



# COMPOUND

## SEMICONDUCTOR

April 1999

Volume 5 Number 3

# Commercial VCSEL

## Manufacturing

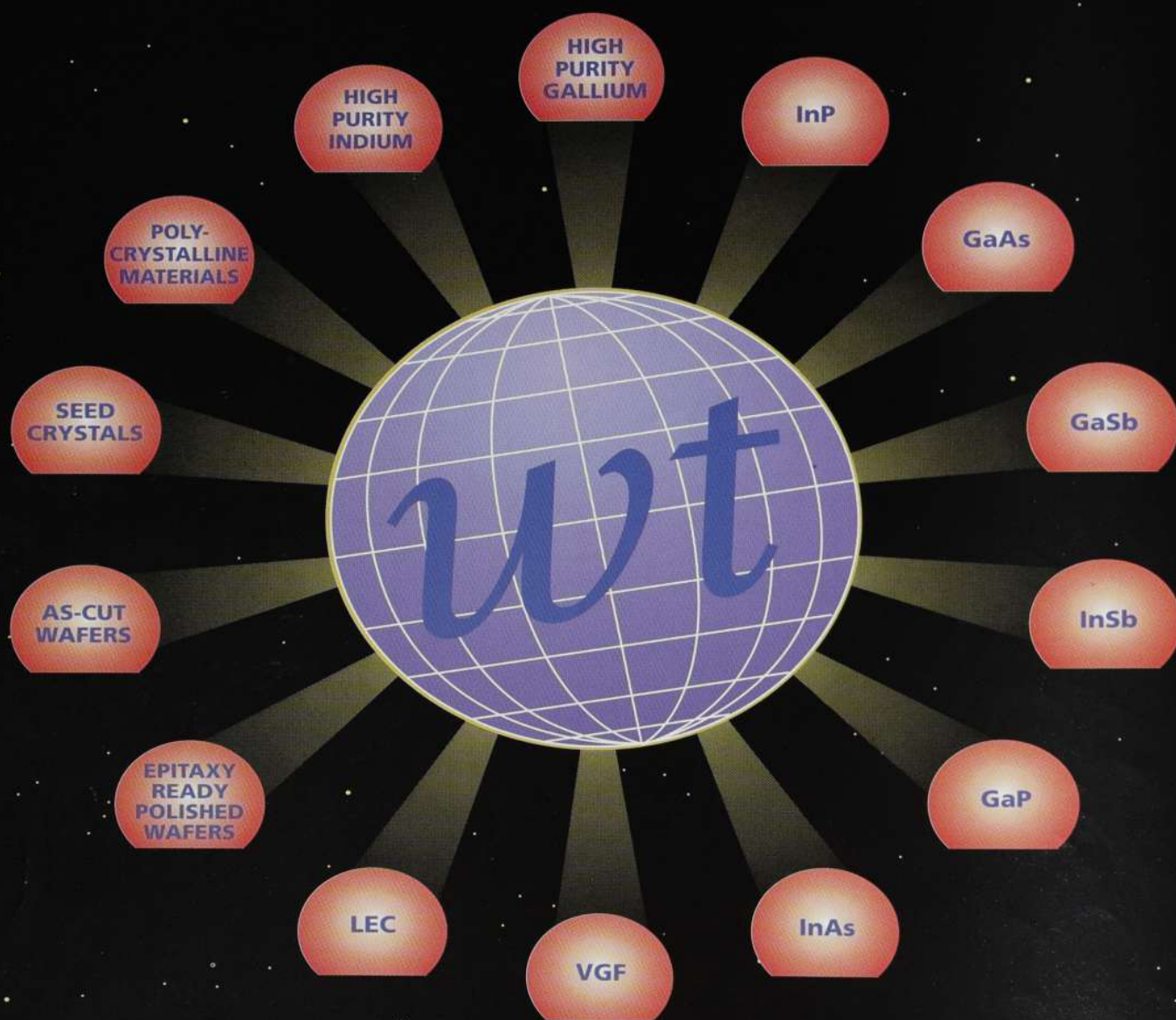
### Trends in InP Wafer Sizes

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- Market forecast for visible LEDs
- Do we need a roadmap?
- Optical Fiber Conference report



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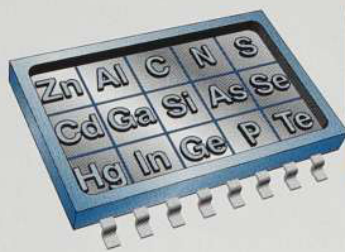
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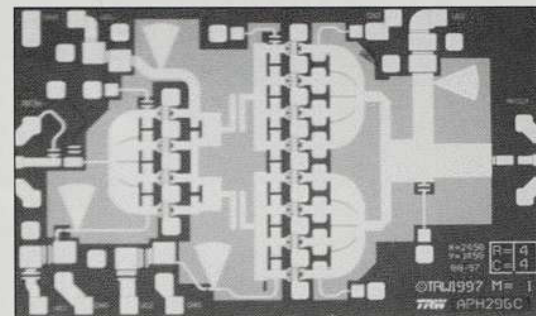
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MMICs fabricated from InP-based HEMTs have achieved outstanding high frequency performance, and will soon be used in a variety of military and commercial millimeter-wave applications. This MMIC, fabricated by TRW, demonstrated 427 mW of output power at 95 GHz. For further details, see page 28. [Photo courtesy of TRW Electronics & Technology Division].

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# COMPOUND SEMICONDUCTOR

**Compound Semiconductor**  
is published nine times yearly by

Franklin Publishing  
163 Cabot Street  
Beverly, MA 01915 USA  
TEL [1] 978 927 9994  
FAX [1] 978 927 9893  
Individual annual subscription  
price: \$90 U.S., \$115 foreign.  
Library rate: \$300 U.S. and foreign.

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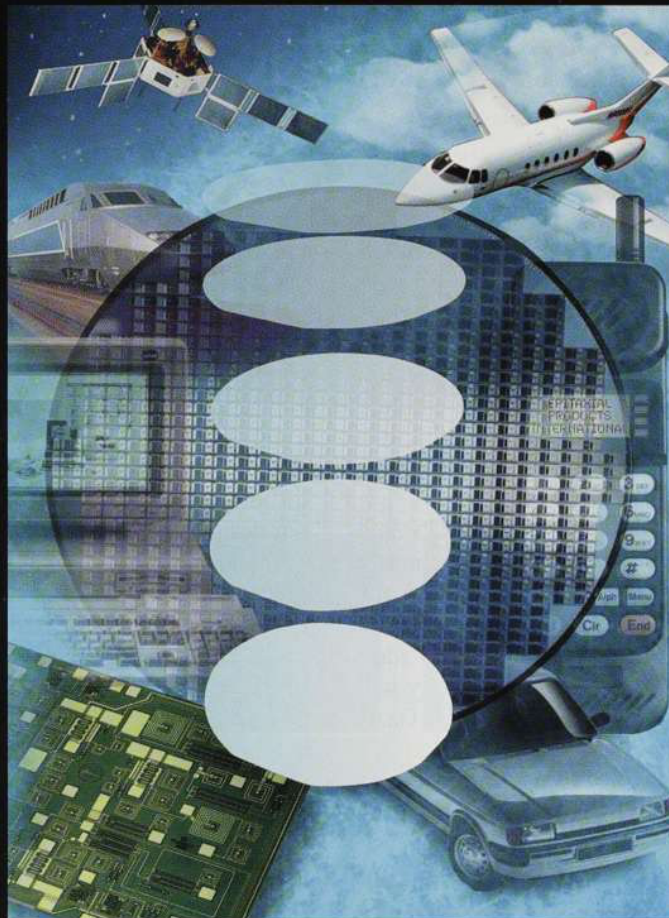
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## Alpha Industries Plans To Introduce HBT Products by Summer

Alpha Industries, Inc. has announced its aim to begin manufacture of GaAs-based HBT ICs for wireless applications within the next few months. Teaming up with Alpha are Infinesse Corporation, a fabless product designer and development house, and Network Device, Inc. (NDI), a new GaAs foundry with HBT fabrication expertise.

David Aldrich, Vice President and General Manager of Alpha's Wireless Semiconductor division, stated: "Alpha has made a major commitment to HBT. We intend to work with our partners to bring HBT products, including power amplifiers, to market as rapidly as possible, and we expect to have our first HBT products ready for market this summer."

Alpha already manufactures GaAs-based PHEMTs and FETs for RFICs used in a wide range of wireless applications.

"As we work with Infinesse and Network Device on the design and manufacture of new HBT products, we also plan to bring HBT process technologies into our GaAs fab as an additional source for high-volume production. HBT technology will complement our existing strength in GaAs PHEMT and GaAs MESFET," says Aldrich.

The addition of HBTs allows Alpha access to those customers who have opted for HBT technology, says Jean-Pierre Gillard, Vice President of Marketing and Business Development. Gillard is convinced GaAs HBT offers the best available performance for wireless applications where linearity is critical. "There is increasing acceptance of the CDMA standard into the third generation of wireless applications, and that will require very linear channels. We believe that HBT technology has a strong future."

### Outsourcing

Why has Alpha decided to outsource? Gillard says that the main reason is the time needed to gain the necessary HBT experience. "We want to have products available that we can market in a reasonable time, and so we elected for alliances. These commercial markets are very dynamic," he added, "and therefore it is very useful to have access to external capacity."

The supply arrangement is part of a broader agreement for Alpha and NDI. "What we're looking at with NDI is a way to second source each other," says Gillard. "That is not limited to HBTs, but will include MESFET and PHEMT processes." Dr. Ding Day, President and CEO of NDI, said: "As a new independent open foundry, we are excited about the opportunities both to support Alpha's HBT foundry needs and to second source Alpha's high-volume FET and PHEMT processes."

NDI, founded in late 1996, already offers a generic HBT process for highly linear power applications based on C-doped MOCVD material. They will also enter into an exclusive agreement to produce MESFET and PHEMT technology for Alpha

based on its designs. The 40-strong workforce is headquartered in Sunnyvale, California and designs, fabricates and tests its wafers within its own 27,000 sq.ft. manufacturing facility. The fab can support volume processes with 250 4-inch GaAs wafers per week.

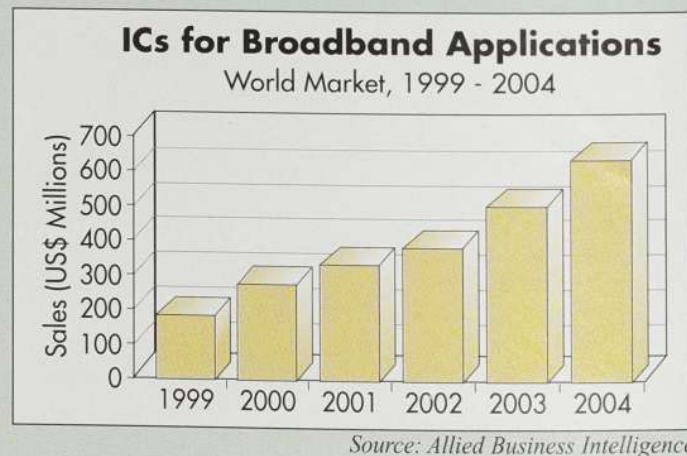
Infinesse started up in Los Angeles in 1991 to develop telecommunication systems and GaAs HBT amplifier RF components. Its 14 employees are located at its headquarters in Los Angeles and its other site in San Jose. President Michael Kim said: "Alpha is a very good teaming for us because it has established customers and a good awareness of how HBT will fit into its business segment. And of course, NDI offers a fast way to get our designs validated."

"Infinesse has a great deal of experience in design work and processing, particularly for linear applications," said Jean-Pierre Gillard, "which is why we decided to work with them."

### IC Chipsets for Broadband Applications to Grow 30% Annually Through 2004

The IC market for "wired" broadband applications (cable modems, ADSL, HDSL, and VDSL) is expected to grow from \$174 million in 1999 to \$638 million in 2004, according to a new report on broadband ICs recently released by Allied Business Intelligence (ABI). The greatest share of this market in 1999 is attributed to cable modems, with 43% of the market. ABI reports that "perhaps surprisingly", GaAs ICs represent 5% of the market for cable modem ICs. ABI predicts greater penetration in this sector, especially for use in the front end.

By the year 2004, ABI predicts that cable modems will have 28% of the market, having been edged out for the lead by ADSL, which will have a 30% market share. HDSL and VDSL are anticipated to hold a 26% and 16% share, respectively.





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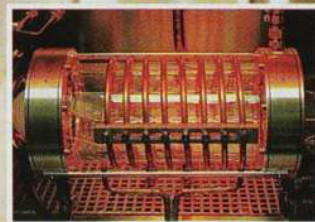
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## Compound Semiconductors Well-Represented Among New IEEE Fellows

The IEEE recently elevated 239 members to "Fellow" status. The list includes several prominent members of the compound semiconductor community. Here is a partial list:

- **Masayuki Abe**, Fujitsu Laboratories Ltd., Atsugi, Japan, for contributions to III-V compound semiconductor optoelectronic and high-speed devices.
- **Ilesanmi Adesida**, University of Illinois, Urbana, IL, for contributions to compound semiconductor devices and circuits.
- **Isamu Akasaki**, Meijo University, Nagoya, Japan, for contributions to and leadership in research and development of group III nitride semiconductor materials and devices.
- **Fazal Ali**, NOKIA Mobile Phones, San Diego, CA, for contributions to the design and development of monolithic microwave integrated circuits and providing leadership in commercial applications of the same.
- **Raymond L. Camisa**, Sarnoff Corporation, Princeton, NJ, for contributions to the development of microwave GaAs transistor power devices and circuits.
- **Hong Kyun Choi**, MIT Lincoln Laboratory, Lexington, MA, for contributions in the development of antimonide-based mid-infrared quantum-well diode lasers.
- **Robert Joseph Deri**, Lawrence Livermore National Lab., Livermore, CA, for contributions to photonic devices and integration on compound semiconductors.
- **Mitra Dutta**, U.S. Army Research Office, Research Triangle Park, NC, for contributions to heterostructure-based optoelectronic and electronic devices.
- **Lawrence S. Goldberg**, National Science Foundation, Arlington, VA, for leadership in formulating research programs in the fields of lasers and optoelectronics.
- **John Aiden Higgins**, Rockwell International Science Center, Thousand Oaks, CA, for contributions to development of GaAs transistor technologies for microwave and high speed integrated circuits.
- **Eli Kapon**, Swiss Federal Institute of Technology, Lausanne, Switzerland, for contributions to semiconductor guided wave optics, phase locked laser arrays, and quantum confined lasers and heterostructures.
- **Michael R. Melloch**, Purdue University, West Lafayette, IN, for contributions to silicon carbide device technology.
- **Yael Nemirovsky**, Technion-Israel Institute of Technology, Haifa, Israel, for contributions to compound semiconductor devices and technology.
- **Arto Veikko Nurmikko**, Brown University, Providence, RI, for contributions to laser science and optoelectronics devices.
- **Stella W. Pang**, University of Michigan, Ann Arbor, MI, for identification and removal of process-induced damage in Si and compound semiconductor devices, and advancing the science of nanofabrication technology.
- **Ken-ichi Sato**, NTT Optical Network Systems Labs., Yokosuka-shi, Kanagawa, Japan, for contributions to the architecture and technologies of Asynchronous Transfer Mode networks and photonic networks.
- **Andrew Jules Steckl**, University of Cincinnati, Cincinnati, OH, for contributions to focused ion beam implantation and semiconductor device fabrication.
- **Michael Bernard Steer**, North Carolina State University, Raleigh, NC, for contributions to the computer aided engineering of non-linear microwave and millimeter-wave circuits.
- **Dwight Christopher Streit**, TRW, Redondo Beach, CA, for contributions to the development and manufacturing of heterojunction materials and devices.
- **Shoichi Sudo**, NTT Opto-electronics Labs., Ibaraki-Ken, Japan, for contributions to optical fiber and laser diode technology.
- **Ruediger Vahldieck**, Swiss Federal Institute of Technology, Zurich, Switzerland, for contributions to the modeling and design of microwave and millimeter-wave circuits.

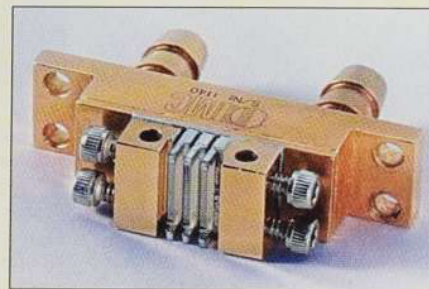
## Industrial Microphotonics Offering High Power Lasers, Foundry Services

**I**ndustrial Microphotonics Company (IMC) of St. Charles, Missouri recently announced the availability of a new family of high power lensed laser arrays, consisting of stacks of 2 to 15 bars mounted on a water-cooled heat exchanger. CW powers from 32W to 320W and pulsed peak powers from 80W to 600W are possible.

IMC is a wholly owned subsidiary of Cutting Edge Optronics, a manufacturer of diode-pumped solid-state lasers (DPSSLs). According to Theodore Konopelski, Director of Marketing, IMC counts its parent as their largest customer, but the operation is not captive. The company sold over \$2.5 million in semiconductor laser products last year, with "a good portion" going to outside customers. Many of the employees at IMC and its parent company worked at McDonnell-Douglas Corporation back in the days when it had a III-V semiconductor effort in the St. Louis, Missouri area.

Konopelski says IMC's strengths are its "uniquely practical approaches to processing and packaging". IMC purchases its epiwafers from outside suppliers. "We are really pleased with the quality of our suppliers," said Konopelski. "There are now several good sources of epiwafers for lasers - and that was not always the case."

IMC offers lasers operating at wavelengths from 791nm to 981nm. Konopelski reports that "the majority of our business is 810nm lasers for pumping, but we are also seeing a lot of interest in other wavelengths and other applications as well." Laser bars are available in output powers up to 40W CW. The company also produces arrays, and has begun offering foundry services.



Industrial Microphotonics



## Suppliers Expanding

**Furukawa** announced in March that it will increase production of **high purity arsenic and GaP polycrystal** in fiscal 1999. The company plans to expand monthly production of the materials at its Iwaki plant from 5.0 to 5.6 tons and from 500 to 600kg, respectively. Furukawa predicts orders for GaP polycrystal will pick up from June. The company says it has a 70% share of the global high purity arsenic market, and it is also the leader in the GaP polycrystal market with a 25% share.

And if you are going to have more arsenic, you'll be needing some gallium to go with it. **Dowa Mining** says it is planning to **double high purity gallium production** to 100 tons. The company will invest 1.5 billion yen (\$12.3 mil) to build a refining facility on a site adjacent to its wholly owned subsidiary Dowa Semiconductor in Akita. The facility will be commissioned in April. Dowa says it has a 40% share of the Japanese market for high purity gallium, and a 27% share of the global market. The company also plans to double GaAs wafer production capacity, and is investing 1 billion yen (\$8.1 mil) in equipment and facilities for producing 6-inch GaAs wafers.

**Sumitomo Chemical** recently completed construction of a new facility at its Chiba plant that will produce 4- and 6-inch MOVPE-grown epitaxial wafers. The 3 billion yen (\$24.5 mil) facility has an annual output capacity of 100,000 wafers. The company is aiming for annual sales of 5 billion yen (\$43.1 mil) two to three years from now.

## Exploring New Applications

**Asahi Chemical Industry** says it will enter the rapidly-growing market for **automotive Hall elements**. The company has started sampling power window motor Hall elements to auto parts makers. Asahi says they can also be used in wheel speed sensors, camshaft sensors, air conditioner fans, and throttle position sensors. The company's subsidiary, Asahi Kasei Electronic, already produces more than 1.2 billion III-V-based Hall sensors a year at its Nobeoka plant, and it is expected to boost the capacity to 1.5 billion units within two years. Asahi intends to more than double sales from the current 10 billion yen (\$87.7 mil) by 2005 by cultivating the automotive demand.

**Mitsubishi Chemical** says it has developed a technology to **grow agricultural produce using LEDs** to stimulate photo synthesis and speed up growth. The company claims that the use of the LED helps cut lighting cost to about 1/5 the cost of using conventional lighting lamps, which together with an airconditioning cost account for 40% of the cost of running an indoor vegetable growth operation. Mitsubishi Chemical plans to team up with electronic component makers to commercialize an "LED vegetable plant" and market it to food processing companies and large-scale farms.

## New Devices

**Matsushita Electronics** reports that it has developed a **GaAs direct orthogonal modulator IC for use in wideband CDMA base stations**. The 1.2x1.5mm device integrates about 1,000 elements including newly developed GaAs FETs which can operate at 100MHz. Slated to be commercialized during fiscal 1999, the IC can directly modulate digital signals into 2.1GHz frequencies.

Matsushita also recently announced sample shipments of **four new GaAs power amps for base stations**. The 5/20/60W amps are sample-priced at 30,000 yen (\$260.87), and the 120W amp is sample-priced at 50,000 yen (\$434.78). The company will begin volume production at its Okayama plant in October.

**Mitsubishi Electric** recently announced that it has developed a **GaAs power amplifier MMIC for use in CDMA handsets**. The MMIC, which operates on 3V and draws 560mA, is available for the 1850-1910MHz and 1750-1780MHz bands. The device measures 6.1x7x1.1mm and is available in a small leadless package.

**Oki Electric** has developed and begun sampling a HEMT-based electromagnetic field absorption (EA) **modulator driver IC** for use in 10Gbps WDM optical communications systems. It achieves rising and breaking times of 30ps and a maximum output amplitude of 3V and consumes 1.2W or less when operating on 5V. Production quantities will be available in April.

### Removal of Hazardous Gases Passive Dry Bed Chemisorption



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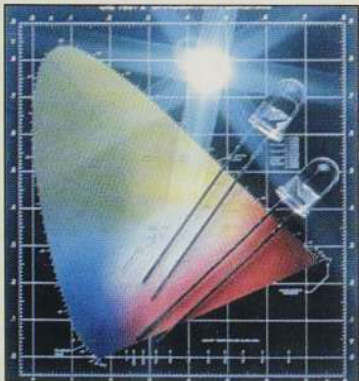
## HP Introduces White LEDs

**H**ewlett-Packard Company has introduced its first white-light LED products. The new lamps use blue-emitting InGaN on sapphire LED chips, inside a package that is coated with a yttrium aluminum garnet (YAG) inorganic phosphor. Luminous intensities are 2 cd at a 15° viewing angle, and 0.8 cd for a 30° viewing angle.

"Traditional colored LEDs have proven themselves in signage, as indicator lights and in automotive lighting," said Frank Steranka, Solid State Lighting business unit manager in HP's Optoelectronics division. "The white LED is important in expanding LED applications toward general lighting, where the opportunities are enormous."

HP's long term aim is to begin to address this market, confirms Doug Silkwood, marketing manager of the Solid State Lighting unit. "We anticipate this being an evolutionary process taking 5 to 10 years." In the near term, he says, applications will be for landscape lighting, flashlights, decorative and architectural lighting, and general purpose indicators. The initial product release is for 5 mm (T-1 3/4) devices, and other packages will be available by the summer.

The new device produces white light with nominal values of  $x=0.31$ ,  $y=0.32$  on the CIE chromaticity diagram. The color rendition index (CRI) is 75 and the color temperature is 6,500K. Prices for quantities of 100,000 begin at 95 cents.



Hewlett-Packard

## Cree Research Claims Top Spot In High Volume Blue & Green LED Production

**C**ree Research reports that it has become the highest volume producer of blue and green LEDs in the world. The company shipped more than 20 million units in March, nearly three times Cree's production for the comparable period last year. The company says it has at least ten high-volume customers worldwide, and at least five of them received "multi-million unit" shipments in the March quarter.

Bob Steele, Director of Optoelectronic Services for Strategies Unlimited, said, "Having recently completed a survey of the nitride LED manufacturers, we believe that this run rate establishes Cree's position as the world's largest producer of nitride based LEDs."

But Naoki Yoshida, Sales Manager for Nichia America Corporation, would seem to disagree. "Our production volume is around 30 million pieces per month in total now," he said. That figure includes blue and green LEDs as well as white and red InGaN-based devices. Yoshida says that while direct comparisons are difficult, "as the manufacturer that first introduced InGaN LEDs to the market, we continue to improve our products to expand the high brightness LED markets".

The other leading high volume producer is Hewlett-Packard. Representatives of the company don't dispute that Cree is shipping more units than they are. However, they do emphasize the differences in their strategies. Cree sells their blue and green LEDs as unpackaged die, whereas HP and Nichia ship finished devices. Accordingly Cree receives significantly less revenue per unit, meaning they are probably not the top producer in terms of revenue. According to HP's Doug Silkwood, "Cree is not a useful benchmark for HP, as we manufacture higher performance materials and sell into different markets such as outdoor applications. HP is making unprecedented investments in InGaN R&D, packaging technology and production to become the market leader."

### The Advantages of SiC

None of which diminishes the fact that Cree's unique strategy for addressing the blue and green emitter market has been remarkably successful. Commenting on reaching the 20 million units per month level, Neal Hunter, Chairman and Chief Executive Officer stated, "We are excited to meet this long-standing internal milestone and it unquestionably validates the fundamental contribution SiC has made to the nitride based LED industry. Our LED chips continue to enable a broadening customer base to expand the marketplace with a wide variety of new and exciting applications."

Cree says their competitive advantage is derived from the use of its proprietary conducting SiC substrate. The differences between their GaN-on-SiC LEDs compared to GaN LEDs utilizing an insulating sapphire substrate include:

- A vertical chip structure resulting in simplified LED assembly;
- A smaller chip size; and
- The highest ratings in the industry for electrostatic damage (ESD) resistance, which reduces the development costs and timing required to tool a product line to use nitride based LEDs.

Mike Dunn, recently appointed General Manager of Cree's Optoelectronics business unit commented, "Until very recently, industry experts were not fully aware of the immense contribution Cree has been making to this market segment."

### Ships 3" SiC Crystal To Faux Gemstone Producer

In other news, it was recently revealed that Cree has shipped a 3 inch diameter crystal to faux gemstone producer C3 under the previously announced development program between the two companies. C3, which is closely allied with Cree, is developing the 3C polytype of SiC, known as moissanite, as a high quality "fake diamond" for costume jewelry.



The delivery of the 3 inch crystal was said to be significant because it demonstrates Cree's ability to produce a large diameter material of acceptable quality with a large percentage of useable material. Future development efforts will focus on moving this achievement to a repeatable process and finally into a manufacturing process. The 3 inch crystal can produce approximately twice as many moissanite gemstones as a 2 inch crystal with the same percentage of useable material.

As a result of reaching this milestone, C3 began discussions with Cree regarding adding crystal growth equipment. A portion of any new crystal growers may be dedicated to three-inch crystal growth.

Jeff N. Hunter, chairman and chief executive officer of C3 (and brother of Cree CEO Neal Hunter), said, "We are encouraged by reaching this milestone in the development program. Once this achievement is moved to a repeatable process our ability to produce high volumes of lower cost moissanite gemstones will be greatly enhanced."

### Briefly...

**Sterling Semiconductor** recently announced that it has begun shipping 2 inch dia. SiC substrates in both 4H and 6H polytypes. "Our 2 inch wafer product is the result of Sterling's commitment to R&D aimed at expanding wafer diameter to make SiC a mainstream semiconductor material," said Gene Lewis, Sterling's Chairman and CEO. "Two-inch wafers are suitable for large-scale production of semiconductor devices. Our R&D plan is now aimed at 3 and 4 inch wafers, which many customers will require in two to three years. At the same time, we recognize that many customers will want to continue to purchase our 35 mm product, as they scale up their development programs." Sterling says these products are a direct result of the joint R&D program established last year with ATMI.

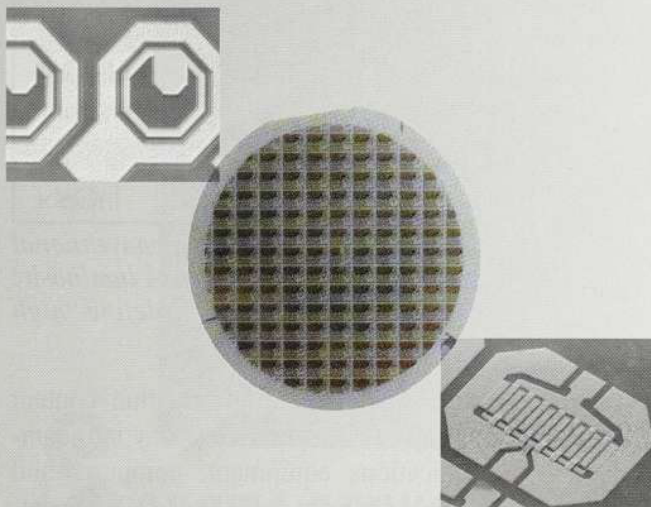
The **US Ballistic Missile Defense Organization** (BMDO) is planning to fund several projects in the area of wide bandgap semiconductors. Up to \$9.8 million will be spent over the next 12 - 15 months for research in several areas, including:

- GaN single crystal material for substrates exceeding 1 inch in diameter;
- Uniform 4 inch dia. SiC substrates for GaN R&D;
- Wide bandgap power amplifier device structures for a 20 W power amplifier for X-band radar;
- GaN wide bandgap device packaging and performance testing for high temperature operation;
- Performance testing of GaN power amplifier devices in diverse temperature domains.

Announcements of awards are expected within the next few months.

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## The Market for Visible LEDs

RICHARD DIXON

There's good news if you're in the business of producing LEDs: in the next five years, the market for LEDs as illumination sources and in displays will grow from its current level of \$1.9 billion to \$3.16 billion by 2003. Overall, the market will expand at a rate of 10.4% per year, according to a recent forecast on future markets for visible LEDs by market research company Strategies Unlimited.<sup>[1]</sup> The document predicts steady gains in traditional applications combining with rapid growth in new ones for high brightness LEDs.

### World LED Suppliers

Japan sells 54% of all of the visible LEDs produced, largely supplying a domestic market, with 7 of the top 10 world companies by shipment value (Figure 1). Nichia's position as the number five supplier is surprising; the company has come very far, very fast since they introduced blue LEDs five years ago. In contrast to the other established big suppliers, Nichia only makes GaN based LEDs. Clearly, despite the high prices of these products (as much as \$1 per piece compared to \$0.25 or less for high brightness LEDs from other leading manufacturers for other colors), the demand for blue and green is driving Nichia's commercial success.

According to Strategies Unlimited, the remaining world market is shared between the Asia-Pacific region, the United States and Europe. Hewlett-Packard (HP) is not only the top US supplier, but also the world leader.

In the Asia-Pacific region, Taiwan-based Lite-On Electronics leads Everlight

### Top 10 LED Suppliers

|    |                     |         |
|----|---------------------|---------|
| 1  | Hewlett-Packard     | USA     |
| 2  | Stanley Electric    | Japan   |
| 3  | Siemens             | Germany |
| 4  | Matsushita Electric | Japan   |
| 5  | Nichia Chemical     | Japan   |
| 6  | Lite-On Electronics | Taiwan  |
| 7  | Toshiba             | Japan   |
| 8  | Rohm Co. Ltd.       | Japan   |
| 9  | Sharp               | Japan   |
| 10 | Citizen Electronics | Japan   |

Source: Strategies Unlimited

### LED Supply by Region

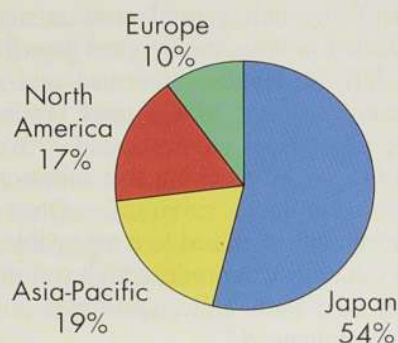


Figure 1. Top ten visible LED suppliers in terms of revenue. More than half of all LEDs are produced in Japan, which has 7 out of the top 10 companies.

Kingbright and a number of other LED companies. In Korea, Optel Semiconductor and Samsung are among the key names.

Finally, Siemens and Vishay Telefunken are the major suppliers in Europe, which accounts for 10% of the world market, says the report.

### Conventional "Low Brightness" Devices

In general, visible LEDs can be divided into two categories for 'conventional' or low brightness, and new high brightness LEDs. These can be distinguished by output, which for high brightness LEDs typically means upwards of 1 cd (see Table).

According to the Strategies Unlimited report, 77% of the market is for conventional LEDs (see Figure 2). These relatively simple devices are characterized by typical outputs of a few mcd to tens of mcd. They are found in cell phones, as indicator lamps for industrial instruments containing simple on/off

| Color            | Conventional | High Brightness   |
|------------------|--------------|-------------------|
| Red              | GaAsP        | AlGaAs<br>AlInGaP |
| Orange           | GaAsP        | AlInGaP           |
| Amber/<br>Yellow | GaAsP<br>GaP | AlInGaP<br>InGaP  |
| Green            | GaP          | InGaP             |
| Blue             | -            | InGaP             |

Materials used to produce conventional and high brightness LEDs. A luminosity of more than 1 cd is used to define "high brightness".

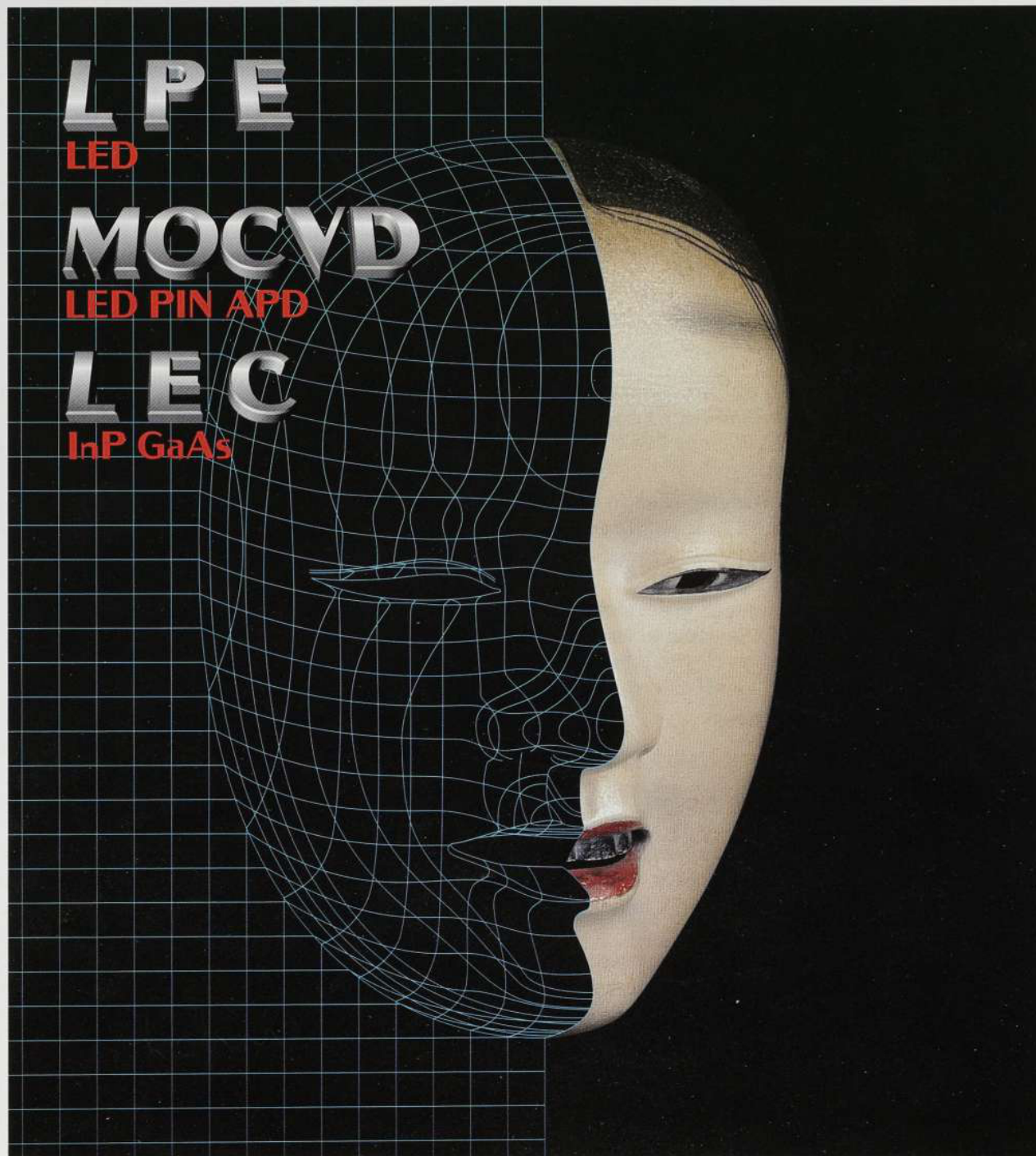
lamps and higher information content displays. Others find their way into communications equipment, computer and office equipment including local area networks, and, of course, consumer products. This market is expected to grow by around 7.1% annually to \$2.09 billion by 2003.

According to Strategies Unlimited's Robert Steele, growth for conventional LED markets is steady and driven by electronics markets. "Conventional LEDs

[1] "Visible LED Market Review and Forecast - 1999" is available from Strategies Unlimited, Mountain View, CA. Tel: [1] 650 941-3438; Fax: [1] 650 941-5120; Web: www.strategies-u.com.



# *Art of Technology A Bright Future Lies Ahead*



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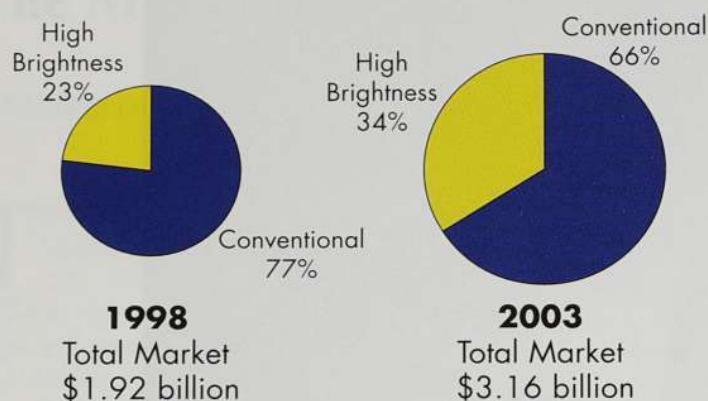
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## Visible LED Market Growth



Source: Strategies Unlimited

**Figure 2.** Although the majority of LEDs are conventional low brightness devices, the market for high brightness LEDs is rising sharply and is expected to exceed \$1 billion by 2003.

are found in just about anything electronic, ranging from an indicator light up to an alpha numeric display," he says. "Most of these markets are well served by conventional LED devices, they don't need to have high brightness."

Conventional LEDs are based on homojunction devices that can be relatively inexpensively produced using the older LPE and VPE growth techniques.

## Growing Markets for High Brightness Applications

Last year, sales for high brightness LEDs jumped by more than 60% to \$440 million. According to the report, the annual growth rate for high brightness LEDs will continue to rise at 19.5%, more than double that for conventional LEDs. This will increase their market share to 34%, or more than \$1 billion by 2003 (see Figure 2).

The majority of this demand has been for devices based on AlGaAs, AlInGaP and InGaN. Full color signs are increasingly being used by sports arenas in the US, taking advantage of lower power requirements, reliability and a weight advantage. Aircraft runway indicators, advertising displays, traffic warning and information signs which need to be seen in daylight, and lamps for automobiles all benefit from high brightness LEDs.

The automobile market for LEDs is potentially very large. Siemens is using packages based on Cree Research's blue LEDs to supply the interior lights for several major German car manufacturers. Steele agrees that the German auto manufacturers have been quick to introduce the new technology. "High brightness LEDs have really taken off in both interior and exterior lighting, partly for styling reasons, but also for reliability reasons. If a bulb goes out, it is very expensive to take the dash apart to replace it."

Another big market is for high mounted rear stop lamps. HP dominates this market, supplying 9 out of 10 cars, according to

a recent report by market research company Frost & Sullivan. Its SnapLED device package needs only half the LED units of a conventional system. On some new high price US sports models, exterior tail lighting systems that use AlInGaP to produce a 626 nm LED red emitter, and an AlInGaP device that operates at 615 nm and appears orange-red are being used. In Europe, the 590 nm wavelength amber color is standard.

In the US, the traffic signal market is being taken seriously, not least because of considerable savings in maintenance, and incentives are also offered by power companies to employ LEDs. Last year many cities in California began replacing their intersection stop lamps with LED versions which cost on average \$200. (Currently, the green "go" lamp, at around \$400, is still too expensive to use as a replacement, according to Strategies Unlimited.) Pedestrian signals that use about 25 orange-colored LEDs are also becoming common in American cities.

In Japan, however, the use of LEDs in traffic signals is still slow in coming. "Japan is more interested in advertising and outdoor signs, and big full color signs are particularly popular in both Japan and Asia," says Steele. "These were previously made from the more conventional LEDs, which rely on a narrower forward viewing angle to achieve the desired output." Much of the outdoor LED use in Japan has been in the form of traffic projects to stimulate the domestic market, he adds.

## What About White?

In the past 6 months there has been great interest in the development of white LEDs for general illumination. LEDs are as much as 3x as efficient as incandescent sources and last up to 10x as long. The problem is they are still too expensive for general use. Prices range from \$30-\$60 for a decorative light that fits in a standard fixture.

Steele, like others in the industry, is convinced that the cost of using white LED technology for general illumination is currently prohibitive. "The next five years are likely to be for specialty lighting applications. It is just too expensive for the general illumination market at present," he says. "We don't see illumination, even in the 2003 timeframe, as being a significant part of the high brightness business."

In addition to cost, a number of technological hurdles still need to be overcome if LEDs are to compete for use in this market. These include the light output per LED unit and developments in phosphor coatings. Despite this, three recent joint ventures between lighting companies and LED manufacturers indicate that the development of LEDs for directed- and general illumination is being considered as a future market. The market for light bulbs and fluorescent tubes is estimated to be currently worth around \$10 billion worldwide.

As Bob Steele puts it: "Nobody in the LED community quite knows where this is heading. It is still really an emerging market. Even though General Electric, Philips and Osram all have activities for LEDs in lighting, I think they understand that in the near term this is a niche market for products that are costly to replace."



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## Materials and Equipment Suppliers Express Their Views

The Gorham/Intertech Compound Semiconductor Outlook '99 Conference, held in San Diego in early March, addressed a variety of business and market aspects of the compound semiconductor industry. It attracted a broad range of device manufacturers, epiwafer vendors, materials and equipment suppliers and industry analysts. In our previous issue, we presented a summary of the keynote address by Stan Breuderle of Dataquest [See CS 5(2), p. 8.] He forecast that the total market for compound semiconductors will reach \$9.0 billion by 2002, with optoelectronics applications accounting for 75% of this total. In this article, we turn our attention to the materials and equipment suppliers who presented their own perspective of the compound semiconductor industry at the conference.

### Aixtron and EPI Form Alliance

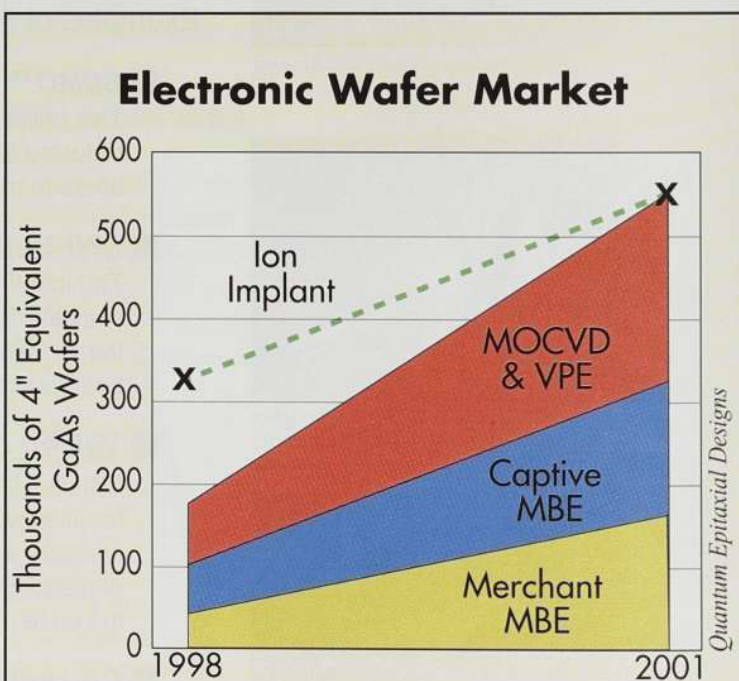
Aixtron and Epitaxial Products International (EPI) chose the conference to announce a strategic alliance between the two companies. Their aim is to "assist device manufacturers to increase their capacity in the shortest time frame with the least risk." The idea is that the customer builds in-house capacity to service long-term requirements (by buying multi-wafer MOVPE reactors from Aixtron) while at the same time addressing shorter-term needs in a flexible manner by purchasing epiwafers from a foundry (EPI) which uses the same MOVPE growth technology platform. Both companies were eager to state that they will remain fully independent, and will maintain their position of never competing with their customers or partners. The two companies also announced a long term supply agreement which calls for phased delivery of up to 10 additional multi-wafer MOVPE reactors to EPI's recently-expanded facility in Cardiff, UK. The first two reactors will be delivered in the second quarter of 1999, with the others to follow over the next 3 years.

### HBTs and MBE

Roger Malik of Ovation Semiconductor reviewed developments in carbon-doped HBTs grown by MBE. The current production volume of HBTs for mobile phone PAs, high speed (10 Gb/s) optical fiber systems and CATV distribution amplifiers, is estimated at approximately 100 million units per year, with a projected growth rate of 30-50% per year. This is expected to increase demand for HBT-based circuits. Carbon doping in the base layers of GaAs HBTs can be precisely controlled using a CBr<sub>4</sub> source, leading to improved HBT device reliability at high

current densities. InP HBT technology is expected to impact next generation handset PAs operating at 1.5 V and 40 Gb/s fiber-optic systems.

Phil Sullivan of VG Semicon countered earlier assertions by Aixtron's Holger Juergensen that production epitaxy is dominated by MOVPE, citing as examples MBE production of HBTs for digital phones by TRW and RFMD, AlInGaP red DVD laser production by Sharp, and production of InGaAsP and InGaAlP lasers by Coherent. Sullivan claimed that "VG's V100 machines produce the majority of all PHEMT material used in the world, along with all the MBE-grown HBT material, and the majority of MBE-grown lasers."



According to Tom Hierl of Quantum Epitaxial Designs (QED), the total GaAs wafer market for electronic applications is expected to increase from 0.5 million 4" equivalent wafers in 1998 to 1.1 million in 2001. The ratio of ion implant to epitaxy will change from 65:35 to 50:50 over the same period. The proportion of epitaxial wafers grown by MBE will stay constant (around 60%), but merchant epiwafer growth by foundries such as QED will increase strongly; the ratio of captive to merchant MBE will change from 60:40 to 50:50. Data compiled from various published market surveys.

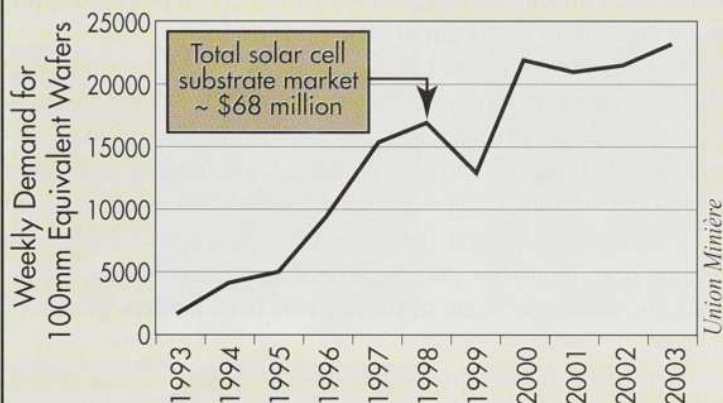


## Substrates

Scott Davis and Masamichi Yokogawa described **Sumitomo Electric Industries'** entry into the 6" GaAs substrate market with a new vertical boat (VB) bulk crystal growth technology. Sumitomo has long been a major supplier of conductive GaAs grown by horizontal Bridgman (HB), and semi-insulating LEC-grown GaAs. The new technique is similar to vertical gradient freeze (VGF), but also draws upon aspects of thermal control technology from the HB method, and LEC carbon control technology. The VB-grown wafers have similar electrical properties to, and can be used interchangeably with, LEC-grown wafers for ion-implantation applications. The speakers claimed that the new material offers several advantages compared to LEC-grown substrates, including lower residual strain, lower etch-pit density, higher mechanical robustness, and lower material loss during crystal growth.

Ignace De Ruijter and Paul Mijlemans of **Union Minière** (UM) described the current market for germanium. The solar cell substrate market accounts for about 35% of the total Ge market of \$200 million at present, and there is a demand for around 15,000 four inch wafers per week (see graph). UM states that its own capacity is around 10,000 wafers a week. Prices for 4 inch wafers purchased in large volumes have dropped from around \$140 to \$80 in the last five years, partly because of very efficient recycling processes. Ge has a number of advantageous properties such as high mechanical strength (allowing the use of thinner wafers) and low cost relative to GaAs. UM has investigated the growth of several device types on Ge, and has now established a collaboration with **Emcore** to develop red, orange and yellow LEDs, Hall sensors and PHEMTs.

### Demand for Ge Substrates



*The weekly demand for Ge substrates during 1998 was equivalent to over 16,000 wafers with a 100 mm (4 inch) diameter. Now that all the Iridium satellites have been launched (barring more failures), a slight decrease in demand is expected in 1999. This trend should be reversed when new projects such as Skybridge and Teledesic are initiated.*

## Briefly...

**Applied Materials** recently announced that it is working with **Epitronics Corp.**, to provide customers with a qualified facility in Mesa, Arizona, for demonstrating and developing SiGe epitaxial processes on the Applied Materials' Epi Centura deposition system. As part of the collaboration, semiconductor companies can use the Epi Centura systems at Epitronics' facility under the guidance of Applied Materials and Epitronics technologists. Epitronics also will use the Epi Centura system to manufacture SiGe epi wafers for customers.

A new company, **SpectraChip LLC**, has been founded in Santa Rosa, CA to provide scribe and break wafer dicing services, focusing on compound semiconductors, as well as MEMs and glass substrates. The company was founded by Peter Thompson, who was formerly the Sales Manager at Dynatex, a manufacturer of scribe and break equipment. According to Thompson, scribe and break services have, until now, typically been performed in-house by the semiconductor manufacturer. However, he reports that there is now growing demand to subcontract out these services to reduce overhead and to handle production bottlenecks and R&D projects.

**Morton International** reports that it has recently invested "significant capital" to enhance the company's processes for manufacturing metalorganic precursors. R&D and customer service also received additional effort. The company also reports that it has hired Mike Timmons as Technical Sales Manager. Timmons was previously with the Research Triangle Institute in North Carolina, where he designed high-efficiency solar cells.

**Allied Business Intelligence** (ABI) is predicting that the silicon industry will see a shortage of wafers by 2000 as it pulls out of its most recent slump. Demand for all semiconductor wafers will reach \$7 billion in 1999. According to Scott Moore, who authored the report, compound semiconductor wafers account for approximately 17% of that market. ABI also says the reclaimed wafer market is emerging as an important factor in silicon technology, now comprising 10% of the market. ABI's new report, "Semiconductor Wafers & Substrate Materials" will be released in April.

**TLC Precision Wafer Technology** reports that it has reached a major milestone in its joint program with **Sanders Lockheed Martin** aimed at production of low-cost millimeter wave components for military and commercial products such as Ka-band transceivers. The two companies were able to design, develop and prototype QA 9000-compliant 9-38 GHz digital radio modules in less than 4 months. These modules are comprised of MMICs developed by TLC and Sanders. To fulfill the production requirement of the contract, the companies worked together to establish viable manufacturing at both facilities: at TLC for prototype and low volume production, and at Sanders for large volume.



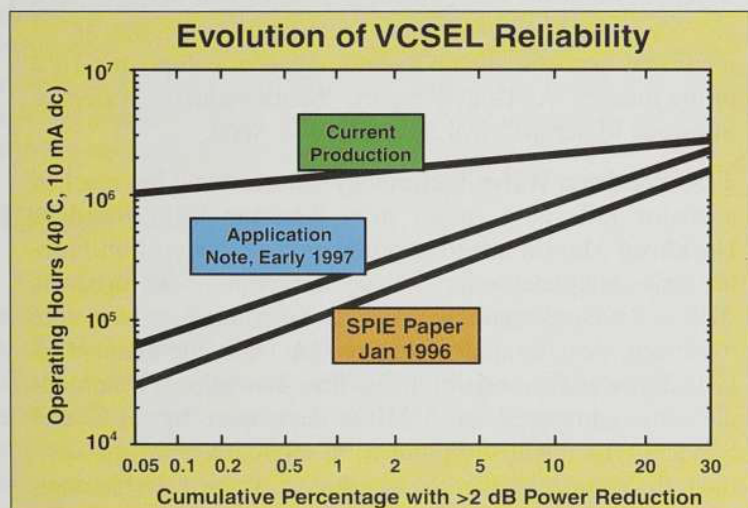
## Commercial VCSELs

*Vertical cavity lasers are no longer rare and exotic devices but are now the component of choice for short-range, gigabit-per-second data communications at 850 nm. Oxide-confined devices are already being shipped, while commercial long- and short-wavelength VCSELs may soon appear on the horizon.*

TIM WHITAKER

VCSEL manufacturing technology has matured very rapidly over the last several years, at least for devices emitting at 850 nm. Gigabit Ethernet transceivers use 850 nm VCSELs to transmit data over multi-mode fiber across distances up to 550 m, depending on the type of fiber, using either serial or parallel links with up to 12 channels. For Gigabit Ethernet and other gigabit-speed applications such as Fibre Channel and ATM OC-12, VCSELs have proved to be a very cost-effective solution because they offer the performance characteristics of lasers, particularly high speed, combined with low cost manufacturing processes similar to those used for LEDs.

Two of the most important features from a high volume manufacturing point of view are the ability to test the devices while still in wafer form, and to package the devices in traditional LED packaging styles. Speaking at Photonics West [1], Torsten Wipiejewski of Osram Opto Semiconductors (a Siemens/Osram joint venture), said, "We can employ standard IC fabrication technologies to manufacture the [VCSEL] devices...we also like the fact that we can mount VCSELs just like LEDs using automated pick and place machines. From the production point of view, VCSELs look just like LEDs with special properties."



*The reliability of Honeywell's VCSELs has steadily improved for a nominally unchanged process, due to a combination of manufacturing controls and improved screening techniques.*

### Mass Production at Honeywell MicroSwitch

Honeywell's MicroSwitch division has been supplying VCSELs to the commercial market for over three years. The company has a production volume in the order of millions of units per year, and has recently increased epitaxial capability by a factor of five. Jim Tatum states that even at these still relatively modest levels, the VCSEL has achieved cost superiority over some CD-type lasers that require heavy screening for reliability [2]. "A wafer containing tens of thousands of chips can be completely tested and mapped in several hours," says Tatum, "providing characteristics such as forward voltage, threshold current, slope efficiency and wavelength, as well as data on thermal performance on the individual devices. All of this data is available before the wafer is sawed into individual devices. In contrast, a CD laser must be fully processed and placed onto a sub-mount before being tested." Consequently, substantial cost reductions are achieved because only proven good dice are packaged, and because each die can be assigned to one of several possible applications depending on its parametric performance.

VCSELs are packaged in a variety of ways, including TO cans for datacomm applications, either with or without monitoring photodiodes. Extremely low cost plastic encapsulation or surface mount techniques can also be used, without modification of the package or packaging equipment used in the production of LEDs. Honeywell reports that they have packaged VCSELs in the same surface mount packages used for many years to package LEDs, with significant improvements in beam divergence for the laser.

Honeywell also reports that over the last three years, VCSELs employed in data communications systems have demonstrated remarkable reliability, and that the reliability has improved steadily for a nominally unchanged process [see left]. These changes are due to a combination of manufacturing controls and improved screening techniques. Jim Tatum described the ongoing reliability program as having collected more than ten million actual device hours under various highly accelerated conditions. Also, Honeywell was the first to publish a reliability report of oxide-confined VCSELs during the LEOS '98 meeting [see graph, page 18].

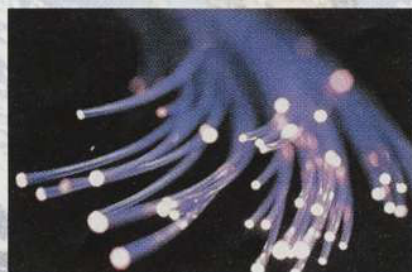
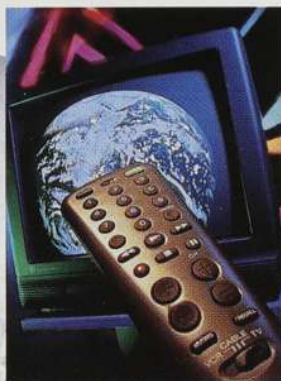
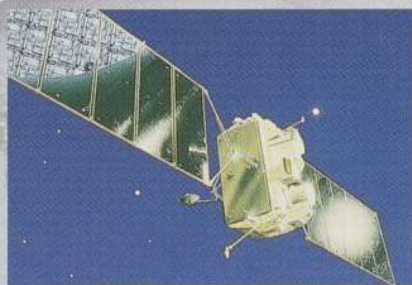


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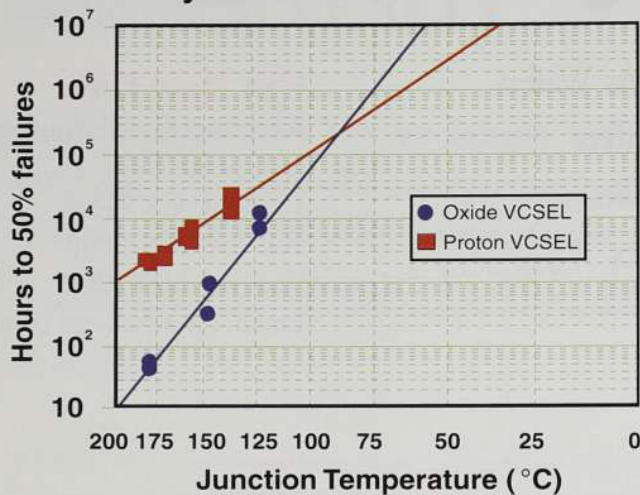
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## Reliability of Oxide-Isolated VCSELs



Honeywell MicroSwitch

*In the first report of oxide VCSEL reliability, Honeywell showed that these devices have similar reliability to ion-implanted VCSELs. Each point represents a sample of ~30 VCSELs.*

## Oxide-Confined VCSELs at HP

The first generation of commercial VCSELs, and the vast majority being shipped today, are ion-implanted devices, in which current confinement through the active layer is achieved by proton implantation. An alternative approach is to use oxide confinement, in which a high Al-content layer is selectively oxidized post growth to create a narrow aperture that funnels current and provides optical confinement. Both Hewlett-Packard and Osram have already started to ship oxide-confined devices.

According to HP [3], oxide VCSELs have lower threshold currents and higher slope efficiencies than implant VCSELs, and also combine a lower operating voltage with a higher speed. The strong index guiding of the oxide layer can give rise to very rich

transverse mode structures that offer better modal bandwidth characteristics for multi-mode fibers. Oxide VCSELs are seen as a key technology for 3.3 V Gigabit Ethernet 1x9 and small form factor 2x5 transceivers. HP claims to be "the first company to mass-produce oxide VCSELs" and reports that "large numbers of 3.3 V modules have already been shipped."

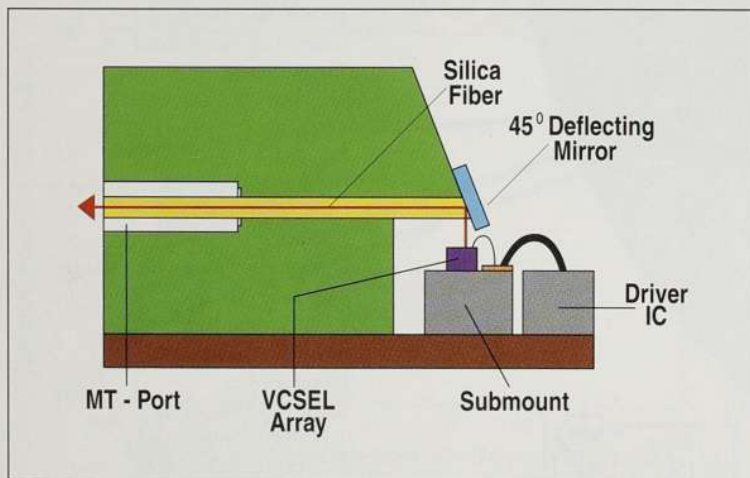
Epitaxial growth of HP's oxide VCSEL structures is carried out by multi-wafer MOVPE. The device structure includes a one wavelength thick active region with 3 GaAs QWs, and a high Al composition layer for oxidation, which is carried out in a furnace with water vapor ambient. Epilayer thickness is controlled to within  $\pm 0.5\%$  across a 2" substrate, with a wafer-to-wafer uniformity of  $\pm 0.1\%$  and a run-to-run reproducibility of  $\pm 0.2\%$ .

Similarly, there is tight uniformity control over the size of the oxide aperture; the aperture width is  $16.5 \pm 0.8 \mu\text{m}$ , with a variation of  $\pm 5\%$  across the wafer. Reliability concerns in oxide VCSELs arise from strain due to wet thermal oxidation and defects at the oxide-semiconductor interface. According to HP, their oxide VCSELs have accumulated over two million device hours at 2 mW and  $70^\circ\text{C}$  without any failures, indicating the excellent reliability of the devices.

## Infineon Technologies' Parallel Links

According to Torsten Wipiejewski, Infineon Technologies (formerly Siemens Semiconductors) is already shipping PAROLI™ PARallel Optical Links containing 14-element arrays of oxide-confined VCSELs developed and manufactured by Siemens, and now produced by Osram Opto Semiconductors (a Siemens/Osram joint venture). The PAROLI link [see figure] has 12 parallel transmission channels with a total data rate of up to 15 Gb/s (the 2 extra channels are used for power control and monitoring). "The main reason Siemens developed oxide-confined VCSELs was to take advantage of the low optical loss and ultra-low threshold current," says Wipiejewski. Although the VCSEL should ideally have a threshold current below 1 mA, this requires a very small oxide aperture, several microns in diameter, which can be difficult to fabricate. A small aperture also results in a high thermal resistance, while the need to minimize the operating temperature and prolong the device lifetime resulted in the decision to use an aperture of over  $10 \mu\text{m}$ . The threshold current was measured as just under 3 mA, with a  $\pm 25 \mu\text{A}$  variation across a 14 element array.

Two major concerns about oxide-confined VCSELs were the manufacturability of the oxidation process, and the reliability of the devices. "The concern was that mechanical stress from the oxidized layer might introduce defects in the active layer," says Wipiejewski. However, aging tests with more than 20 million accumulated device hours show the excellent reliability of Siemens/Osram's oxide-confined VCSELs. Tests were performed at various temperatures (up to  $120^\circ\text{C}$ ) and drive currents. The VCSEL lifetime is several million hours under normal operating conditions at  $40^\circ\text{C}$ . Siemens/Osram's oxide-confined VCSELs are also stable at damp heat storage (85% humidity and  $85^\circ\text{C}$ ) over 2000 hours and temperature cycling ( $-45^\circ\text{C}$  to  $+85^\circ\text{C}$ ).



Infineon Technologies

*Cross-section of a PAROLI™ parallel optical link, showing how the output of the 12-element VCSEL array is coupled in to the optical fiber.*



# INTRODUCING THE NEW GENERATION OF WAFER TECHNOLOGY

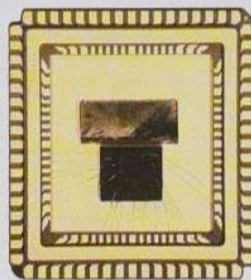


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# The Economics of VCSEL Manufacturing

*Although VCSELs represent a very exciting technology with numerous potential applications, they only have one relatively small market at present, making VCSEL manufacturing a tough business proposition.*

**A**MP is the world's leading supplier of connectors and interconnection systems, and is also a major vendor of VCSEL-based transceivers for Gigabit Ethernet, Fiber Channel and ATM OC-12 applications. In addition, AMP is treating VCSELs as a traditional discrete component and is investing in creative ways to package them cheaply for datacomm. However, the company decided against building its own VCSEL fab in favor of obtaining devices for its VCSEL-based transceiver products from external suppliers. According to Michael Lebby, AMP's director of business development for global optoelectronics, this was a decision taken from a purely business perspective, after studying the economic implications of building a fab in light of the current and projected market for VCSELs.

"At present, the only fully-established market for VCSELs is in transceivers for gigabit-per-second datacomm applications such as Gigabit Ethernet and Fibre Channel," says Lebby. "In this market, VCSELs are considered a commodity, meaning that the bill-of-materials cost of the optoelectronic chip should be almost negligible." However, VCSELs are not

"free", because the datacomm market only amounts to a few million units per year, making it difficult for manufacturers to run their fabs at full capacity. "For example, if a small VCSEL fab could run 10 three inch wafers per week, with 50,000 die per wafer, the entire market could be supplied from this facility," says Lebby. "And just like any fab it would not be profitable unless it was filled to at least 80% capacity."

## Making Money

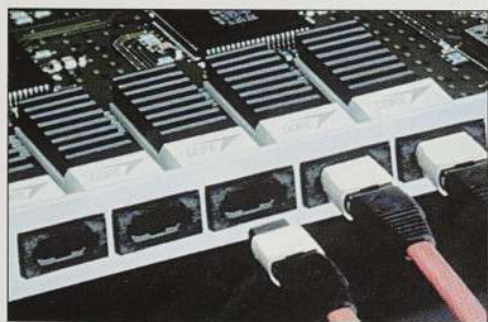
VCSEL manufacturers face the difficult problem of trying to provide a low cost product to the datacomm market, without having a high volume product line to fill their fab. So is there another high volume application? By far the highest unit volume application for edge-emitting lasers is for 780 nm devices in CD players, and this wavelength is also suitable for fiber-optic applications currently served by 850 nm VCSELs. In CDs, the low drive current of VCSELs could offer two major advantages compared to the conventional edge-emitters; a reduced level of electromagnetic interference, and longer battery lifetime for portable equipment.

According to Lebby, 780 nm

VCSELs could easily match all the specifications for CD players, but there is a big problem; the incumbent edge-emitting laser manufacturers. "If a VCSEL manufacturer were to approach a CD player manufacturer with a 780 nm VCSEL priced at the same level as an edge-emitter (~\$1), which would itself be a big challenge, the CD player manufacturer would naturally be interested. However, the existing CD laser manufacturers would then cut their prices in an effort to maintain their market share, and in the end no-one would make money." The same problems exist when trying to establish a high volume market for DVD VCSELs at 650 nm, assuming of course that the technological hurdles can be overcome.

So how do VCSEL manufacturers make a profit when they don't have a high volume product to fill the fab? One strategy is through increasing performance; by moving to 2.5 Gb/s and eventually to 10 Gb/s, manufacturers will be able to charge more money for their products. In this case, the early adopters benefit most from improved market share and profitability margins.

Another strategy is to move up the value chain by developing optical sub-assemblies or packaging the VCSELs.



**Gore's new VCSEL-based module offers up to 18 Gb/s bandwidth.**

## Gore

WL Gore [Newark, DE] is close to commercializing a 1300 nm VCSEL [see page 26] and also has an 850 nm product line. Gore recently demonstrated a new fiber optic data link, offering up to 1.5 Gbit/s on each of 12 channels over multi-mode ribbon fiber. The modules are designed for high bandwidth, high density, point to point interconnects, allowing both parallel and multichannel serial data

transmission. The parallel array module provides 20 Gbps/inch bandwidth density on the edge of the board, an 8x increase compared to 1x9 Gigabit Ethernet serial transceiver modules. Innovative design and high density packaging technologies have enabled Gore to create a module that is only slightly wider than the cable connector that plugs into it.

*[Continues on page 22]*



"However, there is not much money to be made by this approach, because VCSEL-based Gigabit Ethernet transceivers are a commodity market," says Lebby. "In the last two years, transceiver prices have dropped from around \$250 to around \$75 as volumes have increased.

### The Parallel Market

The demand for parallel array transceivers has always been deemed to be very lucrative, with applications in central office cross-connects, terabit switches, workstation clusters, and in combining several serial Gigabit Ethernet links into "ganged serial" solutions. The success of AMP's MPX connector proves this from a fiber array standpoint. Although VCSELs are the only realistic solution for parallel arrays, the market hasn't really taken off yet due to the lack of qualified multiple suppliers. In Lebby's view, the main issues relate to packaging, eye-safety, and the need to monitor the output of all the channels in the array. "You really need to have automatic power control on each channel to deal with the eye-safety issue and to monitor the performance of each channel through to the end-of-life," he says. "Packaging the array with monitoring photodiodes is a very tough challenge." Also, VCSEL manufacturers have to convince their telecom customers that the device reliability is under control, and the array will have a uniform wearout with no sudden failures.

Lebby considers that there is likely to be a good market for single mode VCSEL arrays at 1300 nm, because edge-emitters aren't suitable. "However, my guess is that individual VCSELs will not be able to compete with 1300 nm Fabry-Perot lasers, which are manufactured in high volume at low cost using passive alignment onto silicon wafer board such as we are doing at AMP. VCSELs have to be able to compete on cost and also offer technological advantages, which are not clear at present."

### The Way Forward for VCSELs...

"This is a tough technology, with tough business economics," concludes Lebby. "III-V manufacturers need to follow the rules developed by the silicon industry. They must use an LED cost structure in order to keep the costs down for the fiber-optic community, and without having high volumes, this requires innovative approaches to keep fabs near full capacity." Options might include fabricating other devices alongside VCSELs, or sub-contracting either the epitaxial growth, or the device fabrication (or both). It remains to be seen which type of approach will prove most successful.

Lebby predicts, "Either way, the clear niche for VCSELs is arrays, and manufacturers must figure out how to bring this technology to market economically to complete a rich cycle from research curiosity to product."

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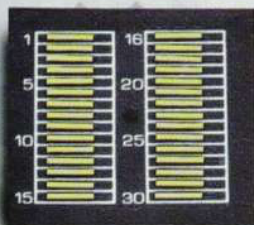
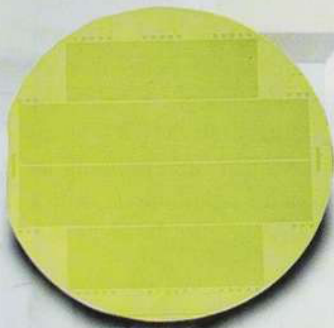


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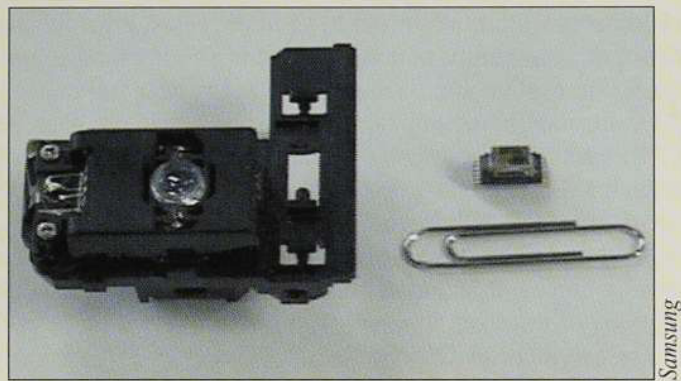


\* Background Photo: IMC's Class 100 Cleanroom



## 780 nm VCSELs at Samsung

As well as selling 850 nm VCSELs, Samsung also offers 780 nm devices, packaged in a hologram module (see photo) or in a TO-46 can. The 780 nm device has an output power of 4-5 mW, a threshold current of 4.5 mA and a slope efficiency of 1.0 mW/mA. The VCSEL structure is grown on a GaAs substrate and contains an  $\text{Al}_{0.14}\text{Ga}_{0.86}\text{As}$  quantum well active region, with AlAs/AlGaAs DBR mirrors.



A 780 nm VCSEL packaged in a hologram module (top right) is shown next to a CD-ROM optical head (left) containing such a module.

780 nm VCSELs have a number of uses, according to Dr Hyun-Kuk Shin, manager of Samsung Electronics' corporate R&D center. "The main use is in CD, CD-ROM and DVD-ROM pick-ups," says Shin. Although DVD uses 650 nm at present, 780 nm sources are usually incorporated into DVD drives/players to enable them to read CD disks. "Some biomedical applications require this wavelength, as do certain bar-code scanners and laser printers," continues Shin. "In short haul optical communications, standards define the use of the whole band between 770 nm and 860 nm. However, it seems that people prefer the 850 nm wavelength since its quantum well is aluminum-free."

According to Dr Shin, Samsung originally developed the 780 nm VCSEL to replace edge-emitting lasers in CD pick-ups. "In combination with a holographic optical element, the 780 nm VCSEL provides a simple optical system as well as much easier assembly process than the conventional pick-up," says Shin. "Also, I am sure that the chip cost of VCSEL can be lower than edge-emitting laser owing to the simple fabrication process and chip test at wafer level. However, due to the lack of experience in mass production and the recent economic crisis, the application of 780 nm VCSELs in optical pick-ups was delayed. Now, we are ready again."

"We buy many epi wafers from external vendors," added Dr Shin. "When the specifications are fixed, it is a convenient and cost-effective approach since we do not have to have and operate all the necessary equipment including many pieces of advanced test equipment."

## MODE and Mitel

MicroOptical Devices (MODE), a division of Emcore based in Albuquerque, NM, is an established volume supplier of single 850 nm VCSELs and is also the only company presently selling commercial 1x12 arrays. "VCSELs are very well-suited for array fabrication," says Bill Leasure, MODE's VP of marketing and sales. "We can test functionality on a wafer level, and also use photolithography and other techniques common to microelectronics manufacturing to fabricate the arrays." Leasure expects MODE to have 2.5 Gb/s devices in the near future, as well as more highly integrated arrays. The company is also focussing on materials research to develop both visible and 1300 nm VCSELs. "Real technical hurdles exist at 1300 nm from a material science standpoint," says Leasure. "However, there are a number of immedi-

ate markets for this technology, and in the future broadband fiber-to-the-home/curb will be greatly enabled by a lower cost device."

At the recent Optical Fiber Conference, Mitel Semiconductor [Sweden] introduced a 12 channel, 840 nm VCSEL array (the 12L485) together with a matching receiver array which provide a cut-off frequency of 2 GHz, suitable for 1 Gbit/s and 2 Gbit/s operation. Power consumption is 15 mW/channel at normal operation of 8 mA drive current, and the spectral bandwidth is 0.5 nm. The array packaging consists of a metal lead-frame, a heat sink, the optoelectronic chip and a metal shield for EMI protection. Also included is "direct optical interface technology" which couples the chip directly to the fiber with no need for external lenses. Mitel also introduced new 850 nm VCSELs, suitable of up to 2 Gbit/s operation, which feature 20 mW

power consumption at 12 mA drive current and have a typical threshold current of 3.5 mA. Coupling into fiber is very efficient since the VCSEL's narrow circular beam matches the fiber core. The new products have a reliability better than 20 FITs ( $\text{MTTF} > 5 \times 10^7$  hours). Finally, the company introduced an MT-RJ small form factor transceiver incorporating an 840 nm VCSEL with a photodiode, with a power consumption of 20 mW at 12 mA drive current.

## References

- [1] T. Wipiejewski et al, "VCSELs for Datacom Applications", 1999, *Proc. SPIE 3627 (VCSELs III)*
- [2] J. Tatum et al, "Manufacturability of VCSEL Components and VCSEL Products", *Proc. LEOS '98*, p. 409
- [3] H. Deng et al, "850 nm Oxide VCSEL Development at Hewlett-Packard", 1999, *Proc. SPIE 3627 (VCSELs III)*



# Long Wavelength Vertical Cavity Lasers

VCSELs are currently used in local or premises network applications such as Gigabit Ethernet and Fiber Channel, for transmission over relatively short distances along multimode fiber (typically up to 550 m, depending on the type of fiber). Longer distances can be obtained using Fabry-Perot lasers at 1300 nm, however these are very expensive compared to an 850 nm VCSEL, and coupling the FP laser output into multimode fiber is complex and adds further cost. Hence, there is increasing interest in developing 1300 nm VCSELs. One further reason is that long wavelength light is much less damaging to the human eye, allowing more power to be launched into the fiber while remaining within eye-safety limits.

In addition, there are plans to develop a 10 Gb/s Ethernet standard as well as Fiber Channel standards operating at 2x or 4x the current speed of 1.064 Gb/s, and increasing the data rate will limit the transmission distance in multi-mode fiber. Long wavelength single-mode VCSELs could prove to be a very cost-effective solution for high data rate transmission at 1.3  $\mu\text{m}$  and 1.55  $\mu\text{m}$  over standard single-mode optical fiber. VCSELs are commonly touted as the low cost solution which will help to bring

about widespread deployment of Fiber-To-The-Home. However, the economic sense of developing a 1300 nm VCSEL has to be weighed against the cost of high volume edge-emitters.

## 1.55 $\mu\text{m}$ Devices

The low volume of the active cavity in a vertical device requires that the mirrors must exhibit high reflectivities, good conductive quality and low thermal resistance. Achieving these properties has proved to be extremely difficult using mirror materials which are lattice-matched to the active region. VCSELs at 1.55  $\mu\text{m}$  commonly have an active region comprising InGaAsP strained QWs with InP barrier layers, lattice-matched to InP. Suitable lattice-matched material systems for DBR mirror growth are InGaAsP/InP, AlGaInAs/AlInAs and AlGaAsSb/GaAsSb, but so far these have all failed to yield a monolithic, room temperature CW VCSEL.

An alternative approach is to use wafer fusion, in which a DBR mirror (or mirrors) fabricated from a non-lattice-matched material system is bonded to the active region.

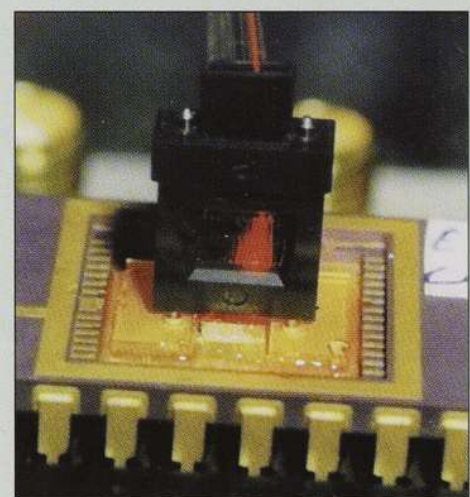
## Visible VCSELs

Red VCSELs operating at 650 nm could find a market in data communication systems using plastic optical fiber (POF), which currently use low cost LEDs or resonant-cavity LEDs [see OFC Report, page 36]. The biggest market for edge-emitters at this wavelength is in DVD, but VCSELs are likely to find it hard to penetrate this area. Both types of laser struggle to achieve good high temperature performance at 650 nm, due to the problem of carrier confinement in the AlGaInP active region.

John Lambkin of the National Microelectronics Research Centre in Ireland leads a consortium, funded by the EU Long Term Research program, which aims to fabricate 650 nm VCSELs with a CW output power in excess of 1 mW at 50°C. Another target is to demonstrate 1x8 arrays coupled into POF ribbon [see photo]. Other groups working in the BREDSELS (Bright RED Surface-Emitting LaserS) project are the Universities of Sheffield

(UK), Gent (BE), Surrey (UK) and Cork (IRL), and Uniphase (NL). So far, a maximum room temperature output power of almost 2 mW per device has been achieved for oxide-aperture VCSELs operating at 663 nm, while at 650 nm the output power has only reached 5  $\mu\text{W}$ .

In part, this is because a selective oxidation layer has not yet been included in the 650 nm device, but other materials issues continue to pose challenges. "The big problem with moving to a shorter wavelength is that the carrier confinement in the AlGaInP active region gets worse," says Lambkin. "Also, there is no advantage in using tensile strained wells. At the same time, the reduced barrier height degrades the thermal performance, so it becomes harder to get the devices to operate at higher temperatures. Our aim is to design devices that allow us to get around these combined problems." Lambkin added that the device performance improved significantly after the



*Demonstrator module from the BREDSELS project, containing a 1x8 array of VCSELs emitting at 663 nm, coupled to plastic optical fiber.*

epitaxial growth was sub-contracted to Epitaxial Products International. "The use of a large-scale manufacturing reactor greatly improved the uniformity and other parameters compared to growth on research scale machines," says Lambkin.



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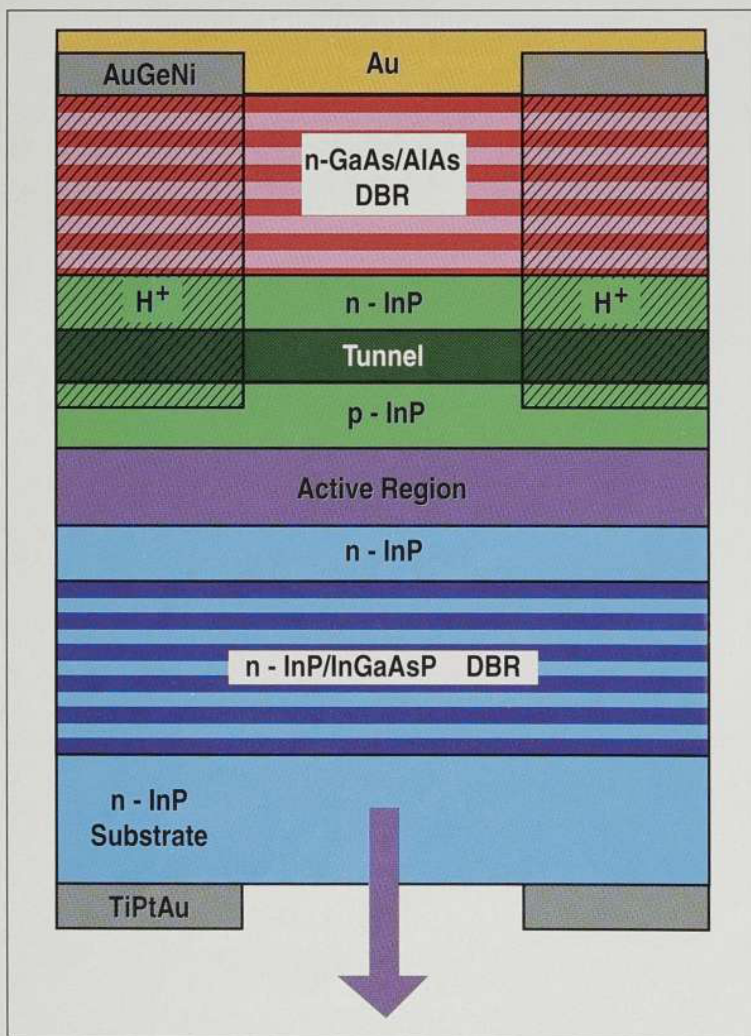
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The best results obtained to date for a 1.55  $\mu\text{m}$  VCSEL are from UCSB, who have recorded CW operation up to 71°C, and 0.5 mW at 25°C, for a device comprising an InGaAsP/InP active region wafer-bonded to two AlGaAs/GaAs DBR mirrors [1]. Although an impressive result, this approach requires 3 wafers and 2" wafer fusion steps, and is not fully compatible with 2" wafer processing. Also, there is a general concern that wafer-fused structures may not be able to match telecom reliability specifications.

Single-fused devices have been demonstrated by Sweden's Royal Institute of Technology, France Telecom and Mitel [2]. The devices, grown on an InP substrate, include an n-GaInAsP/InP bottom mirror and an GaInAsP/InP active region wafer-fused to a p-GaAs/AlGaAs mirror. A current aperture was formed by selective oxidation, and CW operation was observed at 17°C.

Other active region materials have also been investigated. France Telecom has achieved pulsed operation at 18°C of an electrically injected 1.48  $\mu\text{m}$  VCSEL. The structure, grown by MBE on an n-InP substrate, featured an AlGaAsSb/AlAsSb bottom mirror and an active region with InGaAs QWs and AlGaInAs barriers, together with a wafer-fused AlGaAs/GaAs top mirror [3].



*Alcatel's monolithic 1.55  $\mu\text{m}$  VCSEL structure features a top GaAs/AlAs DBR mirror grown on InP, and a tunnel junction which allows this mirror to be doped n-type.*

## Monolithic Structures

The University of Würzburg demonstrated a monolithic 1.5  $\mu\text{m}$  GaSb-based VCSEL grown on GaAs, which was optically pumped at 77K. The structure, grown by MBE, had top and bottom AlGaSb/AlSb mirrors and an active region containing 3 GaSb quantum wells with AlGaSb barriers [4]. Recently, France Telecom showed a monolithic 1.56  $\mu\text{m}$  VCSEL grown on InP with InGaAlAs/InP active region and InGaAlAs/InAlAs mirrors. The 45  $\mu\text{m}$  device, defined by proton implantation, exhibited pulsed operation up to +55°C under electrical injection [5].

### First Monolithic CW VCSEL at 1.55 $\mu\text{m}$

At Alcatel, research has focussed on the development of a metamorphic epitaxial structure [6]. Firstly, growth of a GaAs/AlGaAs Bragg mirror directly onto an InP-based cavity was demonstrated. The mirror exhibited high reflectivity and did not introduce dislocations into the active layer despite the lattice mismatch of 3.7%.

This development was incorporated into a metamorphic structure [see figures] which exhibited 1 mW CW output power at room temperature. The device was grown by GSMBE on an n-InP substrate and consists of a 50 pair n-doped InGaAsP/InP DBR mirror stack, followed by an InGaAsP/InP active region with 9 strain-compensated QWs.

A crucial feature of this device is the use of a tunnel junction above the active layer, which enables the use of an n-type GaAs/AlAs mirror. The absorption coefficient of p-GaAs is very high at 1.55  $\mu\text{m}$ , which limits the p-doping level and results in a high electrical resistance. The n-type GaAs/AlAs is a very simple quarter-wave stack (26.5 pairs) of binary material exhibiting high reflectivity, low absorption and high electrical and thermal conductivity.

Proton implantation is used to define a current aperture through the tunnel junction, locally destroying the junction's conductive properties. The device is mounted epi-side down on a Cu submount to utilize the better heat dissipation through the GaAs/AlAs mirror. Single mode CW operation up to 45°C, with a room temperature threshold current of 11 mA, was obtained from an injection diameter of 25  $\mu\text{m}$ . For 35  $\mu\text{m}$  devices, the CW output power was 1 mW, with a threshold current of 16.5 mA, and a threshold voltage of 1.9 V.

### 1300 nm VCSELs from Gore

There are also several possible approaches to 1300 nm VCSELs. At the moment, the front runner is WL Gore & Associates, who announced at OFC that they are "offering single-mode devices in TO-46 packages to selected customers." A spokesperson added that, "while no official date has been set, [we] are targeting early 2000 for having commercially available devices."

The Gore device uses wafer fusion to attach two AlGaAs/GaAs DBR mirrors to the InP-based active region. The novelty of Gore's approach is that both these mirrors are undoped, because the device does not require electrical injection.



Instead, the 1300 nm active region is optically pumped by the output from an 850 nm VCSEL grown monolithically on top of the upper 1300 nm DBR mirror. [See CS 4(7), p. 30]. The devices operate CW at up to 80°C and have demonstrated 1.3 mW of single-mode power and 2.5 mW of multi-mode power at room temperature, as well as 4 Gb/s modulation [7].

By optically pumping the 1300 nm device, free-carrier losses and resistive heating are greatly reduced. Perhaps most importantly, wafer fusion produces optical rather than electrical interfaces, which should significantly increase the reliability. However, there are manufacturing concerns surrounding the use of a wafer fusion process. Vijay Jayaraman, VCSEL project leader, acknowledges that wafer-fused VCSELs are not a mature technology. "However, we have demonstrated wafer fusion on full 2 inch wafers," he says. "From the data we have collected, it appears we can do this process with high yield."

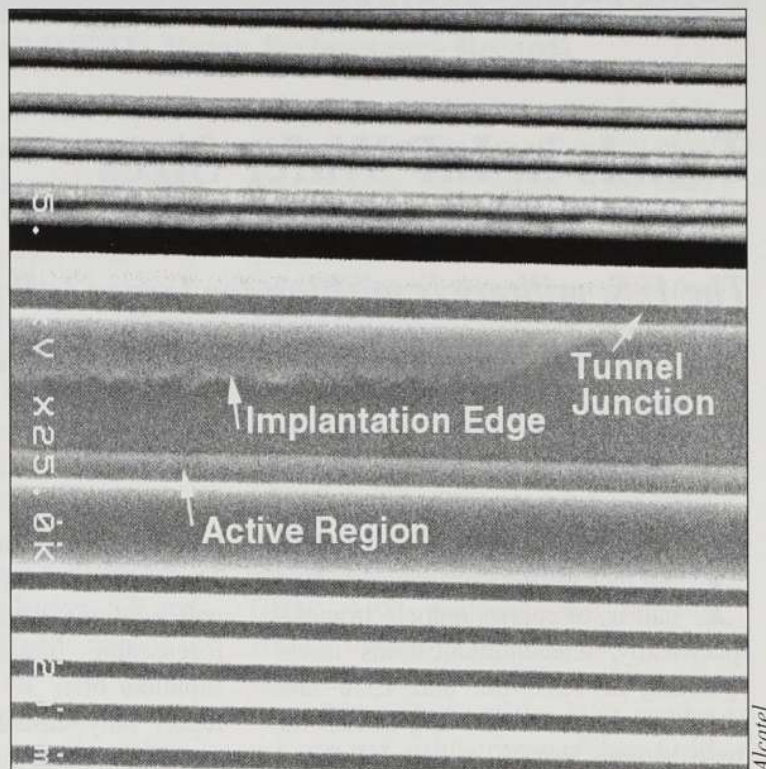
These long wavelength devices also offer some advantages over edge-emitters. "Single-mode VCSELs offer a low-divergence circular beam, which should enable cost reduction in fiber coupling," says Jayaraman. "In addition, single-mode VCSELs have a spectral width comparable to DFB lasers, and should therefore allow large bandwidth-distance products." Gore plans to investigate the use of a 980 nm pump VCSEL to improve conversion efficiency in conjunction with both 1300 nm and 1550 nm emitters, and to develop WDM arrays using the basic optically-pumped device structure.

## GaInNAs-Based Devices

Other CW VCSELs at 1.3  $\mu\text{m}$  have used either one or two dielectric mirrors, and both GaSb-based active regions and InGaAs quantum dots have also been investigated. Perhaps the most promising material for fabricating a monolithic structure is the quaternary GaInNAs alloy, which can be grown lattice-matched to GaAs. Hitachi demonstrated 1.18  $\mu\text{m}$  GSMBE-grown VCSELs with pulsed operation up to 95°C, which had GaAs/AlAs mirrors and a single  $\text{Ga}_{0.7}\text{In}_{0.3}\text{N}_{0.004}\text{As}_{0.996}$  QW with GaAs barriers [8]. More recently, Philipps University Marburg (Germany) used MOVPE to grow a device with an active region containing four stacks of three 7 nm GaInNAs QWs, which operated at 2.6-2.85  $\mu\text{m}$  when optically pumped at room temperature [9].

## References

- [1] K. Black et al, *Proc. Intl. Semiconductor Laser Conf.*, 1998, p. 247
- [2] S. Rapp et al, *Elec. Lett.*, 1999, 35(1), p. 49
- [3] J. C. Harmand, *personal communication*
- [4] J. Koeth et al, *Appl. Phys. Lett.*, 1999, 72(13), p. 1638
- [5] C. Kazmierski et al, *Intl. Semiconductor Laser Conf.*, 1998, Post-deadline paper PD3
- [6] J. Boucart et al, *Photonics Tech. Lett.*, June 1999, accepted for publication
- [7] V. Jayaraman et al, *Elec. Lett.*, 1998, 34(14), p. 1405
- [8] M. Larson et al, *Photonics Tech. Lett.*, 1998, 10(2), p. 188
- [9] C. Ellmers et al, *Appl. Phys. Lett.*, 1999, accepted for publication



SEM photograph of Alcatel's monolithic 1.55  $\mu\text{m}$  VCSEL, showing the top and bottom DBR mirrors, the tunnel junction, the active region and the edge of the ion-implanted area which provides current confinement.

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## Trends in InP Wafer Sizes

*The U.S. military is pushing for larger InP substrates, while 2-inch remains dominant in the laser field.*

MARIE MEYER

There are two halves to the InP field, but they are very unequal. The first half is, of course, optoelectronics - specifically, telecommunications lasers operating at 1310 nm and 1550 nm. There is a large and growing market for these devices. Nearly 2 million InP-based telecom lasers will be shipped in 1999, with an estimated value of \$1.5 billion. This is such a well established application it may come as a surprise to find that most - perhaps even all - of the fabs are still using 2" wafers.

The economies of scale - and therefore the motivations for scaling-up - are different in laser manufacturing, according to Toby Strite, Product Manager at Uniphase Laser Enterprise. "Lasers need a lot more bar and chip level work than transistor circuits, so a lot of the cost is unit dependent, not wafer dependent as it is in silicon" he explains. "Steps such as forming the facets and measuring the devices can only take place at the bar level, and burn-in at the chip level. In a silicon process, a mediocre 12" wafer can still win over a good 8" wafer, because you can just discard the bad die. But in lasers, a lot of work is sunk into those bad die at the bar/chip level, which makes it very costly to toss them out."

Therefore, he concludes, manufacturers need to know that the larger wafers are as good as the currently available 2" wafers before they consider scaling-up. Moreover, the fab would have to be facing capacity constraints before the investment could be justified. One good 2" wafer can yield up to 10,000 lasers. Strite reports that most telecom laser manufacturers are experiencing bottlenecks not in the wafer fab but the

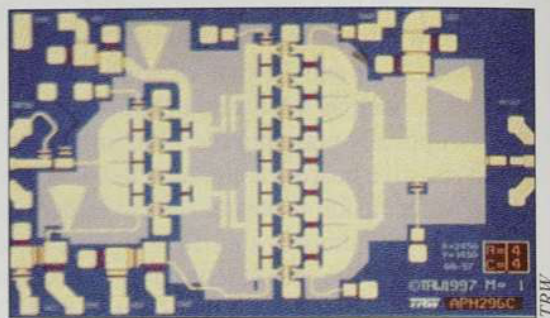
test, pick/place and burn-in functions. Therefore it seems likely that most fabs will continue using 2" wafers for the foreseeable future. Many substrate suppliers offer 3" InP wafers, but they report only casual interest from laser manufacturers at this time.

### InP Microelectronics

The other part of the InP field is microelectronics. It is definitely the "lesser half" in terms of market value, because there are no commercial applications for InP ICs at this time. However, the situation is changing rapidly.

"Currently there are only military and prototype commercial insertions," says Dwight Streit, who heads up TRW's InP development program. "But there are samples of InP MMICs in the marketplace, and there will be commercially available InP parts available for sale in catalogs later this year."

InP microelectronics appear to be following the same model that applied to the development of GaAs over the past two decades: first find military and extremely high performance commercial uses, and then secure higher volume commercial applications once the costs have been brought under control. But Streit thinks that the time frame for InP development will be much more compressed. "Whereas it took many, many years for GaAs to become cost competitive, it will happen much more quickly in InP," he says. "The military insertions will precede the commercial uses by a only matter of years or maybe even months, whereas for GaAs it took a decade or more."



Example of a TRW InP MMIC.

### The Need for 4" Wafers

The key component that is missing for the commercialization of InP microelectronics is a supply of high quality larger diameter semi-insulating (S.I.) InP substrates. Since the biggest prospective user of InP MMICs at this time is the U.S. military, the U.S. government has stepped in to fund developmental work in this area. In 1997, under what is known as Title III of the Defense Production Act, \$7.9 million in matching funds was awarded to American Xtal Technology (AXT) and M/A-Com for the development of large diameter S.I. InP wafers. The program will run until April 1999.

"Our intention was to develop a domestic supply for S.I. InP," says John Blevins, Title III Program Manager. He explains that defense contractors were unenthusiastic about committing to InP development programs, largely because of the inefficiencies involved in fabricating large-area devices on 2" substrates. "Both of our funded companies will have a 4" product at the end of the program," he says. "We also think that Title III has stimulated interest and investment at some of the substrate vendors who weren't part of the program." Crystacomm, another U.S. supplier, is also sampling 4" wafers. Blevins says that stimulating competition was one of the goals of the program, in order to motivate the suppliers to continue to improve their product and lower their prices, even after the program ends.

Title III was originally meant to focus on the production of high quality 3" material. But the monitors found out that many fabs were insisting on 4" wafers. "If



you already have a 3" fab, then 3" InP wafers are acceptable as an entry point into the market," says Streit. But if a company is starting from scratch with a new processing line, "then 3" wafers don't make any economic sense," he says. "In that case, you would definitely want to wait for 4" wafers."

TRW is currently doing its pilot line production on 3" wafers, and the company has recently reported some very impressive results (see box). Streit reports that they have sampled wafers from every supplier they can find, and they have seen a marked improvement in quality and consistency since the Title III program began. Based on his experience, Streit thinks that 4" InP will be ready for production purposes by the end of 2000.

Microelectronics will probably never rival optoelectronics for dominance of the InP field, but it does appear that these two halves of the industry are about to become a bit more equally balanced.

### TRW's InP HEMTs Break Performance Records

**T**RW recently reported record-breaking performance from MMICs fabricated from InGaAs/InAlAs/InP HEMTs.

A two-stage power HEMT amplifier achieved 427 mW of power with 19% power-added efficiency (PAE) and 8.2 dB of gain at 95 GHz. This output power figure is the highest ever reported at 95 GHz, and represents a 30-fold improvement in under four years. At output powers in excess of 400 mW, InP amplifiers have twice the PAE of their GaAs-based counterparts. The TRW MMIC was fabricated on a 0.15  $\mu$ m gate length process.

According to Fred Ricker, VP and general manager of TRW's Electronics & Technology Division, InP MMICs are suitable for a wide range of active electronic systems such as missile seekers, high performance radar, perimeter defense systems and satellite-to-satellite communication links. "Using InP, satellite designers will be able to increase the

strength of a satellite's generated signals while shrinking the size and weight of its power system," says Ricker. TRW plans to have their InP HEMT process space qualified by the end of this year, so that InP MMICs can be used in satellites that will be launched in 2000.

In a separate report, TRW also achieved the highest frequency performance of any MMIC amplifier, with a two-stage, 80 nm gate length HEMT MMIC that had a measured on-wafer peak gain of 7.2 dB at 190 GHz, and greater than 5 dB gain from 170 to 194 GHz. TRW estimated that the InP HEMT in this circuit had an intrinsic  $f_{max}$  in excess of 400 GHz, and that a 2-stage 220 GHz amplifier built on this process will exhibit greater than 6 dB gain.

The work was funded in part by the DARPA Microwave and Analog Front End Technology (MAFET) III program.

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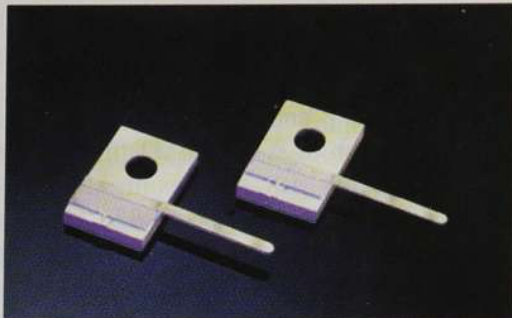
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## Opto Power Diode Laser for Graphic Arts

**Tucson, AZ.** For direct-to-press and direct-to-plate writing applications, Opto Power Corp. has introduced a new high brightness, single emitter diode laser. The H02-A02-830-CT/60 delivers 1.5 W from a 60  $\mu\text{m}$  emitter at a wavelength of 830 nm. Benefits to graphic arts manufacturers include a greater depth of focus as a result of the increased laser brightness (the ratio between output power and emitter size). This translates into higher image resolution across the entire field of view, and relaxed optical and mechanical system tolerances. Conversely, in systems based on lower power diode lasers with 60  $\mu\text{m}$  emitters, the higher output of this laser enables faster writing speeds and increased throughput.



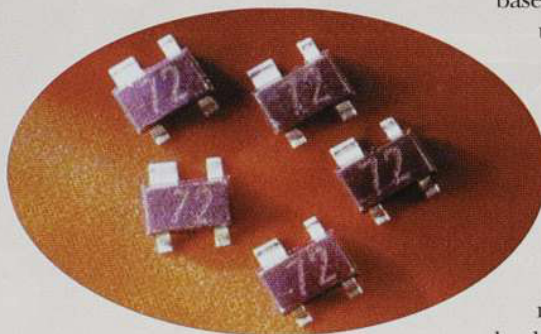
## Temic Launches First SiGe PA for GSM Mobile Phones

**San Jose, CA.** Atmel Corp. recently announced that its wholly-owned subsidiary, Temic Semiconductors [see CS 5(2) p. 40 for more on Temic], has introduced the first 3V SiGe PA, the TST0912, for mobile phones based on the GSM standard. The TST0912 is designed for single-band operation in the 900 MHz (GSM 900) frequency range. 3 V operation allows handset designers to use either single-cell lithium-ion or 3-cell nickel metal hydride (NiMH) batteries for smaller and lighter handsets. As SiGe does not require a negative supply voltage, as needed by some competing devices using GaAs technology, both system and production costs can be reduced, says Atmel. The new PA offers a maximum output power of 35 dBm, as required for GSM handsets. Its PAE value is 50%, enabling longer active times, and it is the first member of a family of GSM PAs based on SiGe. Other dual-band (GSM 900 and 1800/1900). Single-band (GSM 1800/1900) devices from Temic are under development.

## 20-40 GHz PHEMT-based Wireless Handset ICs from HP

**Newark, CA.** Hewlett-Packard Company has recently announced new IC products based on PHEMTs for wireless applications in cell phones. A new family of GaAs-based low-noise PHEMTs, used where high linearity and low noise are premium, such as in wireless communications are now available. The ATF-34143 features an 0.5 dB noise figure, +14 dBm third-order input intercept point and 17.5 dB gain under 2 GHz, 4 V, and 60 mA operating conditions. The new 800  $\mu\text{m}$  gate width transistor is designed for 0.9-2.5GHz cellular PCS

base station low-noise amplifiers (LNAs), but can be used in many other applications in the 450MHz to 10GHz range. The 6-sigma spread (sample of 450 parts from nine wafers) for NF at 2 GHz, 4 V, and 60 mA is only 0.2 dB; the gain variation is less than 1 dB. The 0.5  $\mu\text{m}$  PHEMTs are fabricated using precision optical stepper-projection lithography on MBE material.



HP has also announced a new GaAs PHEMT monolithic RFIC amplifier designed for a four-lead SOT-343 package. This low-noise amplifier/driver is targeted specifically at CDMA handsets in the cellular

and PCS bands. The MGA-72543 is the first release of HP's new CDMA dual-band chipset. The company intends to introduce the remainder of the chipset - including PA, upconverter, down-converter, modulator and demodulator - later this year.

The MGA-72543 features a built-in bypass switch that is designed to be used in an adaptive mode in both transmit and receive chains in CDMA handsets to ensure low current draw and sufficient linearity under all operating conditions. The built-in switch also reduces board space compared to designs which combine separate amplifiers and switches. Featuring a noise figure of 1.4 dB, RF gain of 14 dB and an adjustable third-order input intercept point of +2 dBm to +14 dBm, the MGA-72543 operates from a 2.7-5 V dc power supply.

## Sony Laser Diodes For DVD and CD-R/RW

**Tokyo, Japan.** Sony Corp. has developed new laser diodes for DVD, CD-R and CD-RW pickups. The SLD235VL, for CD-R and CD-RW, is an index-guided AlGaAs laser diode with a maximum optical power output of 100 mW. The unit can support 8x writing speeds. Designed for DVD use, the SLD1134VL is a 650 nm pulsed red laser diode that eliminates the need for external parts to control noise. Sony will start shipping sample units in the spring. According to a private-sector research firm, Sony holds a top share in the market for pickups for optical discs but is still slightly behind Rohm Corp. in laser diodes for optical pickups.



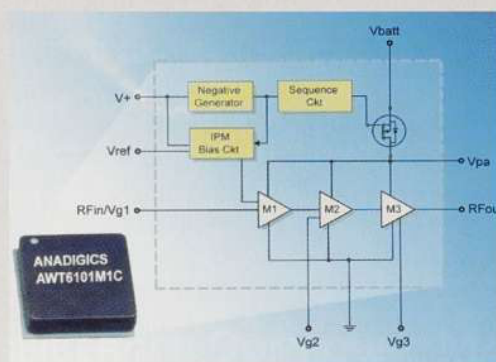
## OKi Surface Mount Laser Diode Modules

**Sunnyvale, CA.** Oki Semiconductor has introduced two 1.3  $\mu\text{m}$  InGaAsP/InP laser diode modules designed for use in fiber-optic communications and optical networks. The OL3300W and OL3300N-02 modules eliminate the need for a condensing lens commonly found in many conventional optical systems. The surface mount optical network modules contain both lasers and photodiodes and are designed for reliability and stability in single-mode fiber operation. Both parts are surface mount mini-DIL laser diode modules coupled to a single mode fiber with a pigtail. The OL3300W is designed specifically for use in 155 Mb/s SONET systems, and the OL3300N-02 is designed for 622 Mb/s SONET systems.

## Anadigics PA Module Reduces Components for CDMA Handset Designs

**Warren, NJ.** Anadigics offers a highly-integrated CDMA PA, the AWT6101, which minimizes design cycle time, saves board space (it is only 7 mm x 7 mm) and reduces cost. Operating from 1850-1910 MHz, it is designed for use in PCS wireless handsets and other communications systems that require high linearity and efficiency, such as wireless local loops (WLLs). Designed as a drop-in PA solution to support CDMA handsets operating at +3 V dc, the AWT6101 features internal RF matching. Additionally, the PA module uses the manufacturer's integrated dc-to-dc converter technology, which allows the benefits of GaAs devices without the need to supply negative voltage and additional supporting components in system designs.

For power management, the AWT6101 delivers linear operation up to +29 dBm with high efficiency of 32%. The part features less than 10  $\mu\text{A}$  leakage, which translates into extended standby times. In addition, it is self-contained and manages voltage turn on and turn off synchronization with a single interface pin.



*Anadigics' AWT6101 is a CDMA PA solution which eliminates the need for a negative voltage supply.*

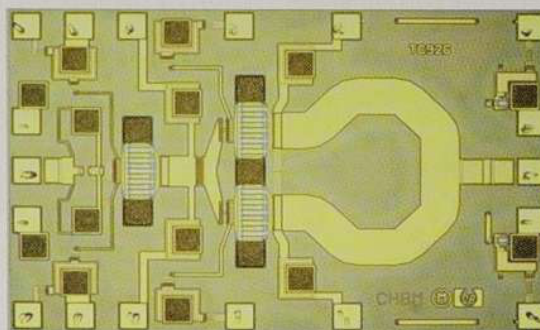
## Millimeter-wave ICs from HP

**Santa Rosa, CA.** The HMMC-5034 is a GaAs MMIC chip targeted for millimeter-wave point-to-point and point-to-multi-point wireless communications systems, including cellular infrastructure, broadband wireless access and European multi-

point video distribution systems (MVDS) in the 37-42.5 GHz range. At 40 GHz the HMMC-5034 provides +23 dBm of output power at 1 dB gain compression and 8 dB of small-signal gain. It is designed to be driven by HP's HMMC-5040, a 20-40 GHz MMIC amplifier, to provide improved lin-

earity or power boosts of 3 dB or more. It is supplied as a 1.6 mm<sup>2</sup> chip. Featuring input and output matching circuitry for operation in standard 50  $\Omega$  environments, the HMMC-5034 offers operation over a broad range of bias currents (4.5 V drain potential), excellent intermodulation distortion (IMD) characteristics and plated through-holes to the chip backside for easy ground connection. It has an integrated output power detector with reference diode.

Two new GaAs Schottky-barrier diode chips for 20-50 GHz cellular infrastructure and broadband wireless transceiver modules. These new products have large bond pads, making them suitable for either wire-bond or flip-chip assembly. The first, the HSCH-9501, is a high-performance mm-wave series pair diode, supplied as a 0.37 mm<sup>2</sup> chip, in a 'tee' configuration that can be used as a sub-harmonically pumped mixer or frequency multiplier in microwave- and mm-wave transceivers. The second is a high-performance millimeter wave antiparallel pair diode that can be used as a balanced mixer or frequency multiplier in microwave- and mm-wave transceivers. The HSCH-9551 is supplied as a 0.20 mm<sup>2</sup> chip. Both diodes feature typical values for junction capacitance of 40 fF per diode and low series resistance of 3  $\Omega$ .





## Optical Fiber Conference

San Diego, February 22-26

*Source lasers, pump lasers, VCSELs<sup>[1]</sup> and microelectronic ICs all featured strongly at this year's OFC, which also included a demo of 40 Gb/s TDM transmission down a single fiber, and the first commercially available resonant cavity LED.*

TIM WHITAKER

In his plenary talk at this year's Optical Fiber Conference (OFC), Jack Wimmer of MCI WorldCom outlined a list of requirements for the next generation of communication systems. According to Mr Wimmer, today's telecommunications world includes 140 million Internet users, over 50 million host computers, 700 million web pages and 830 million telephone lines. The number of Internet users will reach 300 million by 2001, and data demands will grow much more rapidly than traditional voice. "Data already exceeds voice internationally," said Wimmer. "Within 5 years, the data network will grow to be many times the size of the entire network of today - the network that has taken over 100 years to build."

"Advances in photonics are directly responsible for the significant drop in the cost of providing bandwidth," continued Wimmer. "Higher speed transmission, DWDM and optical amplifiers have all contributed to this trend. But you must not become complacent...the requirements for network capability and bandwidth will be orders of magnitude greater than they have been in the past."

Mr Wimmer was able to outline a "shopping list" of system requirements, many of which will be achieved using advanced compound semiconductor devices. "To support the tremendous capacity demands that will be driven by the digital economy, we must have hundreds of wavelengths, with TDM bit rates

reaching 40 Gb/s," said Wimmer. "Also, DWDM now requires systems operating in the L-band (1565-1610 nm). While amplifiers for this wavelength range are at hand, we also require tunable lasers and tracking filters to allow us to use the systems more effectively. With hundreds of wavelengths and very large networks with many nodes, we will need effective wavelength management techniques to use the network efficiently. This will include all-optical networking elements, such as optical cross-connects and wavelength converters. We will also need fiber capable of supporting many wavelengths, at 40 Gb/s, over long distances. Finally, there is a real possibility that submarine systems will become the next bottleneck as we build the global broadband network...we will need to push the state of the art here, just as we are doing with terrestrial systems."

### 40 Gb/s Transmission

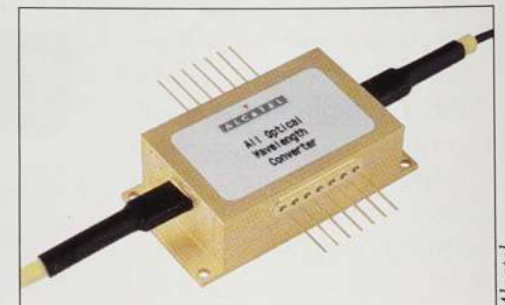
One of the highlights of the OFC vendor exhibition was **Alcatel's** demonstration of a 40 Gb/s optical link using a single laser source, which was capable of transmission along 31 km of single mode fiber without the need for dispersion compensation. Using dispersion compensated fiber, the link was extended to 111 km.

Shortly after OFC, **Lucent Technologies** announced that MCI WorldCom would be the first carrier to test its WaveStar 40G Express system.

Lucent's 40 Gb/s TDM technology enables the system to transmit the equivalent of 500,000 simultaneous phone calls per second over a single wavelength. MCI WorldCom recently hosted early lab system trials of the system, focussing on the performance over standard fiber and through optical switching systems at distances up to 100 km. Lucent will deliver its WaveStar 40G Express to MCI WorldCom for testing by the fourth quarter of 1999, and the system will be commercially available by March 2000.

### All-Optical Networking

Semiconductor optical amplifiers are emerging as crucial components in the development of all-optical networks, in which optical signals are switched, routed and regenerated without electro-optic conversion. SOAs are now available from several vendors including **Alcatel**, **Samsung** and **Uniphase**, while **NTT** was showing an 8-channel SOA gate array module.



*Alcatel's 1901 ICM wavelength converter shifts digital modulation from one carrier wavelength to another.*

<sup>[1]</sup> For news on VCSEL developments, see the Cover Story feature beginning on page 16.



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At OFC, Alcatel introduced a 10 Gb/s wavelength converter, based on an integrated Mach-Zehnder structure. The 19011CM device shifts the digital modulation from one optical carrier wavelength to another and could be used in a wavelength-translating optical cross-connect (OXC), as distinct from an OXC which can shift an incoming wavelength onto a different outgoing fiber.

The new device also achieves 2R optical regeneration. 1R regeneration refers to re-amplification, which is performed by EDFAs; 2R refers to amplification and reshaping, while 3R incorporates 2R in combination with retiming. In today's systems, signals are reshaped and retimed electronically at regular intervals.

## L-band Transmission

To meet the growing demand for more channels in DWDM systems, Alcatel announced new **laser modules for the L-band** (1565-1610 nm), together with an optical fiber amplifier operating in the same window. L-band amplifiers were also exhibited by Nortel Networks and Corning.

A major concern in networks with 80 or more channels is the need to carry spare laser sources at each wavelength

and at every optical node. One way to reduce this problem is through the use of tunable laser sources. At OFC, **Nortel Networks** announced a **DFB laser** with a **15 nm tuning range**, equivalent to 18 channels at 100 GHz spacing or 36 channels at 50 GHz spacing. The laser is a "simple, controllable and easy-to-manufacture device" containing three cascaded sections which can be separately biased and which have a 5 nm tuning range. Each section addresses one region of the spectrum, with the precise wavelength within that region determined by the temperature. The laser is packaged with an internal, Etalon-based wavelength stabilization device that precisely controls the wavelength within narrow tolerances once selected.

## High Performance Source Lasers

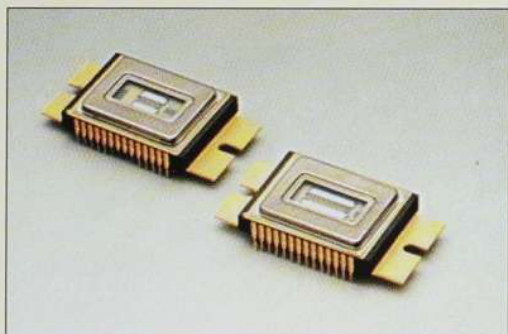
Several companies (e.g. **Ericsson**, **NTT**, **Hitachi**) showed 10 Gb/s source modules containing DFB lasers and electroabsorption modulators integrated on the same chip. **Alcatel** received a new product award from OFC for their 1915 LMM device, an integrated EAM-DFB source that is offered in 40 channels between 1530-1560 nm.

**Mitsubishi Electronics** announced 10 Gb/s transmitter/receiver pairs. The transmitter incorporates a cooled electroabsorption modulator (EAM) integrated with a DFB laser, together with a driver IC, and is priced at \$18,500 in 100 unit quantities. The receiver uses a PD pre-amp and additional ICs for reshaping, retiming and regenerating the optical signal, and is priced at \$8,000. In comparison, Mitsubishi's transceiver module for OC-3 (155 Mb/s) systems, operating from a single 3.3 V supply in the temperature range from -40°C to +85°C, is available for \$405. Mitsubishi also introduced two series of integrated EAM-DFB laser diodes. The 10 Gb/s model is priced at \$5,050 while the 2.5 Gb/s unit is priced at \$2,500.

Both Nortel and Lucent exhibited highly integrated OC-48 modules. **Lucent's** TransLight transponders combine up to 15 optical and electrical ICs in a package measuring 3.5" x 2.5" and contain 2.5 Gb/s transmitters and receivers together with clock synthesis and recovery circuits. In addition, one of the new modules provides electrical mux/demux functionality, while the other converts optical signals from one wavelength to another.

## DWDM Monitoring

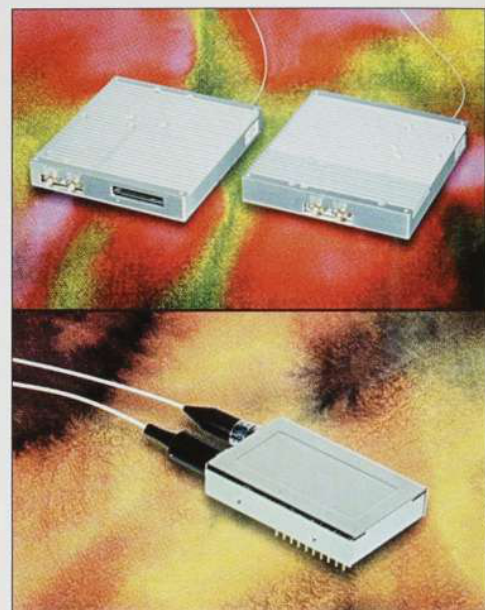
Linear InGaAs arrays are now being used to monitor the optical power of each channel in DWDM systems. The optical signal is spread out according to wavelength, so that each channel falls onto a different section of the array. By reading the signal across the array, each wavelength is detected in sequence. These arrays, sold by **Sensors Unlimited** and **Hamamatsu**, feature 1x128 or 1x256 InGaAs detectors hybridized to a CMOS readout circuit.



Hamamatsu

**Ericsson** introduced another module in its range of 1510 nm laser sources for optical supervisory channel (OSC) applications. The OSC transmits monitoring and alarm signals between EDFAs, using a wavelength outside the usable bandwidth of the fiber amplifier.

*Linear InGaAs sensors are now being used to monitor multi-channel DWDM systems.*



Mitsubishi Electronics

*Mitsubishi Electronics' 10 Gb/s transmitter and receiver modules (top) are priced at \$18,500 and \$8,000 respectively, while 155 Mb/s transceiver modules (bottom) cost only \$405.*



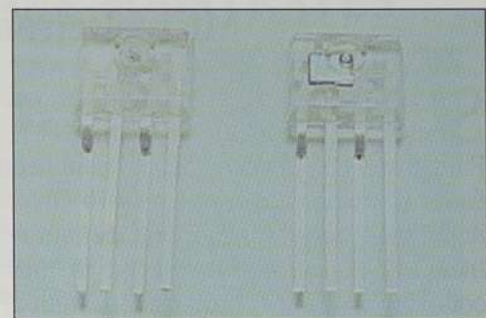
## 650 nm Transmission - Mitel Announces Resonant Cavity LEDs

There are a growing number of applications for low cost data transmission along plastic optical fiber (POF) at 650 nm, including 155 Mb/s ATM local area networks, and 100 Mb/s Fast Ethernet. 5.6 Mb/s proved sufficient for DaimlerChrysler when they replaced the copper wiring in the new S-class Mercedes with POF, linking all the audio, communications and navigation systems in the car. The use of POF provides a significant weight saving and eliminates electromagnetic interference. Another important application is to use POF to link consumer appliances e.g. PCs, DVD

players, digital cameras etc, to provide a low cost, high bandwidth and user-friendly data transfer link.

**Hamamatsu** introduced a red LED for 650 nm POF transmission, which offers a transfer speed up to 50 Mb/s. The rise and fall time is less than 8 ns, light output is at least -7 dBm, forward voltage is typically 1.9 V and the reverse current is 10  $\mu$ A. The LEDs cost \$3.05 in production quantities.

For higher data rate applications, **Mitel Semiconductor** introduced the first commercial resonant cavity (RC) LED. The 1A466 **RCLED** is designed for

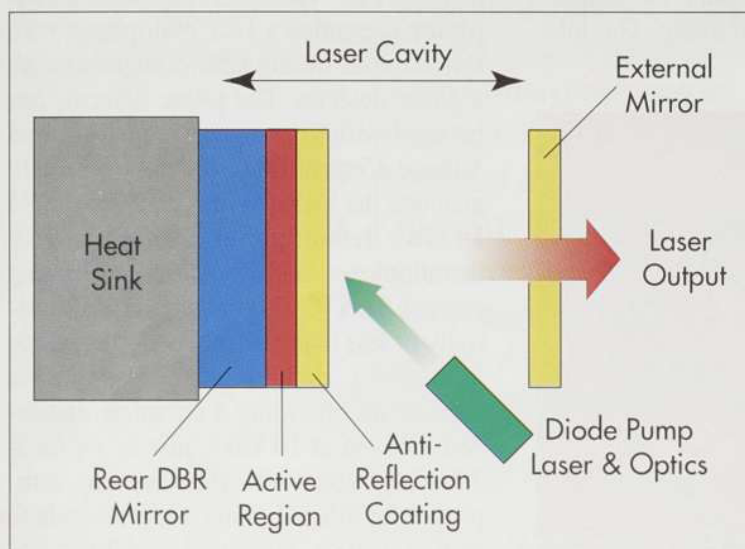


*Hamamatsu's 650 nm red LEDs are suitable sources for 50 Mb/s transmission through plastic optical fiber.*

250 Mb/s POF communication at 650 nm, and features a fiber-coupled power of 0.5 mW at 30 mA drive current. The spectral linewidth is less than 10 nm, and the device is supplied in a non-hermetic plastic package.

## EDFAs and Pump Lasers

While single 980 nm pump lasers are limited to around 200 mW of output power, **Coherent's** new optically-pumped semiconductor (OPS) technology is capable of delivering more than 500 mW, with over 85% coupling efficiency into single-mode fiber. The OPS device (see diagram) contains a GaAs-based surface-emitting structure, grown by MBE at Coherent Tutcore in Finland, which is optically pumped by a separate, multimode 808 nm diode. In the VCSEL-like structure, GaAs cladding layers surrounding the QWs in the active region absorb the pump light. The laser cavity is defined by the rear epitaxial DBR mirror and an external concave mirror which can be aligned to produce a cir-



*Coherent's optically pumped semiconductor (OPS) technology contains an MBE-grown VCSEL-type structure which is pumped by an 808 nm diode, producing over 500 mW of single-mode power.*

cular TEM<sub>00</sub> output mode from the VCSEL. By changing the thickness and composition of the QWs, the output wavelength can be selected in the 750-1300 nm range. Coherent are completing the development of OPS packaging technology suitable for Bellcore qualification, and expect to begin customer trials of prototypes by May of 1999.

**Furukawa Electric** announced a 1480 nm laser module with a record-beating power of 250 mW. The third generation chip incorporates new epilayer and waveguide designs, and better heat dissipation in the packaging to allow an operating temperature of 70°C. The company reports that production capacity for 1480 nm modules, which was around 100,000 units in 1998, will be doubled during 1999. **Mitsui Chemical** announced a 980 nm pump module based on their novel epitaxial decoupled confinement heterostructure (DCH) approach, which offers 200 mW of fiber-coupled output power.

**SDL** was showing several pump products, including a multiplexed pump combining the output of four lasers at 970, 975, 980 and 985 nm. This provides a total output power of 500 mW within the EDFA pump band. Also on show was a multi-mode 915 nm module, suitable for pumping ytterbium-doped double-clad fiber lasers, and offering 800 mW from a 100  $\mu$ m multi-mode fiber. Finally, SDL announced a Raman fiber laser source providing up to 1.5 W at 1480 nm.

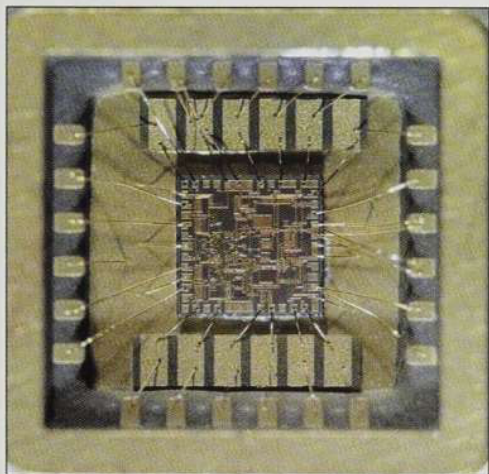
**Uniphase** announced that it is now supplying 980 nm pump modules, based on its fourth generation E2 laser chip technology. Uniphase will continue to supply unpackaged chips to a large number of module vendors, notably **Nortel Networks**, who announced a 200 mW module at OFC. Uniphase has introduced a Bellcore-qualified butterfly package, and says that the new modules are available in all industry standard configurations, with kink-free power levels up to 200 mW. Additionally, Uniphase offers a multi-laser pump module producing 500 mW of rated power within the 980 nm band.



## Microelectronic Components

Several vendors, including those detailed below along with NTT, Fujitsu and Oki Semiconductor, exhibited GaAs ICs with data rates up to 10 Gb/s. **Anadigics** new **transimpedance amplifier** (TIA), the ATA30021, is the company's first product designed specifically for DWDM systems. The part, which is for **2.5 Gb/s DWDM** receivers, offers a very low group delay of less than 50 ps, meaning that the TIA performs with consistent amounts of gain at all frequencies in the bandwidth of the channel. "DWDM systems are now handling up to 80 channels," explains Dan Trepanier, Anadigics' Fiber Optics sales manager, "so the importance of very low group delay is increasing because it allows these channels to be recovered with minimal bit errors." The TIA is fabricated on a **GaAs MESFET** process and operates from a 5 V supply, while the next generation of products will be PHEMT-based, and will operate at 3.3 V.

**Lucent Technologies** announced three new ICs - a clocked laser driver (LG1627BXXC), a modulator driver (LG1626DXC), and a decision circuit (LG1601) - to support OC-48 (2.5 Gb/s) physical layer applications. The devices are fabricated using a **GaAs heterojunction FET** process, and are designed for optical systems with a low amount of jitter and a modulation current of up to 90 mA.

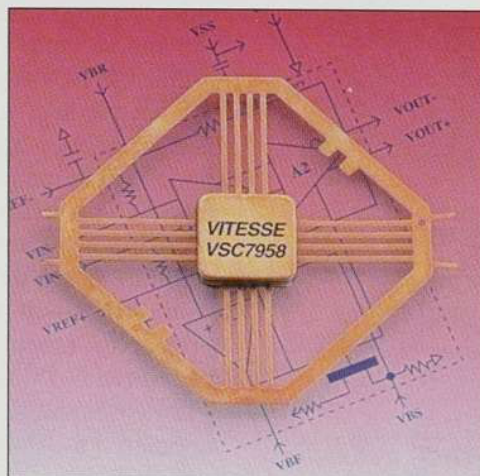


*Lucent Technologies' clocked laser driver is designed for 2.5 Gb/s physical layer applications.*

**Multilink** introduced two **GaAs HBT-based, 16 bit mux/demux ICs for 10 Gb/s** Sonet/SDH transmission systems. These ICs provide an interface between multiple 622 Mb/s data streams and OC-192 line terminal equipment (laser or modulator driver, limiting amplifier). The MTC1203 is a 16:1 multiplexer with an integrated clock multiplier unit, and provides retimed data outputs with 30 ps typical rise and fall times. The MTC1204 is a 1:16 demultiplexer with integrated clock and data recovery, and features 20 mV input sensitivity.

**Nortel Networks** exhibited a **10 Gb/s receiver** module, the ATA9600, which combines a high sensitivity avalanche photodiode with an HBT transimpedance amplifier.

**TriQuint** introduced the first product of its new family of 2.5 Gb/s OC-48 SONET/SDH ICs, which feature extremely low jitter. The TQ8213 is a **32:1 multiplexer integrated with an opto-electronic driver**, which allows the part to directly drive a laser diode or optical modulator without the need for additional driver electronics. The clock synthesis PLL function is integrated with a 10-75 mA laser driver (or a 0.5-3.75 V electro-optical modulator driver) in a single monolithic device. The TQ8223 1:32 demultiplexer incorporates a PLL-based clock and data recovery function in addition to byte and word framing. The inte-



*Vitesse announced the VSC7958 2.5 Gb/s limiting amplifier for use as a post amplifier in wide band fiber-optic links.*

## Packaging

In a step towards low cost fiber-optic components, **Siemens Microelectronics** introduced the OptIC, a surface-mount design providing a common component platform for both telecom and datacom applications. OptIC is compatible with standard automated manufacturing processes including pick-and-place board assembly and reflow soldering, and eliminates special handling of parts, including lead bending and hand soldering. The first products will be a PIN photodiode with preamplifier, and a laser, with others to follow.

grated clock and data recovery function provides reduced optical module cost while improving system level jitter performance. Both ICs are fabricated using TriQuint's **GaAs MESFET** process, and run from a single +5 V supply. Transceivers, 3.3 V operation, and OC-192 (10 Gb/s) products are planned for the future.

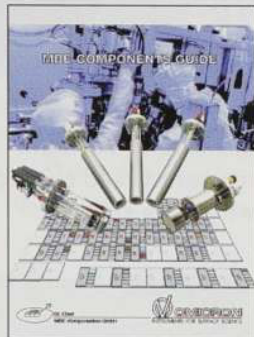
Focussing on reducing the cost of 10 Gb/s transmission systems, **Vitesse** introduced the VSC8073/4 16-bit Mux/Demux chipset. The ICs are in industry standard plastic packaging, making their cost around one-fifth that of comparable alternatives. The VSC8073 **10 Gb/s multiplexer** integrates a 16:1 multiplexer with synchronous timing control together with a phase detector. The phase detector can be used with an external loop filter and Voltage Controlled Oscillator (VCO) to generate the bit rate clock. The VSC8074 **10 Gb/s demultiplexer** integrates a 1:16 demultiplexer with synchronous timing control. This IC also has input data sensitivity of less than 500 mV peak to peak on high-speed data inputs. "Vitesse is focused on providing a complete end-to-end solution at 10 Gb/s, just as we do at 2.5 Gb/s, where we offer the most complete 2.5 Gb/s solutions available today," said Vitesse's Gregg Borodaty. "The VSC8073 and VSC8074 are the first devices in this series of components that will help to enable the growth of the 10 Gb/s market."



# New Products/ New Literature

## New MBE Components Guide from OMICRON

The comprehensive range of MBE equipment now available from OMICRON is detailed in the new MBE Components Guide. The MBE sources are manufactured by Dr. Eberl MBE-Komponenten, Germany - a company with many years of experience and the ability to supply compact and customised solutions. An easy to use selection guide can be found on the homepage dedicated to the MBE product range.



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# Substrates for Compound Semiconductors



## Introduction

American Xtal Technology, an independent, public company (AXTI on NASDAQ) is the premier U.S. supplier of substrates for compound semiconductors. Internationally, AXT is recognized as one of the leading suppliers of these materials. The Company exploits the advantages of vertical gradient freeze (VGF) crystal growth for gallium arsenide (GaAs), indium phosphide (InP), gallium phosphide (GaP) and germanium (Ge). Under development are gallium nitride (GaN) grown by hydride vapor phase epitaxy (HVPE) and silicon carbide (SiC) and aluminum nitride (AlN) grown by sublimation.



Figure 1. AXT's GaAs and InP manufacturing facility in Fremont, CA

The recent explosive growth of the GaAs market has been driven by the rapidly increasing demand for wireless communications technology. With the support of the DoD Title III SI GaAs Program, AXT was able to establish the unique position of VGF technology. Since then, it has become clear to other leading GaAs manufacturers that VGF-like technology will dominate the crystal growth market, especially as the demand for 150 mm, or greater, diameter wafers increases and the market trends towards epitaxial growth technology.

## Indium Phosphide

The next generation military technologies depend heavily on SI InP. However, several high quality Japanese suppliers dominate the supply of SI InP. Again, in order to ensure a commercially viable U.S. supply, AXT was tasked by the Title III Office in 1997 with improving the quality of SI InP, expanding production capacity and increasing the wafer

diameter to 100 mm. As with the SI GaAs, the superior mechanical and electrical properties of VGF-grown wafers will play a key role.

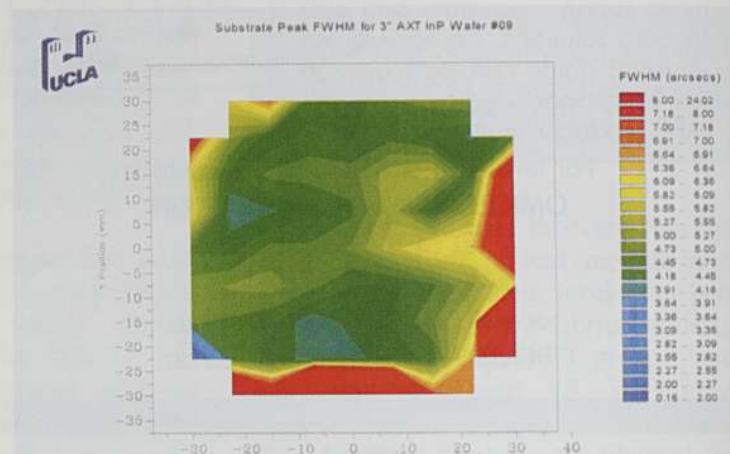


Figure 2. Bragg angle distribution map of a 3" VGF SI InP wafer showing the good crystallinity of the substrate. AXT is now producing high quality 2", 3", and 100 mm (4 inch) semi-conducting (SC) and SI InP by the VGF method.

AXT is now producing high quality 2", 3", and 100 mm (4 inch) semi-conducting (SC) and SI InP by the VGF method.

## Recent Developments at AXT

From 1996 to 1998 AXT has completed the construction of the largest U.S. facility for manufacturing substrates for III-V compound semiconductors. In addition, AXT announced the purchase of a 30,000 square foot facility in Beijing, China to begin production by the middle of 1999.

AXT serves approximately 300 customers in 15 different countries. The customer profile includes leading government research centers and universities, as well as Fortune 500 companies.

## AXT Quality

In September 1995, the company achieved ISO 9002 certification. Since then AXT's QA System has undergone regular surveillance by the certification agency, SGS Yarsley, and in 1998 AXT completed a 3 year certification renewal. All of AXT's commercial substrate product lines are covered



by the ISO 9002 certification, assuring manufacturing to the highest quality standards available.

## Wafer Strength

A direct consequence of the low defect density in VGF GaAs and InP is the increased mechanical strength of the material. High mechanical strength is obviously desirable, since it results in reduced wafer breakage during volume processing. It also allows the use of thin wafers during processing, eliminating the thinning steps often required for devices. The superior mechanical properties of VGF materials have led to a unique AXT feature: extra-thin, 100  $\mu\text{m}$ -thick GaAs wafers. Undoubtedly, VGF wafers will have similar capabilities as InP also.

| Vendor 1 | Vendor 2 | AXT      |
|----------|----------|----------|
| 1.5 lbf  | 6.7 lbf  | 100+ lbf |

Table 1. Comparison of strength of 100 mm diameter LEC and VGF SI GaAs wafers using the TT biaxial stress test.

## Germanium

Ge, the oldest semiconductor, has achieved new prominence as a substrate for space-based, high-efficiency, III-V solar cells. AXT supplies VGF-grown, epi-ready, round wafers up to 100 mm wafers diameter or epi-ready rectangular wafers in a variety of user required dimensions.

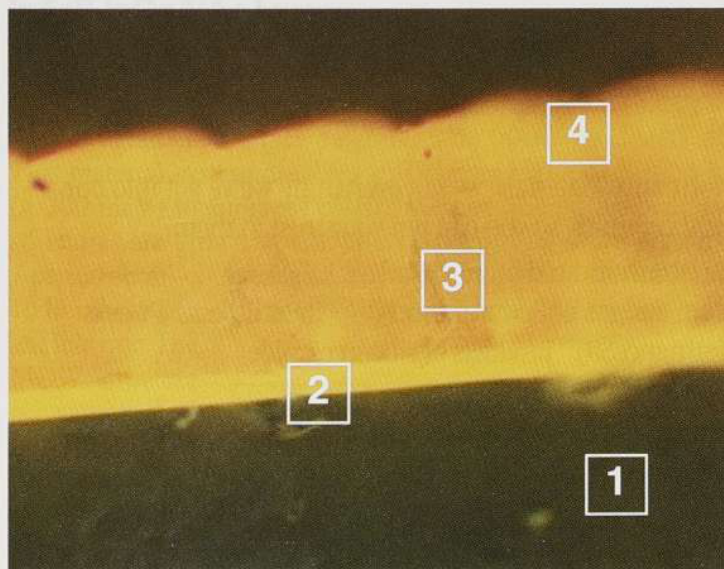


Figure 3. HVPE ELO micrograph with a LOMO luminescent microscope. The initial GaN layer (2) on sapphire (1) luminesces strongly due to high defect density. The luminescence fades away in the mask windows (3) as the defect density is reduced. The grain boundaries (4) above the  $\text{SiO}_2$  mask are visible.

## Gallium Nitride

AXT has licensed the HVPE GaN growth technology developed by Dr. Richard Molnar at MIT-LL. AXT now has available unintentionally doped GaN thin-films on sapphire

for applications. These films have been used by a number of different MOCVD and MBE groups to grow nitride structures. The films still attached to sapphire are suitable for the direct growth of LEDs. In the near future, AXT will supply GaN layers with controlled doping. The longer term objective is to provide low-defect, free-standing GaN substrates up to 2 inches in diameter for laser and power device applications.

## Aluminum Nitride

AlN is an attractive substrate for III-nitride devices since it is well suited for the growth of AlGaIn compounds. AlN has a thermal conductivity that is almost as high as SiC. It is an excellent insulator and may be the most suitable substrate for nitride integrated circuits. AXT is working under a BMDO Phase II SBIR with Prof. James Edgar at Kansas State University to grow AlN boules by the sublimation-recondensation method.

## Silicon Carbide

SiC has already been demonstrated to be an important material for power devices. Its major drawback is the high micropipe density that limits the size of power devices that can be made using currently available substrates. AXT is supporting TDI, Inc. in their development of a micropipe filling process. In the first phase of their SBIR program, TDI demonstrated over a factor of 100 reduction in micropipe density. Micropipe-filled SiC wafers are available. AXT is currently developing the growth of large diameter (75+ mm) boules of SiC that are based on reduced micropipe seeds.

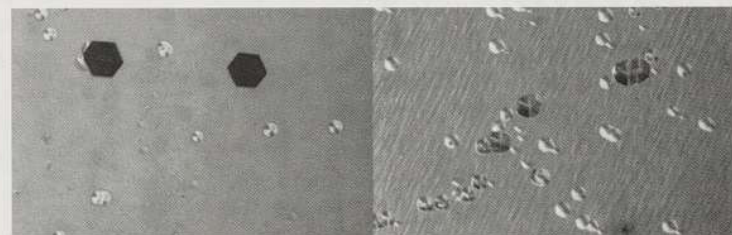


Figure 4. SiC wafer as purchased (left) and with filled defects and micropipes (right). Some residue of the large defects remains. The other defects are gone.

## Conclusions

The demand for AXT's products continues to increase, and the company is playing a more and more important role in this industry. AXT is taking a pro-active approach to meeting the requirements of present and future customers over the entire spectrum of electronic and opto-electronic device substrates from the ultraviolet to the infrared and from low noise to high power.

See our web page at: <http://www.axt.com>  
Contact: [sales@axt.com](mailto:sales@axt.com)



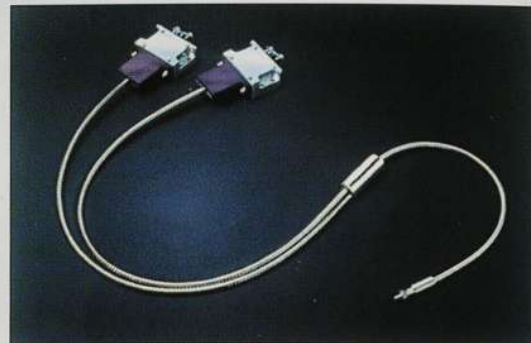
## Optoelectronic Devices

### 11 W from 1.9 $\mu\text{m}$ Laser Diode Arrays

X. He et al, Elec. Lett., 1999, 35(5), p. 397

Diode laser arrays at 1.7-2.1  $\mu\text{m}$  are used to pump some types of solid-state laser, and have potential applications in medicine, remote sensing and eye-safe illumination. This paper, from Opto Power Corp., reports 11 W CW power at 1.87  $\mu\text{m}$  from a 1 cm wide GaInAsP/InP monolithic diode laser array mounted on a conductively cooled heatsink. The lasers were grown by LP-MOCVD on an n-type InP substrate, and consist of an InGaAs strained QW active region with GaInAsP waveguides and InP cladding layers. The arrays consist of 16 broad area devices (100  $\mu\text{m}$  wide aperture) distributed over a 1 cm width (16% fill factor), and are mounted p-side down on a conductively cooled heatsink. The slope efficiency at 3x threshold current was 0.32 W/A, corresponding to a differential quantum efficiency of 48%, and a maximum power conversion efficiency of 23% was achieved at a drive current of 24 A.

A 2D array was also constructed by mounting 12 monolithic laser bars onto a grooved, conductively cooled BeO heatsink with a 2.3 mm pitch. At a 25% duty cycle with 1 ms pulse width the 2D array produced 100 W peak power at a drive current of 40 A.



*Opto Power recently introduced the first commercially available high power diode arrays at 1.8  $\mu\text{m}$ , offering 7 W CW output from a single array, 3.5 W from a fiber-coupled array, and 100 W (25% duty cycle at 1 ms) from a stack.*



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## First Room Temperature CW Bipolar Cascade Laser

S. Patterson et al, Elec. Lett., 1999, 35(5), p. 395

This paper from MIT reports the first CW operation at room temperature of epitaxially-stacked lasers coupled by an Esaki junction. The device is also termed a bipolar quantum cascade laser. The epitaxial structure, grown by GSMBE on a GaAs substrate, contains two identical lasers, in which the active region is a single  $\text{In}_{0.2}\text{Ga}_{0.8}\text{As}$  QW in the center of a  $0.22\text{ }\mu\text{m}$  GaAs waveguide. The cladding layers are  $0.75\text{ }\mu\text{m}$  InGaP doped with Si or Be. The two epitaxially-stacked lasers are coupled by an Esaki junction consisting of heavily Be- and Si-doped,  $25\text{ nm}$  thick GaAs layers. The fully processed gain-guided Fabry-Perot devices measuring  $5\text{ }\mu\text{m} \times 450\text{ }\mu\text{m}$  were mounted to a heat sink. When the second laser junction reaches threshold, the slope efficiency abruptly changes from  $0.313\text{ W/A}$  to  $0.622\text{ W/A}$  per facet, corresponding to a differential quantum efficiency of  $99.3\%$  at the  $992\text{ nm}$  average lasing wavelength.

## Highly Reliable Operation of 650 nm Lasers at $80^\circ\text{C}$

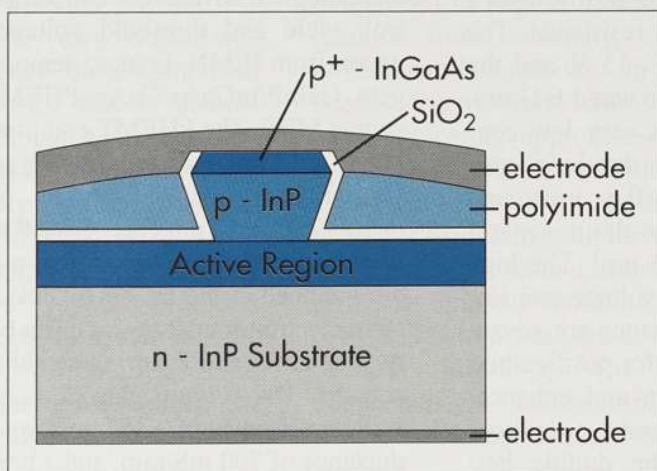
M. Ohya et al, Elec. Lett., 1999, 35(1), p. 46

Highly reliable lasers operating with low current at high temperatures are required for emerging DVD applications such as automobile navigation systems and portable miniaturized systems e.g. personal computers and movie players. Conventional  $650\text{ nm}$  AlGaInP lasers are unable to meet these demands. This paper, from NEC, reports lasers fabricated by a three-step LP-MOVPE process on a (115A) GaAs substrate - this is a (001) GaAs substrate misoriented by  $15.8^\circ$  toward [110]. The misorientation suppresses spontaneous ordering in GaInP and AlGaInP, and minimizes thickness variations in the MQW due to step bunching. In addition, a strained MQW with four  $5\text{ nm}$  compressively strained GaInP wells was employed as an active layer to increase the gain and reduce the threshold current density. With a cavity length of  $500\text{ }\mu\text{m}$ , the devices operated at  $5\text{ mW}$  up to  $115^\circ\text{C}$ . For a  $350\text{ }\mu\text{m}$  cavity length, the maximum operating temperature was  $105^\circ\text{C}$ , with stable operation for more than 1000 hours at  $80^\circ\text{C}$ . The operating current was  $60\text{ mA}$  and the lifetime was estimated as 92k hours at  $80^\circ\text{C}$  and  $5\text{ mW}$ .

## High Temperature Characteristics of $1.3\text{ }\mu\text{m}$ InAsP-InGaAlAs Lasers

M. Yamada et al, Photonics Tech. Lett., 1999, 11(2), p. 164

This paper, from NEC, reports high temperature characteristics of ridge waveguide lasers (see diagram) with InAsP-InGaAlAs strained MQWs. This material system provides sufficiently high conduction band offset  $\Delta E_c$  ( $> 300\text{ meV}$ ) to suppress carrier leakage at high temperatures. The device structures are grown by GSMBE on n-InP. The active region contains a 5 or 7 period strain-compensated MQW region, with  $7\text{ nm}$   $\text{InAs}_{0.45}\text{P}_{0.55}$  wells and  $10\text{ nm}$   $\text{In}_{0.42}\text{Ga}_{0.23}\text{Al}_{0.35}\text{As}$  barriers, and  $5\text{ nm}$  InP spacers between each well and barrier. The MQW structure is sandwiched in an InGaAlAs/InAlAs separate confinement heterostructure. The characteristic temperature of a  $350\text{ }\mu\text{m}$  long laser was  $143\text{ K}$  under pulsed conditions, and  $127\text{ K}$  when operated CW, in the temperature range  $25\text{--}85^\circ\text{C}$ .



*Schematic of the  $2\text{ }\mu\text{m}$  wide ridge waveguide structure. The active region contains an InAsP/InGaAlAs MQW with a conduction band discontinuity of over  $300\text{ meV}$ .*

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## $1.55\text{ }\mu\text{m}$ Lasers With $T_0$ of $122\text{ K}$

N. Ohnoki et al, Elec. Lett., 1999, 35(1), p. 51

Low cost  $1.3\text{ }\mu\text{m}$  and  $1.55\text{ }\mu\text{m}$  lasers capable of operating at high temperatures without cooling systems are required for fiber-optic access networks and datalink applications. In conventional InGaAsP/InP lasers, the small conduction band offset  $\Delta E_c$  results in poor carrier confinement in the quantum wells, and is responsible for poor high temperature characteristics. Improved characteristic temperatures have been reported in the AlGaInAs system, which has a larger  $\Delta E_c$  value. This paper, from the Tokyo Institute of Technology, reports an AlGaInAs-based laser operating at  $1.55\text{ }\mu\text{m}$  with a record high  $T_0$  of  $122\text{ K}$  in the  $25\text{--}85^\circ\text{C}$  range. The device features a highly strained AlAs/AlInAs superlattice which acts as a multiquantum well barrier. The AlAs layer is selectively oxidized to provide current confinement. The device was grown by LP-MOCVD on an n-InP substrate and includes a strain-compensated MQW active region containing  $4.8\text{ nm}$   $\text{Al}_{0.13}\text{Ga}_{0.17}\text{In}_{0.7}\text{As}$  wells and  $10.2\text{ nm}$   $\text{Al}_{0.23}\text{Ga}_{0.28}\text{In}_{0.49}\text{As}$  barriers. This region was sandwiched by AlGaInAs ( $\lambda = 1.15\text{ }\mu\text{m}$ ) layers and a  $1.5\text{ }\mu\text{m}$  InAlAs cladding layer. The MQW barrier was grown in the upper p-InAlAs cladding layer. A  $50 \times 310\text{ }\mu\text{m}^2$  broad area laser with cleaved facets exhibited a threshold current density of  $1.1\text{ kA/cm}^2$  at  $25^\circ\text{C}$ .

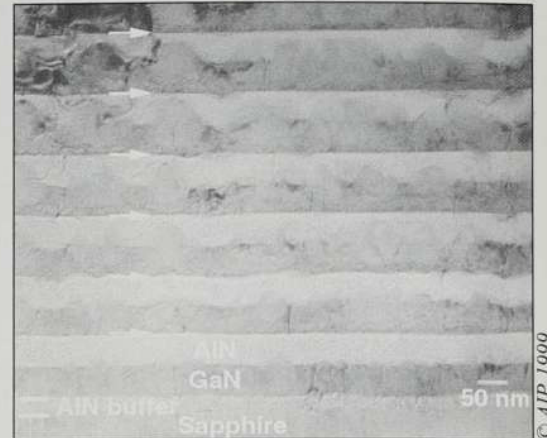


# Compound Semiconductor Materials.

## AlN/GaN Distributed Bragg Reflectors

H. Ng et al, Appl. Phys. Lett., 1999, 74(7), p. 1036

High reflectivity nitride-based multilayers are required for vertical cavity devices such as VCSELs and RCLEDs. While AlN/GaN quarter-wave stacks may be suitable for this purpose, there is a 2.5% lattice mismatch between the two materials. This paper, from Boston University, reports the growth of GaN/AlN multilayer stacks by electron cyclotron resonance (ECR) plasma-assisted MBE. Following nitridation of the sapphire substrate, an AlN buffer was grown, followed by a 20.5 period quarter-wave stack of alternating layers of AlN (50 nm) and GaN (46 nm) at 750°C. TEM studies (see photo) indicated that the GaN-on-AlN interface is always sharper and more distinct than the AlN-on-GaN interface, due to different growth modes which have been observed by other authors. AlN grows on GaN in the two dimensional (Frank-van der Merwe) mode, leading to a smoother and less abrupt interface, while GaN grows on AlN for approximately two monolayers in the 2D mode before switching to the 3D (Stranski-Krastanov) mode. The peak reflectance of the stack was measured as 95% at a center wavelength of 392.5 nm.



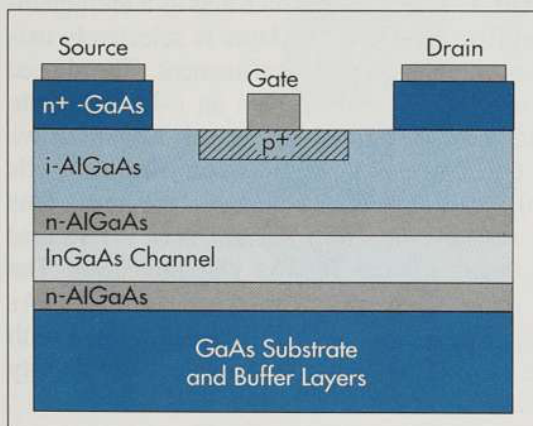
TEM of the first seven periods of the AlN/GaN DBR. The interface of GaN-on-AlN is always sharper and more distinct than the interface of AlN-on-GaN.

## Microelectronic Devices and Circuits

### Buried p-Gate Heterojunction FET

M. Nakamura et al, Elec. Lett., 1999, 35(4), p. 336

Power amplifiers for CDMA and other advanced wireless communication systems need to be highly efficient and have low distortion and positive voltage operation. This requires devices to exhibit a low on-current and good linearity of the drain current against gate bias. A high built-in voltage at the gate contact allows a threshold voltage close to zero, and makes positive bias operation possible. This paper, from Sony, reports the first successful fabrication of a heterostructure FET containing a buried p<sup>+</sup>-AlGaAs gate, which increases the built-in voltage at the gate and suppresses an increase in channel resistance. The device is a double heterostructure FET grown on GaAs (see figure). The undoped In<sub>0.2</sub>Ga<sub>0.8</sub>As channel is located between Al<sub>0.23</sub>Ga<sub>0.77</sub>As layers which contain n-type doping. After removal of the n-GaAs cap layer, the p<sup>+</sup>-AlGaAs gate was formed by Zn diffusion at 600 °C into undoped AlGaAs, resulting in an abrupt doping profile with a Zn concentration of >10<sup>19</sup>/cm<sup>3</sup>, suitable for low contact resistance. The turn-on voltage was ~1.5 V, the breakdown voltage was >15 V, and the threshold voltage at 0.5 mA/mm was 0 V. The on-resistance was 1.6 Ωmm,



which is very low considering the long gate length (0.8 μm) and source-to-drain separation (1.6 μm). The high built-in voltage and low on-resistance are advantageous for positive-bias operation and enhancement mode operation, while the double heterostructure provides excellent linearity of the drain current.

### 0.1 μm GaInP/InGaAs PHEMTs by GSMBE

M. Zaknoute et al, Elec. Lett., 1999, 35(6), p. 501

There are several advantages to replacing the Al<sub>0.2</sub>Ga<sub>0.8</sub>As/In<sub>0.2</sub>Ga<sub>0.8</sub>As/GaAs material system used for conventional PHEMTs with Ga<sub>0.51</sub>In<sub>0.49</sub>P/In<sub>0.2</sub>Ga<sub>0.8</sub>As/GaAs. The presence of DX centers in AlGaAs can affect the threshold voltage, transconductance and saturation current. Using GaInP, a higher breakdown voltage can be obtained since this material has a higher bandgap than AlGaAs. The high selectivity of etching between GaInP and GaAs gives technological advantages concerning gate recess control, yield and threshold voltage uniformity. This paper, from IEMN, France, demonstrates a 0.1 μm T-gate GaInP/InGaAs/GaAs PHEMT grown by gas-source MBE. The PHEMT comprises a 300 nm GaAs buffer, a 12 nm undoped In<sub>0.2</sub>Ga<sub>0.8</sub>As channel, a 3 nm Ga<sub>0.51</sub>In<sub>0.49</sub>P spacer, silicon planar doping at 6x10<sup>12</sup>/cm<sup>2</sup>, a 15 nm Ga<sub>0.51</sub>In<sub>0.49</sub>P barrier and a 25 nm heavily doped GaAs cap. A few monolayers of AlInP are included at the InGaP-InGaAs interface to maximize electron transfer, which can be reduced by intermixing of As and P during switching of the group V sources. The 0.1 μm gate devices exhibited a total source resistance of 0.35 Ωmm, an extrinsic transconductance of 700 mS/mm, and a breakdown voltage of 9 V. Excellent RF performance was observed, with f<sub>T</sub> of 120 GHz and f<sub>max</sub> of 160 GHz for a device biased at peak transconductance.



# Do We Need A Roadmap?

*Perhaps the time has come for consensus-based planning within the compound semiconductor community to help ensure continuing growth as the industry matures.*

*Herbert S. Bennett, Joseph G. Pellegrino, Daniel L. Rode,  
Thomas J. Shaffner, David G. Seiler and Emil Venere<sup>[1]</sup>*

Over the past four decades the silicon semiconductor industry has enjoyed a 15% compound annual growth rate. Such performance might be expected in emerging industries, but it is interesting to note that the silicon industry does not appear to be slowing as it matures. Many observers credit consensus-based planning and deliberate roadmapping efforts for the sustained growth of the silicon semiconductor industry over this past decade.

In the USA, the most important effort has been the National Technology Roadmap for Semiconductors (NTRS); it has been supplemented more recently by the International Technology Roadmap for Semiconductors (ITRS). These roadmaps have been an essential catalyst for the continued down-scaling of CMOS silicon technology, resulting in increased performance and lower cost.

Over the past five years we have witnessed the emergence of a compound semiconductor industry that is distinct from the silicon semiconductor industry. Given this fact, and the obvious success of consensus-based planning in the silicon arena, we wish to propose a question: Does the compound semiconductor industry need its own roadmap? And is the community ready to undertake the challenge of formulating an "International Technology Roadmap for Compound Semiconductors (ITRCS)"?

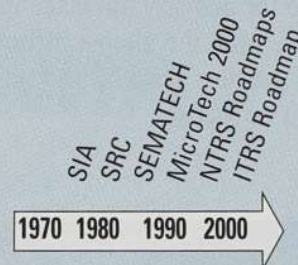
Segments of the compound semiconductor community are already considering the challenge seriously. From the historical perspective given in the sidebar, right, we are reminded that roadmap activities are already ongoing in the U.S. (NEMI) and Europe (MEL-ARI-OPTO) and in focused technology areas (OIDA). These may signify that the time is ripe for a more global roadmap initiative. After all, the major silicon roadmapping efforts of recent years were also preceded by smaller, scattered projects.

But of course, we must recall that there are important differences between the two technologies. Silicon is a large-volume consumer market focused on a narrow class of materials and devices, and based in large part on generic processes. Compound semiconductors were initially driven by defense funding, and even today, tend to require more fundamental research from university, industry and government laboratories. In part, this is because the materials base is very broad, and engineering approaches to process development within each materials system are not consistent. Nevertheless, the market is exploding with the wide variety of products. It should come as no surprise that opinions about the need for an ITRCS are almost as varied.

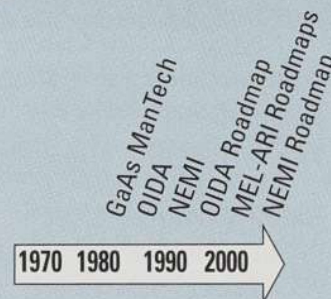
Our Metrology for Compound Semiconductor Manufacturing Project at the National Institute of Standards and

## Historical Events for Road-Mapping Activities

### Silicon Semiconductors



### Compound Semiconductors



## Relevant Roadmaps

- The Microelectronics Advanced Research Initiative Optoelectronics Technology Roadmap (MEL-ARI OPTO) is a European Commission effort in the area of III-V semiconductor interconnects for integrated circuits.

<http://europa.eu.int/>

- Roadmaps from the National Electronics Manufacturing Initiative (NEMI) treat numerous market applications, and have some specifically compound semiconductor-related content in the areas of energy storage and radio frequency devices, and optoelectronic integrated circuits components.

<http://www.nemi.org/>

- Roadmaps from the Optoelectronics Industry Development Association (OIDA) treat several diverse market applications and have some relevance to compound semiconductors in the areas of sensors, detectors, and displays.

<http://www.oida.org/>

<sup>[1]</sup> The authors of this article are in the Semiconductor Electronics Division at the National Institute of Standards and Technology in Gaithersburg, MD, except for Dan Rode, who is employed at Pendragon Corporation in St. Louis, MO.



Technology (NIST) has been concerned with the roadmap issue for some time. Given the mission of our organization, our strategy for compound semiconductor planning highlights critical materials and fabrication technologies where infrastructure development, including standards, can have meaningful impact. Our need was acute for industry guidance in defining where, from the almost infinitude of technical avenues available, our expertise could best be focused.

In the absence of a formal ITRCS, the Pendragon Corporation conducted under contract to NIST an industrial survey within the U.S. to define requirements in the materials technology arena appropriate to our focused mission and limited resources<sup>[2]</sup>. From the inputs of 27 participants representing 15 industrial firms, 16 projects were selected as representative of the gaps most frequently cited within the wireless community. While the scope of our effort was necessarily

limited, we found that this exercise was profoundly positive and successful.

This experience has led us to conclude that other groups might receive similar benefits from focused roadmapping exercises. We speculate that the need might be much larger, more prevalent and generic, considering all of the work going on in industry, university and government laboratories. We invite the question: Is the compound semiconductor industry ready to undertake this challenge? If so, who will lead the charge? What resources are needed? Are they also available for continued refinements and updates of the first edition?

Responses to our inquiries to date span the extremes from "there is no need" to "the need is critical." We would like to invite more responses from the readers of this magazine. Accordingly, we have established a web-site for collecting and discussing ideas, comments and questions relating to the possible creation of ITRCS. Your thoughts are welcome, and can be posted at

<http://www.eeel.nist.gov/812/itrcs.html>.

As "food for thought", we are supplying a preliminary list of action items - see box.

The compound semiconductor industry at times seems quite fragmented, and some segments, especially in the USA, have a certain entrepreneurial character that may seem incompatible with the concept of consensus-based planning. So we conclude with the words of Dr. Avtar Oberai, formerly from IBM and a founding director of SEMATECH: "No one is big enough to drive the totality of the infrastructure and pre-competitive investments on their own." Oberai was a key player in bringing about collaborative planning for the silicon industry. The compound semiconductor industry has much to learn from his experiences and from others in the silicon industry.

**Submit your thoughts about roadmapping via the web at**  
**[www.eeel.nist.gov/812/itrcs.html](http://www.eeel.nist.gov/812/itrcs.html)**

### What are key actions needed to make progress towards an ITRCS?

- Assess which applications are most amenable - are there areas where companies consider it in their long-term financial interests to share intellectual property and capital?
- Identify which organizations will sponsor the development and maintenance of the proposed ITRCS.
- Convene workshops that bring together scientists, engineers, and managers concerned with strengthening the compound semiconductor infrastructure.

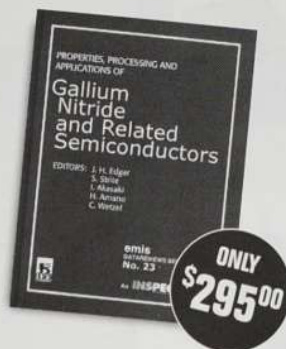
### What are metrics for assessing the impact of ITRCS?

With the diversity of opinions about how to proceed with ITRCS, how might we ultimately determine if it is worth the major investment? The investment itself, or financial outlay can be measured in a straightforward manner by monitoring expenditures, committee meetings and public relations and dissemination functions. However, methods by which to measure the impact the roadmap is having are more elusive. Meaningful metrics applied before the formation of ITRCS are very difficult to define. As with R&D organizations, the lagging-indicators appear more reliable. Several metrics are proposed which indicate leverage and buy-in from the technical and manufacturing communities:

- Growth of the compound semiconductor market relative to growth projected today, or to trends derived from historical performance
- The investment committed by industrial partners to roadmap workshops and activities
- Manufacturing yield enhancement related to allocation of corporate resources based on ITRCS guidelines
- The number of roadmap citations by university, industry and government expressed as a function of time

<sup>[2]</sup> D.L. Rode, "Compound Semiconductor Manufacturing: A Survey of Metrology and Related Technology Needs for the Compound Semiconductor Manufacturing Industry." This report is available from Pendragon Corporation, Nine The Prado, St. Louis, MO 63124.





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### Properties, Processing and Applications of Gallium Nitride and Related Semiconductors

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*Editors: J.H. Edgar, S. Strite, I. Akasaki,  
H. Amano, and C. Wetzel*  
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# SDL Taps Telecoms for Growth

MARIE MEYER

**L**aser manufacturer SDL continues to reinvent itself as a supplier of telecommunications components (as opposed to high power laser diodes for applications such as materials processing). This transformation began in 1995 when the company acquired Seastar Optics. Today the company's strategy is "increasingly focused on providing solutions for optical communications" - especially DWDM and CATV applications, as stated in SDL's annual report filed in late March.

Led by growth in shipments of its 980nm pump laser module, revenue from fiber optic products increased more than 100% in 1998, and communications-related revenue accounted for 66% of SDL's total revenue in the most recent quarter. The company says it has more than twenty customers for its DWDM and fiber optics products. In the most recent quarter, six of these customers purchased over \$1 million of products while another two bought over \$500,000.

The majority of SDL's DWDM revenue to-date has been into the terrestrial long-haul market. However, the company says that the undersea market is emerging as the next large potential market for DWDM systems. SDL was recently selected by Alcatel to supply its 980nm pump lasers and fiber Bragg gratings for undersea DWDM systems, and the company reports the receipt of contracts to qualify its 980nm pump laser and module for two additional undersea DWDM system contractors. SDL also recently announced the introduction of a 1480nm pump laser module which delivers 1.5 watts of optical power, which they say is ten times the power available from traditional pump lasers. This product enables remote pumping of optical amplifiers for short-haul repeaterless undersea fiber optic networks such as those connecting islands or cities along a common coastline.

In the past, SDL's revenue growth was constrained by a shortage in manufacturing capacity, but that problem has now been alleviated. Additional expansion is underway for the future. Due largely to improved yields in manufacturing, the company was able to reduce pump laser costs in 1998 and increase overall corporate gross margins by over five percentage points.

In their annual report, SDL identifies the key elements of their business strategy as follows:

1) Focus on DWDM fiber optic communications. The company supplies both source laser and amplifier components. SDL says there is an excellent match between its core technical strengths and the growing product requirements in the DWDM market.

2) Expand and leverage technology leadership. SDL plans to leverage its technology base in power, reliability and wavelength stabilization to maximize its market share of the pump laser area, for terrestrial, undersea and cable television

| Company                                            | Symbol | Exchange  | Description     | Closing Price<br>March 31 | 52 Week<br>Low | 52 Week<br>High | Market<br>Cap<br>(\$M) | Daily<br>Volume<br>('000s) | P/E<br>Ratio |
|----------------------------------------------------|--------|-----------|-----------------|---------------------------|----------------|-----------------|------------------------|----------------------------|--------------|
| Alpha Ind.                                         | AHAA   | NASDAQ    | GaAs ICs        | 18.38                     | 5.75           | 27.88           | 293.2                  | 273                        | 17.8         |
| Anadigics                                          | ANAD   | NASDAQ    | GaAs ICs        | 17.63                     | 4.63           | 21.38           | 259.8                  | 202                        | -            |
| APA Optics                                         | APAT   | NASDAQ    | Optoelectronics | 7.00                      | 4.00           | 10.00           | 59.6                   | 6                          | -            |
| ATMI                                               | ATMI   | NASDAQ    | Mtls & Equip    | 20.00                     | 10.88          | 33.75           | 442.7                  | 188                        | -            |
| AXT                                                | AXTI   | NASDAQ    | Mtls & Equip    | 22.50                     | 5.25           | 23.00           | 361.6                  | 250                        | 53.6         |
| Celeritek                                          | CLTK   | NASDAQ    | GaAs ICs        | 4.00                      | 2.50           | 12.50           | 29.2                   | 44                         | -            |
| Coherent                                           | COHR   | NASDAQ    | Optoelectronics | 33.25                     | 7.50           | 24.75           | 328.5                  | 109                        | 21.15        |
| Conexant                                           | CNXT   | NASDAQ    | GaAs ICs        | 27.69                     | 13.00          | 28.88           | 2,627                  | 1,945                      | -            |
| Cree                                               | CREE   | NASDAQ    | Optoelectronics | 46.94                     | 10.50          | 53.25           | 610.4                  | 298                        | 71.12        |
| Emcore                                             | EMKR   | NASDAQ    | Mtls & Equip    | 14.06                     | 6.00           | 28.75           | 132.6                  | 53                         | -            |
| Kopin                                              | KOPN   | NASDAQ    | Mtls & Equip    | 13.81                     | 11.38          | 24.88           | 168.8                  | 70                         | -            |
| Ortel                                              | ORTL   | NASDAQ    | Optoelectronics | 7.06                      | 6.50           | 20.25           | 84.2                   | 87                         | -            |
| PlasmaTherm                                        | PTIS   | NASDAQ    | Mtls & Equip    | 2.25                      | 2.25           | 9.00            | 25.2                   | 42                         | -            |
| RFMD                                               | RFMD   | NASDAQ    | GaAs ICs        | 95.69                     | 10.50          | 95.69           | 1,875                  | 371                        | +            |
| SDL                                                | SDLI   | NASDAQ    | Optoelectronics | 90.75                     | 8.13           | 91.50           | 1,330                  | 224                        | +            |
| SLI                                                | SLIC   | NASDAQ    | Optoelectronics | 0.41                      | 0.25           | 2.06            | 4.1                    | 34                         | -            |
| Spire                                              | SPIR   | NASDAQ    | Mtls & Equip    | 3.00                      | 2.38           | 14.50           | 9.7                    | 7                          | -            |
| TriQuint                                           | TQNT   | NASDAQ    | GaAs ICs        | 18.50                     | 11.00          | 26.75           | 175                    | 113                        | -            |
| Uniphase                                           | UNPH   | NASDAQ    | Optoelectronics | 115.13                    | 31.25          | 117.63          | 4,570                  | 831                        | -            |
| Uniroyal Tech.                                     | UTCI   | NASDAQ    | Optoelectronics | 7.94                      | 7.81           | 10.88           | 95.9                   | 34                         | 17.64        |
| Vitesse                                            | VTSS   | NASDAQ    | GaAs ICs        | 50.63                     | 17.13          | 52.94           | 3,764                  | 1,209                      | 69.35        |
| <b>European Companies (Currency data in Euros)</b> |        |           |                 |                           |                |                 |                        |                            |              |
| Aixtron                                            | AIX    | Neur Mkt. | Mtls & Equip    | 200.5                     | 92             | 230             | 1,002                  | 30                         | +            |
| Picogiga                                           | n.a.   | N. Marche | Mtls & Equip    | 11.49                     | 11.30          | 44.52           | 17.81                  | 4                          | 18           |

- = Loss in most recent 4 quarters    + = Over 100





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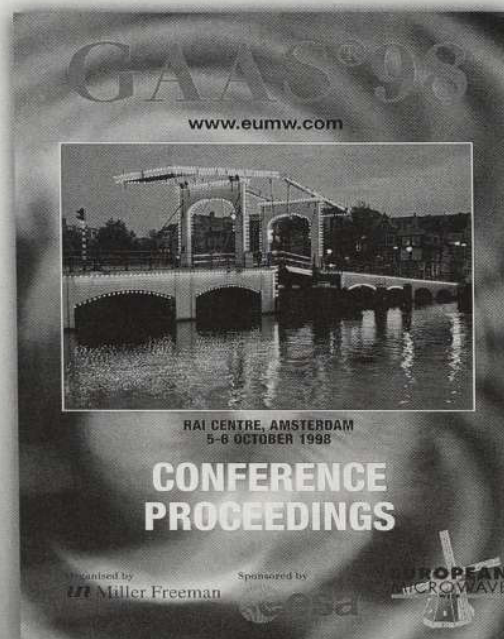
Mr Makaihora – *Kyocera, Japan*  
Mr Ali Fazal – *Nokia Mobile Phones, USA*  
Dr Aiden Higgins – *Rockwell Science Centre, USA*  
Dr Charles Huang – *VP Anadigics, USA*  
Dr. M Rocchi – *Philips, France*

To be included on the registration database please contact Nicola Jedrej on the numbers below.

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We are able to offer the proceedings from 1998 at £75 (\$123) + postage and packing. The conference, chaired by Giuliano Gatti of the European Space Agency, covered 28 sessions, in which 120 papers were presented. These are all fully documented in the proceedings, which amounts to over 700 pages.

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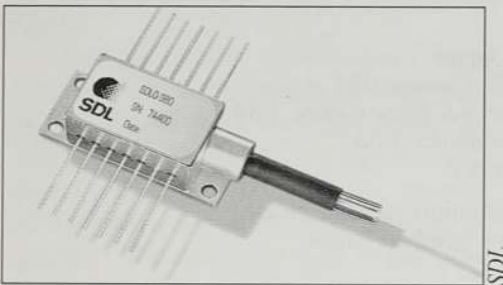
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applications, and to expand into other DWDM fiber optic product areas requiring high power and high reliability.

3) Increase breadth of fiber optic product offering to the existing customer base. As noted above, SDL has multiple customers for its fiber optic products. The company plans to leverage the qualification and quality control arrangements with those customers by offering a wider range of components to those customers.

4) Increase the level of integration on the wafer. SDL claims to have developed the first optoelectronic integrated circuit (OEIC) containing multiple semiconductor lasers. The company believes that OEICs in conjunction with new fiber optic technologies will, in the long run, represent an increasing portion of the communication network's value.



5) Upgrade manufacturing capability. The company is pursuing programs to significantly expand manufacturing capacity, improve yields and reduce unit costs in key product areas. The current fab in San Jose is expected to meet product demand into early 2000. Further expansion is underway for the 2000-2001 time frame. Additional epiwafer capacity is being added, additional laser diode assembly and test space is being added in Santa Clara, and a new 40,000 sq. ft. pump module packaging facility is being built near Victoria, British Columbia, Canada.

6) Partner with leaders. Examples of successful partnerships in the DWDM field include Alcatel, Corning and Lucent; in the printing area, SDL's partners include Kodak, Panasonic and Polaroid.

7) Increase profitability of non-communications businesses. Revenue from non-communications markets, such as printing and materials processing, still account for a third of total revenue. SDL says these areas have been generally prof-

itable, but they lack the same growth prospects as the company's telecommunications business. Therefore the company is investing in non-communications product lines "only where it has a credible plan for profitable growth." In keeping with this philosophy, SDL discontinued several low margin non-communications product lines in 1998.

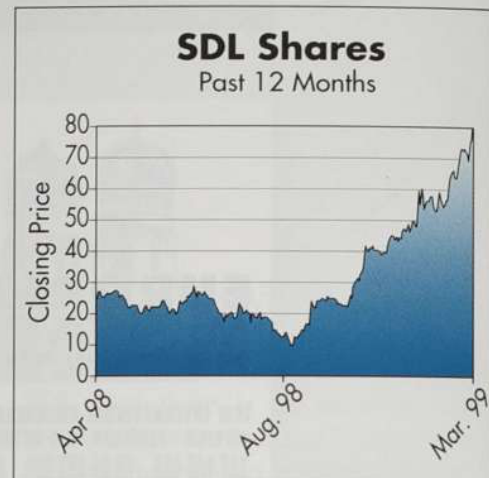
For the 1998 calendar year, SDL reported revenue of \$106 million, up 16% over 1997, and income of \$12.6 million, which was an improvement from the loss of \$25 million reported for the previous year.

### ***Briefly...***

On March 17 **Aixtron** released its results for 1998. Revenues rose 39 per cent to DM 107.9/US \$59.5 million and income was DM 11.0/US\$6 million. With revenues of DM 44.9 million, Asia was the largest market for sales, followed by the US with DM 36.2 million and Europe with DM 26.8 million. The company says that it has increased its market share to "significantly more than 40%", which they believe is twice that of their nearest competitor, Emcore. New order bookings were up 69% over the previous year.

**Anadigics** has announced that it will supply a dual-band power amplifier for a new 900/1900 MHz GSM mobile phone from Ericsson. The two PAs are housed in a single package. "This is a unique part," observes Joe DeMoura, Wireless Product Development Manager at Anadigics, "because its architecture takes advantage of two separate amplifier designs that are now realized in one design." In the past, dual-band phone designs required a separate power amplifier for each band supported.

On March 14 **Plasma-Therm** announced results for its first quarter, which ends February 28. The company reported a net loss of \$1.4 million, compared to net income of \$1.4 million for the same period last



year. Included in the net loss was a one-time restructuring charge of \$805,036 (pre-tax). Net sales were \$9.2 million, compared to \$12.3 million for the year-ago quarter. The company's backlog dropped \$11 million, to \$5 million. The company says it is pursuing a plan for lay-offs and overhead reduction in light of these results. A 15-20% reduction in the workforce is planned. Plasma-Therm believes it will be able to reduce losses in its next quarter and achieve break-even results for the rest of the year.

On March 16 **TriQuint Semiconductor** and GHz Circuit Design Inc. [Newburyport, MA] announced an agreement to utilize GHz Circuit Design's RFIC design services in conjunction with TriQuint's GaAs IC Foundry Services. The agreement is intended to provide customers with "turnkey" GaAs RFIC services and an RFIC design presence in the New England area. Customers, while contracting with TriQuint, will have access to, and be supported by, GHz Circuit Design's RFIC design team. TriQuint will then move the design into production, providing wafer manufacturing, die packaging and IC testing services. TriQuint says it plans to develop a worldwide network of independent, authorized design centers to support its GaAs foundry services.





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October 17 - 20, 1999

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Over the last 21 years, the IEEE GaAs IC Symposium has become the preeminent international forum on developments in integrated circuits using GaAs, InP, and other compound semiconductor devices. Coverage embraces all aspects of the technology, from materials issues and device fabrication, through IC design and testing, high volume manufacturing, and system applications. The IEEE GaAs IC Symposium is the forum where the latest results in high-speed digital, analog, microwave/millimeter wave, mixed mode, and optoelectronic integrated circuits. First-time papers concerned with the utilization and application of GaAs, InP, and other compound semiconductor ICs in military and commercial products are invited.

### Technical areas covered typically include:

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- System Applications (commercial and military; e.g., wireless, vehicular, medical, fiber system IC's)
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## ICSCRM'99

### International Conference on Silicon Carbide and Related Materials 1999

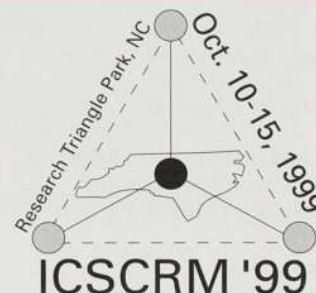
October 10-15, 1999

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Research Triangle Park, North Carolina

In this international conference new research results in the field of wide bandgap semiconductors such as SiC, III-V nitrides and related semiconductors will be presented and discussed. Topics will include, but will not necessarily be limited to:

- Bulk growth
- Epitaxial growth
- Device processes (such as implantation, doping, contacts, etching, etc.)
- Devices (such as power, high temperature, high frequency, sensors, etc.)
- Material properties (such as structural, electrical, optical, defects, etc.)
- Surfaces and interfaces



Abstract Submission  
Deadline:  
May 15, 1999

For more information, visit the conference Web site at <http://www.icscrm99.ncsu.edu/> or contact:

Cindy Allen, NCSU Fax: (919) 515-7614 e-mail: [cindy\\_allen@ncsu.com](mailto:cindy_allen@ncsu.com)



## May

### 11th International Conference on InP & Related Materials (IPRM '99)

May 16-20  
Davos, Switzerland  
<http://www.iqe.ethz.ch/iprm99/>

### 1999 IEEE Custom Integrated Circuits Conference (21st CICC)

May 16-19  
San Diego, California  
Contact: Melissa Widerkehr, [cicc@his.com](mailto:cicc@his.com)

### 9th Biennial Workshop on Organometallic Vapor Phase Epitaxy

May 23-29  
Ponte Verda Beach, FL  
<http://www.tms.org/Meetings/Specialty/OMVPE99/OMVPE99.html>

### 1999 Conference on Lasers and Electro-Optics (CLEO '99) Quantum Electronics and Laser Science 1999 (QELS '99)

May 23-28  
Baltimore, Maryland  
<http://www.osa.org>

### 1999 International Symposium on Power Semiconductor Devices & ICs (ISPSD)

May 25-28  
Toronto, Ontario, Canada  
<http://www.utoronto.ca/ispsd99>

### Workshop on Compound Semiconductor Devices and Integrated Circuits (WOCSDICE) 1999

May 25-27  
Paris, France  
Contact: Joachim Würfl  
FAX: [49] 30 6392 2685  
[wocsdice@fbh-berlin.de](mailto:wocsdice@fbh-berlin.de)

### 3rd International Workshop on MBE Growth Physics and Technology (MBE-GPT'99)

May 23-28  
Warsaw, Poland  
<http://www.warman.com.pl/~itp/MBE-GPT99>

## June

### 1999 MTT-S International Microwave Symposium (IMS) and RFIC '99

June 13-18  
Anaheim, California  
<http://www.mtt.org/ims1999>

### 57th Device Research Conference (DRC)

June 28-30  
University of California, Santa Barbara  
<http://ece-www.colorado.edu/~drc/>

## July

### 41st Electronic Materials Conference (EMC)

June 30-July 2  
University of California, Santa Barbara  
<http://www.tms.org/Meetings/Specialty/EMC99/EMC99.html>

### 3rd Int'l Conf. on Nitride Semiconductors (ICNS-3)

July 5-9  
Montpellier, France  
<http://bilbot.ges.univmontp2.fr/icns3.htm>

### 6th Int'l Workshop on Femtosecond Technology (FST '99)

July 13-15  
Chiba, Japan  
Abstract Deadline: April 16  
<http://www.festa.or.jp/meeting/fst99-e.html>

### 1999 Integrated Photonics Research Topical Meeting (IPR '99)

July 19-21  
Santa Barbara, CA  
<http://www.osa.org>

### 7th International Conference on Chemical Beam Epitaxy (ICBE-7)

July 27-30  
Tsukuba, Japan  
<http://solid.pe.titech.ac.jp/cbe-7>

## August

### 11th American Conf. on Crystal Growth & Epitaxy (ACCGE-11)

August 1-6  
Tucson, Arizona  
<http://www.aml.arizona.edu/aacg>

### 1999 International Microwave and Optoelectronics Conference (IMOC '99)

August 9-12  
Rio de Janeiro, Brazil  
<http://www.mc21.fee.unicamp.br/imoc99/>

### 1999 International Symposium on Compound Semiconductors (ISCS '99)

August 22-26  
Berlin, Germany

Contact: ISCS'99 Secretary  
[ISCS99@pdi-berlin.de](mailto:ISCS99@pdi-berlin.de)

## September

### 3rd Int'l Conf. on Mid-Infrared Optoelectronics - Materials and Devices (MIOMD-3)

September 6-7  
Aachen, Germany  
Abstract Deadline: July 2  
<http://www.iht.rwth-aachen.de/miomd.html>

### International Joint Conference on Silicon Epitaxy and Heterostructures (IJC-Si)

September 13-17  
Miyagi, Japan  
Abstract Deadline: April 30  
Contact: Prof S. Zaima  
[zaima@alice.xtal.nagoya-u.ac.jp](mailto:zaima@alice.xtal.nagoya-u.ac.jp)

### 1999 IEEE Bipolar/BiCMOS Circuits and Technology Meeting (BBCTM '99)

September 26-28  
Minneapolis, Minnesota  
Contact: Janice Jopke  
[jjopke@aol.com](mailto:jjopke@aol.com)

## October

### 1999 US Workshop on the Physics & Chemistry of II-VI Materials

October  
Las Vegas, Nevada  
Contact: Jay Morreale  
[jmorreal@newyork.palisades.org](mailto:jmorreal@newyork.palisades.org)

### European GaAs and Related III-V Compounds Application Symposium (GAAS '99)

October 4-8,  
Munich, Germany  
<http://www.eumw.com>

### 18th North American MBE Conference (NAMBE-18)

October 10-13  
Banff, Canada  
Abstract Deadline: June 1999  
Contact: Dr Z Wasilewski  
National Research Council  
TEL: [1] 613 990 4557  
FAX: [1] 613 941 4667  
[zbeg.wasilewski@nrc.ca](mailto:zbeg.wasilewski@nrc.ca)

### Int'l Conference on Silicon Carbide and Related Materials (ICSCRM '99)

October 10-15  
Research Triangle Park, NC  
Abstract Deadline: May 15  
<http://www.icscrm99.ncsu.edu/>

### 21st Annual GaAs IC Symposium

October 17-20  
Monterey, CA  
Abstract Deadline: April 30  
<http://www.gaasic.org>

### 196th Meeting of the Electrochemical Society

October 17-22  
Honolulu, Hawaii  
Abstract Deadline: May 14  
[ecs@electrochem.org](mailto:ecs@electrochem.org)  
<http://www.electrochem.org/meetings/196/symp.html>

### 46th National American Vacuum Society (AVS) Symposium

October 25-29  
Seattle, Washington  
<http://www.vacuum.org>

## November

### Int'l Conference on II-VI Compounds (II-VI '99)

November 1-5  
Kyoto, Japan  
Abstract Deadline: May 20  
<http://fujita.kuee.kyoto-u.ac.jp/26kyoto/>

### International Workshop on High Performance Electron Devices for Microwave and Optoelectronic Applications (EDMO '99)

November  
London, UK  
Contact: Ali Rezazadeh  
[ali.rezazadeh@kcl.ac.uk](mailto:ali.rezazadeh@kcl.ac.uk)

### Lasers and Electro Optics Society Annual Meeting (LEOS '99)

November 8-11  
San Francisco, California  
Abstract Deadline: July 2  
<http://www.ieee.org/society/leos/>

### 1999 Fall MRS Meeting

November 29-December 3  
Boston, MA  
Abstract Deadline: June 21  
<http://www.mrs.org/meetings/fall99/>

## December

### 1999 IEEE International Electron Devices Meeting (IEDM)

December 5-8  
Washington, DC  
Contact: Ms Phyllis Mahoney  
[pwmahoney@aol.com](mailto:pwmahoney@aol.com)



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**3rd  
International  
Conference  
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Optoelectronics -  
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The conference will cover the following subjects:

- Physical concepts of MIR radiation generation and detection
- Physical concepts of band and quantum dimensional engineering
- Material growth and device fabrication
- Characterization and optoelectronic properties
- Optoelectronic devices and applications

For More Information:

Prof. Dr. K. Heime  
RWTH Aachen  
Institut fuer Halbleitertechnik, Lehrstuhl I  
Templergraben 55  
D - 52056 Aachen  
Tel.: +49 241 807745  
Fax: +49 241 8888 199  
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**October 10-13, 1999**



Banff Centre for Conferences

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[www.nrc.ca/confserv/NAMBE99](http://www.nrc.ca/confserv/NAMBE99)

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