP07	Power	15 GHz	10 GHz		9.5 dB at 6 GHz	0.5 W/mm	I	Production
HP05	Power	25 GHz	20 GHz		6.5 dB at 18 GHz	0.5 W/mm	E	Production
PH25	Very Low Noise	80 GHz	60 GHz	1.5 dB at 40 GHz	8 dB at 40 GHz	250 mW/mm	E	Production
PH15	Very Low Noise	>100GHz	95 GHz	2.0 dB at 60 GHz	6 dB at 60 GHz	300 mW/mm	E	On Request
SA70	General Purpose	25 GHz	15 GHz	1.7 dB at 10 GHz	12 dB at 4 GHz	300 mW/mm	I	On Request
HB200	HBT, VCO, High Power	60 GHz, 50 GHz	40GHz, 20 GHz		15 dB at 10 GHz, 8.5 dB at 10 GHz	3.5 W/mm	E	Under Development
BES100	Mixer	3 THz					E	On Request

* I = ion implant

E = epitaxy

High Temperature GaAs IR LED

Plano, TX. Clairex has introduced what believes to be the first the commercially available IR-emitting LED capable of operating at 150°C. The CLE335 is a double heterojunction AlGaAs LED packaged in a customized TO-46, hermetically sealed package that allows efficient operation at a junction temperature of up to 165°C. Rated forward current of the CLE335 is 20 milliamps at 150°C. Clairex says the device exhibits less degradation in optical power output at 150°C than comparable amphoteric-junction IR LEDs operating at 100°C, and it can be modulated at frequencies up to 10 MHz.

The device is designed for use in automotive high-temperature environments, optical security systems, and optical safety shields. A custom-packaged version of this product has been qualified for military applications.

The CLE335 is priced at \$2.43 in quantities of 1,000, and is available from stock.



HP Introduces New GaAs PHEMT Amplifiers

Palo Alto, CA. Hewlett-Packard Company has introduced two new 3-volt GaAs RF functional building-block ICs in compact, 4.2 mm² SC-70 surface-mount packages. These new RF ICs are intended to give designers practical choices for such higher-frequency emerging markets as Personal Handyphone System (Japan), Personal Communications Service, wireless data and Wireless Local Loop.

The MGA-83563 is a 3-volt, single-power-supply, GaAs PHEMT power amplifier that operates in the 0.8GHz to 6GHz frequency range. It provides +22.3 dBm saturated output power and 22dB gain with 42 percent power-added efficiency (all at 2.4GHz). It is intended for use as a driver or power amplifier in 2.4GHz and 5.8GHz wireless-data-system designs and also is effective in other digital communications systems, such as 1.9GHz personal communications handsets.

The MGA-85563 is a GaAs PHEMT low-noise amplifier that operates from a single 3-volt to 5-volt source and over the 0.6GHz to 6GHz frequency range. It features a 1.6dB noise figure and 19dB gain at 1.9GHz. One special feature is an adjustable bias, which allows the output-power capability (1dB gain compression) to be adjusted between +1dBm and +8dBm. This means that the designer can elect to supply the amplifier with only as much current as is needed for the particular application. The MGA-85563 may be used as a low-noise preamplifier in receivers or as a buffer amplifier in transmitters. Overall, it features excellent linearity for effective operation in digital PCS systems operating in the 2GHz range; in non-licensed applications at 0.9GHz, 2.4GHz and 5.7GHz (U.S. industrial, scientific and medical bands); and in wireless data and radio in the local loop.

U.S. prices for 2,500-piece quantities are; MGA-83563, \$1.80 each; MGA-85563, \$1.70 each. Both products are available from stock.

SDL Telecom Lasers

San Jose, CA. SDL reports that it has started production of a new high power 1550 nm distributed feedback laser diode for use in high capacity, long haul communication links. The company says the new laser will deliver optical power in excess of 30 mW with excellent noise performance. The new laser is designed for use with external modulators in cable television and telephony networks.

SDL's is positioning itself to deliver both source and pump lasers for 1550 nm optical systems. According to Gregory P. Dougherty, Vice President of Communications and Information Products, "The introduction of this product leverages SDL's strong market position in 980 nm pump lasers, since both products are key elements in transmitters based on erbium doped fiber amplifiers. It also marks SDL's first of many planned source laser offerings. We will continue to build off of our competencies in high power devices and stable packaging."

SDL reports that it has completed preliminary reliability qualification for the 1550 nm laser, and that it is currently delivering evaluation units to key OEM customers.

InGaAs Photodiode Array

Princeton, NJ. Sensors Unlimited has announced the availability of the SU512L-1.7T1-1000, a linear InGaAs photodiode array designed for 0.8 - 1.7 micron spectroscopy applications. Linear InGaAs arrays with 50 micron x 1 mm sensing elements are now available with 128, 256, or 512 elements. On-focal-plane readout circuitry provides individual integrating preamplifiers maintaining zero volt bias on each photodiode. Integrated signals are output through on-focal-plane multiplexing circuitry at pixel rates up to 1 MHz. Uncooled options allow for 1 second exposures while thermoelectrically cooled options allow for exposure times greater than 1 minute.

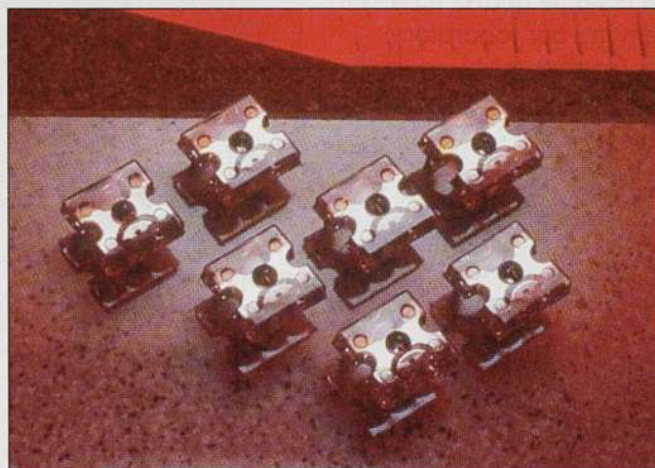
More New AlInGaP Products from HP

Palo Alto, CA. Hewlett-Packard continues to roll out new LED products based on high-brightness AlInGaP materials.

The newest products are a family of LEDs in a package developed especially for meeting the rigorous reliability requirements for transportation, vehicle exterior lighting, outdoor signals and illuminated signs. Available in red-orange (621 nm) and amber (594 nm), the new LEDs have operating lifetimes of 5,000 hours at 70mA; at lower current (40mA), predicted lifetimes are 100,000 hours.

The key features of what HP is calling the "low-profile super flux LED package" are precise optical alignment and low thermal resistance between the LED and the leads. It is used for both absorbing substrate (AS) and transparent substrate (TS) chips. The typical luminous-flux outputs are 1,500 millilumens for red-orange AS AlInGaP and 3,000 millilumens for red-orange TS AlInGaP.

The new LEDs are available from stock, with pricing of 32 cents for AS AlInGaP versions and 46 cents for TS AlInGaP versions in 100,000-piece quantities.



Hewlett-Packard

New Products/New Literature

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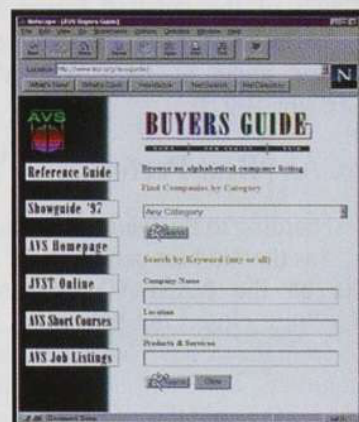
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Topcon Expands WM Series of Wafer Particle Measuring Systems with new 0.1 Micron Sensitivity Instruments

Paramus, NJ. Topcon Technologies has expanded its WM Series of wafer surface particle measuring system with two new systems that automatically detect particles on the surface of a wafer at 0.1 micron sensitivity using scattered laser light detection technology. The new WM-1500 and WM-1700 systems provide a dynamic measurement range of 0.1 to 5.0 μm and high repeatability in a compact footprint of 750 mm².

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Winners and Losers in 1997

MARIE MEYER

Two of the smallest issues in the portfolio standout in this issue as our picks as the "Winner" and "Loser" for 1997.

Spire As "Best Performer"

According to the *Wall Street Journal*¹, Spire was the 3rd best performer of all the stocks on the NASDAQ exchange in 1997. Spire closed the year at 14.50, up 544% from the year before. After years in the doldrums, Spire saw its net income for the first nine months of 1997 climb to \$1,577,000, up from a net loss of \$712,000, for the first nine months of 1996. Net sales and revenues for the first nine months of 1997 increased 36 percent to \$17,060,000 from \$12,540,000 for the first nine months of 1996.

¹ WSJ, 1/2/98, page R4.

² NYT, 1/8/98, page D9.

But, we have to be a bit of a wet blanket and point out that Spire's share volume was about 17 times lower than the average of the rest of the shares in the *WSJ* top five. Which doesn't make for a good direct comparison among the companies - although it takes nothing away from Spire's dramatic improvement in their fundamentals.

SLI: Can it Get Any Lower?

For the biggest disappointment of 1997, you could take your pick between ISSM, a tiny (<\$3 million market cap) over-the-counter-stock which simply shut down in May (*CS* 3(4), p. 23); and Semiconductor Laser International, which seems to be heading straight for the bottom, trading as low as \$0.60/share in December.

More than 18 months after its IPO, SLI has yet to begin producing any significant amounts of product. Revenues for the quarter ended September 30, 1997, the last period for which data is available, were just \$147,916, with a Cost of Sales (materials, production labor and overhead) of \$517,466. Not surprisingly, the company is strapped for cash, and it has sought to bail itself out via some financing

arrangements which diluted their current shareholder's investments.

None of which has stopped the company from promoting itself as a hot investment. According to an article in the *New York Times*², SLI has retained the services of Marketing Direct Concepts, a stock promotion firm that runs an Internet site called the "Stock-Up Report" which promotes "undervalued" stocks. Marketing Direct Concepts got \$75,000 in cash up front, plus \$10,000 a month, plus SLI shares and warrants.

SLI has a history of over-representing itself. When it bought a fairly routine single wafer MBE system - one not too different from those found at hundreds of universities around the world - it was billed as "the most advanced epitaxial reactor in the world". The company has also claimed that it is exclusively entitled to produce Al-free lasers, on the basis of some MOCVD patents it has licensed from Northwestern University. Coherent, which has been shipping MBE-grown Al-free laser diodes in one form or another for five years, has reportedly forced SLI to remove such claims from its ads.

The "StockUp Report" does nothing to clear the air. In fact, it seems to be intentionally obscure. For example: it

waxes enthusiastic about the DVD market, without ever explaining how a small U.S. start-up might gain entrance to a highly-competitive field dominated by Japanese electronics giants with captive laser diode manufacturing capability. It also makes the claim that "SLI manufactures its superior product at a much lower cost than the competition". Given the paucity of SLI's shipments, it is difficult to understand where this comparison comes from.

Of course, SLI isn't the first company in the world to try to "talk-up" its stock. But for the way it is being done, we are singling them out as our loser for 1997.

Company	Symbol	Last 52 Weeks		Closing Price		Change	Volume	P/E Ratio
		Hi	Lo	Jan 2	Dec 31			
Alpha	AHA	20 5/8	5 1/2	8	15 3/4	97%	52,000	♦
Anadigics	ANAD	51 14	21	25 1/3	29 2/3	17%	1,131,000	24
APA Optics	APAT	9 1/4	4.25	4 1/2	8 5/8	92%	8,000	♦
ATMI	ATMI	42 1/4	15 3/4	16 7/8	23 1/8	37%	1,026,000	42
Celeritek	CLTK	18 3/8	9 3/16	15 1/2	13 1/2	-13%	20,000	26
Cree Research	CREE	29 1/2	9 1/4	10 5/8	17 3/4	67%	1,919,000	81
Emcore	EMKR	25 1/4	9 1/4	10 5/16*	19 1/4	87%	65,000	♦
Kopin	KOPN	29	9 7/8	11 5/8	16 2/3	44%	60,000	♦
Ortel	ORTL	25 5/8	10 7/8	22	15 3/4	-28%	251,000	25
RF Micro Devices	RFMD	23 3/4	10 1/8	15 5/16*	13	-15%	188,000	♦
SDL	SDLI	29	8	24 5/8	15 1/8	-39%	375,000	♦
SLI	SLIC	9 3/4	5/8	7	1 3/4	-75%	126,000	♦
Spire	SPIR	24 3/4	2 1/4	2 3/8	14 5/8	516%	53,000	28
TriQuint	TQNT	45 1/2	17 3/8	27 3/8	20 1/4	-26%	2,517,000	61
Vitesse	VTTS	56 1/2	21 1/8	28 1/8	35 5/16	26%	715,000	45

* Closing price on first day of trading: 3/6/97 for EMKR; 6/3/97 for RFMD

♦ = Loss in most recent 4 quarters.

Oppenheimer Rates the GaAs Companies

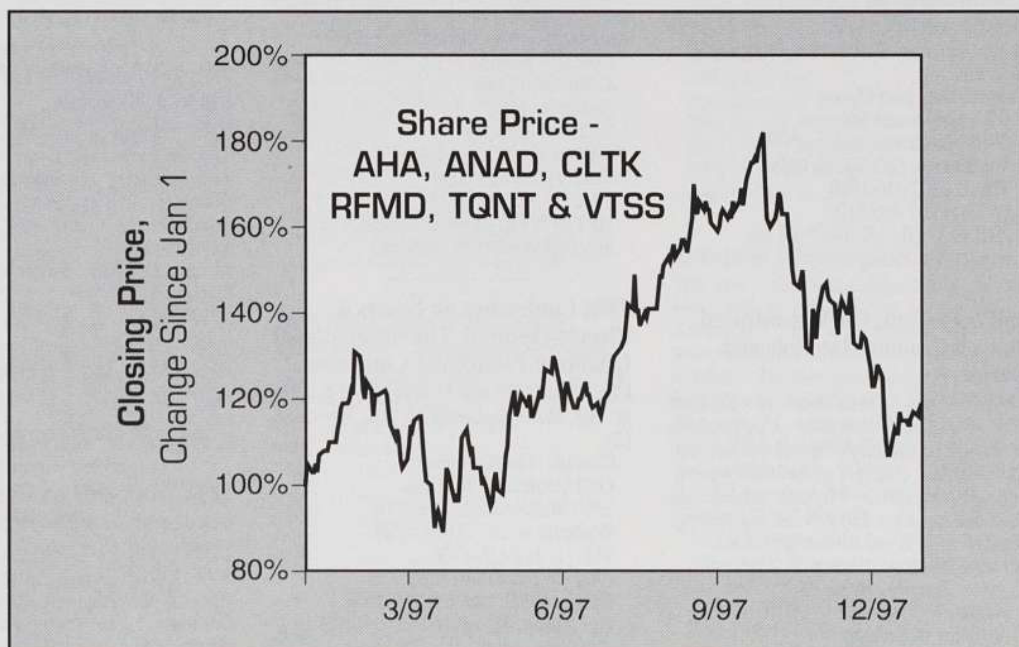
How do the professional stock-pickers view the GaAs companies? To answer that questions, we spoke with Earl Lum at the San Francisco office of CIBC Oppenheimer & Co. Before joining the equity analyst team at Oppenheimer, Lum monitored the wireless and GaAs semiconductor industries for Dataquest.

Of the six GaAs companies we discussed - Alpha, Anadigics, Celeritek, RFMD, TriQuint and Vitesse - Oppenheimer rates all but TriQuint as "Strong Buys". TriQuint is classified as a "Hold".

"TriQuint has had execution problems and we are cautious on the recent acquisition of the TI fab", says Lum. Some analysts have suggested that the operation was probably not profitable when TI was running it, and therefore it is unlikely to add directly to TriQuint's bottom line in the immediate future.

Oppenheimer is much more bullish about Anadigics and Vitesse. "We like **Anadigics** because of their sound management team, and because they continue to be on the cutting edge of technology", said Lum. Anadigics' biggest wireless semiconductor products are power amps for transmitters, which sell at \$4 - \$5 a piece. In contrast, LNA mixers for the receiver side of the handset - an area which TriQuint has specialized in - sell for less than \$1.50 each, because of what Lum describes as "cut-throat competition". In addition to wireless, Anadigics is also active in several other growing markets, including selling low noise blocks for DBS receivers; tuner chipsets for cable modem boxes, and transimpedance amplifiers for high speed fiber optic networks.

Likewise, Lum is enthusiastic about the future prospects for **Vitesse**. He expects great things from their new fab. "Right now, Vitesse can sell everything they can make. Therefore, the new fab, which is a big boost to their capacity, should translate into greater revenue and earnings almost right away." He foresees steady growth in their telecommunications products, as well as big gains in their two other areas, test equipment and data communications.



The Next Generation

Oppenheimer is forecasting good things for the three remaining GaAs companies as well.

Alpha's historical strengths are in control components, such as varactor and pin diodes. Results as of late have been weighed down somewhat by troubles in a ceramics-making subsidiary, but Lum says "as of March 1997 they have really begun to turn things around, and they have now recorded six consecutive quarters with a book-to-bill greater than 1". Motorola accounts for around one-quarter of the company's revenues, and Lum says that Alpha is now shipping a 3V power amp for Motorola GSM phones that has the potential to becoming a "leading edge" product for Alpha.

Celeritek has been, until now, primarily a subsystems company with a captive, vertically integrated GaAs fab. But, according to Lum, about a year and half ago the company began to branch out with their semiconductor operations, and they are now receiving "significant bookings" for PCS handsets. Of particular interest is a 3V PHEMT-based power amp for CDMA phones - one of the first such products to appear on the market. Lum says "our expectations are that revenues

from GaAs semiconductor sales may hit ~25% of fiscal 1998 revenues for Celeritek. We see them as an emerging player in this market."

RFMD is the most recent arrival on the scene, having conducted their IPO in the summer of 1997. Lum says that Oppenheimer's "Strong Buy" rating is premised on the belief that they will be able to get their new GaAs fab up in running later this year on schedule. RFMD is specializing in HBT technology, and Lum says that the company enjoys a close relationship with Nokia, which is interested in HBT-based power amps for 3V applications. According to Lum "there is tremendous upside potential for RFMD with Nokia once the new fab is up and running - just this one customer could, potentially, use up all of RFMD's 20,000 wafer/year capacity."

Overall, Lum characterizes Alpha, Celeritek and RFMD as "up-and-coming companies that are about ready to make more of an impact with their GaAs products than they have in the past".

*In our next issue:
1997 earnings roundup*

1998 Conference on Optical Fiber Communication

OFC '98 will be held Feb. 22 - Feb. 27, 1998 at the San Jose Convention Center in San Jose, CA.

Contact: Ms. Lisa Myers
OSA Conference Services
2010 Massachusetts Ave., NW
Washington, DC 20036-1023
TEL [1] 202 416-1980
FAX [1] 202 416-6100
NET or WEB: ofc.info@osa.org
http://www.osa.org

2nd Int'l Conf. On Mid-infrared Optoelectronics Materials and Devices

MIOMD-2 will be held March 26 - 27, 1998 in Prague, Czech Republic. Contributions are invited on the following mid-infrared topics: Physical concepts of radiation generation and detection; Physical concepts of band and quantum dimensional engineering; Material growth and device fabrication.

Abstract Deadline: January 20, 1998
Contact: Tomislav Simecek
Institute of Physics
Academy of Sciences
Cukrovarnická 10
Praha 6, 162 53 Czech Republic
TEL ++420 2 24311137 ext.580
FAX ++420 2 3123184
NET or WEB: miomd98@fzu.cz or
http://sun186b.fzu.cz/dep/semicon/miomd/

Integrated Photonics Research Topical Meeting

IPR '98 will be held March 30 - April 3, 1998 in Victoria, British Columbia, Canada. It will consist of a technical meeting and a tabletop exhibition.

Abstract Deadline: December 1, 1997
Contact: OSA
2010 Massachusetts Ave.
Washington, DC 20036-1023
TEL [1] 202 416 1985
FAX [1] 202 416 6100
NET or WEB: ofc.info@osa.org
http://www.osa.org

1998 Spring MRS Meeting

The 1998 Spring MRS Meeting will be held April 13 - 17, 1998 in San Francisco, CA. The Symposia at this year's meeting include Wide-Bandgap Semiconductors for High Power, High Frequency and High Temperature; Reliability of Photonics Materials and Devices; and Epitaxy and Applications of Si-Based Heterostructures, as well as several others.

Contact: Materials Research Society
506 Keystone Drive
Warrendale, PA 15086-7573 USA
TEL [1] 412 779-3003
FAX [1] 412 779-8313
NET or WEB: webmaster@mrs.org
or http://www.mrs.org

1998 GaAs MANTECH

The 1998 GaAs MANTECH Conference will be held April 27 - April 30, 1998 in Seattle, Washington. Papers that deal with manufacturing "how to" in the following subject areas will be covered: manufacturing; processing; test & reliability; device technologies; materials; packaging; optical devices (integration

with GaAs or InP, process simplification); and the future of GaAs (business outlook, trends, competition, new applications).

Abstract Deadline: November 3, 1997
Contact: Kuohsiung Li,
Conference Chair
Anadigics Inc.
35 Technology Dr.
Warren, NJ 07059 USA
TEL [1] 908 668 5000
FAX [1] 908 668 5132
NET or WEB: gaas@ee.wustl.edu or
http://www.ee.wustl.edu/GaAs

1998 Conference on Lasers & Electro-Optics & The International Quantum Electronics Conference

CLEO/IQEC '98 will be held May 3-8, 1998 at The Moscone Center in San Francisco, CA.

Contact: Ms. Amy Hutto
OSA Conference Services
2010 Massachusetts Ave., NW
Washington, DC 20036-1023
TEL [1] 202 416-1980
FAX [1] 202 416-6100
NET or WEB: cleo.info@osa.org
http://www.osa.org

193rd Meeting of the Electrochemical Society

The 193rd ECS Meeting will be held May 3-8, 1998 at the Sheraton San Diego Hotel & Marina in San Diego, California. Symposia include: E1 - Third International Symposium On Low And High Dielectric Constant Materials (covering all aspects of low and high dielectric materials in silicon and compound semiconductor); F3 - First International Symposium On Environmental Issues With Materials And Processes For The Electronics And Semiconductor Industries (including III/V semiconductor materials and processes); I2 - State-Of-The-Art-Program On Compound Semiconductors (SOTAPOCS XXVII); K1 - Light Emitting Devices For Optoelectronic Applications
Abstracts Deadline: January 2, 1998
Contact: The Electrochemical Society
10 South Main Street
Pennington, NJ 08534-2896 USA
TEL [1] 609 737 1902
FAX [1] 609 737 2743
NET or WEB: ees@electrochem.org
or http://www.electrochem.org

1998 Custom Integrated Circuits Conf.

The 20th Custom Integrated Circuits Conference (CICC) will be held May 11 - 14, 1998 in the Santa Clara, CA. This is the leading technical conference for design, fabrication and integration of ASIC and system-on-a-chip applications using CMOS and other technologies. Topics of interest for this year's meeting include: Analog Techniques; RF IC Technology; Wireless; DSP; Custom Design; Clocking and Low-Power Design Methodologies; Deep Submicron Design; Modeling and Interconnects; PLD architectures; System-on-a-Chip; and design success stories.

Contact: Melissa Winderkehr
CICC
101 Lakeforest Boulevard
Gaithersburg, Md. 20877 USA
TEL [1] 301 427 0902

FAX [1] 301 527 0994
NET or WEB: cicc@his.com or
http://www.ieee.org/conference/cicc/

10th Int'l Conf. On InP and Related Materials

IPRM '98 will be held May 11-15, 1998 in Tsukuba, Japan. The scope of the conference will include optoelectronics, electron devices, processing, epitaxy, bulk growth and characterization, and new materials and nanostructures.

Abstract Deadline: November 25, 1997
Contact: IPRM '98
IEEE/LEOS
445 Hoes Lane
Piscataway, NJ 08854 USA
TEL [1] 908 562 3896
FAX [1] 908 562 8434
NET msarcone@calypso.ieee.org

22nd Workshop on Compound Semiconductor Devices and Integrated Circuits

WOCSDICE 98 will be held May 24-27, 1998 at the Pannonia Hotel in Zeuthen, Germany. The European Workshop on Compound Semiconductor Devices and Integrated Circuits aims to bring together scientists and engineers working in the area of III/V compound semiconductor devices and integrated circuits for microwave, mm-wave and optoelectronic applications. To encourage interaction between participants and to permit sufficient discussion, presentations are kept short and focused on the main results and new ideas presented by the participants. The Workshop is open to European and world wide participation.

Abstract Deadline: February 16, 1998
Contact: Joachim Würfl
Ferdinand-Braun-Institut
für Höchstfrequenztechnik
Rudower Chaussee 5
D-12489 Berlin Germany
TEL [49] 30 6392 2690
FAX [49] 30 6392 2685
NET or WEB: wocsdice@fbh-berlin.de
or http://www.fbh-berlin.de

1998 Electronic Components & Technology Conference on Optoelectronics

The 48th ECTC Optoelectronics Conference will be held May 25-28, 1998 in Seattle, WA. Papers are solicited on all topics pertaining to the design, development, and technology of packaging active/passive hybrid and integrated photonic components, devices, circuitry and systems.

Abstract Deadline: October 15, 1997
Contact: Mark W. Beranek
The Boeing Company
PO Box 3999, M/S 2W-51
Seattle, WA 98124-2499
TEL [1] 253 657 5748
FAX [1] 253 657 8903

9th Int'l Conf. On Metal Organic Vapor Phase Epitaxy

ICMOVPE IX will be held May 30 - June 4, 1998 at the Sheraton Grande Torrey Pines in LaJolla, CA. Topics of interest include precursors, process design/communication issues; developing applications of MO compounds; growth technologies; advances in

devices by MOVPE, and characterization.

Abstract Deadline: January 15, 1998
Contact: Barbara Laitwood

TMS
420 Commonwealth Drive
Warrendale, PA 15086 USA
TEL [1] 412 776 9000 x234
FAX [1] 412 776 3770
NET kamperman@tms.org

10th Int'l Conf. on Semiconducting and Insulating Materials

SIMC-X will be held June 1-5th 1998 in Berkeley, CA. This conference is the tenth in a series of bi-annual conferences which aim to bring together scientists and engineers interested in materials problems of compound semiconductors of relevance for the performance of electronic and optoelectronic devices. The purpose of the meeting is to discuss growth, characterization, theory, device applications, and materials problems related to semi-conducting and insulating compounds such as GaAs, InP, III-nitrides, II-VI compounds, SiC and SiGe. Special areas of interest for this Conference are: III-nitrides, III-oxides, and non-stoichiometric III-V compound semiconductors.

Abstract Deadline: December 15, 1997
Contact: Dr. Zuzanna Liliental-Weber
Berkeley National Laboratory
1 Cyclotron Road MS 62-203
Berkeley, CA 94720, USA
NET: zlw@ux5.lbl.gov
sime@ux5.lbl.gov

1998 MTT-S International Microwave Symposium

MTT '98 will be held June 7-12, 1998 at the Baltimore Convention Center in Baltimore, MD.

Contact: Mr. Steven Stitzer
Westinghouse Electric Corp.
P.O. Box 1521
MS 3T15
Baltimore, MD 21203
TEL [1] 410 765-7348
FAX [1] 410 993-7747

1998 IEEE Radio Frequency Integrated Circuits Symposium

RFIC '98 will be held Jun. 07, 1998 - Jun. 12, 1998 at the Baltimore Convention Center in Baltimore, MD (in conjunction with MTT '98).

Contact: Dr. Vijay Nair
Motorola Inc.
2100 E. Elliot Rd.
M/D EL508
Tempe, AZ 85234
TEL [1] 602 413-5922
FAX [1] 602 413-5934

4th International Workshop on Expert Evaluation and Control of Compound Semiconductor Materials and Technologies

EXMATEC 98 will be held June 22-24, 1998 in Cardiff, Wales, UK. This conference aims to bring together research, development, and production specialists involved in compound semiconductor material physics, chemistry, process technology, and device fabrication. Central issues to be addressed are the improvement of yield, reliability, performance, lifetime and reproducibility of electronic and optoelectronic devices and circuits

through characterisation, optimisation, and control of materials and processes. Papers on investigations ranging from perfection of crystal growth and improvement of intermediate processing steps to device lifetime testing are solicited. Material systems to be discussed include wide band gap (GaN, ZnSe, SiC ...), intermediate band gap (GaAs, InP, SiGe ...) and narrow band gap (HgCdTe ...) compound semiconductors.

Abstract Deadline: December 1, 1997

Contact: Cherrie Summers
Cardiff School of Engineering
PO Box 917, Newport Road
Cardiff, Wales CF2 1XH UK
TEL [44] 1222 874000
FAX [44] 1222 874421
NET or WEB: summerse@cardiff.ac.uk

1998 Device Research Conference

The 1998 DRC will be held at the University of Virginia in Charlottesville, VA on June 22 - 24, 1998

Abstract Deadline: March 2, 1998

Contact: Emmanuel Crabbe
Tel: [1] 914 892-2056
Fax [1] 914 892-2568
NET or WEB: crabbe@watson.ibm.com

Third European GaN Workshop

EGW-3 will be held June 22-24, 1998 in Warsaw, Poland. This meeting will encompass all areas of research related to physical properties, crystal growth, epitaxy, doping, processing, device manufacturing and applications of nitride semiconductors.

Abstract Deadline: March 1, 1998

Contact: Conference Secretariat
EGW-3
High Pressure Research Center
01-142 Warsaw, Sokolowska 29/37
Poland
TEL [48 22] 632 5010
FAX [48 22] 632 4218
NET or WEB: stach@unipress.waw.pl or
http://www.unipress.waw.pl/egw-3/info.html

1998 Electronic Materials Conference

The 40th EMC will be held at the University of Virginia in Charlottesville, VA on June 24-26, 1997. This conference provides a forum for topics of current interest and significance in the areas of preparation and characterization of electronics materials. Individuals actively engaged or interested in electronic materials research and development are encouraged to attend this meeting, and papers in this general subject area are solicited.

Abstract Deadline: February 6, 1998

Contact: Barbara Loitwood
TMS
420 Commonwealth Drive
Warrendale, PA 15086 USA
TEL [1] 412 776 9000 x234
FAX [1] 412 776 3770
NET kamperman@tms.org

1998 IEEE Photovoltaics Specialist Conference

Wien, Austria July 6-10, 1998

Abstract Deadline: December 1, 1997

Contact: JRC-Ispira
WC02
Ispira (VA) Italy I-21020
TEL [39] 332 785 885
FAX [39] 332 789 646
NET or WEB: wcon22.prog@jrc.it

OE Expo '98

The 1998 International Optoelectronics Exposition will be held July 11 - 14, 1998 in Taipei, Taiwan. The only annual optoelectronics exhibit in Taiwan, this conference provides an excellent introduction to this rapidly expanding market. Areas of interest include materials, optoelectronic components, equipment and systems, and processing equipment related to the optoelectronic industry.

Contact: Photonics Industry & Technology Development Association
Taipei, Taiwan
FAX [886] 2 396 8513

ICCG-12 & ICVGE-10

The Twelfth International Conference on Crystal Growth in conjunction with the Tenth International Conference on Vapor Growth and Epitaxy will be held July 26 - 31, 1998 at the Renaissance Jerusalem Hotel in Jerusalem, Israel

Abstract Deadline: November 1, 1997

Contact: Conference Secretariat
ICCG-12 / ICVGE-10
International Travel and Congresses Ltd.
P.O. Box 29313, 9 Rothschild Blvd.
Tel Aviv 61292 ISRAEL
TEL [972] 3 5102538
FAX [972] 3 5160604
NET or WEB:
100264.2432@compuserve.com or
http://www.technion.ac.il/~iccg12

10th Int'l Conference on Molecular Beam Epitaxy

MBE-X will be held August 31 - September 4, 1998 in Cannes, France. This conference will cover the full spectrum of MBE-related topics, in the pleasant surroundings of the south of France. Topics of interest include: MBE growth of semiconductors, metals, insulators and other materials; applications and devices; alternative sources and methods; novel in-situ process control; nanostructure engineering; control of surfaces and interfaces; production technology and manufacturability issues.

Abstract Deadline: March 15, 1998

Contact: Prof. Jean-Pierre Faurie
CRHEA-CNRS Sophia Antipolis
Rue Bernard Gregory
F 06560 Valbonne France
TEL [33] 4 9395 4220
FAX [33] 4 9395 4142
NET or Web: org@mbex.unice.fr
http://www.crhea.unice.fr/mbex

First Int'l School on Crystal Growth Technology

ISCGT-1 will be held September 5-16, 1998 at Beatenberg above Interlaken, Switzerland. This School will treat in 54 one-hour lectures, from leading crystal growth and epitaxy technology experts, the major technologies for fabrication of large commercial crystals including crystal machining, crystal growth machines, and saws. Emphasis will be on silicon, III - V and II - VI compounds, and sapphire. Posters are welcome.

Contact: Dr. Hans Scheel
Cristallogenese
Ch. de Bellerive 34
CH - 1007 Lausanne Switzerland
Tel. (41) 21 693-4452
Fax. (41) 21 693-4750
NET or WEB: Hans.Scheel@epfl.ch

1998 Conference on Lasers & Electro-Optics Europe & The 6th European Quantum Electronics Convention

CLEO EUROPE/EQEC will be held Sep. 13 - Sep. 18, 1998 at the Scottish Exhibition & Conference Center in Glasgow, Scotland.

Contact: Ms. Melissa K. Estrin
IEEE/LEOS
445 Hoes Lane
Piscataway, NJ 08855-1331
TEL [1] 908 562-3896
FAX [1] 908 562-8434
NET or WEB: m.estrin@ieee.org
http://www.ieee.org/leos/meet.htm

1998 IEEE Bipolar/BiCMOS Circuits and Technology Meeting

BBCTM '98 will be held Sep. 27 - Sep. 29, 1998 in Minneapolis, MN.

Contact: Ms. Janice V. Jopke
CCS Associates
6611 Countryside Dr.
Eden Prairie, MN 55346
TEL [1] 612 934-5082
FAX [1] 612 934-6741
NET or WEB: jjopke@aol.com

2nd Int'l Symposium on Blue Laser and Light Emitting Diodes

The 2nd ISBLLED Conference will be held September 29 - October 2, 1998 at the Chiba, Japan. The main objective of this symposium is to provide a joint forum for both the GaN community and the ZnSe community to discuss common problems extending from the growth and characterization of materials to device performance and reliability. Papers are solicited in many areas, including, but not limited to, the following: substrate issues; epitaxy; p-type doping; material characterization; device degradation mechanism; device processing; ohmic contacts; device design; laser oscillation mechanism; detectors; and new materials.

Abstract Deadline: May 15, 1998

Contact: Prof. F. Hasegawa
University of Tsukuba
Institute of Materials Science
1-1-1 Tennodai
Tsukuba, Ibaraki 305 Japan
TEL [81] 298 53 5287
FAX [81] 298 55 7440
NET or WEB:
hasegawa@mat.ims.tsukuba.ac.jp
or http://www.etl.go.jp/etl/divisions/
/material/isblled2/isblled2.html

17th North American MBE Conf.

NAMBE-17 will be held October 4-7, 1998 at Pennsylvania State University (State College, PA).

Abstract Deadline: TBA
Contact: David L. Miller
Pennsylvania State University
121 E.E. East Building
University Park, PA 16802
TEL [1] 814 865 2730
FAX [1] 814 865 7065
NET or WEB: dlm15@psu.edu

1998 IEEE/LEOS Semiconductor Laser Conference

The 1998 IEEE/LEOS Semiconductor Laser Conference will be held Oct. 5, 1998 - Oct. 10, 1998 at the Nara Public Hall in Nara, Japan. The scope of the meeting includes semiconductor laser physics; mate-

rials and processing; design and modeling; long & short wavelength laser; high power & high speed laser; VCSELs, novel laser structures; and integration and packaging.

Abstract Deadline: May 8, 1998

Contact: Ms. Elsie L. Vega
IEEE/LEOS
445 Hoes Lane
Piscataway, NJ 08855-1331
TEL [1] 732 562-3897
FAX [1] 732 562-8434
NET or WEB: e.vega@ieee.org
http://www.ieee.org/leos/is/c.htm

European Microwave Week

The new "European Microwave Week" event will be held October 5 - 9, 1998 in Amsterdam, The Netherlands. This event incorporates three previously existing conferences: The European GaAs Applications Symposium (GAAS '98), The European Microwave Conference (EuMC '98), and The MTT-S European Topical Congress on Technologies for Wireless Applications (MTT-S European Wireless '98).

Contact: David Roberts
Miller Freeman Plc
Microwave Engineering Europe
30 Calderwood Street
London SE18 6QH UK
TEL [44] 181 855 777 x 5953
FAX [44] 181 316 3174
NET or WEB: droberts@unmf.com

25th Int'l Symp. on Compound Semiconductors

ISCS '98 will be held October 12 - 16, 1998 in Nara, Japan. This symposium covers all aspects of compound semiconductors - including growth, processing, devices, ICs, and applications - and deals with III-V compounds such as GaAs, InP, and GaN; II-VI compounds such as ZnSe and ZnS; IV-IV materials such as SiC and SiGe; etc.

Abstract Deadline: May 18, 1998

Contact: Kimiyoshi Yamasaki
NTT System Electronics Laboratories
3-1 Morinosato Wakamiya,
Atsugi, Kanagawa, 243-01 Japan
TEL [81] 462 40 2500
FAX [81] 462 40 2872
NET: kyama@aecl.ntt.co.jp
WEB: http://www.ieice.or.jp/es/iscs98.html

3rd Int'l Workshop on Novel Index Surfaces

NIS '98 will be held October 13 - 16, 1998 in La Casona (San Rafael), Spain. The scope of this conference is the growth, characterization and exploitation of epitaxial compound semiconductors on novel index surfaces. All communications in close relation with the topics of the workshop are welcome: growth mechanism of III-V and II-VI compounds on high index planes; patterned growth and regrowth; relaxation of pseudomorphic layers; self assembling quantum wires and dots; doping and defect incorporation; spontaneous ordering and composition modulation; piezoelectric effects and applications; structural, optical and electronic properties; devices using above novel physical properties; and theoretical aspects

Abstract deadline: May 15, 1998

Contact: Mariano Gonz-lez
ETSI TelecomunicaciUn-UPM
Ciudad Universitaria
28040-Madrid, Spain
FAX [34] 1 336 73 23
NET or WEB: mariano@die.upm.es

1998 IEEE GaAs IC Symposium

The 1998 IEEE GaAs IC Symposium will be held Nov. 01 - Nov. 04, 1998 at the Westin Peachtree Plaza in Atlanta, GA.
Contact: Dr. William Stanchina
Hughes Research Labs., RL61
Plasma Physics Lab.
3011 Malibu Canyon Rd.
Malibu, CA 90265
TEL [1] 310 317-5089
FAX [1] 310 317-5483

194rd Meeting of the Electrochemical Society

The 194rd ECS Meeting will be held November 1-6, 1998 at the Sheraton Boston Hotel & Tower in Boston, Massachusetts. Symposia include: G1 - Dielectric Science

And Technology/Electronics Joint General Session; H1 - Interconnect And Contact Metallization: Materials, Processes And Reliability; I1 - III-V Nitride Materials And Processes; J1 - Fifth International Symposium On Quantum Confinement: Nanostructures; N1 - Compound Semiconductor Power Transistors; N3 - Sixth International Symposium On Long Wavelength Infrared Detectors And Arrays: Physics And Applications; N4 - State-Of-The-Art Program On Compound Semiconductors (SOTAPOCS XXVIII); P1 - Photovoltaics For The 21st Century
Abstracts Deadline: June 1, 1998
Contact: The Electrochemical Society
10 South Main Street
Pennington, NJ 08534-2896 USA
TEL [1] 609 737 1902
FAX [1] 609 737 2743

NET or WEB: ecs@electrochem.org
or <http://www.electrochem.org>

FAX [1] 412 779-8313
NET or WEB: webmaster@mrs.org or
<http://www.mrs.org>

45th National AVS Symposium

The 1998 AVS National Symposium will be held November 2-6, 1998 at the Baltimore Convention Center in Baltimore, MD. AVS Technical Divisions include: applied surface science; nanometer-scale science and technology; surface science; vacuum metallurgy; electronic materials and processing; plasma science and technology; thin film; and vacuum technology.
Abstract Deadline: May 1, 1998
Contact: Marion Churchill
AVS
120 Wall Street
New York, NY 10005 USA
TEL [1] 212 248 0200
FAX [1] 212 248 0245
NET: marion@vacuum.org
WEB: <http://www.vacuum.org>

1998 IEEE International Electron Devices Meeting

The 1998 IEDM will be held Dec. 06- Dec. 09, 1998 in San Francisco, CA.
Contact: Ms. Phyllis Mahoney
Widerkehr & Associates
101 Lakeforest Blvd., Suite 270
Gaithersburg, MD 20877
TEL [1] 301 527-0900
FAX [1] 301 527-0994
NET or WEB:
pwmahoney@aol.com

Conf. on Optoelectronic and Microelectronic Materials and Devices

COMMAD '98 will be held December 14-16, 1998 in Perth, Australia.
Abstract Deadline: August 31, 1998
Contact: Lorenzo Faraone
Univ. of Western Australia
EEE Department
Nedlands, WA 6907 Australia
TEL [61] 8 9380 3104
FAX [61] 8 9380 1095
NET or WEB: faraone@ee.uwa.edu.au
<http://www.ee.uwa.edu.au/~COMMAD98>

If you would like your conference to be included in future issues, send the appropriate information by E mail to calendar@compsem.com, or by FAX to [1] 978 750 9740, attention "Calendar"

Contributions must be received by February 15 to appear in our next issue.

1998 Fall MRS Meeting

The 1998 Fall MRS Meeting will be held November 30 - December 4, 1998 in Boston, MA.
Contact: Materials Research Society
506 Keystone Drive
Warrendale, PA 15086-7573 USA
TEL [1] 412 779-3003

PATENTS

U.S. Patents related to compound semiconductors issued in November and December. Headlines contain U.S. Patent # / Date Issued / Assignee.

Electronic Circuits & Devices

05686737 / 1997 11 11 / Cree Allen, Scott T.

SiC Self-aligned MESFET. A MESFET is disclosed that exhibits reduced source resistance and higher operating frequencies. The MESFET comprises an epitaxial layer of SiC, and a gate trench in the epitaxial layer that exposes a SiC gate surface between two respective trench edges. A gate contact is made to the gate surface, and with the trench further defines the source and drain regions of the transistor. Respective ohmic metal layers form ohmic contacts on the source and drain regions of the epitaxial layer, and the edges of the metal layers at the trench are specifically aligned with the edges of the epitaxial layer at the trench.

05686325 / 1997 11 11 / Fujitsu Moriuchi, T. & Yokoyama, T.

T-Gate MESFET. It is an object of the present invention to provide a semiconductor device wherein variation of a threshold voltage caused by difference of stresses between a T-shaped gate electrode and a compound semiconductor layer is easily controlled. The transistor has a structure in which a first insulating film is formed only under an overhang of a gate electrode an upper part of which is formed widely, and a second insulating film for threshold voltage adjustment is formed on the side of a gate electrode and the first insulating film.

ly controlled. The transistor has a structure in which a first insulating film is formed only under an overhang of a gate electrode an upper part of which is formed widely, and a second insulating film for threshold voltage adjustment is formed on the side of a gate electrode and the first insulating film.

05686741 / 1997 11 11 / Fujitsu Ohori, T. & Fukuzawa, K.

III-V HEMTs on Si Substrate. E and D mode HEMTs are integrated in a laminated layer of pairs of GaAs/AlGaAs layers formed on the same GaAs-on-Si substrate. The gate electrodes of E and D mode HEMTs are formed on different GaAs layers. The GaAs layer on Si contains crystal defects. It is hypothesized that the defects extend upward in the laminated layer of pairs of GaAs/AlGaAs layers formed on the GaAs layer with such crystal defects. Etch pits are generated as the AlGaAs layer is etched by ammonium etchant. Generation of etch pits can be suppressed by etching the whole part of the exposed AlGaAs layer and exposing the GaAs layer under the gate electrode.

05698868 / 1997 12 16 / Fujitsu Awano, Y; Hirachi, Y; Hikosaka, K

High-Speed Heterojunction Transistor. The present invention generally relates to high-speed transistors such as GaAs FETs which operate with high-velocity carriers in which there is no decrease in the operation speed due to intervalley scattering of electrons even when operated at a high voltage.

05701019 / 1997 12 23 / Hitachi Matsumoto, H; Yazawa, M; Hiruma, K

FET Contacts. The present invention relates to contacts to sources and drains of FETs, in particular, of hetero-junction field-effect transistors that use III-V materials. The disclosed device has decreased capacitance between the gate and drain, and decreased source resistance. Disclosed is a structure in which a contact layer comes in contact with the side surfaces of a channel layer but does not come in contact with the side surfaces of a barrier layer, which enables capacitance between the gate and drain to be decreased.

Electronic Circuits & Devices, con't

05693964 / 1997 12 02 / Matsushita Elec. Ohta, Y.; Inoue, K.; Tanabe, M.

FET and Fabrication Method. The present invention pertains in particular to a FET where high drain breakdown voltage is required and to its fabrication method. A channel layer of n-type GaAs doped with Si as an impurity is formed on a GaAs semi-insulating substrate. A gate electrode of, for example, aluminum is formed on the channel layer. The gate electrode is in Schottky-contact with channel layer. Formed on opposite sides of the gate electrode on the channel layer are drain- and source side electric field relaxation layers of n-type In GaAs doped with impurities. Each electric field relaxation layer substantially produces a potential difference at its lateral edge portion by an electric current flowing across the lateral edge portion. A WSi drain electrode is formed on the drain-side electric field relaxation layer. A WSi source electrode is formed on the source-side electric field relaxation layer.

05698462 / 1997 12 16 / Mitsubishi Denki Sasaki, Hajime

FET with Improved Stability. A microwave IC comprises an IC disposed on a semiconductor substrate, including at least an FET as a circuit element; and a dome-shaped metal film disposed on the semiconductor substrate. In this structure, the FET is protected from external environment and electromagnetically shielded by the dome-shaped metal film without producing parasitic capacitance between a gate electrode of the FET and the dome-shaped metal film. As a result, the FET operates stably for a long period.

05698871 / 1997 12 16 / Mitsubishi Denki Sakai, M & Shimura, T

HBT With Reduced Base-Collector Capacitance. It is an object of the present invention to provide an HBT with reduced base-collector capacitance without implanting ions to make portions of the collector layer below the external base regions high resistance. The result is an HBT having an improved high frequency gain.

05693969 / 1997 12 02 / Motorola Weitzel, C. E.; Moore, K. E.; Thero, C.

MESFET Having A Termination Layer In The Channel Layer. A lateral MESFET utilizes a drain and a source damage termination layer to improve the breakdown voltage of the MESFET. The source and drain damage termination layers are very shallow to prevent interfering with lateral current flow in the channel layer. The source and drain damage termination layers are formed by implanting large inert ions using high implant doses and low implantation energies.

05698862 / 1997 12 16 / National Science Council (Taiwan)

Liu, W-C; Lour, W-S; Tsai, J-H

Heterostructure-Emitter And Heterostructure-Base Transistor (HEHBT). The invention presents a structure of heterostructure-emitter and heterostructure-base transistor. The device structure are, from bottom upward in succession, a substrate, a buffer layer, a collector layer, a base layer, a quantum well, an emitter layer, a confinement

layer and an ohmic contact layer. Of them, except the quantum well which is made of InGaAs and the confinement layer which is formed by AlGaAs, the rest are all made of GaAs material. Base on the design of the heterostructure of base and emitter, a transistor of such structure, under normal operation mode, possesses high current gain and low offset voltage so as to reduce undesirable power consumption.

05701020 / 1997 12 23 / National Science Council (Taiwan)

Liu, W-C; Lai, L-W

Pseudomorphic FET. A pseudomorphic step-doped-channel field-effect transistor is provided, which has advantages of large transconductance, high electron mobility, high gate voltage swing and high current density, and can increase the pinch-off voltage tolerance. Thus the pseudomorphic step-doped-channel field-effect transistor is suitable for high-speed, high-power, and large-input signal circuitry systems.

05686740 / 1997 11 11 / NEC Hida, Hikaru

FET With Recessed Gate. In an FET structure, an n-type AlGaAs electron supplying layer is provided above a GaAs channel layer, and a low-resistivity n-type GaAs contact layer (the first semiconductor layer) is provided between the source/drain electrode and the electron supplying layer. A high-resistivity AlGaAs layer (the second semiconductor layer) is formed on the sidewalls of the contact layer and the immediately adjacent region between the gate electrode and the contact layer. According to the present invention, since a semiconductor film is used as the thin film formed on the sidewall and the adjacent electron supplying layer instead of a conventional insulating film, and moreover since AlGaAs is substantially lattice matched to GaAs and has a larger band width, parasitic resistance is reduced significantly, and the fluctuation of device performance properties is prevented while still maintaining high breakdown voltage. A semiconductor layer having a conduction type opposite that of the contact layer may also be used in place of the high resistivity AlGaAs layer.

05686756 / 1997 11 11 / NEC Hori, Yasuko

III-V FET with Chalcopyrite Passivation Layer. It is an object of the present invention to provide a field effect transistor having a III-V group compound semiconductor layer which can prevent the semiconductor device characteristics from being deteriorated by a passivation film. The transistor has a semiconductive layer made of a compound which consists of a single III group element and a single V group element or a compound which consists of two III group elements and a single V group and a passivation film for protecting the surface of the semiconductive layer. This passivation film is formed of a chalcopyrite made of a compound which consists of a single I group element, a single III group element and two VI group elements or chalcopyrite made of a compound which consists of a single II group element, a single IV group element and two V group elements in the periodic

table. Those chalcopyrites have lattice constants close to or equal to a lattice constant of the semiconductive layer. Those chalcopyrites have band gaps wider than that of the semiconductive layer. The semiconductive layer may be GaAs and InP. The chalcopyrite may be (Cu_{0.12}Ag_{0.88})AlS₂ and (Zn_{0.04}Cd_{0.96})SiP₂.

05696453 / 1997 12 09 / NEC Maeda, Tadashi

GaAs Logic Circuit. The invention provides a logic circuit which ensures sufficient noise margin to temperature variation, resulting in a lower supply voltage. In addition, the logic circuit makes it possible to compensate for a variation in logical threshold value of DC transfer characteristic caused by an increase in temperature.

05698888 / 1997 12 16 / NEC Fukaishi, Muneo

Elimination of Piezoelectric Effects. This invention relates to a compound semiconductor FET free from piezoelectric effects due to stress of a dielectric over layer regardless of the gate electrode orientation. The device has a Y-letter shaped gate electrode standing on an active layer, and the Y-letter shaped gate electrode prevents piezoelectric charges induced beneath both ends of the wing portions thereof from undesirable merger so as to restrict variation of the threshold.

05698897 / 1997 12 16 / NEC Nashimoto, Y & Tsutsui, H

Plated Heat Sink. A semiconductor device having a plated heat sink structure is provided, in which an Au layer high in thermal expansion coefficient is formed on the lower surface of a GaAs substrate having a source electrode, a gate electrode and a drain electrode of a FET on the upper surface, and, a W layer low in thermal expansion coefficient is formed on the lower surface of the Au layer. Warping of the device after mounted on a package is reduced on the ground of such a plated heat sink structure.

05689124 / 1997 11 18 / Nippon Steel Morikawa, Yoji & Aigo, Takashi

III-V Transistor on Si Substrate. The present invention relates to a semiconductor device in which an element such as a FET or a HEMT having superior characteristics in a high-frequency band, or with a high-speed digital signal, is formed on a compound semiconductor layer. The device comprises a silicon substrate, at least one compound semiconductor layer formed on the silicon substrate and including a GaAs semiconductor layer for serving as a source/drain regions of at least one field-effect transistor (FET), an insulating layer selectively formed on at least one compound semiconductor layer; and first, second and third electrodes each having a first portion, formed on the GaAs semiconductor layer, and serving as one of gate/source/drain electrodes, respectively, of at least one FET, at least one of the first, second and third electrodes having a second portion formed on the insulating layer.

Electronic Circuits & Devices, con't

05698460 / 1997 12 16 / TI

Yang, J-Y; Plumton, D; Morris, F

HBT with Self-Aligned Emitter Contact. A method of self-aligning an emitter contact in a planar HBT is provided which substantially eliminates problems associated with other HBT fabrication processes. One technical advantage is in fabricating a planar HBT that overcomes misalignment problems in the placement of the emitter contact. Another technical advantage is in self-aligning the emitter contact to the implantation layer.

05684310 / 1997 11 04 / TI

Liu, William Uei-Chunt

Multiple Layer Wide Bandgap Collector

Structure for HBTs. A need exists for a bipolar transistor with independent control of J_{max} and BV_{ceo} . The present invention is directed towards meeting those needs. Generally, and in one form of the invention, a multiple layer wide bandgap

collector structure is provided which comprises a relatively thick, low doped or non-intentionally doped layer and a relatively thin, highly doped layer.

05698870 / 1997 12 16 / U.S.A.F.

Bozada, C. et al

HEMT/PHEMT With Single Metalization Layer.

Disclosed is a HEMT/PHEMT device which uses a single metalization for ohmic and Schottky barrier contacts, employs selective etching with a permanent etch stop layer, employs a non-alloyed ohmic contact semiconductor layer and includes a permanent non photoresponsive secondary mask element affording several practical advantages during fabrication and in the completed transistor.

05698900 / 1997 12 16 / USAF

Bozada, Christopher A.

FET With Single Metalization Layer. Disclosed is a III-V FET which uses a single metalization for

ohmic and Schottky barrier contacts, permanent plural etch stop layers, employs a non-alloyed ohmic connection semiconductor layer and includes a permanent semiconductor material-comprised secondary mask element, a mask element which can be grown epitaxially during wafer fabrication to perform useful functions in both the device processing and device utilization environments.

05698875 / 1997 12 16 / The Whitaker Corp.

Varmazis, Costas Dimitrios

MESFET. A MESFET having a reduced control voltage while maintaining appropriate performance characteristics is disclosed. It is fabricated by a two step implantation technique for fabricating the ohmic contact region in the channel between the source and drain. This implant process results in higher doping levels of the active channel and a increased conductivity. Additionally, this step defines the channel depth, which in turn defines the pinch-off voltage.

Laser Diodes

05699373 / 1997 12 16 / Canon

Uchida, M & Ouchi, T

Oscillation Polarization Selective Laser. The present invention relates to a semiconductor laser whose state of polarization of oscillated light can be switched and which is suitable for a light source used in optical communications and optical information processing. The present invention further relates to an optical communication system using the oscillation polarization selective semiconductor as a light source in a transmitter.

05701325 / 1997 12 23 / Canon

Ouchi, T; Sakata, H; Ohguri, N

Method of Growing DFB Lasers. An improved compound semiconductor device, such as a distributed Bragg reflection type or distributed feedback type laser device, having regions with and regions without a diffraction grating. The device is fabricated without exhibiting surface irregularities by growing a first epitaxial layer on a semiconductor substrate, forming a fine uneven structure on the surface of the first epitaxial layer and growing a second epitaxial layer on the fine uneven structure. The fine uneven structure has a surface shape which exposes crystal orientations that facilitate subsequent epitaxial growth. In one embodiment, portions of the fine uneven structure are formed as a diffraction grating while other portions are formed insufficiently uneven to have a diffraction effect for any usable light wavelength.

05703899 / 1997 12 30 / Canon

Mizutani, Natsuhiko

Gain-Coupling DFB Laser. There is a phenomenon that, when an epitaxial growth is performed on an uneven surface, p- and n-type layer portions can be simultaneously formed depending on growth surface. In a gain-coupling DFB laser of the present invention, that phenomenon is utilized, and a current restraint

layer, which includes alternately-arranged p- and n-type layer portions, is formed in the vicinity of an active layer. Thus, current is unevenly injected into the active layer, and a periodical gain structure can be established. As a result, a DFB structure is achieved, which performs a gain-coupling operation.

05684818 / 1997 11 04 / Fujitsu

Anayama, C; Fukushima, T; Furuya, A

Stepped Substrate Laser. In a slant plane light emission type semiconductor laser whose laser structure can be formed on a stepped substrate by a series of MOCVD growth processes, the width of the active layer at the slant portion is set to 2.5 micron or less or the angle between the flat portion and slant portion is set to 12 degrees or less. The semiconductor laser having such a structure can emit light having a single peak at the near field.

05689378 / 1997 11 18 / Fujitsu

Takashima, Yuichirou et al

Laser Diode Module. A laser diode module includes a laser diode emitting a laser beam, and a lens for collimating the laser beam. The lens is tilted with respect to an optical axis along which the laser beam is propagated.

05692082 / 1997 11 25 / Fujitsu

Fukushima, Nobuhiro

Laser and Depolarizer. A compact, inexpensive laser diode module having a depolarizer function of converting linearly polarized light into unpolarized light. The laser diode module includes a laser diode; a polarization-maintaining optical fiber arranged so that an axis of polarization of the fiber forms an angle of 45.degree. with respect to a plane of polarization of incident light, the fiber having a length set so that an optical path difference between two polarization modes of transmitted light is greater than a coherence length of the incident light; and

an optical coupling element for coupling emitting light from the laser diode to the polarization-maintaining optical fiber.

05703893 / 1997 12 30 / Fujitsu

Komiyama, Manabu et al

Telecommunications Laser Diode Module.

Disclosed herein is a laser diode module having a thermoelectric cooling element, a laser diode, and a thermistor in a housing. The thermoelectric cooling element has a first surface and a second surface between which heat exchange is performed. The first surface is in close contact with an inner surface of the housing. A base is provided on the second surface in close contact therewith. A laser carrier and a thermistor carrier are provided on the base in close contact therewith. The laser diode and the thermistor are provided on the laser carrier and the thermistor carrier in close contact therewith, respectively. A portion of the base in the vicinity of the laser carrier is thermally connected to the housing by a metal plate, for example, thereby allowing high-precision temperature control of the laser diode.

05693558 / 1997 12 02 / Hyundai Electronics

Lee, Soo Won et al

Method For Fabricating A Laser Diode. The present invention relates to a method for fabricating a semiconductor laser diode in optical communication system, having the steps for forming current blocking layers on the resulting structure of the mesa structure and then forming an opening through the current blocking layer on the mesa structure.

05685904 / 1997 11 11 / Lucent Technologies

Pinzone, Christopher James

Method of Making MQW Laser. The present invention is a method for making multi-quantum well structures having superior interfacial crystalline

Laser Diodes, con't

quality. In particular, it is an LP-MOCVD crystal growth method using continuous growth stages to produce well-defined heterojunctions of uniform thickness for multi-quantum well (MQW) lasers, including MQW lasers structures having output wavelengths less than approximately 1.55 μm .

05684900 / 1997 11 04 / Matsushita Electric Nishiwaki, S & Asada, J

Wavelength Locking Device. The present invention relates to a wavelength locking device which locks the wavelength of output light beams from a semiconductor laser, a beam collimating device which comprises the wavelength locking device, and further relates to an optical disk apparatus which reproduces signals of an optical disk by using the devices.

05684823 / 1997 11 04 / Mitsubishi Denki Goto, K & Mihashi, Y

DFB Quantum Wire Laser. The present invention relates to a quantum wire laser, and a method of fabricating a quantum wire laser, a method of fabricating a diffraction grating, and a distributed feedback type semiconductor laser.

05684902 / 1997 11 04 / Mitsubishi Denki Tada, Hitoshi

Semiconductor Laser Module. It is an object of the present invention to provide a semiconductor laser module in which a semiconductor laser and an optical fiber are easily and accurately aligned in the optical axis direction with no damage to a laser facet or a fiber facet, as well as to provide for the alignment in the optical axis direction to be performed self-alignedly with higher accuracy.

05694410 / 1997 12 02 / Mitsubishi Denki Motoda, Takashi & Ono, Kenichi

Semiconductor Laser Device. In a semiconductor laser device including a strained multiquantum well active layer having a plurality of well layers and a plurality of barrier layers, alternately laminated, each well layer includes a main region having a strain while each barrier layer includes a main region having a strain different from the strain of the well layer. Either or both of the well layers and the barrier layers has transition regions at both sides of the main region. The transition regions have a strain that gradually varies from the strain of the main region to the strain of the main regions of adjacent layers toward interfaces between the well and barrier layers. The difference in strains between adjacent layers at the interfaces is smaller than the difference in strains between the main regions of adjacent layers. Therefore, lattice defects, such as dislocations, at the interfaces of the well layer and the barrier layers are reduced, so that the strained multiquantum active layer is grown with improved surface morphology. As a result, the optical characteristics of the strained multiquantum active layer are improved, and the laser characteristics of the semiconductor laser including this active layer are improved.

05701322 / 1997 12 23 / Mitsubishi Denki Nagai, Yutaka

Pump Laser. An object of the present invention is to provide a 980 nm laser suitable for pumping a

light amplifier employing a doped optical fiber. A further object of the invention is to provide a semiconductor laser having a stable first order horizontal transverse mode of oscillation without oscillating in higher order modes, while having a stable current-light output characteristic and satisfactory coupling efficiency with an optical fiber. Yet another object of the invention is to provide a low noise laser so that the longitudinal first order mode of oscillation is maintained.

05692002 / 1997 11 25 / NEC Mizutani, Tomoko

Buried Heterostructure Laser On A P-Type Substrate. A buried heterostructure semiconductor laser formed on a substrate having a first semiconductor of p-type conductivity has a mesa-striped active layer region having a height extending from a first p-type semiconductor layer at the foot of the mesa to a n-type cladding layer on the top of the mesa. On both sides of the mesa-striped region, a second p-type semiconductor layer, a first n-type semiconductor layer, a third p-type semiconductor layer, and a second semiconductor layer having a band gap smaller than that of the other layers except the active layer are sequentially formed from the substrate side. Additionally, the entire structure is further buried with a n-type semiconductor layer. The second semiconductor layer may be inserted in between the second p-type semiconductor layer and the first n-type semiconductor layer as well. Furthermore, the second semiconductor layer may be of a semiconductor material with lower carrier concentration doping than the other layers except the active layer, which is usually undoped.

05693965 / 1997 12 02 / NEC Yamada, Hirohito

Laser Diode Having Narrowed Radiation Angle Characteristic. An active layer and a clad layer are formed on a semiconductor substrate. The active layer including an optical guide layer and an optical confinement layer/formed so that the thickness of the active layer gradually decreases toward a light-emission-side end facet. Since a spot size is gradually expanded toward an emission end, the radiation angle of an emitted beam is narrowed and characteristics including a threshold current become superior.

05703898 / 1997 12 30 / NEC Ogura, Ichiro

Surface Emission Laser. A surface emission laser is formed by sequentially stacking an n-type semiconductor multilayer reflector, an n-type clad layer, an active layer, a p-type clad layer, and a p-type semiconductor multilayer reflector on a semiconductor substrate. The p-type semiconductor multilayer reflector is etched to form a mesa. An electrode is formed on at least on the mesa side surfaces and a portion of the mesa bottom surface.

05692003 / 1997 11 25 / NEC Research Institute Wingreen, Ned Scott & Stafford, Charles A.

Quantum-Dot Cascade Laser. A quantum-dot cascade laser which eliminates single phonon decays associated with quantum-well devices. The elimination of single phonon decays is realized by a three-dimensional confinement resulting in a sever-

al-order-of-magnitude reduction in the threshold current. Dot size, dot density and dot uniformity requirements are presented along with several embodiments.

05689358 / 1997 11 18 / NTT Nakao, Masashi et al

Integrated Optical Devices Having A Ridged MQW Structure. An object of the present invention is to provide an optical functional device, particularly a semiconductor light emitting device which is integrated on a semiconductor substrate having an unevenness pattern (ridges) by crystal growth and which has a wide-band oscillating characteristics. Another object of the present invention is to provide a monolithically integrated optical device having a plurality of such optical functional devices on a semiconductor substrate.

05696784 / 1997 12 09 / Opto Power Srinivasan, Swaminathan Thandalai

Reduced Mode Laser. A reduced, lateral mode laser diode is fabricated using a self-aligning process which produces a well controlled weakly index-guided waveguide with strong current confinement. The structure includes ion implants for controlling current injection into the active region from the top of the ridge. The number of modes may be reduced to unity, resulting in a single lateral mode laser. A laser diode array is fabricated in the same way.

05696862 / 1997 12 09 / R.Bosch GmbH Hauer, H.; Kuke, Albrecht; Schwaderer, B.

Optical Transmitting And Receiving Device Having A Surface-Emitting Laser. The invention relates to an optical transmitting and receiving device having a surface-emitting laser

05689521 / 1997 11 18 / Rohm Co. Nakata, Naotaro

Semiconductor Laser Light Source Unit. A rod lens or a cylindrical lens is disposed in front of a semiconductor laser to increase a divergence angle of a laser beam emitted from the semiconductor laser so as to form a substantially circular far field pattern. In another constitution, there is disposed in front of a semiconductor laser a composite lens having two cylindrical surfaces whose cylindrical axes are perpendicular to each other. The cylindrical surface on the side of the semiconductor laser is a convex surface and the other cylindrical surface is a convex or concave surface. In still another constitution, two semiconductor lasers emitting the same optical signal are arranged adjacent each other so that respective light emitting portions of two pn junction planes are located in the same plane and perpendicular to each other, and that laser beams form orthogonal spots at a single predetermined position.

05696779 / 1997 12 09 / SDL Welch, D. F.; Mehuys, D. G.; Scifres, D. R.

Wavelength Tunable Semiconductor Laser With Mode Locked Operation. The present invention relates to external-cavity semiconductor lasers, especially to those lasers that include a frequency-selective tuning element for broadband tunability and narrow linewidth light emission. The invention

also relates to lasers with single spatial mode, diffraction-limited emission, and to light amplifying diode heterostructures with flared gain regions.

05703897 / 1997 12 30 / SDL
Welch, D; Mehuys, D; Scifres, D

Integral Spatial Mode Filter. The invention relates to external-cavity semiconductor lasers, especially to those lasers that include a frequency-selective tuning element for broadband tunability and narrow linewidth light emission. The invention also relates to lasers with single spatial mode, diffraction-limited emission, and to light amplifying diode heterostructures with flared gain regions.

05684817 / 1997 11 04 / Thomson-CSF
Houdre, R; Weisbuch, C; Berger, V

Semiconductor Laser Having A Structure Of Photonic Bandgap Material. Disclosed is a semiconductor laser that is constituted by at least one active layer sandwiched between two confinement

layers with P and N type doping to constitute a PN junction. In at least one of the confinement layers and/or the active layer, holes are designed on each side of the cavity so as to form structures of photonic bandgap material along the lateral walls of the cavity and the ends of the cavity.

05692001 / 1997 11 25 / U.S. Philips
Tiemeijer, Lukas F.

Semiconductor Diode Laser. An optoelectronic semiconductor device with at least one laser and two mutually parallel, strip-shaped active regions, whose ends are optically coupled at one side, is a very suitable radiation source or amplifier, for example as a tunable radiation source. More than one kind of radiation is often present in such a device, whereas it is desirable for only one kind of radiation to pass through a gate of the device. To achieve this in prior devices, an additional component, such as a filter or isolator, is necessary. In a device according to the invention, the ends of the active regions are coupled to a first and a second radiation

coupler at two respective ends, the first radiation coupler forming a first and a second gate, and the second radiation coupler forming a third and a fourth gate for the device, while the geometry and material properties of the radiation couplers and the active regions are so chosen that electromagnetic radiation generated, amplified, or reflected in the device during operation moves diagonally through device owing to constructive interference. In such a device, at most one kind of radiation will pass through a gate.

05703894 / 1997 12 30 / U.S. Philips
Valster, Adriaan et al

Highly Efficient Optical Device. A radiation-emitting semiconductor diode, such as a laser or LED, with high efficiency and, in the case of a laser, low starting current. The diode has a passive mirror region with an excellent COD suppression and is easy to manufacture. The active layer of the diode comprises a III-V mixed crystal such as InGaP, whose emission lies below 1 micron.

Other Optoelectronics

RE035665 / 1997 11 18 / ITRI
Lin, Jyh-Feng

Surface LED with Electrically Conductive Window Layer. A surface emitting AlGaInP LED having an ITO layer as a window layer to eliminate the current crowding effect, and an ohmic contact layer between its double hetero-structure of AlGaInP and the ITO layer, so that ITO can be utilized with the double hetero-structure of AlGaInP.

05689122 / 1997 11 18 / Lucent
Chandrasekhar, S.

InP/InGaAs Monolithic Integrated Demultiplexer, Photodetector, And HBT. The present invention relates to a monolithic integrated demultiplexing photoreceiver that is formed on a semi-insulating InP substrate. A frequency routing device is formed on the substrate and includes a first plurality of In/InGaAs semiconductor layers. At least one p-n photodiode is also formed on the substrate and includes a second plurality of InP/InGaAs semiconductor layers. Additionally, at least one single HBT is formed on the substrate and includes a third plurality of InP/InGaAs semiconductor layers. At least one layer from each of the first, second and third plurality of layers are substantially identical to one another.

05703989 / 1997 12 30 / Lucent
Khan, M. N. & Zucker, J. E.

OEIC Waveguide. An optical waveguide for use in an OEIC which is formed by the successive layering of varied waveguide materials on a III-V semiconductor substrate, thereby producing a slab waveguide.

05684307 / 1997 11 04 / Mitsubishi Denki
Ishimura, Eitaro

Semiconductor Photodiode. It is an object of the present invention to provide a semiconductor opti-

cal device having a small difference in height between a portion on which an electrode at an anode-side is provided and a portion on which an electrode at a cathode-side is provided, whereby succeeding processing and mounting are easy.

05693560 / 1997 12 02 / Mitsubishi Denki
Hattori, Ryo et al

Semiconductor Device Electrode. An electrode of a semiconductor device includes an oxygen absorbing layer disposed on a surface of a semiconductor layer and a refractory metal layer disposed on the oxygen absorbing layer. Oxygen of a spontaneous oxide film on the semiconductor layer is taken to the oxygen absorbing layer, preventing the formation of interface levels within an interface metamorphic layer, preventing Id drifting.

05684308 / 1997 11 04 / Sandia
Lovejoy, M. L. et al

CMOS-compatible Digital Photoreceiver. The present invention relates to a monolithic InP/InGaAs digital photoreceiver which provides an amplified output signal at a level that is sufficient for directly driving integrated circuitry including CMOS circuitry.

05689123 / 1997 11 18 / SDL
Major, Jo S.; Welch, David F.; Scifres, D.R.

III-V Arsenide-Nitride Materials and Devices. Group III elements are combined with group V elements, including at least nitrogen and arsenic, in concentrations chosen to lattice match commercially available crystalline substrates. Epitaxial growth of these III-V crystals results in direct bandgap materials, which can be used in applications such as light emitting diodes and lasers. Varying the concentrations of the elements in the III-V crystals varies the bandgaps, such that materials emitting light spanning the visible spectra, as well as mid-IR and near-UV emitters, can be created. Conversely,

such material can be used to create devices that acquire light and convert the light to electricity, for applications such as full color photodetectors and solar energy collectors. The growth of the III-V crystals can be accomplished by growing thin layers of elements or compounds in sequences that result in the overall lattice match and bandgap desired.

05698865 / 1997 12 16 / Temic
Gerner, J & Gillesen, K

LED With High Luminous Efficiency. The object of the invention is to provide a LED whose structure allows an improved luminous efficiency. This object is provided by a LED comprising a substrate, a light-emission-generating layer embedded between the cladding layers of a double heterostructure, a current diffusion layer located on the top cladding layer and a contact layer structure disposed on the current diffusion layer there is, wherein the current diffusion layer is sufficiently thin to absorb hardly any light-emission and to allow economic manufacture by means of the MOCVD process, and wherein the contact layer structure features branched and finger-type electrodes, which, together with the current diffusion layer, distribute the current in sufficient measure across the surface area of the light-emission-generating layer.

05696389 / 1997 12 09 / Toshiba
Ishikawa, Masayuki et al

Light-Emitting Semiconductor Device. A light-emitting semiconductor device comprising an n-type cladding layer provided on a surface of a substrate and having concentric first and second parts, a first electrode mounted on the first part of the n-type cladding layer, a p-type cladding layer provided above the surface of the substrate and surrounding the first electrode and the second part of the n-type cladding layer, and a second electrode provided on the p-type cladding layer.

Nitrides

05686738 / 1997 11 11 / Boston University
Moustakas, Theodore D.

Highly Insulating Monocrystalline GaN. This invention relates to a method of preparing highly insulating GaN single crystal films by MBE. A molecular beam source of Ga and source of activated atomic and ionic nitrogen are provided within the growth chamber. The desired film is deposited by exposing the substrate to Ga and nitrogen sources in a two step growth process using a low temperature nucleation step and a high temperature growth step. The low temperature process is carried out at 100-400 C. and the high temperature process is carried out at 600-900 C. The preferred source of activated nitrogen is an ECR microwave plasma.

05701321 / 1997 12 23 / Mitsubishi Denki
Hayafuji, N & Kawazu, Z

Short Wavelength Laser. A semiconductor laser includes an electrically insulating substrate (preferably sapphire, MgO, and spinel) having an opening; and various semiconductor layers, preferably GaN materials. The layers consist of a first conductivity type first contact layer within the opening in the substrate; a laminated semiconductor layer structure on the first contact layer and comprising a first cladding layer, an active layer, a second cladding layer, and a second contact layer wherein the first contact layer includes an aperture within the opening; a first electrode disposed on the electrically insulating substrate and extending to and contact-

ing the first contact layer; and a second electrode in electrical contact with the second contact layer. The electrode makes direct, reliable contact to the first cladding layer through an opening in the electrically insulating substrate without the need of mechanically working or etching the substrate.

05684309 / 1997 11 04 / NCSU
McIntosh, F.G. et al

Stacked Quantum Well AlInGaN LEDs. Stacked quantum well light emitting diodes include a plurality of stacked active layers of InGa_xN_{1-x}, separated by barrier layers of AlGa_yN_{1-y} or AlInGa_zN_{1-z}, wherein the ratios of In to Ga differ in at least two of the stacked active layers. Preferably, the differing ratios of In to Ga are selected to produce emission wavelengths from the stacked active layers, such that the emission wavelengths are combined to produce white light. Controlled amounts of hydrogen gas are introduced into a reaction chamber during formation of InGa_xN_{1-x} AlInGa_zN_{1-z} to produce high quality materials which incorporate large percentages of In and possesses excellent optical and surface properties.

05693180 / 1997 12 02 / Sharp
Furukawa, K. & Sugahara, S.

Dry Etching Method for GaN. A dry etching method for etching a gallium nitride type compound semiconductor is disclosed. The method uses a

mixed gas including silicon tetrachloride (SiCl₄) gas and chlorine (Cl₂) gas as an etching gas in a reactive ion etching.

05693963 / 1997 12 02 / Toshiba
Fujimoto, Hidetoshi et al

GaN LED. A light emitting diode is arranged on a sapphire substrate. The light emitting diode includes an n-GaN layer, an n-InGa_xN_{1-x} light-emitting layer, a p-AlGa_yN_{1-y} layer and a p-GaN layer, which are grown through vapor phase growth in this sequence. Within the p-GaN layer and p-AlGa_yN_{1-y} layer, 1 x 10²⁰ cm⁻³ of Mg and 2 x 10¹⁹ cm⁻³ of Mg are contained, respectively. Within each of the n-GaN layer and n-InGa_xN_{1-x} light-emitting layer, 5x10¹⁸ cm⁻³ of hydrogen is contained, thereby preventing Mg from diffusing therein from the p-GaN layer and p-AlGa_yN_{1-y} layer.

05700713 / 1997 12 23 / Toyota Gosei
Yamazaki, S; Shibata, N; Koike, M

Blue LED. There is provided an LED comprising an n-layer of AlGaInN; an i-layer of semi-insulating group AlGaInN formed on the n-layer; an insulating film formed on said i-layer covering said i-layer except for a region which is then processed to have p-type conduction; and wherein the region comes to have p-type conduction by annealing the whole device in a nitrogen atmosphere.

Other Topics

05698472 / 1997 12 16 / ABB Research
Harris, Christopher

Oxidation of SiC. A method and device for oxidation of a semiconductor layer of SiC, forming an insulating surface layer of SiO₂, wherein the surface of the semiconductor layer is illuminated by vacuum ultraviolet light during at least a phase of the oxidation to improve the quality of the SiO₂ layer.

05686350 / 1997 11 11 / ETRI (Korea)
Lee, B.; Yoon, M-Y, Baek, J-H

Defect-Free Compound Semiconductor Thin Film On Dielectric Thin Film. A method for fabricating a defect-free compound semiconductor thin film on a dielectric thin film which oxidizes multi-semiconductor layers consisting of a hetero compound semiconductor thin film made of one of GaAs, InGaAs or InAs over a thin film containing a carbon impurity of a high concentration and made of AlGaAs series by an annealing at a vapor ambient, thereby rapidly growing a hetero-semiconductor thin film over a dielectric thin film made of Al₂O₃ with no defect.

05698771 / 1997 12 16 / NASA
Shields, V; Ryan, M; Williams, R.

SiC Gas Sensor. A hydrocarbon gas detection device operates by dissociating or electro-chemical-

ly oxidizing hydrocarbons adsorbed to a SiC detection layer. The device can operate at elevated temperatures. The dissociation reaction is detected either as a change in a capacitor or, preferably, as a change of current flow through an FET which incorporates the SiC detection layers.

05696377 / 1997 12 09 / NEC
Kanzaki, Masayuki

Hybrid Infrared Ray Detector. The present invention relates to a hybrid infrared ray detector, and more particularly to a hybrid infrared ray detector with an improved bonding structure between an Si substrate having integrated circuits and an HgCdTe layer having two-dimensional photodiode arrays and a method for fabricating the same.

05700714 / 1997 12 23 / OKI Electric
Ogihara, Mitsuhiro et al

Method of Forming PN-Junctions on a Compound Semiconductor Substrate. A pn-junction element is formed in a compound semiconductor substrate by depositing an aluminum-nitride film on the surface of the substrate, patterning the film to form a diffusion mask, depositing a diffusion source film on the mask, diffusing an impurity from the diffusion source film into the substrate, and removing the diffusion source film with buffered hydrofluoric acid.

05689125 / 1997 11 18 / U.S.A.F.
Vaccaro, Kenneth et al

CdS Interface Layers in III-V Devices. One desired goal of the present invention is to reduce the gate leakage of HEMTs, whereby the Schottky barrier has a low leakage current and full depletion of the conducting channel is enabled. A further goal of the invention is to reduce the dark current of the optical detectors. These goals have been substantially achieved by producing an interface layer of cadmium sulfide (CdS), having a thickness of between 50-70 angstroms, positioned between the epitaxial semiconductor and the insulator or Schottky metal of the aforesaid devices.

05696023 / 1997 12 09 / Univ. Illinois
Holonyak, Jr., Nick & Dallesasse, John M.

AlGaAs Device With Native Oxide Layer. A method of forming a native oxide from an aluminum-bearing Group III-V semiconductor material is provided. The method entails exposing the aluminum-bearing Group III-V semiconductor material to a water-containing environment and a temperature of at least about 375 C to convert at least a portion of said aluminum-bearing material to a native oxide characterized in that the thickness of said native oxide is substantially the same as or less than the thickness of that portion of said aluminum-bearing Group III-V semiconductor material thus converted.

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Contact: Professor April S. Brown
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School of Electrical and Computer Engineering
Georgia Institute of Technology
Atlanta, GA 30332-0250 USA
april.brown@ee.gatech.edu

UNIVERSITY OF ROCHESTER

Post-doctoral Position Available **Semiconductor Epitaxial Growth / Materials** **Characterization**

Post-doc position involving MBE growth of a wide range of III-V materials, and their characterization. Nitride materials and antimonide type II quantum wells will be emphasized, but arsenide and phosphide growth are possible also. Optical, electrical and x-ray characterization techniques will be used to analyze the properties of the epitaxial layers. The successful candidate will have a doctoral degree in Physics, EE, Material Science or a related field, and experience in some, but not necessarily all, of the following areas: MBE growth, electrical measurements (Hall, CV, external electron emission), optical measurements (PL, Raman, FTIR), x-ray diffraction.

Contact: Prof. Gary W. Wicks
The Institute of Optics
University of Rochester
Rochester, NY 14627
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GaAs Substrates:

- ▶ epi-ready SI and SC
- ▶ 2", 3", 100 mM and 150 mM
- ▶ all variety of orientations

InP Substrates:

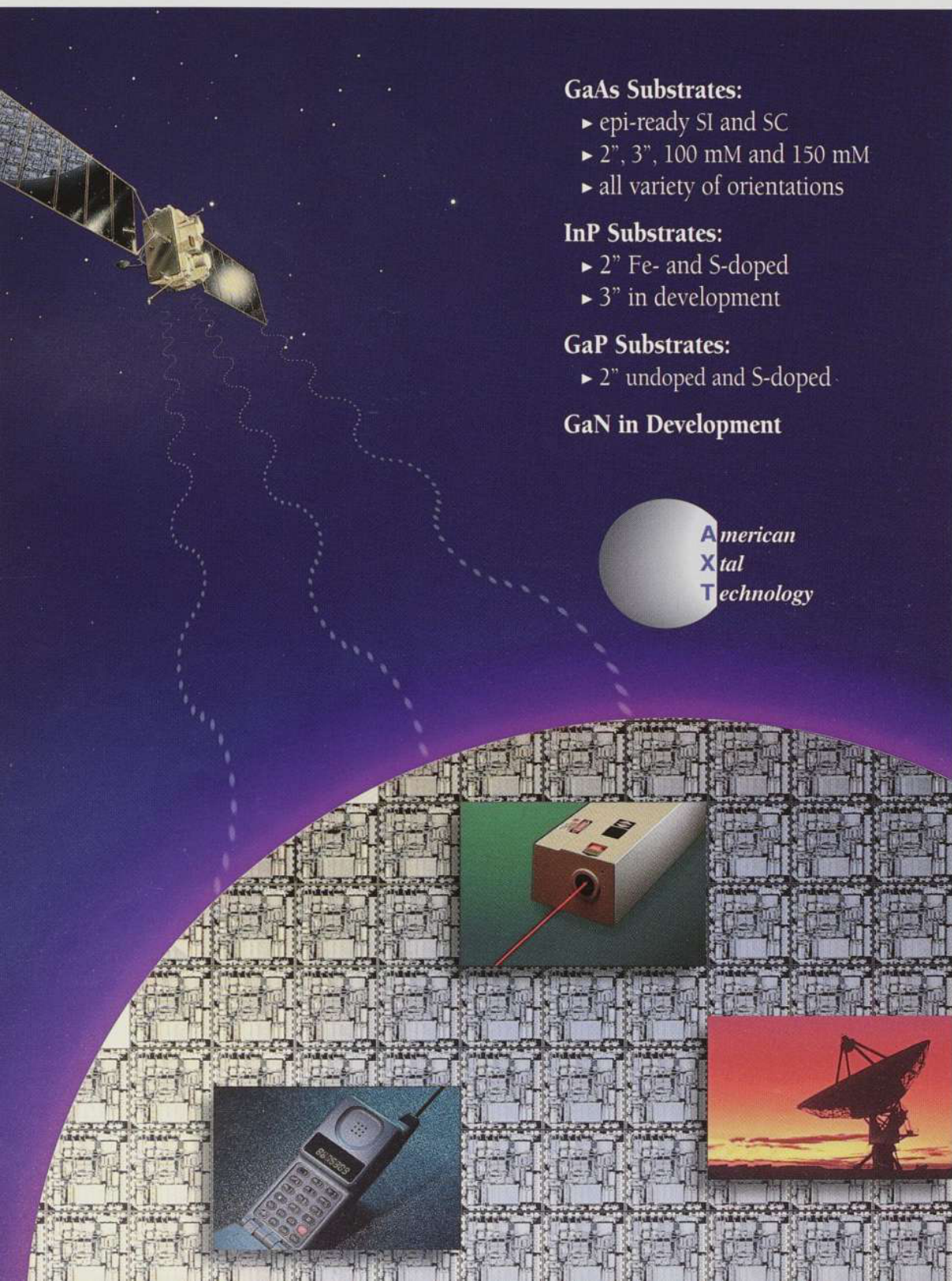
- ▶ 2" Fe- and S-doped
- ▶ 3" in development

GaP Substrates:

- ▶ 2" undoped and S-doped

GaN in Development

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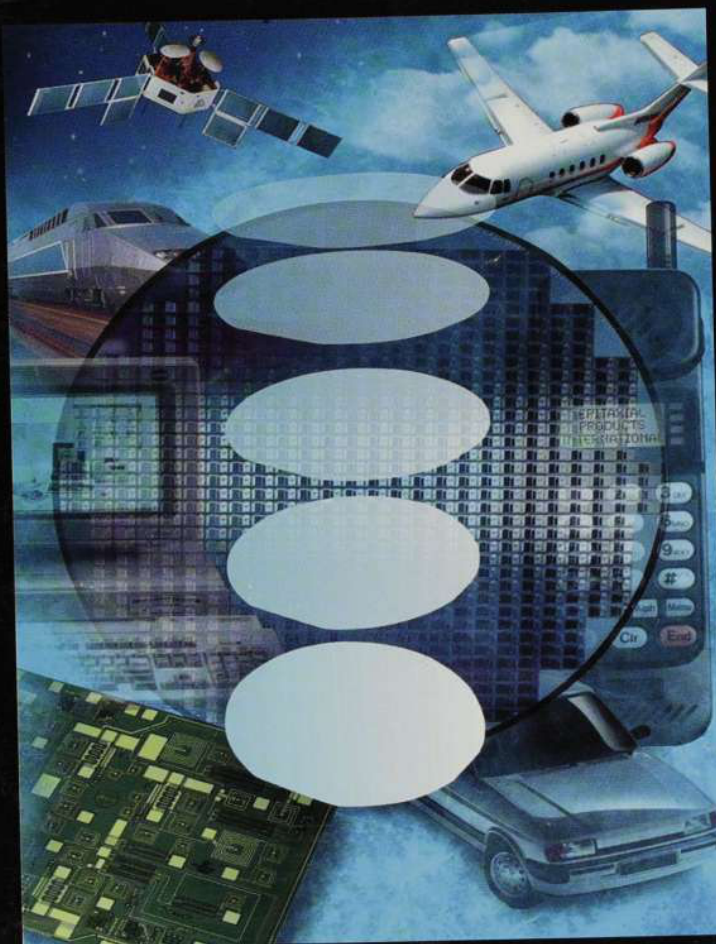
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