

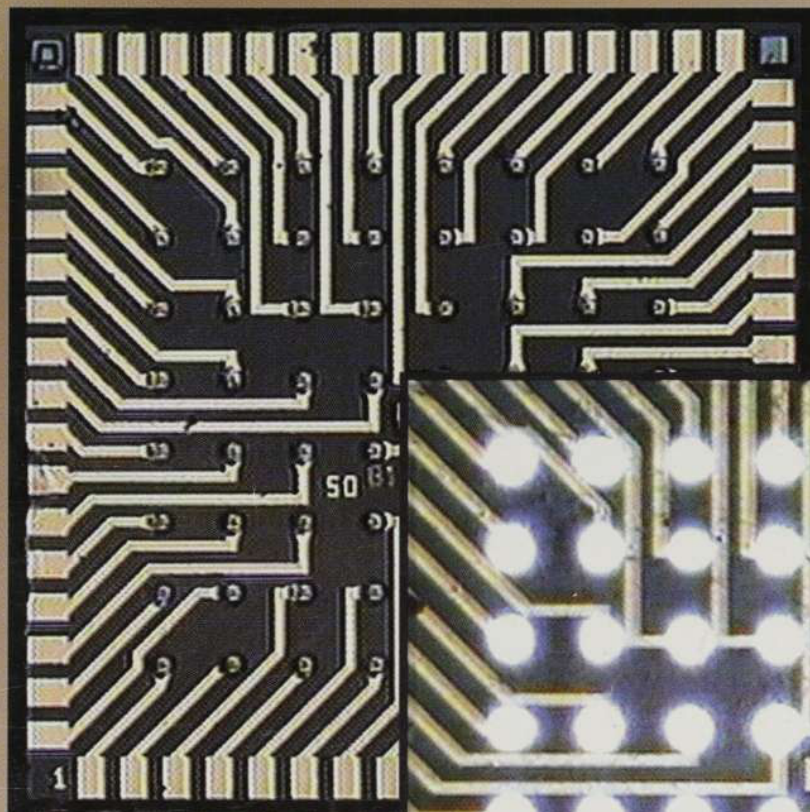


COMPOUND

SEMICONDUCTOR

Winter II - March, 1998

Volume 4 Number 2



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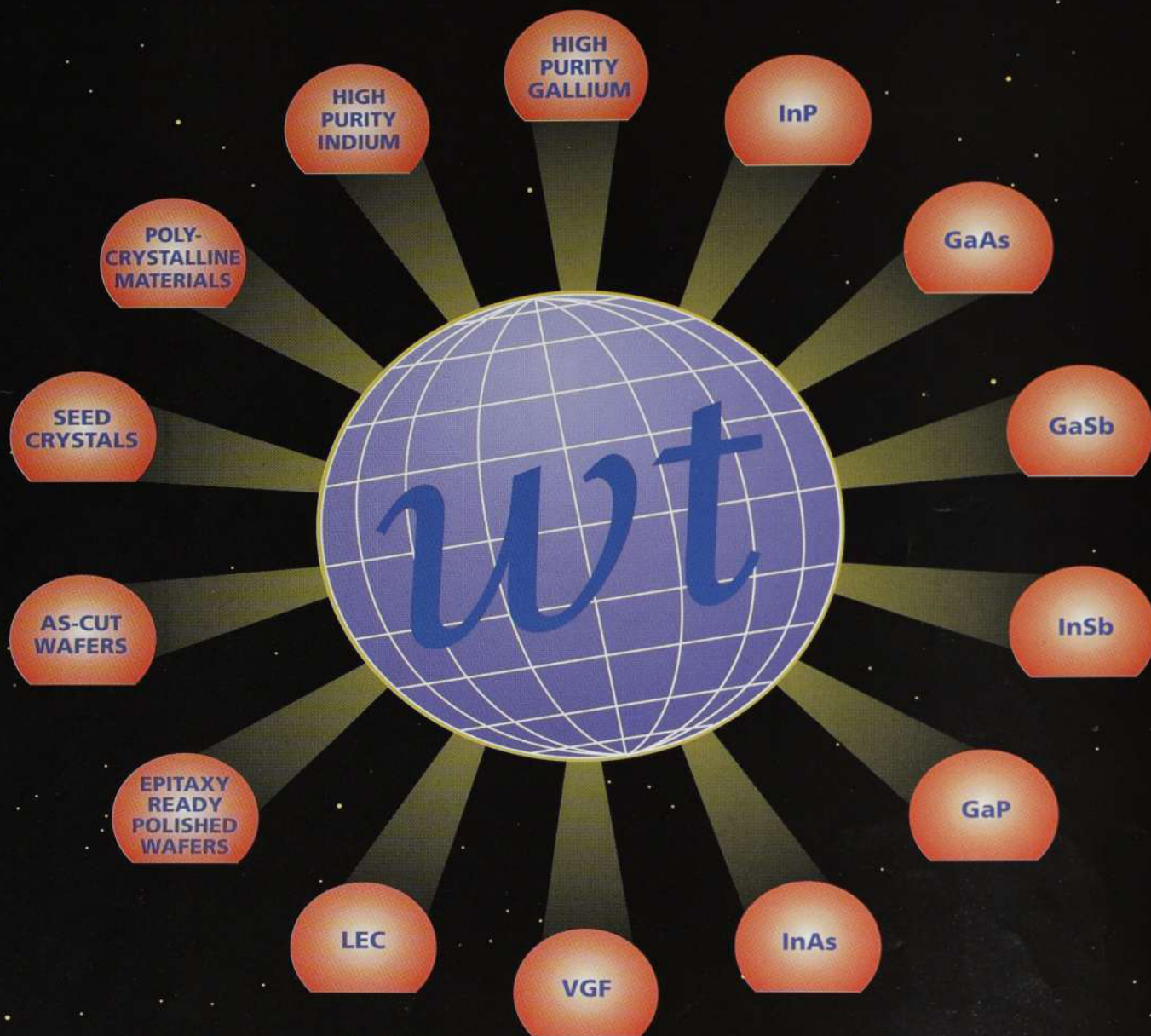
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- GaN Detectors Reach Market
- Why is CMOS Setting the Speed Records?
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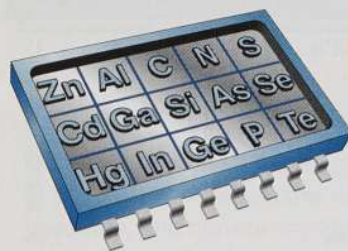
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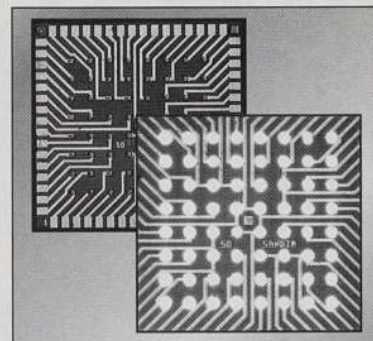
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Optoelectronic Devices: Organic Lasers and Displays...New Bipolar Cascade Laser

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A 2-D VCSEL array constructed by Sandia National Lab. The bottom photo shows the 8x8 array, the top photo shows the same array with all 64 individually addressable VCSELS working. Such a device might find applications in the areas of optical interconnects, data transmission, and printing. Coverage begins on page 18.

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Asian Financial Crisis Unlikely to Slow Down Japanese Investment in Compound Semiconductors

Despite near-zero growth in Japan's economy and Asia's economic downturn, Fujitsu's GaAs business will likely get more investment and sales, not less, in 1998. As the largest player in the global GaAs market, with a claimed 40% market share, Fujitsu remains bullish for this year because of strong sales for compound semiconductor devices for satellite and mobile communications, microwave and radio communications as well as fiber systems.

Any cuts in Fujitsu's semiconductor investments are all in the memory area, which was headed for a slowdown even before the Asian crisis. However, that situation will have little affect on their compound semiconductor business, says Mike Bierne, representative for Fujitsu Ltd. (Tokyo). The poor DRAM business is prompting them to focus more on areas where they have a technical and manufacturing advantage.

That means compound semiconductors. Fujitsu started strengthening their GaAs group last year, by consolidating all the design and sales groups for compound semiconductors into their manufacturing division, Fujitsu Quantum Devices (FQD). They now run the world's largest GaAs wafer and device fabrication plant in Yamanashi Prefecture, with 1300 employees and a revenue base near 50 billion yen (\$400 million). FQD is targeting revenue of 100 billion yen in the year 2001.

At present, compound semiconductors, notably monolithic microwave ICs, are the fastest growing area of Fujitsu's semiconductor business, aside from MPU/Logic, notes Bierne. The growth is fueled by the continued huge growth in the mobile phone market, satellites, and big orders from Fujitsu's submarine cable group. For example, in addition to multiple global projects, there are plans to lay 8500 kilometers of deep-sea fiber cables around Japan. This project, called Japan Information Highway, is scheduled to begin operations on March 31, 1999.

Ups and Downs in Compound Semiconductors

The microwave market appears to be the most attractive opportunity in the compound semiconductor field for Japanese companies: NEC, which says that it is aiming for 30% share of the MMIC market, will raise this production to 4-5 million units per month from early fiscal 1998. Oki Electric also plans a 30% increase in microwave device output by spring of this year to 3 million units per month.

Deregulation in Japan's telecom market is underlying much of the growth in demand GaAs-based devices. Sales of mobile communications equipment, for example, have surged in Japan over the past three years, after being artificially held back by the regulators — the Ministry of Posts and Telecommunications (MPT, Tokyo). Since 1994 the number of mobile telephone users has doubled every year, and is now about 30 million (about 25% of the population). MPT also forecasts strong growth of Personal Handyphone System (PHS) subscribers to 38 million by 2010. In both mobile and PHS, Fujitsu

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is a system supplier and systems integrator. As for mobile communications in North America, Fujitsu sees opportunities in the CDMA market as well as in Asia and Oceania for both CDMA and PHS markets. New wireless markets are also attractive for Fujitsu. These include the intelligent transportation system (ITS), wireless local loop (WLL) and wireless LAN. The WLL is ideal for low-to-medium population densities (typical in Central Asia), and advantages include short installation time [it can overlay with the existing wireline system or cellular system]; a lower system cost-per-subscriber than wireline system; easy

deployment in remote areas; and low maintenance costs.

On the opposite end of the spectrum, the DVD laser market, which looked like the best growth opportunity a few years ago, has been disappointing. DVD equipment shipments reached just 750,000 units last year. The Electronic Industry Association of Japan (EIAJ, Tokyo) has scaled back its forecast to a little more than 10 million DVD players to produced annually by 2001. This is grim news for Japanese firms that have bet heavily on DVD and related devices such as laser diodes, including Toshiba, Matsushita and Pioneer.

CTI to Proceed With New GaAs Fab

CTI Semiconductor Corporation plans to proceed with construction of a new GaAs fab in Chungchong Province, South Korea, despite the turmoil in that country's financial sector.

The project has been scaled-down from its original projected capacity of 10,000 6" wafers/month, which would have made it by far the world's largest GaAs fab. The new plans call for capacity of around 5,000 6" wafers/month, which would make it comparable with Vitesse's new 6" GaAs fab in Colorado Springs, CO.

CTI has around 1,000 employees,

with annual sales of \$230 million. The company is engaged in a variety of electronics and semiconductor-related businesses, including a joint venture with Raytheon for packaging RF semiconductors. The GaAs fab will be part of a new division, CTI-MMIC, which was formed in October, 1997.

Groundbreaking for the new fab is scheduled for the 2nd quarter of this year. The new fab will be equipped for MESFET, HEMT and HBT technologies, and the company plans to offer both standard products and foundry services.

Motorola Drops VCSEL Products

Motorola's Semiconductor Products Sector (SPS) has announced their intention to terminate production of all optical data link products, including the VCSEL-based Optobus module. The decision was taken as part of an overall strategy to focus on a smaller product portfolio.

Although production of these optoelectronic devices has already ceased, the story doesn't end there, according to Gary Kleinkopf, VP and Director of Operations of SPS. 'Motorola holds a strong base of intellectual property in this area, which we will be looking to leverage,' he says. 'An internally driven effort, at the cor-

porate research level, is set to continue, and we may re-enter the business at a later date'. He added that many of Motorola's customers had been very positive about Motorola's optical products since the decision was announced, and there had been several inquiries regarding IP licensing and even the possible purchase of manufacturing facilities. Kleinkopf still believes there is a strong future for high speed, high bandwidth optical datacom and telecom products, and advised that Motorola's interest is not completely dead, although for the moment it is certainly on hold.

Diode Laser-Based Mammography System

Philips Research Labs in Eindhoven have prototyped a fast, harmless and relatively inexpensive method to image breasts using laser light. Because of the strong scattering properties of breast tissue, 255 optical paths are used. The breast hangs freely inside a 13cm diameter conical cup (see below) which contains the 255 optical fiber sources and diode detectors. Low-power laser light at three different wavelengths, to image blood, water and fat, can be directed through the fibers. The sources are broad area quantum well lasers operating at 658nm, 780nm or 865nm, with power levels around 100mW. The detectors are high sensitivity Si PIN diodes, capable of detecting power levels between 25fW and a few mW. The 255 channels are used to reconstruct a 3-D image of the breast, from which it should be possible to distinguish, for example, malignant tumors from cysts filled with water.



Philips Research Labs



Philips Research Labs

Philips' new laser-diode-based mammography system. The imaging cup contains 255 pairs of optical fiber sources and diode detectors.

New Developments at Cree

In January Cree Research announced that it had signed a \$2.4 million contract to supply Asea Brown Boveri AB ("ABB") with SiC wafers. Shipments began during the quarter ended December 1997 and will continue through calendar year 1998. The agreement represents the single largest purchase commitment for SiC wafers ever received by Cree and marks the continuation of a customer relationship Cree has enjoyed with ABB for several years.

Cree President Neal Hunter commented, "ABB is one of the premiere companies developing power semiconductors based on silicon carbide. Our high quality wafers are essential to these devices, and we are pleased to be working closely with ABB to help make this next generation of SiC technology a reality."

ABB's Vice President for Technology Evaluation, Christer Ovren, noted, "In order to be successful in the current phase of our SiC development efforts, a reliable supply of high performance SiC wafers

with tight specifications is of prime importance. Our cooperation with Cree will make it possible for ABB to verify new advanced device designs in real-world applications."

Cree also recently announced an amendment of the agreement under which it supplies blue LEDs to Siemens, extending the arrangement through calendar year 1998. Under the amendment, Cree will ship stipulated quantities of the LED chip during 1998 with a fixed contract price in excess of \$6 million for the first six months. Cree has been supplying Siemens with its LED products under the existing agreement since September, 1996. Siemens resells a component incorporating Cree's chip to an automobile manufacturer for use in dashboard back lighting.

In other news, Cree and faux-gemstone maker C3 Inc. say they have accelerated the timetable for Cree to develop larger crystals for C3 to use for its gemstones. Because Cree has recently pro-

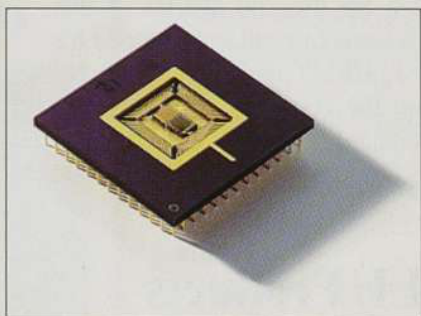
duced advances in increasing its crystal sizes for other applications, C3 and Cree have signed a supplemental development agreement that calls for Cree to develop a fully repeatable process for producing larger-diameter silicon carbide crystals that meet color and other specifications during 1998; the existing development agreement had called for mid-1999 delivery dates for the larger-diameter crystals.

Although Cree has not yet met its initial target for colorless crystals, C3 has agreed to continue the development agreement to pursue that target. Cree is currently supplying C3 with crystals that do not fall within the target color grades, and C3 is using those crystals to build inventories of gemstones of less than 0.5 carats for use in selected jewelry applications.

C3 is finalizing the development of lab-created moissanite gemstones as a diamond substitute, which it intends to begin marketing in the first half of 1998. C3 raised \$45 million in a 3 million share initial public offering last fall.

TriQuint Supplies GaAs Switching Matrix Chip

NHC Communications Inc., based in Montreal, recently announced completion of testing on its SX88 chip for fiber optic switching applications. The GaAs-based chip is fabricated by TriQuint according to NHC's designs, which were developed over the past 2 years to address a performance deficit in existing components. The SX88 is a bi-directional, 8x8 analog matrix chip supporting applications up to 700MHz, and provides high-speed, cross-connect switching in the physical layer without the need to manually adjust LAN and/or WAN connections. This is the first of a family of products which will eventually address desktop video, resource sharing, fall-back switching for Internet service providers, security, and moves, adds and changes (MACs). NHC's large R&D investment has positioned the company to take advantage of a very large potential market - there will be around 30 million MACs worldwide by 1999, and most of these connections are done manually. Nortel, the other main player in this area, offers a similar product but without the same high bandwidth. Product manager David Nezry expects to ship between 60-100k SX88 chips in the next fiscal year.



NHC Communications' switching matrix chip, which uses GaAs ICs fabricated by TriQuint.

Russian Gallium for Sale?

Reports from Europe indicate that the Russian government plans to sell off seven tons of gallium to raise funds to pay disgruntled coal miners. According to a report published in the British newspaper *The Independent*, the source of the material is a 60 ton stockpile of gallium that is used by a telescope in the mountains of southern Russia that studies neutrino emissions from the sun. However, several scientists are protesting the move, in the belief that it will ruin the ongoing neutrino experiments. Twelve Nobel Prize-winning physicists from the US and Russia have written to Viktor Chernomyrdin, the Russian Prime Minister, to ask that the sale be stopped.

The Russian government says it hopes to raise \$6 million dollars in the sale, and that their plan will not halt research at the telescope.

RFMD Lands Nokia 3V Order

In January RF Micro Devices, Inc. (RFMD) announced that it has received production contracts to supply 3.0 volt power amplifiers for Nokia's new series of GSM-based handsets including the 6110, 6130, 6190, and 6138 models.

The new Nokia phones are a family of "next generation" GSM products unveiled by Nokia Mobile Phones last November. The highly advanced handsets feature an infrared PC/phone linkage, multimode caller identification and grouping, an onboard appointment calendar, memo/message functions, one-touch voice mail, a calculator, a real time clock, multilingual options, color-changing "chameleon" covers and even three built-in games.

"We are very proud our GaAs HBT amplifiers have been chosen by Nokia for their new GSM-based handsets. We believe this fully validates our choice of HBT as the premier new GaAs technology", said William J. Pratt, RFMD's Chairman and Chief Technical Officer. The amplifiers will be fabricated at both TRW's Redondo Beach, California location and RFMD's new wafer fabrication facility in Greensboro, North Carolina.

TRW provides RFMD with HBT GaAs technology through a strategic alliance between the two firms established in 1996. "These contracts are further evidence that the combination of TRW's advanced GaAs HBT technology and RFMD's design and marketing capabilities continues to break new ground in the development of high-performance integrated circuits for cellular and PCS handsets," said Timothy W. Hannemann, executive vice president and general manager, TRW Space & Electronics Group.

Spire Plans Entry Into Space Solar Cell Production

Spire Corporation (Bedford, MA) has announced plans to enter into the satellite solar cell business. The company reports that it has shipped a prototype high-efficiency GaAs solar cell panel to Composite Optics, Inc. (COI) of San Diego, CA, for attachment to lightweight concentrator array panels built by COI. The panels, which use lightweight mirrors to focus sunlight onto the cells, will be used to provide a portion of the electric power for two upcoming satellite missions: NASA's Wide Field Infrared Explorer (WIRE) mission and the U.S. Air Force's MightySat mission.

"With telecommunications companies worldwide planning to launch more than 500 satellites over the next five years, we expect the demand for space solar cells for powering satellites to expand substantially. We believe that Spire's solar cell manufacturing expertise, coupled with 25 years experience in developing our advanced MOCVD technology, gives us an excellent springboard into the manufacture of photovoltaic components for space applications," said Roger G. Little, Spire Chairman and President.

Spire says that the company is already the world's largest supplier of photovoltaic module manufacturing and testing equipment.

In other news, Spire also recently announced the receipt of a grant from the National Institutes of Health for the development of advanced detector arrays for X-ray computed tomography by monolithically integrating CdTe photodiodes on scintillators. The company hopes to employ thin-film technology similar to that used in solar-cell construction to reduce the cost of fabricating the detectors.

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Top Si and Compound Semiconductor Suppliers

The Compound Semiconductor Top Ten

(worldwide 1997 sales of III-V semiconductors in \$M)

Rank	Company	Revenue
1	Hewlett-Packard	803
2	Sharp	581
3	NEC	406
4	Toshiba	394
5	Siemens	388
6	Fujitsu	323
7	Matsushita Electric	284
8	Lucent Technologies	248
9	Stanley Electric	245
10	Rohm	242
		<u>Total \$3,914</u>

Source: Strategies Unlimited

Hewlett-Packard was the top supplier of compound semiconductor devices in 1997, according to data compiled by Strategies Unlimited. HP, which had compound semiconductor device sales of \$800 million in 1997, was also tops in Strategies Unlimited's previous rankings, which were for the 1995 calendar year. Sharp, which had 1997 compound semiconductor sales of

The Silicon Top Ten

(worldwide 1997 sales of all semiconductors in \$M)

Rank	Company	Revenue
1	Intel	21,083
2	NEC	10,656
3	Motorola	8,120
4	Texas Instruments	7,660
5	Toshiba	7,660
6	Hitachi	6,523
7	Samsung	6,010
8	Fujitsu	4,872
9	Philips	4,435
10	Mitsubishi	4,097
		<u>Total \$81,116</u>

Source: Dataquest

\$581 million, rose from #3 on the 1995 list to #2 in 1997, trading places with NEC, whose sales were \$406 million. Toshiba, with sales of \$394 million, retained its fourth position. The biggest mover was Siemens, which leapt from #9 on the 1995 list to #5 in 1997, with sales of \$388 million. Siemens was the sole European company on the list. Rounding out the top ten were Fujitsu, Matsushita, Lucent, Stanley and Rohm.

We thought it might be interesting to compare this data with the top ten rankings for the semiconductor industry as a whole. According to figures recently released by Dataquest, Intel was the top chip producer in 1997, with sales of over \$21 billion dollars. NEC, Motorola, Texas Instruments and Toshiba round out the top five for silicon.

The overall semiconductor market was valued at \$150 billion in 1997. According to Strategies Unlimited, total compound semiconductor sales were approximately \$7.5 billion last year, which means that compound semiconductors represent around 5% of the semiconductor industry. The top ten compound semiconductor suppliers, with total sales of \$3.9 billion, were responsible for 52% of all compound semiconductor sales for the year.

Greater Interest in SiC Development Seen in Japan

Representatives of fourteen Japanese research centers met in January to discuss the development of SiC semiconductors for applications requiring a higher level of power efficiency. The participants were drawn from industrial, academic and government labs. The convention was hosted by the Kansai power company research institute.

Japanese researchers estimate that practical SiC devices could be developed in about ten years. Uses are envisioned in electric cars, the bullet train, and in steel production facilities. The group reported that use of SiC will help silicon devices increase pressure resistivity tenfold, reduce current loss 100-fold and function at 500°C.

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Participants included representatives of Hitachi, Mitsubishi Electric, Matsushita Electronics, Nippon Steel, Kyoto University, Osaka University, and the Electrotechnical Laboratory.

Funding for more research into SiC is expected when MITI announces a five-year "National Program on Hard Electronics", to begin sometime in 1998. An estimated at 5-7 billion yen, or \$40-55 million, has been allocated to this program for industrial and government laboratories. Areas of interest will include (i) high power, high speed, low loss power switching devices, (ii) devices for severe conditions such as space, nuclear energy and well logging, and (iii) devices for information and communication electronics. In addition to SiC, other materials such as diamond, III-Nitrides, and vacuum microelectronics will be included. Goals will be to reduce the electrical losses of power electronics by a factor of 100, to increase the frequency of communication devices by a factor of 100, to increase radiation tolerance by a factor of 100, and to achieve working temperatures in the 500 - 800°C range. In the SiC area, the goals are to produce larger substrates (3-4 inch dia.), to improve substrate material quality, and to conduct a parallel research effort on device fabrication issues.

In other news, the Sanyo Electric Micro-Electronics Research Center recently announced that it has successfully made FETs on a SiC substrate using ion implantation to make both source and drain. The devices were operated at up to 400°C. According to a company press release, the SiC FET was made using a process and temperatures similar to those used to silicon semiconductors. p-type SiC was grown by epitaxy on top of an n-type layer, then another n layer was grown. The source and drain electrodes were made of nickel and the gate electrodes were gold. The voltage-current characteristics were said to be close to those found in GaAs.

Fujitsu Engineer Receives 1998 IEEE Liebmann Memorial Award



Dr. Naoki Yokoyama

Dr. Naoki Yokoyama, Director of the Quantum Electron Devices Laboratory, Basic Technology Group of Fujitsu Laboratories has been awarded the 1998 IEEE Morris N. Liebmann Memorial Award for his contributions to the development of self-aligned refractory-gate GaAs MESFET integrated circuits. The award ceremony took place at the International Solid-State Circuits Conference (ISSCC) in San Francisco in February.

The technology pioneered by Dr. Yokoyama enabled the integration of compound semiconductor devices, such as GaAs ICs which are widely used in supercomputers (GaAs LSIs), mobile telephones (power amplifiers) and satellite broadcasting receivers. Patented in Japan, the U.S. and Europe, the technology has been adopted by a majority of the world's major electronics manufacturers.

Born in Osaka on March 28, 1949, Dr. Yokoyama graduated from Osaka University in 1973 with a Masters degree in Physics. In 1984, received his Ph.D. in Basic Engineering and Research from the same university.

The Morris N. Liebmann Memorial Award, first awarded in 1919, is the oldest of IEEE's Technical Field Awards and honors individuals for emerging technology development in the field of Electronics.

Application Update



Hewlett-Packard

IR transceivers allow wireless data transmission between portable and fixed equipment.

IR Transceivers for Portable Communications Products

One of the fastest growing markets for IR devices is in transceivers used to communicate remotely between portable equipment, such as laptop PCs, and other devices such as modems, printers or fax machines. The Infrared Data Association (IrDA), which sets standards for these types of components, estimates that 20 million notebook PCs have already been shipped with IR capacity. Major companies including Sharp, Temic, Hewlett-Packard and Siemens ship individual transceiver units or supply embedded products.

Hewlett-Packard recently announced a transceiver featuring an adjustable optical-power feature, which conserves battery lifetime by detecting and supplying the minimum power required to maintain a reliable IR link. The module incorporates a 870nm AlGaAs LED, a silicon photodiode and a BiCMOS IC, and has a range of 1m. The operating voltage and peak drive current are 2.7-3.6V and 400mA respectively. The module is able to switch between operation at 9.6kbit/s to 115.2kbit/s serial IR data rates, and operation at 0.576Mbit/s to 4Mbit/s, within the so-called fast IR data rate regime defined by the IrDA. Another feature of the product is integrated shielding against electromagnetic interference, which allows operation next to an RF device such as a portable telephone. The HSDL-2300 transceiver is available at \$4.75 in volumes of 1,000-4,999.

APA Optics Offers Gallium Nitride UV Detectors

New products are believed to be the first GaN-based detectors to reach the market.

APA Optics (Blaine, MN) announced in late January a family of four UV detectors which are believed to be the first GaN-based detectors to reach the market. The new devices use GaN Schottky diodes grown on sapphire substrates.

The primary advantage of the new detectors is their solar blind characteristic, which allows them to detect in the UV wavelengths, while being unaffected by longer wavelength radiation. GaN has a sharp responsivity cutoff at about 365nm. The responsivity of the new detectors drops off by more than three orders of magnitude across the cutoff wavelength (see chart), thereby reducing filter requirements.

"These GaN ultraviolet detectors are far more effective operating in visible light than their silicon counterparts" said Anil K. Jain, APA's president and chief executive officer. He notes that silicon detectors have a major limitation, in that they are more responsive to the unwanted visible light than ultraviolet light. Another major benefit is the ability of these Schottky barrier detectors to operate in high temperature environments. The GaN detectors can operate at temperatures up to 300°C, as opposed to the ceiling maximum of 150°C for silicon detectors.

Applications for GaN detectors include flame sensing, ozone monitors, pollution monitors, blood analyzers, mercury lamp sterilizer

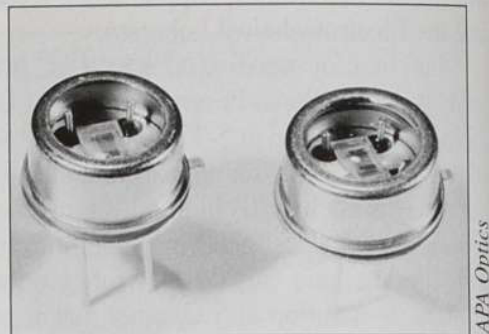
monitors, laser detectors, and other applications that require solar blind characteristics. Jain said the company is now accepting orders for these detectors and that there are short lead times for delivery. The UV-2500 series Schottky detectors will be fabri-

cated at APA's new optoelectronics manufacturing center in Aberdeen, S.D., although some initial production is being carried out at the company's headquarters in Blaine, Minn.

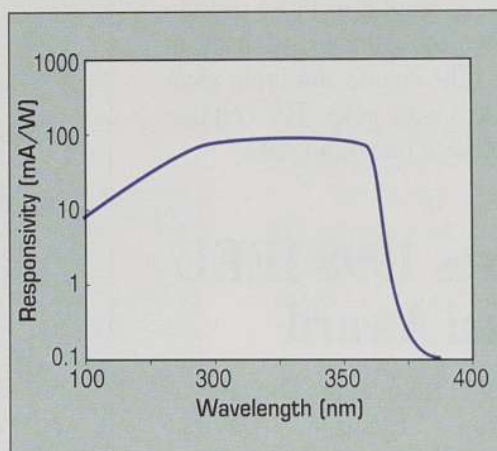
The detectors operate in a high speed photovoltaic mode and are packaged in standard TO-5 cans.

Other GaN work being done at APA is focused on heterostructure FETs (HFETs). The key advantages of GaN based HFETs are their abilities in high temperature and high power operations. Potential applications of GaN HFETs include: high temperature and high power switches; high power radars, cellular ground stations, satellite communications and high temperature pressure sensors. HFETs also can be used as high temperature pre-amplifiers to increase the gain of GaN based UV detectors, so that the hybrid detector/HFET combination may be used as a very effective flame sensor, operable at high temperatures, up to 225 - 300°C.

APA Optics has been awarded two patents in HFET technology. It is one of the publicly traded companies tracked in the "Portfolio" section, beginning on page 39.



Examples of APA Optics new GaN-based UV detectors. Several other packages styles are also available.



Responsivity of a typical visible-blind GaN photodetector showing the abrupt responsivity cutoff at 365 nm.

APA Optics' New GaN UV Detectors

Parameter	Min	Typ	Max	Units
Active Area Dia.	.240	.250	.260	mm
Spectral Range*	200		365	nm
Spectral Range**	300		365	nm
Dark Current at -1V Bias	1	2	5	nA
Response Speed		10		MHz
Field of View		80		Degrees
Open Circuit Voltage***	0.4	0.5		Volts
Responsivity 300-365 nm				
UV-2501	0.1	0.13		A/W
UV-2504	0.07	0.08	0.099	A/W
UV-2507	0.03	0.045	0.069	A/W
Operating Temp.	-20	70		Degrees C

All measurements are at 25°C and are a 0-Volt bias except where noted.

*At 1mA/W

**Flat portion of response curve

***At 1 μW input power

Uniroyal Technology Plans to Use Emcore Connection to Enter Blue & Green LED Market

Uniroyal Technology Corporation (Sarasota, FL), a manufacturer of specialty high performance plastics, plans to enter the blue and green LED market using GaN processes licensed from Emcore. The first products, which will likely be epitaxial wafers and package-ready die, are planned for release in the 3rd quarter of this year, according to Robert Soran, Uniroyal's CFO. The company also plans to produce packaged devices.

Uniroyal is using its connections with Emcore to catapult itself into this market. Thomas J. Russell, the Chairman of the Board of Directors of Emcore, is a director and major stockholder of Uniroyal, and Howard R. Curd, the Chairman of the Board of Directors and CEO of Uniroyal, is a

director of Emcore. Last September the company paid \$5 million to license GaN LED processes from Emcore, and Uniroyal will also be purchasing MOCVD reactors from Emcore. Manufacturing will be done in Florida, at a yet to be determined site.

"We want to be a major player in this business," said Soran, "and we think that we can be largely because of Emcore's technology". He says that the company is also considering making longer wavelength high brightness LEDs using AlInGaP technology which would also be licensed from Emcore.

Uniroyal Technology Corporation is a publicly traded company which was spun-off from Uniroyal Tire in 1986. 1997 sales were \$208 million.

Nichia Takes Off the Substrate

One of the major factors contributing to the success of Shuji Nakamura of Nichia Chemical in fabricating blue laser diodes with long lifetimes is his clever use of epitaxial lateral overgrowth (ELOG) to overcome the lattice mismatch between the sapphire substrate and the epitaxial GaN material. See CS 3(6), p. 4. But problems remain: the use of sapphire makes it difficult to obtain cleaved mirror facets, and it has poor thermal conductivity.

At the Photonics West Conference in San Jose in January, Nakamura reported what may be the next phase in the rapid evolution of his laser diodes. After using the ELOG technique to obtain a 20 micron thick layer of low-defect GaN, he grew a 100 micron thick GaN layer, and then removed the sapphire substrate by polishing. This gives him an ~80 μ m thick GaN substrate for the subsequent growth of the laser diode. Samples with output powers of 5 mW and estimated lifetimes of 10,000 hours were reported.

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Water	<	200	ppb

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IBM Demonstrates World's First 1 GHz Microprocessor

Why is CMOS Winning the Speed Records?

On February 4, 1998, engineers at IBM Research announced what they described as the world's first demonstration of a microprocessor that can operate at 1 GHz. In comparison, the fastest Pentium-type processors which are currently available typically operate at speeds less than 300 MHz, while the more specialized DEC Alpha chip can reach speeds of 600 MHz or more.

The 1 GHz chip was designed at IBM's Austin Research Lab, which was established in 1995 to focus on new design techniques and tools for high performance microprocessors. Although it is fast, the experimental chip lacks some of the functionality of its commercial counterparts. It contains ~1 million transistors, compared to ~5.5 million for a Pentium Pro. It was fabbed using IBM's existing 0.25 μm CMOS 6X technology at the Advanced Semiconductor Technology Center in East Fishkill, NY and tested at the T.J. Watson Research Center in

Yorktown Heights, NY. The company says that the results of this project will eventually be merged with IBM's recently introduced CMOS 7S "copper chip" technology.

"Circuit and architecture innovations, including the merging of some functions and performing others in parallel, enabled us to reach the 1000 MHz milestone quickly and efficiently," said Sang Dhong, the Austin-based IBM engineer who led the development effort. New developments include:

- A multifunctional unit, which combines addition and rotation operations into a single circuit, and an innovative cache design, that combines the address calculation with the array access function.

- A dynamic circuit approach that greatly reduced the number of stages through which signals must propagate.

- Innovative clocking methods that further reduce the chip's cycle time and overcome the challenge of generating and

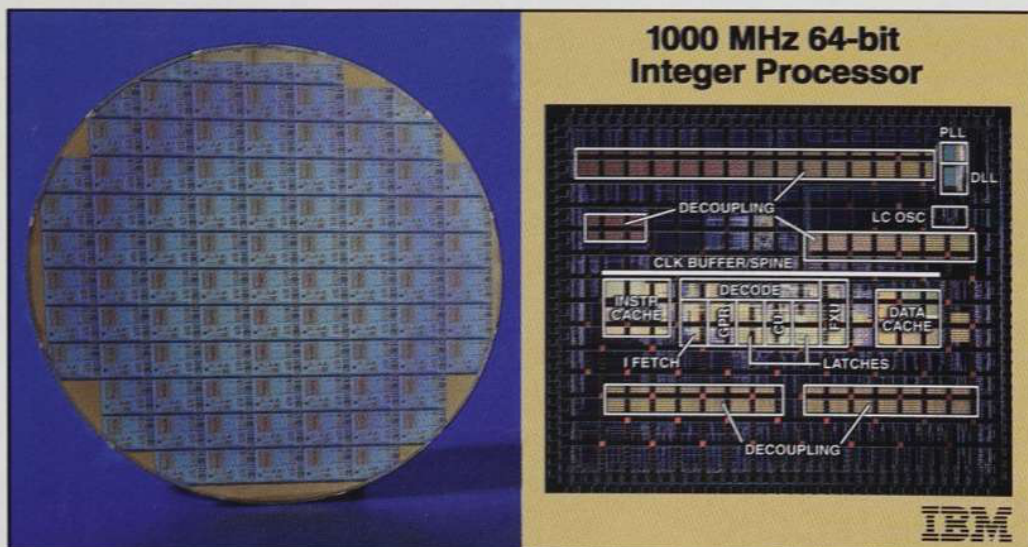
distributing a timing signal — or clock — with a high degree of precision.

- A new testing technique that enables the tester to operate at a fraction of the speed of the processor core.

Where is the 1 GHz GaAs Processor?

Given that GaAs's electron mobility is more than 6 times greater than silicon's, it seems logical to wonder why is CMOS setting the speed records. But, in reality, silicon has this field all to itself. At the present time, there are no known efforts to build super-fast GaAs processors, and the prospects for launching such a project are very dim. According to Lou Tomasetta of Vitesse Semiconductor, commercial interest in GaAs processors died around five years ago "when it became clear that it would require as many engineers and as much investment to make a super-fast GaAs processor as would be required to make one from silicon, but you could only hope to capture at most 5 - 10% of the market with the GaAs product". Research done at Vitesse indicated that if you could make a processor with the same architecture in silicon and GaAs, the GaAs chip would be 2 - 3 times faster, but Tomasetta says he cannot foresee a time when GaAs processors are economically feasible for mainstream application.

And as time goes by, it becomes increasingly difficult to make comparisons between GaAs and CMOS chips, because GaAs designers cannot compete with the sophistication of silicon VLSI design tools and fabrication processes. CMOS benefits greatly from massive investment in scaling down feature sizes. Products based on 0.25 μm technology are in mass production, and 0.18 μm products



Left: 200mm wafer containing the experimental 1 GHz microprocessors. Right: A close up view of the integer processor portion of the 1 GHz chip.

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are in the design stage. In comparison, GaAs LSI and VLSI design uses linewidths of 0.5 μm or more.

According to Richard Brown of the University of Michigan, the high integration levels of CMOS have enabled a number of improvements in chip architecture that have led to high performance. Examples include the use of deeply-pipelined datapaths, large on-chip cache memories, and "super-scaling" or multiple-instruction issue. Brown heads the "PUMA Project", a VLSI complementary GaAs project supported by DARPA and Motorola. Unfortunately, he says, the GaAs processes which are currently available to researchers "simply wouldn't produce any yield if we tried to use as many transistors as they use in state-of-the-art CMOS processors".

A GaAs Chip for Space

Although there are no obvious mass-market opportunities for GaAs processors, it is likely that the rapidly growing satellite industry will create a niche market for rad-hard GaAs processors for use in space. According to Brown, "high-speed CMOS, with its small dimensions and thin oxide layers, is going in exactly the wrong direction for radiation hardness, whereas GaAs is nearly ideal for this application". His group is developing a PowerPC chip in the Motorola GaAs [complementary GaAs] process. Work thus far has been based on 0.5 μm linewidths (large by CMOS standards!). Brown remains reluctant to concede the speed field to CMOS. "All of the architectural improvements that have contributed to the performance of today's microprocessors have begun to reach their points of diminishing return," he says. "Recent CMOS performance improvements have come mainly through increasing clock speeds, as in the recent IBM chip. This helps justify investment in other materials which are capable of supporting even higher clock speeds." Perhaps when CMOS reaches limiting dimensions, III/V materials will enable microprocessors to continue to improve in performance. Nevertheless, Brown appreciates the satellite niche as an opportunity to exploit GaAs where it has a clear advantage.

BiCMOS for Communications

ROBERT A. METZGER

BiCMOS combines the best that Silicon has to offer - the low power digital capabilities inherent to CMOS and the high power capabilities of Bipolar. If communication electronics push to higher levels of integration, in which a single chip solution is desired for both the RF front end as well as baseband applications, then BiCMOS will be a strong contender for this application. At the present, this fully integrated solution has been slow in coming, owing to the difficulty of obtaining high quality passive elements (inductors and capacitors) on a conductive Si substrate, as well as manufacturer's hesitancy in using expensive chip real estate for passives which typically require large areas. It should also be remembered that fabrication in BiCMOS is both complex and lengthy, requiring up to 3 times more mask layers than a basic GaAs MESFET process. However, despite these issues, initial work of implementing BiCMOS for communication applications is starting to appear.

Robert Meyer at the University of California at Berkeley and coworkers from Philips Semiconductors at Sunnyvale CA, report [IEEE Journal of Solid-State Circuits, 32(12), December 1997 pg. 2097] on a 2.5 GHz BiCMOS transceiver for Wireless LAN's. This 2.7 mm² die, mounted in a 24 pin plastic package (TSSOP24), contains a LNA with 14 dB gain and 2.2 dB NF when operated in its high gain mode, a downconversion mixer with 8 dB gain and 11 dB NF, and an up conversion mixer along with a medium power buffer to generate a gain of 17 dB and an output power of 3 dBm (2 mW) which can then be fed into a separate power amplifier. Using a 3 V supply, 34 mA is consumed in the transmit mode, 21 mA in the receive mode, and 1 microamp in the sleep mode. This circuit uses on-chip LC filters. The on chip inductors have an impressive

unloaded Q of 5 at 2.1 GHz, and the oxide capacitors deliver 2 fF/sq micron. This BiCMOS process supports 20 GHz f_t NPNs and 0.7 micron L_{eff} CMOS plus three layers of metal. Although this effort does not incorporate any baseband applications, it is apparent that BiCMOS can handle the RF portion of this application (although for higher power levels it would appear that a high PAE GaAs part is still the best solution).

If you think that BiCMOS communications efforts are confined to university efforts, then you should take note of what Texas Instruments is now offering in the way of a commercial product. TI has a RF BiCMOS process which utilizes 22 GHz Bipolar drive transistors along with CMOS for baseband and IF signal processing elements. TI is currently offering the TRF1500PBF - a dual mode receiver which can operate at 900 MHz (analog and digital) as well as 1900 MHz (digital). This chip includes an LNA, RF mixer and IF amplifier, all designed to run from a 3.6 V lithium battery. For power, TI is also offering the PTRF7003PK discrete MOSFET power amplifier - fabricated in what TI calls its RF-MOS process. Designed to operate up to 1 GHz, this device requires a 4.8 V supply and can produce power up to 32.5 dBm (1.8 watt).

And just how far might the CMOS portion of BiCMOS be scaled before it hits a performance wall? F.G. Pikus and K.K. Likharev of the State University of New York at Stony Brook [Appl. Phys. Lett. 71(25), 22 December 1997] have modeled ultra small MOSFETs. Their conclusions indicate that for the case of n-MOSFETs that gate lengths can be reduced to 10 nm (a factor of 20 below current state of the art CMOS production) and the device still shows sufficient voltage gain for logic applications, while the conductance modulation remains sufficient for memory applications with L as small as 4 nm.

New Developments at Picogiga

Les Ulis, France. Picogiga reports that it has become the first epiwafer vendor to offer "metamorphic HEMT" or MHEMT wafers. Unlike pseudomorphic HEMTs, metamorphic HEMTs can have greater than 30% indium content in the channel. According to the company, "this new generation of HEMT is distinguished from its predecessors by the alloy composition of the semi-conducting material which can now be chosen without any limitation of mismatch in the lattice parameter of the substrate material on which the material is epitaxially grown". Producing MHEMT wafers requires the epitaxial growth of two materials with large lattice mismatch without creating the so called 'cross-hatch' array of mismatch dislocations. Picogiga says it has a policy of spending 20% of their revenues in order to develop the technical expertise needed to address such issues. The company hopes to patent their MHEMT design. Potential applications cover frequency ranges from 900 MHz to 94 GHz.

In a separate announcement, Picogiga has revealed that it is working with LETI-CEA (Grenoble, France) on a method for bonding bulk GaAs or epitaxial III-V layers to silicon substrates. The company says that it has achieved the first-ever transfer of a 75 mm dia. thin film of GaAs onto a silicon wafer. The demonstration was made with both bulk GaAs as well as an epitaxial GaAs wafer with heterojunctions.

Previous work done at LETI includes the silicon-on-insulator technology which has been successfully commercialized by SOITEC (Grenoble, France).

And, finally, Picogiga also recently released their financial results for 1997. Sales totaled FRF 60 million / US \$10 million, an increase of 9% over 1996. The U.S. now represents 75% of Picogiga's total sales, with the remainder divided roughly equally between Europe and Asia.

QED Withdraws IPO

Bethlehem, PA. Epiwafer vendor Quantum Epitaxial Designs has withdrawn its plans for an public offering of stock in the company. According to CFO Bill Burg, market conditions for the offering soured in November due to a sudden drop in the share prices of several other compound semiconductor-related companies, and the first shockwaves of the Asian financial crisis.

According to Burg, "we still have an ambition to become a public company", although QED has no plans for another try at an IPO in 1998. Instead, the company recently signed an agreement with underwriter Needham and Co. for a private placement of stock that will net \$6 million for QED. The proceeds will be used to reduce short term indebtedness and purchase capital equipment.

Briefly...

American Xtal Technology (AXT) and Emcore were recently awarded U.S. Small Business Administration "Tibbetts Awards" in Washington, DC. These awards are made annually to recognize achievements in the SBIR Program...CVD Products, a manufacturer of crucibles and other products of pyrolytic boron nitride (PBN), has reorganized and re-capitalized. The company has also changed its name to Performance Materials, Inc., to reflect an expanded strategic focus...

Alpha Metals Inc., Cranston, RI. has announced the acquisition of a worldwide license from the Federal Manufacturing & Technologies business unit of Allied Signal Inc. to manufacture and sell its hydrogen and moisture getter product to the semiconductor industry. This product is used in hermetically sealed semiconductor packages containing GaAs, InP, Si ICs, RF absorbers, etc.

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They are also becoming established commercially, with individual devices, data link transceiver modules and epitaxial wafers all available from a small range of suppliers. Further research breakthroughs continue to lower the threshold current and power consumption of VCSELs, extend their operating wavelength, and develop methods to integrate and package devices for a wide range of applications. Here, we explore some of these issues.

This Page - VCSELs For Sale
Manufacturing and production issues

Page 20 - Inside VCSELs
An overview of device types

Page 22 - Optical Interconnects
Including 2-D arrays and Smart Pixels

Page 28 - Back In The Lab ...
A review of recent research development

VCSELs For Sale

Over the last few years, VCSELs operating near 850nm have emerged from advanced research into the marketplace, targeting high-speed, medium distance data link applications such as LAN backbones, telecommunications switching and links to remote peripherals. The first offerings, from Motorola and Hewlett-Packard, were packaged data link modules, and subsequently Honeywell MicroSwitch offered discrete devices. More recent additions to the list of suppliers include Mitel Semiconductor, Vixel Corp., and MODE. All the companies mentioned here offer

packaged modules, with Honeywell, Mitel and MODE also offering discrete devices. A larger number of companies offer products incorporating VCSELs from some of these suppliers, notably AMP, which has an agreement with MODE. Several companies including Epitaxial Products International, Spire and MODE offer custom-grown VCSEL epiwafers.

Somewhat suprisingly, given the growing levels of interest in VCSELs as commercial products, word was received as this issue was going to press that Motorola was dropping its VCSEL product line. See page 5.

Parameter	Typical value
Maximum operating temp	0 to +70°C
Peak wavelength	840 nm
Temp. coefficient- wavelength	0.06 nm/°C
Spectral width	0.5 nm
Beam divergence	15 deg
Forward voltage	1.8 V
Threshold current	3.5 mA
Threshold Current variation 0 to 70°C	+/- 0.6 mA
Optical power	1.5 mW
Optical power variation 0 to 70°C	+/- 0.7 dB

Operating characteristics of a packaged VCSEL, part 1A444, supplied by Mitel Semiconductor.

Mitel Semiconductor

Product Specifications

In research devices, the use of oxide apertures to define the VCSEL optical cavity has resulted in some very impressive improvements in threshold currents, efficiencies and other important parameters.

In contrast, commercial devices are invariably ion-implanted structures, with performance characteristics that at first sight seem fairly unimpressive (see Table). However, as is usually the case with production devices, there are other factors to consider. Honeywell reports that ion-implanted devices are capable of achieving adequate performance goals while also meeting the equally important criteria of producibility, and compatibility with other electronic and optoelectronic technologies. This includes aligning with existing communications standards, particularly the 850nm wavelength assigned to local area data communications. Cost considerations at present require wavelength compatibility with readily available Si- and GaAs-based receivers. In terms of manufacturing considerations, ion-implanted structures are simpler to fabricate, since they do not require a complex oxidation process, and also result in planar devices.

For VCSELs in general, low drive voltages (<2V) and operating currents (<10mA) simplify design, allowing easier thermal module management and simplification of driver circuitry, and are compatible with drive technologies such as emitter-coupled logic. Long-term reliability, eye-safety, and modulation speed are also important design criteria.

Data Link Modules

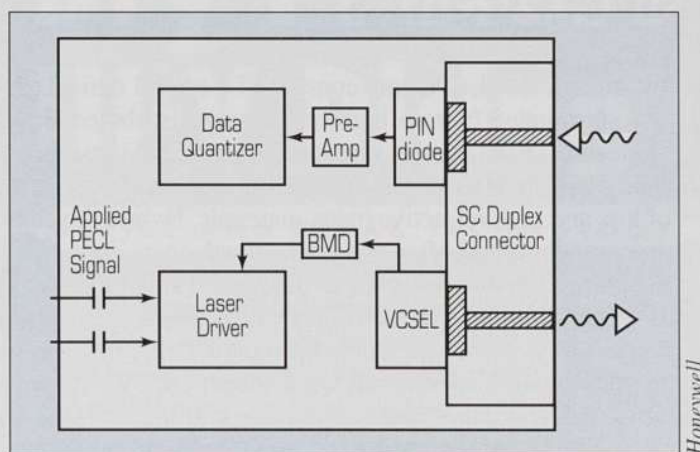
Commercial transceiver products containing VCSELs address data communication applications in the regime of Gigabits per second. These include 1.25Gbit/s for Gigabit Ethernet, 1.0625Gbit/s for Fibre Channel and 622Mbit/s for ATM applications. A cir-

cuit diagram for the 1.25Gbit/s module sold by Honeywell (part HFM2450) is shown right. The VCSEL source and silicon PIN photodetector are both driven by silicon bipolar ICs, and the optical input and output are transmitted by fibers coupled to the module by a duplex connector. Hewlett-Packard's products have similar layouts and are designed to operate at distances of up to 500m in 50/125 μ m multimode fiber-optic cable and up to 300m in 62.5/125 μ m fiber.

The range of products containing VCSELs is actually fairly limited at present, and Hewlett-Packard for one has no immediate plans to change this. However, VCSEL-based products are sure to emerge in areas such as IR links between portable information/communication devices, where LED-devices are limited to about 4Mb/s. Other issues relating to optical interconnects are explored elsewhere in this issue.

Temperature Stability

Constant output power across a temperature range is a prerequisite for certain applications, such as CD and barcode scanners. This demands improved VCSEL temperature stability, or a method to incorporate complex monitoring and feedback circuitry, thus relaxing the VCSEL specification. Motorola has investigated methods to incorporate APC ('auto power control')



Circuit diagram for a 1.25Gbit/s transceiver module available from Honeywell (part HFM2450). The module size is 1" x 1.54".



VCSEL-based optical transceiver module available from Hewlett-Packard.

into packaged devices, although their current OptobusTM product is able to tolerate output power variances. VCSELs will not emit back through a GaAs substrate below 870nm (due to substrate absorption), so a back facet detector, as used for feedback control in edge-emitters, is not feasible. Two APC solutions have been tried, one using a closely spaced VCSEL pair with a flip-chip bonded detector monitoring the output of one VCSEL. The other uses an angled TO-can to deflect some of the VCSEL output onto an adjacent detector. These appear to be competitive solutions for production, although Motorola's future in VCSEL-related products is quite uncertain at present.

Inside VCSELs

The basic VCSEL structure consists of a central optical cavity surrounded by two high-reflectivity distributed Bragg reflector (DBR) mirrors to ensure longitudinal optical confinement. The quarter-wave DBR mirrors consist of repeating pairs of low and high refractive index materials. Hybrid dielectric DBR mirrors deposited after epitaxial growth (e.g. ZnSe/CaF₂) have a high refractive index ratio so that only a small number of periods are required for high reflectivity. Semiconductor mirrors (e.g. GaAs/AlAs) can be fabricated monolithically, but require more periods due to the lower refractive index ratio. Wafer bonding allows optical cavities to be combined with high reflectivity mirrors in non lattice-matched material systems. In addition to high reflectivity, the mirrors must be transparent at the laser wavelength, and should permit current injection with the minimum possible resistance. Methods to achieve this include modification of the mirror heterojunctions with composition grading or short-period chirped superlattices.

The optical cavity, which is usually one wavelength thick, contains an active layer constituting one or more quantum wells formed in a material which corresponds to the desired laser wavelength regime. The commonly used QW materials with corresponding wavelengths are; InGaP at 650nm, AlGaAs at 780nm, GaAs at 850nm, InGaAs at 980nm and InP at 1300nm.

There are several general methods to achieve transverse optical and electrical confinement within the structure. The four most common are shown below. The most straightforward is to use dry etching to form a pillar or post (Fig a). Such structures feature simple fabrication, strong index-guiding and low threshold currents, but suffer from poor thermal dissipation and scattering losses due to sidewall roughness which result in poor laser performance.

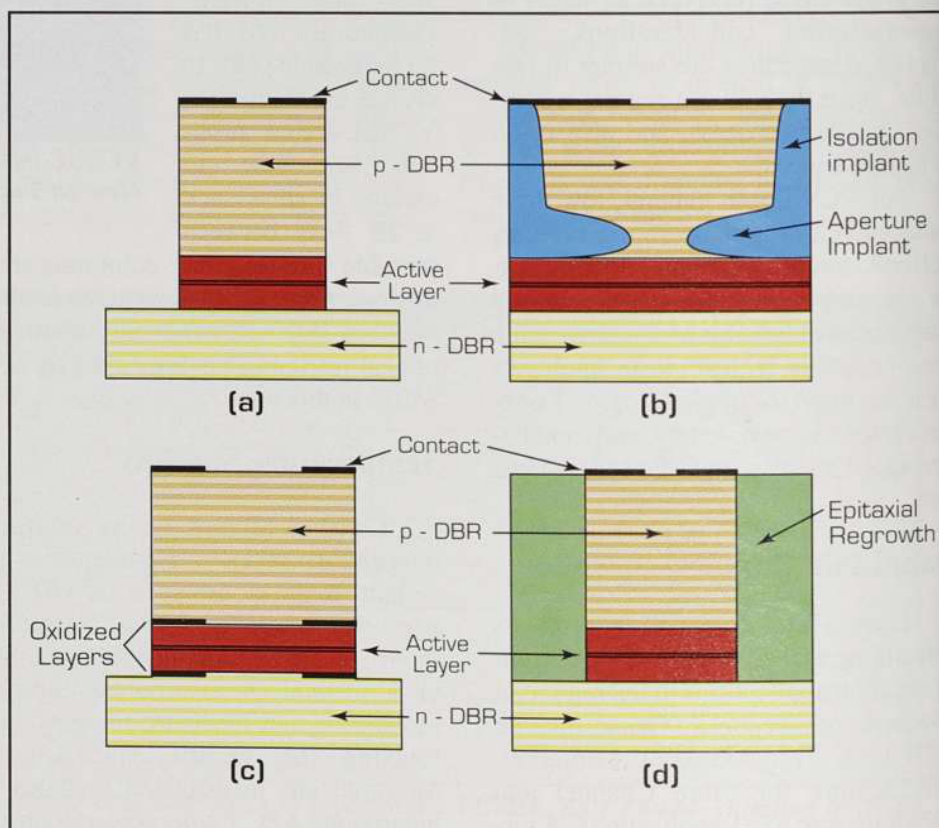
A method to achieve planar devices is ion-implantation (Fig b), in which the implanted region within the top DBR mirror funnels the injection current into the active region. This process does not result in optical confinement, although this can be achieved by thermal lensing. Further implantation isolates the devices. Despite the inherent crystal damage in this type of structure, good laser reliability has been observed and all commercial devices currently available are fabricated using implantation methods, due largely to planar geometry and good heat sinking properties.

The use of a dielectric aperture funnels the current into the active region whilst also achieving optical confinement. A large amount of current research activity is focussed on devices containing apertures formed by the selective oxidation of buried AlGaAs layers in a steam environment at 350-500°C. The oxidation rate is very

strongly dependent on alloy composition, and the resulting material is robust, inert and insulating, with a low refractive index. Fig c depicts a structure formed by a mesa etch followed by lateral oxidation of two AlGaAs buried layers either side of the optical cavity. The oxide aperture provides very efficient current injection and optical confinement and can be extremely small (~1µm), leading to very low threshold operation. Lateral confinement of the carriers within the active region is not achieved. Devices have been demonstrated at most common wavelengths and long-term reliability testing is underway. Monolithic oxide-apertured VCSELs have established a number performance benchmarks, including lowest threshold current (<10µm), lowest threshold voltage (1.33V) and highest efficiency. Disadvantages include non-planar topology (in the example shown) and the need to develop a manufacturable oxide process.

Epitaxial re-growth of a lower index semiconductor around a mesa-etched VCSEL (Fig d) should result in a structure with good current, optical and lateral carrier confinement in a planar configuration for thermal management. However, re-growth on highly reactive Al-containing DBR mirrors is extremely challenging, and the difficulty and expense associated with these structures is not presently worthwhile.

[With additional material by Kent Choquette of Sandia National Labs]



Structures for transverse optical confinement in VCSELs (a) etched air-post (b) ion-implanted (c) oxide-aperture (d) buried heterostructure.

Epitaxial Growth

Growth of VCSELs containing of as many as 100 layers, all with precisely controlled thickness, presents many challenges. As noted by Drew Nelson of Epitaxial Products International, not only does the absolute accuracy and repeatability of the laser emission wavelength become critical, but matching between the reflectivity spectra of the two Bragg mirrors, the cavity resonance and the peak PL wavelength of the active region has a dominant effect on the output characteristics of the device. 'Generally, the growth rate needs to be controlled to better than 1%, which is dramatically tighter than for conventional laser structures, where 5-10% thickness tolerance is acceptable', says Nelson. 'A 1% change in thickness of the epitaxial layers could lead to a 0.5nm change in emission wavelength for a conventional laser, compared to approximately 8.5nm for the VCSEL structure'.

Two general approaches can be utilized to gain the desired control over growth rate, namely understanding the causes of growth rate variations and changing growth conditions accordingly, or using real-time in-situ growth techniques. Although in theory in-situ control should be better, it cannot compensate for large deviations in the growth process by altering a single parameter when several other parameters are almost certainly being affected at the same time. The optimum approach seems to be combining in-situ monitoring with a well-understood process.

Although MBE offers both precise control and many in-situ monitoring techniques, MOVPE is the universal choice for production. Hewlett-Packard states that MOVPE provides high growth rate, high optical quality and relatively easy maintenance for high throughput. Also, the interface grading in the DBR mirrors required for low device series resistance is more readily accomplished with MOVPE.

In terms of cost, VCSEL epiwafers have only been offered for about 2 years, and shipped quantities are still fairly low, so the benefits of volume manufacturing are not yet realized. Due to the range of device structures available, cost comparisons are difficult, but as a guide the cost of VCSEL epiwafers exceeds conventional lasers by 2-5x, and high brightness LEDs by 5-10x. These figures are certain to change as demand for VCSELs increases in the future.

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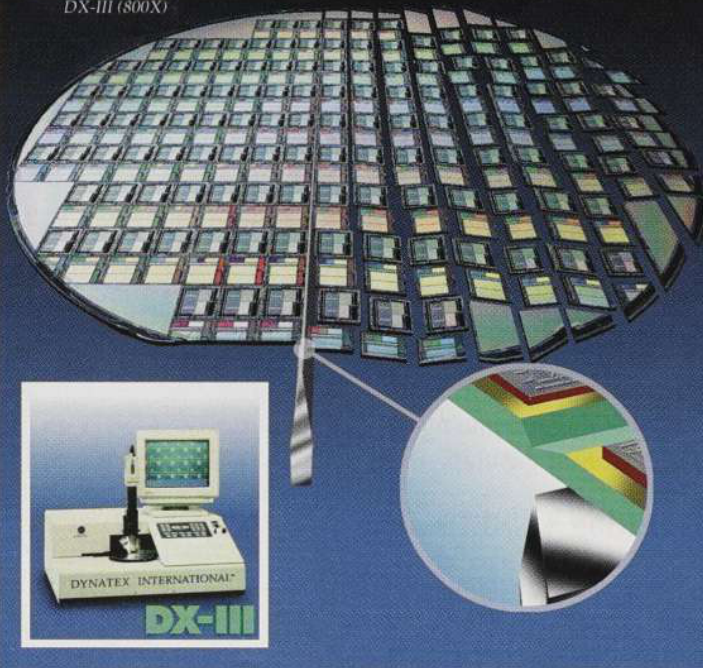
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Optical Interconnects

The most promising applications for VCSEL are in the field of optical interconnects. The use of optics to transmit data over short distances (less than 1km, down to about 1cm) has many advantages over copper wire, particularly high bandwidth, parallelism and immunity from electromagnetic interference. VCSELs are already used in serial fiber transceivers for Gigabit Ethernet, Fibre Channel and ATM applications, and in parallel fiber transceivers such as Motorola's Optobus.

A great deal of current research focuses on free-space optical interconnects operating at the 1-10cm range. Accompanying the continuing increase in scaling of electronic systems is the need to reduce device and interconnect dimensions. When combined with increased die size, this can require combinations of local and global interconnect hierarchies, which all add to system complexity. The overall drivers to move to optical interconnects are reduced size, and the prospect of massively increased bandwidth.

Free-space optical interconnects are arrays of optical input and output devices with a lens array to collimate and route the light as it passes through the air. When the transmitters and detectors are combined on a single chip with controlling electronic logic, the result is a smart pixel, perhaps the 'Holy Grail' of this area of research.

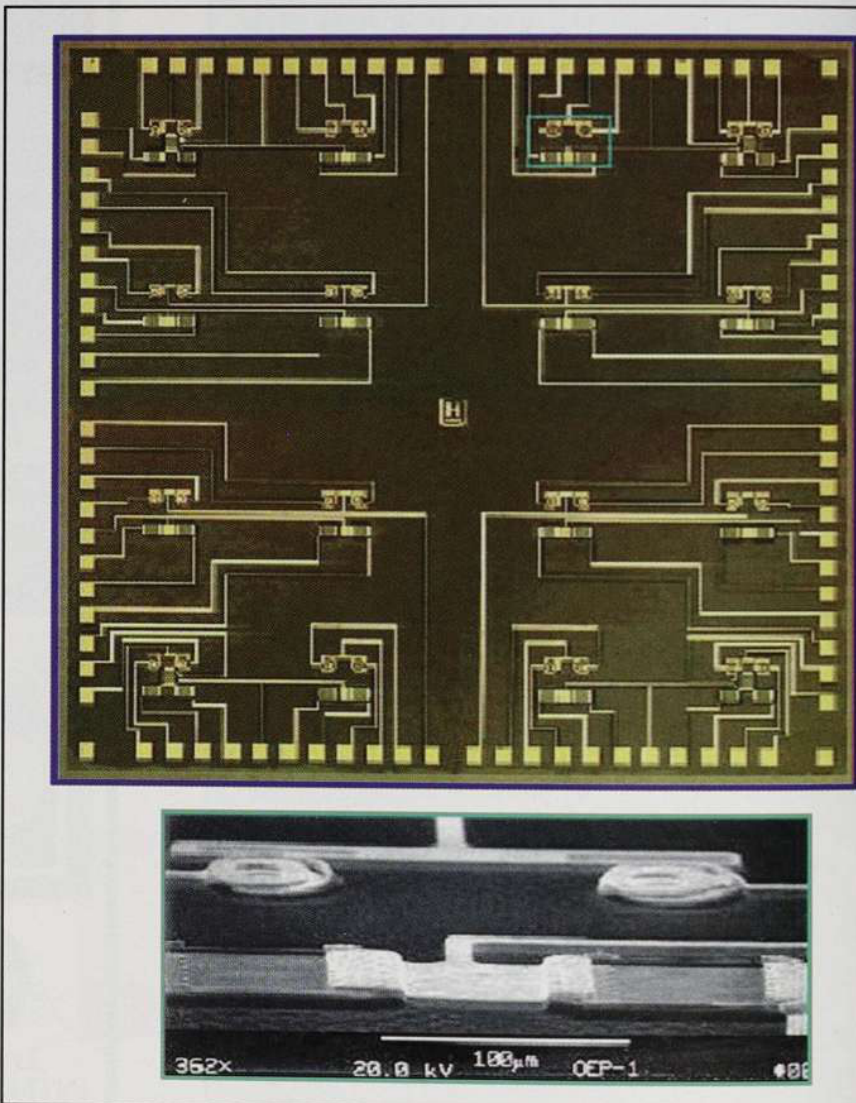
Honeywell predicts that the density of free-space optical interconnects will eventually reach several thousand input/output (I/O) channels per square centimeter, each operating at 1Gbit/s or more. To achieve this level of I/O density, the optoelectronic devices must be intimately integrated with the electronic logic. Equally importantly, to achieve viable optical links which are cheap and robust, highly efficient emitters and receivers with high modulation bandwidths must be packaged with optics, such as microlens arrays, in low cost packages.

Smart Pixels

For smart pixels, integration of the three component technologies (electronic logic, optical I/O devices, and microlenses) is required in a compact, low cost, robust package. There are several methods to combining electronic and opto-electronic functions, in a manner appropriate to high density interconnects. One approach is to monolithically integrate the opto-devices, resulting in VCSELs and photodetectors with coplanar contacts, then combine these through epitaxial lift-off or flip-chip bonding with the electronics. Another is to start with chips which already feature both logic functions and MSM photodetectors, which can be fabricated without epitaxy, and then add the VCSEL either by flip-chip bonding or by epitaxial growth of the device on the chip.

Integrating VCSELs and MSMs

Honeywell Technology Center has demonstrated monolithic integration of optical sources and detectors, to create large arrays for smart pixel applications. VCSELs and metal-semiconductor-metal (MSM) photodetectors were grown side by side in a single epitaxial run on a GaAs substrate. The VCSEL layers were grown first, followed by the photodetector layers. These were subsequently removed in the area where the VCSEL was fabricated, to prevent absorption. Arrays containing 32 VCSELs and 36 MSM devices on a chip measuring approx 2mm² are shown opposite.



Microphotograph of a 2D array, approximately 2mm x 2mm in size featuring 32 VCSELs and 36 MSM photodetectors. The SEM photo beneath magnifies a region containing two VCSELs (circular structures) and two MSMs (rectangular objects at the bottom of photo). [see M. Hibbs Brenner et al, Proc. SPIE CR70, 1998].

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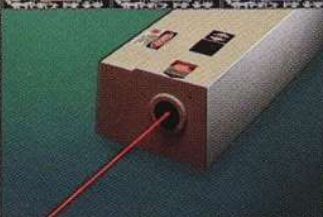
GaP Substrates:

- ▶ 2" undoped and S-doped

GaN in Development



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Integrating VCSELs with Microelectronics

The Flip-Chip Approach

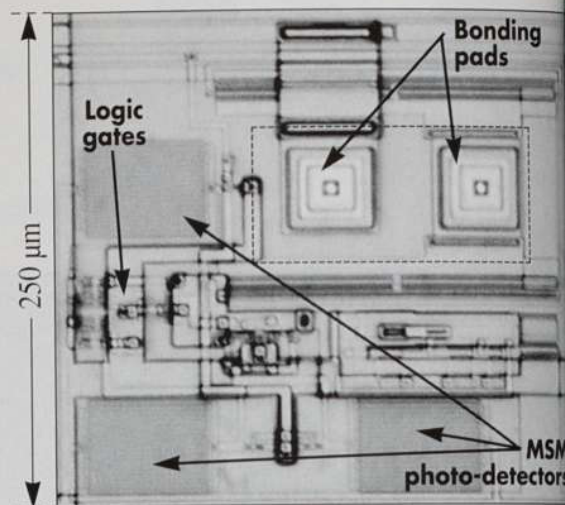
Flip-chip bonding of VCSELs and arrays to CMOS and GaAs-based electronics has been tried by several groups. For example, Colorado State University and Sandia have fabricated smart pixel arrays by directly bonding 8x8 VCSEL arrays to GaAs chips from Vitesse. The GaAs ICs were designed on a 1.0µm E/D MESFET process using direct coupled FET logic circuits. The chips also held monolithically integrated MSM photodetectors. The smart pixel circuit contained 32 MESFETs and 3 MSM PDs to perform the selection function of a data filter and provide the current drive for the VCSEL. The chips were supplied with pads for flip-chip bonding as shown at right. The final structure was mechanically sound, though only 30-50% of the bonded VCSELs were operational. This result should be enhanced by improving the substrate removal etch and the VCSEL-bond pad alignment. Most importantly, the GaAs electronic circuits are unaffected by the processing required to attach the VCSEL array.

Epitaxial Lift-off

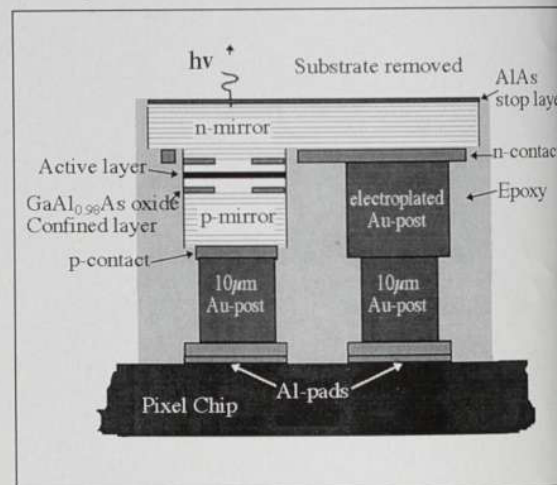
Epitaxial lift-off consists of growing the optoelectronic device layers, removing these layers from the substrate and transferring them to another substrate. At the wafer level, this is not a practical method for integrating AlGaAs opto-devices with CMOS wafers, due to the non-planarities of the processed Si substrate, and the incompatibility of size between 8-12" CMOS and 4-6" GaAs. However, epitaxial lift-off could be viable at the chip level.

VCSELs Grown on GaAs ICs

Monolithic integration of opto-devices directly onto GaAs ICs offers the promise of wafer-scale integration, although the relatively high GaAs cost and lack of design flexibility can be restrictive. Vitesse supply GaAs VLSI chips for the Epitaxy-on-Electronics project, which enables monolithic integration of epitaxial devices onto foundry chips featuring MESFETs and MSM PDs. The chip is supplied with a dielectric growth window exposing an device epitaxy area, which has electrical interconnects already in place. Epitaxy is limited to 470°C and 5 hours duration. LEDs and QWIPs have been demonstrated by a group led by MIT, who are currently working on the growth of VCSELs.



Optical photograph of a Vitesse-fabricated smart pixel chip. The dotted line represents the position of the VCSEL after bonding. A schematic of the final assembly is shown below [see R. Pu et al, IEEE Photon. Tech. Lett., 1997, 9(12), p.1622].



Optics and Microlenses

As mentioned previously, the active functions of smart pixels must be combined with microlenses or other optics to route the light. Honeywell's approach has been to fabricate Ni stand-off pillars up to 50 µm in height, which attach a microlens array to the substrate containing the optical I/O devices.

Another approach is to use internal optics. By using reactive ion etching it is possible to fabricate a microlens directly from a semiconductor materials. If the substrate is transparent at the laser wavelength, the VCSEL can be made to emit backwards through the substrate and the microlens. Alternatively, the VCSEL can be flip-chip bonded to the substrate on which the microlens has been fabricated. Detector arrays can be fashioned in a similar manner to create interconnects with no external optics. A low divergence output is required from the microlens of the emitter section, which

requires that the VCSEL has a highly divergent beam to fill the microlens. This is compatible with the desire for small diameter devices to reduce threshold current.

At the recent Photonics West 98, several speakers discussed techniques for packaging passive and active optical components for free-space optical interconnects. Companies such as GE and NEC reported the development of low-cost packaging techniques using, respectively, polymer waveguides and molded, snap-together plastic housings.

One of the exciting potential uses for optical interconnects is to incorporate spatial light modulators (SLMs) to create optical cross-bar switches for massively parallel optical processing. By signaling a certain line in a VCSEL array to emit, and a certain pixel in the SLM to allow the light to pass through, each pixel in the detector array can be individually addressed.

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BaSrTiO
PbZrTiO
SrBaTi(N)
SrTiO
YBaCuO
Si
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Pd
TiN

2-D VCSEL Arrays

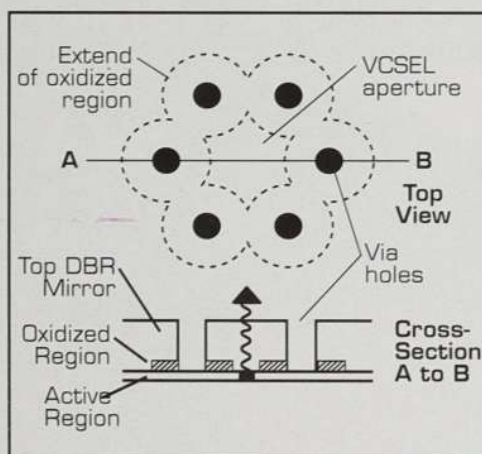
The geometry of VCSELs, particularly their surface-normal output, make them ideally suited for the formation of densely-packed 2-D arrays, for applications such as interconnects, data transmission, printing and even pumps for solid state lasers. As the array size increases, serious constraints are placed on the device power consumption, so that low-threshold, oxide aperture devices are of increasing interest. Sandia National Labs have constructed 2-D, 8x8 arrays of individually addressable VCSELs, with either high power 850nm devices or lower power 1060nm devices. A total output power of 650mW was obtained from the 850nm array, compared to a sum of 960mW from running the devices individually at 15mW. Heat dissipation is the hurdle to obtaining a higher array output power; when operated without active cooling, an array temperature rise of 35°C was observed and power was limited to 350mW.

Planar Oxide Aperture Arrays

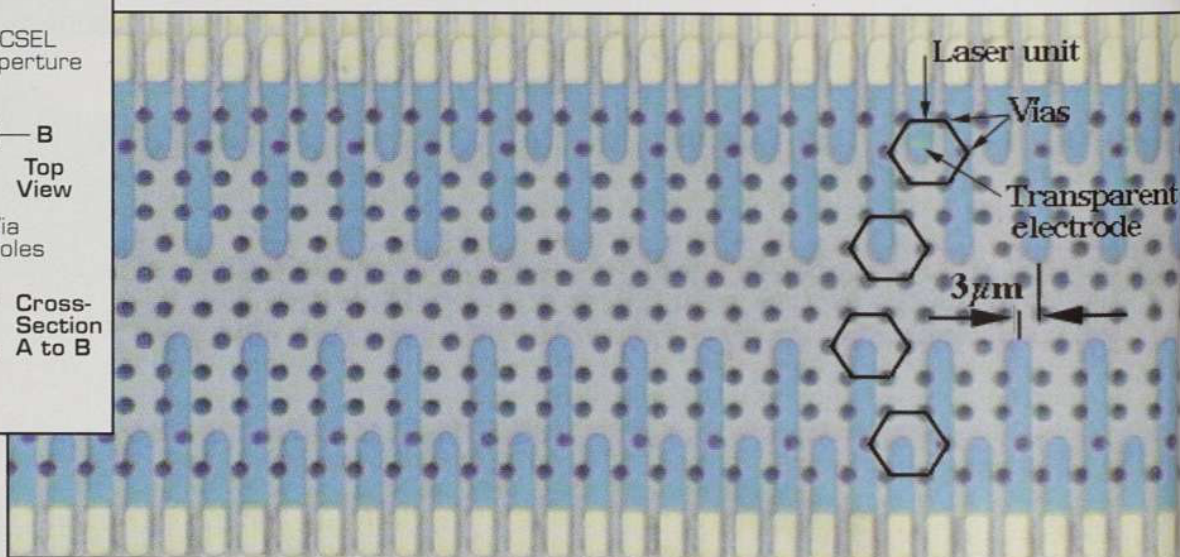
One disadvantage of oxide aperture structures is their non-planarity, since the mesa etch needs to remove several microns of top DBR mirror before the buried AlGaAs oxidation layer is exposed. One solution is through the use of dielectric top mirrors, which require a much shallower etch, but this involves two different deposition technologies. Researchers at Xerox have proposed the use of a planar laterally oxidized (PLO) structure, which accesses the benefits of buried-oxide confinement but retains planarity. This improves fabrication and contacting of small, closely packed VCSEL arrays. The ultimate aim of the work at Xerox is to produce arrays containing many thousands of independently addressable laser elements. Scientist Robert Thornton stated that recent progress towards this goal has been 'encouraging'.

Uniformity is crucial to the success of an array. Sandia reported the threshold current variation across the 850nm array as 2.5 ± 0.1 mA (or $\pm 5\%$ variation), which should be adequate for many proposed applications. Non-uniformities arise due to epilayer thickness variations, the oxidation process, and the precision with which the mesa size can be defined. Yield issues are also of paramount importance - the yield of individual devices must be very high to ensure adequate array yield. A further factor is that if the array is to be bonded with electronic circuitry, the drive voltage and the temperature stability of the VCSELs must be compatible with the operating parameters of the electronics. This can mean operation at up to 100°C, so that lifetime becomes a critical issue. Higher operating temperatures are one of the important goals of ongoing VCSEL research. [see K. Geib et al. *Proc. SPIE* 3286, 1998].

The PLO structure is fabricated by etching small via holes arranged around the perimeter of a circle or at the corners of a polygon, which penetrate the top DBR mirror to expose the buried AlGaAs oxidation layer. Upon oxidation, an oxide region develops laterally outwards from each hole until the regions merge, leaving an oxide-enclosed laser aperture at the center of the circle or polygon (see Figure). The retention of large amounts of epitaxial material improves both mechanical stability and heat sinking properties. Recent replacement of the metal annular contact with a transparent ITO layer has relaxed the design rules allowing both sharing of the via holes between adjacent structures, and staggering of the rows of devices to achieve an aggregate pitch of only 3µm. [See C. Chua et al, *IEEE Photon. Tech. Lett.*, 1997, 9(8), 1060].



Top and cross-sectional views showing formation of VCSEL apertures by lateral oxidation of buried AlGaAs regions.



A planar VCSEL array. Each blue finger is a transparent ITO electrode terminating at a VCSEL aperture, which is defined by buried oxide regions radiating outwards from each of the surrounding via holes. There are four staggered rows of VCSELs, so that the pitch (separation of VCSEL apertures) in the horizontal direction is 3µm.

Multi-Wavelength Arrays

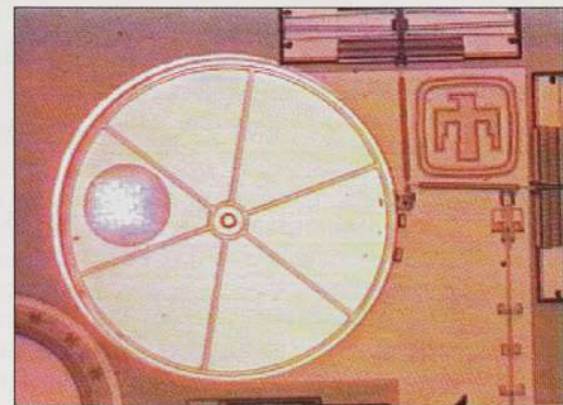
Wavelength division multiplexing requires multiple laser sources at closely spaced, well-defined wavelengths. The prospect of creating these sources on a single array using VCSELs is very attractive, particularly if the outputs can be directly butt-coupled into fiber without the need for a multiplexer. Since a VCSEL resonates in only one Fabry-Perot mode, the output wavelength can be changed by altering the length of the cavity. This can be done by interrupting the growth, and trimming the cavity length by selective oxidation and etchback, or by varying the optical cavity thickness during growth using a thermal gradient. It is also possible to create tunable VCSELs, using a structure in which the top DBR mirror is suspended on a deformable membrane supported by cantilevers, and separated by an air gap from the rest of the VCSEL structure. By altering the tuning voltage, the size of the air gap (and therefore the optical cavity) can be adjusted. Stanford University has recently shown tuning over 23nm wavelength range.

Novel VCSEL Applications from Sandia

Sandia National labs has recently demonstrated several new applications for VCSELs, including integration with microelectromechanical system (MEMS) technologies. A device has been fabricated in which the output of a VCSEL is shuttered using a micromachined wheel (see photo). The shutter wheel was machined from a silicon substrate, which is transparent to the VCSEL output at 1.06 μm . The wheel itself was coated in gold after fabrication to ensure opacity. A hybrid package was used to locate the VCSEL close to the wheel without the need for auxiliary optics. By using a mechanical shutter to block or transmit optical signals or power, the device provides fail-safe weapons surety functions.

A rotary position monitor has also been demonstrated. In this device, the VCSEL output passes through guiding micro-optics and is reflected by a marker on a rotating wheel back to the detector array.

Sandia is also working towards a number of 'Chemlab-on-a-chip' concepts. One of these involves the detection of blood disorders by passing the fluid directly through the cavity of a VCSEL structure, via microgrooves in a glass slide. The VCSEL output is then monitored to detect changes in blood composition and cell shape and size.



Top view of a micromachined shutter wheel, showing the VCSEL output beam visible through the hole in the shutter.

Sandia

A separate system features a VCSEL mounted on a silica substrate. The laser output is internally reflected through the substrate to a detector, and the optical pathway also passes through a capillary. The contents of the capillary, which could be chemical or biological agents, or dye-tagged strands of DNA, modify the VCSEL output in various ways and hence can be identified.

New from Spire...

VCSEL WAFERS

Spire Corporation is now shipping MOCVD-grown, GaAs-based epitaxial wafers for fabrication into vertical cavity surface emitting laser (VCSEL) devices and arrays. Wafers are being used by our customers to fabricate devices and large arrays with high performance and excellent uniformity and yield.

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Typical applications:

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Meanwhile, Back in the Lab...

While sophisticated manufacturing techniques are being developed for the first generation of VCSEL products, the research community is paving the way for additional wavelengths and applications.

VCSELs at Telecommunications Wavelengths

VCSELs are of obvious interest for future low-cost optical fiber communications, due to properties such as single longitudinal mode operation, high optical coupling efficiency and ease of fabrication and testing. Although the InGaAsP-InP material system is traditionally used for the active layers of laser diodes at 1.3 and 1.55 μm , there is a serious drawback for VCSELs. DBR mirrors in this material system have a very poor refractive index contrast, so that even with a large number of mirror periods the net reflectivity saturates at around 98%. This property, combined with low thermal conductivity, makes epitaxially grown DBRs impractical. Additionally, it is difficult to obtain good thermal characteristics using InGaAsP-InP active layers, partly due to the small conduction band offset, which gives poor electron confinement. Also, it is desirable to use a high gain medium to and reduce threshold for long wavelength VCSELs.

To achieve long wavelength operation, there are two basic approaches; use alternative materials to obtain high reflectivity DBR stacks, or investigate alternative active layer materials. Strain-compensated quantum wells formed in the AlGaInAs-InP system are emerging as a strong candidate for 1.3 μm VCSELs, offering superior temperature and gain characteristics compared to InGaAsP-InP. An example is discussed below in the wafer bonding section. Other emerging choices are InGaAs quantum dots, the GaInNAs alloy system, and antimonide-based devices.

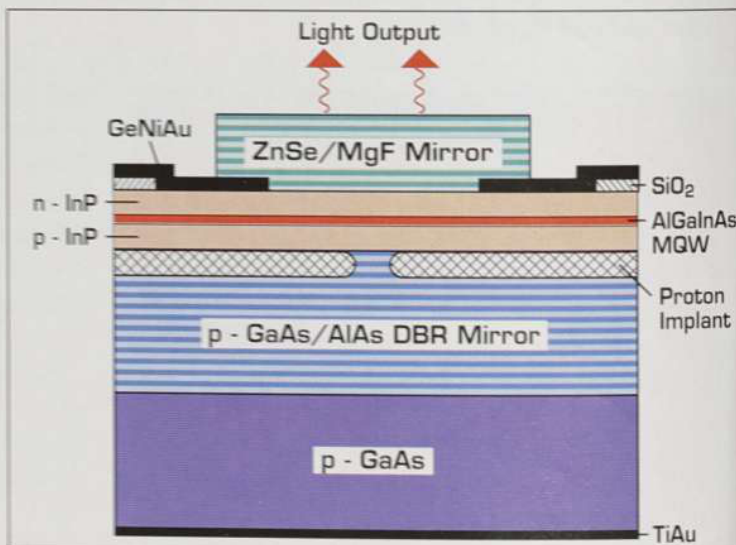
Good Mirrors For Long Wavelength Emitters

Several alternatives has been tried in the search for good mirrors in long wavelength VCSELs. Wafer fusion, which is the bonding of high reflectivity mirrors to a non lattice-matched optical cavity region, has been extensively demonstrated (see below). Another approach is to combine the active layer with dielectric DBRs, although this creates further problems due to the poor electrical and thermal properties of the mirrors.

Hewlett-Packard has achieved optically-pumped, room temperature lasing at 1.22 μm from a VCSEL grown in a single run using all InP-based materials. The active layer was InGaAsP, and the mirrors were formed by growth of an InGaAs/InP stack, followed by selective etching of the InGaAs to create air gaps. Due to the high refractive index contrast of InP to air, only 3 mirror periods were required.

Wafer Fusion

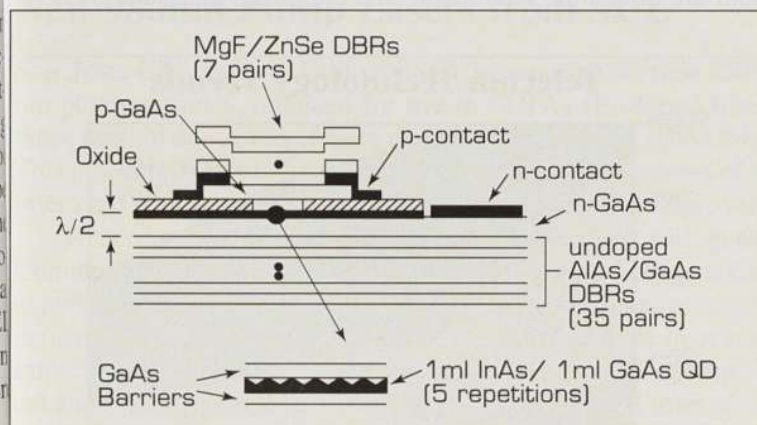
Wafer fusion, or wafer bonding has been used to fabricate 1.54 μm VCSELs with a strain-compensated InGaAsP-InP active region bonded to two Al(Ga)As-GaAs mirrors. Also, 1.3 μm VCSELs formed by bonding an AlGaInAs-InP cavity between two GaAs-AlAs DBR mirrors have been fabricated. An extension of this work, by Cornell University, Sandia and other co-workers, used a wafer-bonded GaAs-AlAs bottom mirror in combination with a ZnSe/MgF top mirror. This structure, shown below, is easier to fabricate and test than the double-fused structure. The high reflectivity of the dielectric mirror leads to a shorter effective cavity length, suppressing side-modes and reducing diffraction loss. The active region and the GaAs-AlAs mirror were grown separately by MOCVD on n-type InP and p-type GaAs substrates respectively. The mirror was bonded to the uppermost, p-type InP layer of the cavity at 560°C with a hydrogen flow, and the InP substrate was then removed. After metal contact formation and proton implantation to define the VCSEL cavity, the top ZnSe/MgF was deposited. A threshold current density of 1.13 kA/cm² and a threshold current of 2 mA were achieved for 15 μm devices.



A 1.3 μm VCSEL with proton-implanted current confinement regions, a top dielectric mirror, a wafer-bonded bottom mirror and a strain-compensated AlGaInAs MQW active region [Y. Qian et al, IEEE Photon. Tech. Lett., 1997, 9(7), p.866]

Quantum Dots Reach 1.15 μ m

The use of InGaAs quantum dots allows the wavelength of VCSELs grown monolithically on GaAs to be extended beyond 1 μ m. Researchers at the University of Texas at Austin have recently published results describing a quantum dot VCSEL at 1.154 μ m, with a CW threshold of 502 μ A, corresponding to a threshold current density of 640A/cm². The structure has a lower GaAs-AlAs DBR, a single-layer quantum dot active region, an oxide aperture and an upper MgF/ZnSe DBR stack. This scheme allows the use of intracavity contacts to minimise cavity losses. The active layer contains 5 repetitions of single monolayers of InAs and GaAs, a growth scheme shown to extend the emission wavelength of coherently strained quantum wells and dots. Growth of this region is crucial, and in fact the group III and V materials are deposited independently so that surface transport effects lead to the formation of larger dots. The quantum dots cause 3-D confinement of the injected carriers, thus providing the lateral confinement absent in normal oxide aperture structures. Spontaneous emission has been observed at still longer wavelengths, suggesting that with correct growth control and tuned cavities, low-threshold lasing might be achieved beyond 1.25 μ m.



Schematic illustration of the QD VCSEL. Intracavity contacts are used along with undoped lower and upper DBRs. [see D. Huffaker et al, IEEE Photon. Tech. Lett., 1998, 10(2), p.185]

GaNAs-based VCSELs at 1.18 μ m

VCSELs with GaInNAs-GaAs quantum-well active layers emitting at 1.18 μ m have been demonstrated by researchers at Hitachi. The entire structure, using GaAs-AlAs DBR mirrors, was grown monolithically on an n-type GaAs substrate. Usually, when the lattice constant of a semiconductor falls, the bandgap increases. The incorporation of N into InGaAs has the unusual effect of causing the bandgap to fall with decreasing lattice constant, due to significant bowing of the conduction band. The result is a strain-compensated active layer with relatively long wavelength emission. The Hitachi device used a single Ga_{0.7}In_{0.3}N_{0.004}As_{0.996} QW which had a threshold current density of 3.1 kA/cm², an output power of 5mW and a threshold current variation of less than 7% between 20-60°C.

[see M. Larson et al, IEEE Photon. Tech. Lett., 1998, 10(2), p. 188]

Antimonide-based Devices

Room temperature operation of antimonide VCSELs at fiber wavelengths has yet to be achieved. Universite de Montpellier II have shown highly efficient AlGaAsSb/AlAsSb mirrors lattice-matched to InP, (see p.36) for both 1.3 and 1.55 μ m, and are investigating the incorporation of InGaSb-based active layers.

As reported in the last issue, a different group at Universite de Montpellier II have shown a 2.2 μ m VCSEL operating at room temperature, which features AlAsSb/GaSb DBR mirrors and an InGaAsSb/GaSb active region, all grown on GaSb.

Visible VCSELs

Visible VCSELs have a series of potential applications including displays, optical data storage, sensors, bar-code scanners and printing. While most red VCSEL structures operating at 650-700nm feature AlGaInP/GaInP active regions, Sandia has also demonstrated all-AlGaAs structures at 700nm.

At shorter wavelengths, growing high reflectivity mirrors lattice-matched to nitride emitters is very problematic and remains an ongoing challenge for companies such as Nichia. Second harmonic generation of visible light using nonlinear effects has been demonstrated. Researchers at Hokkaido University, Japan, are making progress towards monolithically grown II-VI VCSELs by growing high (94.5%) reflectivity ZnSe/ZnS DBR stacks on GaAs(311B). [see page 37].

Strained QW Structures

The growth of InGaAs-GaAs quantum wells on GaAs is limited due to the critical layer thickness of strained InGaAs. However, the large compressive strain in the InGaAs layer can be compensated by a tensile strained barrier layer, using an appropriate material such as GaAsP. This allows higher In compositions in the InGaAs QW, increasing the wavelength of emission. Sandia have demonstrated strain-compensated InGaAs-GaAsP QWs in room temperature, CW devices grown on GaAs, which operate at 1.06-1.1 μ m. The devices were oxide-confined, and had a very low threshold current of 190 μ A and threshold voltage of 1.255V.

Introduction of even more strain in InGaAs may allow operation at wavelengths as high as 1.15 μ m. Operation at 1.06 μ m is significant due to the competition for applications currently dominated by Nd:YAG, and the possibility for second-harmonic generation of green laser light. Also at these wavelengths, silicon is transparent, providing a pathway and loss-free penetration through Si optical mounts or circuitry for free-space interconnects.

Strained layer growth has also been used by UC Santa Barbara to achieve ultra-low threshold operation in 850nm VCSELs. The structures used featured AlGaAs DBRs with an active region containing AlGaInAs/AlGaAs QWs. A threshold current of 156 μ A was obtained a 2.8 μ m diameter oxide-apertured device.

[see H. Hou et al, IEEE Photon. Tech. Lett., 1997, 9(8), p.1057; J. Ko et al, Electron. Lett., 1997, 33(18), p.1550].

Oki Introduces Digital GaAs Products for 10 Gb/s Networks

Oki Semiconductor has introduced a new family of 10 GHz GaAs ICs intended for use in 10 Gb/s telecommunications networks (also known as OC-192 networks). The availability of the first four devices - a 8:1 multiplexer, a 1:8 demultiplexer, an exclusive-OR/NOR circuit; and a decision circuit - was announced at the Optical Fiber Conference in San Jose in late February. Ten more digital GaAs products are scheduled for introduction later this year.

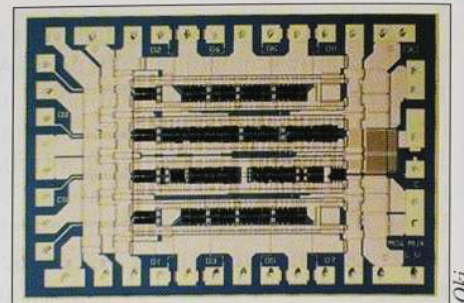
OC-192 networks are the cutting edge of telecommunications technology, and they have just recently begun to make the transition from the R&D lab to real-world usage. But Oki is predicting rapid acceptance, beginning in 1999. See Chart. Oki believes that OC-192 networks will become the dominant telecom technology in 5 - 6 years.

Oki's 10 GHz logic devices are manufactured using a 0.2 μ m ion-implanted process with gold-based, three-level metal interconnections. It is one of four GaAs logic processes available from Oki. See Table. A phase-shifting edge line (PEL) masking method is used for gate fabrication. Gold-based, three-level metal interconnects are used for high density and shorter wiring paths. An optional buried "p" channel structure is used when reduced short channel effects are needed.

The new 8:1 Multiplexer and 1:8 Demultiplexer are specified for 2 volt, 2.4 watt operation. They are used to transfer data to and from lower frequencies by synchronously merging/separating eight 1.25 Gb/s data streams. A two-phase 1/8 clock is generated, propagated through the logic, and made available for the system designer to synchronize the downstream data and clock signals.

The exclusive-OR/NOR circuit is specified for 1.5 volt, 0.6 watt operation. It is designed to extract a clock signal from a 10 Gb/s serial data stream. It is a HEMT device, operating at an equivalent speed of over 20 Gb/s using direct coupled FET logic (DCFL) and super-buffer FET logic (SBFL).

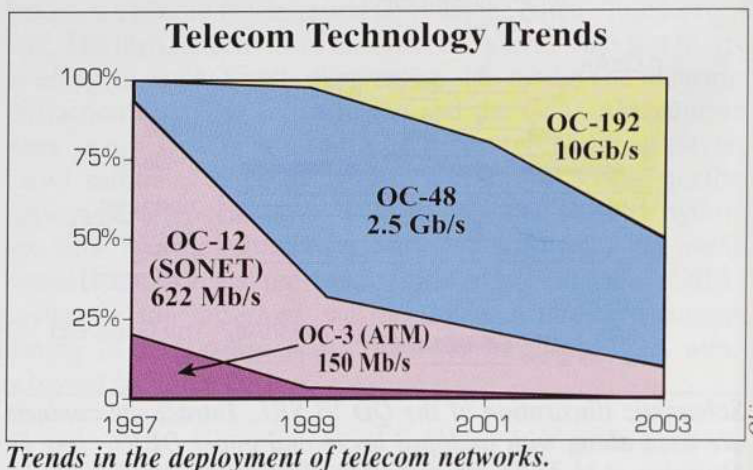
The decision circuit is specified for 1.5 volt, 1 watt operation. It is a mixed signal device, designed to extract data from high-speed serial bit data streams. Using a clock input up to 10 GHz



The KGL4201 8:1 MUX, one of four new GaAs ICs recently introduced by Oki for use in 10 Gb/s networks.

and using D-flips-flops, exclusive-OR/NOR circuits, and phase detectors, this circuit separates a 10 Gb/s data stream into the following: clock output; data output; "phase" variation output; and data density output.

For all four of the devices, signal interfaces are 50-ohm with direct coupling data input and output. The circuits are packaged in ceramic flat-packages with ground plane and heat sinks. All four are in volume production, and are priced at around \$1,000.



	MESFET	MESFET	Pseudomorphic-inverted HEMT	HEMT + Air Bridge
Basic Gate Circuit	DCFL or SBFL*	DCFL or SBFL*	DCFL or SBFL*	Analog only
Photo Masking	I-line printing	I-line phase shift masking	Deep UV masking	Deep UV
Gate Length	0.5 μ m	0.2 μ m	0.17 μ m	~0.15 μ m
Ft (GHz)	30	~65	>85	>110
Gate Delays (ps)	25	9	7	Analog only
Max. Usable Frequency	<3 GHz	<15 GHz	<30 GHz	>40 GHz
Application	<2.4 Gb/s standard cell	>12 Gb/s hand-routed logic	>20 Gb/s low-density logic	Analog amplifier

*DCFL = direct-coupled FET logic; SBFL = super-buffer FET logic

Summary of GaAs process currently offered by Oki for fiber and wireless logic applications. The 0.2 μ m MESFET process is used for the 10GHz telecommunications ICs.

GEC Offers 60 mW DFB Laser

Towcester, England. GEC Marconi Materials Technology has introduced a new family of strained-layer MQW DFB lasers capable of delivering 60 mW of output power per facet at moderate drive current with exceptionally low RIN. The devices are offered in a variety of package styles, including submount, butterfly and 5.6 mm dia. cans. Integral optical isolator, TE cooler, and monitor photodiode are included with the butterfly option, which launches >30 mW into optical fiber. All options can be supplied to a wavelength accuracy of +1 nm between 1530 and 1560 nm.

10 Gb/s DFB Laser from Ericsson

Richardson, TX. The Opto Electronic Products Division of Ericsson Components recently extended its laser offerings by introducing the PGT 20110, a 1550 nm DFB laser with integrated electro-absorption modulator. It is designed for 10 Gb/s applications within the SDH and SONET standards (also known as STM-64 and OC-192). The new laser has a typical bandwidth of 12 GHz and typical performance is 40 km with linear transmission and 80 km with non-linear transmission (i.e. with fiber amplifiers). The PGT 20110 joins a portfolio which ranges from discrete lasers and detectors to fully integrated fiber optic SONET modules for up to 10 Gb/s.

New 980nm Pump Lasers from SDL

San Jose, CA. In early February SDL announced the new 2500 Series high power 980 nm pump modules, intended for use in EDFAs (Er-doped fiber amplifiers), especially those used in dense wavelength division multiplexing (DWDM) transmission networks. This new family of products offers kink-free power in excess of 165 mW, based on a new laser chip which is said to provide high reliability and improved manufacturability.

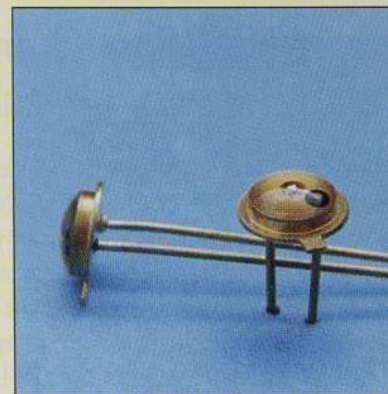
According to Greg Dougherty, vice president and general manager of SDL's Communications Group, "The SDLO-2500 series pump module leverages SDL's key expertise, the development of reliable, high power semiconductor lasers, to address the demands of the fast-growing market for EDFAs. This increase in module power is an important step toward a lower price per delivered mW of pump power, a key goal of optical amplifier designers in today's competitive DWDM market. Our unique position as a vertically integrated supplier of chips and fiber-coupled modules has enabled us to move this product quickly to market."

SDL reports that the 2500 Series package has demonstrated reliability through qualification and lifetesting according to Bellcore guidelines, as well as field deployment. The company says that the fiber Bragg grating stabilization developed and patented by SDL and utilized in these modules ensures power and wavelength stability over the life of the product.

More New Products from UMS

Orsay, France. In early February United Monolithic Semiconductors (UMS) announced the availability of 2 new power MMICs to cover the frequency band 20-40GHz. Both are 3-stage circuits based on PHEMT technology with 0.25 micron gate length. The CHA4092 offers 22dBm of output power and 17dB gain in the 20 - 30GHz band. The CHA4094 offers 22dBm of output power with 9dB gain in the 36 - 40GHz frequency band.

UMS also recently introduced an integrated RF front end for 900 MHz applications. The 3V chips integrates a power amplifier (17dBm of Pout), an LNA (17dB of gain and 1.6dB of Noise), and a switch. It is available in chip form or SS020 plastic package.



Clairex

High Power IR Diode

Plano, TX. Clairex

Technologies recently introduced the CLE330E, a high speed, high quantum efficiency 850nm AlGaAs die mounted on a TO-46 header and encased in a water-clear epoxy dome. This type of construction allows a 140° radiation pattern at the half power points.

According to the company, the double-double-heterostructure junction provides 50% higher quantum efficiency than an equivalent Si-doped, amphoteric junction 880nm AlGaAs LED. It is intended to be used in open air optical communications systems where the entire area is to be flooded with IR radiation. Typical output power at $I_F=1.5A$ is 300mW. The device can be modulated at frequencies in excess of 10 MHz. It is priced at \$1.92 each in 1,000 unit quantities.

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TopoMetrix Product Brochure

Santa Clara, CA. TopoMetrix Corporation has issued a new brochure describing its wide range of scanning probe microscope (SPM) products. This brochure describes TopoMetrix products for both industrial and research applications. Systems are available for analyzing samples of any size. The company's products offer all commercial SPM operating modes, including:

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Heterostructures in Semiconductors

London, England. World Scientific Publishing has announced that 'Heterostructures in Semiconductors: Proceedings of the Nobel Symposium 99, Arild, Sweden 4 - 8 June, 1996' is now available. The volume is edited by H.G. Grimmeiss (University Lund, Sweden). 120 pages, ISBN: 981-02-31644. Price: US\$48, £33.

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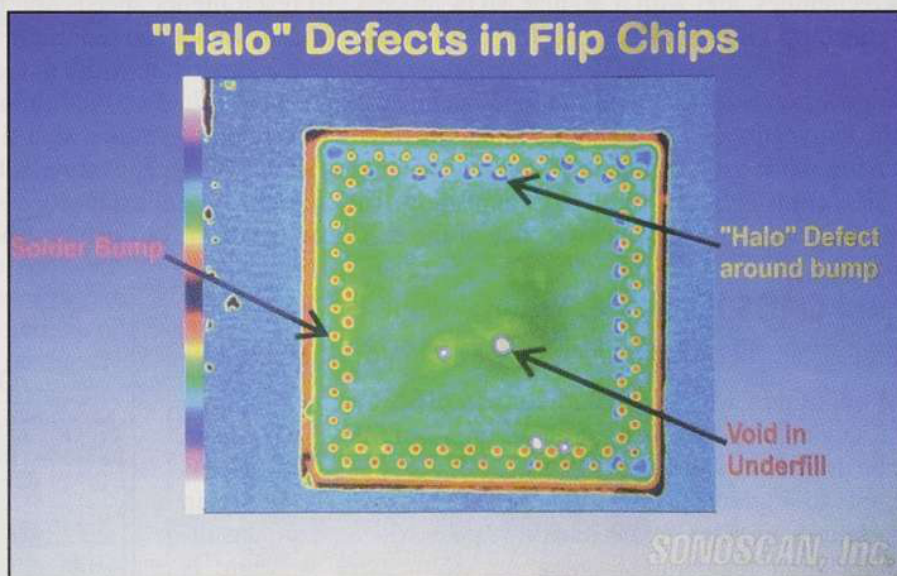
For more information, contact Anatech, Ltd., 6621-F Electronic Drive, Springfield, VA 22151-4303 USA, TEL [1] 703 941-8860; FAX [1] 703 941 8077.

Sonoscan Demonstrates "Halo" Defect in Flip Chips

Bensenville, IL. A flip chip defect in which underfill material flows around but does not come in contact with solder bumps has been demonstrated in Sonoscan's applications laboratory. The defect consists of a tubular delamination partly or completely surrounding the solder bump. Although the precise cause of the defect is undetermined, it may result from incomplete wetting of the solder bumps as a result of flux residue. Since the tubular delamination is quite thin, it is extremely difficult to detect by either x-ray or destructive physical analysis. And since migration of bump material occurs slowly, this type of defect would be undiagnosed during initial electrical testing.

A family of high-resolution ultrasonic transducers with the good penetration needed to image flip chips is currently under development at Sonoscan. The 180 MHz transducer, the first transducer expressly designed for flip chips, was released earlier this year.

For further information, contact Steven R. Martell, Technical Marketing Department, Sonoscan, Inc., 530 East Green St., Bensenville, IL USA 60106 TEL [1] 630 766 7088; FAX [1] 630 766 4603, Email sonoscan@worldnet.att.net.



Research Review

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

Microelectronic Devices and Circuits

High Performance InP PHEMT

S. Piotrowicz et al, IEEE Microwave & Guided Wave Lett., 1998, 8(1), p.10

InP-based HEMTs have demonstrated superior microwave performance compared to other transistor types. For low-noise and low-power applications, InGaAs/InAlAs devices are often used, as in this example (see right). The active part of this structure is a 15nm $\text{Ga}_{0.35}\text{In}_{0.65}\text{As}$ pseudomorphic channel with two AlInAs spacer layers. The bottom AlInAs layer is lattice-matched, while the upper, pseudomorphic AlInAs layer has a high Al mole fraction (0.65) to enhance the conduction band discontinuity. High current density in the channel, necessary to attain a high power density under low-supply conditions, is achieved using silicon δ -doping. Hall measurements indicated an electron sheet charge density of $4.6 \times 10^{12} \text{ cm}^{-2}$, with an approximate mobility of $15000 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$.

Devices were fabricated with a gate width of $2 \times 50 \mu\text{m}$ and a gate length of $0.25 \mu\text{m}$. When operated at a drain-source voltage of 2V, the measured power performance at 60GHz had the following characteristics; Power density = 370 mW/mm ; Power-added efficiency = 28.3%; Power gain = 5.2dB. Although higher numbers have been reported, this is described as a state-of-the-art simultaneous optimisation of these three parameters. [Work carried out at the Institut d'Electronique et de Microelectronique du Nord, France]

GaInAs ($5 \times 10^{18} \text{ cm}^{-2}$)	7nm
$\text{Al}_{0.65}\text{In}_{0.35}\text{As}$	15nm
δ - doping = $4 \times 10^{12} \text{ cm}^{-2}$	
$\text{Al}_{0.65}\text{In}_{0.35}\text{As}$	5nm
$\text{Ga}_{0.35}\text{In}_{0.65}\text{As}$ Channel	15nm
$\text{Al}_{0.48}\text{In}_{0.52}\text{As}$	5nm
δ - doping = $2 \times 10^{12} \text{ cm}^{-2}$	
$\text{Al}_{0.48}\text{In}_{0.52}\text{As}$ Low T	300nm
$\text{Al}_{0.48}\text{In}_{0.52}\text{As}$	100nm
InP semi-insulating substrate	

Layer structure for a double δ -doped AlInAs/GaInAs/InP PHEMT.

Vertical SiGe-based MOSFET Using Solid Phase Epitaxy

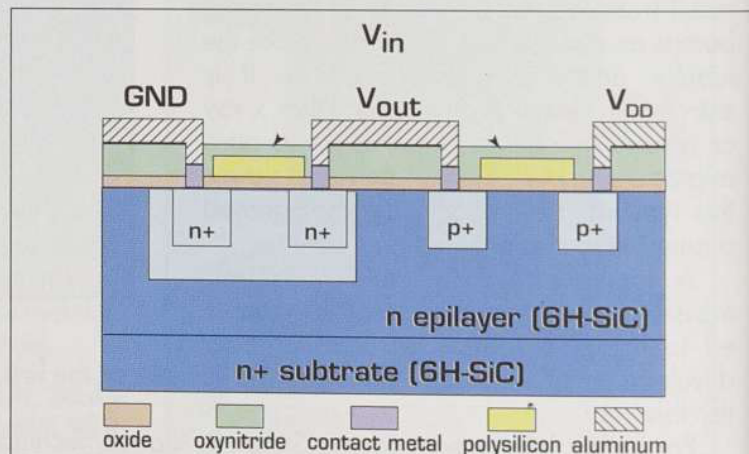
K. Lui et al, IEEE Electron. Dev. Lett., 1998, 19(1), p.13

A method is presented to fabricate SiGe-based transistors with gate lengths below $0.2 \mu\text{m}$ without using sophisticated lithographic techniques, and with a regular MOS process. To reach higher speeds and packaging densities, the geometry of ultra-large scale integrated MOSFET devices is being continuously scaled, which can require increasingly complex lithographic processes. One alternative is to use vertical MOSFET structures, which give a larger gate width in the same area compared to a conventional planar device. Also in vertical structures, the channel width scaling is not limited by the minimum lithographic resolution. The device reported here by the University of Texas and the Indian Institute of Technology starts with a silicon wafer with an etched mesa for the vertical channel. After oxide growth and polysilicon deposition to define the gate, Ge implantation was carried out, followed by recrystallization of the SiGe films at 590°C by furnace annealing. This solid phase epitaxial process produces a graded SiGe layer with a built-in electric field. Device results indicate evidence of the enhancement of the out-of-plane hole mobility of this layer.

Digital CMOS ICs in SiC

S-H Ru et al, IEEE Trans. Electron. Dev., 1998, 45(1), p.45

Monolithic CMOS digital circuits in 6H-SiC operating on a single 5V power supply between 0 and 300°C have been demonstrated at Purdue University (see opposite). Previous attempts to implement CMOS processes in SiC have resulted in large supply voltages, which stress the gate oxide and are unsuitable for high temperature operation. The device structure is formed using a 6H-SiC epilayer grown on a 6H-SiC substrate, which is ion-implanted and subsequently oxidized. The resulting PMOS devices had a threshold voltage of -4.2V at room temperature and -3.2V at 300°C . One of the problems of this technology is the surface state density at the SiC/SiO₂ interface, which is currently being improved. Several digital logic circuit were fabricated, which all exhibited stable operation up to 300°C .



Cross-sectional view of the structure of the p-well CMOS device in SiC.

Indium Antimonide Transistors

Indium antimonide has certain properties which are extremely attractive to device designers, such as a low field electron mobility which is 9x higher than GaAs at room temperature and a saturation velocity which is 5x higher (see Table). Although this suggests, amongst other things, the possibility of high speed transistor operation at very low drive voltages, the properties cannot be easily accessed. This is due to the narrow bandgap of InSb and the consequent high intrinsic carrier concentration, which results in unacceptably high transistor leakage currents. However, through sophisticated MBE-grown device heterostructures utilising the phenomena of carrier exclusion and extraction, scientists at the UK's Defence Evaluation and Research Agency in Malvern have been able to significantly reduce transistor leakage currents. Research devices with impressive statistics have been produced, including non-optimised 0.7 μm gate structures with f_T of 74GHz at room temperature.

Room temperature operation

The basic device structure for the DERA InSb devices, which include mid-IR LEDs and detectors as well as transistors, is shown in Figure 1. The active region, designated π , is not intentionally doped, so it is near intrinsic (usually $p \sim 1\text{--}3 \times 10^{15} \text{cm}^{-3}$, dependent on the MBE reactor background). The n^+ contact region is highly doped ($n \sim 1 \times 10^{18} \text{cm}^{-3}$), creating a large step in the valence band which minimises hole transport across the πn^+ junction. For the p^+ contact, a thin region of $\text{In}_{0.85}\text{Al}_{0.15}\text{Sb}$ (designated p^+) is required to create a barrier in the conduction band, which controls electron flow. Under reverse bias, extraction and exclusion removes carriers from the active π -region and prevents their re-introduction, decreasing the density of electrons and holes by several orders of magnitude and dramatically reducing the transistor leakage current.

Transistor performance

In early MISFET structures, f_T was limited by a large gate metal overlap capacitance. To overcome this, an ion-implanted enhancement-mode FET was fabricated (Figure 2), featuring a 0.7 μm gate with 70nm SiO_2 gate insulator. With the substrate biased at -0.35V relative to the source, the device had a maximum transconductance (g_m) of 120mSmm $^{-1}$. The measured f_T of 74GHz is believed to be the highest for a 0.7 μm gate in any mate-

rial system. The unity unilateral power gain frequency (f_{max}) was 89GHz. A recessed-gate doped channel depletion-mode MISFET is also under development.

Presenting at IEDM 1997, Tim Phillips of DERA was keen to stress these are non-optimised devices, and further performance improvements are expected. Modelled results for the enhancement-mode device show g_m of 188mSmm $^{-1}$, f_T of 68GHz and f_{max} of 202GHz at 1 μm gate length, rising to 500mSmm $^{-1}$, 185GHz and 264GHz respectively at 0.25 μm . Future plans will include growth on semi-insulating or virtual substrates to enable incorporation in microwave integrated circuits.

While the f_T :gate length ratio and operating voltage compare extremely well with other technologies, some observers are skeptical that these devices will find application niches due to concerns over low breakdown voltages. The DERA group believe that exclusion/extraction techniques suppress the effects of low breakdown voltage to some extent, so enabling operation for low to medium power requirements. In the shorter term, optoelectronic exclusion/extraction devices operating in the mid-IR region are likely to be the first to be commercialized. [see T. Ashley et al, *Appl. Phys. Lett.*, 1995, 66, p.481; T. Ashley et al, *Proc. IEDM*, 1997]

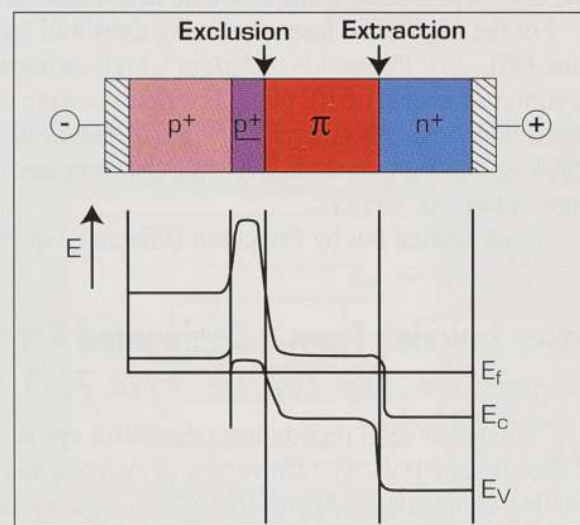


Figure 1. Band profile of InSb-based exclusion/extraction devices

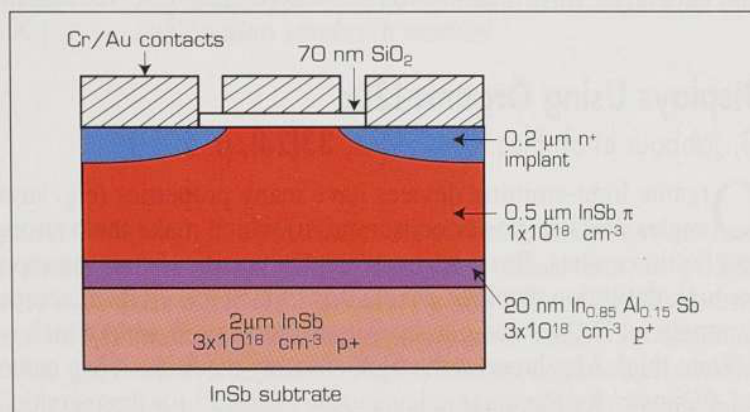


Figure 2. Structure of an InSb-based ion-implanted enhancement-mode FET

Property	Silicon	GaAs	InSb
Band gap (eV)	1.12	1.43	0.175
Effective electron mass	0.19	0.072	0.013
Bulk mobility (cm ² /Vs)	1,500	8,500	78,000
Saturation velocity (cm s ⁻¹)	1x10 ⁷	1x10 ⁷	> 5x10 ⁷
Mean-free path (μm)	0.04	0.15	0.58
Intrinsic room temperature carrier conc. (cm ⁻³)	1.6x10 ¹⁰	1.1x10 ⁷	1.9x10 ¹⁶

Comparison of electronic material properties of InSb, silicon and GaAs

Optoelectronic Devices - Organic Lasers and Displays

Optically Pumped Red and Blue Organic Lasers

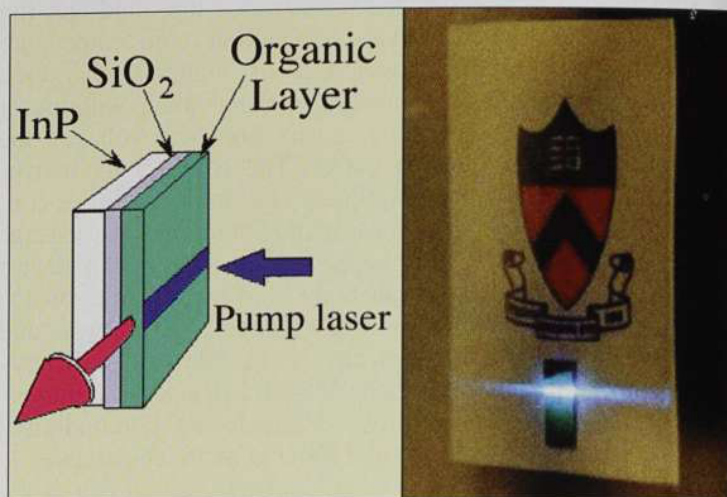
Kozlov et al, Appl. Phys. Lett., 1997, 71(8), p.2575; Kozlov et al, Appl. Phys. Lett., 1998, 72(2), p. 144

Organic semiconductor lasers (OSLs) have been demonstrated using conducting thin films of small organic molecules doped with a laser dye. Red laser emission at (620-660nm) has been reported from a thin film of tris-(8-hydroxyquinoline) aluminum (Alq_3) doped with DCM laser dye, while blue laser emission 460-510nm) is observed using 4,4'-di(N-carbazole)biphenyl (CBP) doped with perylene or Coumarin. In both cases, optical pump energy is absorbed by the host material, and transferred through a highly efficient, non-radiative (Förster) process to the organic dye. In small organic molecules such as Alq_3 /DCM, the electrons are confined within the bands defined by the vibrational levels of single molecule, hence forming a natural quantum well.

The blue OSL (see figure) has a 120nm thick organic film deposited by high vacuum (5×10^{-7} Torr) thermal co-evaporation onto an InP substrate pre-coated with SiO_2 . This coating, together with the air on the other side, provides optical cladding. The red laser was formed using a double heterostructure, with the doped film sandwiched between two Alq_3 layers.

For the Alq_3 /DCM laser, the lasing threshold $1 \mu\text{J}/\text{cm}^2$, and output power were independent of temperature from 0 to 140°C . For the blue OSL, low thresholds of $5 \mu\text{J}/\text{cm}^2$, high differential quantum efficiencies of 15%, high peak output powers of 20W, and operating lifetimes in excess of 10^5 pump laser pulses were observed. Laser cavity modes were observed in both devices. The ability to deposit amorphous thin films on many materials including silicon and flexible, transparent plastics, in combination with the high temperature stability, wavelength tunability and other properties, will make electrically pumped organic devices potential competitors for conventional inorganic sources.

[Work carried out by Princeton University and University of Southern California]



Schematic diagram of an organic semiconductor laser device, together with a photograph of the CBP/perylen-based blue laser output.

Laser Emission From a Conjugated Polymer

Schulzgen et al, Appl. Phys. Lett., 1998, 72(3), p.269

Although several reports have described optical gain in conjugated polymers, no one has unambiguously described laser action in such materials. The University of Arizona and Donnelly Corp. have investigated the optically-pumped emission from a semiconducting conjugated polymer BEH:PEV, a phenylenevinylene derivative, inside a high quality planar cavity composed of alternating layers of SiO_2 and TiO_2 . The mirrors were produced by electron beam deposition and the polymer was spin-coated from solution. With the cavity in place, unambiguous features of laser emission such as a sharp intensity threshold at $55 \mu\text{J}/\text{cm}^2$, a high degree of polarization and strong directionality were observed. The observed laser wavelength was at 626nm.

Displays Using Organic LEDs

G. Jabbour et al, Elec. Lett. 1997, 33(24), p. 2070

Organic light-emitting devices have many properties (e.g. structural flexibility, ease of processing, color tunability, large viewing angles and low power consumption) which make them strong contenders for many applications currently using inorganic LEDs and liquid crystals. Researchers at the University of Arizona report a simple fabrication method for the type of pixel arrays required for high definition displays. Pixel sizes (which are uniform across the arrays) varied in size from $450 \times 450 \mu\text{m}^2$ down to $25 \times 25 \mu\text{m}^2$. Commercial ITO-coated glass substrates were used, onto which was deposited a 60nm thick, hole transport layer (TPD), followed by a 50nm thick Alq_3 layer as the light emitting medium. A Mg cathode capped with Al finished the structure. The deposition rates were $0.1\text{-}0.2 \text{ nm/s}$ for the organic layers and $1\text{-}2 \text{ nm/s}$ for the metallic layers. Pixels were defined by an evaporation mask of the appropriate size, placed on either the ITO, the Alq_3 , or the TPD layer. The brightness equivalent of the maximum photocurrent was estimated as $\sim 28,500 \text{ cd/m}^2$, more than two orders of magnitude higher than required for display purposes.

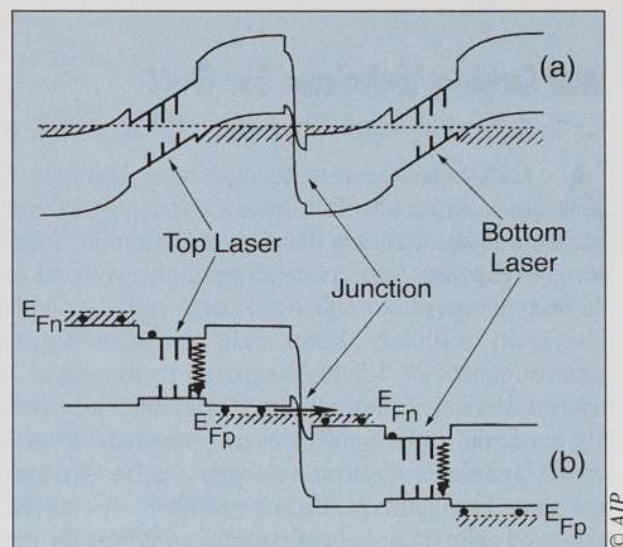
Optoelectronic Devices

A New, Epitaxially Stacked, Bipolar Cascade Laser

J.Ch. Garcia et al, Appl. Phys. Lett., 1997, 71(26), p.3752

A method is described to combine laser diodes by stacking them during epitaxial growth and linking them with low resistivity Esaki junctions. High semiconductor laser power output is required for applications such as diode-pumped solid-state lasers, or micromachining. This approach uses the high, stable n- and p-type doping available with C and S in CBE growth of GaAs and InGaAs. Tunnel junctions formed from n⁺/p⁺ GaAs or incorporating an In_{0.15}Ga_{0.85}As QW were shown to have a very low resistivity of $2.5 \times 10^{-4} \Omega \text{cm}^{-2}$ and $3 \times 10^{-5} \Omega \text{cm}^{-2}$ respectively.

A GaAs homojunction was used to interconnect two separate confinement heterostructure lasers, with the entire structure grown in a single run by CBE. The lasers featured AlGaAs cladding layers, GaAs confinement layers and InGaAs QWs, with slightly different In compositions to give different wavelength outputs. The energy-band diagram of the structure clearly shows that under forward bias, electrons injected into the top laser diode conduction band make an optical transition and are recycled into the conduction band of the bottom laser diode through the tunnel junction. A further optical transition occurs, and the structure can be considered to be a bipolar, cascade laser. [Work carried out at Thomson-CSF Central Research Labs]



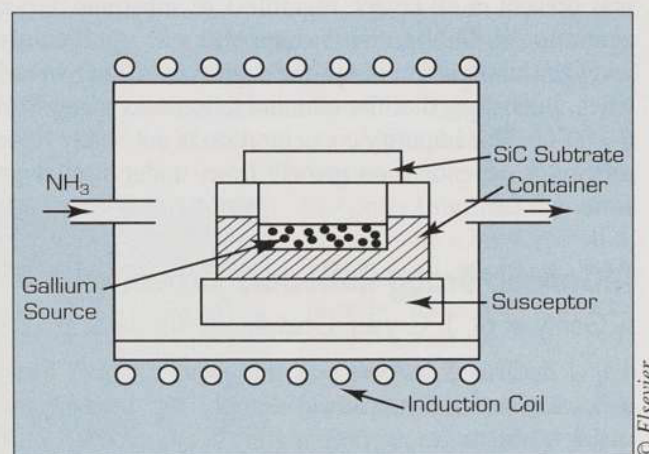
Schematic energy-band diagram of the epitaxially stacked, two laser structure with a central tunnel junction (a) at 0V (b) under forward bias.

Compound Semiconductor Materials

GaN Growth at 1mm Per Hour

Y. Vodalov et al, J. Cryst. Growth, 1998, 183, p.10

The lack of an ideal substrate for GaN growth remains somewhat of a problem, and large, free-standing crystals of GaN are not generally available. However, researchers at the Ioffe Institute, St. Petersburg, have now improved their so-called Sublimation Sandwich Method (SSM) for growing high-quality, very thick GaN layers at rates as high as 1mm/hour. The experimental set-up (see Figure) uses a horizontal reactor with RF heating to reach the optimum growth temperature range of 1150-1230°C. The substrates used were 6H-SiC and the sources were metallic Ga or powdered GaN, and a flow of ammonia gas at atmospheric pressure. The growth rate decreased drastically above 1200°C, due to GaN decomposition, and also decreased as the Ga source-substrate distance increased. At 1200°C, a growth rate of ~1.25mm/hour was achieved for a separation of 2mm. The high quality of epitaxial GaN grown was confirmed by X-ray rocking curve measurements showing a FWHM of 0.09 arcdeg.



Apparatus for growth of thick GaN layers by the sublimation sandwich method.

ZnSe/ZnS DBR Mirrors in the Blue Region

T. Tawara et al, Jpn. J. Appl. Phys., 1997, 36(1), 6672

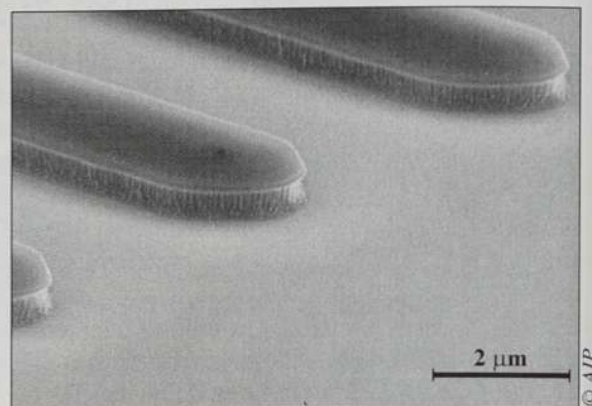
Blue VCSELs present yet another challenge for wide bandgap materials. Although it is possible to use dielectric multilayers or metals as DBR mirrors, high reflectivity stacks in semiconductor materials, which will allow monolithic fabrication of VCSEL devices, have not yet been realized. Researchers at Hokkaido University have demonstrated the growth, by MOVPE, of ZnS/ZnSe mirrors. The substrate used was GaAs(311)B, which allows the growth of VCSEL structures with good polarisation selectivity. Cleaning was carried out using TDMAAs [trisdimethylaminoarsenic, or As-(NMe₂)₃] to achieve an atomically flat starting surface as shown by AFM. The maximum reflectivity measured for only 10 mirror periods was 94.5% at 468nm, which is much higher than for previous attempts with similar mirror stacks and many more periods. A lattice-matched system such as ZnSSe/MgSSe is expected to yield improved results when the growth of zincblende MgSSe becomes possible.

Compound Semiconductor Materials (cont.)

Wet Etching Technique for GaN

C. Youtsey et al, Appl. Phys. Lett., 1998, 72(5), p.560

As GaN-based devices become more common, low damage etching techniques for device fabrication are required. High density plasma dry etching techniques are being developed, but simple, low damage wet etching is also sought. Previous reports describe high levels of surface roughness on GaN etched using photo-enhanced wet etching methods. This work, by the University of Illinois, Xerox and Cree, yields very smooth etched surfaces with rms roughness of 1.5nm, compared to roughness on a scale of hundreds of nanometers in previous reports. The etchant was a 0.02M KOH solution, and an Hg arc lamp (intensity 40mWcm^{-2}) was used to provide uniform illumination, which generates electron-hole pairs at the surface to enhance the oxidation reaction. Using n-type GaN grown on SiC, an etch rate of 50nm/min was achieved. The process is of particular interest for the fabrication of GaN-based electronic devices, particularly gate recessed FETs.



SEM micrograph of GaN features smoothly etched to a depth of 400nm.

Impurity Contamination in GaN Grown on Different Substrates

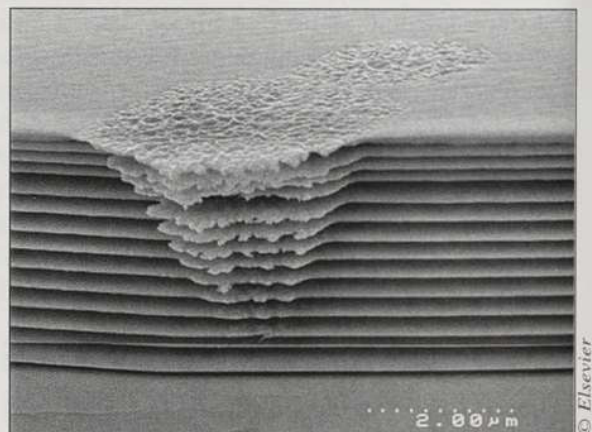
Popovici et al, Appl. Phys. Lett., 1997, 71(23), p.3385

A SIMS study of impurity incorporation in GaN epilayers grown by reactive MBE on sapphire, SiC and ZnO substrates show these substrates are likely sources of considerable contamination during growth. GaN grown on SiC with a 60-80nm AlN buffer layer shows high concentrations of Si, which fall below the SIMS detection limit ($\sim 10^{17}\text{cm}^{-3}$) for an epilayer thickness of 0.8μm. Oxygen was present in all layers, regardless of substrate, as a result of contamination from the ammonia source. However, the SIMS O concentration in GaN grown on sapphire was significantly higher than the SiC-grown layer, contaminating the first 1μm of growth. Zn and O contamination in epilayers grown on ZnO was also observed. Longer growth times resulted in thicker depths containing impurities, indicating that the contamination was a result of diffusion of the impurities into the epilayer at the growth temperature used ($\sim 800^\circ\text{C}$). The impurity concentration is not solely linked to defects, since the thickness of the near-interface defective layer is not significantly dependent on growth time, under similar growth conditions. [Work carried out at the University of Illinois and Dayton Research Institute].

AlGaAsSb Bragg Reflectors Grown on InP

F. Genty et al, J. Crystal Growth, 1998, 183, p.15

As described in detail in this issue's Cover Story, VCSELs operating at telecommunications wavelengths are arousing much research interest. A major problem is matching high reflectivity DBR mirrors with active layers in the correct wavelength regime. The antimonide-based quaternary sub-system, AlGaAsSb, has been investigated as a possible material for high contrast mirrors. Universite de Montpellier II reports the growth of high quality mirrors consisting of alternating stacks of AlGaAsSb and AlAsSb, using MBE and an InP substrate. The growth is problematic on two counts; firstly, neither of the group V incorporation coefficients is unity, and both vary with substrate temperature and group V flux. Secondly, phase separation must be avoided, and a growth temperature of 470°C was chosen as a compromise. DBR mirrors were characterized by a large number of stacking fault defects, as clearly shown by the SEM picture opposite. The pyramidal shape terminates at the mirror-substrate interface, indicating this to be the source of the defects. The problem is thought to arise during cleaning of the InP wafer under an As overpressure, when three-dimensional islands of InAs form on the surface after oxide removal. The same problem is not observed using a phosphorus overpressure during cleaning. The same group have also grown fully-doped VCSEL structures with AlGaAsSb/AlAsSb DBR mirrors and an InGaSb active layer on a GaSb substrate, and have observed electroluminescence at 80K.



Cross-sectional SEM photo of a cleaved and etched AlGaAsSb/AlAsSb DBR stack with 15 mirror pairs, showing pyramidal stacking fault defects. The dark areas are AlAsSb, the lighter areas are AlGaAsSb.

Is There Trouble Ahead?

MARIE MEYER

Is there trouble ahead for some of the Compound Semiconductor Portfolio companies? Or, more to the point: has it already arrived?

Shares in Anadigics were battered after the company warned of lower sales and profits in 1998. Ronald Rosenzweig, Anadigics' President and CEO, told analysts that the company is experiencing "a substantial reduction in orders and forecasts for orders from our wireless customers", which will result in significantly lower sales in the first quarter of 1998 and may even produce a net loss for the period. He went on to say "We believe the lower demand is attributable to several factors including increased competition, a shift in demand to lower costs phones not using Anadigics' products, customer delays in the ramp-up of new generation dual-band phones using our new products and, in part, to effects of the Asian financial crisis on the wireless market."

As a result of these warnings, at least four analysts (Goldman Sachs, CIBC Oppenheimer, Needham & Co., and Volpe Brown) all cut their rating of Anadigics from "buy" to "hold" (BankAmerica Robertson Stephens kept the stock at "long-term attractive."). Share prices dropped like a rock (down more than \$19 in one day!) with the result that the company closed at \$14.25 on January 30 - their lowest closing price in 93 weeks.

Other companies are also issuing earnings warnings. Ortel said it expects to just break even in the coming quarters, due to declining sales caused by the Asian economic crisis, which is said to be "more than offsetting" recent improvements in Ortel's domestic broadband business outlook. APA Optics is also forecasting declining earnings in the coming quarter. However, the company says their circumstances are slightly different,

as the shortfall is due to cut-backs in low-margin contract research activity. They are holding out the possibility of increased production revenues in coming quarters.

And on January 23 Volpe Brown Whelan & Co. analyst Eric Rothdeutsch said he was downgrading Emcore to a "buy" from a "strong buy". He said he is bullish on the stock in the long term, but is concerned that Emcore relies on Asian markets for about one-third of its business. He cut his earnings estimates for fiscal 1998 to 65 cents a share from 72 cents, and lowered his 12-month target price for Emcore stock to 25 from 30. The shares were recently trading at 14 7/8.

Good News

But the latest round of earnings announcements also brought some good news for the Portfolio companies.

Alpha Industries says it continues to project growth, in orders, shipments and profits, with a book-to-bill of 1.05 over the past nine months. Sales for the quarter ended December 31, 1997 totaled \$30.8 million, which was up 38% over the comparable period in 1996. Alpha attributes the increase in part to continued strong demand for the company's GaAs RFICs for wireless applications. Gross profit for the quarter was \$11.8 million, compared with \$5.2 million for the same period in 1996.

Celeritek reported revenues of \$14.4 million for the recent quarter, compared with revenues of \$10.5 million for the year-ago period. Net income was \$1.17 million, up 64%. Most of

Company	Symbol	52 - Week		Closing Price		Change	Volume (000's)	P/E Ratio
		Hi	Lo	Jan 2	Feb 13			
Alpha	AHA	20 5/8	5 1/2	15 3/4	16 7/8	7%	93	■
Anadigics	ANAD	51 14	13 1/2	29 2/3	15 3/8	-48%	954	15
APA Optics	APAT	9 1/4	4.25	8 5/8	7 3/4	-10%	4	◆
ATMI	ATMI	42 1/4	15 3/4	23 1/8	29	25%	118	■
Celeritek	CLTK	18 3/8	9 1/2	13 1/2	13 1/4	-2%	71	23
Cree Research	CREE	29 1/2	9 1/2	17 3/4	16 1/8	-9%	197	54
Emcore	EMKR	25 1/4	9 1/4	19 1/4	14 7/8	-23%	34	◆
Kopin	KOPN	29	9 7/8	16 2/3	17 1/8	3%	142	◆
Ortel	ORTL	25	10 7/8	15 3/4	13 1/8	-17%	144	21
RF Micro Devices	RFMD	23 3/4	9 3/4	13	12 5/8	-3%	108	◆
SDL	SDLI	25 1/4	8	15 1/8	23	52%	83	◆
SLI	SLIC	9 3/4	4/7	1 3/4	1 3/4	0%	180	◆
Spire	SPIR	24 3/4	2 1/4	14 5/8	14 3/4	1%	20	28
TriQuint	TQNT	45 1/2	17 3/8	20 1/4	24 3/4	22%	246	33
Vitesse	VTTS	56 1/2	21 1/8	35 5/16	49 1/2	40%	702	52

Notes ◆ = loss in most recent 4 quarters ■ = P/E ratio greater than 100

Celeritek's gains are the result of an ongoing conversion from defense to commercial markets. "Celeritek continued to experience solid growth in the commercial arena," said Tamer Hussein, Celeritek's President and CEO. "Our GaAs RF IC semiconductor sales volume grew by approximately 50% over the third quarter of last year and we received a \$2.1 million order for RF IC power amplifiers for cellular handsets from Phillips...We remain very dedicated to the GaAs market and are investing in people and capital equipment to grow that business."

Cree Research reported net income of \$1.4 million for the quarter, compared to \$0.3 million for the year-ago period. Total revenues \$10.1 million, representing a 55% increase. Neal Hunter, Cree's President and CEO, commented, "These solid earnings results demonstrate the success of our ongoing efforts to reduce manufacturing costs, particularly in our LED product line where the results reflect increased yields obtained from implementing a smaller chip size and larger two-inch wafers." The company noted that the substantial increases in revenues over the comparable prior year periods were driven by larger purchases by exist-

ing customers and by development fees paid by C3, Inc. for the program to develop colorless SiC for use in gemstones. In addition, LED product sales for the quarter increased 116% over the prior year period.

1997 Profit and Loss Results

With this latest round of earnings announcements, it is now possible to piece together a nearly complete picture of earnings performance for the Portfolio companies in calendar year 1997. Results from all of the companies except Ortel, Power Spectra, SLI and Spire were available as this issue went to press. The information is summarized in the charts below.

Seven of the Portfolio companies posted profits for the year: Alpha, Anadigics, Celeritek, Cree, RFMD, TriQuint and Vitesse. Vitesse was the leader in both revenues (\$117.7 million) and profits (\$37.2 million). And while Vitesse also posted impressive growth

in revenue and profit (up 59% and 121%, respectively, over 1996), the biggest growth was shown by Cree, whose revenues of \$35.7 million were up 65% over 1996, and profits of \$3.9 million were up 163% over 1996. And two of the companies made the big leap from loss-making in 1996 to profitability in 1997: Alpha turned a \$10 million loss into a \$1.2 million gain, and RFMD turned a \$1.3 million loss into a \$3.9 million gain.

Five of the companies posted a loss for 1997: APA Optics, ATMI, Emcore, Kopin and SDL. ATMI's loss stems from its recent acquisition of two companies, the ADCS Group and Lawrence Semiconductor. SDL's loss was caused by an expensive patent lawsuit with Spectra-Physics, which cost them \$30.9 million to settle. Without that one-time charge, they would have shown around \$6.3 million in profit.

1997 Profits

All numbers in thousands
"Change" is comparison with 1996 calendar year

	<u>Revenue</u>	<u>Income</u>
Alpha	\$107,790	\$1,265
Change	Up 23%	Up from loss of \$10,065
Anadigics	\$102,536	\$15,330
Change	Up 49%	Up 28%
Celeritek	\$52,139	\$4,192
Change	Up 17%	Up 14%
Cree	\$35,758	\$3,919
Change	Up 65%	Up 163%
RFMD	\$41,864	\$3,980
Change	Up 59%	Up from loss of \$1,370
TriQuint	\$71,366	\$6,860
Change	Up 20%	Up 9%
Vitesse	\$117,719	\$37,264
Change	Up 59%	Up 121%

1997 Losses

All numbers in thousands
"Change" is comparison with 1996 calendar year

	<u>Revenue</u>	<u>Income</u>
Alpha Optics	\$2,664	-\$528
Change	Up 7%	Increase from loss of \$203
ATMI	\$69,616	-\$712 [1]
Change	Up 24%	Down from profit of \$3,539
Emcore	\$51,508	-\$1,318 [2]
Change	Up 60%	Increase from loss of \$6,081 [3]
Kopin	\$17,398	-\$6,260
Change	Down 11%	Up from loss of \$21,596
SDL	\$91,364	-\$24,679 [4]
Change	Up 11%	Down from profit of \$7,121

Notes

- [1] ATMI Q4 1997 results reflect acquisitions of the ADCS Group and Lawrence Semiconductor Laboratories.
- [2] Emcore Q4 1997 figures are based on a pro forma statement which does not include the MODE acquisition, which resulted in a one-time charge of \$29,294 million from acquired R&D expense.
- [3] Emcore 1996 Q4 figures include \$4.3 million in amortization of debt issuance cost.
- [4] SDL 1997 figures include \$753,000 one-time write-off of in-process R&D in connection with the acquisition of MR Laser, Inc. in November, 1997 and one-time charges totaling \$30,911 million relating to settlement of Spectra-Physics lawsuit in June, 1997.

PATENTS

Patents related to compound semiconductors issued from Jan. 1, - Feb. 5, 1998
Headlines contain Patent # / Date Issued / Assignee.

Sources:

"05..." = U.S. Patent Office; "EP..." = European Patent Office;

"WO..." = World Intellectual Property Organization



Electronic Circuits & Devices

**WO9802924 / 1998 01 22 / ABB Research
Bakowski, M et al**

SiC Semiconductor Device Comprising a PN Junction with a Voltage Absorbing Edge. A semiconductor component which comprises a SiC pn junction, where the edge of the higher doped conducting layer of the pn junction exhibits a charge profile with a stepwise or uniformly decreasing total charge or effective surface charge density from the initial value at the main pn junction to a zero or almost zero total charge or charge density at the outermost edge of the junction following a radial direction from the central part of the junction towards the outermost edge.

**WO9802916 / 1998 01 22 / ABB Research
Harris, Christopher**

Method for Producing a Channel Region Layer in a SiC Layer for a Voltage Controlled Semiconductor Device. Both n type and p type dopants are implanted into a surface near layer of the SiC layer. The p type dopants implanted have a higher diffusion rate in SiC than the n type dopants implanted. The SiC layer is then heated at such a temperature that p type dopants implanted diffuse from said surface near layer into the surrounding regions of the SiC layer being lightly n doped to such a degree that a channel region layer in which p type dopants dominates is created.

**EP0820636 / 1998 01 28 / ABB Research
Konstantinov, A; Janzen, E**

Method For Producing a Semiconductor Device Having a Semiconductor Layer of SiC. Abstract not available.

**EP0820637 / 1998 01 28 / ABB Research
Harris, C; Konstantinov, A; Janzen, E**
Use of a Highly Doped Amorphous Layer as a Source for Dopant Diffusion into SiC. Abstract not available.

**EP0820642 / 1998 01 28 / ABB Research
Harris, C; Konstantinov, A; Janzen, E**
Method for Producing a Semiconductor Device Having a Semiconductor Layer Of SiC Comprising a Masking Step. Abstract not available.

**EP0817276 / 1998 01 07 / Hitachi
Hirata, K et al**

Selective Etching of III-V Device. In a semiconductor layer of a polycrystalline or amorphous undoped III-V compound semiconductor or an alloy thereof is formed a through hole for contact of a size permitting exposure of at least part of a first conductor layer and a dielectric Si alloy layer present around the first conductor layer, and a second conductor layer is formed within the through hole so as to contact the first conductor layer. Since the semiconductor layer can be subjected to a selective dry etching for the dielectric Si alloy layer, the dielectric Si alloy layer is not etched at the time of forming the above through hole in the semiconductor layer, whereby an electric short-circuit of the second conductor layer with a single crystal semiconductor layer which underlies the dielectric Si alloy layer can be prevented.

**05708283 / 1998 01 13 / Hughes Aircraft
Wen, C; Wong, W; Gray, W**

Flip Chip MMIC. The present invention relates to high power, flip-chip microwave monolithic integrated circuit (MMIC) modules having thermally conductive bumps to carry heat from the integrated circuit to the module substrate, and more particularly to bumps that are shaped to improve thermal conductivity.

**WO9805064 / 1998 02 05 / Northrop
Grumman
Chen, LS; Clarke, R.; Siergie, R.**

Self Aligned Gate Fabrication Process For SiC Static Induction Transistors. A method of aligning a gate and a source of a SiC static induction transistor comprising the steps of depositing an oxide layer over the transistor, forming oxide spacers from the oxide layer where the oxide spacers are adjacent the source, depositing a metal layer over the transistor and removing the oxide spacers so that the resulting gates are accurately aligned with the source.

**05712189 / 1998 01 27 / TI
Plumton, D & Kim, T**

Epitaxial Overgrowth Method. A vertical field effect transistor and fabrication method with buried gates having gate sidewall crystal

orientation the same as the substrate surface and a low index substrate crystal orientation without tilt to a higher index direction. The gate may have modulated doping along the channel, and the drain may have a lighter doping level than the channel which may be accomplished by an epitaxial overgrowth of the gates to form the channels.

**EP0818810 / 1998 01 14 / TRW
Lammert, Michael**

High Beta HBT Devices. A method for controlling the spacing between the emitter mesa and the base ohmic metal of a HBT to obtain a relatively high gain (beta) with a low-parasitic base resistance.

**05710058 / 1998 01 20 / TRW
Schneier, N & Berenz, J**

Multi-Terminal Resonant Tunneling Transistor. A transistor according to the invention for simultaneously providing at least two current-voltage characteristics includes a base, a collector, and an emitter. At least one of the base, collector, and emitter includes a first layer grown using MBE. The first layer includes a first strip having a first doping characteristic created using focused ion beam processing. A second strip has a second doping characteristic created by focused ion beam processing. A middle section of undoped material is located between the first and second strips. A resonant tunneling junction is grown on the first layer using MBE and includes a plurality of layers.

**EP0822655 / 1998 02 04 / TRW
Smith, Duncan M**

Improved Low Noise Block Downconverter. A small elliptic high pass filter is incorporated into a low noise block downconverter (LNB) to reject image frequencies in a 12 GHz DBS. A waveguide transition with separate electric probes receives Ku-band satellite signals and transmits the signals to low noise amplifiers (LNAs), a power combiner, an elliptic high pass filter, and a HEMT MMIC receiver. Due to the unique response of the elliptic high pass filter, the elliptic high pass filter provides a superior image rejection with lower insertion loss for the LNB, and therefore provides improved television reception quality.

Materials

05705406 / 1998 01 06 / ABB Research Rottner, K; Schoner, A; Nordell, K

SiC Device Using Ion Implantation. A method for producing a semiconductor device having semiconductor layers of SiC with at least three doped layers on top of each other, comprises the steps of growing a first semiconductor layer of SiC; implanting an impurity dopant into the first layer to form a second doped surface layer as a sub-layer therein, the second doped surface layer being surrounded, except for the top surface thereof, by the first semiconductor layer; and epitaxially growing a third semiconductor layer of SiC on top of the second layer of SiC and regions of the first layer adjacent thereto to totally bury the second semiconductor layer. The impurity dopant implanted into the first semiconductor layer is of a first conductivity n or p type, and the first semiconductor layer being doped with a second, opposite conductivity type, so as to form a pn-junction at the interface between the first and second layers.

05704985 / 1998 01 06 / ABB Research Kordina, O; Hallin, C; Janzen, E

Device for Epitaxially Growing SiC by CVD. The invention comprises a substantially cylindrical susceptor having continuous circumferential walls with a substantially uniform thickness surrounding a chamber receiving the substrate, the walls being surrounded by thermal insulation. The circumferential susceptor walls and thereby the substrate and a gas mixture fed to the substrate for the growth are heated to a temperature level in the range of 2000° - 2500°C. at which sublimation of the grown material starts to considerably increase. The gas mixture is fed into the susceptor with a composition and at a rate that ensures a positive growth.

05707890 / 1998 01 13 / Alcatel N.V. Emery, J & Goldstein, I

Method Of Shifting A Wavelength In A Semiconductor Structure Having Quantum Wells. From a top face of a semiconductor structure of the III-V type, inter-diffusion of elements between the wells and the barriers of an internal quantum structure is hot induced. The inter-diffusion is performed in

one segment of the structure only, namely a segment in which the characteristic wavelength is to be shifted so as to constitute an amplitude modulator, another segment of the structure including a Bragg grating so as to constitute a laser emitter. In accordance with the invention, the inter-diffusion is induced by a layer of indium maintained in contact with the top face by means of a dielectric encapsulation layer. The invention is applicable in particular to optical telecommunications.

05705403 / 1998 01 06 / ETRI Baek, J et al

Real-time Doping Measurements. A method of sensing the concentration of a doped impurity on a semiconductor in real time and a method of sensing the change of its growth rate dependent on time among the changes of the growing conditions due to doping by using a real time analysis apparatus in growing a heterostructured semiconductor by a MOCVD method. A reflecting signal during the growth by means of a real time analysis apparatus has a periodic property, an amplitude change of a reflecting signal is dependent on an absorption coefficient when an absorption exists on an epitaxial layer, an impurity concentration can be obtained by using the relation of an absorption coefficient and an impurity concentration. In addition, if each peak is independently analyzed, the respective growth rate dependent on time are measured individually, so that the reduced growth rate dependent on time of the growth rate is sensed in a carbon doped AlAs layer.

05705831 / 1998 01 06 / Matsushita Electric Uemura, N. et al

Growth of ZnCdSe Using Compound Sources. According to one aspect of the invention, a crystal-growing method for forming a II-VI single crystalline semiconductor expressed by $Zn_{1-x}Cd_xSe$ (where $0 < x < 0.35$) is provided. The crystal-growing method includes a step of epitaxially growing the II-VI single crystalline semiconductor on a substrate by: supplying a II element Zn onto the substrate by using a molecular beam from a ZnSe compound source and a molecular beam from a Zn elemental source; supplying a II element Cd onto the substrate by using a molecular beam from a CdSe compound source; and supplying a VI element Se onto the substrate by using a molecular beam from a ZnSe compound source.

EP0817283 / 1998 01 07 / Matsushita Electric Ishibashi, Akihiko ; et al

GaN Growth. The method for producing GaN compound semiconductor includes the steps of: forming a polycrystalline nitride layer in a first temperature range on a substrate; forming a nucleus layer of GaN single crystals in a second temperature range on the polycrystalline nitride layer; growing the nucleus layer of GaN single crystals in a third tempera-

ture range such that resulting crystals of the nucleus layer of GaN single crystals come into contact with each other in a direction parallel to a surface of the substrate; and growing the nucleus layer of GaN single crystals in a fourth temperature range in a direction vertical to the surface of the substrate.

05714391 / 1998 02 03 / Matsushita Electric Omura, Kuniyoshi

II-VI Thin Film For A Photoelectric Or Solar Cell Device. This invention relates to a manufacturing method of a compound semiconductor thin film derived from a metal sulfide produced by thermal decomposition of a sulfur-containing metal organic compound, the compound containing at least one functional group having at least one metal atom selected from the group consisting of copper, zinc, cadmium, mercury, and lead, and the functional group also containing at least one sulfur atom. Since the obtained metal sulfides are of high-purity and dense, they can be utilized in various photoelectric devices. Particularly, the photoelectric conversion efficiency of a CdS/CdTe system thin film compound semiconductor solar cell can be improved remarkably by employing a layer made of a CdS thin film as a window of the solar cell.

05714006 / 1998 02 03 / Mitsubishi Denki Kizuki, H & Kajikawa, Y

Group III-Nitride Grown on CdTe. A method of growing a compound semiconductor layer includes epitaxially growing a III-V compound semiconductor layer including nitrogen for as the Group V element on a front surface of a semiconductor substrate of CdTe. Therefore, the atoms of the crystal lattice of the III-V compound semiconductor layer are periodically lattice-matched with the atoms of the crystal lattice of the CdTe semiconductor substrate, whereby the III-V compound semiconductor layer is epitaxially grown with high crystalline quality.

05704975 / 1998 01 06 / NEC Kobayashi, R & Hotta, H

Selective Growth Of Compound Semiconductor. Disclosed is a selective metalorganic vapor phase growth method of a group III-V compound semiconductor containing at least Al and In, in which a ratio of an HCl gas supply amount to a supply amount of a group III metalorganic material is set in a range of 0.01 - 0.3. Hence, a polycrystal density is decreased to ensure a selectivity, and a grown crystal composition can be controlled so as not to be excessive in the Al composition so that composition control can be done easily.

05714014 / 1998 02 03 / Showa Denko Horikawa; Shunji

Semiconductor Heterojunction Material. A semiconductor heterojunction material

The full text of any of these patents can be obtained by e-mail from MicroPatent for \$2.00 each.

See <http://www.micropat.com> and select the "PatentWEB™ option."

Materials cont.

includes a heterojunction configured by successively overlaying first, middle and third layers of semiconductor, some or all of the constituent elements of the first and third layers being different and the middle layer containing all elements contained in the first and third layers.

**05707446 / 1998 01 13 / Siemens
Volk, J & Lanig, P**

Device For Producing SiC Single Crystals.

SiC single crystals are produced in a reaction chamber, in which there is a seed crystal for the separation of a SiC single crystal from the gas phase. The reaction chamber is connected to a storage chamber, which is at least partly filled with a supply of SiC, by a gas channel with a predetermined cross-section for conveying the SiC in the gas phase. The supply of SiC is sublimated in a heating device and a temperature gradient is adjusted in the reaction chamber. It is, thus, possi-

ble to produce SiC single crystals with any desired cross-sectional area and of high crystalline quality and single-crystal yield, because the conveyance rate of the gas molecules can be precisely adjusted.

**05707900 / 1998 01 13 / Stanley Electric
Sano, M & Kawaguchi, K**

MBE Growth of II-VI Compounds. Known MBE methods of heat-treating semiconductor crystal of a group II-group VI compound for crystal growth are accompanied by a problem of releasing the component elements during the heat-treatment to produce a coarse crystal surface that adversely affects the subsequent crystal growth steps. According to the invention, this problem is eliminated by irradiating a substrate of a group II-group VI compound, specifically ZnSe, with Zn beams and Se beams depending on the vapor pressures of the elements between the respective starting points and

the respective terminating points to compensate the released Zn and Se so that consequently no oxide film is formed on the ZnSe substrate when the heat-treatment is completed to produce a plane crystal surface that is free from coarseness.

**05708301 / 1998 01 13 / Sumitomo Chemical
Iyechika, Y et al**

Electrode for III-V Semiconductor. The invention provides an electrode material having the low contact resistance against a III-V group compound semiconductor, thereby realizing a light emitting device having a high luminance and driven at low voltages. The electrode material of the invention is applied to a III-V group compound semiconductor, which is expressed as a general formula of $\text{In}_x\text{Ga}_y\text{Al}_z\text{N}$, and doped with p-type impurities. The electrode material comprises an alloy of Au and at least one metal selected from the group consisting of Mg and Zn.

Optoelectronics

**05710439 / 1998 01 20 / Furukawa Electric
Ohkubo; Michio**

OEIC. In an optoelectronic integrated device having an optical element section in the wavelength region of 1.33 to 1.55 μm and an electronic element section such as an HEMT integrated in a monolithic form on a GaAs substrate, the optical element section includes light receiving elements or light emitting elements, and an optical absorption layer of the light receiving element or a semiconductor layer forming an active layer of the light emitting element is formed of GaAsN-series compound semiconductor which is lattice-matching with the GaAs substrate, particularly, one of GaAsN, InGaAsN, InGaAsPN, GaAlAsN, InGaAlAsN, AlGaAsPN and InGaAlAsPN.

**EP0816826 / 1998 01 07 / GEC Marconi
Pye, John Albert**

Light Emitting Diode Assembly. A LED is mounted on the surface of a header and a photodiode is mounted on an orthogonal extension of the header such that some of the light emitted by the LED falls directly on the photodiode without having undergone reflection from other surfaces. The photodiode is used to sense the output intensity of the LED. The direct optical path between LED and sensor means that the photodiode output is insensitive to movement between the assembly and its surroundings, which movement can give rise to errors in prior art arrangements involving reflection from a further surface. The assembly may be used in an exhaust gas sensor in conjunction with a further photodiode.

**EP0817983 / 1998 01 14 / Hughes Electronics
Yap, Daniel**

**Substrate System For
Optoelectronic/Micro-wave Circuits.**
Abstract not available.

**05710440 / 1998 01 20 / Mitsubishi Cable
Okagawa, H et al**

InGaAlP Semiconductor Light Emitting Element. The present invention relates to a semiconductor light emitting element comprising an InGaAlP compound semiconductor as a material of a light emitting part. The InGaAlP compound semiconductor material is defined by the formula: $\text{In}_y(\text{Ga}_{1-x}\text{Al}_x)_1\text{-yP}$.

**05710441 / 1998 01 20 / Motorola
Ackley, D; Shieh, C; Lebby, M**

Microcavity LED with Photon Recycling. A microcavity LED with photon recycling including a substrate having at least one layer of material positioned thereon, and a first cladding layer, a second cladding layer and an active region sandwiched therebetween forming a mesa on the layer of material. The mesa has generally vertical sides and an upper surface with an electrically conductive and light reflective system positioned on the vertical sides of the mesa and partially covering the upper surface to form a first electrical contact for the LED, the electrically conductive and light reflective system defining a centrally located light emitting opening on the surface of the mesa, the mesa having a diametric dimension of the surface greater than one time larger than a diametric dimension of the opening.

**05705834 / 1998 01 06 / NASA
Egalon, C & Rogowski, R**

Increased Efficiency LED. In an LED a large portion of the light produced is lost due to total internal reflection at the air-semiconductor interface. A reverse taper of the semiconductor is used to change the angle at which light strikes the interface so that a greater portion of the light is transmitted.

**WO9805078 / 1998 02 05 / Nichia
Shimizu, Y. et al.**

Light Emitting Device And Display Device. A light emitting device provided with a light emitting element having a semiconductor light emitting layer and a photoluminescence fluorophor which absorbs part of the light emitted from the light emitting element and emits light having a wavelength which is different from that of the absorbed light. As a result, a white light emitting diode having high luminance and a light emitting characteristic which is not deteriorated even when the diode is used for a long period of time is obtained.

**EP0818696 / 1998 01 14 / NORTEL
Kovacic, Stephen J**

Hybrid Integration of OEIC Elements. A method and apparatus is provided for locating with improved vertical positioning accuracy a discrete element on a semiconductor optoelectronic integrated circuit. The method employs an etch stop layer located beneath a series of semiconductor layers.

Optoelectronics, cont.

**05707891 / 1998 01 13 / Sharp
Izumi, T; Harada, M; Inoguchi, Y**

Method of Manufacturing a LED. A method of manufacturing a light emitting diode, which includes the steps of bringing a semiconductor substrate of p-type or n-type into contact with a growth solution at a high temperature and thereafter, lowering the temperature so as to form a monocrystalline epitaxial layer of the same type as the semiconductor substrate on the semiconductor substrate, subsequently, further lowering the above temperature to form a first monocrystalline epitaxial layer of a reverse type to the epitaxial layer on the epitaxial layer and then,

cutting off the growth solution to form an epitaxial wafer as a result, a growth solution to contact the first epitaxial layer of a epitaxial wafer at a high temperature, and thereafter, the temperature is lowered to form a second monocrystalline epitaxial layer of the same kind and type as the first epitaxial layer on the first epitaxial layer.

**EP0817282 / 1998 01 07 / Sumitomo Electric
Tanaka, M & Sogabe, K**

Nitride Device. A semiconductor device comprising single crystal films consisting of at least one III-V nitride selected from the

group consisting of GaN, AlN, BN, InN, and single-crystalline alloys of these nitrides, the single crystal films being provided on a single crystal substrate of AlN either directly or through a low-temperature growth buffer layer of at least one III-V nitride. This semiconductor device is useful as a short-wavelength light emitting device capable of conducting continuous oscillation or a diode which is operated at a high temperature. The AlN single crystal substrate is matched in lattice constant and coefficient of thermal expansion with the single crystal film of a III-V nitride and the single crystal films is grown with good crystallinity on the substrate.

Laser Diodes

**05712188 / 1998 01 27 / ETRI
Chu, H et al**

Polarization-Controlled Surface-Emitting Laser Diode. A fabrication method of a surface-emitting laser diode which permits easy control of polarization in a desired direction is disclosed. The laser emits light from an emitting surface having a sidewall inclined with respect to a normal to the emitting surface. An ion beam is provided for etching the inclined sidewall of the laser and a substrate is positioned having a face which is formed into the emitting surface in the ion beam to cause the ion beam to intercept a sidewall of the substrate to form the inclined sidewall. The face is tilted about either one of a [110] or a [110] direction. An angle is formed ranging between 5.degree. and 45.degree. measured between the inclined sidewall and the [001] direction.

**EP0822630 / 1998 02 04 / Hewlett-Packard
Yang, Long ; Mars, Danny E.**

IR VCSEL on a GaAs Substrate. A VCSEL that generates light having a wavelength greater than one micron. The central quantum well region includes a quantum well layer consisting essentially of GaN_xAs(1-x). The quantum well layer may additionally include a fraction of indium to lattice match the quantum well layer to the substrate.

**05707892 / 1998 01 13 / LG Electronics
Yoo, Tae Kyung et al**

Method For Fabricating A Semiconductor Laser Diode. Includes the steps of forming a double hetero structured semiconductor layer on a substrate, forming a dielectric layer on the double hetero structured semiconductor layer, selectively etching the dielectric layer to expose a portion of the double hetero structured semiconductor layer, selectively removing the exposed semiconductor layer using the dielectric layer as a mask by liquid phase etching, and re growing a semiconductor layer on the etched portion by liquid phase epitaxy.

**EP0822628 / 1998 02 04 / Lucent
Technologies
Chakrabarti, Utpal Kumar et al**

Facet Coating for GaAs-Based Laser. A fully processed wafer is cleaved, typically in the ambient atmosphere, into laser bars, the laser bars are loaded into an evacuable deposition chamber and exposed to a H₂S plasma. Following the exposure, the cleavage facets are coated in the chamber with a protective dielectric (preferably silicon nitride) layer. The method can be practiced with high throughput, and can yield lasers (e.g., 980 nm pump lasers for optical fiber amplifiers) capable of operation at high power.

**05706304 / 1998 01 06 / Mitsubishi Denki
Ohkura, Yuji**

GaAs/AlGaAs Semiconductor Laser Device. The present invention relates to a 0.78 micron band buried ridge type semiconductor laser device and a method for fabricating the semiconductor laser device.

**05715266 / 1998 02 03 / Mitsubishi Denki
Takagi, Kazuhisa**

Semiconductor Laser. The present invention relates to an improvement in performance of a high output power semiconductor laser having two laser structures and a tunnel diode structure between these two laser structures.

**05706306 / 1998 01 06 / Motorola
Jiang, W; Ramdani, J; Lebby, M**

VCSEL with Distributed Bragg Reflectors for Visible Light. The VCSEL includes a semiconductor substrate having a first surface on which a first set of distributed Bragg reflectors are deposited. The distributed Bragg reflectors are made of alternating layers of InAlGaP and AlAs. An active region is disposed on the distributed Bragg reflectors with a subsequent of and active region and another cladding region. Another distributed Bragg reflector is deposited on cladding region.

**EP0820131 / 1998 01 21 / Motorola
Jiang, W ; Claissse, P; Lebby, M.**

Passivated VCSEL. A passivation layer having an optical thickness of an integral multiple of approximately one half of the wavelength of emitted light is disposed on a VCSEL.

**EP0818857 / 1998 01 14 / NEC
Sato, Kazuyoshi**

Laser with Stable Optical Output And Wavelength. A semiconductor laser unit includes a semiconductor laser device, a first temperature detector that detects a temperature in the vicinity of the semiconductor laser device, and an electronic cooler that heats or cools the semiconductor laser device. The output level and the wavelength of the oscillation light from the semiconductor laser are stabilized.

**WO9802944 / 1998 01 22 / W.L. Gore &
Associates, Peters, Frank, H.**

A VCSEL With Enhanced Second Harmonic Generation. A VCSEL is constructed so as to include a top mirror stack which is organized to be reflective of electro-magnetic radiation at the fundamental wavelength and partially transmissive of electromagnetic radiation at the harmonic of the fundamental wavelength.

**05708674 / 1998 01 13 / Xerox
Beernink, K et al**

Semiconductor Laser Formed By Layer Intermixing. A fabrication process and several structures for an index-guided laser diode or for a multiple wavelength laser array containing stacked semi-conductive active layers with quantum wells. The laser wavelength is varied laterally by effectively inactivating quantum wells which have transition wavelengths longer than that desired in the selected portion of the device. The quantum wells are inactivated by intermixing them with the surrounding high band gap semiconductor layers.

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 Submission Deadline: November 3, 1997

Contact: Kuohsiung Li, Confer. 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 Submission 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:
ecs@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 Submission 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 Submission Deadline: February 16, 1998

Ferdinand-Braun-Institut
für Höchstfrequenztechnik
Rudower Chaussee 5
D-12489 Berlin Germany
TEL [49] 30 6392 2690
FAX [49] 30 6392 2685
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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 Submission 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 Submission Deadline: January 15, 1998

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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 Submission 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
or simc@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

European MRS 1998 Spring Meeting

The 1998 E-MRS Spring Meeting will be held June 16 - 19, 1998 in Stasbourg, France. Symposia include

Growth, Characterization and Applications of Bulk II-VI's; Thin Films, Epitaxial Growth and Nanostructures; and Nitrides and Related Wide Band Gap Materials.

Contact: E-MRS
BP 20
67037 Strasbourg Cedex 2
France
TEL [33] 3 88 10 65 43
FAX [33] 3 88 10 62 93
Net or Web:
emrs@phase.c-strasbourg.fr

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 Submission Deadline: December 1, 1997

Contact: Cherrie Summers
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TEL [44] 1222 874000
FAX [44] 1222 874421
NET or WEB:
summersc@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 Submission 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 relat-

ed to physical properties, crystal growth, epitaxy, doping, processing, device manufacturing and applications of nitride semiconductors.

Abstract Submission 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 Submission Deadline: February 6, 1998

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1998 IEEE Photovoltaics Specialist Conference

Wien, Austria July 6-10, 1998

Abstract Submission Deadline: December 1, 1997

Contact: JRC-Ispira
WCON2
Ispira (VA) Italy I-21020
TEL [39] 332 785 885
FAX [39] 332 789 646
Net or Web: wcon2.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 in 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 Submission 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 Submission 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@mbe-x.unice.fr
http://www.crhea.unice.fr/mbe-x

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.

This meeting provides a forum for technical communication focused on the needs and interests of bipolar and BiCMOS engineers. Papers covering the design, performance, fabrication, testing and application of bipolar, BiCMOS and BiFET ICs, bipolar phenomena, and discrete devices are solicited.

Abstract Submission Deadline: March 16, 1998

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 in 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 Submission 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 Conference

NAMBE-17 will be held October 4-7, 1998 at Pennsylvania State University (State College, PA). Abstract Submission 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; materials and processing; design and modeling; long & short wavelength laser; high power & high speed laser; VCSELs, novel laser structures; and integration and packaging.

Abstract Submission 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 (Including GAAS '98)

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 Submission 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 sur-

faces. 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 submission deadline: May 15, 1998

Contact: Mariano Gonzalez
 ETSI Telecomunicación-UPM
 Ciudad Universitaria
 28040-Madrid, Spain
 FAX [34] 1 336 73 23
 Net or Web: mariano@die.upm.es

If you would like your conference to be included in future issues, send the appropriate information by E mail to

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 by FAX to [1] 978 750 9740,
 attention "Calendar"

Contributions must be received by April 3
 to appear in our next issue.



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Applications are invited for a post-doctoral position in the area of compound semiconductor devices and materials. Research activities include material growth by Molecular Beam Epitaxy, material characterization, and device fabrication. Candidates should contact or send a resume with a list of publications, a single page summary of research interests, along with the names and addresses of three references to:



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

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Contact: Prof. Gary W. Wicks
The Institute of Optics
University of Rochester
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wicks@optics.rochester.edu

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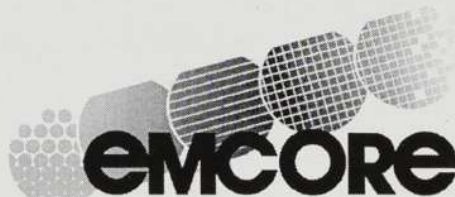
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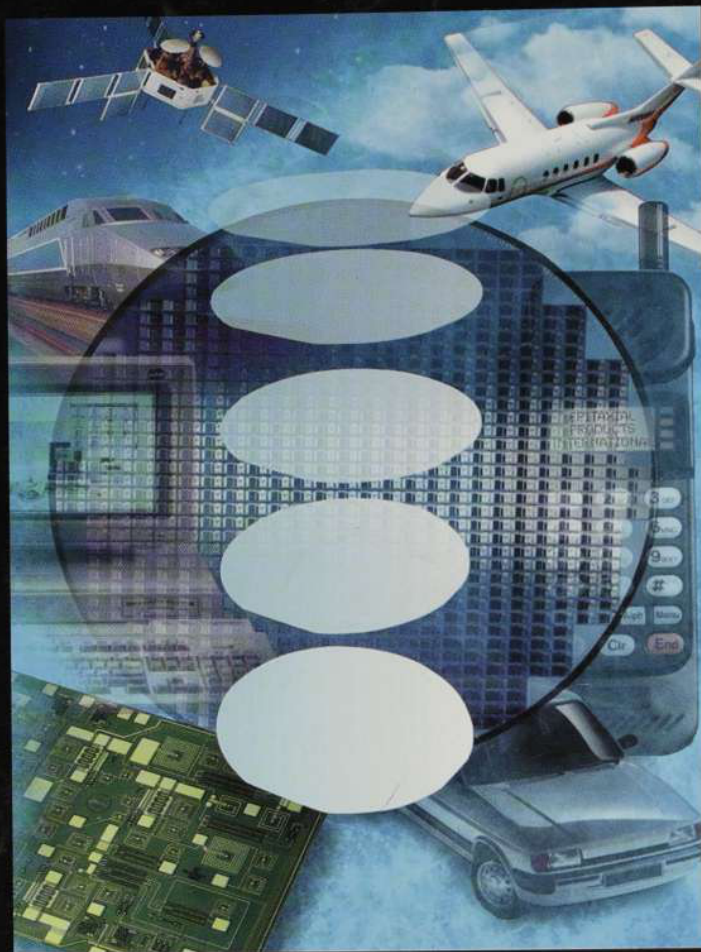
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