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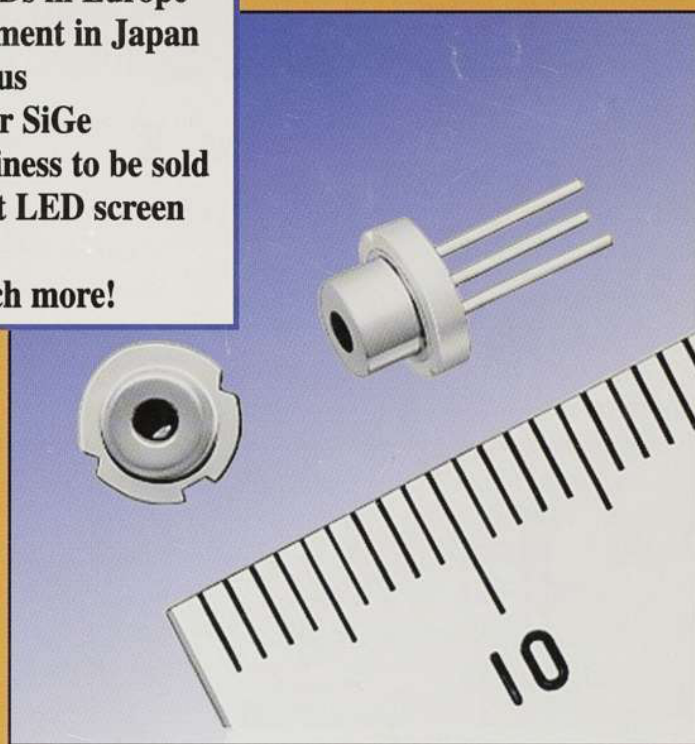
July/August 1997

Volume 3 Number 4

SEMICONDUCTOR LASERS

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- Blue Laser Update
 - Lasers and LEDs in Europe
 - Laser Development in Japan
plus
 - IBM's plans for SiGe
 - TI's GaAs business to be sold
 - World's largest LED screen
 - InP at TRW
- and much more!



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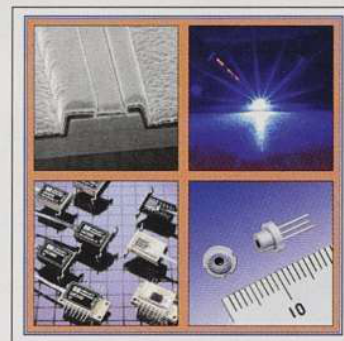
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that no other MOCVD company in the world offers you the **unique**, **versatile**, and **constantly high quality** technology you're assured of from AIXTRON, whether you're producing LED's, Lasers, Detectors, HEMTs, HBTs, OEICs...
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RFMD Linear Amplifier for PCS

Greensboro, NC. RF Micro Devices has announced the availability of the RF2146, a high-power, high-efficiency linear amplifier designed for use as the final amplifier in 4-cell CDMA hand-held digital cellular equipment and spread spectrum systems in the 1500 MHz to 2000 MHz band.

Manufactured using GaAs HBT process technology, the RF2146 offers over 28dBm linear output power with 18.5dB gain. Typical efficiency is 37% for 28dBm linear output power operating at 4.8V, in some circumstances efficiency can be over 40% and still meet the requirements of the CDMA standard. The self-contained device features an on-board power-down mode, 50W input match, and it is designed so that the output can be easily matched to maximize operating power, efficiency and linearity characteristics.

The RF2146 is designed for the following applications: 4.8V CDMA PCS handsets, 4.8V TDMA PCS handsets, 4.8V PACS PCS handsets, cellular base stations and portable battery-powered equipment. Offered in a SOP-16 QBW1 package, the RF2146 sells for \$7.32 or less per unit in quantities exceeding 10,000 units.

RFMD also recently announced the availability of a 10dB-switched attenuator for communications systems that require RF power control by digital means. The RF 2421, which is manufactured using a GaAs MESFET process, features 1-bit digitally controlled attenuation with a single step attenuation of 10dB and an insertion loss of only 1 dB. Offered in a SOP-8 package, the RF2421 sells for \$1.23 or less per unit in orders exceeding 10,000 units.

Single Supply ICs from Fujitsu

Tokyo, Japan. Fujitsu has announced that it has developed a new family of ICs that do not require exterior parts for purposes of control. The company says that its enhancement-mode GaAs FET processing eliminates the dual supply requirement, and because fewer components are necessary (e.g., there is no need for a drain switch or negative voltage generator), the cost of manufacturing the cell phone or wireless handset is reduced.

The first products offered will be 4.8V ICs for AMPS and GSM phones, with +23.5dB and +32dB gain, respectively. The company is to start mass production at a monthly level of 1.5 million units starting in August. The sample price is 800 yen.

Ka & C-Band GaAs from Toshiba

Irvine, CA. Toshiba America Electronic Components recently introduced a new Ka-Band GaAs FET module that operates at 38 GHz with an output power of 25dBm. This is one of the highest power modules available with such a high frequency range. The company says that the module, designated KMC00880A, is the first to take advantage of the newly FCC-allocated Ka-bandwidth.

"Toshiba maintains a focused effort to lead the industry in technology breakthroughs. In doing so, we are committed to utilizing new opportunities in the communications technology industry," stated Malcolm Wood, product marketing manager, microwave devices for Toshiba's semiconductor group. "With the introduction of the new Ka-Band module, Toshiba continues to uphold its leadership role." The module is targeted towards the point-to-point digital communications market, specifically the base stations used in cellular phone transmission and Local Multipoint Distribution Systems (LMDS).



One of Toshiba's new MMIC modules for use as a C-band amplifier.

Toshiba also recently announced some new additions to its C-band GaAs product line-up. The first is a new C-Band GaAs FET, designated TIM5964-45SL, which has an output power of 46.5dBm at a frequency range of 5.9 to 6.4 GHz. The company believes this is the first C-Band GaAs FET to achieve such a high output power at this frequency range. The new device is targeted for use in satellite, military and wireless communications, as well as point-to-point radio. Pricing in 100 piece quantities is \$1,060, with full production scheduled to begin in October.

The other new C-band parts are three MMIC modules offered at frequencies of 3.7 - 5.1, 5.1 - 7.2, and 7.1 to 8.5 GHz. Each offers 33 dBm of output power. They are targeted toward all stages of C-band amplifiers used in satcom, wireless and military communications, as well as point-to-point radio applications. Pricing in 100 piece quantities is \$124, with full production scheduled to begin in September.



Anadigics

Anadigics is Hopping

Warren, NJ. Anadigics recently announced a new GaAs power amplifier which it says will allow cellular handset manufacturers to "leapfrog to the next generation of phones". The new chip, the AWT1903, is intended for use with PCS 1900 MHz CDMA applications.

According to the company, the power amplifier is designed and optimized to accommodate the linearity requirements of the CDMA signal spectrum by significantly minimizing spectral regrowth. It is composed of a 5V three stage class AB GaAs MESFET amplifier requiring an external -3.6V supply to establish the gate bias voltages. The IC typically exhibits 26 dB gain, -12 dB input return loss, 33% efficiency and an ACPR @1.25 MHz offset of 33 dBc at an output power of 28 dBm in the 1850 to 1910 MHz PCS band.

The AWT1903 is packaged in a 28 pin thermally enhanced SSOP package. It is available at \$8 in quantities of 100,000.

Crosspoint ICs from Vitesse

Camarillo, CA. Vitesse Semiconductor Corp. recently announced the availability of the VSC850 16 x 32 crosspoint switch IC for high-speed digital data-switching systems used for Gigabit Ethernet and ATM applications. It replaces simple 8 x 8 switches that require a large array of devices to achieve the same bandwidth and additional resynchronization and driver ICs on each channel to achieve the same performance. The VSC850 provides both higher performance and a more cost-effective system solution in a single IC. In addition to Gigabit Ethernet and ATM, the VSC850 is also well suited to other datacom and telecom switch cores, high-speed routers, Fibre Channel applications and proprietary computer networking systems.

The VSC850 IC features a 16 x 32 crosspoint switch core with 1.25Gb/s fully differential serial I/Os. It has a non-blocking architecture with standard TTL interfaces for control logic and ECL interfaces for high speed differential serial I/O. It performs with less than 100ps duty cycle distortion, less than 200ps of skew in broadcast mode, and has a typical power dissipation of less than 4.6W.

"Compared with high-speed silicon BJT and other GaAs crosspoint switch ICs, the VSC850 offers lower power and higher bandwidth," said Barry Sandefur, director of ATM and datacom switch products at Vitesse. "Getting the same bandwidth in CMOS would require a multiple, high-pincount device architecture, requiring more board space and more complex interconnect. The VSC850 is a more cost-effective, less complex solution."

The VSC850 marks Vitesse's entry into the development of high bandwidth network switching products for datacom applications and follows Vitesse's significant success with custom and ASIC switches for SONET/SDH telecommunications applications. The VSC850 is supplied in a 208 pin PQFP package with 1,000- piece quantities priced at \$143. Samples and production quantities are available now.



Power Amps and Upconverter from Motorola

Phoenix, AZ. Motorola has announced the addition of the MRFIC1813 GaAs upconverter to its personal communications line of RFIC devices. It combines a balanced upmixer and transmit exciter amplifier in low-profile TWWOP-16 surface mount plastic package. This RF upconverter requires minimal off-chip matching, and is optimized for low-side injection and provides more than 15 dB of conversion gain with more than 0 dBm output at 1 dB gain compression. It features high linearity and low power consumption (75 mW typ.), with a low LO power requirement (0.5dBm typ.). Designed for use in wireless personal communications, the upconverter is used in 1.9 GHz applications such as the Digital European Cordless Telephone (DECT), Japan's Personal Handy System (PHS), and US Personal Communication Services (PCS). It is also applicable to 2.4 GHz ISM equipment. It is priced at \$1.95 per unit in quantities of 100K units. Samples and small quantities are available from stock; production quantities have an 8-10 week lead-time.

Motorola also recently announced the availability of two new GaAs MESFET power amps. The first, part number MRFIC0913, is designed for GSM handsets. From a 4.8 V supply it provides 48% minimum power efficiency and outputs 2.8 watts. Input, output and some interstate matching is accomplished off-chip, allowing the device to operate over a usable frequency of 800 to 1000 MHz. It is packaged in Motorola's proprietary PFP-16 power flat package, which improves thermal performance through a solderable backside contact. The MRFIC0913 is priced at \$4.30 per unit in quantities of 100,000. Samples are available now; production quantities have a 12-week lead-time.

The other new power amp, the MRFIC1917, is designed for Pan European digital 1.0 watt DCS1800/PCS1900 handled radios operating in the 1.7 to 1.9 GHz band. Major features of this device are low negative current requirement (-2 mA max), and guaranteed stability and ruggedness. It operates at 33.5 dBm typical output with power gain over 27 dB from a 3.6 V supply. Like the MRFIC0913, it is also packaged in the PFP-16 power flat package. Pricing is \$9.45 for quantities of 10,000. Samples are available now; production quantities have a 22-week lead-time.



Motorola's new power amp for 1.9 GHz digital handsets.

1997 North American Conference on Molecular Beam Epitaxy

The 16th Annual North American Conference on Molecular Beam Epitaxy (NAMBE-16) will be held October 5-8, 1997 at the University of Michigan in Ann Arbor.

In the tradition of the previous conferences in this series, this meeting will cover a range of topics pertaining to epitaxial growth by MBE and related techniques. Topics include but are not limited to:

- Advances in epitaxial growth techniques
- In-Situ measurement and control
- Deposition of New Materials
- Heterostructures
- Patterned and selective growth
- Devices and novel concepts
- Production MBE technology

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Or visit the conference Web site at
<http://www.cms.housing.umich.edu/MBE97/>

3V RF Receiver ICs from TriQuint

Hillsboro, OR. TriQuint Semiconductor has unveiled a new line-up of new GaAs MESFET 3V RF Receiver ICs for wireless handsets. Two of the chips, the TQ9225 and TQ9228, are designed for PCS band mobile phones using the CDMA standard. Both components contain a multi-stage downconverter (LNA + mixer) chain and include an LO buffer to drive the transmitter circuitry.

"In designing the TQ9225 and TQ9228 receivers, we were striving for a high level of RF integration to reduce receiver cost," said Chris O'Connor, marketing manager for the receiver product line at TriQuint's Wireless Communications Division. "These ICs are significantly less expensive than alternatives based on discrete functions."

The downconverter architecture used in the TQ9225 and TQ9228 is split in a way that maximizes LNA dynamic range while maintaining excellent overall down-converter RF performance needed for CDMA products. RF performance -- conversion gain of 28dB, noise figure of 2.4dB and input third-order intercept point of -9dBm -- enables the design of standards-compliant mobile phone products, while the high LNA output IP3 minimizes the self interference caused by the transmitter power amplifier. The two components are designed to support a full range of LO and IF frequency ranges. The TQ9225 has a LO frequency range of 1710-1790 MHz and an IF frequency range of 210-212, while the TQ9228's LO frequency range is 2015-2075 MHz and IF range 84-86 MHz.

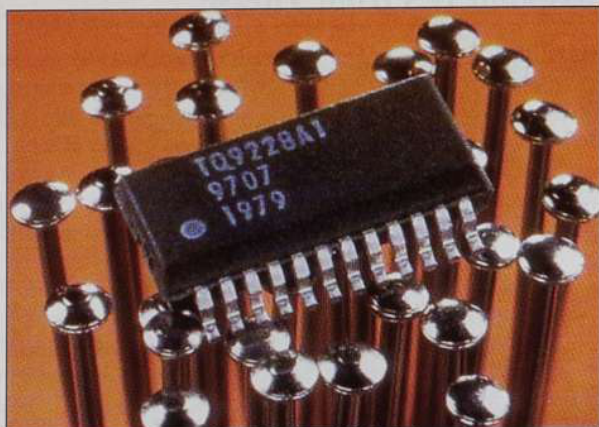
TriQuint reports that a wide supply voltage range of 2.7-4.0V is possible, which permits the use of these receiver ICs in a variety of applications. In addition to CDMA 1900 handsets, they are also suitable for wireless local loop and PCS micro-cell applications.

The TQ9225 and TQ9228 come in a small 24-pin surface mount plastic package. They are available from stock at a unit price of \$3.86 at 100,000 quantities.

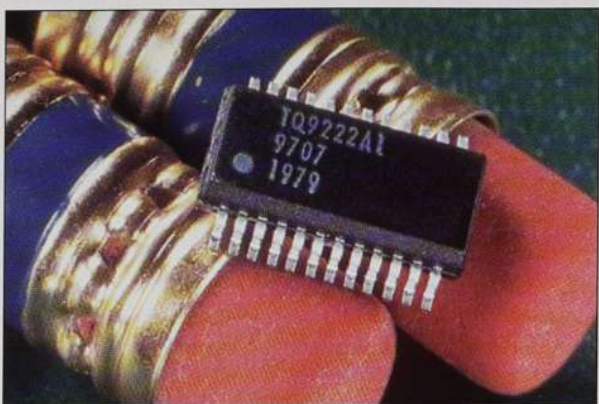
Also new from TriQuint is a dual-band receiver designed specifically to support the time division multiple access (TDMA), or IS-136, and the GSM standards. Two separate LNA + mixer circuits in the new receiver IC handle both the 800/1900MHz TDMA bands and the 900/1800MHz GSM bands.

Running off a single supply voltage ranging from 2.7V to 3.0V, the TQ9222 provides good RF performance with low current consumption, using only 10mA and 20mA, respectively, for the cellular and PCS bands. The device is capable of operation with supply voltages up to 5V with slightly higher current consumption. "Our new dual-band IC offers the lowest power consumption on the market today, maximizing standby times for portable applications," said O'Connor.

The TQ9222 is housed in the small QSOP24 package (0.025 inch lead pitch) to minimize required board space. Samples will be available in third quarter of 1997 at a unit price of \$5.00 in order quantities of 100,000.



TriQuint's RF receiver IC for CDMA handsets.



Also new from TriQuint: a dual-band receiver which accommodates the TDMA and GSM standards.

Attention Semiconductor Manufacturers

If your company manufactures GaAs ICs, laser diodes, LEDs or any other compound semiconductor-related device, we'd like to hear from you. Instruct your PR department to send new product announcements to:

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Siemens Wireless GaAs Offerings

Cupertino, CA. Siemens Components is expanding its family of GaAs devices for cellular and PCS handsets with the introduction of two new MMICs: a variable gain driver amplifier suitable for fixed gain final stage PA; and a low current version of its CMY210 high linear up/down converter. Each can function in cellular, PCS (CDMA & TDMA) and GSM 1900 designs.

"These devices give the designer more flexibility, and still deliver outstanding performance characteristics," said Andreas Nitschke, product marketing manager, GaAs components. "These new products should provide even more confidence in the Siemens road map for the next generation of gallium arsenide, with dramatic gains in integration and performance," he said.

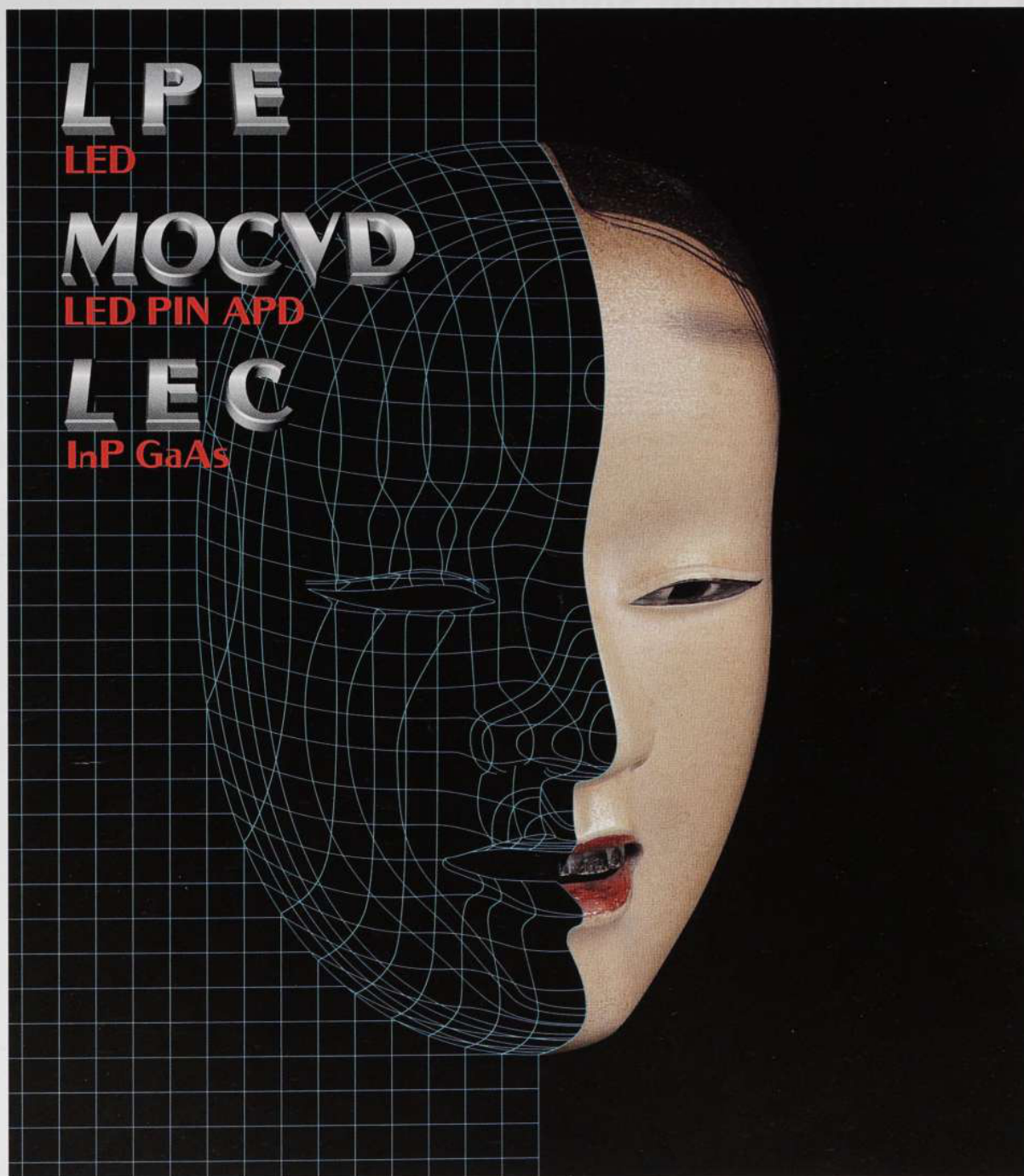
The CMY211 is a low current, high linear mixer for RF front-end designs. It features an

integrated LO buffer amplifier and an LO frequency range from 0.5 to 2.5 GHz. It operates down to 2.7V power supply, and offers IIP3 performance of +16dBm at a drain current of 3.5mA, RF=1.96GHz, IF=210MHz, LO=1.75GHz, P(LO)= 0dBm.

The CGY121A and CGY121B are variable gain amplifier (VGA) MMICs that can deliver a gain control range of +55 dB range for cellular, PCS, or wireless 2.4GHz Wireless LAN. With its 50ohm input and output broadband matching on chip, both devices can be used in today's wireless communication designs up to 2.5GHz.

The CMY211 mixers will be available in MW6 SMD package, initially priced at \$2.00 in quantities of 100k. The CGY121A/B variable gain amplifier will be shipped in MW6 SMD package, priced at \$2.00 in quantities of 100k.

Art of Technology
A Bright Future Lies Ahead



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Cape Cod, Massachusetts

MARIE MEYER

Official Japanese statistics report that the volume of information generated by our society is growing at the phenomenal rate of 34% per year - which means that the information load (or overload, depending upon your point of view) doubles every 2.5 years, and will increase by an order of magnitude in less than ten years.

Optical communications networks - constructed using InP lasers - are critical for moving all that data around. The 1997 IPRM conference made it clear that the future of the InP sector is tied to the continued development of communications systems. However, it was also evident that in the future there will be more to InP than just lasers, and that InP components should find applications in other types of networks in addition to optical systems.

Electron Devices

More than 50 papers at this year's IPRM discussed FETs, HEMTs and HBTs. TRW alone turned in seven reports, demonstrating their early leadership in the production of InP microelectronics.

Among the TRW papers was a report on the fabrication and demonstration of a three-stage InP HEMT low noise amplifier (LNA) (see Figure One). This circuit produced 12.5 decibels (dB) of gain at a frequency of 155 GHz, which is the highest operating frequency ever reported for a solid state amplifier. (12.5 dB of gain is equivalent to amplifying a signal by a factor of 18.) TRW says that the 0.1 micron MMIC process used to build this chip has attained a high level of maturity, with consistent wafer to wafer uniformity. The company believes the process is suitable for higher levels of production volumes.

TRW also discussed a power InP process. Due to the relative immaturity of InP HEMT development, reports on output power for InP HEMT amplifiers have thus far been limited to around 50 mW. But TRW reported that it has optimized a gate recess process which enabled

the development of a 640 micron single-stage InP HEMT MMIC amplifier which delivered 130 mW output power with 13% power added efficiency at 94 GHz. This result is believed to be the best output power fixture data from a single InP HEMT MMIC at this frequency.

Records are one thing - reproducibility is another. Happily, TRW also presented two papers discussing the conversion of their InP HEMT and HBT program from research to production. Part of this work was done under a \$22 million contract from ARPA's MAFET program, aimed at improving MMIC production. (See CS 1(3), p. 14).

The InP technology transfer at TRW involved not only reorienting the InP program from a R&D focus to a volume manufacturing mode, but also converting from 2" to 3" wafers. The overall InP wafer production flow for both HEMT and HBT MMICs at TRW is described in Figure Two. All production is now done on 3" wafers, with typical linewidths of 1.0 micron for HBTs and down to 0.1 micron for HEMTs. Half of the steps are shared by both technologies. In addition, there is a large degree of process commonality with TRW's GaAs MMIC program - around 70% for the HEMTs. This allows the company to take advantage of the lessons learned in that higher volume and more mature process. Over 50 different MMICs, including LNAs, mixers, frequency converters, VCOs and high linearity amplifiers from X-band through W-band have been manufactured using this process.

Commenting on these results, Dave Vandervoet, vice president and general manager of TRW's Electronics Systems & Technology Division, said, "We're delighted with the results of our InP development program. We believe that it will soon be possible to produce InP integrated circuits with operating frequencies as high as 220 GHz. These low noise, high performance chips will enable a whole new class of faster, more capable telecommunication systems for our government and commercial customers."

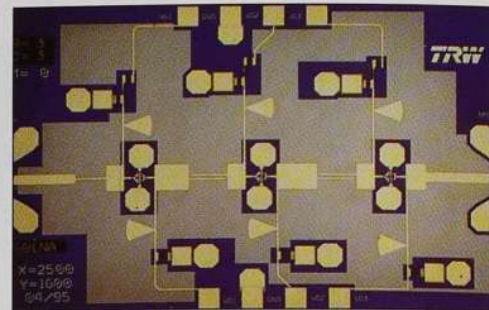


Figure One. TRW's three-stage InP HEMT low noise amplifier (LNA), which produces 12.5 decibels (dB) of gain at a frequency of 155 GHz. This is the highest operating frequency ever reported for a solid state amplifier. TRW also reported that the 0.1 micron MMIC process used to build this chip has attained a high level of maturity, with consistent wafer to wafer uniformity. The company believes the process is suitable for higher levels of production volumes.

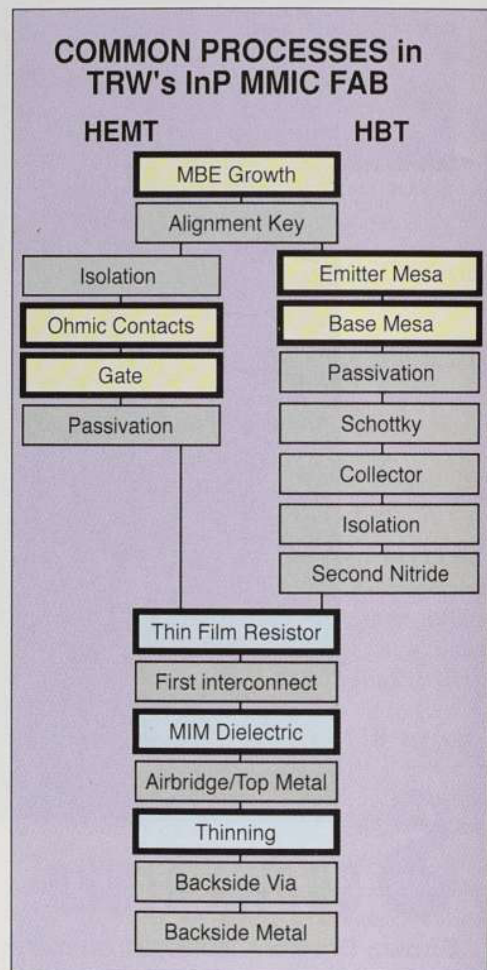


Figure Two. TRW's InP MMIC manufacturing process flow. Half of the steps are common to both HEMT and HBT fabrication. Color boxes indicate critical nodes - yellow for transistor performance critical nodes, blue for passive component critical nodes.

Telecom Lasers - Ready for 1 Tb/s?

Of course, one normally thinks of lasers, not transistors, when discussing InP and the majority of papers at this year's IPRM dealt with optoelectronic topics. In the plenary session Herbert Haupt of Alcatel Telecom Research Division set out his company's views on the immediate future for telecom laser development. For their basic laser design, Alcatel has adopted the buried ridge stripe (BRS) structure shown in Figure 3. Haupt reported that its advantages include very high

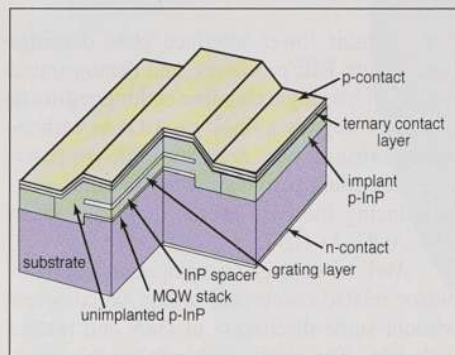


Figure Three. Schematic of the buried ridge stripe (BRS) laser structure which Alcatel has adopted as their basic telecom laser device.

reproducibility in the manufacturing process combined with high reliability. He reported that they can be manufactured in volume with precise control over the emission wavelength, with a variation over the 2" wafer within ± 1 nm.

Applications for this type of structure include low cost 1500 nm DFB lasers for systems operating at 622 Mb/s, where high temperature operation with a limited current consumption is required. Using facet coated lasers with low threshold currents (<20 mA) and high quantum efficiency (>0.2 W/A) at 75°C , Alcatel has been able to demonstrate system operation across 188 km with only 0.2 dB BER penalty. For shorter-range 1300 nm systems, Hewlett-Packard has obtained sufficient laser operation up to 85°C without facet coating. Haupt also reported that Siemens has used a loss coupled grating to increase the single-mode yield of DFB lasers from the usual 50% - 60% to up to 90% at moderate emission power, without essential reduction of CW performance. Of course, there are many other types of systems, usually requiring a "tweaking" of the design to optimize performance. For example, Alcatel produces a 6 QW version for 2.5 Gb/s systems where low chirp requirements are important. Here links as long as

200km have been successfully implemented.

In another plenary talk, Osamu Wada of Fujitsu discussed the future of InP-based telecom lasers. He told the audience that signal-processing systems would need to exceed 1 Tb/s by the year 2010. He predicts that that goal cannot be met by incremental improvements in the performance and cost of the existing types of devices. One of the solutions he discussed was the use of devices and circuits operating in the femtosecond range. To make that a reality, several new developments are needed, including monolithically integrated mode-locked semiconductor lasers that can generate an ultra-short pulse width and ultra-high repetition rate; and new types of all-optical switches to replace ordinary photoreceivers. Achieving these goals may require a return to basic science. Dr. Wada, who is also affiliated with Femtosecond Technology Research Association in Tsukuba, Japan reminded the attendees that the application of some "novel physics in In-P based materials" would likely be required to overcome the present carrier lifetime-governed speed limit in existing devices.

Dr. Wada will be the chairman of the 1998 IPRM meeting, which will be held next May in Tsukuba.

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What Does Gordon Moore Think of Us?

SOTAPOCS XXVI

May 4-9, 1997

Montréal, Québec, Canada

COLOMBO BOLOGNESI

The twenty-sixth State-of-the-Art Program on Compound Semiconductors (SOTAPOCS) was held during the 191st Meeting of the Electrochemical Society (ECS). The program consisted of six half-day sessions on topics ranging from materials growth and characterization to processing and device fabrication. But for this author, a major highlight was the ECS Plenary Lecture by Gordon Moore, co-founder of the Fairchild Semiconductor and Intel Corporations. As a prophet of future challenges facing chip makers, Moore has no equal in terms of credibility - after all, this is the fellow who, in 1965, predicted the need for annual doubling of transistor density in microprocessors (now known as "Moore's Law").

Equipped with illustrative and entertaining examples, Moore attempted to put the staggering development of the semiconductor industry in perspective. He pointed out that the current annual worldwide transistor production is approximately 10^{17} units: roughly corresponding to the total ant population on the planet. Another way to gauge the progress accomplished is by examining the per transistor cost through time: whereas in 1970 the per transistor cost was 1\$, it had fallen to a "microbuck" (1 μ \$) by 1995.

In Moore's view, the ultimate limits of silicon technology may be reached when the minimum feature size runs to 0.05 to 0.1 μ m, and will be due to local variations in doping density in the semiconductor material making up an individual device. To put this in perspective, consider that the industry now runs 0.35 μ m product with I-line steppers, 0.25 μ m DUV or 248 nm excimer lithography processes are now at the integration stage, and 0.18 μ m processes relying on 193 nm radiation (or 1:1 x-ray imaging) are currently being developed. In principle, Moore believes the scaling down to 0.18 μ m should be fairly straightforward whereas the next step, to 0.13 μ m, will be a lot more difficult because of the lack of transparent materials for optics below 193 nm. He recalled that with shrinking device geometries MOS gate oxides have to be thinned to

minimize short-channel effects, and that high-quality pinhole-free gate oxides of 30-50 Å are now possible. Interestingly, these ultrathin gate oxides do not appear to suffer too much from quantum mechanical tunneling because the operating voltages are dropping faster than the oxide thickness (and the normal electric fields are reduced). Besides the lithography challenge, he pointed out that some of the other major difficulties facing the semiconductor industry over the next ten years will involve managing the tremendous complexity as well as the functional validation of increasingly complex products, minimizing interconnect delays (which are becoming significant speed limiters), and searching for lower dielectric constant insulators.

Moore expressed the belief that silicon is the ultimate semiconductor for complex integrated circuits: this, he believes, will become particularly evident when the industry reaches the stage where interconnections become the principal speed limiting factor, thus masking the intrinsic speed advantage found in other materials. This, according to Moore, "is not to say there is no place for compound semiconductors," but they will likely be restricted to cellular phone front ends and related applications, rather than in complex circuits. In other words, Moore subscribes to the belief that the current status quo will hold.

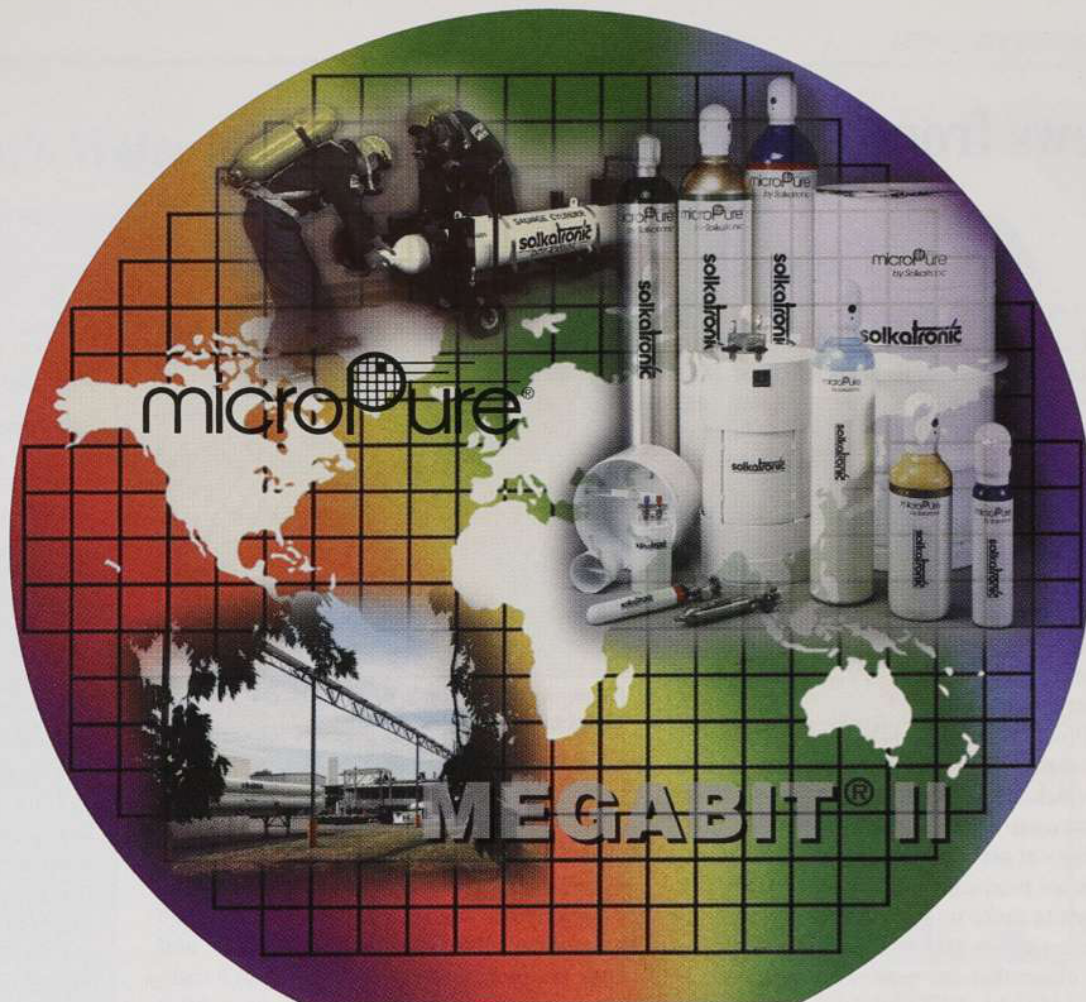
Other Highlights

Among the other highlights from the conference was a report from Charles Tu from UC San Diego who described the use of trisdimethylaminoarsenic (TDMAs) to perform in-situ etching and epitaxial regrowth in a single growth chamber. TDMAs does not contain As-H bonds and it is considered to be safer than the more commonly used AsH₃. In addition, TDMAs also contains no As-C bonds, and therefore results in a lower carbon contamination in epitaxial material. Etching occurs at substrate temperatures greater than 550°C, and growth at around 500°C. The etch rate of GaAs can be as high as 0.3 μ m/hr at 650°C. Tu showed that in-situ etched and regrown sur-

faces exhibit lower interface state densities than ex-situ RIE processes, and demonstrated the use of his single chamber etching/regrowth process to regrow a thick p+ AlGaAs carbon-doped extrinsic base region in order to passivate the emitter periphery while simultaneously reducing the base access resistance in an AlGaAs/GaAs HBT.

And, of course, no compound semiconductor related conference would be complete without some discussion of GaN and related materials. The nitride highlight for this meeting was a report from L.F. Lester from the University of New Mexico on the results of Ohmic contact studies on MOCVD grown n- and p-GaN, with a particular attention placed on the impact of nitrogen loss during high temperature annealing steps. For n-contacts to GaN, annealing of the wafer at 1120°C prior to metallization allows non-alloyed Ti/Al Ohmic contacts to be formed. In contrast, unannealed samples with the same metallization display Schottky-like characteristics. This result is most likely due to the creation of N vacancies which act as donors in GaN, and leave the near surface region n+. In order to activate Mg acceptors in p-GaN, a 20 minute anneal at 700°C is often used to drive out compensating hydrogen in MOCVD-grown material. The possibility of inadvertently causing dopant compensation and degrading Ohmic contacts to p-GaN by nitrogen desorption was investigated and it was found that the way in which the sample is capped during the anneal has no apparent effect on the specific contact resistance. However, the lowest contact resistance on p-GaN was achieved when a post-metallization heat treatment is used to activate the dopant and alloy the metal simultaneously because of a reduced nitrogen loss and hole compensation near the surface. For p-GaN contacts, it was noted that the contact resistivity does not strongly depend on the contact metal because of Fermi level pinning.

The full technical program of the 191st Meeting of the Electrochemical Society can be found on the WWW at <http://www.electrochem.org>.



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News from Japan

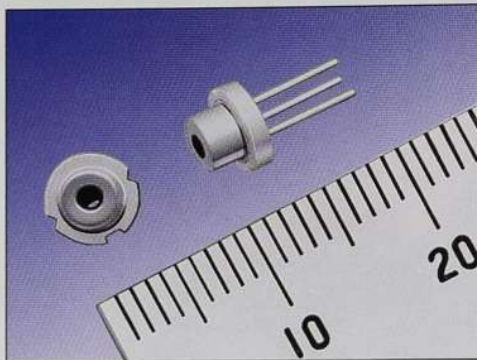
CD & DVD Laser News

CD laser market leader **Rohm** is reportedly **launching volume production of DVD lasers**. The company has been in small-scale production of DVD lasers since January. Rohm recently installed a 1 million-unit-per-month production line at subsidiary Wako Electric's Okayama plant. The new line is expected to become fully operational one year from now. The company says its 650nm MQW strained layer DVD laser operates at 50mA, 35% lower than the operating current required of conventional DVD lasers, and can operate stably at 90°C.

Production of the DVD lasers will use a **multi-wafer MBE** growth process similar to that which ROHM uses for CD lasers. Rohm is somewhat late to the market with its DVD offering - at present, at least seven other companies are producing DVD lasers. Rohm says it hopes to make up for lost time by being the first to go into to very high volume production. They claim that the present volume leaders, such as Hitachi and Toshiba, have a maximum capacity of 300,000-500,000 units per month, and that Rohm will soon offer double or triple that output.

In July **Hitachi** plans to begin sample shipments of a **650nm laser for DVD-RAM drives**. The HL6501MG is an AlGaInP-based laser diode with an output of **35mW**. It uses an inclined substrate to optimize the crystal growth conditions to reduce the wavelength and uses a distortion compensated multiple quantum well structure to increase the light emitting efficiency to achieve both the high output and a low power consumption of 90mA on average. The laser is housed in a 5.6mm-diameter package and sample-priced at ¥5,000 (\$43.86). Plans call for producing 20,000 units a month from October 1997 and raising output to 100,000 units in April 1998.

Toshiba has started marketing **650nm red semiconductor lasers for DVD-ROM and barcode readers**. The company, which currently sells 635-685nm lasers for a range of applications including MOD, DVD, and measuring instrument, has developed the TOLD944-MC/MD, a 7mW 650nm laser for DVD, and the TOLD9442M, a 5mW 650nm laser for barcode readers. The company says it is now able to produce 400,000-500,000 red semiconductor lasers per month. The compa-



Examples of Rohm's new 7mW DVD lasers in 5.6 mm packages

ny will also expand its visible LED offerings, focusing on high-brightness models made of quaternary (InGaAsP) material.

Sony has announced plans to **strengthen its optical disk semiconductor laser and laser coupler business**. According to a company spokesperson, in response to a brisk demand for laser couplers for CD/CD-ROM, the company has increased laser coupler production to 5 million units a month, up 40% compared to 6 months ago. The laser coupler integrates a semiconductor laser, a beam splitter and prism, and a photo detector. SONY has recently developed a MD (mini disk) recording/playback laser coupler and will respond to the increase in demand for this device. The company, which produces 300,000 red semiconductor lasers a month for bar code readers, plans to establish a supply system for DVD applications as soon as possible.

Sanyo Electric reports that it has developed a **multipurpose thin DVD-ROM pick-up** that can play CD, CD-ROM and CD-R as well. The new device, part number SF-HD2R, uses a newly-developed wire-suspension actuator and a glass objective lens to reduce the thickness of the pick-up to 8.6mm, 40% slimmer than its predecessor, making it a suitable choice for the 17mm-thick DVD-ROM drive for notebook computers. It uses a 645nm red semiconductor laser to read DVD and a 780nm infrared semiconductor laser to read CD, CD-ROM and CD-R. The company is currently shipping ¥150,000 (\$1,316) samples and plans to launch volume production in August. Forecasts call for producing 50,000 units a month in late 1997.

For more on laser diode development in Japan, see page 28 of this issue.

Other News

Nichia Expanding

Nichia Chemical Industries intends to concentrate green and blue LED and gallium nitride semiconductor production at its headquarters plant in Shikoku. The company, which began producing CRT phosphors at the plant in spring 1995, has acquired land adjacent to the plant and will build a facility that will manufacture phosphors as well as LEDs and gallium nitride semiconductors. This move will allow the company to expand its production volume for blue and green LEDs, which is currently around 10 million units per month. Plans also call for completing an R&D center at the plant by October.

Showa Denko to Double Compound Semiconductor Sales

Showa Denko says it plans to double compound semiconductor sales to ¥20 billion yen (\$172.4 mil) by 2000. This is part of a plan which calls for increasing information and electronics sector sales, which include compound semiconductors, ¥140 billion (\$1.21 bil) or 26% of total sales in the year through December 2000, up from the current 17%.

Showa Denko produces compound semiconductor materials as well as GaAs, GaP and InP LEDs. The company reports that demand for its LEDs is rapidly increasing for cellular phone, notebook computer backlight and various display applications. The company spent some ¥3 billion (\$25.9 mil) on the expansion of its Chichibu plant in 1996 in an attempt to boost output.

Off Year for Japan's Wafer Makers

Japanese manufacturers of compound semiconductor substrates saw a slowdown in their overall business in fiscal 1996, according to the bi-annual report of the Japan Manufacturers' Society of Compound Semiconductor Materials (JAMS-CS). For the twelve months ended March 31, 1997, compound semiconductor wafer shipments totaled ¥38,140 million (\$328.8 million), a decrease of 5.2% from fiscal 1996.

For the three previous years, the JAMS-CS members had reported double-digit increases in shipments. Nevertheless, this slump did not come as a surprise. There were warnings as far back as January 1996 that some sort of correction was likely, especially in the LED sector (see CS 2(1), p. 10). LED manufacturers account for over 60% of the demand, but their orders dropped off by 10% in fiscal 1996 (see Table, below). So despite the fact that other areas posted respectable gains (shipments for lasers were up 10%, and shipments for microelectronic applications were up an impressive 31%), the large volume of the LED business was sufficient to make the overall outcome disappointing.

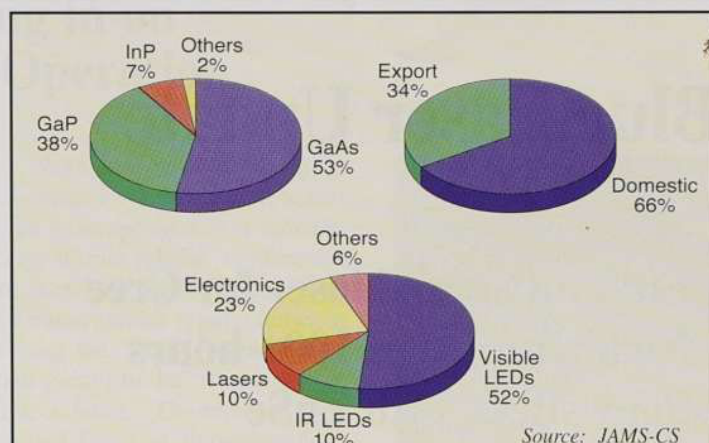
Mr. Hitoshi Inui of Sumitomo Electric, the secretary of JAMS-CS, commented, "exports of LEDs to Asia sharply declined because manufacturers in Asia expanded LED production in 1995 and caused a saturation of the market." Not surprisingly, the JAMS-CS report shows that of the four material categories tracked, shipments of GaP, which is used primarily in LED production, suffered the most. GaP shipments were down 14% to ¥14,632 million (\$126.1 million).

GaAs shipments were roughly even with the previous year at ¥19,920 million (\$171.7 million). JAMS-CS does not offer any sub-categorization for GaAs, but given that the statistics for applications show a sharp up-turn in shipments for electronic devices, it is obvious that sales of semi-insulating GaAs grew while sales of semi-conducting GaAs shrank. According to Mr. Inui, "GaAs shipments increased on the back of the increase in demand for electronic devices for mobile communications equipment such as cellular phones, which was offset by the decline in GaAs shipments for the infrared LED and visible LED markets where price competition is intensifying. As a result, GaAs shipments, which account for about a half of total compound semiconductor shipments, remained fairly flat". He also said "production of substrates for electronic devices soared because the market for mobile communications equipment continued to grow significantly and because demand for epi wafers for device makers was on the rise."

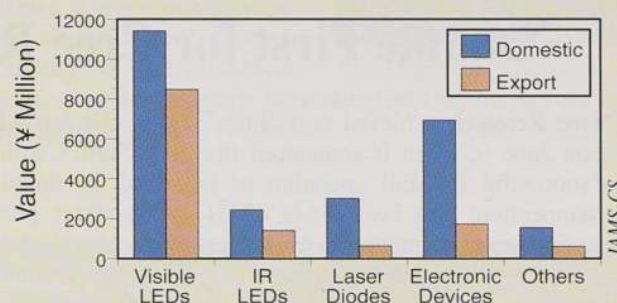
Shipments of InP were also up, totaling ¥2,710 million (\$23.4 million); an increase of 6% over 1997. And shipments of "other" compound semiconductor substrates, which includes InSb, InAs, GaSb, CdTe, and SiC, rose 38% to ¥878 million (\$7.6 million).

JAMS-CS predicts that compound semiconductor production will surpass ¥40 billion (\$344.8 million) in fiscal 1997. This would return the business to its 1995 level. The JAMS-CS members report that monthly shipments have been higher than year-ago levels since the beginning of this year.

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



The value of shipments made by the members of JAMS-CS during FY 1996, segmented according to material type (top left) and destination (top right) and application.



Value of shipments by JAMS-CS members in FY 1996 according to application and destination.



Total value of the compound semiconductor wafer shipments by JAMS-CS for the years 1990-1996, plus the forecast for 1997.

JAMS-CS Statistics for Fiscal 1996

Figures based value of shipments of compound semiconductor materials by Japanese manufacturers

Material	Value		% of Total	Change*	Application	Value		% of Total	Change*
	¥M	US\$M				¥M	US\$M		
GaAs	19920	171.7	52%	-0.3%	Visible LED	19886	171.4	52%	-11%
GaP	14632	126.1	38%	-14%	IR LED	3830	33.0	10%	-9%
InP	2710	23.4	7%	+6%	Laser Diode	3629	31.3	10%	+1%
Other	878	7.6	2%	+38%	Electronics	8645	74.5	23%	+31%
Total	38142	328.8	100%	-5%	Other	2150	18.5	6%	-44%

*Change since fiscal year 1995

Blue Laser Update

- First SiC-based laser for Cree
- Nichia promises 100+ hours
- Sony sticks with ZnSe
- SHG blue laser from Matsushita



Edge emission from Cree's cleaved-facet InGaN/GaN MQW index guide laser diode grown on SiC.

Double First for Cree Research

Cree Research achieved two "firsts" on June 9, when it announced the successful (pulsed) operation of a room temperature blue laser diode. This was the first announcement of a blue laser from a company outside of Japan and, more significantly, it was also the first laser to be fabricated on a SiC substrate.

The successful diode was grown on 6H-SiC at Cree using MOCVD. The structure, which is shown in Figure One, is a multi-quantum well (MQW) separate confinement heterostructure (SCH) consisting of an 8-well $\text{In}_{0.14}\text{Ga}_{0.86}\text{N}/\text{GaN}$ MQW region, with $\text{Al}_{0.06}\text{Ga}_{0.94}\text{N}$ waveguide regions and $\text{Al}_{0.13}\text{Ga}_{0.87}\text{N}$ cladding layers. The devices were fabricated into index-guided structures, with bars being formed by facet cleaving with a cavity length of 500 micron.

The device was operated in pulsed mode at room temperature with a duty cycle of 0.1%. Preliminary measurements indicate a threshold (I_{th}) of 1.2 A at 42V, which corresponds to a current density of 48 kA/cm² for a 5 micron wide stripe. Laser emission occurred at 403 nm with a mode FWHM of 0.8 Å.

Cree co-founder and scientist in charge of the development program, John Edmond remarked, "This is a milestone toward achieving a commercially viable laser, but we still have a lot of development work ahead of us. This is similar to the development cycle we went through for our blue LED. The next step is to improve device performance and process repeatability."

Dr. Jan Schetzina, professor of physics at North Carolina State University discovered the initial laser operation. Dr. Arto Nurmikko, professor of physics at Brown University, also observed blue laser operation from sample devices received from Cree.

Cree is now the fourth organization to report the successful fabrication of a GaN semiconductor laser. The first breakthrough was made by Nichia Chemical, which announced a pulsed laser in December 1995, and a CW laser last November. Nichia was followed by Meijo University and Toshiba - neither of which have yet announced a room-temperature laser.

With the exception of Cree, all of the major blue laser announcements to-date have been based on GaN/InGaN grown on sapphire (although Nichia has been known to dabble in spinel (MgAl_2O_4) - see CS 2(3), p. 22). Cree, which is a leading supplier of SiC substrates, has a vested interest in promoting an alternative. They hope to eventually demonstrate superior laser performance due to SiC's closer lattice match with GaN (3%) and better thermal conductivity, which is 10 times greater than that of sapphire. Cree also hopes that the use of SiC will result in higher-quality cleaved facets. In addition, the use of the semiconducting SiC substrate allows vertical structures with top and bottom contacts, similar to all other laser diodes currently in production. In contrast, the use of sapphire, which is an insulator, requires lateral device designs, which may complicate processing.

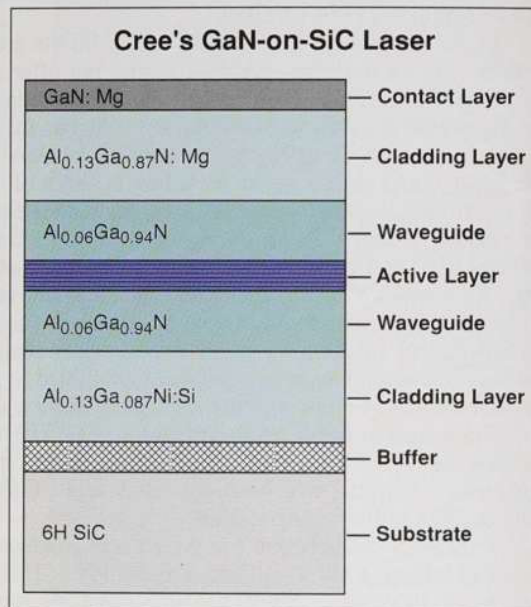


Figure One. Epitaxial structure of the SiC laser. The active layer is an 8-well $\text{In}_{0.14}\text{Ga}_{0.86}\text{N}/\text{GaN}$ MQW structure.

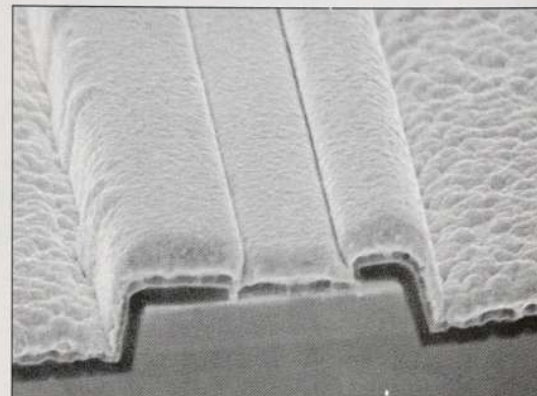


Figure Two. SEM image of cleaved facet of Cree's SiC blue laser.

Nichia Closing in on 100+ Hours of Operation

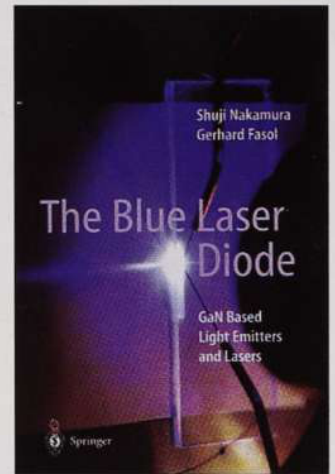
Nichia Chemical reported their first pulsed GaN laser over 18 months ago, and announced their first CW laser last November. So where are they now?

Shuji Nakamura, who heads the R&D effort at Nichia, says he is planning to present a paper at the International Conference on Nitride Semiconductors (ICNS'97, Tokushima, Japan, October 27-31) which will include a demonstration of the longest lifetime ever reported for either II-VI or III-V-nitride laser diodes. This means that Nichia is either close to or has already achieved at least 100 hours of room temperature CW operation.

In his most recent presentation, at the European MRS Meeting held in Stasbourg, France on June 16-20, Nakamura reported the current status of the Nichia's blue laser development efforts. Room temperature CW operation of InGaN MQW structures was achieved with a threshold current of 25 mA, a threshold voltage of 5.8 V, and output power of 30 mW, and an operating temperature up to 100°C. Lifetimes were around 35 hours.

Nichia reports that it still has a goal to begin commercialization of blue lasers sometime next year.

Nakamura is very much in demand as a speaker, and he seems to put in an appearance at virtually every nitride-related conference. But somehow, in the midst of all that travel and his regular duties in keeping the Nichia research program going, he has found time to write a book. Co-authored with Gerhard Fasol of Eurotechnology Japan K.K., *The Blue Laser Diode: GaN Based Light Emitters and Lasers*, is now available from Springer-Verlag. With 246 figures and 49 tables, it provides a detailed discussion of the current state of understanding of nitride-based light emitters, as well as some interesting data on the history of the Nichia nitride development program.



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Sony Sticks with ZnSe

*Is the first blue laser still the best?
Sony is designing a new optical data
storage system around a II-VI laser.*

In the excitement over the rapid progress in the Group III nitrides, many people have forgotten about II-VI lasers. This despite the fact that ZnSe was the material of choice for much of the early work in shortwavelength lasers.

The first blue-green laser (490 nm) ever reported was fabricated from ZnSe by Michael Haase and coworkers at 3M in 1991. Their original diode operated only under pulsed conditions at temperatures of 77 K, but by 1993 they had demonstrated CW operation at room temperature. Then in February 1996, Sony announced that they had achieved 101.5 hours of room temperature CW operation from a ZnMgSSe/ZnCdSe laser diode with a wavelength of 515 nm. This is still the record for all shortwavelength laser diodes.

But the amount of work being done today in II-VI's pales in comparison to huge volume of resources going into GaN. Nevertheless, a few groups are continuing to address the problems that have slowed ZnSe's development. ("Slow" here meaning in comparison to the rapid rate of progress in the

nitrides. For example: after the report of the first ZnSe laser, it took approximately 5 years to achieve 100+ hours of room temperature CW operation. Nichia's Shuji Nakamura hopes to do the same in less than 2 years with a InGaN laser- see previous page.)

The major problem with II-VI lasers is device degradation due to defects and dislocations in the material. These defects result from lattice mismatch in the heteroepitaxial layers, and they can rapidly propagate into the active layer because of the weak bond strength that is characteristic of the ZnSe materials system. Great strides have been made in reducing the number of defects that are grown into the material during epitaxy. Reports of defect densities in the 10^4 or 10^5 cm^{-2} range are now common, whereas they were originally as high as 10^6 . But the problem of the weak bond strength remains. As we reported in a previous issue (see CS 3(2) p. 28), it may be necessary to implement new II-VI materials, such as BeSe, which have higher cohesive energies than ZnSe.

Sony's New System

But despite these problems, Sony is not giving up on II-VI's. Proof comes in the form of a recent announcement by the company that it has invented a new technology for high-capacity optical discs with recording and playback capability. The system, which is still in the development stage, is designed around a 515nm ZnSe laser. Sony reports that the system has demonstrated a storage capacity of 12 gigabytes (GB) for a single side of a CD-sized disc (12 cm). Thus each side of the disk could store approximately 5 hours of DVD-quality (at a bit rate of 4 Mbps) or 80 minutes of HDTV-quality video (at about 18 Mbps). The company hopes that the system may be the basis of new home recording appliances that could replace the VCR in the era of digital television.

One of the keys for the demonstration of the new system was increasing the power output of the 515 nm ZnSe laser. Sony's first long lifetime ZnSe laser provided just 1 mW of output; subsequent progress has provided diodes with 20 mW of output for these demonstrations. And further progress is being made. According to Dr. Akira Ishibashi, who leads Sony's Blue Laser Diode Project, one of the critical steps for achieving high power operation is to reduce loss from the rear facet. The cleaved facets are asymmetrically coated; the rear facet being prepared with high-reflectivity coating using dielectric stacks, while single-layer antireflection coating is employed at the front facet to reduce the reflectivity to 1%. Figure One(a) shows L-I characteristics at room temperature for such a chip. The maximum output power reached 87 mW. The slope efficiency below 60 mW was about 1.91 W/A, corresponding to an external differential quantum efficiency of 80%. Temperature dependence of the CW L-I curve is shown in Figure One(b). The laser generates 30 mW light output even at 60°C with a slight increase of the slope efficiency.

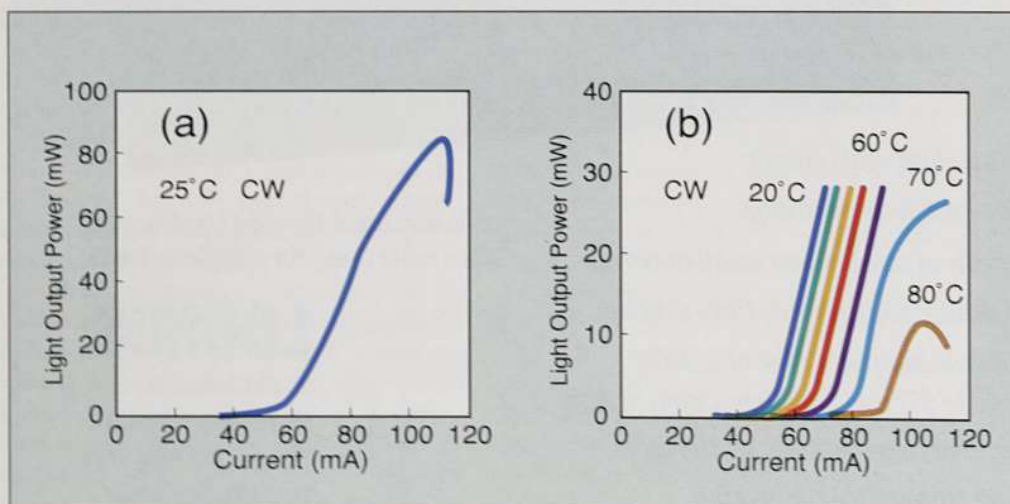
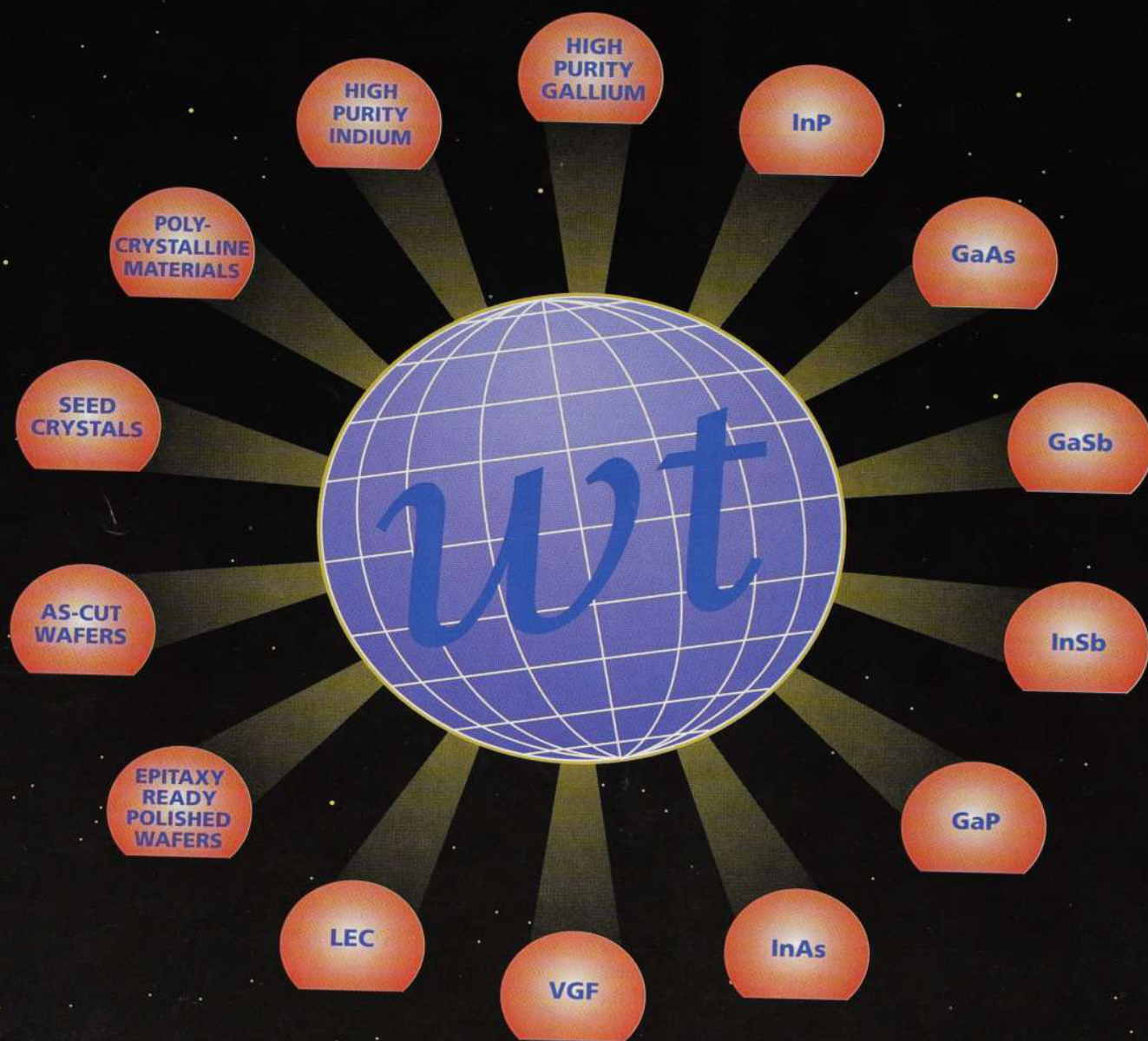


Figure One. (a) L-I characteristic of coated laser diode at room temperature; (b) L-I characteristics of coated laser diode as a function of temperature.

cont'd on page 18

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Of course, the next challenge will be to increase the lifetime of the laser. Everyone seems quite confident that GaN lasers will be commercially viable within the next few years, but few would say the same for II-VI lasers. But that doesn't phase Ishibashi. He says that Sony hopes to "make the II-VI laser practical within this century". He also said, "according to what has officially reported so far, the best (low-power) ZnSe-based laser lived for 101 hours, while the best (low-power) GaN-based laser lived for 37 hours. At the current time, (high-power) ZnSe-based laser is proven to be able to be used for 12 GB rewritable optical disk, while a GaN-based laser is not."

Optical storage is a huge market, which means that the stakes are high for Sony. Therefore, it is not surprising that, despite their optimism about the II-VI laser's prospects, Sony is simultaneously researching nitride materials. Ishibashi reports that they have not yet achieved lasing emission.

Issues of lifetime and output aside, one clear advantage of the GaN system is that it can produce shorter wavelengths than ZnSe. Sony's current approach to II-VI lasers uses

ZnCdSe active layers with ZnMgSSe cladding layers and ZnSSe guiding layers. By varying the Cd content in the well (20-40%) and the well width (3-6 nm), the lasing wavelength of such a structure can be varied from 505 to 520 nm within the critical thickness. Other II-VI structures can produce wavelengths as short as 460 nm, although there is not much data on their reliability. But for a GaN laser, the range of possible wavelengths is approximately 380-440 nm, which leads directly to greater storage capacity. So while

they work to extend the lifetimes of their ZnSe lasers, Sony is also investigating what their new system might be able to do if a 410 nm GaN laser was used in place of the 515 nm ZnSe laser. See Table below.

And for the supposed competition between ZnSe and GaN, Ishibashi says, "We believe that technological progress for both materials systems is inevitable. Because ZnSe is further developed at this stage, for the time being we will proceed with development using ZnSe."

System	Laser	Storage Capacity	
		Per square inch	Per 12 cm disc (single side)
CD	780 nm AlGaAs (infrared)	750 Mbits	680 Mbytes
DVD	650 or 635 nm AlGaInP (red)	3.2 Gbits	4.7 Gbytes
New Sony System	515 nm ZnSe (blue-green)	9.5 Gbits	12 Gbytes
New Sony System	410 nm GaN (blue)	14.25 Gbits*	18 Gbytes*

*Theoretical data - this system has not been demonstrated

Comparison of two commercially available optical data storage systems with two versions of Sony's new system.

Matsushita 15 mW SHG Blue Laser

Not everyone is waiting around for a fully functioning blue laser diode. In June Matsushita Electric announced that it has developed a technique to record 15 GB of data on a single side of a phase-change optical disk (PD). This is enough capacity to record two hours of high-definition video pictures.

The technique uses a 425nm optical waveguide-type SHG (second harmonic generation) blue laser. The SHG laser, developed at Matsushita using a 100 mW 850 nm tunable DBR laser diode supplied by SDL, provides up to 15mW of output power, which is believed to be a record for this type of laser. The 10.0x0.5x0.5mm SHG device uses a lithium niobate waveguide doped with magnesium oxide.

The IR laser, which SDL developed specifically for this application, includes integrated control and feedback mechanisms linked to a photodetector which monitors the blue light output. This arrangement allows wavelength tuning and locking, and direct modulation of the blue light.

Product or Stop-Gap?

We asked the Matsushita development team about the future prospects of SHG lasers. With work progressing on direct diodes, it seems logical to question whether a SHG laser can be competitive in the long run.

The Matsushita team seems to think that it can. Speaking on their behalf, Deborah Lamascus, a PR officer with Matsushita, reported:

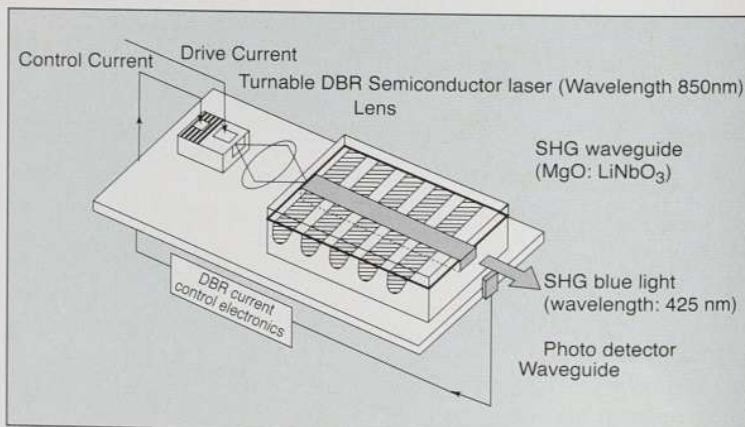
"We are now investigating the SHG blue laser because we can think it is competitive with the GaN blue laser. Performance regarding noise, optical feedback insensitivity, and beam quality will be the factors that make the SHG blue laser superior to the direct laser, even

though the latter could attain long life and high reliability in time."

"We started work on SHG waveguide around 1986, when it was believed that no direct blue laser could be applied to optical disks. In 1991 we started a project on the SHG blue laser based on quasi-phase-matching waveguide and laser diode. We recognized that it would take over ten years after successful continuous wave oscillation of direct laser at room temperature before it could be installed on an optical head of a practical optical disk drive. No one knows when GaN could be applied to rewritable optical heads"

The company says it plans to commercialize the technique in the early 2000's.

In an unrelated announcement, Toshiba also recently demonstrated an advanced DVD System based on a SHG blue laser. For more on that, see page 30.



Schematic diagram of Matsushita's newly developed SHG blue laser.

IBM Plans to Challenge GaAs

A SiGe product line scheduled for next year is key to Big Blue's strategy for establishing a presence in the market for communications semiconductors.

IBM Microelectronics is gearing up for a new campaign to promote its SiGe technology as a commercially viable process. In doing so, it plans to challenge GaAs IC makers in virtually every high volume application. IBM is hoping that its unique ability to manufacture SiGe-based bipolar and BiCMOS circuits in large volumes will enable it to establish greater credibility as a supplier of semiconductors for communications systems - a red-hot market which Big Blue has largely missed out on.

The First Customers

On June 19 IBM announced that it had signed an agreement with Nortel for the development of SiGe ICs for high-speed telecommunications and wireless applications. Nortel will design prototype microchips and IBM will manufacture the devices.

"SiGe-based devices can move information across a network at speeds traditionally considered to be beyond the reach of silicon technology," said Robert Hadaway, director, technology access and applications, Nortel. "Nortel's prototype microchips will be used in fiber transport products as well as for several high-speed cellular and personal communications services' (PCS) wireless applications. Our objective is to work towards developing advanced devices at commodity-level costs."

Nortel is said to be designing the new chips already. Early prototypes will reportedly be manufactured and validated later this year.

IBM considers Nortel to be their second customer for its SiGe process. In May of 1996, they announced a collaborative effort with Hughes Electronics to prototype devices for potential applications in several Hughes divisions, including Network Systems, Aircraft, Telecommunications & Space, and Delco Electronics. (See CS 2(4), p. 19.) According to Ron Finnilla of Hughes, that work is continuing, and he says that Hughes' interest "remains high". The SiGe circuits under consideration are still in the prototype stage, and at this point there is no public forecast for when production will start. Finnilla reports that an automotive collision avoidance system is one of several applications that are being investigated.

What about Analog Devices?

The Hughes and Nortel announcements are, in reality, the second introduction of IBM's SiGe plans. The first came in 1993 when IBM announced an agreement with Analog Devices to commercialize RF and mixed-signal SiGe circuits for wireless communications. There were also plans for high-speed SiGe circuits such as a 1 GHz digital-analog converter for multi-media telecom and datacom markets such as

ATM/SONET and digital CATV. However, both parties to the deal apparently got cold feet, and the agreement was terminated before any chips were produced. There is no current active relationship between the two companies.

According to Ron Soicher, vice president of analog and mixed signal development for IBM Microelectronics, the Analog Devices agreement was "a little bit ahead of its time". In the two years since then IBM has increased its commitment to the SiGe process, raised its funding levels, and improved its marketing savvy for communications semiconductors. He reports that IBM is "committed to building a business" on its SiGe process. As a result, IBM is putting in place a volume manufacturing capability for next year, and more announcements about deals with other electronics companies are planned for the very near future.

cont'n on page 20

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Targets

IBM's standard high volume ion-implant BiCMOS process is targeted at a maximum frequency of 18 - 20 GHz. The SiGe technology is being developed in bipolar-only and BiCMOS iterations, both with an f_{max} of around 50 GHz. According to Bernie Meyerson, who has led the IBM SiGe development program, at above 10GHz IBM employs a polyimide based backend process to lift transmission lines and passives well off the substrate to eliminate coupling and associated losses.

Soicher says that whereas IBM might be legendary for indulging in some pretty exotic bipolars, in the present case they have reduced the complexity because the potential applications don't require it. In the case of SiGe BiCMOS, he says, "we are trying to build a process profile that is very cost competitive and close to a standard BiCMOS, but is also 'super-charged' through the use of epi and the addition of the Ge in the base, as well as the implementation of deep trench isolation."

IBM's target markets include virtually all of the high volume applications where GaAs is currently thriving, with the possible exception of 900 MHz analog phones. For applications above 1.5 GHz, Soicher says, the high frequency and noise attributes give SiGe "compelling advantages over BiCMOS and GaAs in terms of cost, power dissipation and other features." Therefore, he says, "we want to go after the high volume GaAs sockets in digital cellular, GPS receivers, and high performance wireless LANs at 2.4 GHz and 5.2 GHz." Other possible applications mentioned include direct broadcast satellite (DBS) receivers at 11-12 GHz; global positioning satellite (GPS) receivers at 1.6 GHz; TV set-top box tuners at 1.2 GHz and above; collision avoidance radar at 24 GHz, as well as high-speed data communications circuits for standards such as SONET and ATM.

"I don't want this to be viewed as a technical curiosity, but as a commercial and highly manufacturable process" Soicher says. "That is why we have waited until we were well into our qualification processes before making announcements." He reports that the bipolar version is already qualified, and that IBM is in the process of qualifying the BiCMOS version. Both are run on the same high volume 8" lines are also used for IBM's standard BiCMOS and CMOS.

Can IBM Cut It In Communications?

IBM's historical strengths in semiconductors lie in the computing area. They are not known as a leader in the communications sector. Soicher says it will be necessary for them to earn some credibility in the field, perhaps by implementing SiGe designs into IBM products in the networking and communications field, as well as continuing to work with outside customers such as Hughes and Nortel. To that end, IBM plans to introduce its own line-up of merchant and captive SiGe BiCMOS circuits next year. The first captive application may be for 5.2 GHz wireless LANs which will be offered by another IBM division.

SiGe technology appears to be an important component of IBM's strategy for establishing a presence in the communications area. They hope that SiGe will give them an exclusive niche that will help to make up for their late entry into this sector. But it might be dangerous to have a too exclusive position, because buyers will likely be reluctant to make volume commitments to a new technology without having a qualified second source. Therefore IBM is encouraged to see that other companies are also pursuing their own SiGe R&D programs. "All of the major semiconductor companies that are active in communications today have SiGe projects, in varying levels of maturity" says Soicher. "We think that you will see, over the next 2-3 years, a lot of these companies getting into the market."

Raytheon/TI Deal to Proceed, But With Sale of GaAs Unit

On July 3 the U.S. Justice Department approved Raytheon's plan to acquire Texas Instruments' Defense Systems & Electronics Group (DS&EG). However Raytheon will be required to sell the DS&EG's microwave IC division, which manufactures GaAs MMICs. Approval by a Federal Court in Washington DC is now required for the transaction to proceed.

The acquisition, which is valued at \$2.95 billion, has been under review for the past six months as the Justice Department considered whether it would give Raytheon a monopoly on GaAs MMIC technology for aircraft radar. Allegations to this effect were made by rival missile producers Lockheed Martin and Northrop Grumman and others when the acquisition plan was first announced in January (see CS 3(2), p. 22.)

The DS&EG microwave IC division had revenue of about \$40 million in 1996. How is it that such a small unit can hold up a \$3 billion transaction? According to Joel Klein of the Justice Department's antitrust unit, TI's GaAs technology is critical to three contracts, worth as much as \$10 billion, for advanced missile targeting radar systems that are likely to be awarded by the Pentagon in the next five years. Lockheed and Northrop told the government they were concerned about maintaining access to TI's GaAs MMICs if Raytheon's acquisition plan was allowed to go forward in its original form. Raytheon, which had fought for a less-restrictive agreement allowing it to license the technology to competitors, agreed to sell the TI GaAs operation instead when the Justice Department threatened to block the entire acquisition.

Under the terms of the settlement, Raytheon is required to sell the Dallas-based TI GaAs business within 180 days. The buyer must have both the capability and the intent to continue to develop, make and sell MMICs that meet Defense Department requirements.

Next up for Raytheon is another blockbuster deal: a \$9 billion acquisition of the Hughes Electronics defense operations from General Motors. The principals are eager for completion in the third quarter of this year, but that may be optimistic, as this transaction is currently the objective of an even more intensive Justice Department probe of possible anti-competitive issues.

Low Cost Quaternary LEDs from HP

Hewlett-Packard will soon begin offering AlInGaP LEDs priced at just 10 cents each in quantities of 1 million units. A company spokesperson said that HP's volume manufacturing capabilities, coupled with its leading packaging and materials technology, enabled the company to realize this price breakthrough. HP believes that this new pricing structure will give their customers the opportunity to use LEDs in new applications such as solar-powered security lighting, bicycle safety, panel illumination, and upscale toys.

The LEDs will be available in red (626 nm), red-orange (615 nm) and amber (590 nm), and will be housed in 5mm or 3mm packages. Maximum luminous intensity ($I_f = 20$ mA) will range from 650 mcd for red, 900 mcd for red-orange, and up to 1100 for amber. Samples are expected to be available from HP distributors in July.

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SDL, Spectra-Physics Settle Lawsuit

SDL and Spectra-Physics reached an out-of-court settlement of all of their outstanding litigation on May 21, ending a two year intellectual property dispute.

When SDL was formed in 1983, it entered into a technology agreement with its former parent companies, Xerox and Spectra-Physics. Among the features of that agreement was a grant by SDL to Spectra-Physics of a non-exclusive license to certain patented and non-patented technology developed by SDL. On March 20, 1995, Spectra-Physics initiated a lawsuit in California Superior Court, alleging that SDL was not complying with that agreement, and asking for the transfer to Spectra-Physics all the technology developed by SDL between 1983 and 1993. Spectra-Physics' subsidiary Opto Power Corporation, a competitor of SDL's in the high power laser field, was also a plaintiff in the suit.

Under the terms of the settlement, SDL will pay \$15 million to Spectra-Physics to cover legal fees and expenses. Spectra-Physics retains the license granted under the 1983 technology agreement, but will not receive any of the additional technology that was in dispute. On the basis of this fact SDL declared their a victory of sorts in the settlement, even though the combination of the payment to Spectra-Physics and their own legal fees forced them to take a \$28 million charge against second quarter earnings.

SLI Contracts & Bids

Semiconductor Laser International Corp. (SLI) announced on June 19 that it has received a contract with the Defense Special Weapons Agency (DSWA) of the U.S. Department of Defense. SLI will conduct research on high power visible semiconductor diode lasers for exploratory development of laser-supported denial/delay technology. This technology will support the agency's physical security missions.

Phase I of the contract calls for an initial one year duration with Phase II calling for an additional six months. Projected revenue to SLI from Phase I is approximately \$350,000.

Dr. Geoffrey T. Burnham, president and chief executive officer of SLI, said, "This is a significant opportunity for SLI and it will add to SLI's ongoing efforts in the development of high power single mode red lasers that have applications to the optical storage DVD market. This market is estimated to grow from \$10 million in 1997 to over \$4 billion by 2001."

In an unrelated announcement, at the company's annual meeting on June 20 SLI announced that it was submitting bids for DVD lasers to three major companies. Burnham said he was pleased with interest shown by the companies. "We hope to get substantial business in this area," he said.

Among other remarks to shareholders at the meeting, Burnham reported that the company's production is fully on line at its 15,000 sq. ft. facility in Binghamton, NY, and that SLI has an order backlog of about \$1.8 million.

Contracts for Spire

Spire has announced the receipt of two new development contracts. The first is from the Wright Laboratory Armament Directorate to develop sensitive, high speed, extended InGaAs avalanche photodiodes (APDs) for use at wavelengths up to 2.3 microns. The program will adapt Spire's commercial InGaAs power converter technology and is expected to result in working APD prototypes. According to Steven Wojtczuk, Staff Scientist, the long wavelength response of the devices will be extended past that of common 0.75 eV lattice-matched InGaAs by the use of an InGaAs grading layer that will permit both the absorption and multiplication/junction regions to utilize lower bandgap (0.55 eV) InGaAs.

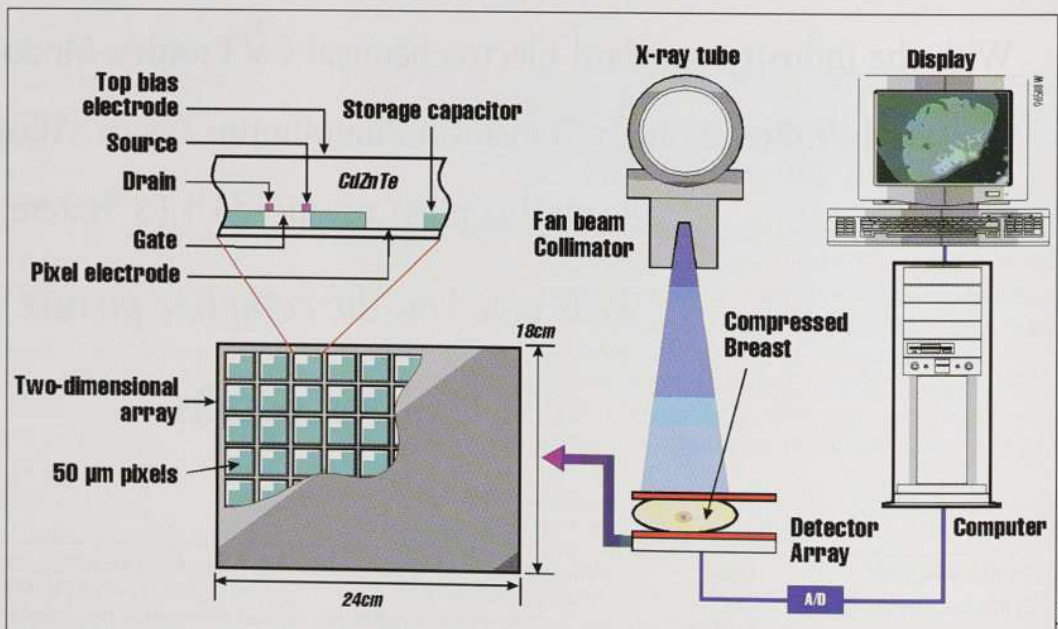
The second new contract, from the U.S. Army Medical Research Command, is for the development of thin film CdZnTe detectors for digital mammography. According to Rengarajan Sudharsanan, the manager for the project, CdZnTe offers direct detection, high signal-to-noise ratios, and a wide dynamic range in comparison with conventional technology. Spire says that the planned large-area, self-scanned flat panel X-ray detectors that are the goal of this project will be more efficient than scintillator-based X-ray detector systems.

Spire plans to employ a continuous photoconductive CdZnTe layer as a direct converter of X-ray to electrons, and to integrate detectors with large-area, active-matrix CdSe thin

film transistor pixellated arrays for readout.

Development will take place in three phases. In Phase I, Spire will demonstrate CdZnTe thin film detectors by fabricating and testing a passive matrix detector structure deposited on glass or Si substrates. In Phase II, the feasibility of integrating CdZnTe detectors with readout circuitry will be demonstrated by fabricating detectors on a Si multiplexer. And in Phase III, the company will monolithically integrate CdZnSe with CdSe TFTs and perform imaging experiments.

The contract is scheduled to last four years.



Spire's approach to implementing CdZnTe flat-panel detector arrays for digital mammography.

International Semiconductor Shuts Down Operations

On May 27 International Semiconductor Corporation [Santa Monica, CA] announced that it was shutting down its subsidiary, GAD Semiconductors. GAD, located in the Migdal H'amek industrial park in Israel, has been attempting for the past three years to cost effectively manufacture GaAs diodes. (See CS 2(4), p. 12.) ISSM said that despite the fact that GAD had perfected the technological process for producing the diodes, delays in the receipt of orders meant that the company could no longer meet its overhead requirements.

ISSM reports that it is now negotiating with a "well-financed electronics manufacturer in the United States" to produce products using ISC's technology. ISC Robert Terry stressed that company is not filing for bankruptcy, that it is debt-free, and that it is still a going concern. He also told investors that if the current round of negotiations should fall through, "there are 3 other companies that are interested in talking with ISSM."

ISSM is traded as an over-the-counter stock in the U.S., and is one of the 17 companies tracked in the Compound Semiconductor Portfolio (see CS 3(2), p.46)

Title III InP Awards

The U.S. Air Force, through Wright Laboratory at Wright-Patterson AFB, has awarded contracts to American Xtal Technology (AXT) and M/A-COM for the development of InP. The awards were made under Title III of the Defense Production Act. The purpose of the contracts, which have a total value of \$7.9 million but are based upon cost sharing contributions from the companies, is to improve the availability of high-quality, large surface area semi-insulating InP substrates. The primary focus will be on producing less expensive 3" InP wafers of more consistent quality, but the program will also look ahead to the production of 4" InP wafers.

Title III allows the U.S. government to offer appropriate incentives to develop and expand the production capacities of domestic sources for critical components and resources essential for the execution of the national security strategy. It was previously used to improve the domestic supply of semi-insulating GaAs wafers, although the funds which have been made available for the InP program are considerably less.

The contracts are scheduled to run for 30 months.

Cree Claims Major Reduction in Micropipe Densities

In late May Cree Research announced what it describes as "tremendous progress" in its efforts to reduce micropipe defect densities in its SiC material. The company expects this development to expand the applications for SiC, and to improve device performance in existing applications.

The new low-defect wafers, with a maximum of 30 micropipes/cm², are being offered as a top-of-the-line product. They are said to represent a 40% reduction in defects. In addition, Cree will also offer two other grades - a select grade, which will have a range of 31 to 100 micropipes/cm², and a standard grade, which will have a range of 101 to 200 micropipes/cm². The latter represents a 50% reduction in micropipe defect densities for this category of material.

Rhone-Poulenc Closes Aussie Ga Plant

In early May Rhone-Poulenc announced it was suspending its gallium extraction activities at its Pinjarra facility in Western Australia. The move was attributed to a slow-down in the growth of demand for gallium, especially in Japan. Rhone-Poulenc says that it can meet the forecasted demand "for several years to come" from its current stockpiles and production in France and Germany. The plant closure was described as a "mothballing", which would allow a quick recommissioning when the situation warrants it.

LEDs on Tour

What does the well-equipped rock-n-roll band take on tour with them? In the case of the hugely popular Irish rock group U2, the equipment list includes a million LEDs.

The band is currently touring the U.S. with its "PopMart" extravaganza, and the centerpiece of the stage is the world's largest display screen. Manufactured by SACO Controls Inc. of Montreal, Canada, trapezoidal display measures 170 by 56 feet at its widest part. Over one million LEDs are used to form 150,000 red-green-blue (RGB) pixels. The screen is used during the concerts to display live video of the band as well as computer-generated abstract images and animated art by Keith Haring and Roy Lichtenstein. At the end of the show the screen folds up like an accordion, and fits in two semi-trailers.

SACO built the screen, at a reported price of \$6 million, specifically for the PopMart show. The company's normal line of work includes producing LED displays for more routine applications such as industrial process control, power plants and power networks, mass transit systems and H.V.A.C. systems.

According to Fed Jalbout of SACO, one of the biggest challenges in meeting the specifications for the U2 show was developing the special software needed to provide real time full motion video on such a scale. The screens can refresh at a rate of 60 frames per second. In addition, the display had to be designed to provide an extremely wide viewing angle - in excess of 170 degrees.

Jalbout says his company used red LEDs from Sharp and blue and green LEDs from Nichia.



The centerpiece of U2's Popmart Tour: a 170 x 56 foot LED screen, the largest of its kind in the world.

Jeff Scheid, Las Vegas Review Journal

OSA Fellows Announced

On May 28 the Optical Society of America announced the names of 51 members who had been awarded the rank of Fellow in 1997. Compound semiconductor specialists in the group included Connie Chang-Hasnain of U.C. Berkeley, Weng W. Chow of Sandia, Shun Lien Chuang of the Univ. of Illinois, Gordon W. Day of NIST, Paul Lee Gourley of Sandia, Robert J. Lang of SDL, David D. Nolte of Purdue, Tadasi Sueta of Setsunan University (Japan), and Thomas H. Wood of Bell Labs.

Semiconductor Laser and LED Manufacturing in Europe

BRIDGET MARX

It is no secret that Europe runs a distant third behind Japan and North America in the compound semiconductor industry. For example, in the last issue of this magazine it was pointed out that European companies account for only 7% of GaAs IC shipments (CS 3(3), p. 28). But when it comes to lasers, European manufacturers are in a much better position, and in fact Strategies Unlimited estimates that they are not too far distant from their North American competitors - see Figure One.

European manufacturers appear to be ready, willing and able to continue to compete in the global market. There is an excellent technology base in Europe for this kind of work, substantial numbers of potential employees with advanced educational credentials, and firm funding commitments from the EU and national governments. At the same time, the European laser diode industry is attracting outside investment. At least five North American companies have established a presence in Europe through acquisition.¹ While in some circles this might seem injurious to national pride, in others it is a cause for optimism.

There are several laser suppliers in many countries across Europe. This article tries to take a snap shot of the state of art of commercially produced diode lasers and specialist LED products from Europe.

Visible Light Sources

In the diode laser area, it appears that only Philips Optoelectronics are producing visible lasers in Europe. The company produces a 5 mW 635 nm chip for scanning applications and a range of AlGaInP lasers at 675 nm with a maximum output power of 30 mW for printing and scanning applications. They also produce a near infrared laser at 785 nm with 40 mW output for data storage and printing.

There is more European activity in visible LEDs, especially with regard to development efforts in the area of Ultra High Brightness (UHB) LEDs and nitride emitters.

A major research project aimed at investigating GaAlInN for multicolor light sources was launched in February. Entitled "Rainbow", the project is funded by the EU within the Brite-Euram Programme. The total budget is undisclosed but thought to be several millions USD.

The research consortium includes major players from across

¹ Nortel (Canada) and Hewlett-Packard (US) acquired their European manufacturing arms by buying STC and BT&D (both of the UK); more recently, Mitel (Canada) purchased the ABB Hafo laser operation in Sweden. Coherent (US) bought Finnish epiwafer maker Tutcore; and Uniphase (US) purchased the IBM Laser Enterprise unit located in Zurich, Switzerland.

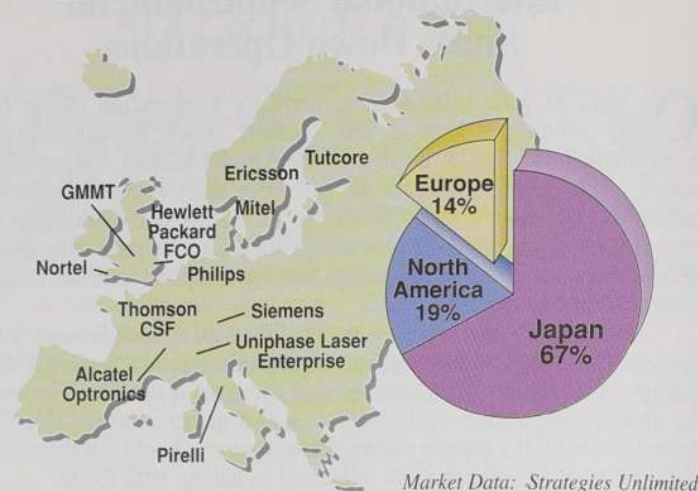


Figure One. Europe's major laser manufacturers, and the geographic distribution of world-wide laser production in 1996.

Europe, including Thomson-CSF (as manufacturers of electronic components), Philips (as manufacturers of laser diodes), AIXTRON, Epichem, and several research groups. During the three and a half years that the programme will run it is expected to develop both LEDs and lasers, and optimize prototypes for the market place.

Specific aims of the project include demonstrating UHB-LEDs emitting in the range 400 nm to 590 nm with luminous intensity of 4 cd and laser diode samples operating at a wavelength of around 400 nm with CW output power of 5 mW at room temperature. The project will also develop a device processing technology for GaAlInN based alloys, applicable to both multicoloured UHB-LEDs and blue laser diodes. New MOVPE processes and group III and nitrogen precursors are also expected.

In a different project, Siemens and the Fraunhofer Institute for Applied Solid State Physics (Freiburg, Germany) are teaming up to produce white LEDs. Volume production is expected next year. The LED, which was developed at the Fraunhofer, is based on a blue GaN/SiC chip coated with a layer of epoxy material containing a fluorescent dye. Blue light from the chip produces yellow emission from the dye. Adding extra layers of red and/or green emitting dyes shifts the colour closer to measured white. The current samples have lifetimes in excess of 60,000 hours. Siemens is already engaged in the production of red and yellow UHB LEDs, and the company maintains close ties with U.S. SiC LED manufacturer Cree Research to secure a steady supply of blue LEDs.



Figure Two. A white light "LUCOLED" LED produced by Siemens as a result of color conversion techniques developed at the Fraunhofer IAF. Siemens is expected to launch volume production sometime next year.

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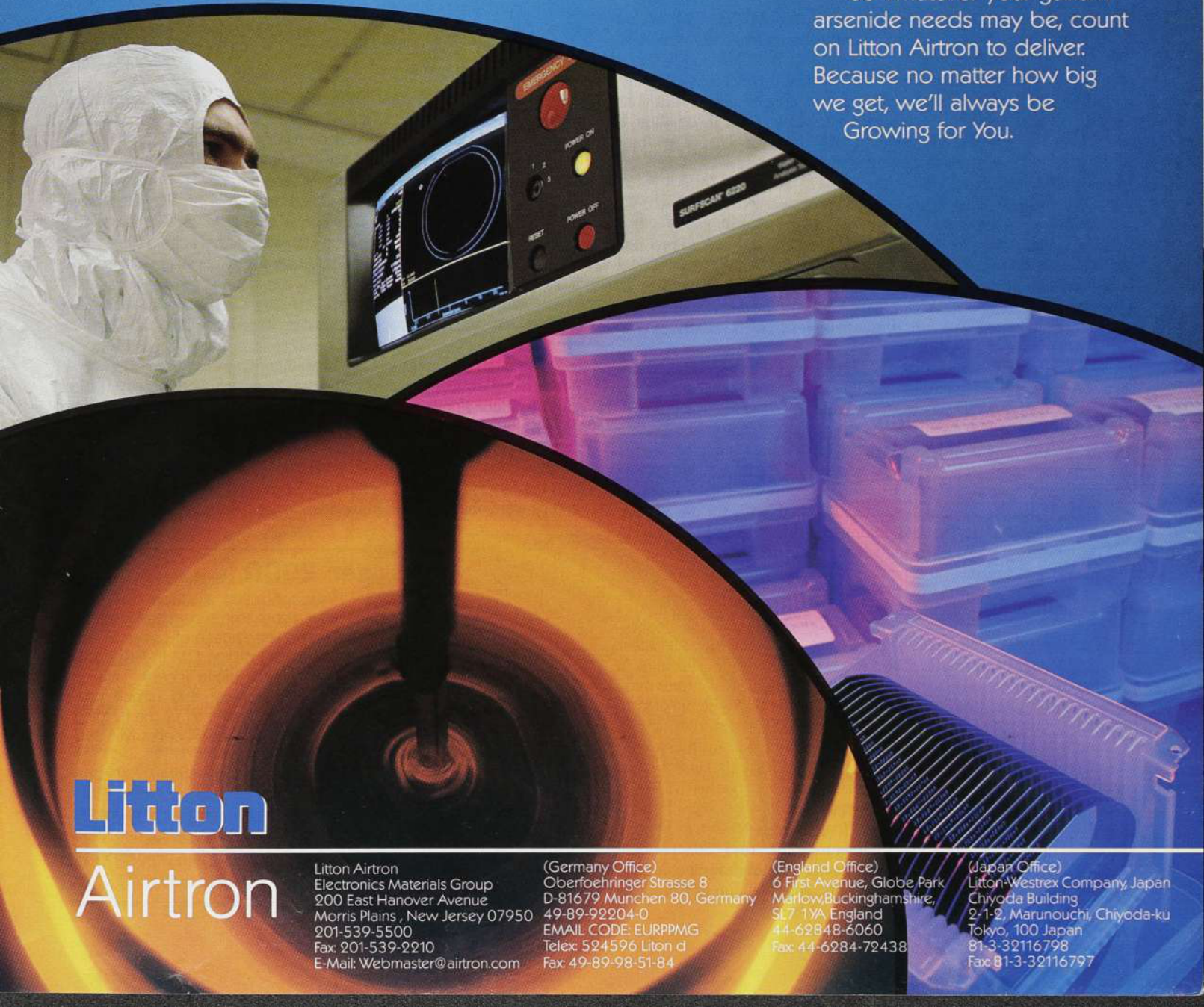
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High Power Diode Lasers

Around the globe, high power laser diodes are one of the fastest growing segments of the laser market, prompted by significant increases in reliability and decreases in price. The growth over the past year was around 25%, and similar results should be recorded this year, bringing sales of well over \$100 million.

There are several European suppliers of high power (10 mW and up) diode lasers. Siemens is the largest, but there are several other substantial efforts as well, including Thomson-CSF, Nortel, Uniphase Laser Enterprise (the former IBM Laser Enterprise business in Switzerland), and Philips. In addition, Tutcore (Finland) also makes high power laser diode wafers and bars; their new owner, Coherent, does packaging and productising in the US. (However, Tutcore still sells epi material, some of which is packaged and sold by other European manufacturers.)

The following is a survey of very high power units for materials processing and solid state laser pumping. High power lasers supplied specifically for telecommunications (such as EDFA pumping) are covered in the section on telecommunications.

Siemens high power diode lasers are based on strained quantum wells in InGaAlAs, using MOVPE. Standard units produce around 1 W CW (up to 10 W pulsed), with wavelengths of 808, 940 and 980 nm, with wall plug efficiencies around 35%. Special wavelengths are available on request. Diode lasers with beam shaping or fibre optics coupling are available. Siemens also produce pulsed laser diodes with a peak power 10 - 15W (100ns duration, 0.1% duty) mounted in low cost plastic package for large volumes. For these the standard wavelengths are 850 and 905nm, and the emitting area is 200µm x 2µm. These lasers will operate over a temperature range between -20°C and +85°C, and are finding applications in range finding and security areas.

Individual diodes can be combined in arrays and bars to produce higher powers and Siemens' current product range includes unmounted laser bars with powers up to 30 W CW and up to 100 W quasi CW. Wavelengths, materials and efficiencies are as for the single diode products. The unmounted bars are 10mm x 600microns x 115microns in size.

As part of the Laser 2000 collaboration (see box), Siemens has been actively involved in a full programme of enhancement of the properties of their high power lasers. This includes especially the efficiency, reliability (lifetime) and usable optical power density of the lasers. Results on 940 nm and 808 nm devices (1 W from 200 micron diameter single emitters and 25 W from 10 mm bars) show impressive results. Efficiencies of over 50% have been obtained with lifetimes exceeding 50,000 hours for the 940 nm devices and 20,000 hours for the 808 nm devices, adding fuel to the aluminium free materials debate. Using beam combination into a fibre optic delivery system a power density of 50 kW/cm² was obtained in a numerical aperture of 0.22. Such high powers are being exploited by Laser 2000 partner Dilas in materials processing, with a system producing 800 W already demonstrated.

Packaging for Siemens' high power products is provided by other companies such as **Jenoptik Laserdiode** and **Dilas** (both located in Germany). For example, Dilas is already offering a 800 W fibre optic delivery system for materials processing which is based on the 808nm high power lasers developed under the Laser 2000 program.

Jenoptik is also producing high power bars made from aluminium free material produced by **Tutcore**. The Tutcore/Jenoptik laser is a linear bar array, consisting of 20 emitters, each 150 microns wide and spaced by 500 microns. The bars operate at 808 nm and even up to power densities on the face of 8.6 MW/cm² there is no sign of the catastrophic optical damage that prematurely destroys conventional AlGaAs devices. Tutcore claims that their lasers are now reaching the output power of their AlGaAs competitors, and they aim to have a 50

W bar on the market in two to three years. The lifetime of this is projected to be 10k hours. They are already selling 20 W bars and have a prototype GaInAsP/GaInP bar array that emits more than 100 W with a wall-plug efficiency of 50%.

Last month German company **Applied Photonic Systems**, APHS, introduced commercial high power diode lasers which have also been developed as part of the Laser 2000 programme. Using a technology developed at the Fraunhofer Institute in Freiburg, the new lasers produce 1 Watt output power at a standard wavelengths of 1020 nm (940 nm to 1070 nm are in preparation). The laser is claimed to have excellent beam properties and fibre coupling is offered.

Nortel, although specialising in telecommunications lasers, also produces high power lasers for automotive and military applications. Using AlGaAs devices between 800 and 870 nm and InGaAs devices between 890 and 900 nm, either single or multichip systems are produced. Peak powers are between 0.4 W and 100 W for the two materials, with output in 35 ns long pulses at a repetition rate of 15 kHz. The diodes are produced using MOCVD.

Nortel also manufactures lasers for use in instrumentation. These offer higher powers than are needed in the standard telecommunications lasers, and Nortel use MQW technology to produce systems at 850 nm (powers up to 1 W), 1300 nm (powers up to 100 mW) and 1550 nm (powers up to 60 mW).

French industrial giant **Thomson-CSF** offer a considerable range of high power diode lasers, in bars and stacked arrays of bars, all manufactured and packaged at its facility in Orsay. The majority of the products offered are based on MOCVD produced AlGaAs single quantum well lasers operating between 790 and 830 nm. CW bars of up to 20 W are available, with fibre coupled bars up to 15 W. The newest products in this range have efficiencies as high as 40%. Quasi CW devices offer extremely high powers, with efficiencies above 40%. Operating with 200 microsecond pulses at 100 Hz peak powers of up to 2.5 kW are specified.

A more limited range of InGaAlAs bars are available, operating between 940 and 980 nm. These can produce up to 20 W CW with an efficiency of 35%.

Research at Thomson-CSF is producing new and modified products at a high rate. A recent collaborative project with nearby Institut d'Electronique Fondamentale has produced subnanosecond pulses from a high power stacked array. The short pulse system was based on a 10 bar stack producing around 600 W at 805 nm with a standard power supply. When excited with a power supply designed to pump power into the 50 Ohm matched system in 50 ps, optical pulses shorter than 400 ps were obtained with pulse energies of 0.3 microJoule.

Laser 2000

A major German collaborative programme reached its first milestone this year. The initial three year phase of Laser 2000 ends this summer, having invested 100 million DM in R&D projects covering all aspects of high power diode lasers. Major focal points included crystal growth, epitaxy, and device processing and packaging for diode lasers. Over half of the funding was provided by the government through the Federal Ministry for Science and Technology (BMB+F).

The partners in Laser 2000 included major industrial companies, such as Siemens, and research groups in German universities, numbering over 20 in total. The commercial partners say they are already putting the research to good use (see above), and plans to extend into a second three year phase of the programme were recently announced.

Telecommunications Products

There are many European manufacturers of complete laser diodes systems for the telecommunications market. In terms of their corporate structure and ownership, they run the gamut from classic corporate giants (Siemens, one of the world's 100 largest companies) to nationalized industry (Thomson-CSF) to foreign-owned manufacturing operations (five are owned by North American companies). But all rely on technical developments made in Europe. The main development thrusts are towards VCSELs and higher power EDFA pump lasers.

Alcatel Optonics

Alcatel markets a full range of optoelectronic products for optical communications, including lasers. Both FP and DFB type lasers are produced from InGaAsP at both 1300 nm and 1550 nm. A 1565 DFB laser specifically for WDM applications is available, as is a 1480 nm EDFA pump laser.

Tutcore

Aluminium free material for high power bars for solid state laser pumping is what originally attracted Coherent to purchase Tutcore. Another key development is the production of high power GaInAsP 980nm single laser chips. When packaged these offer up to 250 mW output power in a single spatial mode and with a beam shape optimised for pumping EDFAs. Packaging is not currently offered by Tutcore although the company is actively developing new customers for the wafers, processed wafers, chips and bars that come out of Finland.

Acronyms

used in this article:

CATV	cable television
DFB	distributed feedback
EDFA	Er-doped fiber amplifier
FP	Fabry-Perot
LPE	liquid phase epitaxy
MBE	molecular beam epitaxy
MOCVD	metalorganic chemical vapor deposition
MOVPE	metalorganic vapor phase epitaxy
MQW	multi-quantum well
RWG	ridge wave guide
SCH	separate confinement heterostructure
UHB	ultra-high brightness
VCSEL	vertical cavity surface emitting laser
WDM	wavelength division multiplexing

Ericsson

Ericsson has more than 20 years of experience in fibre optics. It offers complete transmitter and receiver modules for bit-rates up to 2.5 GB/s, based on in-house development and manufacturing of laser diodes, PIN diodes and high speed custom ICs. The technology base is GaInAsP/InP, and the company offers a wide range of advanced, high performance laser diodes and detectors based on a well established InP process. Ericsson are developing InP integrated optic devices such as optical switches, devices for WDM and high bitrate systems (10 GB/s). As well as packaged modules, Ericsson supply discrete laser diodes and detectors. DFB and Fabry Perot lasers are tailored to telecom applications at 1310 and 1550 nm.

GMMT

Originally a specialist in military systems and components, GEC Marconi Materials Technology is now an established supplier of diode lasers for telecommunications applications. The company grows and processes the diodes in the UK, and packages all military systems in house, while some of the telecoms systems are packaged outside. The product range is limited at present, being largely dictated by the components used in its own systems, but GMMT expect to have more products on-line in the near future.

The standard product for the telecoms market is the 1550 nm DFB laser, with up to 60 mW output power, based on strained layer QW technology. A spin-off from this is a tunable DFB laser that is being marketed as a gas sensing system. The central lasing wavelength can be targeted to be between 1250 and 1600 nm, and this can be tuned by ± 1 nm by varying the drive current. The range of central wavelengths available matches with CO₂, CO, H₂S and NH₃ gas absorption features and these lasers can form the basis of a sensor for these gases.

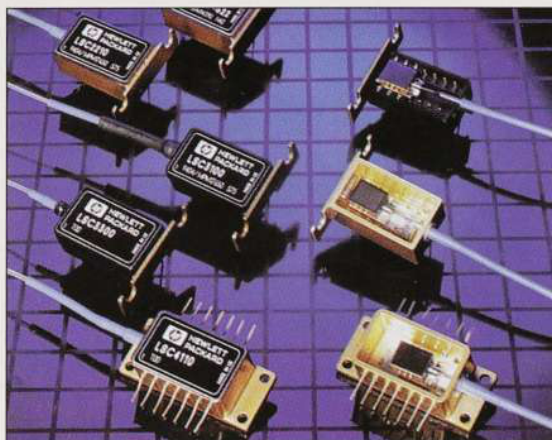


Figure Three. Examples of some of the laser modules produced by Hewlett-Packard FCO.

Hewlett-Packard

Hewlett-Packard FCO (formerly BT&D Technologies) offers a range of products and technologies, all aimed at the telecoms and datacoms market. H-P buys produces laser materials by in-house epitaxy and then packages components at their facility in Ipswich. The 1300 nm laser is based on a buried heterostructure design. The 1550 nm DFB laser is based on InGaAsP RWG structure. The distributed feedback is provided by a second order grating fabricated in the waveguide layer adjacent to the active region. Higher power 1480 nm lasers are built for EDFA pumping and also for the instrumentation market. H-P hopes to offer 980 nm pump lasers soon.

The 1480nm pumps use a planar buried heterostructure design, based on MQW separate confinement heterostructure (MQWSCH), grown entirely by atmospheric MOVPE. The conduction band consists of 9 InGaAsP (wavelength 1500 nm) wells with 8 InGaAsP barriers (wavelength 1200 nm). The thickness of the quantum wells is adjusted to give the required wavelength.

H-P started introducing VCSEL technology in 1996. The company has based a new generation of fibre optic products in this technology; the first product offering is a 850 nm VCSEL used as a source in a Gigabit Ethernet multimode fibre system. 1300 nm VCSELs are in development, and it is expected that these will be used in both multimode and the more demanding single-mode fibre applications in the near future.

Mitel

In 1996 Canadian semiconductor manufacturer Mitel acquired ABB HAFO based in Sweden, a company with a 30 year background in the design and manufacturing of high performance optoelectronic devices. Now operating as Mitel Semiconductor AB, the facility provides capacity of 35,000 100mm wafers per year. Short and long wavelength LEDs, Lasers, and other components are aimed at the telecom and datacom markets, including CATV and WDM applications.

Mitel's range of lasers includes short wavelength VCSELs (GaAs/GaAlAs) designed for use with multimode fibre, targeted at datacoms applications. The company also produces long wavelength FP lasers for telecommunications.

Nortel

The Nortel manufacturing facility in the UK, formerly STC, is one of the largest telecoms laser diode suppliers worldwide. They offer a full range of diode lasers for telecoms and datacoms applications, with powers

around 2 mW. Standard products include 1310 nm and 1550 nm RWG lasers with DFB options for narrow bandwidth operation, using MQW GaInAsP technology. A laser especially developed for the cable TV market produces 20 mW at 1550 nm with a very narrow linewidth (single longitudinal mode) and good side mode suppression. For long haul telecomms applications very stable temperature controlled DFB lasers are produced, and these can operate at up to 10 Gbit/s over a long distance.

Nortel also produces high power EDFA pump lasers. The 980 nm lasers are based on a SQW design in an RWG configuration and can produce powers up to 130 mW. 95% of this power is in the 970 to 985 nm region, where the EDFA absorbs. Nortel have patented their fibre to laser coupling scheme used in EDFA pumping.

Philips

Philips produces a range of telecommunications systems, and a separate range aimed at cable TV applications. CATV systems include 1310 nm FP lasers up to 1 mW and DFB lasers up to 12 mW. MQW 1550 nm lasers are offered up to 30 mW. Telecoms lasers have output powers around 1 mW and are offered in DFB versions at 1310 nm and 1550 nm, and also a MQW DFB system between 1557 and 1540 nm for WDM systems. A 1480 nm FP MQW laser at 100 mW is available for EDFA pumping.

Pirelli

Best known as a supplier of optical fibre, Pirelli have recently entered the laser market by licensing the 980 nm EDFA pump laser technology from Laser Enterprise. Pirelli produce EDFAs, and for some years have collaborated with Laser Enterprise to supply complete systems of pump laser, supplied from Switzerland, and fibre amplifiers. Three years ago the company decided to go into laser production itself, became a qualified supplier last year and have started full production this year. They use their in-house MBE facility to produce the laser chips.

According to Pirelli, the Italian 980 nm laser performs as well as the Swiss version, with linear power up to 140 mW in the fibre and a specified power of 120 mW. The company has plenty of field information from several years of supplying Laser Enterprise lasers with EDFAs and say that the only changes they have made to the design given to them under license are those that improve the reliability.

Siemens

The Siemens range of products for telecommunications is based on MQW diode lasers, suitable for bit rates up to 1 Gbit/s. 1300 nm and 1500 nm products are supplied.

Thomson CSF

Thomson offers a wide range of telecoms lasers. 1310 nm and 1550 nm FP lasers are available with powers of a few mW, and a 1550 DFB laser offers up to 10 mW output power. A 3 mW 840 nm FP laser has been available for some time. New on the market is an 840 nm VCSEL (1mW) aimed at the high speed datacoms market. Thomson supply these packaged but will also supply processed wafers, diced or undiced, or provide a non-exclusive transfer of technology to process and manufacture VCSELs. Preliminary details have been released for a MQW 980 nm EDFA pump laser with 100 mW output power.

Uniphase Laser Enterprise

Uniphase Laser Enterprise is another company which has changed hands recently. Formerly part of IBM, Laser Enterprise is a specialist in 980 nm EDFA pump lasers (see CS 3(3), p. 20). The company uses MBE to produce GaAs/AlGaAs and InGaAs/AlGaAs material systems. The RWG structure is chemically etched onto the substrate. The technical breakthrough made by the company in the late 1980s was the development of a mirror passivation process, E2, which dramatically extends the lifetime of 980 nm lasers. This prevents catastrophic optical facet damage, and allows the lasers to be run at higher output powers for longer periods.

Laser Enterprise is currently developing a narrow stripe 980 nm laser for operation above 200 mW, a 980 nm chip for submarine applications and broad area lasers with 500 mW and 1.5 W output power and wavelengths of 917 nm, 960 nm and 974 nm. The focus remains on high power, high reliability lasers for fibre amplifiers and fibre lasers.

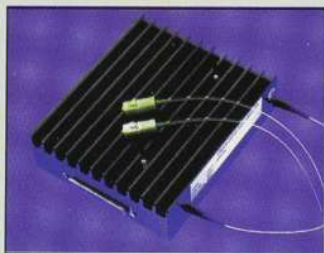
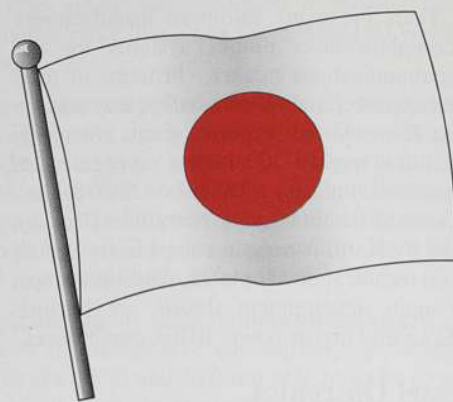


Figure Four. An Er-Doped Fiber Amplifier produced by NORTEL in the UK.



Laser Diode Development at NEC, Fujitsu and Toshiba

Fiber optics and DVD are the major areas of interest for Japan's large optoelectronic manufacturers

PAUL MORTENSEN

Laser diodes for fiber-to-the-home (FTTH) and high-density multimedia storage are the main research topics for Japan's major optoelectronic companies.

The production of optical pick-ups for audio CD players and CD-ROMs has been virtually monopolized by Japanese laser makers. Many of the companies involved in that work are now hard at work to preserve their competitive edge for DVD, the next generation of optical storage system.

In telecommunications, much of the research is driven by the vision of Japan's main telecom carrier, Nippon Telegraph and Telephone (NTT) for a nationwide all-fiber network. But if NTT is going to make FTTH a reality (see box, next page), it needs to find vendors who can strike the right compromise in cost and function for its laser-based components. But both Fujitsu and NEC are convinced that with the right component design, the cost of a nationwide all-fiber system can match that of the metallic system by the year 2000. But to do that they will need to produce four million modules a year for 15 years in order to get 60 million access lines fibered at a cost of about \$10 a module.

Telecomm at NEC

A leader in optoelectronics, NEC Corp. last year spent ¥713 billion (\$7.13 billion) on R&D. Despite a four-year domestic recession, the company has maintained an R&D expenditure of about 10% of net sales over the past ten years. Kohroh Kobayashi, general manager Opto-Electronic Research Laboratories, NEC Corporation (Tokyo) notes that their priority is translation of research results into low-cost products for major markets; and includes speedy transference of R&D to the factory floor.

Earlier this year, for example, researchers at NEC's Opto-Electronic Device Research Laboratories (Tsukuba) developed a way to manufacture different wavelength laser diodes from a single wafer, overturning the conventional process which required all lasers on the same wafer to have the same lasing characteristics.

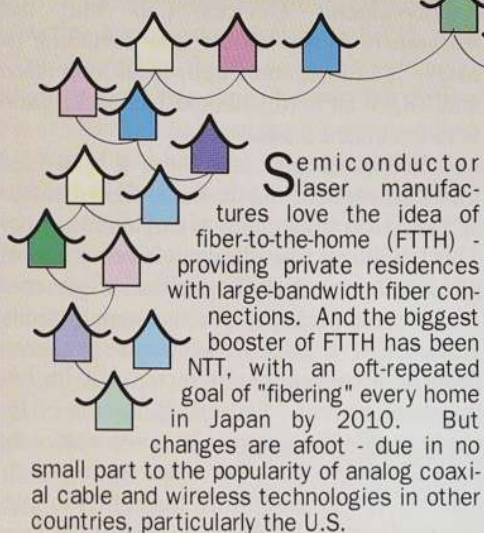
The new process demonstrated that lasers diodes in a 75-nm-wide wavelength range and in a frequency band of up to 10THz can be produced on the same single InP wafer with uniform lasing characteristics, and with a threshold current stabilized at 9mA irrespective of the wavelength of the diode. Masayuki Yamaguichi, assistant manager at Opto-Electronic Device Research Laboratory (Tsukuba), predicts a 100-fold reduction in fabrication costs of laser diodes especially for wavelength division multiplexed (WDM) lightwave systems as well as greatly reduced production times.

The Tsukuba lab is now targeting the development of order-made, simultaneous fabrication of different wavelength laser diodes from a wafer to match the pre-assigned wavelength grids of future WDM systems. Ideally, each laser diode with different wavelength should have uniform lasing characteristics over a wide range of the erbium-doped fiber amplifier (EDFA) gain band (1530nm-1560nm) or more. For that, NEC believes that fine pitch control of grating by electron beam (EB) lithography combined with bandgap energy control by selective metal-organic vapor phase epitaxy (MOVPE) will reduce costs of WDM light sources.

To control the wavelength of distributed feedback laser diode arbitrarily, the grating pitch must be controlled to less than 0.01nm. However, the current minimum drawing step of a conventional electron beam (EB) machine is 2.5nm which means that all laser diodes from the same indium phosphide (In-P) wafer had the same lasing characteristics. To reduce that value, researchers introduced a field-size variation technique which continuously varies

Is Fiber-to-the-Home Going to

Happen?



Semiconductor laser manufactures love the idea of fiber-to-the-home (FTTH) - providing private residences with large-bandwidth fiber connections. And the biggest booster of FTTH has been NTT, with an oft-repeated goal of "fiberizing" every home in Japan by 2010. But changes are afoot - due in no small part to the popularity of analog coaxial cable and wireless technologies in other countries, particularly the U.S.

Japan's Ministry of Posts and Telecommunications (MPT) recently expanded its vision of the future of residential multimedia services to include alternatives to fiber. NTT has responded by revising its FTTH plan for 2010 to say that instead of *reaching every home*, they will be *close to nearly every home* by that year - that is, they plan to terminate fiber close to groups of homes and then provision individual homes on a willing-to-pay basis. But there is already some doubt here that this scaled-down plan can be achieved on time and at reasonable costs.

the electric field and the positioning of the electron beam before it hits the wafer. The field size can be changed by 0.05% allowing a fine pitch control of 0.0012nm steps. In one experiment, researchers formed forty-channel different pitch gratings from 235.98nm to 247.68nm by 0.3nm steps on an In-P wafer.

They also developed a selective MOVPE growth technology for bandgap energy control of the active layer. Yamaguichi says that the lasing characteristics of DFB laser diodes deteriorates if the lasing wavelength deviates greatly from the active layer gain peak wavelength. Selective MOVPE growth adjusts the gain peak wavelength to the lasing wavelengths, obtaining uniform LD performance for all channels. In the MOVPE chamber, the precise use of different lengths of silicon-oxide masks controls the amounts of Ga, As, In and P that are absorbed into the active layer (since these elements migrate at different rates in the mask). The mask widths varied from 24um to 35.7um in 0.3um steps depending on the grating pitch.

These technologies, Yamazaki predicts, will produce laser diodes in a 100nm-wide wavelength range and in a frequency band of up to 10THz on one wafer, with stabilized the threshold direct current. In sum, by lowering

NTT is keying in on laser costs as one of seven key factors that will influence the affordability of FTTH. To reduce component costs, NTT plans to use the passive double star (PDS) for FTTH. The PDS system allows up to 10 customers to share a feeder fiber by way of a passive optical splitter - reducing the number of fibers and optical transmitters and receivers needed.

Another way to lower costs is de-facto standardization. NTT is promoting their standards in local telecommunications projects in Asian countries, hoping that they may eventually offset some of the expense of FTTH by exporting systems to other markets. But this won't happen before political roadblocks to an expanded international presence for NTT are removed.

But if NTT can succeed on both fronts - successful implementation of FTTH at home, and then exporting their system abroad - it could be a bonanza for component manufacturers. NEC and Fujitsu, as major suppliers to NTT, will likely land the biggest contracts, but other companies, including Hitachi, Oki, Mitsubishi, Sumitomo Electric, Fujikura, and Furukawa Electric could also benefit.

fabrication costs, they may speed the development of a high-capacity multimedia (WDM) infrastructure.

For other laser diodes, NEC's research covers three broad fields: time, space and wavelength. The company is participating in the national femtosecond project (started last April) which aims to develop solid-state and semiconductor femtolasers for telecom and for testing high-speed ICs. They are also researching massively parallel optical interconnections; some of this research is for optical computers of the national Real World Computing Project (Tsukuba). And another project combines plastic-clad silica-core fiber with 970-nm-to-930-nm vertical-cavity surface emitting lasers (VCSELs) for low-cost optical interconnection systems.

For optical subscriber networks, NTT wants compact and cheap transmitter/receiver modules with two-way transmission capability. Hybrid as well as monolithic integration schemes have been tried, but monolithic packages are favored to reduce chip connections. In line with this aim, NEC research teams have now successfully integrated a laser diode, a photodiode, and a waveguide directional coupler on an InP substrate by using selective-area MOVPE.

Fujitsu

Fujitsu Ltd. is another company that continues to invest heavily in R&D. The notes that telecom systems are of growing importance to the company, providing in the first half of '97 their largest percentage growth in sales, compared to sales of its major products which include mainframe computers and PCs. In fiscal 1996, Fujitsu invested about ¥346 billion in research. This is a 7% increase over the previous year, and it is equal to 9.2% of company sales.

Most optoelectronics research takes place at the Electron Devices and Materials Labs (Atsugi) which is composed of six laboratories (each with about 40 researchers). The labs are: ULSI Technology Lab, ULSI Fabrication Technology Lab, Compound Semiconductor LSIs Lab (studying HEMTs and HBTs, this lab was added in 1996 in anticipation of more integration of high-speed electronics with optical devices), Quantum Electron Devices Lab (quantum-dot lasers), Optical Semiconductor Devices Lab (laser diodes), and Infra-red Devices Lab, (infra-red sensors for Japan's military forces). This year's annual budget is about 1,500 million yen, a 10% increase over last year.

The Optical Semiconductor Devices Lab focuses on laser diodes for both telecom and

optical disk applications; with telecom applications representing around 60% of the effort. Dr. Shigenobu Yamakoshi, director, Optical Semiconductor Devices Lab said that researchers at the lab are now focussing on MQW (multi-quantum-well) local-loop lasers and MQW DFB (distributed feedback) lasers with integrated modulators.

The local-loop lasers use a spot-sized transformer to expand the mode-field diameter and desensitize coupling to single-mode fiber. This facilitates the design (fewer precision parts) and production (less-critical alignments) of low-cost packages for loop applications. However, it is difficult to achieve a narrow beam in a conventional laser diode with low threshold current. Because expansion of the mode profile for a narrow beam decreases the optical confinement and raises the threshold current. A solution for this tradeoff is to integrate a spot-size transformer within the laser diode. And this transformer must be transparent at the lasing wavelength, since absorption increases the threshold current.

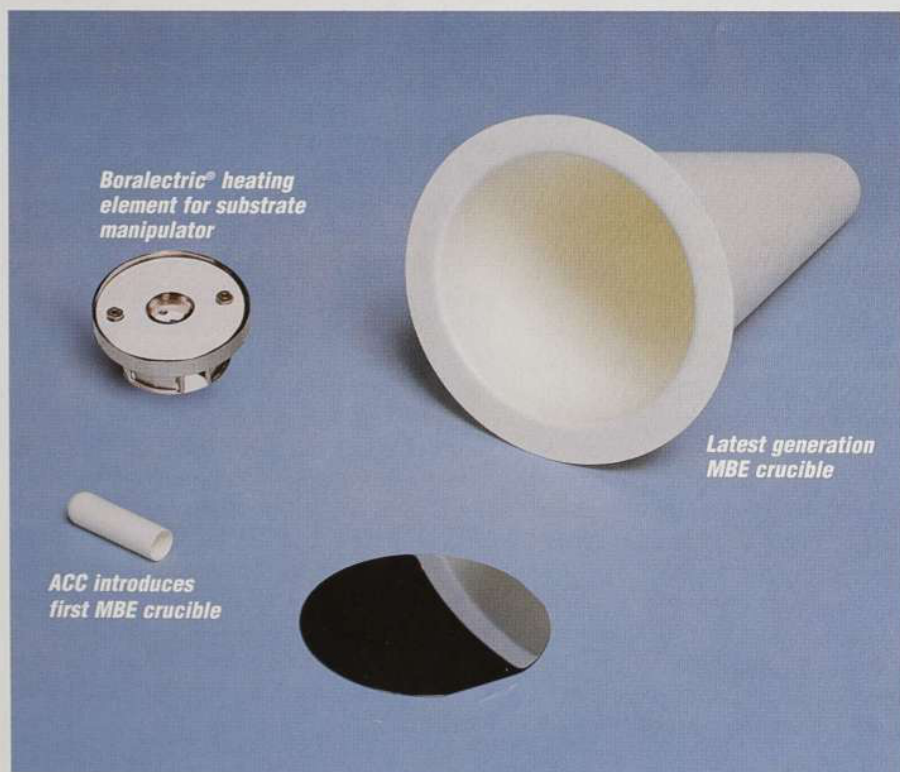
They succeeded in integrating a tapered thickness spot-size transformer to a 1.3-um MQW laser diode. The 200-um long tapered waveguide and the 300-um long MQW active layer were simultaneously fabricated on an n-doped InP substrate using a one-step selective-area MOVPE growth.

By using this technique, they reduced the thickness of MQW and guide layers along the axis in the spot-size transformer. Thinner MQW layers give a transparent transformer in a Fabry-Perot resonator because the absorption edge in the spot-size transformer shifts to a shorter wavelength than the lasing wavelength. The gain region has five 60A unstrained InGaAsP wells, 150A InGaAsP barriers and 100nm guide layers. They used a conventional p-n blocking buried heterostructure to get a low threshold current and stabilize the transverse mode.

They found that by optimizing the electrode length, the increase in the threshold current was limited to only 30% compared to that of a conventional laser with the same cavity length even if the spot size was expanded by four times. For a laser with high-reflection-coated rear facets, the calculated threshold currents were just 6.5mA at 25C and 22.2 mA at 85C. At 50% coupling efficiency, 1 dB additional loss corresponds to +/-2 microns of fiber transverse motion rather than the usual +/-0.7 microns. The output beam shape is almost circular.

With these results, Fujitsu believes it is very close to developing a \$10 laser module that has passive and lens-free alignment for FTTH.

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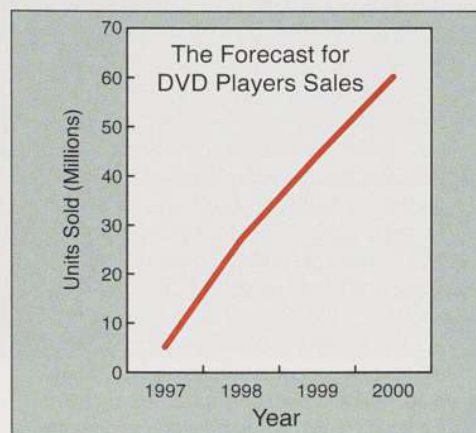
Quantum Dot Results

In another lab, Fujitsu researchers want to establish nano-fabrication technologies and nano-scale optical characterization techniques to make a quantum-dot laser for optical systems that need ultra-low power consumption. This laser reduces threshold current because of enhanced quantum effects and reduced volume of the active region.

For nanostructures fabrication, they are studying selective-growth techniques and Stanski-Krastanov growth for 5-nm-high InGaAs quantum dots which are self-organized without lithographic processing. Fujitsu reported the first current-injection laser oscillation from indium gallium arsenide quantum dots at 80K. The dots, which emit at 1300nm, were grown on GaAs substrates by atomic layer epitaxy (ALE) and demonstrate three-dimensional quantum confinement. Threshold current for the quantum dot laser is still too high, but they have had a number of successes, says Hajime Shoji, researcher at Quantum Electron Devices Lab (Atsugi).

Highlights of their research efforts include continuous lasing at the ground state of quantum dots and observation of clear discrete peaks in electroluminescence spectra of quantum dot structures. They have also demonstrated for the first time that the lasing wavelength jumps from higher-order subbands to lower-order subbands by changing device parameters such as cavity loss and number of dots in a layer.

This year the research team fabricated a closely-stacked quantum dot laser (1300nm) which produced a narrow emission spectrum. The FWHM of the photoluminescence was just 25 meV, which was less than one-third of their conventional value (~80 meV). They also achieved laser oscillation at room temperature.



The forecast for DVD player sales. At 60 million units per year by 2000 this market would be valued at ¥3,000 billion (\$23 billion). Alas, semiconductor lasers account for less than 1% of that figure.

DVD and Beyond

Telecom isn't the only big business in Japan. The consumer electronics industry is expecting huge market growth for DVD, with 60 million units sold by 2000 - about ¥3,000 billion a year. See chart, below. But before this can happen, issues about the supply of red lasers must be addressed. At present, there are believed to be only a few makers can reliably supply 100,000 units a month of DVD lasers. Part of the problem is although the basic DVD units require a fairly simple laser with ~5mW of output power, the popular rewritable versions require 35mW lasers. Toshikazu Yosumi, director of Matsushita's Optical Disk Systems (Osaka), notes they are difficult to mass-produce. "We get a very low yield for 35-mW laser diodes", he says. "But we expect the same yield as the CD-player laser diode in three years."

Of course much of Japan's laser research effort is now directed to creating the blue-light-emitters that will be needed for the generation of optical storage systems which follows DVD. Recent events have produced some surprises in this area.

Toshiba recently hosted a demonstration of future high-definition optical storage system equipment. Their experimental system used a green (532nm) second-harmonic-generation (SHG) laser module. And market pressure is also forcing Matsushita Electric to consider SHG lasers for optical pickups (for more on this story, see page 18).

Meanwhile, researchers at Toshiba Materials and Devices Laboratories (Kawasaki) continue to work on conventional direct blue-light-emitting laser diodes. So far, they have developed a GaN blue-purple (417nm) laser diode that emits a pulsed beam at room temperature. They are working around-the-clock to achieve continuous wave operation and thus catch up with Nichia Chemical Industries Ltd. who have achieved at least 35 hours of continuous wave operation at 80°C.

About two years ago, says Masure Nakamura, a manager at the Kawasaki Lab, the company shifted from working with ZnSe, which offered the possibility of a low-dislocation material, to GaN in the belief that it is more suitable for producing a stable, short wavelength laser beam.

Toshiba credit two developments to enable blue-purple lasing at a threshold current of 5A and operating voltage 20V. First was success in fabricating very thin layers of GaN compound crystals in a multi-quantum well structure using MOCVD. They grew a GaN buffer layer on a sapphire C-face substrate followed by a 2-um thick undoped-GaN, a 4-um Si-GaN contact layer, a 0.1-um undoped-GaN optical guiding layer, 25 periods of a InGaN/InGaN multi-quantum-well (MQW) structure consisting of 20-A thick InGaN well layers and 40-A thick InGaN barrier layers.

The second development was a new way to cleave the GaN crystal grown on the C-face sapphire substrate, assuring a smooth surface. Previously, cleaving GaN crystals on a sapphire substrate usually produces a rough surface unsuitable for laser emission,

so dry etching was used instead. Also, cleaving is less expensive than dry-etching and requires fewer manufacturing processes.

For optical-disk applications, they will need to stabilize at least 10,000 hours of operation. Fortunately for Nichia, since the development cycle follows a logarithmic scale, achieving 10,000 hours from a start of 35 hours is much less of a struggle than achieving the first few hours of CW operation - a problem which Toshiba is now facing.

Once the diode becomes a practical reality, however, other problems remain. They include the sensitivity of current optical detectors (Si-PIN), which drops precipitously in the region of the operating wavelength (420nm); lowering noise from light reflected into the laser from the disk; lowering the beam-aspect ratio; and, of course, price. Toshiba notes that for a \$500 DVD player, the optical head is budgeted at 5%-10%, which means that the laser diode cannot exceed 1-2% of the total system cost. It follows that the price pressures on the blue lasers, when they are available, will be substantial.

Does it seem odd to be discussing the price of a product that doesn't exist? Not in Japan, where the consumer electronics giants are focused on producing exquisitely engineered products at mass-market price points. Given their commitment to excellence in optical data storage, and NTT's leadership in telecommunications, Japan's leading laser diode manufacturers have a bright future in front of them.

"Toshiba notes that for a \$500 DVD player, the optical head is budgeted at 5%-10%, which means that the laser diode cannot exceed 1-2% of the total system cost."

Laser Diode Development on Ternary Substrates

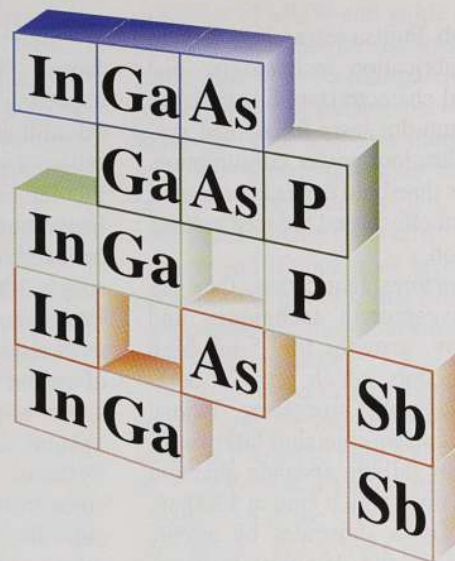
Ten years ago semiconductor laser technology was taking its first small steps toward volume manufacturing; today, laser diodes are commonplace in the developed world. It seems logical that the next ten years will bring demand for more and cheaper lasers. But it will also likely create opportunities for new and different types of lasers.

One of the more interesting things to consider when thinking about the years to come is whether future generations of laser diodes will continue to rely solely on binary substrates. Or, instead, will lasers grown on ternary substrates such as InGaAs, GaInP, GaInSb and the like be as common in ten year's time as GaAs and InP-based lasers are now?

The motivation for interest in ternary substrates is obvious: they provide the device designer and epi grower with additional degrees of freedom to employ when addressing a new laser requirement. Figure One shows the additional lattice constants and bandgaps that are available in the III-V ternaries. If "designer substrates" based on these materials were to become readily available, it could usher in a whole new era of bandgap engineering.

Of course, ternary substrates will likely be more expensive than their binary counterparts. In some cases, higher levels of device performance will undoubtedly compensate for that factor. In other cases, ternary substrates might actually reduce the cost of the finished product. For example, they could obviate the need for compositionally graded buffer layers, which are currently used in many cases to minimize strain and deduce misfit dislocations. These buffer layers add to the cost of the epi, and are sometimes only marginally effective, so it is possible that eliminating them could sufficiently increase yield and epilayer quality to make up for the extra cost of the substrate.

The first part of this report overviews recent work in the bulk growth of ternary substrates. The second part summarizes recent attempts to grow lasers operating at telecommunications wavelengths on those substrates.



LEC Growth of Bulk Ternaries

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Composition uniformity has been the dominant issue in the development of bulk ternary III-V crystals since work began in the mid 1950's. Historically, crystal growth studies of the III-V ternary materials systems were confined principally to unseeded, horizontal boat directional solidification techniques. Failure of early investigators to grow large single crystals of the bulk ternary III-V's was attributed to the phase relations and kinetic parameters. All of the respective pseudobinary III-V materials systems form solid solutions with significant separation between the liquidus and solidus phase regions. This results in strong compositional segregation, associated supercooling effects and potential for interface breakdown resulting in polycrystalline growth.

With the exception of a few isolated studies in Ga(As,P) and (Ga,In)As, the Czochralski pulling technique had been largely ignored for ternary III-V growth. But work done at Crystallog and elsewhere suggests that liquid encapsulated Czochralski (LEC) growth may be best suited to ternary growth. To be sure, LEC growth from a finite volume melt is still subject to the problem of segregation and non-uniformity. But it also can provide solutions to the problems. For example, the melt can be mixed during growth by mechanical stirring. And indeed, recent private and government funded research programs to grow bulk ternary III-V single crystals, have demonstrated the ability to produce crystals in research sizes and quantity. To date, crystals of $Ga_{1-x}In_xAs$; $x \sim 0.10$ ^[1,2], $Ga_{1-x}In_xSb$; $x \sim 0.12$ ^[3], and $InP_{1-x}As_x$; $x \sim 0.10$ ^[4], have been prepared using this technology. $Ga_{1-x}In_xAs$ single crystals approaching 1Kg and 2" diameter have even been reported.

An $InP_{1-x}As_x$ ternary single crystal is shown in Figure 1. These boules can typically be grown up to 2-3cm diameter, 4-8cm long and 100-150gms in weight. Growth conditions approximate those employed for LEC InP for low arsenic concentration crystals. To date, crystals with "x" values up to ~ 0.14 have been grown. Antimonide crystals have also been grown, but to date this system has proven to be more difficult than the others, and equivalent sizes have not been achieved.

con't on page 34

	Melting Point (°C)	Lattice Constant	Bandgap
Binary Systems			
GaAs	1238	5.654	1.40
InP	1062	5.869	1.35
GaSb	706	6.095	0.69
Ternary Systems			
InGaAs	943 - 1238	5.654 - 6.058	0.356 - 1.40
GaInP	1062 - 1467	5.447 - 5.869	1.35 - 2.24
InAsP	943 - 1062	5.869 - 6.058	0.356 - 1.35
GaAsP	1238 - 1467	5.447 - 5.654	1.40 - 2.24
InGaSb	525 - 706	6.095 - 6.497	0.18 - 0.69
InAsSb	525 - 943	6.058 - 6.497	0.18 - 0.356

Figure One: Melting Point, Lattice Constant and Bandgap of the three most common binary substrates and six ternary systems.

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Figure One. An example of an InPAs ternary single crystal. These boules can typically be grown up to 2-3cm. diameter, 4-8cm long and 100-150gms in weight.

The Starting Seed

Ternary III-V single crystal growth by LEC requires compositionally compliant, lattice matched and melting point compatible seeds. Seeds are generated and composition changed by a series of iterative growth runs or "bootstrapping" whereby the alloy composition is increased from the appropriate binary compound. This is an extremely time intensive process. However, once a seed base is established any discrete composition may be compositionally tuned.

At present, ternary crystals exhibiting a high degree of radial composition uniformity can be grown by LEC. However, the composition does change moderately along the length of the boule, as a function of the separation between the liquidus and solidus phases. As a result, individual wafers cut normal to the growth direction of a given crystal may be of uniform composition, but there will still be some wafer-to-wafer composition variation.

Ironically, the nonuniformity along the length of the boule is the same phenomenon that is used to beneficial effect in the bootstrapping process. Obviously, it becomes a detrimental feature when growing large crystals. At present the wafer-to-wafer non-uniformity can be put to good use, as the small compositional differences wafer-to-wafer, permit investigation of the effects of subtle compositional differences in epitaxial growth and device design without the need to grow large numbers of crystals. But in the long run it will be necessary to tame this problem.

Applications for Ternary Substrates

When ternary substrates become available in production quantities, there will likely be virtually no limit to their potential applications. Some of the likely uses are already under investigation.

Small diode lasers operating at 2-3 μ m with low power requirement and a high degree of spectral purity exemplify one set of devices, which mandate ternary substrates. Work done at Sensors Unlimited shows that distributed feedback (DFB) lasers based on InP_{1-x}As_x have particular promise for such applications. Specifically, it is predicted that InP_{1-x}As_x $x \approx 0.4$ substrates will provide the proper lattice parameter to achieve 2.77 μ m emission from strain compensated MQW lasers comprised of In_{0.94}Ga_{0.06}As wells.

State-of-the-art techniques for detecting several important atmospheric gases currently use mid-infrared diode lasers. Strained layer

DFB lasers based on ternary InP_{1-x}As_x substrates could be competitive with antimonide or lead-salt lasers for these applications. The use of the very mature InGaAsP materials, which have well understood properties, could simplify processing and increase yields. Further, the spectral purity of DFB type lasers will permit the ppb to ppt detection levels that are currently desired. Quantum cascade lasers are also often mentioned for this application, but the InP_{1-x}As_x structures would be significantly easier to grow.

Recently, strained MQW (InGa)As lasers grown on a ternary InP_{0.92}As_{0.08} substrate have been demonstrated [5]. The MOVPE fabricated structure consisted of two 12nm thick In_{0.75}Ga_{0.25}As compressively strained quantum wells separated by a 20nm thick In_{0.81}Ga_{0.19}As_{0.51}P_{0.49} barriers. The active region was completed with two 300nm thick InGaAsP barriers and constant lattice parameter was preserved throughout the structure with InAs_{0.08}P_{0.92} cladding layers. Lasing was achieved at 1.75 μ m, as measured at T = 250K and a pulsed current of 3A. A threshold current density of 9.6kA/cm² and power output of 60mW were recorded at 250K. While still distant from the goal of ~40 mole % arsenic, proof-of-concept for ternary InP_{1-x}As_x substrates for fabrication of MQW laser structures has been demonstrated.

In addition to improved characteristics and yield for current device applications, ternary substrates should also open new areas in device physics and novel device concepts. It must be realized, however, that bulk ternary crystal growth for all of the pseudobinary III-V systems is far from a mature technology and must be viewed today as being at the level of maturity of InP in the early 1970's. But progress is being made at a faster pace than was possible in the binary systems. Therefore there is reason to hope that someday in the near future ternary substrate-based lasers will become a reality.

Laser Development on InGaAs Substrates

ALAN MOORE
EG&G CANADA
VAUDREUIL, QUEBEC
CANADA

Among the most common - and economically important - laser diodes are telecommunications lasers emitting at 1.3 micron and 1.55 micron wavelength. Despite extensive developmental efforts, at present the temperature performance of these devices, which are grown on InP substrates, is somewhat inferior to other devices based on GaAs substrates. It is believed that the shallow conduction band potential well in these structures is the principal reason for their poor performance.

A number of potential solutions have been proposed. One is the use of AlGaInAs material, which has been pioneered by a group at Bellcore/Lasertron. In this alloy system the conduction band offset is larger than that of the conventional GaInAsP compounds.

Another alternative is to use ternary substrates. Theoretical work at Fujitsu suggests that growth of conventional alloys on In_{0.26}Ga_{0.74}As substrates could result in a 1.3 micron emission laser with a characteristic temperature of over 150K.

Ternary Substrate Lasers

The literature on ternary substrates shows a trend of utilizing substrates of steadily increasing indium compositions. Initially the investigations were based on either the InGaAsP or AlGaInAs system, but more recently a combination of these alloys has been used.

Fujitsu reported the first results of laser growth on ternary substrates [6]. They grew a SQW laser on a semi-insulating In_{0.05}Ga_{0.95}As using InGaP cladding layers and InGaAsP as a waveguide. The active layer was a 70Å In_{0.25}Ga_{0.75}As well giving an emission wavelength of 1.03 micron. CW threshold current densities were as low as 222 A/cm² and the maximum output power of greater than 60 mW. The estimated α_i and η_i for these diodes were 7.3 cm⁻¹ and 58% respectively. Encouragingly the characteristic temperature was 221K, much superior to the conventional InP based laser figures.

The first reported lasers using the AlGaInAs alloy system and the first using doped (semi-conducting) substrates were made by EG&G [7]. In this case In_{0.035}Ga_{0.965}As substrates were used with Al_{0.24}In_{0.03}Ga_{0.73}As clad and In_{0.03}Ga_{0.97}As waveguide regions.

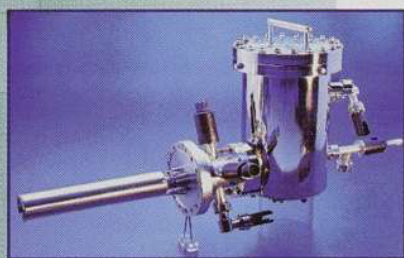
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The active regions were either 200Å of $\text{In}_{0.11}\text{Ga}_{0.89}\text{As}$ or 100Å of $\text{In}_{0.2}\text{Ga}_{0.8}\text{As}$. These devices were driven under pulsed conditions and the α_i and η_i for these diodes was 7.0 cm^{-1} and 61% respectively. The highest slope efficiency was 0.7W/A for a 250 micron device. The highest powers were recorded for higher indium containing wells, 16.2 W at 40A when driven under 120ns, 3kHz conditions. Typical emission wavelengths were between 1.029 and 1.035 micron. The characteristic temperature for these devices was up to 100K in the 10-70°C region.

Devices using partial strain relaxation were reported by the group at The University of Illinois^[8]. Again doped $\text{In}_{0.03}\text{Ga}_{0.97}\text{As}$ was used. The clad layers were InGaP and the active region was 50Å $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$ surrounded on either side by 650Å of tensile strained GaAs. Figure 2 shows details of the laser structure. Broad area devices were fabricated and tested under pulsed conditions. The α_i and η_i for these diodes was 10.0 cm^{-1} and 56.3% respectively. The emission wavelength from a 1mm long device was 1.140 micron.

Growth has also been carried out at the university on doped $\text{In}_{0.062}\text{Ga}_{0.938}\text{As}$ substrates. In these structures a 87Å $\text{In}_{0.31}\text{Ga}_{0.69}\text{As}$ active was surrounded on either side by 1000Å $\text{In}_{0.06}\text{Ga}_{0.94}\text{As}$. The α_i and η_i for these diodes was 12.6 cm^{-1} and 99% respectively. The emission wavelength from a 915 micron long device was greater than 1.095 micron.

Further work by the University of Illinois team using selective area MOCVD enabled a wide range of InGaAs quantum well thicknesses and compositions to be grown on the $\text{In}_{0.03}\text{Ga}_{0.97}\text{As}$ substrates^[9]. In this technique growth inhibition from a silicon dioxide mask is the mechanism used for selective area growth rate enhancement of the active area. By varying the width of the oxide stripe open-

ings, growth rate variations lead to quantum wells of different thicknesses. Thus QW lasers of a variety of active layer compositions and thicknesses can be grown on the same wafer. The longest emission wavelength from these buried hetero structure diodes was 1.150 micron for a 3 micron wide active device. These results demonstrate that the ability of ternary substrates to extend the upper wavelength emission of GaAs based emitters from ~1.1 micron into the region normally serviced by InP based alloys.

Encouraging Results

Arguably the most promising results to date have been published by the Fujitsu group using $\text{In}_{0.21}\text{Ga}_{0.79}\text{As}$ un-doped substrates^[10]. The clad layers were InGaP and the waveguide layers AlGaInAs ($\lambda = 0.97$ micron). The active layer consisted of a 70Å $\text{In}_{0.38}\text{Ga}_{0.62}\text{As}$ DQW separated by a 100Å AlGaInAs barrier. The three metal quaternary was chosen as the waveguide material since a miscibility gap exists the conventional GaInAsP alloy with a compositional wavelength around 1 micron. The reported threshold current densities under CW operation were 355A/ cm^2 for a 900 micron long diode. Maximum output power was 8mW and the lasing wavelength was 1.219 micron for a 900 micron device as shown in Figure 3. This emission wavelength represents a considerable step for the realization of a 1.3 micron emitter on InGaAs substrates. The characteristic temperature was 84K. This low value resulted from the use of InAlGaAs barrier layers with an emission wavelength of 0.97 micron. From theoretical calculations of characteristic temperature as a function of the compositional wavelength of the barrier it is claimed that a T_0 of greater than 150K could be achieved using a AlGaInAs

barrier layer with an emission wavelength shorter than 0.9 micron.

The use of the AlGaInAs alloy system lattice matched to InGaAs also has some theoretical advantages for the fabrication of VCSELs^[11]. The development of these structures on InP substrates for 1.3 micron laser emission has been somewhat hindered by the lack of refractive index difference in the InGaAsP/InP alloy system. These problems could, in theory, be significantly reduced by the use of either the AlInGaAs alloy system lattice matched to InP or InGaAs ternary substrates. For example, the refractive index difference of $\text{In}_{0.26}\text{Ga}_{0.74}\text{As}/\text{In}_{0.25}\text{Al}_{0.75}\text{As}$ on $\text{In}_{0.26}\text{Ga}_{0.74}\text{As}$ substrates is approximately 0.4 (that of InGaAsP system on InP is approximately 0.2). This effectively reduces, to a practical figure, the number of layers required in order to achieve the necessary reflectivity in the mirror region of the device. Thus 1.3 micron VCSELs can be made a commercial possibility with ternary substrate technology.

It can be seen that there is considerable potential for a number of devices, particularly 1.3 micron laser structures grown on InGaAs substrates. To date only limited material has been available but impressive results have been achieved. A number of problems still need to be overcome in bulk crystal growth before commercial realization is achieved. If these are overcome a new and exciting area for telecoms devices will develop.

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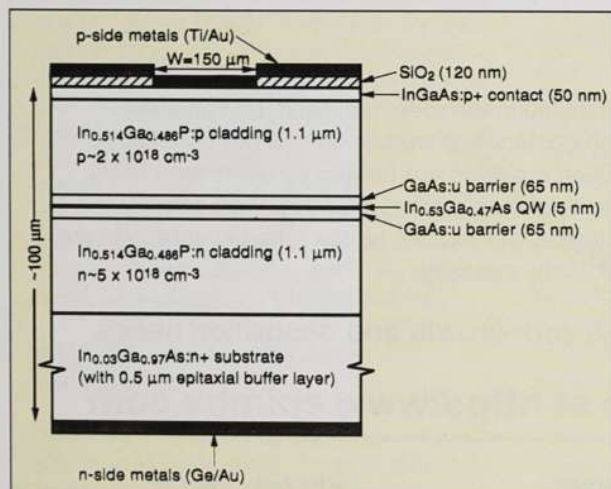


Figure Two. Schematic of a laser structure using partial strain relaxation fabricated by the University of Illinois.

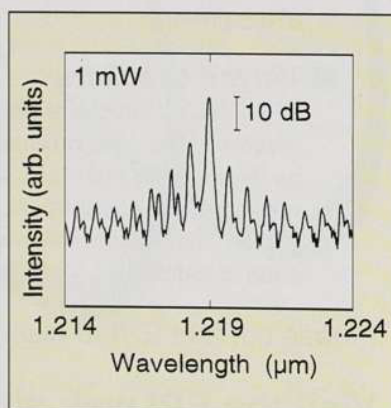


Figure Three. Lasing spectrum at an output power of 1 mW for a InGaAs DQW laser grown on InGaAs semi-insulating substrate by Fujitsu. The lasing wavelength is 1.219 micron.

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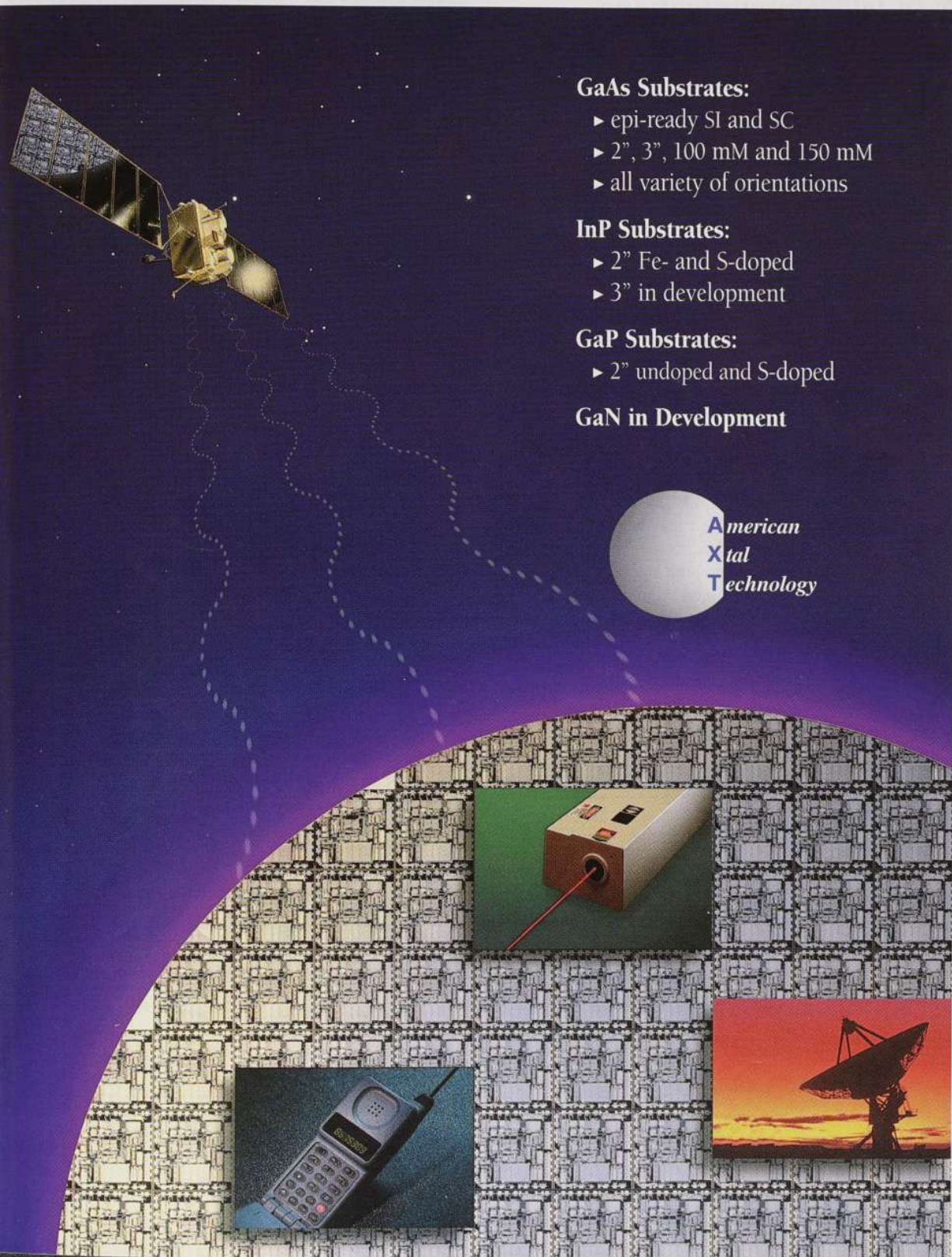
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- ▶ 3" in development

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GaAs ICs for High Bandwidth Fiber Optics

The use of III-V's in telecommunications doesn't stop at lasers - Vitesse is developing GaAs ICs for improved optoelectronic transmitter and receiver designs

JEREMY BUNTING
VITESSE SEMICONDUCTOR CORPORATION

Fiber Optic and lightwave technologies promise inexpensive access to untapped and virtually limitless bandwidth. The major standards [see box, next page] offer telecommunications and data communications at rates in excess of 1 gigabit per second (Gb/s). Thanks to optical fiber and optoelectronic (OE) transmit and receive modules, not only will long-haul telecommunications adopt lightwave technology but so will computer and video connections to homes and desktops.

However, there's a catch.

The technology may be available, but the requisite OE ICs are only just coming on stream at an attractive price point. At 1Gb/s bit rates and above most optoelectronic circuits are custom-made. Until the required ICs become standard products, readily available from volume manufacturers, the supply of the required optoelectronic modules will be low and the price relatively high, thereby slowing market growth.

Breaking the current price point of the ICs, and hence optoelectronic module assemblies was Vitesse's challenge when we started to develop a new line of high-speed optoelectronic ICs. By targeting Fibre Channel applications at 1Gb/s, Gigabit Ethernet applications at 1.25Gb/s and SONET/SDH/ATM applications at 622Mb/s and 2.5Gb/s, Vitesse is attacking today's price points with a combination of higher circuit integration and volume production.

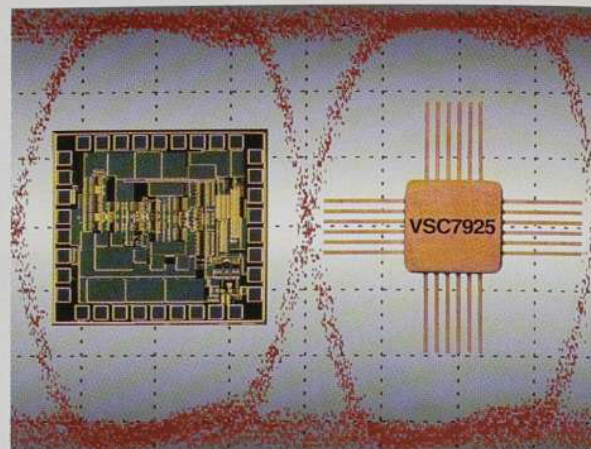
Optoelectronic Components

In the context of this discussion, the term "optoelectronics" refers to semiconductor circuitry which connects an optical fiber transmission medium to an electronic system. This system may be analog, in the case of contemporary cable TV and cellular radio distribution networks, or it may be digital, as in long-haul telecommunications and computer networks. However, in both analog and digital cases the requisite circuit requirements are very similar.

As an example, Figure 1 shows a simple optoelectronic system used for digital communications within networks of telephone switch arrays or computers. An optical carrier signal modulated by data couples into the optoelectronic system's receiver from the fiber, and is detected typically by a PIN diode or an

Avalanche Photodiode (APD). The signal-dependent current from the diode is then amplified into a usable voltage by a transimpedance amplifier (TIA). Digital systems require a stream of clearly defined bits, and this is generally achieved by further amplifying and then limiting the signal using a limiting post-amplifier. The subsequent digital signal is then passed to a clock and data recovery circuit that generates a system clock synchronized with the data. This dual signal is passed to the system core after any required demultiplexing.

A signal transmitted by the system core follows the reverse path. After any required multiplexing the digital bit stream modulates a light source, typically a laser, and this lightwave signal is coupled to the optical fiber for transmission to the target receiver.



The VSC7925, a 2.5 Gb/s laser driver compatible with the SONET/SDH and ATM standards.

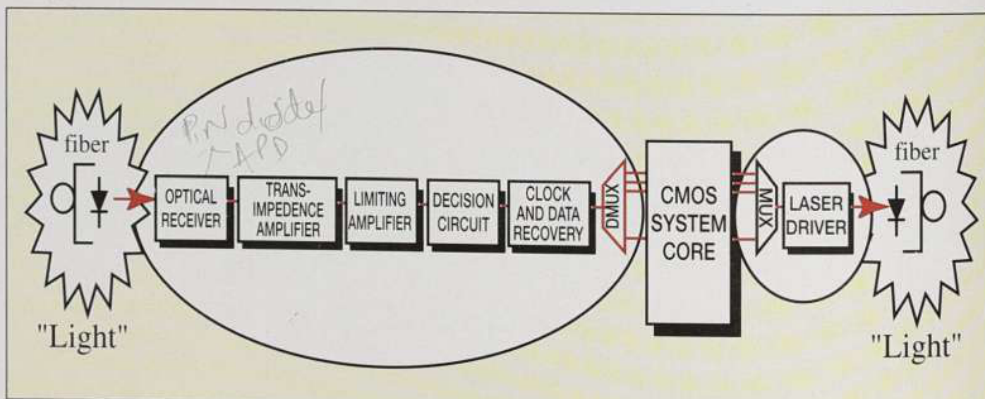


Figure 1. A simple schematic of the type of optoelectronic system for digital communications described in this article. Vitesse plans to market all of the components shown (outside of the CMOS system core and the fiber) for applications at 1Gb/s and above.

Primer on Communications Standards

Keeping up with digital GaAs requires keeping up with telecommunications and networking terminology. Here is Vitesse's summarization of the four most commonly referenced standards in this field.

SONET Synchronous Optical Network

Usage: Long Haul Telephony
Speed: 50 Mb/s to 10 Gb/s

The basis of long-haul telecommunications systems, SONET is a digital transmission standard that defines formats that allow the integration of equipment from diverse manufacturers. SONET defines optical carrier (OC) bit rates from OC-1 (51.84Mb/s) to OC-192 (9.95Gb/s) that are used to transmit data and digitized voice. SONET is compatible with SDH (Synchronous Digital Hierarchy), a world-wide telecommunications standard.

ATM Asynchronous Transfer Mode

Usage: Wide Area Networks
Speed: 1.5 Mb/s and 2.5 Gb/s

ATM is a transmission technology that defines the segmentation of digital signals and the routing of signals across a telecommunications network. Suitable for voice, data and video, ATM offers QOS (Quality of Service) such that all data arrives at a predetermined data rate. This ensures that teleconferencing for example, flows smoothly and with voice synchronisation.

Gigabit Ethernet

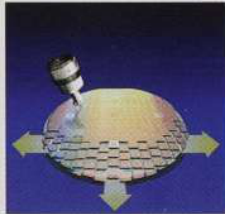
Usage: Local Area Networks
Speeds: 1.25 Gb/s

Gigabit Ethernet is the emerging, highest bandwidth standard for LAN (Local Area Network) data communications. Today's most common standard is Ethernet, running at 10Mb/s. Recently Fast Ethernet was introduced which increased the data rate to 100Mb/s. ATM and Fibre Channel have both been considered for increasing LAN bandwidths even further. In 1996, however, the draft Gigabit Ethernet standard appeared to have garnered the most support as the favoured future technology for LAN environments.

Fibre Channel

Usage: Peripherals Data Storage
Speed: 1 Gb/s

Fibre Channel is a standard used for data communications, such as those between computers and peripherals. It greatly increases the bandwidth, and hence speed of data transmission. Where as today's fastest standards such as SCSI (Small Computer system Interface) run at 10Mb/s, Fibre Channel runs at 1Gb/s. It's initial market, currently emerging, is in disk drives and data storage arrays.



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Analog Amplifier Technology

Note that the core components of optoelectronic systems, besides the laser and the photodetector, are analog amplifiers - the TIA, the limiting post-amplifier, and the driver. All these components need sufficient bandwidth to cover not only the highest transmission rates but also the low frequencies generated by long sequences of zeros or ones encountered in some SONET/SDH frames. For example, in a 2.5Gb/s design each component must have a low cut-off frequency of less than 30kHz and associated passband ripple of less than 1dB.

In addition, each component has specific and challenging design requirements. So that standard optoelectronic receivers can be used with a wide range of fiber length, the TIA must compensate for greatly differing fiber losses using Automatic Gain Control (AGC)

circuits. As well as demanding high sensitivity, the TIA's design introduces significant demands on dynamic range and stability. A

Vitesse has set as a goal the development and volume manufacture of optoelectronic components for all applications at and above 1Gb/s, outside the systems core.

typical Fibre Channel TIA has a sensitivity of -25dBm and dynamic range of over 20dB. Similar demands are made on the post-amplifier. In the transmitter the driver circuit must modulate the laser's current with a fast

enough rise time to enable long distance, error-free transmission. At 2.5Gb/s a 50mA drive rise time of under 100ps is a typical requirement. Such performance is not readily available from standard ICs.

It is Vitesse's goal to deliver a line of standard products that meet these requirements and deliver them in volume at a price substantially below the cost of custom designs. Referring again to Figure 1, Vitesse has set as a goal the development and volume manufacture of optoelectronic components for all applications at and above 1Gb/s, outside the systems core. The supply of all OE and mux/demux components from a single vendor will lead to further simplifications in system design and implementation, as well as in component procurement.

The Vitesse Optoelectronic Product Line

Vitesse is actively developing and testing new optoelectronic components for Fibre Channel, Gigabit Ethernet and SONET/SDH applications. Already a family of integrated 1Gb/s optoelectronic receivers is available in volume production. More recently a family of 2.5Gb/s laser drivers was announced. Both the receiver and the driver families break the price point of high bandwidth optoelectronics by enabling less expensive manufacture of optoelectronic modules through either greater circuit integration or reduced component costs.

In April 1995 Vitesse announced a 1Gb/s optoelectronic receiver (VSC7800 family) designed for Fibre Channel optical module applications. This receiver, developed in conjunction with IBM (shown in Figure 2), is unique in that it includes the optical detector and the TIA on a single semiconductor die. As such, it is the world's first commercially available, high volume integrated optoelectronic IC. For the first time module designers can go from light to an amplified electronic signal using a single IC. Aside from the semiconductor technical and manufacturing breakthrough this represents, the design enables the receiver IC to be integrated into the fiber connector/detector assembly. Integrating these components together eliminates the need for discrete photodetectors and TIAs, thereby reducing the part's count of the final optoelectronic module.

Assembly costs are reduced and the OE receiver printed circuit board is also reduced in size by up to one third. An additional benefit is that by placing the TIA intimately close to the detector the sensitivity of the entire receiver is increased, enabling longer optical transmission lengths. In short, not only does the Vitesse optoelectronic receiver reduce manufacturing costs of high bandwidth optoelectronic modules but it increases their performance.

Vitesse announced the availability of a 2.5Gb/s SONET/SDH-compatible laser driver IC (VSC7924/25) in February 1997. The intent of this design was to meet or exceed the jitter and rise time performance of currently used custom laser driver ICs in OC-48/STM-16 telecommunications applications while reducing the price of the component to the point that makes volume 2.5Gb/s WAN and short-haul telecom and

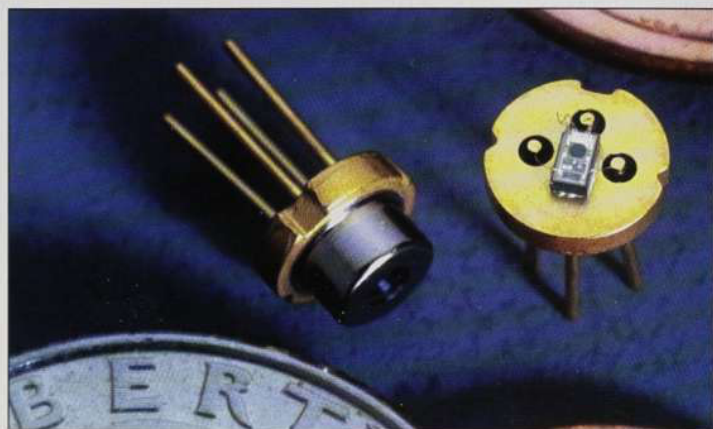


Figure 2. The Vitesse 7810, a 1Gb/s optoelectronic receiver which integrates optical detection and electronic amplification on a single die.

Contributions Welcome

We welcome contributions which discuss technology or applications of interest to our readers. Maximum length: 1500 words. If you are interested in contributing, please contact:

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datacom implementations economically viable. In addition, these circuits were to be compatible with Vitesse's extensive line of integrated 2.5Gb/s SONET/SDH physical layer ICs that are typically used in the adjacent multiplexing and clock multiplier stages of the system.

The VSC7924 laser driver delivers 50mA of laser bias current and an additional 60mA of programmable bias current from a single 5V supply with a rise time of under 100pS. The eye diagram of the laser driver compared to the SONET requirements frame is shown in Figure 3. Note the width and clarity of the eye opening and the extent to which the driver exceeds the SONET-specified requirements at 2.5Gb/s. The circuit offers direct access to modulation and bias drive devices for precision monitoring and setting of modulation levels. The data input accepts ECL levels and the IC provides a data density output for use in adjusting bias settings during unbalanced data conditions. The VSC7925, a variation of the VSC7924, provides the same capability with the addition of on-chip clock-data re-synchronization and a duty cycle offset function.

Initial sampling with telecommunications system vendors suggests that these drivers exceed their electrical performance requirements. More significantly, Vitesse is able to set a new price point by applying its high volume, high bandwidth IC manufacturing capabilities. This will open up availability of these components to vendors of mass implementation 2.5Gb/s networks.

How Does Vitesse Do It?

The key to Vitesse's ability to deliver high bandwidth OEICs in volume and at competitive prices stems from the underlying GaAs technology, Vitesse's ability to manufacture high yield VLSI GaAs ICs at low cost, and Vitesse's design experience in communications ICs at 1Gb/s and above.

While GaAs ICs are often mistakenly associated only with low density RF and microwave designs, Vitesse has taken the larger GaAs wafers and applied standard CMOS fabrication techniques to develop a manufacturing process that uses less process steps than CMOS but provides substantially greater bandwidth. Since 1992 Vitesse has volume manufactured VLSI GaAs ICs that integrate in excess of 1 million transistors. This technology is used to produce the widest range of Fibre Channel physical layer components at 1Gb/s, the first Gigabit Ethernet transceiver at 1.25Gb/s, SONET/SDH/ATM physical layer ICs at 2.5Gb/s and, most recently, 10Gb/s SONET/SDH mux and demux circuits.

Having developed an economical process for fabricating VLSI GaAs ICs, Vitesse is now using the same technology to produce analog OE designs such as TIAs and laser drivers. Using a technology that already delivers 10Gb/s standard product ICs provides design margins that enable Vitesse to easily meet technical requirements at 1Gb/s and 2.5Gb/s. Additionally, through Vitesse's experience in developing communication ICs with integrated multiplexing, clock and data recovery, and clock multiplication - designs which are inherently mixed-signal in nature, Vitesse has refined analog as well as digital aspects of its design and implementation capabilities.

Looking Out

The OE IC demands of telecom applications such as SONET/SDH and ATM are slightly different from the datacom requirements of Fibre Channel and Gigabit Ethernet, even though the core technology requirements are identical. Essentially, telecom applications that meet SONET/SDH specifications require a higher sensitivity than datacom applications to ensure that longer transmission distances are safely achieved.

Vitesse is developing a family of 2.5Gb/s OE components that meet these needs. The VSC7924/25 laser drivers are the first products to be made available. A family of compatible TIAs and limiting post amplifiers will also be delivered.

Datacom applications typically have more stringent limits on power dissipation, size, and external component count. This is so datacom OE modules for computers, network switches, disk drive assemblies, and similar applications are easily and inexpensively assembled in volume, and then run sufficiently cool in highly compacted final systems. The VSC7800 family of integrated OE receivers is designed particularly with these applications in mind. Over the coming year, compatible laser drivers and limiting post amplifiers will also be delivered.

Ultimately the slightly varied requirements of telecom (higher sensitivity at lower volumes) and datacom applications (power, size, and integration) will converge. Vitesse expects that in the same time frame the 1Gb/s OE market will mature and the 2.5Gb/s rate will see ubiquitous use in core datacom as well as telecom networks. With this in mind, Vitesse is increasing levels of integration among the OE components and between the OE functions and other digital physical layer circuits. Given our ability to deliver such parts at low cost, coupled with volume manufacturing, Vitesse expects to significantly change the price point of high bandwidth OE components and enable the more rapid growth of optoelectronics in 1Gb/s and 2.5Gb/s communications markets.

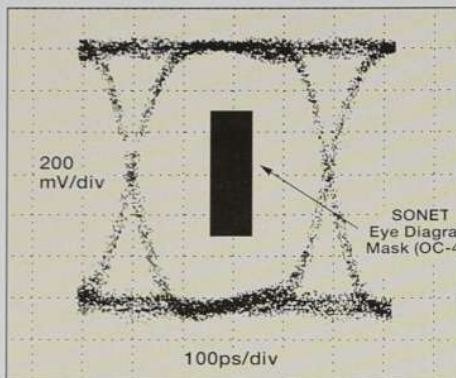


Figure 3. Eye diagram for the Vitesse 7925 2.5 Gb/s laser driver, which clearly exceeds the requirements of the SONET OC-48 specification.

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Research Review

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

Electronic Circuits and Devices

94 GHz High Power InGaAs/InAlAs/InP HEMT Amplifier

Y.C. Chen et al, IEEE Microwave and Guided Wave Letters, 7(5), 133 [May 1997].

W-Band high-power MMIC amplifiers are reported on which were fabricated using 0.15 μm gate length InGaAs/InAlAs/InP HEMTs. Optimum output power was obtained by varying the gate recess depth, during which g_m dropped from 900 to 680 mS/mm, while I_{max} increased from 450 to 650 mA/mm. The gate recess etch was optimized to produce a device for which the peak g_m occurs at a gate voltage of -0.1 to -0.15 V. Using this structure, a 640 μm single stage MMIC amplifier was fabricated which produced an output power of 130 mW with 13% PAE and 4 dB associated gain at 94 GHz. This result represents the highest output power to date measured from a single fixtured InP-based HEMT MMIC at this frequency. Work performed at TRW [Redondo Beach, CA] and Wright-Patterson AFB [OH].

6H-SiC Implanted P-Well CMOS ICs

S. Ryu et al, IEEE Electron Device Letters, 18(5), 194 [May 1997].

Because of the large bandgap of SiC (3.0 eV for the 6H polytype), CMOS technology based on this material system is expected to provide low-power, high temperature tolerant circuits. One of the major challenges for SiC-based CMOS has been to reduce the threshold voltages of the PMOS devices. By utilizing an ion implanted p-well process, devices were fabricated which exhibited threshold voltages of -7.6 V for PMOS (a large improvement as compared to the -17V threshold voltage previously obtained in an n-well process), and 2.5 V for NMOS. The p-wells are formed on Si-face, n-type epilayers doped at $8 \times 10^{15} \text{ cm}^{-3}$ by boron implantation, to create p-type regions that have an acceptor concentration of $1 \times 10^{17} \text{ cm}^{-3}$ near the surface. Using this process, a wide range of circuits were fabricated, including inverters which showed stable operation at temperature up to 300°C, NAND, NOR, XOR, flip-flops, half adders, and an 11 stage ring oscillator which operated at 50 kHz with a V_{dd} of 10 V. These are the first reported p-well CMOS circuits fabricated in 6H-SiC. Work performed at Purdue University [West Lafayette, IN].

AlGaIn/GaN Double Heterostructure Channel MODFETs

Zhifang Fan et al, Electronics Letters, 33(9), 814 [24 April 1997].

AlGaIn/GaN double Heterostructure MODFET is reported, in which Si-doped AlGaIn donor layers are inserted both above and below a 70 Å GaN channel. As determined by Hall effect measurements, this double doped structure exhibited a channel mobility of 304 cm^2/Vs and a sheet carrier density of $3.7 \times 10^{13} \text{ cm}^{-2}$. Fabricated with 1.5-1.75 μm gate lengths, these MODFETs exhibited record channel currents and transconductances of 1100 mA/mm and 270 mS/mm, respectively, where these large values can be attributed to the large sheet carrier density in the channel. Near pinch-off, the drain breakdown voltage is 80 V. These devices also exhibited excellent high temperature characteristics, operating at a temperature of up to 500°C, at which the maximum drain current was reduced to 380 mA/mm and the transconductance to 70 mS/mm. Work performed at the University of Illinois [Urbana-Champaign, IL].

A 277-GHz f_{max} Transferred-Substrate HBT

B. Agarwal et al, IEEE Electron Device Letters, 18(5), 228 [May 1997].

One of the major rate limitations for improvement in f_{max} of an HBT is that of the collector-base capacitance. In order to reduce the collector-base junction area, which in turn reduces the junction capacitance, a transferred substrate process has been developed which permits the fabrication of both narrow and aligned collector-base and emitter-base junctions. An AlInAs/GaInAs HBT is fabricated with aligned 0.7 μm emitter and 1.6 μm collector stripes. This HBT incorporates a 500 Å GaInAs base which is Be doped at a level of $5 \times 10^{19} \text{ cm}^{-3}$, and a 3000 Å GaInAs collector which is Si doped at a level of $1 \times 10^{16} \text{ cm}^{-3}$. The device shows a small signal current gain of 27, and a breakdown voltage, BV_{CEO} , of 2V. Due to the reduced junction capacitances, and the reduced transit times as a consequence of the thin base and collector thicknesses, these HBTs exhibited an extremely high f_{max} of 277 GHz and an f_t of 127 GHz. Work performed at the University of California [Santa Barbara, CA].

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Quantum Dot Lasers Comparable with the Best Quantum Well Lasers

N.N. Ledentsov et al, Appl. Phys. Lett. 70 (21), 2888 (26 May, 1997), and A.E. Zhukov, Electronic Materials Conference, Ft. Collins, CO, 25 June, 1997].

Quantum dot (QD) lasers are sometimes considered to be the way of the future for semiconductor laser diodes. Just as quantum well (QW) lasers represented a large improvement over double heterostructure lasers, it is hoped that the development of practical QD lasers, which provide even better confinement of carriers, will result in large gains in performance. It is believed that QD lasers will offer lower thresholds, higher differential gains, higher modulation speeds, and less temperature sensitivity.

But QD laser performance currently lags behind, largely because the technology is much newer and less developed than QW laser technology. However, a recent German/Russian collaboration demonstrates QD lasers with characteristics as good as those of the best previously reported QW results. The best laser in this study had a continuously grown active layer with average thickness and composition values of 70 Å and $\text{Ga}_{0.8}\text{In}_{0.2}\text{As}$, respectively. Plan view transmission electron microscopy showed, however, that these values were just averages - significant lateral modulation in thickness and composition occurred during the MOCVD growth. These TEM images resembled those of MBE structures that were intentionally grown as quantum dots. The laser characteristics were very impressive: threshold current density as low as 43 A/cm², cw output power of 3 W, pulsed output power of 15 W, and a total conversion efficiency of 52%.

Some of the quantum dot lasers examined exhibited a curious effect, a *negative* value of the characteristic temperature, T_0 . This means that the threshold current of the device decreases with increasing temperature. The negative values of T_0 occur at low temperature (~150K). The explanation was based on a non-equilibrium trapping of carriers in QD's with a range of energies. As the temperature is increased, carriers can be redistributed between different QD's and occupy the states with the lowest energies. A key aspect of the design of these lasers is the incorporation of the QD's in a matrix of an AlGaAs rather than GaAs. The AlGaAs matrix doubles the confinement energy of the QD's enabling a reduced threshold and a factor of 3 improvement in output power.

Work performed at A.F. Ioffe Physico-Technical Institute (Russia), Institut für Festkörperphysik, Technische Universität Berlin (Germany) and Max-Planck-Institut für Mikrostrukturphysik, (Germany).

Optoelectronic Devices

Quantum Dot VCSEL with Stable Polarization

H. Saito et al, Electronic Materials Conference, Ft. Collins, CO, 25 June, 1997].

Conventional vertical cavity surface emitting lasers (VCSEL's) are circularly symmetric structures with no preferred direction to select the polarization of the output emission. Usually, the output is linearly polarized, but the direction may be random and may change with drive current. A recent report shows that the use of asymmetric quantum dot (QD) active regions in VCSELs solves the problem. An examination of In(Ga)As QD's grown by MBE on GaAs (100) substrates showed that the dots are nearly twice as long along the $\bar{0}11$ direction as along the perpendicular $[011]$ direction. Photoluminescence (PL) from the QD's was polarized along the $[011]$ direction by a factor of about 1.4, whereas PL from other layers in the structure was unpolarized. A batch of 20 QD VCSEL's was examined - every laser was polarized along $[011]$, with the opposite polarization suppressed by 18 dB. Work performed at NEC.

Integrated QWIP / LED Infrared Up-Converter for Imaging

L.B. Allard et al, Appl. Phys. Lett. 70(21), 2784 [26 May, 1997].

Silicon CCD two dimensional detector arrays for IR imaging are efficient and relatively inexpensive. They operate out to wavelengths slightly longer than 1 μm . For longer wavelength imaging applications, 2D photodetector arrays constructed of InSb, HgCdTe or GaAs-based Quantum Well infrared photodetectors (QWIP's) are required. These longer wavelengths imaging arrays are quite expensive and require hybridization with silicon readout circuits. An attractive alternative is to convert the longer wavelength IR photons to near IR photons, then use a silicon CCD array to do the imaging. A convenient wavelength converter was recently reported that consists of an IR GaAs / GaInAs LED epitaxially grown on top of an AlGaAs/GaAs QWIP. Wavelengths in the range of 7-8 μm are absorbed in the QWIP and create a photocurrent that turns on the LED, producing 875 nm wavelengths. The QWIP is constructed of p-type quantum wells to enable normal incidence operation. Work performed at the National Research Council, Canada.

High Power, Low Threshold Diode Lasers Operating at 2 μm

D.Z. Garvuzov et al, Appl. Phys. Lett. 70(22), 2931 [2 June, 1997].

Diode lasers at 2 μm wavelengths are needed for pumping lasers such as Ho-doped YAG's. Record performance for a 2 μm laser was recently reported. At 10 - 15°C, the cw output power was 1.9 W, threshold current density was 115 A/cm² and the differential quantum efficiency was 53%. The device was constructed of MBE AlGaAsSb / InGaAsSb materials grown on GaSb substrates. A key aspect of the design of these devices is the use of a broadened waveguide to decrease the free carrier losses, which are more severe than in shorter wavelength lasers. Work performed at Sarnoff Corporation.

A New Type of Quantum Cascade Laser

C-H Lin et al, Elec. Lett. 33(7) [27 March, 1997]

The original quantum cascade (QC) laser developed at Bell Labs involved intersubband transitions within the conduction band of quantum wells (QW's). Among its advantages are the use of well developed, robust III-V materials to produce mid-IR wavelengths. A difficulty of this structure is that the radiative intersubband transitions have stiff competition from very efficient non-radiative intersubband transitions. A recent report introduces a new type of QC laser that uses type-II *interband* transitions. Since non-radiative, phonon-assisted energy relaxation is very rapid for intersubband transitions, but several orders of magnitude slower for interband transitions, the radiative efficiency of this new type of QC laser should be superior. The first demonstration of this type-II QC laser was implemented in InAs/(In)GaSb/(In)AlSb type-II QW's grown by MBE. Laser emission occurred at 80 - 170K at a wavelength of 3.8 μm with a threshold current of 2 A. Work performed at the University of Houston and Sandia National Laboratories.

Compound Semiconductor Materials

Photoconductivity Study of Deep Levels in GaN

C. H. Qiu et al, Appl. Phys. Lett. 70 (15), 1983 [1997]

Photocurrent decay in GaN thin films was studied in the time span from a few seconds to several days. The persistent photoconductivity (PPC) behavior was observed not only in Mg-doped *p*-type GaN films but also in undoped *n*-type GaN films. The photoconductivity spectra and the photocurrent response time were measured using a weak probe light at several times after the samples had been kept in the dark. During the relaxation, the photocurrent due to the sub-bandgap probe light decreased more than the photocurrent due to the UV probe light. It is suggested that metastable centers at 1.1, 1.40, and 2.04 eV above the valence band edge are responsible for the PPC behavior in Mg-doped GaN, and that Ga vacancy is the candidate for PPC effect in *n*-type GaN. Work done at Astralux Incorporated, Boulder CO.

Step-Free InAs Monolayer Quantum Well on (111)B GaAs

T. Nishida et al, Appl. Phys. Lett. 70 (20), 2726 [1997].

An InAs/GaAs quantum-well structure was selectively grown by metalorganic vapor phase epitaxy on a GaAs (111)B substrate with a SiO₂ mask. The precursors were TEGa, TEIn and arsine. A 100 nm thick and 8 μm diameter step-free GaAs buffer layer was first grown at 800°C, and a step-free monolayer of InAs was then grown on this surface at 650°C. For the growth of InAs, TEIn was supplied in five periodic pulses of nominally 1/6 ML. Each TEIn pulse duration was 1 s, and its period was 3 s. The pulse supply procedure was found to eliminate two-dimensional nucleation attributed to a high surface concentration of indium atoms. To eliminate indium segregation during the capping procedure, the InAs layer was buried by GaAs under a stable As-rich condition. The formation of a step-free InAs monolayer quantum well was confirmed by ex situ atomic force microscopy, and by spatially resolved photoluminescence measurements. Work done at the NTT Basic Research Laboratories, Japan.

Au-Ag/Ni/Te Multilayer Low-Offset Contact to *p*-Type ZnSe

S. Yoshii et al, Jpn. J. Appl. Phys. 36 (4A), L386 [1997].

A new approach for the formation of a *p*-type contact to ZnSe is reported. The multilayer contact scheme consists of 5 nm of Te, 10 nm of Ni, and 120 nm of a Au-Ag alloy (80:20) where all layers were thermally evaporated. When annealed in nitrogen at 250°C for 5 min., the contacts showed a significantly reduced I-V curve voltage offset of 3 V compared to the 9 V offset achieved with Au/Pd contacts. Cross-sectional TEM and electron probe microanalysis revealed the formation of a NiZnSe amorphous layer between a polycrystalline NiTe and the *p*-ZnSe material. The reduced offset voltage is attributed to the presence of both the amorphous layer and of a heavily doped layer due to Ag diffusion at the contact interface. Work done at the Matsushita Electric Semiconductor Research Center, Japan.

Direct Photoetching of SiC by Multiwavelength Laser Ablation

J. Zhang et al, Appl. Phys. A 64, 367 [1997].

Single crystal silicon carbide is characterized by low etching rates because of its large binding energy. Some of the highest reported etching rates (7.5 nm/s) have been achieved by magnetron enhanced ion etching. A much faster etching rate of 35 nm/s was achieved by simultaneous irradiation of VUV-266 nm multiwavelength beams from a VUV Raman laser shone through a Ni contact mask with a 1 Hz repetition rate. SEM and SPM measurements revealed well-defined patterns with sharp sidewalls and flat bottoms, and XPS analysis indicates that etched samples have a stoichiometry similar to that of virgin SiC material. Work done at the Institute of Physical and Chemical Research (RIKEN), Japan.

High Temperature Annealing of InN, GaN, AlN and Their Alloys

J. Hong et al, Solid-State Electr. 41 (5), 681 [1997].

High-temperature rapid thermal annealing is used in several process steps during the fabrication of nitride-based devices. The powders of InN and AlN were compared as methods for providing a nitrogen partial pressure within a graphite susceptor for the high temperature annealing of nitride compounds. The AlN powder provides adequate surface protection to 1100°C for AlN, >1050°C for GaN, 600°C for InN, and ~800°C for the ternary alloys. Although the InN powder provides a higher nitrogen partial pressure than AlN powder, the evaporation of In above 750°C is sufficiently high to result in the condensation of In droplets on the surfaces of the annealed samples. Work done at the University of Florida (Gainesville), Sandia National Laboratories (Albuquerque, NM), and Lucent Technologies (Murray Hill, NJ).

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Mid-Term Report

In which we see how our stocks have done in the first six months of 1997. But first, we welcome a newcomer.

MARIE MEYER

RFMD IPO Receives Warm Welcome

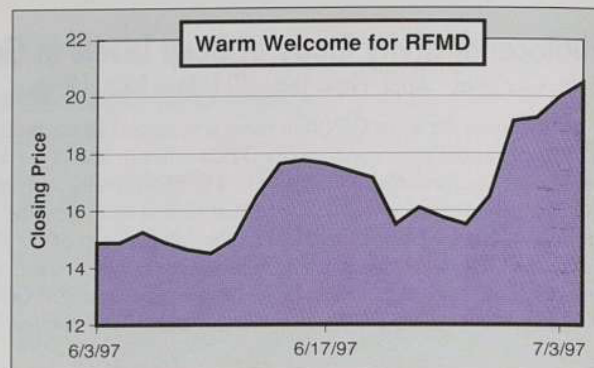
The initial offering from RF Micro Devices received a warm welcome on Wall Street in June. RFMD's shares were priced at \$12 each, which was above the expected range of \$9 to \$11, and the shares closed over \$15 on June 3, the first day of trading. Since then the stock's price has made steady progress, closing over \$20 on July 3.

The size of the offering was increased to 3 million shares from the originally planned 2.5 million shares. Proceeds from the offering will be used to complete the \$50 million GaAs HBT fab currently under construction in Greensboro, NC, and for product development and working capital.

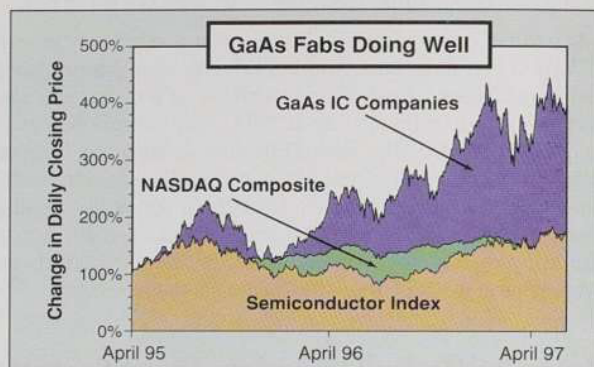
TRW, which is RFMD's partner in HBT product development, owns 31.1% of the outstanding shares of RFMD.

The warm welcome should not come as a surprise. The company has shown remarkable growth over the past 3 years. In fiscal year 1995, sales were just \$1.69 million; in 1996 they reached \$9.5 million, and in 1997 they topped \$28.8 million. Profitability is also much improved, reaching \$1.65 million (\$0.06/share) in 1996, compared to a loss in the previous two years.

Analysts at the firm of Hambrecht & Quist started coverage of RFMD with a buy rating. This was something of a "gimme", given that H&Q underwrote the offering. Nevertheless, the company did forecast earnings of \$0.44/share on revenue of \$52.7 million in fiscal 1998, rising to \$0.66/share on revenue of \$98.7 million in 1999, with long term growth exceeding 30% annually.



Shares in RFMD rose from \$15 to \$20 in the first month of public trading.



Shares in Anadigics, TriQuint and Vitesse have risen around 400% since Anadigics' IPO in April, 1995.

But there are a few question marks surrounding RFMD. The biggest is whether they can quickly and efficiently start up their new fab, the first in the world to be dedicated to HBT manufacturing. Then, of course, they'll have to prove they can compete with silicon and GaAs MESFETs. RFMD also needs to find some new customers. As we reported in our last issue (CS 3(3), p. 32), the company recently lost its biggest customer,

Qualcomm, because it could not meet their requested delivery times and quantity requirements. Qualcomm accounted for 32% of RFMD's sales last year. Another former big customer, Cincinnati Microwave, recently went bankrupt. The company, which used RFMD circuits in cordless phones, accounted for nearly 12% of RFMD's sales in fiscal 1996.

Nevertheless, it is likely that RFMD will enjoy something of a honeymoon with stock analysts, if for no other reason than the likelihood of comparison with the other independent GaAs fabs, which have proven to be excellent investments. Collectively, shares in Anadigics, TriQuint and Vitesse have risen around 400% in the past two years (see chart, above). RFMD may not be bullish on MESFET technology, but it certainly shouldn't mind being mentioned in the same breath as these companies, at least for the time being.

Company	Symbol	Exchange	Last 52 Weeks		Closing Price		Change	P/E Ratio
			Hi	Lo	June 30	Jan 2		
Alpha	AHA	AMEX	9 3/4	5 1/2	8 5/16	8	+4%	♦
Anadigics	ANAD	NASDAQ	37 5/8	14	31	25 1/3	+22%	31
APA Optics	APAT	NASDAQ	6 3/4	4 1/4	5 3/4	4 1/2	+28%	♦
ATMI	ATMI	NASDAQ	29 3/4	10 3/4	29 3/8	16 7/8	+74%	70
Celeritek	CLTK	NASDAQ	16 1/2	8 1/4	12 1/2	10 5/8	+18%	25
Cree	CREE	NASDAQ	15 7/8	8 1/4	12 1/4	10 5/8	+15%	77
Emcore	EMKR	NASDAQ	19 1/2	9 1/4	16 13/16	10 5/16*	+63%	♦
Int'l Semi	ISSM	OTC	3 3/8	1/32	1/16	9/16	-89%	♦
Kopin	KOPN	NASDAQ	16 3/4	7	15 5/8	11 5/8	+34%	♦
Ortel	ORTL	NASDAQ	26 1/4	10 7/8	18	22	-18%	27
Power Spectra	PWSP	OTC	2	3/8	7/16	11/16	-36%	♦
RFMD	RFMD	NASDAQ	18 7/8	14 1/2	19 1/8	15 5/16*	+25%	-
SDL	SDLI	NASDAQ	29 1/2	8	19 1/8	24 5/8	-22%	46
SLI	SLIC	NASDAQ	10	4	4 3/4	7	-32%	♦
Spire	SPIR	NASDAQ	5 1/2	2 1/4	5	2 3/8	+111%	♦
TriQuint	TQNT	NASDAQ	40 3/4	15 5/8	34 3/8	27 3/8	+26%	42
Vitesse	VTSS	NASDAQ	38 3/8	11 1/8	32 11/16	28 1/8	+16%	52

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

♦ = Loss in most recent 4 quarters.
- = Over 100

Mid-Term Report

At the half-way mark for 1997, the shares of the Portfolio companies are up 16%.¹ This is a little better than the NASDAQ composite², which is up 13%, but not as good as the Semiconductor Sector Index³, which was up 28% in the same period.

Of the 16 stocks, there were only five decliners. They included our two over-the-counter issues, Power-Spectra (PWSP) and International Semiconductor (ISSM). The latter has become virtually worthless since the announcement that the company was shutting down its current operation (see page 23). The other decliners were all optoelectronics companies: Ortel, SDL, and Semiconductor Laser International. Collectively, these three were down 22% for the period. While SLI's downturn has been of the slow and gradual type, apparently brought on by lack of interesting news and some sell-offs by former employees, SDL and Ortel have taken investors on more of a wild and woolly ride. Neither is currently a good investment for the faint of heart. For example: disappointing 1st quarter results (earnings of \$0.04 per share compared to \$0.18 per share for year-ago period) drove SDL all the way down to \$10 in mid-April, but the price then more than doubled in the fol-

lowing weeks. And while Ortel's results have been closer to the mark, management has warned of slow growth for a few quarters due to a drop-off in orders for cable television products - touching off a 33% decline in a single day. The company has since made up about half of the lost ground, but is still down \$4 from the first of the year.

There was better news from the GaAs IC manufacturers, where Anadigics, TriQuint and Vitesse continue their pink bunny routine - they just keep going, and going. They are up an average of 21% since January.

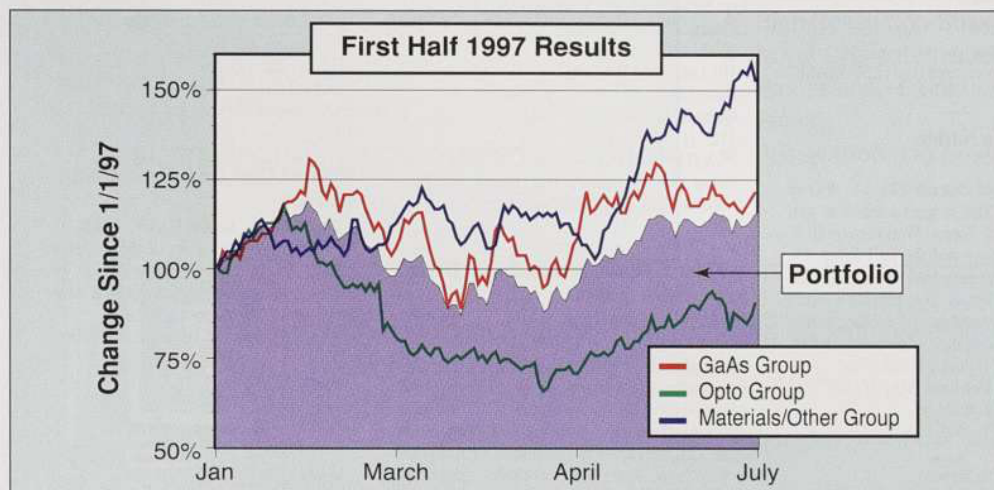
But the biggest gainers of all come from the somewhat less glamorous materials and equipment area. Thinly-traded Spire was up 111% for the period, on the basis of some improvement in revenue and earnings. And ATMI was up an impressive 74% for the period. This apparently represents an endorsement of the company's strategy of growth-by-acquisitions. ATMI has announced two such deals so far this year: in April their NovaMOS division acquired Advanced Delivery & Chemical Systems in a stock swap valued at \$92 million; and then in May their Epitronics division merged with Lawrence Semiconductor in a \$78 million deal. Lawrence specializes in silicon CVD epi.

Of course, it also helps that ATMI has turned in some good numbers recently - their first quarter earnings were more than double those of the year-ago period (\$1.1 million on sales of \$12.4 million, compared to \$469,000 on sales of \$10 million for the first quarter of 1996). And there is nothing like good profits for keeping investors happy - ATMI closed the first half of the year by trading at an all-time high.

¹ For the purposes of this discussion, we excluded Emcore and RFMD from the Portfolio, as they did not begin public trading until after January 1, 1997.

² We use the NASDAQ composite as a reference point instead of more common standards like the S&P 500 because the large majority of the Portfolio stocks are traded on the NASDAQ.

³ The Semiconductor Sector Index is compiled by the Philadelphia Stock Exchange. It is composed of issues from 16 U.S. companies such as Motorola, Intel, TI, Novellus, Micron, Applied Materials etc. that are primarily involved in semiconductors or semiconductor equipment.



Composite results for the first half of 1997. GaAs Group = AHA, ANAD, CLTK, TQNT & VTSS; Opto Group = APAT, CREE, ORTL, SDLI, SLIC; Materials/Other Group = ATMI, ISSM, KOPN, PWSP, SPIR.

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NET rawat@ee.unr.edu

IEEE Summer Topical Meetings

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August 25 - 29, 1997 in Grenoble, France.
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II-VI Conference Secretariat
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Net or Web: lesidang@spectro.grenet.fr

ICSCIII-N '97

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Contact: Prof. E. Janz'n
Linköping University
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III-V Nitride Materials and Processes Symposium

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Contact: Electrochemical Society
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5th European GaAs Applications Symposium

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Contact: Prof. Vito A. Monaco
University of Bologna
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Net: gaas97@deis.unibo.it
Web: <http://www.micrel.deis.unibo.it/~eletl/>

24th Int'l Symp. on Compound Semiconductors

September 7 - 11, 1997 in San Diego, CA.
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Int'l Conf. on Secondary Ion Mass Spectrometry

September 7-12, 1997 at Disney World (Orlando, FL).
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6th Int'l Conf. on CBE and Related Growth Techniques

September 8-10, 1997 in Montreux, Switzerland.
Contact: Dr. Alok Rudra
Swiss Federal Institute of Technology
FAX [41] 21 693 54 90
Net or Web: rudra@eldp.epfl.ch

If you would like your conference to be included in future issues, send the appropriate information by E mail to calendar@compsem.com, or by FAX to [1] 508 750 9740, attention "Calendar"

Contributions must be received by August 28 to appear in our next issue.

Microwaves, RF & Communications Technologies

The 1997 Microwaves, RF & Communications Technologies Conference will be held September 30 - October 2, 1997 at the Wembley Conference and Exhibition Centre, London, England. This is an annual international conference and exhibition for companies involved in RF, microwave and millimetre wave components and application technologies.

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16th North American Conference on Molecular Beam Epitaxy

NAMBE 16 will be held October 5-8, 1997 at the University of Michigan in Ann Arbor. Topics will include but are not limited to: advances in MBE, CBE, etc. growth techniques; in-situ measurement and control; deposition of new materials; heterostructures; patterned and selective area growth; devices and novel concepts; production MBE technology.

Abstract Submission Deadline: TBA
Contact: Pallab K. Bhattacharya
University of Michigan, Dept. Of EE & CS
1301 Beale Ave.
Ann Arbor, MI 48109 USA
TEL [1] 313 763 6678
FAX [1] 313 763 9324
Net or Web: pkb@eecs.umich.edu

1997 IEEE GaAs IC Symposium

The 1997 IEEE GaAs IC Symposium will be held October 12 - 15 1997 in Anaheim, CA. Coverage embraces all aspects of the technology, from materials issues and device fabrication through IC design and testing, high volume manufacturing and systems applications.

Abstract Submission Deadline: May 2, 1997
Contact: Jaelene Berry
IEEE
445 Hoes Lane
Piscataway, NJ 08855 USA
TEL [1] 908 562 3875
FAX [1] 908 981 0538
Net: j.berry@ieee.org
Web: <http://www.eece.umich.edu/VLSI/GAASIC>

2nd Int'l Conf. On Nitride Semiconductors

ICNS '97 will be held October 27 - 31, 1997 in Tokushima, Japan. This is the successor to two 1995 conferences: the Topical Workshop on III-V Nitrides held in Nagoya and the Int'l Symp. On GaN and Related Materials held in Boston. The objective of this conference is to provide a forum for active nitride researchers to exchange their knowledge by presenting their latest results and by carrying out in-depth technical discussions.

Abstract Submission Deadline: May 31, 1997
Contact: Dr. Sadafumi Yoshida
Electrotechnical Laboratory
1-14 Umezono
Tsukuba, Ibaraki 305 Japan
TEL [81] 298 54 5222
FAX [81] 298 58 5434
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201 Varick Street, Suite 1006
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FAX [1] 212 620 3379
Net: jmorreal@newyork.palisades.org

44th National AVS Symposium

The 1997 AVS National Symposium will be held October 20-24, 1997 in San Jose, CA. AVS Technical Divisions include: applied surface science; nanometer-scale science and technology; surface science; vacuum metallurgy; electronic materials and processing; plasma science and technology; thin film; and vacuum technology.

Abstract Submission Deadline: May 1, 1997
Contact: Angela Mulligan
AVS
120 Wall Street
New York, NY 10005 USA
TEL [1] 212 248 0200
FAX [1] 212 248 0245
Net: angela@vacuum.org
Web: <http://www.vacuum.org>

1997 International Electron Devices Meeting

IEDM '97 will be held December 7 - 10, 1997 in Washington, DC. A special emphasis on RF devices is planned for this year's meeting. Papers are requested in all areas of quantum electronics and compound semiconductor devices. Other areas of interest are: CMOS devices and reliability; detectors, sensors and displays; device and interconnect technology; integrated circuits; modeling and simulation, and solid state devices.

Abstract Submission Deadline: June 30, 1997
Late News Deadline: September 17, 1997
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IEDM Conference Office
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TEL: [1] 301 527 0900
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1997 International Semiconductor Device Research Symposium

ISDRS '97 will be held December 11, 12, 13, 1997 in Charlottesville, VA (following IEDM in Washington, D.C.). The Symposium will emphasize fundamental concepts in novel devices and advanced processing technologies. Participation of students and foreign researchers is strongly encouraged. Original papers are solicited in the following areas: Novel Semiconductor Device Ideas and Concepts, New Material and Device Characterization Techniques, Microwave and Millimeter Wave Devices, Wide Band Gap (SiC, GaN, ZnSe, etc.) Devices, High Speed Electronics,

High Power Semiconductor Devices, Nanoelectronics, Micro-electromechanical (MEMS) Devices, New Dielectric and Interconnect Approaches, SiGe(C) Devices and Circuits, Photonics and Optoelectronics, Simulation and Modeling, New Device Fabrication Technologies. Abstract Submission Deadline: August 29, 1997
Contact: William C. B. Peatman, Program Chair
Department of Electrical Engineering
Thornton Hall
University of Virginia
Charlottesville, VA 22903-2442 USA
TEL: (804) 979-4103
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2nd Int'l Conf. On Nitride Semiconductors

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Abstract Submission Deadline: May 31, 1997
Contact: Dr. Sadafumi Yoshida
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1-1-4 Umezono
Tsukuba, Ibaraki 305 Japan
TEL [81] 298 54 5222
FAX [81] 298 58 5434
NET icns-inquiry@eee.tokushima-u.ac.jp

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ISSCC '98 will be held February 5-7, 1998 in San Francisco, CA. The theme of this year's meeting is "Global Communications". Original papers are solicited in subject areas including but not limited to the following: analog, communications, digital and memory circuits; sensors, imagers & displays; signal processing; and technology directions.
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Contact: ISSCC '98
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2000 L Street N.W. Suite #710
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10th Int'l Conf. On InP and Related Materials

IPRM '98 will be held May 11-15, 1998 in Tsukuba, Japan. The scope of the conference will include optoelectronics, electron devices, processing, epitaxy, bulk growth and characterization, and new materials and nanostructures.
Abstract Submission Deadline: November 25, 1997
Contact: IPRM '98
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445 Hoes Lane
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- ★ High-Resolution Structural Characterization
- ★ Novel Characterization Techniques
- ★ Processing - Oxidation
- ★ Etching
- ★ Passivation and Growth Issues



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Semiconductor Lasers - Design and Fabrication

05633887 / 1997 05 27 / Iowa State Univ.
Chung, R. W.; Weber, R. J.

External Cavity Laser. The present invention relates generally to optical devices incorporating semiconductor lasers, and more particularly to an external cavity diode laser configured as a traveling wave amplifier or as a dual-mode optical amplifier-oscillator device.

05627383 / 1997 05 06 / Lucent
Cunningham, J.E. et al

MQW PIN Structures. Optoelectronic devices such as photodetectors, modulators and lasers with improved optical properties are provided with an atomically smooth transition between the buried conductive layer and quantum-well-diode-containing intrinsic region of a p-i-n structure. The buried conductive layer is grown on an underlying substrate utilizing a surfactant-assisted growth technique, and a surface impurity concentration of from 0.1 to 1 monolayer of dopant atoms is provided. The presence of the impurities promotes atomic ordering at the interface between the conductive layer and the intrinsic region, and subsequently results in sharp barriers between the alternating layers comprising the quantum-well-diodes of the intrinsic layer.

05627854 / 1997 05 06 / Lucent
Knox, Wayne H.

Saturable Bragg Reflector. This invention relates an intensity dependent reflector for use in modelocking lasers for the generation of ultrashort optical pulses. Low optical loss and simplified fabrication are achieved by a nonlinear reflector which incorporates one or more semiconductor quantum wells within a standard semiconductor quarter wave stack reflector. The nonlinear reflector provides an intensity dependent response which permits it to be used for saturable absorption directly in a main oscillating cavity of a laser. Saturation intensity of the nonlinear reflector and thereby related laser modelocking properties can be controlled by disposing the quantum well at a particular position in the reflector structure.

05629233 / 1997 05 13 / Lucent
Chand, N.; Chu, S.N.; Syrbu, A. V.

Method of Making III/V Lasers. The disclosed novel method of making III/V semiconductor lasers involves cleaving of the wafer along predetermined cleavage planes, defined by means of aligned non-continuous depressions. The depressions are spaced from the laser contact regions, and typically are V-grooves produced by photolithography and anisotropic etching. A further surface feature, typically a precisely positioned scribe mark, facilitates cleavage initiation. When carried out in vacuum the novel method can provide high quality, accurately positioned cleavage surfaces, and consequently can facilitate increased yield of high power lasers.

05636235 / 1997 06 03 / Mitsubishi
Miyazaki, Yasunori

Laser With Non-Central Emitter. A semiconductor laser device includes unit semiconductor lasers having facets and having side surfaces, active layers disposed in the respective unit semiconductor lasers so that the ends of the active layers are exposed to the facets of the respective unit semiconductor lasers and having centers at the facets. Two adjacent columns respectively include unit semiconductor lasers in the same number which are laminated so that light is emitted from each of the unit semiconductor lasers in the same direction. The active layer in the facet of each unit semiconductor laser is located at a position closer to the adjacent column than the center of the facet of the unit semiconductor laser. Therefore, the region where the active layers are distributed, i.e., the light emitting region, is narrowed, whereby the collection of the emitted light using a lens is facilitated.

05638391 / 1997 06 10 / Mitsubishi
Shima, A.; Tanigami, Y.; Aoyagi, T.

Semiconductor Laser Optical Disc Apparatus. A semiconductor laser device that has less variation in the interval between light emitting points due to thermal deformation in a multi-point light emitting laser diode having light emitting points arranged in close proximity to each other, and an optical disc apparatus provided with the semiconductor laser device.

05642373 / 1997 06 24 / Mitsubishi
Kamizato, T.; Hirano, R.

Array Of Radially Disposed Lasers. A monolithic semiconductor laser array includes an insulating substrate, a plurality of semiconductor layers epitaxially grown on the substrate and forming a laser structure, and at least one groove transverse to the substrate extending through the semiconductor layers into the substrate, dividing the semiconductor laser structure into at least two mutually isolated parts. Within each of the isolated parts of the semiconductor laser structure, a first groove includes a side wall transverse to the substrate and forming a first resonator facet of a semiconductor laser. A second groove in each of the parts includes a second side wall transverse to the substrate and opposite the first side wall, forming a second resonator facet of the semiconductor laser in that part. Each second groove also includes a third side wall oblique to the substrate and opposite the second side wall for reflecting light from the respective semiconductor laser so that light from each of the semiconductor lasers is emitted along a common axis transverse to the substrate. The second grooves are arranged radially about a common point on the substrate. The semiconductor lasers may be electrically connected in series to each other.

05636236 / 1997 06 03 / NEC
Tada, K.; Yamazaki, H.

MQW Laser. A semiconductor laser with a low threshold lasing current and a high external differential quantum efficiency. A n-type AlGaInP clad layer, a AlGaInP MQW active layer, a p-type AlGaInP clad layer, p-type GaInP hetero-buffer layer and a-type GaAs layer are successively grown on a n-type GaAs substrate, wherein Al contents of a barrier in the MQW layer is so varied that holes are uniformly distributed in each quantum well. Next, a mesa is formed by an etching process, then a n-type GaAs block layer is grown, and electrodes are formed on both p and n-side surfaces. Finally, the processed substrate is cleaved, and laser diodes are obtained therefrom. An Al content of the barrier layer in the MQW active layer is slowly decreased from a p-side to a n-side, and thereby holes are uniformly distributed in each quantum well and few electrons overflow a quantum well.

05636237 / 1997 06 03 / NEC
Terakado, T.; Torikai, T.

High-Speed Laser. In a laser device in which a first cladding layer of InP of p-type, an active layer of InGaAsP, and a second cladding layer of InP of n-type are successively formed on a predetermined area of a base layer of InP of p-type. Also formed are a current confining structure that includes a pair of first buried layers of p-type InP on a remaining area of the base layer, a pair of first current blocking layers of n-type InP on the pair of first buried layers, a pair of second current blocking layers of a semi-insulating InP on the pair of first current blocking layers, and a second buried layer of m-type InP on the pair of second current blocking layers. The pair of first buried layers have a pair of projecting portions projecting over inner edge portions of the pair of first buried layers with the first cladding, the active, and the second cladding layers interposed between the pair of projecting portions and with the pair of projecting portions brought into contact with side surfaces of the active layer and with inner edge portions of the pair of second current blocking layers so that the pair of first current blocking layers are electrically isolated from the active layer.

05642372 / 1997 06 24 / NEC
Tomita, Akihisa

Multi-Layered Quantum-Well Layer. The present invention provides a quantum-well semiconductor laser device having a substrate, a clad layer on the substrate, an optical confinement layer on the clad layer, an active layer on the optical confinement layer, an optical confinement layer on the active layer and a clad layer on the optical confinement layer each of which formed of a semiconductor wherein the active layer formed of a multi-layer quantum-well structure of which each layer comprising a quantum-well layer, a first barrier layer adjacent the quantum-well layer and a second barrier layer adjacent the first barrier layer wherein the semiconductor of the first barrier has a higher ener-

Semiconductor Lasers - Design and Fabrication, con't

gy level at a point of a valence band than that of the second barrier layer.

05640410 / 1997 06 17 / Samsung
Yang, Seung-kee

Ridge Type Laser Diode. The present invention relates to a semiconductor laser diode and manufacturing method therefor, and more particularly, to a ridge-type semiconductor laser diode having an improved ohmic contact surface and a manufacturing method therefor.

05640409 / 1997 06 17 / Sony
Ito, Satoshi et al

Blue-Green Laser. A semiconductor light-emitting device capable of emitting blue to green light is disclosed. The device comprises a first cladding layer of the first conduction type stacked on a compound semiconductor substrate and made of ZnMgSSe compound semiconductor; an active layer stacked on the first cladding layer; a second cladding layer of the second conduction type stacked on the active layer and made of a ZnMgSSe compound semiconductor; and ZnSSe compound semiconductor layers provided on the second cladding layer and/or between the compound semiconductor substrate and the first cladding layer. The device has good optical confinement characteristics and carrier confinement characteristics, generates only a small amount of heat during its operation, and is fabricated easily.

05627100 / 1997 05 06 / Thomson-CSF
Maurel, P.; Garcia, J.C.; Hirtz, J.P.

Surface-Emitting Diodes. A method for making a set of surface-emitting laser diodes comprises the making of Bragg reflectors in situ, removing the need for the ion etching.

05629954 / 1997 05 13 / TRW
Jansen, Michael et al

Integrated Etalon. A single-frequency semiconductor laser diode structure and a method for its fabrication. The structure includes a built-in etalon, which limits the frequency of operation of the device to a very narrow frequency band. For an edge-emitting diode, the etalon is formed over a cleaved end face of the semiconductor diode structure, and light is emitted from an opposed cleaved end face. For a surface emitting diode, the etalon is formed as an additional plurality of layers between a plurality of semiconductor layers forming the diode and a substrate on which the structure is formed.

05629097 / 1997 05 13 / Univ. of Oklahoma
McCann, Patrick J.

Apparatus for Fabricating Semiconductor Lasers. The present invention is directed to a semiconductor laser and a method for making such, having a high thermal conductivity heat sink component enabling the laser to be operated at higher temperatures. A semiconductor epitaxial layer is

bonded to a cleaving assembly that allows the epitaxial layer to be manipulated without use of traditional substrate forms. The resulting semiconductor laser is bonded to a metal portion that serves as a heat sink for dissipating heat from the active lasing region. The resulting semiconductor lasers can be cooled by thermoelectric cooling modules, thus eliminating the necessity of using more bulky cryogenic systems.

05642376 / 1997 06 24 / Vixel
Olbright, G. R.; Jewell, J. L.

Visible Surface Emitting Laser. A vertical-cavity surface-emitting laser is disclosed comprising a laser cavity sandwiched between two distributed Bragg reflectors. The laser cavity comprises a pair of spacer layers surrounding one or more active, optically emitting quantum-well layers having a bandgap in the visible which serve as the active optically emitting material of the device. Electrical pumping of the laser is achieved by heavily doping the bottom mirror and substrate to one conductivity-type and heavily doping regions of the upper mirror with the opposite conductivity type to form a diode structure and applying a suitable voltage to the diode structure. For radiation in the yellow to green portion of the spectrum, the laser includes an active layer of GaP or AlGaP quantum wells and AlP/AlGaP mirrors. For radiation in the blue portion of the spectrum, the laser includes an active region of InGaN or GaN quantum wells and AlN/AlGaP mirrors.

Semiconductor Lasers - Packaging and Control

05640407 / 1997 06 17 / Accu-Sort Systems
Freyman, C. A.; Di Domizio, R. A.; Robb, J. S.

Temperature Regulating Assembly. An improved laser diode assembly includes a laser diode unit that is mounted directly on a compact thermoelectric cooler, which is mounted on a heat sink. A thermally insulating gasket, mounted around the thermoelectric cooler, seals the thermoelectric cooler from the ambient environment, thereby preventing condensation from forming on the cold face of the thermoelectric cooler. A thermally conductive gasket, mounted around the circumference of the laser diode window, returns heat from the heat sink to the window to prevent condensation from forming on the window. The laser diode is the only component cooled by the thermoelectric cooler. Since a portion of the heat transferred by the thermoelectric cooler is utilized to warm the laser diode window, a separate heating element is not required.

05629952 / 1997 05 13 / Corning
Bartholomew, R.F. et al

High Power Laser Packaging. A package for a high power semiconductor laser comprising a hermetically sealed container filled with a dry gaseous medium containing oxygen. The presence of oxygen in the laser atmosphere is counter to standard practice of use of an atmosphere of a dry inert gas. The package also includes a getter

for organic impurities, e.g., a getter composed of a porous silica or a zeolite. The hydrogen content of the materials used to form the package are reduced by baking at an elevated temperature for an extended period of time.

05633761 / 1997 05 27 / Fujitsu
Takashima, Yuichirou
05636233 / 1997 06 03 / Fujitsu
Sato, Shinichi et al

Laser Diode Module. The present invention(s) generally relates to laser diode modules suitably applied to a bar code reader in which a laser diode is used as a light source.

05638390 / 1997 06 10 / Methode Electronics
Gilliland, P.B.; Goryachev, A.A.

Optoelectronic Transceiver Module. A power stabilizer for maintaining a constant level of output power from a laser transmitter. The laser transmitter has a laser diode which produces an optical output which corresponds to the level of bias current received. In addition, the laser transmitter has a photodiode which produces a feedback signal which corresponds to the optical output power being produced by the laser diode. Furthermore, the power stabilizer consists of a digitally controlled potentiometer for producing a reference input signal and an op-amp for comparing the

feedback signal and the reference input signal to produce a control signal to supply bias current.

05636234 / 1997 06 03 / Mitsubishi
Takagi, Kazuhisa

Heat Sink with pn Junction. The present invention relates to a semiconductor laser device producing relatively high power light to use in measuring a distance, for optical communication, and for other applications. In particular, the present invention relates to a semiconductor laser device mounted on a heat sink that includes a pn junction.

05640188 / 1997 06 17 / Xerox
Andrews, John R.

Multiple Diode Lasers. The present invention is a multiple spot laser assembly, comprising a plurality of laser diodes, and a plurality of mounts, which include a support surface, upon which the laser diode are permanently affixed. The mounts, including the base plate and/or heat sink, further include a mating feature along an edge thereof for aligning a first mount with an adjacent mount, the two mounts abutting along at least one common edge. The mating features assure the accurate alignment of the laser diodes on the adjacent mounts when the mounts are assembled into a multi-spot laser light source.

Other Optoelectronics

05631190 / 1997 05 20 / Cree
Negley, G. H.

High Efficiency SiC LEDs. A method of producing LEDs from SiC with increased external efficiency is disclosed which includes directing a beam of laser sufficient to vaporize the SiC surface that it strikes to thereby define a cut; and then dry etching SiC portion to remove the by-products generated.

05631768 / 1997 05 20 / France Telecom
Bruno, Adrien

Optoelectronic Device. This invention concerns an optoelectronic device, that makes it possible to separate signals of different wavelengths, for example signals of different wavelengths arriving from a same fiber, towards different users, each receiving its own wavelength. The device may also be used in optical interconnections between, for example, high-integration fast electronic micro-chips or between computers, or again inside computers.

05631489 / 1997 05 20 / Max-Planck-Gesellschaft
Roser, Hans P.

Optoelectronic Device. The invention relates to the use of an optoelectronic device as a heterodyne radiation detector as well as an optoelectronic converter, in particular for operation in the frequency range between 3 and 3000 GHz. The invention relates furthermore to a spectrometric system containing an optoelectronic device of this kind. The optoelectronic device is based on a conduction constriction through which charge carriers pass ballistically.

05631475 / 1997 05 20 / Mitsubishi Cable
Watabe, Shinichi et al

Semiconductor Light Emitting Element. The present invention relates to an AlGaInP semiconductor LED having a high luminance and a long service life. The LED comprises an AlGaInP active layer and a AlGaInP cladding layer, which is formed on a GaAs substrate, and an AlGaAs layer and a GaInP layer deposited in this order on said light emitting part, wherein said GaInP layer has a thickness of not more than 1.0 micron. According to the present invention, absorption of the emitted light by an electrode contact layer and the occurrence of an interfacial distortion between the electrode contact layer and the layer thereunder can be suppressed, permitting easy production and high luminance and a long service life.

5635733 / 06/03/1997 / Mitsubishi Cable
Okagawa, H. et. al

LED with Current Diffusing Layer. In the light emitting element comprising an n-type semiconductor

substrate, a lower electrode formed on the lower surface of the substrate, and a light emitting part having a pn junction, which is composed of an InGaAlP compound semiconductor material, a p-type current diffusing layer and an upper electrode which are laminated on the upper surface of the substrate in that order from the substrate side, the improvement wherein a carrier concentration of the current diffusing layer is lower on a light emitting part side thereof than that on an upper electrode side thereof, and at least the upper electrode side of the current diffusing layer is composed of GaP. By employing such structure, diffusion of the dopant to a light emitting part can be suppressed even when the carrier concentration of the upper part of the current diffusing layer is set to be higher, thereby affording a lower resistance of the current diffusing layer as a whole. The GaP being a compound semiconductor without Al, the amount of the dopant necessary for affording the superior effects of suppressing the diffusion of the dopant to the light emitting part can be less. Consequently, the luminous efficiency can be improved as compared with conventional ones, and a light emitting element having a long service life and superior reliability can be obtained.

05639158 / 1997 06 17 / NEC
Sato, Yuko

Led-Array Light Source. A linear light source used in a facsimile device or scanner and, more particularly, to an LED-array light source in which a number of LEDs (Light Emitting Diode) are linearly arranged as a light source for a contact-type image sensor.

05633514 / 1997 05 27 / Sony
Shiraishi, M. et al

II-VI LED with Lattice-Mismatching. The LED includes a semiconductor a first conductivity type first cladding layer deposited on a semiconductor substrate, an active layer (deposited on the first cladding layer, and the second conductivity type second cladding layer deposited on the active layer. The first and the second cladding layers are made of the II-VI-compound semiconductors including at least one kind of group II elements such as Zn, Hg, Cd, Mg and at least one kind of group VI elements such as S, Se, Te. The lattice mismatching between at least one of the first cladding layer and the second cladding layer and the substrate is set within a specific range.

05635407 / 1997 06 03 / TI
Goodwin, Michael W.

HgCdTe S-I-S Two Color IR Detector. A HgCdTe S-I-S (semiconductor-insulator-semiconductor) two color infrared detector wherein the semiconductor

regions are group II-VI, preferably HgCdTe, with different compositions for the desired spectral regions. The device is operated as a simple integrating MIS device with respect to one semiconductor. The structure can be grown by current MBE techniques and does not require any significant additional steps with regard to fabrication.

05627386 / 1997 05 06 / U.S. Army
Harvey, J.F.; Lux, R.A.; Tsu, R.

Silicon Nanostructure LED. The invention provides light sources which are easily compatible with standard silicon VLSI processing and can be located directly in the material of the silicon VLSI chip. A native oxide film (SiO₂) is caused to develop on the surface of the silicon substrate. A thin, transparent, conductive film is then deposited on top of the SiO₂. The carriers for electroluminescence are supplied by the P-doped silicon substrate (holes) and the conductive film (electrons).

05629232 / 1997 05 13 / Whitaker Corporation
Jiang, Ching-Long

Method Of Fabricating Semiconductor Light Emitting Devices. The present invention relates to semiconductor light emitting devices with increased operating speed and near linear light output versus current input characteristics, and lasing suppression mechanisms. The problems of intrinsic capacitance associated with conventional semiconductor heterojunction devices are reduced by the reduction of pn junction capacitance as well as the use of a semi-insulating blocking layer and a conductive substrate. Furthermore, a light absorbing layer is disposed on one side of an unetched portion of the semi-insulating material and an active layer disposed on opposite side. Also, the interface of the semi-insulating material and the active and absorbing layers are at prescribed angles that reduce back reflections to the absorbing and active layers. This arrangement reduces pumping in the absorbing region and thus reduces the lasing effect, allowing for a stable LED.

05638108 / 1997 06 10 / Xerox
Nacman, A.; Appel, J.J.; Charnitski, G.A.

Lower Resolution LED Bars. A method for achieving high resolution printing using low resolution LED bars is performed by arranging the bars at particular angles to the photoreceptor and timing the activation of the pixels within the LED bars according to the movement of the photoreceptor. In addition, the LED bars may be segmented and arranged so that the segments abut one another at different locations. Each of the abutting segments is disposed at a particular angle to the photoreceptor in the process direction. A lens arrangement is used to image the LED bars.

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and select the "PatentWEB™" option.*

Electronics

05639677 / 1997 06 17 / ETRI (Korea)
Lee, J.L. et al

Low Voltage GaAs Power Device. Disclosed is a GaAs power semiconductor device operating at a low voltage and a method for fabricating the device. Parasitic carriers in interface between the substrate and the GaAs buffer layer can be prevented from being introduced into the channel layer by a superlattice layer during operation of the device.

05642080 / 1997 06 24 / ETRI (Korea)
Whang, In-Gap et al

LNA. A low noise amplifier of the present invention may be useful to a portable cellular phone or a microwave communication system, particularly to a monolithic circuit in which the amplifier includes an input impedance component consisting of capacitors and an inductor, two MESFETs in a cascade connection and a capacitor connected between the two MESFETs so as to enhance the stability of the amplifier when a node strapping a plurality of ground terminals of the amplifier is connected to an external circuit by means of a bonding wire.

05633183 / 1997 05 27 / Honeywell
Swirhun, Stanley E.

Minimized Parasitic Gate Capacitance. It is an object of the present invention to produce a heterostructure FET having a capacitance between the gate pad and the channel layer that is much less than similar type capacitances of related art FETs. This object is achieved by a process which utilizes an ion implant isolation of the channel layer beneath the gate pad without affecting or damaging the surface of the heterostructure wafer.

05633179 / 1997 05 27 / Kamins, Theodore I.

Si/SiGe HBT. A HBT in which an active region is defined on a silicon collector layer. A silicon-germanium base layer characterized by an integral polycrystalline and epitaxial structure is deposited over the collector such that the epitaxial portion of the base covers substantially the entire active region of the collector. In one version, a field oxide region separates the polycrystalline part of the base layer from the remainder of the collector layer. Alternatively, the collector layer is also characterized by an integral polycrystalline and epitaxial structure; in this version the epitaxial part of the base overlies the epitaxial part of the collector.

05631479 / 1997 05 20 / Mitsubishi
Shiga, Toshihiko

Laminated Schottky Barrier. The present invention relates to a semiconductor device such as a field effect transistor provided with a Schottky barrier electrode on a compound semiconductor substrate, or an MMIC or a logic IC using this MESFET. The gate resistance of the Schottky barrier gate electrode can be held low and the internal stress can be reduced, whereby peeling off of the can be suppressed.

05640026 / 1997 06 17 / Mitsubishi
Terazono, Shinichi

Implanted Isolation. A method of performing element separation by ion implantation for a compound semiconductor device. A highly reliable element separating technique and a highly reliable device are obtained.

05627385 / 1997 05 06 / Motorola
Bhatnagar, M. Weitzel, C.E.

Lateral SiC Transistor. A lateral SiC transistor utilizes a modulated channel region to form an accumulation region that facilitates a low on-resistance. A doped region of the channel layer forms a channel insert that also lowers the on-resistance of the transistor. Field plates are utilized to facilitate providing a high breakdown voltage.

05631175 / 1997 05 20 / Motorola
Gilbert, James G. et al

Elevated-Gate FET. A field effect transistor has an active layer formed in a substrate. A gate is disposed on an elevated platform formed from the active layer. The elevated platform raises the bottom surface of the gate relative to the top surface of the active region on either side of the gate. A fabrication method for the transistor forms the elevated platform by etching the active region surface on both sides of the gate so that the bottom surface of the gate is elevated relative to the top surface of the surrounding active region. The gate itself and/or a patterned photoresist layer may be used as a mask for performing this etch.

05640025 / 1997 06 17 / Motorola
Hashemi, M. et al

High Frequency Semiconductor. A high frequency transistor including a heavily doped first current carrying layer positioned on a substrate and a semi-insulating layer of LTGaAs epitaxially grown on the first layer. The semi-insulating layer is etched, using a layer of AlAs as an etch stop, to define an active region and a first current carrying electrode is grown on the exposed first layer in the

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Electronics, con't

active region. A control layer is grown on the semi-insulating layer and the first current carrying electrode, and a second current carrying electrode is grown on the control layer. External contacts are formed on the first current carrying layer, the control layer, and the second current carrying electrode.

05627090 / 1997 05 06 / Murata Manufacturing Marukawa, Takashi; Nakano, Hiroyuki

Schottky Electrode Process. A Schottky electrode is formed on the active layer of a semiconductor substrate and the region is subjected to the plasma treatment. In a GaAs MESFET, the gate withstand voltage can be improved and the current leakage at the gate electrode can be suppressed. Further, in the diode such as a Schottky barrier diode, the forward and the reverse characteristics of the diode are improved.

05633517 / 1997 05 27 / NEC Saitoh, Yasuo

Multi-Stage Power Amplifier. A semiconductor device has a multi-stage power amplifier, which is composed of a plurality of transistors disposed on a semi-insulating GaAs substrate. All transistors constituting an ultra-high frequency multi-stage power amplifier are implemented onto a single chip, thus enhancing device miniaturization and preventing undesirable oscillation.

05635735 / 1997 06 03 / NEC Miyamoto, H.; Onda, K.

Improved Schottky Gate Structure. The invention relates to a high frequency and high speed field effect transistor with an improved Schottky gate structure. The Schottky gate electrode has two

layers, the second layer being made of a second compound semiconductor having a higher conduction band edge than that of the first layer.

05641977 / 1997 06 24 / NEC Kanamori, Mikio

Compound Semiconductor FET. A compound semiconductor FET wherein a gate electrode is formed on the center of a recess, portions of which are formed of a material (InGaAs) difficult to cause dislocation. Therefore the FET can prevent degradation of characteristics in high temperature burn-in test.

05641975 / 1997 06 24 / Northrop Grumman Agarwal, Anant K. et al

AlGaN HBT. A heat tolerant, frequency responsive AlGaN HBT for use in the microwave region mounted on a SiC or sapphire substrate.

05629648 / 1997 05 13 / RFMD Pratt, William J.

HBT Power Amplifier. An improved HBT power amplifier circuit providing an efficient and linear amplifier.

05637889 / 1997 06 10 / SGS-Thomson Groover, R.O.; Blanchard, R. A.

Composite Power Transistor. A power device structure which is formed of two merged device structures: an FET control device is located in a surface layer of narrower-bandgap material, and a blocking device which provides high-voltage-withstand capability is located deeper in the device, in a substrate of wider-bandgap material.

05633610 / 1997 05 27 / Sony Maekawa, I.; Ohgihara, T.; Tanaka, T.

MMIC Apparatus. The present invention relates to a bias stabilizing circuit of a field effect transistor formed of a compound semiconductor for use in a bias stabilizing circuit of a MMIC and a circuit using the same.

05631173 / 1997 05 20 / TI Delaney, J.B.; Bracey, K. E.

Collector Up HBT. A process and structure for an improved collector-up bipolar transistor. The base is formed after the emitter is implanted to eliminate base damage during oxygen implantation typical in prior art collector-up bipolar transistors. In a preferred embodiment, an emitter layer of GaAlAs is implanted with oxygen in the extrinsic emitter region to damage the material and make it insulative. The base is epitaxially grown at low temperature to insure the emitter material remains damaged and insulative.

05631477 / 1997 05 20 / TRW Streit, D.; Oki, A.K.; Tran, L.T.

Quaternary Collector InAlAs-InGaAlAs HBT. An InAlAs/InGaAlAs heterojunction bipolar transistor that includes a constant quaternary InGaAlAs collector layer. Graded InGaAlAs collector layers are provided on each side of the quaternary collector layer to minimize transitions through the constant collector layer. The InAlAs/InGaAlAs HBT may also include one or more of a graded InGaAlAs emitter-base transition region, a graded-doping InGaAs base layer, and a graded-composition InGaAlAs base layer.

Other Topics

05633192 / 1997 05 27 / Boston Univ.

Moustakas, T.D.; Molnar, R.J. A method of preparing monocrystalline GaN thin by ECR-assisted MBE and the preparation of n-type and p-type GaN films and a method for forming p-n junctions from these films.

05631472 / 1997 05 20 / Lucent

Cunningham, J.E. et al. An accurate in-situ growth technique based upon reflection high energy electron diffraction dynamics for accurate lattice matching of dissimilar materials.

05633193 / 1997 05 27 / Lucent

Baillargeon, J. N. et al. A method which comprises providing an InP-based semiconductor which is patterned such non-planar surface features result, and growing a phosphorus containing semiconductor material on the patterned major surface using solid sources.

05635732 / 1997 06 03 / Motorola

Davis, K.L.; Weitzel, C.E. Methods of forming SiC vertical MOSFETs utilizing local oxidation of silicon (LOCOS) procedures.

05641381 / 1997 06 24 / NASA

Bailey, S.G. et al. A liftoff method employing a sacrificial layer of ternary material. A layer of InP is placed on the ternary layer and a layer of wax is applied to the InP layer to apply compressive force and an etchant material is used to remove the sacrificial layer.

05637531 / 1997 06 05 / Polish Academy

Porowski, S. et al. A process for fabricating a multilayer crystalline structure of Group III nitrides, which includes forming a first crystal under an equilibrium nitrogen pressure and forming a second crystal layer by decreasing the nitrogen pressure such that the second crystal layer grows with a slower growth rate.

05637146 / 1997 06 05 / Saturn Cosmos

Chyi, J.-I. A method for the growth of Group III nitrides in a UHV chamber wherein low energy atomic nitrogen is generated by a plasma-excited radical atom source.

05633513 / 1997 05 27 / Seiko

Koyama, K. et al. A diamond FET incorporating a p-type semiconducting diamond layer of a specific thickness and B-doping concentration.

05639299 / 1997 06 17 / Sumitomo

Inoue, T. et al. A method of making a compound semiconductor single-crystalline substrate for LPE growth with relatively low cost and excellent practicality.

05639673 / 1997 06 17 / U.S.A.F.

Vaccaro, K. et al. Transparent ohmic contacts for Schottky diode optical detectors on thin and inverted epitaxial layers of InGaAs/InAlAs.

05637530 / 1997 06 10 / U.S. Philips

Gaines, J.M. et al. Epitaxial layers of II-VI semiconductor compounds having low incidence of lattice defects such as stacking faults are produced by by migration enhanced epitaxy (MEE).

05633194 / 1997 05 27 / Univ. of Waterloo

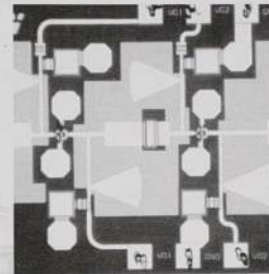
Selvakumar, C. R. et al. A low temperature ion-beam assisted deposition process for SiGe/Si

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Dobkin, D. M. et al. A method of characterizing a group III-V epitaxial wafer in a characterization profiling apparatus having an electrolytic cell.

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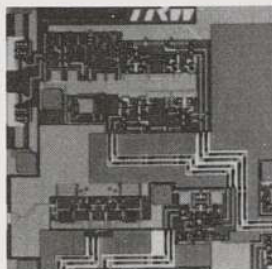
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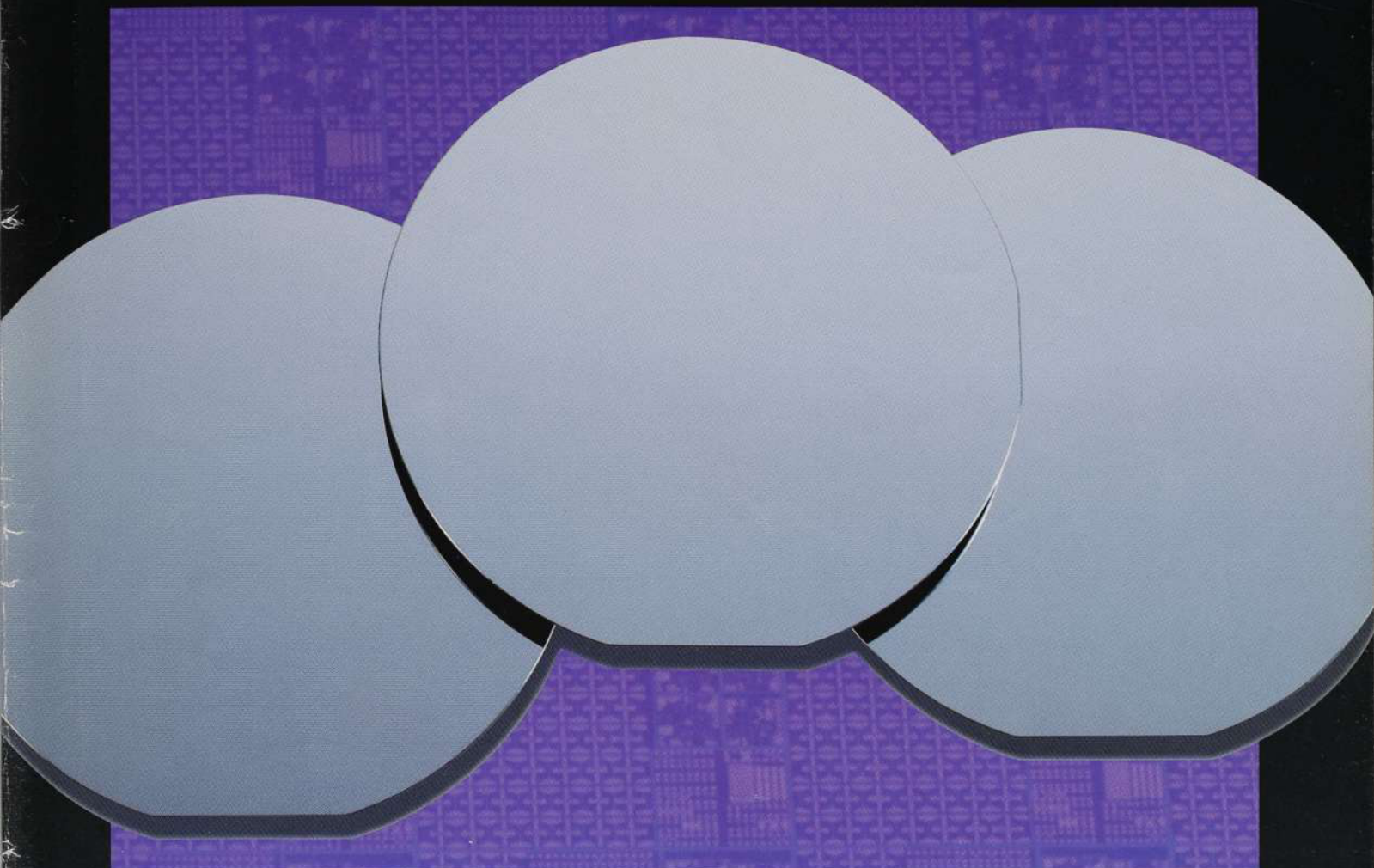
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