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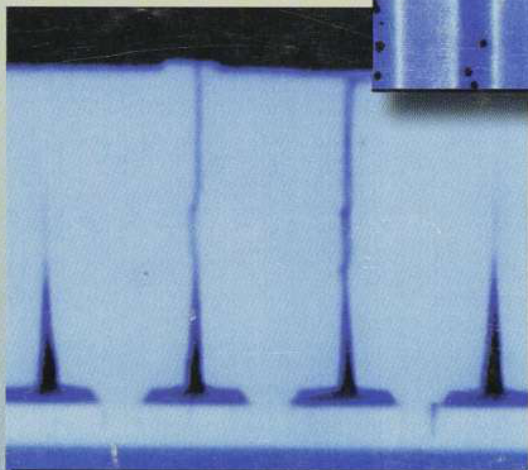
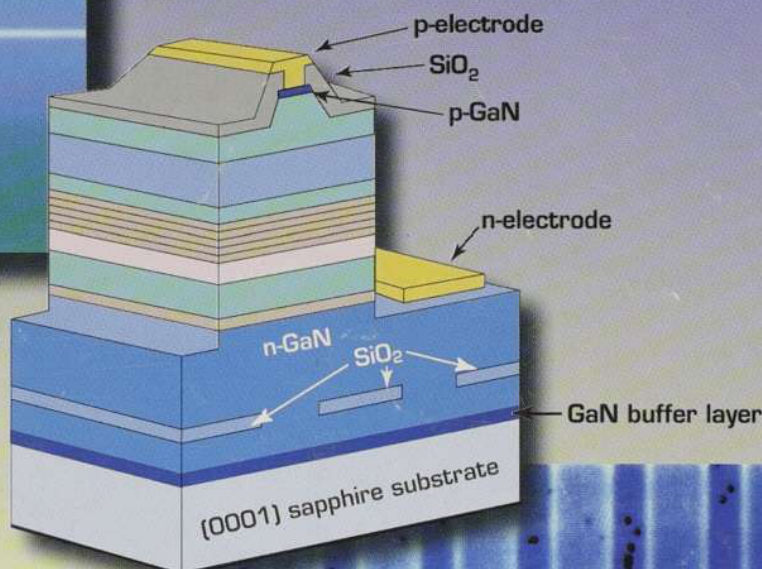
SEMICONDUCTOR

November/December 1997

Volume 3 Number 6

Nichia Reports

10,000 Hour Blue Laser



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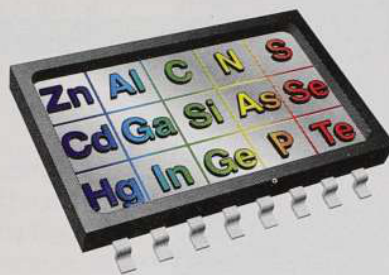
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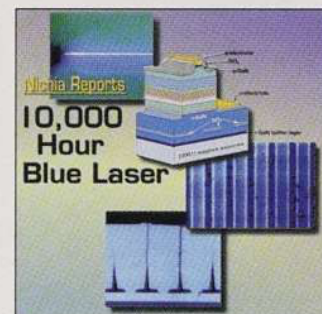
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Nichia Surpasses 10,000 Hours, Announces Blue Laser Prototyping Plans

New structure allows major milestone to be reached; company will begin sample shipments by the end of 1998

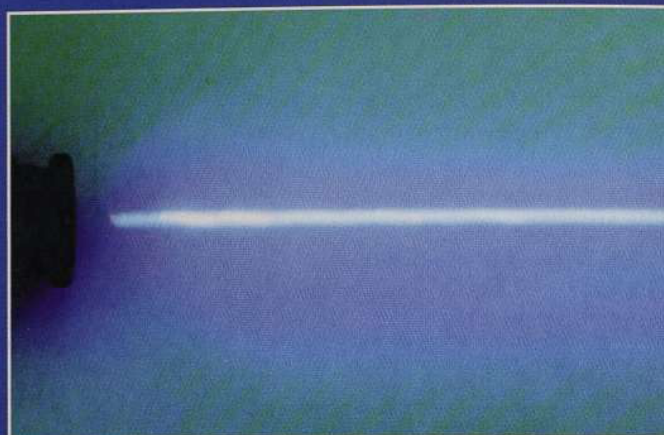
Nichia Chemical has passed a major milestone in the development of blue laser diodes with the demonstration of a InGaN/GaN/AlGaIn device with an estimated lifetime of more than 10,000 hours under CW operation at 20°C. The announcement was made by Shuji Nakamura of Nichia on October 30, at the 2nd International Conference on Nitride Semiconductors (ICNS), held in Tokushima, Japan. It closely followed Nakamura's announcement of the first diode to exceed 1,000 hours, which was made on September 8 at the International Symposium on Compound Semiconductors (ISCS) in San Diego, CA.

At the time of the ICNS conference, the diodes had already demonstrated real lifetimes in excess of 3,000 hours at 20°C. The estimate of 10,000 hours or more was made using conventional high temperature testing methods. Operation at 50°C for over 1,100 hours was reported.

This remarkable achievement was made less than two years after Nakamura's first-ever demonstration of lasing action in a GaN-based device. See Figure One. On the basis of these developments, Nichia has announced to the Japanese press that it plans to begin sample shipments of blue laser diodes by the end of 1998.

New Structure

In his ISCS paper, Nakamura revealed for the first time two significant changes to the epitaxial structure of his laser diodes. First, he is now using modulation-doped strained-layer superlattices (MS-SLSs) as the cladding layers in his epitaxial structure. Previous structures, which used a thick $\text{Al}_{0.07}\text{Ga}_{0.93}\text{N}$ layer for the clads, suffered from cracks during the growth of the layers, due to stress caused by lattice mismatch and the difference in thermal expansion coefficients between the AlGaIn cladding layer and the GaN layers on either side of them. The strained layer superlattice was introduced to prevent cracks, and improve optical confinement, and modulation doping was used to reduce the operating voltage.



Example of one of Nichia's blue laser diodes in action.

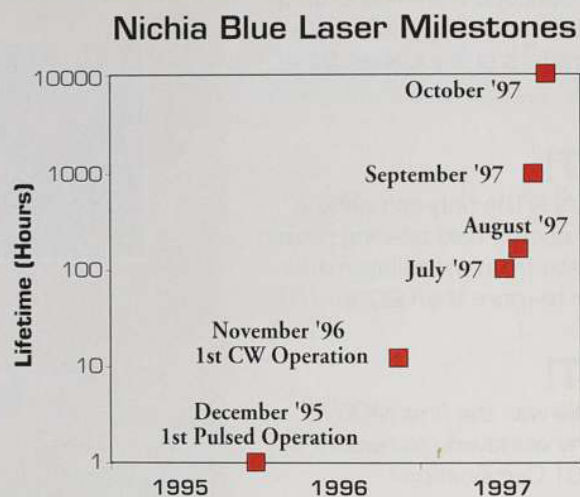


Figure One. Plot of Nichia's milestones in CW blue laser development. Less than two years elapsed between the first demonstration of pulsed operation and the announcement of 10,000 of hours CW operation.

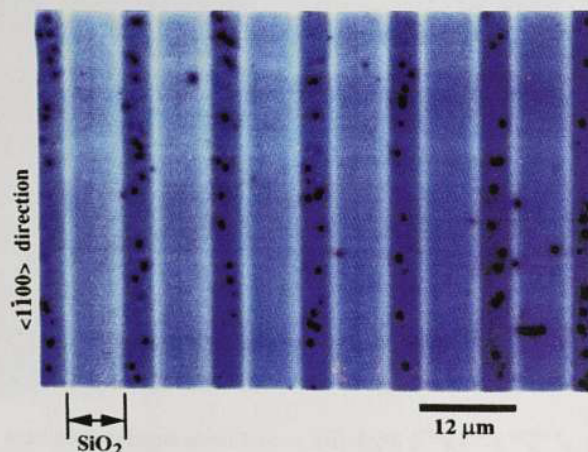


Figure Two. An ELOG (epitaxial laterally overgrown GaN) substrate, etched to a depth of 2 μm. The narrow, dark blue bars are the GaN "windows", and the wide, light blue bars show GaN grown on top of the SiO_2 stripes.

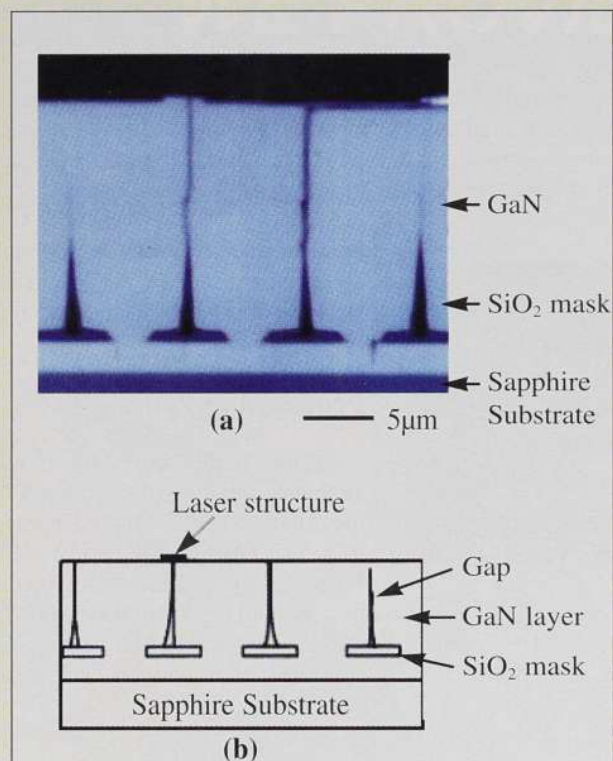


Figure Three. Cross section of the laser diode structure grown on the ELOG substrate. (b) shows the schematic drawing of (a). There is a gap or crack at the center region of the SiO₂ stripe, probably due to the imperfect coalescence of the lateral GaN growth. Devices fabricated from this area exhibited shorter lifetimes than those fabricated from the remainder of the material.

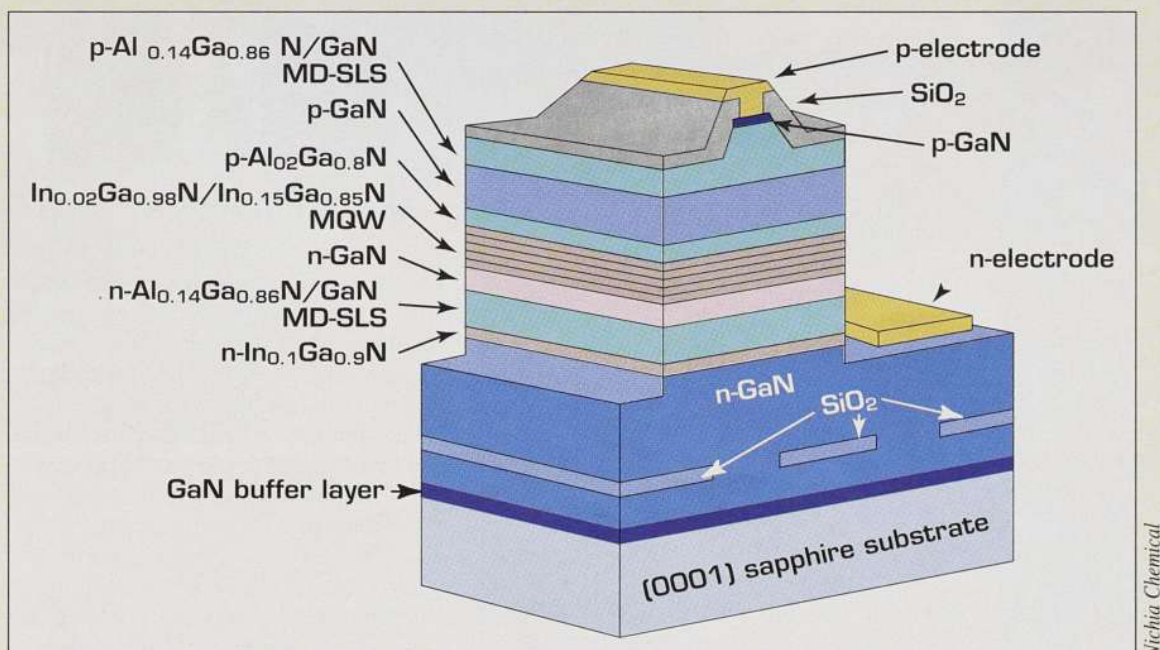


Figure Four. The structure of the new laser diode, indicating both the MD-SLS cladding layer and the ELOG substrate. The laser cavity was formed within the SiO₂ stripe.

The second new twist to the structure is the use of lateral overgrowth on a patterned substrate to reduce the number of threading dislocations. Nakamura calls it an "ELOG (epitaxial laterally overgrown GaN) substrate". It consists of a GaN layer deposited on a (0001) sapphire substrate. A 0.1 μm SiO₂ mask is deposited on the GaN to form 4 μm wide stripe windows in the GaN <1-100> direction, spaced at 12 μm intervals. A 10 μm thick GaN layer is then grown on the SiO₂ mask. It coalesces to form a flat GaN surface over the entire substrate.

Figure Two shows an ELOG substrate, etched to a depth of 2 μm by reactive ion etching with Cl₂ plasma. The narrow, dark blue bars are the GaN "windows", whereas the wide, light blue bars show GaN grown on top of the SiO₂ stripes. Many hexagonal etch pits are visible in the windows, due to dislocations in the GaN. Nakamura reported an etch pit density (EPD) of around $2 \times 10^7/\text{cm}^2$ in these areas. This is a significant improvement over typical results from growth of GaN on conventional sapphire substrates, where reports of EPDs around $10^{10} - 10^{12}/\text{cm}^2$ are common. Nakamura says "In simple terms, the area of the interface region is decreased through the use of the SiO₂ mask. From the interface, the dislocations have to originate due to the large (15%) lattice mismatch between GaN and sapphire. In the case of the ELOG substrate, because the area of the interface is small, the average number of dislocations has to be smaller."

Figure Two also shows that the EPD in the region of the SiO₂ stripes is almost zero. In the window regions, the dislocations can propagate directly up from the interface. But in the regions over the SiO₂ stripes, the GaN is grown laterally from the window regions. For dislocations to be present in these area, they would most likely have to bend over from the window area. Therefore, the number of dislocations, and the EPD, is greatly reduced.

The new lasers with the record-setting lifetimes was fabricated from the low-defect material on the stripe. Nakamura told *Compound Semiconductor* that it is possible, depending on the growth technique used, that the center of the stripe, where two adjacent overgrowths meet, may contain increased defects or anti-phase domains. See Figure Three. Lasers fabricated from this region exhibited shorter lifetimes than those which were not centered on the SiO₂ stripes.

Figure Four shows the structure of the new laser diode, indicating both the MD-SLS cladding layer and the ELOG substrate. The laser cavity was formed within the SiO₂ stripe, parallel to the direction of the stripe. The mirror facets were formed by dry etching, similar to previous reports.

The area of the diode reported at ISCS was 4 μm x 550 μm, with a cavity length varying from 550 μm to 300 μm. For a 550 μm long device, Nakamura reported a threshold current of 90 mA, which corresponds to a threshold current density of 4 kA/cm², with an operating voltage of 4.6V. In comparison the operating voltages of laser diodes which used the same structure, but which had uniformly doped, not modulation-doped, strained layer superlattices, were around 6-7 V.

Thoughts on Quantum Dots

Earlier this year, a group of researchers at Kyoto University published an intriguing analysis of Nichia's laser diodes. They found that the InGaN active layers grew as two dimensional arrays of quantum dots, rather than homogeneous quantum well layers. (See box.) The quantum dots consist of indium-rich regions with typical dimensions of 3 nm. The dots made up only 2% of the active layer volume, yet they dominate the emission process because of their efficient trapping of excitons. The localization or trapping energy of the quantum dots is around 200 meV - more than enough to localize excitons at room temperature. The localization of excitons may cause the high quantum efficiency of InGaN-based emitters by inhibiting the movement of carriers to non-radiative recombination centers - which would help to explain why it is possible to obtain lasing action from heavily defective material.

We asked Nakamura about his opinions on this topic. "It's hard to reproduce the same TEM pictures as the Kyoto group" he said, "because In composition fluctuations differ from sample to sample. So, I'm not sure whether there is a quantum dot structure in our laser diode structure exactly. However, it is sure that there are deep localized energy states in the InGaN well layer where carrier recombination takes

place. Using EDX measurements, we estimated In-content of 17 % in the In-rich region and 12% in the In-poor region. However, this measurement can obtain relative In content, not absolute In content. Also, resolution is not enough to determine the exact In composition because the 3 nm dot is too small for the EDX measurement. If there would be deep localized energy states in the InGaN well layer where the carrier recombination takes place, the non-radiative recombination center caused by defects cannot work because injected electron and holes are captured at the deep localized states before they are captured at the defects centers."

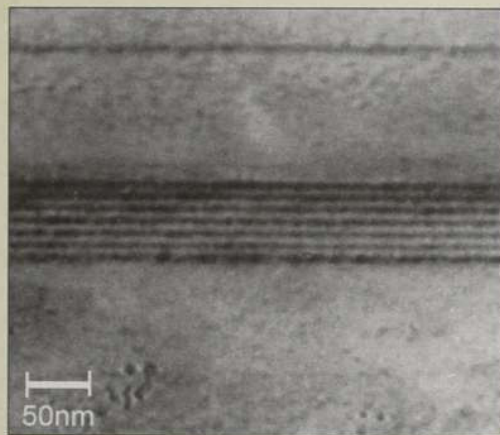
On September 10 Nichia announced in the Japanese press that they plan to begin sample shipments of a blue laser by the end of 1998. Japanese commentators are predicting that Nichia will monopolize this new market, due to their extensive patent portfolio. The company reportedly has around 500 active patent applications

Prototyping Plans

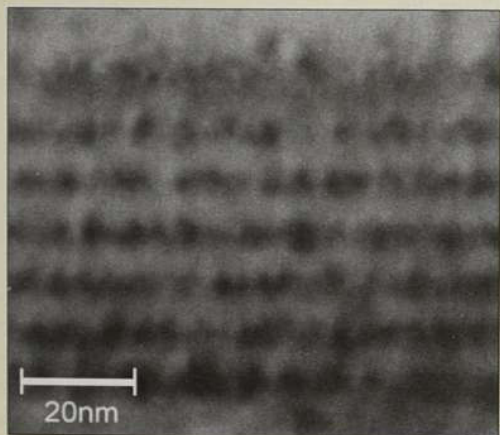
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Japanese commentators are predicting that Nichia will monopolize this new market, due to their extensive patent portfolio. The company reportedly has around 500 active patent applications, and Nichia has already received around 20 GaN-related patents.

A Nichia spokesperson indicated that the company plans to zealously guard its patent rights, and reports that the company is already involved in patent disputes with other companies that are manufacturing GaN-based LEDs.



Kyoto University



Kyoto University

The Quantum Dot Question

Medium (top) and high (bottom) TEM images of a Nichia laser diode structure. Analysis done at Kyoto University suggests that the InGaN active layers in these devices grow as two dimensional arrays of quantum dots or quantum-dot-like structures. EDX measurements have been used to estimate In-content of 17% in the In-rich region and 12% in the In-poor region.

According to Yoichi Kawakami of Kyoto University, "laser diode operation has been achieved from 380nm to 430nm in the Nichia samples. Quantum-dot-like structures have been observed in the diodes with longer wavelength (i.e. those with higher In content in the active layers), but not clearly in the diodes which emitted at 380-400nm. This indicates that the phase separation plays an important role for the self-formation of In-rich quantum dots, as can be expected from the thermodynamic calculation."



Akasaki to Receive Award

Isamu Akasaki, professor emeritus at Nagoya University has been named in the biannual Japanese government autumn honors list. He will be one of 29 people to receive the Medal with Purple Ribbon for their achievements in science, education and culture. Emperor Akihito will meet the recipients in November.

Akasaki is being honored for his contributions to semiconductor technology. He has been a pioneer in the GaN field since 1974, and he was instrumental in demonstrating techniques for activating p-type dopants in GaN and using buffer layers to improve GaN material quality.

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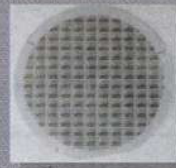
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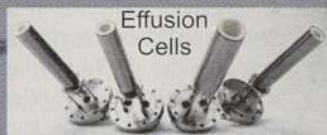
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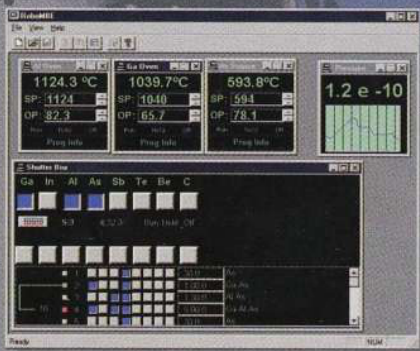
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Gallium Nitride Device Forecast: \$3 Billion by 2006

A new study predicts that GaN-based devices will comprise 20% of the total compound semiconductor market in 10 years

MARIE MEYER

A new era in the history of the compound semiconductor industry is about to begin. If the preceding article on blue lasers did not convince you of that, then consider the following: according to a new report recently released by market research firm Strategies Unlimited¹, the market for GaN-based semiconductors will reach \$3 billion by 2006. This means that sales of GaN devices - which were non-existent three years ago - should comprise 20% of the total compound semiconductor market within the next 10 years.

The current market for GaN devices is tiny. In fact, it is made up entirely of three companies (Nichia, Cree and Toyoda Gosei) selling blue and green LEDs². Strategies Unlimited calculates that the actual market for GaN devices was just \$77 million in 1996, and they estimate it will be \$143 million for 1997. In comparison, sales of other types of III-V devices - transistors, ICs and optoelectronic devices - will exceed \$6 billion in 1997.

But the Strategies Unlimited study forecasts a phenomenal 44% compound annual growth rate for the GaN sector, making it by far the fastest growing area of the compound semiconductor industry. Demand for blue

and green LEDs will drive the market for the next five years; however, shortwavelength laser diodes are expected to dominate demand after the turn of the century. Applications for GaN-based transistors should also emerge around the year 2000, but the study concludes that this will remain a small niche for the foreseeable future, comprising less than 5% of the total GaN device market.

Behind the Numbers

We recently had the opportunity to interview several of the staff members at Strategies Unlimited who participated in preparing the report. We asked them to share some of their insights with our readers.

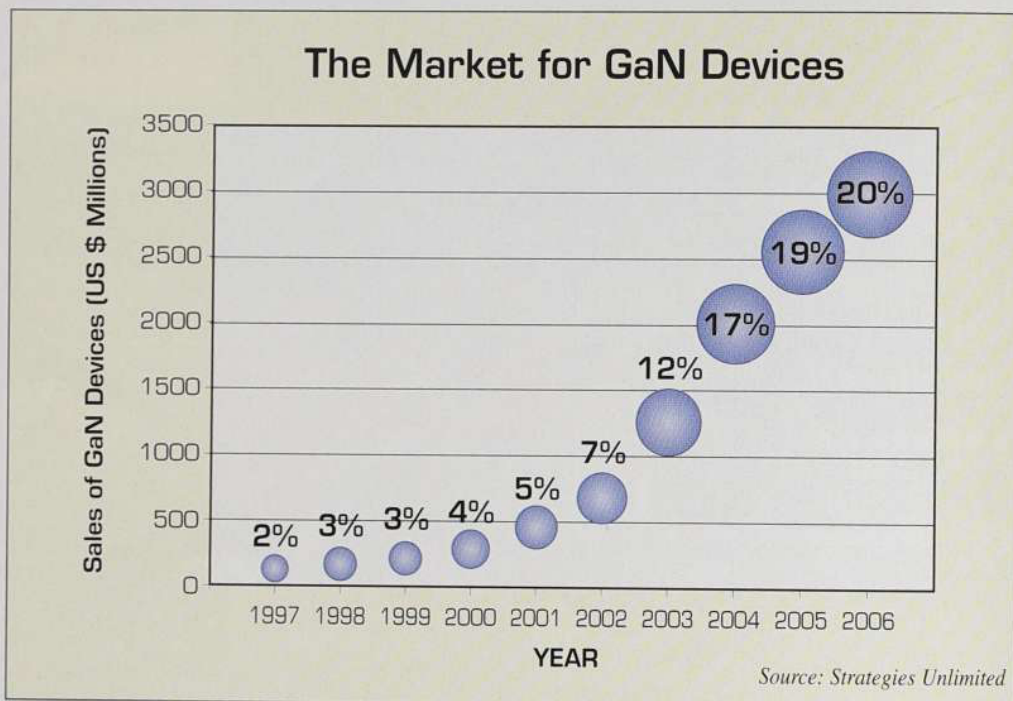
CS: You've been following the compound semiconductor industry for 15 years - can you put the recent activity in the GaN field into historical context?

SU: "We've certainly never seen this level of concentrated interest and effort before. But then again, the circumstances are different. There is a ready-made market out there just waiting for blue and green LEDs and blue laser diodes. This is something you didn't have with the first GaAs ICs and the first GaAs lasers - we really weren't sure what they were going to be used for. But the uses for the GaN opto products are so immediate and obvious, and the markets are so large, that they provide a great deal of inspiration and encouragement."

1 "Gallium Nitride - 1997: Technology Status and Applications Analysis". 169 pages, covering the market forecast for 1997-2006; R&D issues and technology developments; market applications analysis; and profiles of major industrial suppliers, university research centers, and government agencies funding GaN programs. \$1,950.

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Email info@strategies-u.com, or
Internet home page <http://www.strategies-u.com>.

2 In our last issue, we reported on Hewlett-Packard's entrance into this market. (See CS 3(5), p. 8). However, as they will not begin volume production until late 1997 at the earliest, their impact will not be felt until 1998 or later.



The 10-year forecast for GaN-based devices, according to a new report recently released by Strategies Unlimited. (See Footnote 1) The position of the each marker indicates the forecasted annual value of shipments (left hand axis). The size (diameter) of each marker represents the size of the GaN market as a percentage of total compound semiconductor sales.

EPI

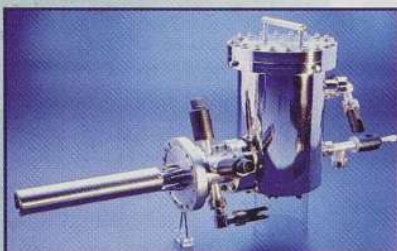
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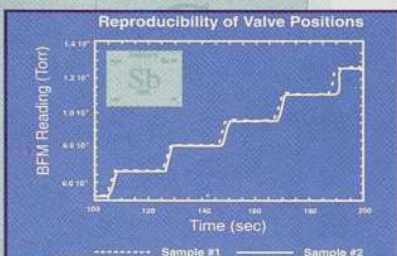
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CS: Hewlett-Packard is a giant in the LED business, but they were a relatively late entrant to the GaN field. Nevertheless, they plan to become the leading supplier of blue and green LEDs. Can they pull it off?

SU: "In the last issue of your magazine, you quoted them as saying 'we fully expect to surpass everyone else on the market by the end of the century'. (CS 3(5) p. 8) Usually, we'd advise that such statements should be taken with a grain of salt. But in the case of HP, with their already substantial position in the LED business, their excellent R&D resources, their high-volume LED manufacturing capability, and their very deep pockets, it tends to have a lot more credibility. We certainly do expect to see them at or near the top of the GaN LED sector."

CS: Besides Nichia, which Japanese companies have the potential to become players in the nitride-based LED and/or laser market?

SU: "There are any number of companies that could become the second major player in Japan - it seems that every optoelectronics manufacturer has a GaN development program underway. You certainly have to take note of Toshiba and Fujitsu, as they have both reported a working laser. And of course Toyoda Gosei is already shipping GaN/InGaN blue and green LEDs - but they are not really thought of as a major opto company."

On the whole, we would say that it is still too early to say that any of the them are pulling away from the rest of the pack, much less closing on Nichia."

CS: Which substrate option looks best? Sapphire or SiC?

SU: "Actually, we disagree a bit among ourselves on this question - which probably makes us representative of the industry as whole!"

We estimate that SiC is currently 10 times more expensive than sapphire. Price is a crucial issue in the LED business, so we predict a continuing preference for sapphire there. And some of us think that sapphire will also dominate the laser business as well. But others hold out the possibility that SiC will find a major

role in the laser business as well. We are unconvinced that SiC will produce better devices, but it does allow the use of a process which is more similar to that used for GaAs- or InP-based diodes.³ For some laser companies, that extra level of process similarity may be determinative in SiC's favor."

CS: If you had to single out one technical issue that needs to be addressed in the laser field, what would it be?

SU: "Material quality. There are some processing issues that need to be solved, but most of the problems in this area seem to be well in hand. But until the material quality can be improved, the yields will be too low to allow economical fabrication of even small batches of lasers."

"The next most important thing for the GaN sector is the emergence of additional sources of supply...the OEM manufacturers won't put a blue-laser optical data storage system into production until they know they have a second and even a third source they can rely on."

CS: Three questions about "white light" LEDs: When will the market emerge? Can they successfully challenge incandescent light bulbs? And what will be the preferred technology for making them?

SU: "Nichia is already shipping white light LEDs⁴, and Siemens should begin very soon, using Cree LED chips. It should be a nice, steady growth niche, but we don't really see them challenging incandescents in the broader market, because they will continue to be more expensive. So they really make sense only in applications where the cost of replacing a burnt-out bulb is high - like cars, and airplane interiors."

As for the preferred technology: without a doubt, we think that color conversion - the use of a phosphor or dye inside the package - is the winner. This is the technique which both Nichia and Siemens are using. The alternative - to combine red, green and blue LED chips in a single package - is just too hard to do, because it is difficult to get the right balance among the colors. Also, it is expensive. The "3-chip" approach will remain popular in situations where you want a pixel that can deliver white and multiple colors; but when you want

just white like, color conversion is the more economical way to go."

CS: When will the first GaN-based transistors hit the market?

SU: "Probably around 2000. We see this area as a very small piece of the pie. There are still a lot of technical problems to overcome, and, possibly worse yet, you just don't see that really compelling use or the "killer app" that you see for lasers and LEDs."

CS: What are the driving forces that will determine the future of GaN semiconductors?

SU: "Putting aside the obvious technical issues that still need to be grappled with, the next most important thing for the GaN sector is the emergence of additional sources of supply. This is especially true in the laser field. Nichia is miles ahead of everyone else - but even they would probably acknowledge that they can't have the market all to themselves. The OEM manufacturers won't put a blue-laser optical data storage system into production until they know they have a second and even a third source they can rely on."

CS: This past year has seen some historic events - the first CW blue laser, the first GaN laser on a SiC substrate, the first white light LEDs in production, and, most recently, Nichia's announcement that they had a laser which passed the 10,000 hour milestone. Where do you think we are in the "race" to develop the nitride materials? To borrow Winston Churchill's phraseology, are we at the end of the beginning? Or will we look back to 1997 as the beginning of the end?

SU: "The development phase is certainly proceeding much, much faster than probably anyone anticipated. And much of that is directly attributable to the phenomenal individual contributions of Shuji Nakamura. The 10,000 hour lifetime milestone is particularly significant, because once it was reached, Nichia can, and apparently did, begin making plans for delivering prototypes to potential OEM customers. So in some respects, perhaps we are near the beginning of the end of the developmental phase."

But in broader terms, the current activity is just the tip of the iceberg. The GaN material system is on its way to joining GaAs and InP as one of the mainstays of the compound semiconductor industry."

³ Because it can be cleaved, and because it allows use of top and bottom electrical contacts. Sapphire, on the other hand, must be etched, and requires the use of two topside contacts, because it is an insulator. SiC also offers the additional benefit of better thermal characteristics.

⁴ See "White Light Burning Bright at Familiar Site", CS 2(6), p. 14.

Welcome to the Club

Two U.S. research groups are the latest to demonstrate a blue laser

Researchers from the University of California Santa Barbara (UCSB) and the Xerox Palo Alto Research Center (PARC) have become the latest to report the successful fabrication of a blue laser diode operating in pulsed mode at room temperature. Thus they enter the ranks of the elite blue laser club, joining Nichia, Toshiba, Cree Research (aided by Brown University and NCSU), and Fujitsu.

UCSB Results

The UCSB group made their announcement in mid-September. Credit for the work was given to two graduate students, Michael Mack and Amber Abare, who are advised by Steven DenBaars and Larry Coldren.

The laser is shown in Figure One. Sharp lasing spectra at 420 nm, peak output powers up to 17 mW, and a narrow coherent output beam

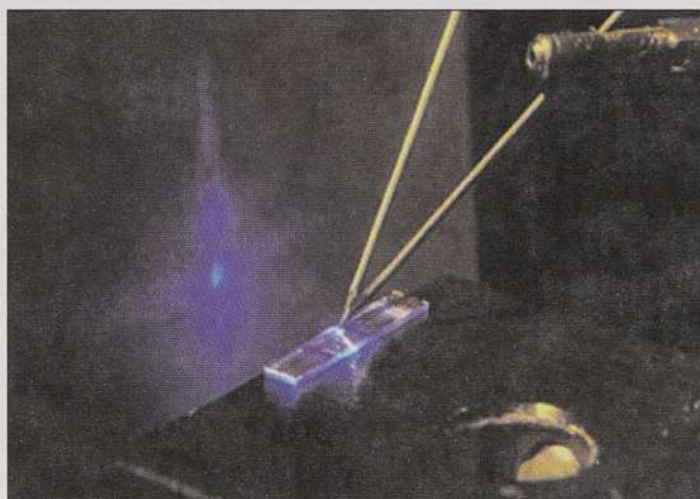


Figure One. The UCSB laser. Shown in this figure is the elliptical far field pattern created when the coherent blue laser beam strikes a sheet of paper held 1cm away. The 20x400 micron blue laser bar is contacted by the two probes to the n and p-type metal contacts.

were observed from the InGaN/GaN MQW structure, which was grown on sapphire by MOCVD. A typical light vs. current (LI) curve for the UCSB structure is shown in Figure Two. The lowest threshold current density observed was 12.7 kA/cm² for a 10x1200 µm laser bar with uncoated facets at room temperature.

Commenting on their achievement, Coldren said "except for the seminal work of Nichia Chemical, ours is clearly one of the best results in the world." DenBaars added "no one else, except Nichia, has reported threshold current densities as low as ours".

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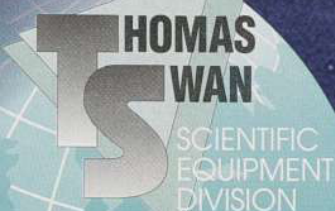
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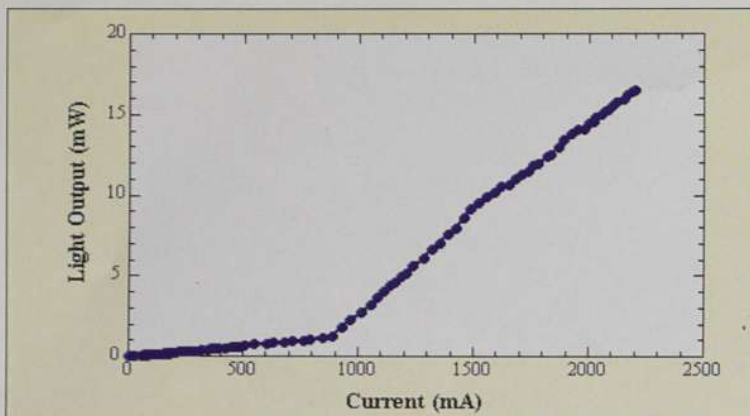


Figure Two. Typical light vs. current (LI) curve for the UCSB laser. The lowest threshold current density observed was 12.7 kA/cm² for a 10x1200 micron laser bar with uncoated facets at room temperature.

The UCSB team has been working on GaN materials since early 1994, and they began work on blue lasers in 1995. According to DenBaars, "the team effort of several other groups at UCSB, including those led by Professors Mishra, Hu, and Speck, played a key role in achieving the laser". He sites as particularly important the achievement of good p-GaN materials and NiAu p-contacts which was done by Peter Kozodoy of Professor Mishra's group. "Also, growing a lot of GaN crystals by MOCVD and improving the efficiency of InGaN MQW active region enabled lasing", he added.

When asked what would be done next to achieve a CW laser, DenBaars said "The next step is to reduce threshold voltage by improving the p-contact and p-layer resistance. Also, epitaxial lateral overgrowth such as that reported recently by Nichia (see page 4) looks like a promising way to reduce the defect density and increase lifetime."



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Xerox's Unique Application Focus

Xerox made their announcement on October 27. The company brings a unique perspective to the club, as they are interested in blue lasers not for data storage, but printing applications. The company described the breakthrough as "a pivotal step in next-generation laser printing technology".

"Having invented the 1st high-speed laser printer at PARC some 20 years ago, this breakthrough reinforces Xerox's leadership position in the field of laser document production and places us well ahead of our competitors," said Mark B. Myers, Xerox senior vice president for Corporate Research and Technology (CR&T). "While we still have much work ahead of us, this is a significant step towards realizing our goal of using this technology in Xerox printers and digital copiers."

Due to its shorter wavelength, the spot diameter of a blue laser is half that of an infrared laser. Xerox officials say this is a particularly critical factor for color laser printing, where accurate spot placement and size control are necessary for higher quality images. They claim that "magnitudes greater performance will be realized when Xerox's blue laser technology is advanced to the point of custom laser arrays for document products".

According to David Bour, a principal scientist at the Electronic Materials Laboratory at Xerox PARC, the diodes were fabricated from a 10 quantum well GaN/InGaN/AlGaIn structure grown on c-face sapphire by MOCVD. The mirrors were fabricated by chemically assisted ion beam etching (CAIBE), which is unique - previous results have focused on reactive ion etching (RIE). Lasing at wavelengths from 422 to 432 nm was obtained under pulsed current-injection conditions. Both spectral line narrowing and a far-field interference pattern were observed. The threshold current density was 25 kA/cm², and the beam was TE polarized. Lasing was demonstrated in a series of test diodes with metal stripes from 4 to 20 microns wide and cavity lengths ranging from 300 to 1000 microns. The output power was greater than 10 mW.

The work at Xerox PARC was partially supported by the two U.S. government agencies. Xerox is teamed with SDL to develop multi-wavelength laser arrays at visible wavelengths as part of a Department of Commerce Advanced Technology Program (ATP). In addition, Xerox and SDL, along with Hewlett Packard and five universities (Boston, MIT, New Mexico, Texas, and Utah) are part of the Blue BAND II Consortium, which is funded by DARPA for the development of commercially-viable single-mode, ridge-waveguide laser diodes and VCSEL diodes.

This achievement marks the culmination of over 2 years of intense research," said Noble Johnson, a PARC principal scientist. "We can now begin the exciting task of fine-tuning the performance of these devices for their intended commercial applications."



Figure Three. The latest blue laser. Xerox is unique in that it hopes to develop blue lasers for printing applications.

Briefly...

Philips Bows Out of Race - Plans on Buying, not Making, Blue Lasers

Philips Electronics - a pioneer in the field of optical data storage - has decided to withdraw from the blue laser race. The company has terminated the GaN and ZnSe research effort at Philips Research in Briarcliff Manor, NY as a result. Of the 20 or so people who worked on the project, half have been laid off and the rest reassigned.

A company spokesperson said this development was the result of a "make-or-buy" decision, and Philips has decided they would prefer to look for a supplier of blue laser diodes rather than make the "substantial investments" in R&D that would be required to develop the capability in house.

Stanford Spin-Off & Matsushita to Explore New GaN Substrate Options

Matsushita Electronics says that it has signed an agreement with a California-based venture CBL under which the companies will jointly develop a blue-light laser. CBL, which is located in Redwood City, CA, was recently founded by researchers from Stanford University to develop new large-diameter low-defect substrates for the growth of GaN and related materials. The substrates will be fabricated using what is described as "technology related to HVPE".

Matsushita hopes to commercialize a blue-light laser for next-generation DVD drives by 1999. CBL also plans to explore applications in high temperature power electronics.

Setting the Record Straight on Sony

A Japanese news service is reporting that Sony has developed a ZnSe blue-green laser has a lifetime of over 1,000 hours. Unfortunately this story, which has been widely circulated on the Internet, is not true. Apparently the misunderstanding sprang from a recent presentation wherein a Sony researcher reported on the lifetime of a ZnSe LED which, when driven at current density 2 ~ 3 times higher than that for a laser diode, exhibited a half-decay-time of ~10 hours at 80°C. He concluded that this result *might* correspond to laser diodes with a lifetime longer than 1000 hours - but these devices haven't been demonstrated yet. Sony's best lifetime for a ZnSe diode is still 101 hours.

Setting the record straight, a Sony spokesperson said "laser diode realization is a two-step process. The first is to establish the basic stability of the material and the second is to make the best of the stability to achieve a long lifetime. For Sony, the first step has been done, and we are now currently at work on the second step — achieving the long lifetime."

Japanese White Light LED Program

Japan's MITI is planning to launch a program in fiscal 1998 to develop white light LEDs using color conversion. The goal is to develop by 2005 an energy-efficient UV LED encapsulated in a fluorescent tube to emit white light. It is hoped that the end product will consume 1/8 the power of an incandescent lamp and half that of a fluorescent lamp. It should also have 50-100 times the life of the conventional fluorescent lamp. The program participants will include universities, electronics companies and chip makers. MITI will provide ¥5 billion (\$43.4 million) in funding over five years.

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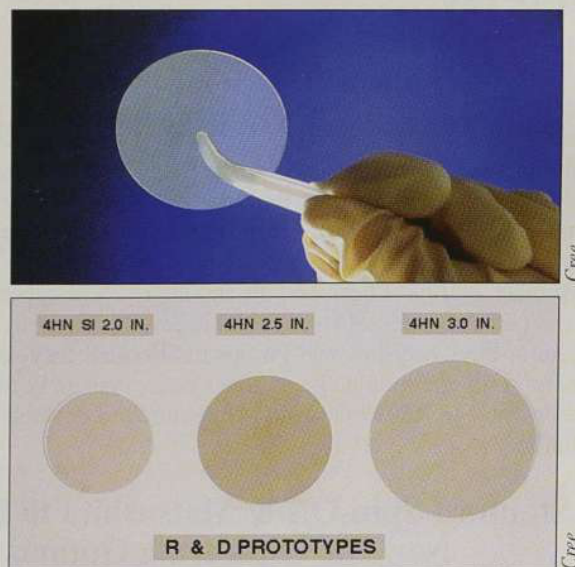
A Group of Chemical and Pharmaceutical Companies

2" SiC Wafers Now Available

In August Cree Research announced that its 6H n-type on-axis and 4H n-type 8 degree off-axis research grade SiC wafers are now available in 2" diameters, in limited quantities. Cree says the majority of their wafer sales will continue to be 1.375" diameter material for the time being, but it hopes that, over time, it can transition all wafer sales to the new 2" material. Cree also made its first public demonstration of a 3" 4H SiC wafer in August at the International Conference on SiC, III-Nitrides and Related Materials in Stockholm, Sweden.

Company officials say this development marks a key milestone in the evolution of SiC as a commercially significant semiconductor material. "These larger diameters definitely put SiC on track for the commercialization of more complex semiconductor devices such as microwave and power transistors," commented Dr. Calvin Carter, co-founder of Cree and Director of Materials Technology.

"DARPA is very pleased that Cree is now selling two-inch SiC wafers. This is crucial for further device development. The 3" demonstration is especially critical for the development of SiC power semiconductor devices. The power area represents a tremendous market opportunity for SiC semiconductors and the larger diameter wafers can make these devices a reality," remarked Dr. Jane Alexander, Deputy Director of DARPA's Defense Sciences Office. DARPA has funded a portion of the companies research aimed at producing larger wafer diameters.



Examples of Cree's new 2" SiC substrates (top) which are now available in limited quantities, plus some samples of larger diameter substrates (bottom) which are in development.

APA Optics Reports on GaN Electronics

At this year's IEDM (International Electron Devices Meeting), which will be held December 7-10 in Washington DC, APA Optics will present three papers describing recent work in the field of GaN-based electronic devices.

The first of the papers, which is a collaboration with the University of Illinois, is entitled "DC and RF performance of High Current AlGaIn/GaN Heterostructure FETs Grown on p-type SiC Substrates". It reports on a sub-micron gate length AlGaIn/GaN HFETs grown by MOCVD on SiC and demonstrated improved DC and RF properties over comparable devices made on sapphire. It also describes other improvements in device performance and concludes that even better results should be possible when semi-insulating SiC substrates become available.

The second paper is a collaboration between APA Optics and Michael Shur of Rensselaer Polytechnic Institute. Entitled "Novel High Power AlGaIn/GaN HFETs on SiC Substrates", it reports on comparative studies of DC performance of AlGaIn/GaN HFETs grown on sapphire and conducting SiC substrates. These devices yielded DC powers of up to 0.8 W cm², some of the highest reported for wide bandgap semiconductor FETs. Sapphire-based devices, however, are judged to be inferior because of larger self-heating effects. The workers estimate that the AlGaIn/GaN HFETs on SiC substrates should yield a microwave power of some 30 times that of state-of-the-art GaAs power FETs. These should also make better power switches than FETs made only from SiC because of the enhanced 2DEG and higher breakdown voltage in GaN.

The third paper is entitled "Low Frequency Noise in GaN pn Junction Photodetectors". It is the result of a joint effort with Texas Tech University. The paper describes fabrication and low frequency noise characterization of GaN-based solar blind UV photodetectors with very low dark currents, based on sapphire substrates.

ABB and TMA To Develop SiC IC Design Tools

Sweden's ABB Group and Technology Modeling Associates, Inc. have agreed to jointly develop simulation capabilities for integrated circuit fabrication processes associated with SiC power device technologies. Specific capabilities to be created include implementing a new implant model using Monte Carlo techniques for SiC in TMA's process simulator.

"This is a significant partnership for us," said TMA President and CEO Roy E. Jewell. "Only through working closely with a leader in power device design and manufacturing such as ABB can the development of TCAD products appropriate for emerging semiconductor technologies like SiC be expedited." This contract is said to follow an earlier partnership between ABB and TMA that yielded software capabilities for simulating the electrical performance of SiC power devices.

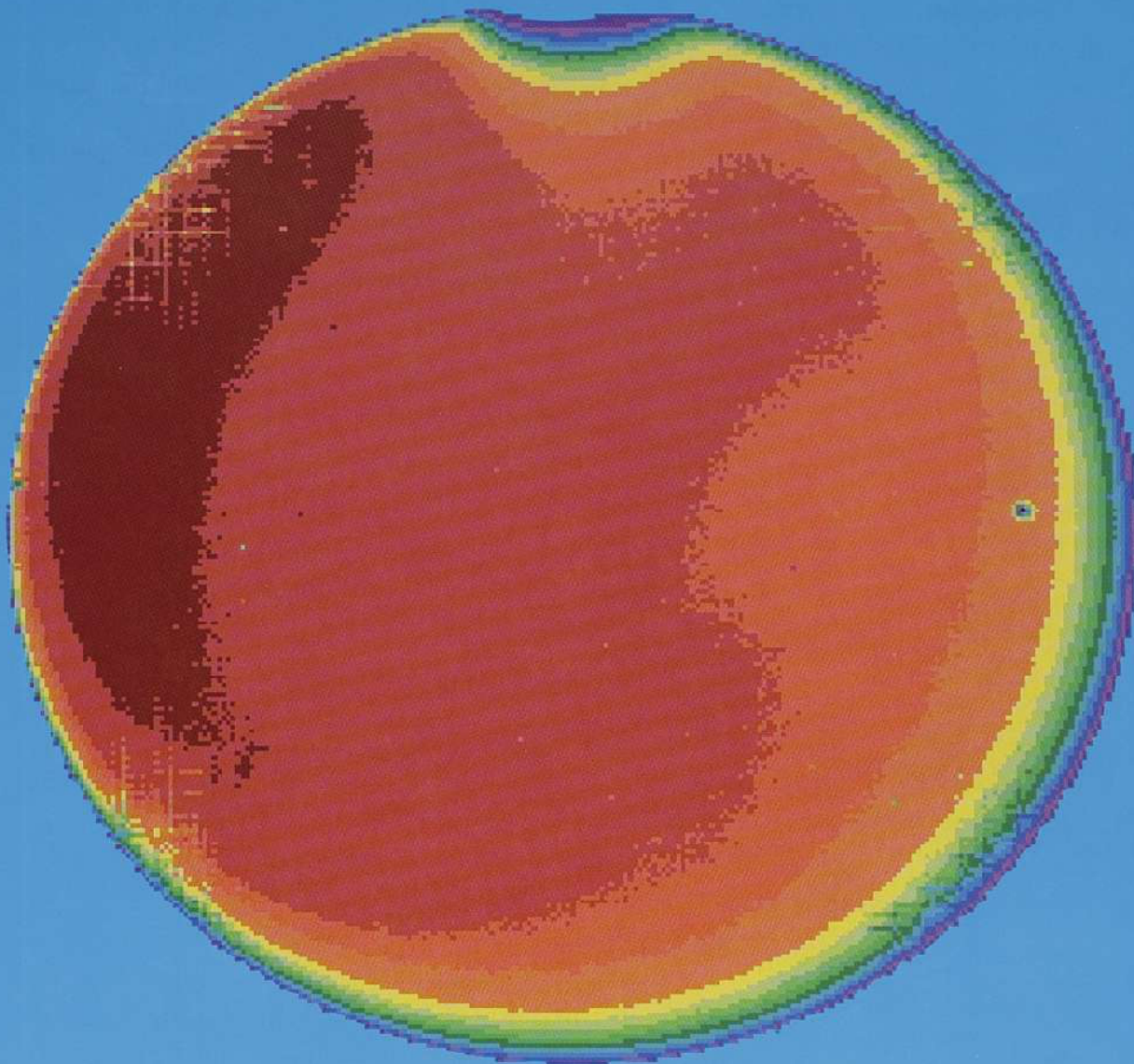
Special Issue on SiC Electronic Devices

A Call for Papers has been issued for a Special Issue of the IEEE Transactions on Electron Devices entitled 'Silicon Carbide Electronic Devices'.

The goal of this special issue is to survey recent device development activities in the wide bandgap semiconductor SiC, to highlight current problems, and to consider innovative new directions for future device research in this material. Topics include development of fabrication technology for devices, theoretical analyses and predictions of performance, characterization techniques, measurement of fundamental parameters relevant to devices, experimental device results, and innovative device concepts.

The manuscript submission deadline is 1 May 1998, and the scheduled publication date is March 1999. Interested parties should contact James A. Cooper, Jr. at Purdue University, Tel +1 765 494 3514; Fax +1 765 494 6441; E-mail: cooperj@ecn.purdue.edu

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NEWS FROM JAPAN

GaAs News

Conversion to 4" GaAs at NJR to Triple Production

New Japan Radio intends to more than triple its GaAs IC output capacity to 3 million units per month by June 1998. The company will invest nearly ¥1.5 billion (\$12.3 million) to install a new 4" wafer line at its Kawagoe plant and at the same time upgrade the existing 3" line to 4". Once both 4" wafer lines are fully operational, the company expects GaAs IC sales will expand from an estimated ¥700 million (\$5.7 million) in fiscal 1997 to ¥3 billion (\$24.6 million) in fiscal 1998.

More GaAs from Oki

Oki Electric plans to expand microwave device output by 30% by Spring 1998. The company says it is responding to "firm domestic demand and rising demand in the overseas market". The company mainly commercializes microwave devices for use in optical and mobile communications equipment and intends to boost output from the current 2.3 million units to 3 million units monthly by spring 1998. A further increase to 6 million units by the second half of 1998 is also being considered. The company has a current monthly capacity of 1,500 3" wafers at its Hachioji plant.

Oki also says it will begin to sample a converter-free single-voltage FET for use in GSM digital cellular handsets in the U.S. in January 1998 and increase MMIC production from the current 10% to 30% of total production in fiscal 1998.

NEC to Boost MMIC Production

In late September NEC announced that it is planning to increase its MMIC business. The company says that in a response to growing demand from cellular phone and other mobile communications applications, it will raise MMIC production from the current 2-3 million units per month to 4-5 million in early fiscal 1998. NEC Yamagata, Kyushu Densi and Chuo Electronics, which assemble MMICs for NEC, will raise their output capacities by about 30% toward 1998. The company says that it will also diversify its MMIC product line, aiming for a 30% share of the market.

HBTs from Mitsubishi

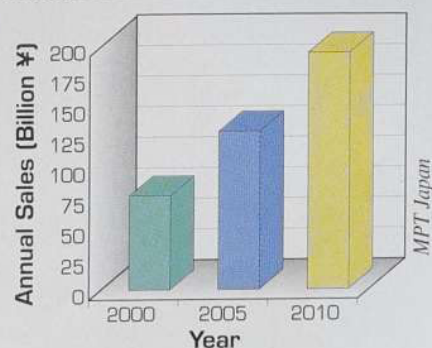
Mitsubishi Electric has developed an AlGaAs/GaAs HBT two-step amp module which operates on 3.4V. Designed for use in GSM-IV system cellular phones at 900MHz, the module generates 2.8W. The sample price is set at ¥1,000 (\$8.20). Sample shipment is slated for the first quarter of 1998.

MPT Allocates Use of Automotive Radar Band

Japan's Ministry of Posts and Telephones (MPT) has decided to allocate the 76 GHz band for small-output millimeterwave applications such as automotive collision prevention radars. Japan's auto makers are already developing products which use the 60 GHz band, and the ministry has decided to add another bandwidth to avoid radar interference. This decision will help Japanese companies find export markets for their products, as the 77 GHz band has been picked for automotive applications in many other regions, including the US and Europe.

MPT predicts that the millimeterwave radar market will reach ¥193.8 billion (\$1.69 billion) in 2010.

Forecasted Automotive-Use Millimeter Wave Radar in Japan



Asahi Chemical to Increase Hall Element Production

The Asahi Chemical Industry Group will expand its Hall element production capacity by 50% to 1.5 billion units per year by 2000. The company will invest some 5 billion yen (\$43.4 million) in their Nobeoka plant to increase its annual capacity to 1.1 billion units next year, with further increases scheduled in 1999.

A wholly owned subsidiary of Asahi Kasei, Asahi Kasei Electronics controls more than a 70% share of the world's Hall element market. The majority of their production is based on polycrystalline InSb films on mica substrates. However, the company also produces some higher performance models based on Si-doped InAs/GaAs and InAs MQW structures (CS 2(5), p. 38). Asahi Chemical hopes to increase sales by 50% to ¥15 billion (\$127.1 million) per year by the turn of the century.

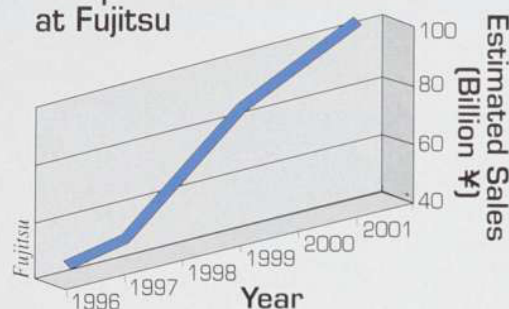
Fujitsu Sets ¥100 Billion Target for Compound Semiconductor Sales

As part of its previously announced reorganization, Fujitsu announced in early October that it has completed the consolidation of its III-V operations into Fujitsu Quantum Devices (FQD), a production subsidiary in Yamanshi Prefecture which is dedicated to compound semiconductors. FQD produces RF and microwave devices, as well as digital GaAs ICs and optoelectronic devices. As part of the move, FQD has set up an R&D center in Atsugi and sales offices in Shinjuku, Osaka and Nagoya.

FQD claims to be the world leader in market share in the compound semiconductor industry. They also claim to operate the world's largest GaAs fab.

The company, which will increase its capitalization from the current ¥1,740 million (\$14.4 million) to ¥4,490 million (\$37.1 million) in January 1998, now employs 1,200 people. FQD plans to achieve compound semiconductor sales of ¥50 billion (\$413.2 million) in fiscal 1997 and ¥100 billion (\$826.4 million) in fiscal 2001.

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EpiWafer News

Sumitomo Chemical to Enter EpiWafer Business

Sumitomo Chemical says it will enter the compound semiconductor epitaxial wafer market. The company has set up a MOCVD line at its Tsukuba research laboratory with the capacity for up to 2,000 4" wafers per month. According to a company press release, the product offerings will include structures which employ an oxygen-containing buffer layer to improve insulating characteristics. The structure is said to be conducive to reducing current leakage between devices even when high voltage is applied.

Plans call for starting production on three lines at the lab and investing ¥200-300 million (\$1.7-2.5 million) to set up a new line in April 1998 to increase output capacity to 4,000-5,000 wafers monthly. Output will be raised to 6,000 wafers per month by 2000. Sumitomo Chemical - a separate company from Sumitomo Electric, which is already active in the epiwafer field - is aiming to achieve ¥1 billion (\$8.5 million) in sales the first year and ¥5 billion (\$42.4 million) five years from now.

Dowa Mining Expanding LED EpiWafer Business

Dowa Mining has announced plans to strengthen its compound semiconductor business. The company says it has developed an AlGaAs epitaxial wafer for the production of LEDs with a brightness of 53mcd. The company plans to double its epitaxial wafer production by the end of fiscal 1997. Dowa Mining, which offers InP wafers and wireless data transmission infrared LEDs as well as visible LED products, aims to increase compound semiconductor-related sales to ¥5 billion (\$42.4 million) in 2-3 years.

Expansion at Mitsubishi Chemical

Mitsubishi Chemical will step up its drive to expand its compound semiconductor business. Claiming an already a high share in the VPE GaAs epitaxial wafer market, the company plans to set up a technology development center at its Tsukuba plant to beef up R&D for epitaxial wafers for use in high-power laser diodes.

With compound semiconductor sales approaching ¥10 billion (\$82.0 million), Mitsubishi intends to launch VGF GaAs wafer production aiming to raise sales to ¥20 billion (\$163.9 million) within four to five years.

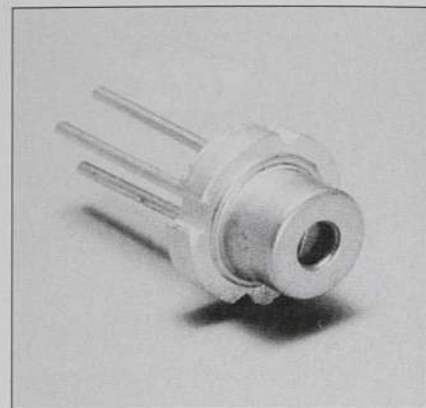
Lasers and Other Optoelectronics

More on Mitsubishi CD & DVD Lasers

Mitsubishi Electric recently announced the expansion of its CD-R (CD recordable) drive semiconductor laser production to 100,000 units monthly. The 780nm device provides an output of 30mW. The company plans to increase production to 200,000 units per month next summer. Mitsubishi has installed a 3" GaAs line at its Itami plant for use on this project.

As we reported in our last issue (*CS* 3(5), p. 24), Mitsubishi also recently announced plans to begin mass-production of DVD-RAM lasers. Two 650nm lasers will be offered, with an output of 30mW and operating lifetimes over 10,000 hours at 60°C. The lasers are sample-priced at ¥5,000 (\$44.25), and will cost below ¥1,000 (\$8.85) in the second half of 1998,

when full scale production is at its peak. The company will initially produce 10,000 units per month and boost output to 200,000 units a month in August 1998, aiming to grab a 50% share of the market by 2000.



Mitsubishi

NEC Stakes a Claim in the DVD Laser Area

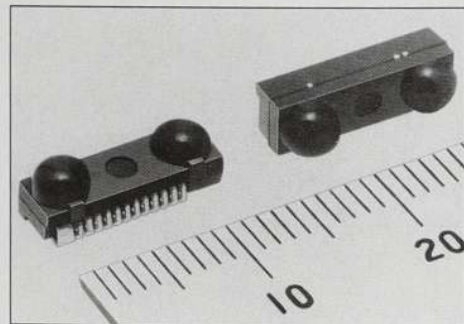
NEC has announced plans to bolster its optical storage semiconductor laser business. The company, which produces red-light semiconductor lasers for DVD-ROM and other applications at 300,000 units per month, plans by year end to launch volume production of a high-output laser for DVD-RAM use. Plans call for raising the combined production capacity to 1 million units per month. Anticipating that demand for DVD-related semiconductor lasers will reach several million units per month by 2000, the company is aiming for a 30% share of the market. NEC is currently converting its process from 2" to 3" in anticipation of increased demand.

In related news, in mid-October NEC said it has developed a high-power laser diode for PC DVD-RAM drives. The device can achieve a stable output of 30mW at 70°C and has an estimated lifetime of 8,000 hours or more. The company says it has optimized the number and the thickness of the wells in a strained MQW structure in order to control drive current at high temperature, as well as making a steep distribution of dopant density in the cladding layers to reduce ineffective current.

Rohm IR Module

A new high-speed IR data transmission module has been added to ROHM's product line. It provides data transmit and receive functions at 1.152 to 4 Mb/s for equipment such as notebook computers and digital still cameras.

The module complies with IrDA Ver.1.1FIR standards. Sample shipments are underway at a unit price of ¥600 (\$4.79). Mass production is planned for December, and will begin at an initial rate of 100,000 units/month and then increase to 500,000 units in six months time.



Rohm

Hewlett-Packard Japan Steps Up IrDA Production

Hewlett-Packard Japan will bolster infrared communications device sales. The company will sample-ship the industry's first surface-mount IrDA1.1 standard-compliant module which incorporates its proprietary technologies for coping with electromagnetic interference (EMI) problems. The module has its photo detector/receiver unit wrapped with a metal shield, a structure conducive to enabling portable device makers to lower their effort to deal with EMI issues. The company will manufacture the modules in Singapore and began shipping samples in August.

Research News

A joint team consisting of researchers from Sony and the Agency of Industrial Science and Technology's Electrotechnical Laboratory has confirmed the **operation of a resonance tunnel diode at room temperature**. The diode, which is an ultra-small, ultra-fast semiconductor device, is made from a InAs/AlSb heterostructure. In theory, the 20nm-diameter device operates at 100GHz, 10-100 times the speed of existing fast devices, and consumes 1/20 the power. Although the group has yet to integrate the device into a circuit, the recent achievement is expected to pave the way for implementation of devices for supercomputers and communications equipment. The research is part of MITI's Quantum Functional Devices project.

The light generation and transmission technology group of the Femto Second Technology Project of Tsukuba has developed a **light source capable of generating ultra-short pulses** for use in large-capacity optical transmission. The system consists of a semiconductor laser made of InGaAsP and an optical fiber and can gener-

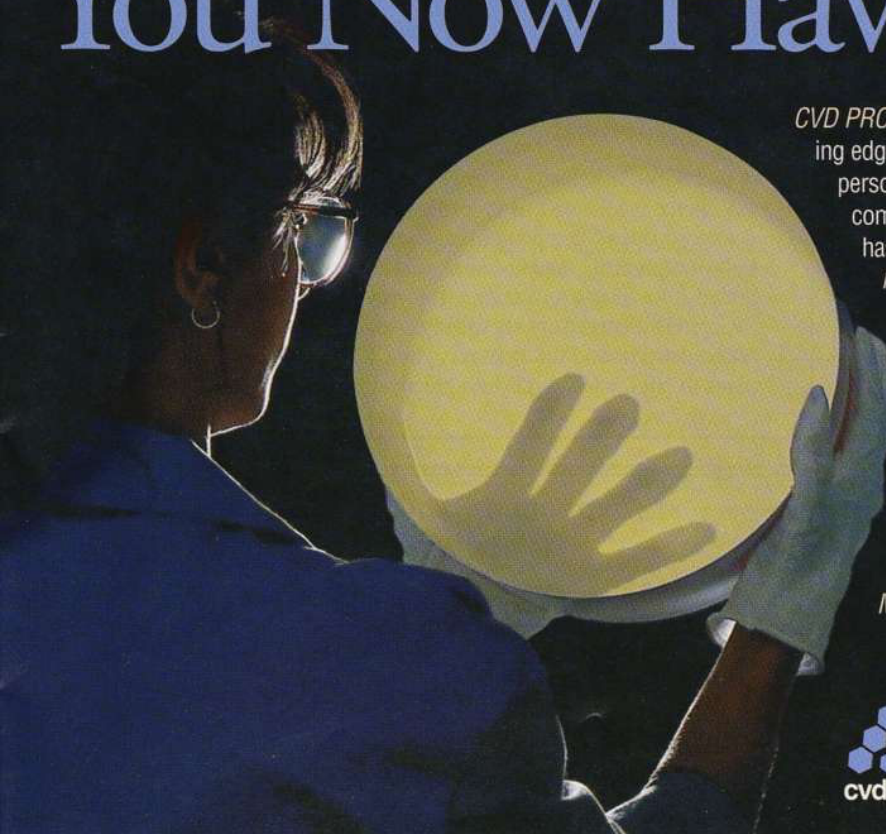
ate 200 billion pulses per second. As pulsed light transmitted from the light source passes through the optical fiber, the system creates ultra-short pulses by using difference in speed of the passing light which differs depending on wavelengths. In an experiment, the group succeeded in generating 98-196GHz pulses with an output of 5mW through 1.5-micron light. The optical control and distribution technology group of the project has developed an InP-based optical switch achieving a switching speed of 880 femtoseconds with 1.5-micron ultraviolet light.

The Electrotechnical Laboratory (ETL) and Hamamatsu Photonics report that they have jointly developed a **technique to display the flow of electrons inside a quantum well**. It uses a semiconductor laser to generate excitons (electron-hole pairs) in a quantum well structure. Since the emitting image moves along the flow of electrons, the flow can be visualized by taking a picture of it with an ultra-high speed camera capable of taking a picture every 90ps.

The Joint Research Center for Atom Technology (JRCAT) has discovered a **magnetic resistant effect in a GaAs-containing superlattice**. The experimental sample consists of a three-layered superlattice which employs a non-magnetic epitaxial GaAs buffer layer between ferromagnetic metal layers made of manganese and gallium. The GaAs layer was grown by MBE using low temperature growth (~230°C) to prevent manganese from being diffused into the GaAs layer. JRCAT explains that the new effect is being studied for possible non-volatile memory and magnetic transistor applications.

The Japan Atomic Energy Research Institute has developed a **high intensity, short pulse green solid state laser**. The device achieves a pulse energy of 0.62J, an average output of 105W and an oscillation efficiency of 2.0% by repeating emission 170 times per second. The neodymium-doped YAG laser is pumped with an AlGaAs laser diode. The institute plans to use the laser as a light source for an ultra-high intensity laser known as the T cube laser with a peak output of 1 terawatts.

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The National Institute for Research in Inorganic Materials will in fiscal 1998 launch a second phase of the COE (center of excellence) project with a plan to develop **technology to enable practical use of diamond semiconductors**. Through the first phase of the project, which was launched in fiscal 1993 and will be completed this fiscal year, the institute has synthesized a negative diamond semiconductor. It plans to form p-n junction film and research into emission from diamond outside the range of ultraviolet rays in the second phase.

Sanyo Electric reports that it has prototyped a **light emitting device which uses organic electroluminescence (EL)** to continuously emit light for more than 20,000 hours. Based on the company's proprietary material, the EL device emits yellow light with an initial brightness of 130 cd per sq. meter. It also achieves an initial light emitting efficiency of 8.6 lm/W.

The Hokkaido National Industrial Research Institute, a MITI organization, reports an **unusual method for fabricating optoelectronic materials**. The materials were synthesized in a fine-gravity environment, which was achieved in 1.2 seconds by being dropped from a 10 meter high tower. The report claims an "optical semiconductor having 40% higher infrared light absorption than a typical material, and which may be applied to infrared reception and optical sensors". MITI hopes to demonstrate that a drop tower facility can be used in the industrial production of electronic materials.

The National Institute for Advanced Interdisciplinary Research (NAIA) of the Agency of Industrial Science and Technology and five private firms including Hitachi have launched **research for an optical disk with recording density 1,000 times higher than conventional CDs**. The purpose of the project is to develop a 12cm-diameter optical disk capable of storing 1Tbyte of data, an equivalent of 2,000 years' worth of newspapers. The technology the participants will be working on will write data on a disk using a proximity light beam which will be emitted from the tip of an optical fiber probe. Using a similar approach, Hitachi developed a 125Gbyte CD in 1996.

Fujitsu also recently announced new developments leading toward **1Tbyte optical memory technology**. Aimed to be commercially viable by 2010, the technology uses a multiple wavelength system which emits 1,000 types of light with varying wavelengths on a recording medium. The company has created a semiconductor medium with InAs spots ranging in size from 10-20nm in diameter, and has confirmed that information is stored on spots using an infrared beam at -233°C and is read on electric signals.

The Tohoku Research Laboratory of the Agency of Industrial Science and Technology has developed a **material for absorbing highly toxic arsenic contained in waste water from GaAs fabs** and a process for filtering the waste water using the material. The technique selectively picks up trivalent arsenic ions, a difficult task with conventional approaches. The new system can continuously filter an arsenic solution with a density of less than 1ppm.

R&D News from NEC

Recent R&D news from NEC includes:

- **A technique to mass-produce 1.3 μ m semiconductor lasers at low costs.** NEC says the technique uses selective epitaxy to eliminate chemical etching process steps and increase production yield. A 1.3 μ m laser has been demonstrated which has an output 15mW at 85°C and achieves a standard deviation for driver current of 1.3mA (which is reportedly less than 1/10 the previous record) while drawing 51.6mA. The company claims that the laser can function at 100°C running 73mA, which is also a record. NEC plans to promote the low-cost semiconductor laser for use in subscriber line optical fiber communications networks which are expected to be completed by around 2010.
- **A 40-channel laser with integrated modulators created on a single epitaxial wafer.** The device is being developed for use in large-capacity WDM optical communications systems. NEC had previously announced the development of a process that allows laser diodes in a 75 nm-wide wavelength range to be grown on the same InP wafer. (CS 3(2), p. 28). Now the company says that it can control the optical absorption layer of the modulator and the active layer of the laser over a 150nm-wide wavelength range. The prototype supports 40 channels at intervals of 200GHz and achieves an average threshold current of 10mA and an on-off ratio of 100:1. In an experiment, the company used an optical fiber amplifier which used the prototype to transmit data at 2.5Gbps over a distance of 600km.
- **A prototype infrared wireless transmission system which uses IR LEDs to dispatch signals at 125Mbps over a distance of 10m.** The technology, which the company claims will pave the way for the development of a home wireless multimedia network system, complies with the IEEE1394 interface standard for transmission of image, sound and computer data, as well as the IEC825-1 Class 1 standard, the industry's toughest safety standard. The system uses a silicon photo detector for its receiver unit. NEC intends to commercialize the system by fall 1998.
- **A technique to selectively grow SiGe on Si.** Conventional optical interconnects tend to be expensive because they use a photo detector made of compound semiconductor such as InGaAs and a light reception IC made of silicon, which are difficult to be integrated on a single substrate. The new technique, which grows SiGe and silicon layers alternately, was used to integrate both the photo detector and the light reception IC on a single chip. NEC plans to put the technique into practical use around 2000.

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Even in Microelectronics, GaN was Big News in 1997

ROBERT A. METZGER

GaAs is becoming a relatively mature technology. Evidence of that fact comes from several industry analysts who believe that the market for GaAs devices passed the \$1 billion mark for the first time in 1997.

As the emphasis in the GaAs field swings over to production and cost issues, the R&D community is becoming more interested in looking at new material systems to find promising candidates for the next generation of devices. As a result, the list of the past year's significant advances in compound semiconductor electronic circuits and devices includes topics such as GaN- and SiC-based FETs. But there were also some very interesting developments in the more traditional areas of GaAs- and InP-based RF devices, and high speed III-V analog and digital devices.

Top Developments of 1997

- AlGaIn MODFETs with record DC characteristics & power density - Univ. Illinois & UCSB
- GaN FETs on SiC - NRL/ATMI & APA Optics / Rensselaer Polytech.
- SiC MESFET with record PAE - Motorola/Cree Research
- Digital circuits in 6H-SiC using CMOS processing - Purdue
- Low power MESFET power amps - Nat'l Chiao-Tung Univ. & Matsushita
- InP HEMT with record mobility - Nat'l Chiao-Tung Univ.
- InP HFET with f_t of 265 GHz - T.U. Munich
- AlInAs/GaInAs transferred-substrate HBT with f_{max} of 277 GHz - UCSB
- InP HEMT MMIC amplifier operating at 155 GHz - TRW
- Demonstration of integrated enhancement and depletion mode InAlAs/InGaAs/InP - Purdue
- 35 GHz AlGaAs/GaAs HEMT static frequency divider - Fraunhofer IAF

Wide Bandgap Devices

This issue is filled with references to GaN as a blue light emitter. However, its large direct bandgap and excellent thermal conductivity also make GaN a good candidate as a high power RF source. 1997 saw GaN-MODFET structures becoming as sophisticated in epitaxial design as many of their GaAs- or InP-based counterparts. University of Illinois researchers reported on a double

donor MODFET structure, in which charge to the channel was supplied by AlGaIn donor layers placed both below and above the channel¹. This device exhibited record level DC characteristics with drain currents of 1100 mA/mm and transconductances of 270 mS/mm. Further refinements in AlGaIn/GaN MODFET structures were implemented by

researchers from UCSB with the utilization of a thin 200Å donor layer in order to increase the active input capacitance and improve f_t . Using 0.2 μ m gate lengths, these devices exhibited a record f_t of 50 GHz, with drain currents of 800 mA/mm and transconductances of 240 mS/mm. When operated at 10 GHz, these devices delivered a record level power density of 1.7 W/mm, a value exceeding any other HEMT structure in any other material system at this frequency².

As the RF output power levels of GaN-based FETs continued to increase throughout 1997, it became more and more obvious that the need to thermally dissipate the DC power required to bias these devices becomes more and more critical. The standard substrate for GaN growth is that of sapphire. Although marked device improvement has been seen using this substrate, it is a very poor thermal conductor. During 1997, the first reports of GaN FETs fabricated from GaN material grown on SiC have been reported.

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ed, this research driven by the excellent thermal conductivity of SiC. The first reported fabrication of GaN HEMTs on SiC substrates was that by a joint Naval Research Laboratory/ATMI effort³, which showed DC characteristics similar to those of HEMTs grown on sapphire, while later in the year, an APA Optics/University of South Carolina/Rensselaer Polytechnic Institute team fabricated AlGaIn/GaN HFETs on SiC which exhibited maximum transconductances of 142 mS/mm, drain currents of 950 mA/mm, and showed that the use of the SiC substrate resulted in a power dissipation of 0.6 MW/cm², which is three times higher than that obtained for similar devices fabricated on sapphire⁴.

As impressive as these results are, GaN-based FETs still face very stiff competition from SiC power FETs. Researchers from Motorola and Cree Research reported on a 4H-SiC MESFET which exhibited a PAE of 65.7% PAE at 850 MHz operation, and for a V_{ds} of 50 V delivered an RF power density of 3.3 W/mm. This PAE is the highest to date for a SiC MESFET⁵. In addition to very impressive RF power characteristics, a unique attribute of SiC is its ability to support the growth of SiO₂, which in turn permits the fabrication of CMOS structures. Researchers at Purdue University reported on the fabrication of a wide range of digital circuits in 6H-SiC, including NAND, NOR, XOR, half adders, and 11 stage ring oscillators⁶.

Intermediate Bandgap Devices

Of course, GaAs and InP remain the workhorse III-V electronic devices (with InP more of a thoroughbred used for those very high frequency, and high performance applications). For the commercial segment of the market, RF operation in the 1-2 GHz range for cellular communication continues to be the driver of this industry, and GaAs is the material which makes it possible. Of critical importance for this application, and a requirement if GaAs-based devices are to maintain market

Matsushita Electronics Corporation developed a GaAs MESFET for 900 MHz operation which when biased at 1.5 V, delivered an output power of 31.5 dBm with a 70% PAE. This device remained operational down to a bias of only 0.5 V, while still delivering an impressive PAE of 60%. Si-based devices will be extremely hard-pressed to approach any of these results in the coming years.

share in the face of the always encroaching Si, is to use the superior material characteristics of GaAs in order to reduce DC operating voltages, and improve PAE, so that battery lifetimes, and therefore talk time between recharging, can be lengthened. Impressive results along these lines during 1997 included researchers at the National Chiao-Tung University [Taiwan] reporting on the use of an ion implanted MESFET for the 1.9 GHz Japanese Personal Handy Phone system, which for 2.2 V operation, exhibited a PAE of 57.2% at an output power of 21.3 dBm⁷.

Using a spike gate structure, a group from Matsushita Electronics Corporation, developed a GaAs MESFET for 900 MHz operation which when biased at 1.5 V, delivered an output power of 31.5 dBm with a 70% PAE. This device remained operational down to a bias of only 0.5 V, while still delivering an impressive PAE of 60%⁸. Si-based devices will be extremely hard-pressed to approach any of these results in the coming years.

For those applications which require the maximum speed possible, the alloy system of choice is that of InP and its associated alloys of AlInAs and GaInAs. Using a sophisticated profile consisting of a InAlAs/InAs superlattice buffer and a 7 nm InAs/3.5 nm Ga_{0.25}In_{0.75}As composite channel, researchers at the National Chiao-Tung University fabricated a HEMT with a record setting room temperature mobility of 20,200 cm²/Vs, which was able to contain a high carrier concentration of 2.7×10^{12} cm⁻²⁹. Another pseudo-

morphic InP-based effort using 4 nm InAs channels by researchers from the Technische Universität München [Germany], resulted in the fabrication of a InAlAs/InGaAs/InAs HFET with a 0.13 μ m gate length which exhibited a transconductance of 1400 mS/mm and an f_t of 265 GHz¹⁰. Besides taking advantage of superior materials characteristics (in the case of InP-based alloys) in order to improve device performance, the other route to performance improvements can be obtained by novel processing in order to reduce parasitic components which degrade RF performance.

Researchers at UCSB reported on a AlInAs/GaInAs novel transferred-substrate HBT, in which the transferred substrate process permits the fabrication of narrow and aligned collector-base and emitter-base junctions, thereby reducing the collector-base capacitance and increasing the device's f_{max} . With this process, an HBT with aligned 0.7 μ m emitter and 1.6 μ m collector stripes was fabricated which showed an f_{max} of 277 GHz and f_t of 127 GHz¹¹.

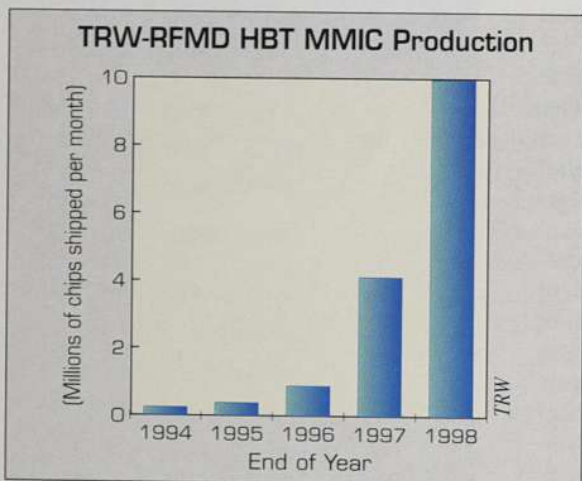


Figure One. TRW's forecast for demand for GaAs-based HBTs, based on production at its GaAs fab plus a new fab currently under construction by its venture partner RF Micro Devices. The company recently predicted that InP-based circuits will follow a similar demand curve in three to five year's time.

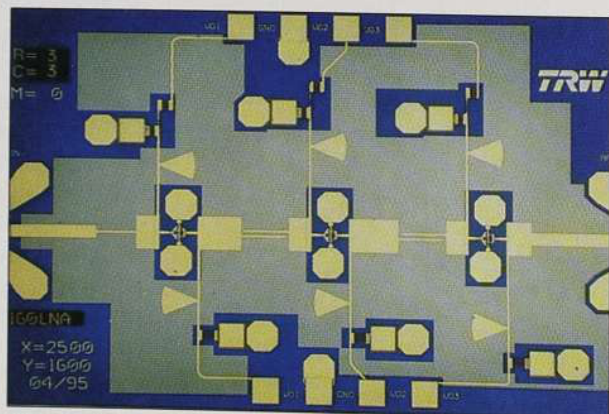


Figure Two. Photograph of TRW's three-stage InP HEMT low noise amplifier (LNA) that produces 12.5 decibels (dB) of gain at a frequency of 155 GHz. This is the highest operating frequency ever reported for a solid state amplifier. TRW also reported that the 0.1 micron MMIC process used to build this chip 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.

InP-Based Circuits

The biggest news in the InP area in 1997 came from TRW, which will likely be the first company to put InP circuits into volume production. Earlier this year the company raised some eyebrows by forecasting that demand for its GaAs HBT circuits would soon exceed 10 million units per month. See Figure One. But in October, company representatives at the GaAs IC Symposium made the even more surprising prediction that InP-based circuits would follow the same demand curve in three to five years time.

TRW made several reports on its InP technology in 1997, including a 0.1 μm gate length InAlAs/InGaAs/InP PHEMT which was the highest frequency amplifier ever reported using three terminal devices. This three stage MMIC amplifier operated at 155 GHz, exhibiting a small signal gain of 12 dB¹². Using 0.15 μm gate length HEMTs, TRW also demonstrated a W-band high power MMIC amplifier which delivered a record level output power of 130 mW with 13% PAE at 4 dB of gain at 94 GHz¹³. Other reports included an InP-based HBT distributed amplifier operating over the bandwidth of 50 MHz to 55 GHz, these results representing both the widest bandwidth and the highest frequency of operation so far demonstrated for a bipolar amplifier¹⁴. In addition, TRW continues to develop its merged InP-based HEMT/HBT technology, having monolithically integrated a single stage HBT op-amp current regulator with a single stage HEMT amplifier. The amplifier achieved an RF gain of 5.9 dB at 94 GHz along with a minimum noise figure of 4.2 dB¹⁵.

On the digital scene, researchers at the University of Illinois have developed an integrated enhancement and depletion mode InAlAs/InGaAs/InP technology¹⁶. Using 0.5 μm gate length devices, an 11 stage ring oscillator was fabricated which exhibited a propagation delay time of 22.4 ps/stage and a power dissipation of 120 μW /stage, giving a power delay product of only 2.65 fJ/stage. And even though it may appear that InP-based technology is taking all the speed records, GaAs technology has not relinquished all the titles. Researchers at the Fraunhofer Institute of Applied Solid State Physics [Freiburg, Germany], used 0.2 μm AlGaAs/GaAs HEMT technology to fabricate a 35 GHz static frequency divider, the fastest speed realized so far in any HEMT technology¹⁷.

1997 was a banner year for III-V devices and circuits. When the rapid advances in wide bandgap devices are coupled with the growing commercial GaAs markets, and the continuing improvement in high speed GaAs- and InP-based circuits, 1998 should prove to be every bit as exciting as was 1997.

References

1. Z. Fan et al, AlGaIn/GaN double heterostructure channel modulation doped field effect transistors, *Electron. Lett.*, 33(9), 814, 24 (1997).
2. Y.-F. Wu et al, "Short Channel AlGaIn/GaN MODFET's with 50-GHz f_t and 1.7 W/mm Output-Power at 10 GHz," *IEEE Electron Dev. Lett.*, 18(9), 438, (1997).
3. S.C. Binari et al, AlGaIn/GaN HEMT's Grown on SiC Substrates," *Electron. Lett.*, 33(3), 242, (1997).
4. R. Gaska et al, "High Temperature Performance of AlGaIn/GaN HFET's on SiC Substrates," *IEEE Electron Dev. Lett.*, 18(10), 492, (1997).
5. K. Moore et al, "4H-SiC MESFET with 65.7% Power Added Efficiency at 850 MHz," *IEEE Electron Dev. Lett.*, 18(2), 69, (1997).
6. S. Ryu et al, "Monolithic CMOS Digital Integrated Circuits in 6H-SiC Using an Implanted P-Well Process," *IEEE Electron Dev. Lett.*, 18(5), (1997).
7. Y.-L. Lai et al, "High Efficiency and Low-Distortion Directly Ion-Implanted GaAs Power MESFET's for Digital Personal Handy-Phone Applications," *IEEE Electron Dev. Lett.*, 18(9), 429, (1997).
8. T. Tanaka, "Low Voltage Operation GaAs Spike-Gate Power FET with High Power Added Efficiency," *IEEE Transactions on Electron Dev.*, 44(3), 354, (1997).
9. A. Chin, "In_{0.52}Al_{0.48}As/InAs/InAl_{0.48}As Pseudomorphic HEMT's on InP," *IEEE Electron Dev. Lett.*, 18(4), 157, (1997).
10. D. Xu, et al, "High-Performance Double-Modulation-Doped InAlAs/InGaAs/InAs HFET's", *IEEE Electron Dev. Lett.*, 18(7), 323, (1997).
11. B. Agarwal et al, "A 277-GHz f_{max} Transferred-Substrate Heterojunction Bipolar Transistor," *IEEE Electron Dev. Lett.*, 18(5), 228, (1997).
12. H. Wang et al, "A 155 GHz Monolithic InP-Based HEMT Amplifier," 1997 IEEE MTT-S Digest, pg.1275.
13. Y.C. Chen et al, "A 94 GHz 130 mW InGaAs/InAlAs/InP HEMT High-Power MMIC Amplifier," *IEEE Microwave and Guided Wave Lett.*, 7(5), 133, (1997).
14. K.W. Kobayashi, "A 50 MHz - 55 GHz Multidecade nP-Based HBT Distributed Amplifier," *IEEE Microwave and Guided Wave Letters*, 7(10), 353, (1997).
15. K.W. Kobayashi, "An InP HEMT W-Band Amplifier with Monolithically Integrated HBT Bias Regulation," *IEEE Microwave and Guided Wave Lett.*, 7(8), 222, (1997).
16. A. Mahajan, "Fabrication and Characterization of an InAlAs/InGaAs/InP Oscillator Using Integrated Enhancement- and Depletion-Mode High-Electron Mobility Transistors," *IEEE Electron Dev. Lett.*, 18(8), 391, (1997).
17. Zhihao Lao, "35 GHz Static and 48 GHz Dynamic Frequency Divider IC's Using 0.2 μm AlGaAs/GaAs HEMTs," *IEEE Journal of Solid State Circuits*, 32(10), 1556, (1997).

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1997 Semiconductor Laser R & D Review

GARY WICKS

The past 12 months saw the continuation of many of the same battles from 1996 between competing laser options, as well as some new developments. As in recent years, the GaN vs. ZnSe battle for short wavelengths continues. GaN has now passed the older ZnSe technology in performance, but has not yet delivered the knockout blow. In the near IR, the AlGaAs vs. aluminum-free battle continues with no clear victor at this point. At the longer wavelengths, new materials and structures are springing up to challenge the traditional approaches.

Green/Blue/Violet/UV Lasers

GaN-based lasers

For the second consecutive year, the biggest news in semiconductor lasers is the GaN-based laser diode. The story is remarkable: GaN, a material without a lattice-matched substrate, being made into unexpectedly high performance lasers by Nichia, a company without much experience in optoelectronic devices or nitrides. The sky rocket rise of the device has been amazing to watch - from the first room temperature operation in 1996 to the very recent report by Nichia's Nakamura of an extrapolated room temperature cw lifetime of 10,000 hours¹ (see page 4). A key to this recent achievement is the use of epitaxial lateral overgrowth. Nichia now is poised to move from research to production with these devices. The devices lase around 400 nm, the border between violet and ultraviolet.

II-VI lasers

No major breakthroughs or advances were announced this year in the standard ZnSe-based II-VI laser structure. Instead new II-VI laser materials have appeared. One such material system is the beryllium chalcogenides (beryllium-based II-VI's). The ZnSe system has suffered from device degradation problems relating to the weak Zn-Se bond. Beryllium chalcogenides are expected to have stronger bonds than other wide bandgap II-VI's, and can lattice match GaAs substrates. Researchers from the University of Wurzburg in Germany² recently constructed lasers

diodes using these beryllium-based II-VI's². The cladding layers consisted of BeMgZnSe, the waveguide layer of BeZnSe and the active quantum well of BeZnCdSe. Broad area, 0.5 - 1 mm long devices lased at 77K with threshold current densities of 240 A/cm².

ZnO, a second II-VI material for short wavelength lasers, was also in the news this year. Optically pumped lasing at room temperature in epitaxial ZnO was reported.³ The material lased in the violet at 404 nm and is believed to be excitonic in nature. The excitation intensity at threshold, 240 kW/cm², compares with that of GaN.

Red/Near IR Lasers

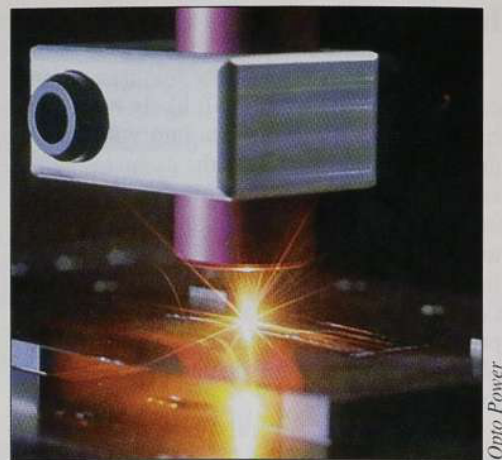
High Power

A power record was set this year for monolithic laser diode arrays. Researchers at Opto Power Corp. (Tucson, Arizona) reported a device with an output aperture of 4.8 mm producing 155 W of cw output power.⁴ The device was water cooled with a water temperature of 3°C. The drive current was 210 amps, and the wall plug efficiency was 40 %. The laser, fabricated in AlGaAs/InGaAs materials grown by MOCVD, lased around 915 nm.

Quantum Dots

Quantum dot lasers created a lot of interest this year. Although much less developed than their quantum well siblings, quantum dots lasers are already showing comparable performance. A German-Russian collaboration⁵ reported a GaInAs quantum dot laser with a 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%.

Quantum dots have also been useful in solving the polarization problem of vertical cavity surface emitting lasers (VCSEL's). Conventional 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 is random and may change with drive current. Researchers from NEC Corporation found their quantum dots grew asymmetrically and that this asymmetry pro-



Example of one of Opto Power's high power laser diodes in action. The company set a record in 1997 with a monolithic laser diode array producing 155 W of cw output power.

duces polarized emission. They reported InGaAs quantum dots grown by MBE on GaAs (100) substrates that are nearly twice as long along the [011] direction as along the perpendicular [011] direction. A batch of 20 QD VCSEL's was examined - every laser was polarized along [011], with the opposite polarization suppressed by 18 dB.

New Materials for 1.3 and 1.55 μm Lasers

The use of group III nitrides is not confined to only short wavelength lasers. Two different nitride materials have found their way into lasers in the 1.3 / 1.55 μm communication band. In Japan, Ricoh researchers have been working with GaInNAs emitters and recently pushed the wavelength out to 1.3 μm⁶ in an edge-emitting laser operating under pulsed conditions at room temperature. The advantage of this material is that it can be incorporated into a GaAs-based laser, rather than the traditional InP-based 1.3 / 1.55 μm lasers. This allows the use of larger diameter, cheaper, higher quality substrates. Additionally it points the way to being able to make 1.3 μm VCSEL's using the highly successful mirror technology of the GaAs-based materials.

A second group III nitride, InNAsP, was also made to lase at 1.3 μm. This nitride is incorporated into InP-based materials, and makes "deeper" quantum wells than the conventional GaInAs or GaInAsP materials. The expected result is better high temperature performance. A collaboration between University of California at San Diego and Northwestern University⁷ reported on two optically pumped quantum well microdisk lasers, one with an InNAsP active region and one using GaInAs instead. The InNAsP device lased at temperatures up to 340 K, while the GaInAs laser only reached 220 K.

Mid-IR Lasers

Type II Quantum Wells

Until recently Type II quantum wells have been neglected as laser structures because they separate electrons and holes to adjacent layers, rather than confining them to the same layer as do type I quantum wells. This year, however, two different varieties of type II lasers in the mid-IR were reported.

The first, reported by researchers from Université de Montpellier II (France), used the type II InAs/GaSb heterojunction.⁸ In this heterojunction, if the layers are thick, the bandgap is negative, i.e. the valence band maximum of the GaSb lies at a higher energy than the conduction band minimum of the InAs. In the present work, however, the InAs layers were thin, ranging from 6 to 24 Å. The quantum size effect pushes the ground state of the InAs conduction band electrons to energies above the valence band maximum of the GaSb. Holes in the GaSb valence band are pulled up against the interface by their attraction to electrons in the InAs conduction band quantum well, producing a triangular quantum well in the GaSb valence band. Room temperature lasing was observed at 1.98 and 2.32 microns for structures with 6 and 12 Å thick InAs QWs, respectively. Strong electroluminescence was observed at wavelengths out to 3.4 microns in structures with wider InAs wells.

A second type II quantum well laser reported this year is a quantum cascade (QC) laser. A difficulty of original QC laser developed at Bell Labs is that the non-radiative intersubband transitions are very efficient and compete very effectively with the desired radiative transitions. A collaboration between the University of Houston and Sandia National Laboratories⁹ has produced 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 microns with a threshold current of 2 A.

Antimonides

Lincoln Labs researchers¹⁰ have constructed a 3.9 µm semiconductor laser system with a cw power several times greater than previously reported for wavelengths longer than 3.6 µm. The laser consists of a 2 µm thick InAs_{0.91}Sb_{0.09} active layer sandwiched between two 4 µm thick AlAs_{0.07}Sb_{0.93}

cladding layers grown by MBE on a GaSb substrate. The device is optically pumped by a cw 0.98 µm laser diode array and produces 270 mW of cw output power at 84K. It is packaged in a liquid nitrogen dewar allowing 5-8 hours of turn-key operation. On the exterior of the dewar, a rigidly mounted lens produces a 200 mW collimated beam. Fiber coupling with 62% efficiency was also demonstrated.

Diode lasers at two micron wavelengths are needed for pumping lasers such as Ho-doped YAG's. Sarnoff Corporation recently reported¹¹ a two micron laser that produced record performance. 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 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.

1997 was a year of diversity in semiconductor lasers. In almost every wavelength range, there are multiple competing approaches, and in many cases the number of these approaches has increased during the year. The main exception is in the red, which is ruled by the AlGaInP materials, and the yellow, where there are no viable options at present. Nitrides have begun to dominate the blue end of the spectrum and compete at 1.3 microns. Perhaps in the upcoming year, they will penetrate the yellow void and give AlGaInP some competition in the red.

References

1. S. Nakamura, presented at Int'l Conf. On Nitride Semiconductors (Tokushima, Japan, October 27 - 31, 1997).
2. A. Waag et al., Appl. Phys. Lett. 70(3), 280 (1997).
3. D.M. Bagnall et al., Appl. Phys. Lett. 70(17), 2230 (1997).
4. X. He et al, Electronics Lett. 33 (14), 1221 (1997).
5. N.N. Ledentsov et al, Appl. Phys. Lett. 70 (21), 2888 (1997) and A.E. Zhukov, paper presented at Electronic Materials Conference (Ft. Collins, CO, 25 June, 1997).
6. S. Sato et al, Electronics Lett. 33 (16), 1386 (1997).
7. W. G. Bi et al, IEEE Photonics Lett. 9 (8), 1072 [(1997)].
8. A. N. Baranov et al, Appl. Phys. Lett. 71 (6), 735 (1997).
9. C-H Lin et al, Elec. Lett. 33 (7) (1997).
10. H. Q. Le et al., Electronics Lett. 32(25), 2359 (1997).
11. D.Z. Garvuzov et al, Appl. Phys. Lett. 70 (22), 2931 (1997).

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1997's Notable Developments in Compound Semiconductor Materials

C. R. BOLOGNESI

As the year comes to an end, one takes a step back and realizes that we witnessed some impressive developments over the last twelve months: we have seen the possibility of "everything-on-everything-else" epitaxy with twist-bonded compliant substrates, new mobility records were set for GaAs/AlGaAs two-dimensional electron gases, steady progress was realized in the field of wide bandgap materials, and new designer III-V alloys have emerged with much technological potential. The following review summarizes some of the important developments of 1997 in the area of compound semiconductor materials.

Lattice-Mismatched Epitaxy

Among the most striking developments was the introduction of twist-bonded compliant universal substrates by Felix Ejeckam and co-workers from Cornell University^{1,2}. Ejeckam and colleagues established that new universal compliant substrates could be formed by wafer bonding a thin GaAs layer to a conventional GaAs substrate with a $\sim 40^\circ$ rotational misalignment about the surface normal. The very dense network of screw dislocations resulting from the arrangement is intended to elastically deform and absorb the strain resulting from the lattice-mismatch between the GaAs substrate and the epitaxial layers. Figure 1 illustrates the process of forming a CU substrate.

TEM measurements demonstrated that InSb films grown on the compliant substrates showed no observable threading dislocations, whereas InSb films grown on conventional GaAs substrates exhibited dislocation densities as high as 10^{11} cm^{-2} due to the 15% lattice mismatch between InSb and GaAs. See Figure 2. While there is obviously a great deal of work left to be done before practical applications for the CU substrate can be developed, these early results offer the tantalizing prospect of new degrees of freedom in the heteroepitaxial growth of exceedingly large lattice-mismatched crystals.

Record Mobility 2DEGs

Remember the days when dozens of research groups were pursuing record-setting GaAs mobilities? Most of that work has gone out of fashion now that the industry is more focused on delivering products to the market. Nevertheless, V. Umansky and co-workers of Weizmann Institute in Israel recently reported a new mobility record of $14.4 \times 10^6 \text{ cm}^2/\text{Vs}$ at 0.1 K in GaAs/AlGaAs quantum wells³. The most interesting aspect of the work is that it indicates that ultrahigh mobility material is still limited by scattering from residual background impurities. The samples were grown in an extremely clean MBE system which reached an ultimate pressure of 10^{-12} Torr. It was found that the chamber pressure, though of great importance, did not limit the ultimate material purity of layers grown in the system. Rather, the limiting factor appeared to come from impurities emanating from the substrate heater and the source materials during epitaxy - especially the arsenic source.

The low-temperature mobility dependence on the carrier density revealed that the remote delta-doping impurities contribute only 10% of the total scattering rate whereas the residual background impurities account for 90% of the scattering rate in the best structures.

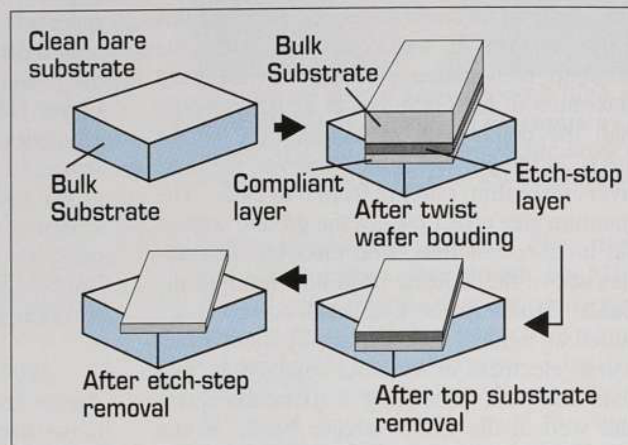


Figure 1: A conceptual schematic illustrating the process of forming a compliant universal (CU) substrate using twist wafer bonding. Note that the 30 Å GaAs layer has been twisted about its surface normal before being wafer bonded to the new GaAs substrate.

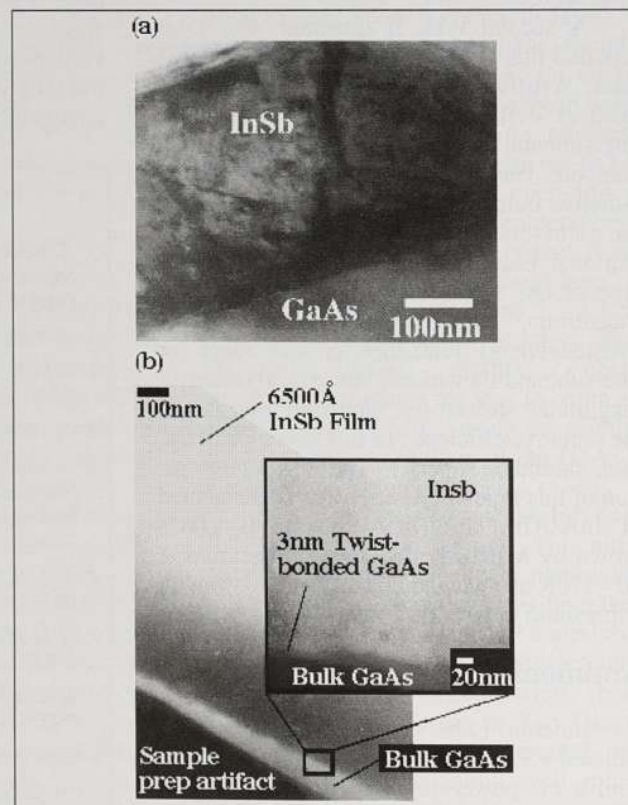
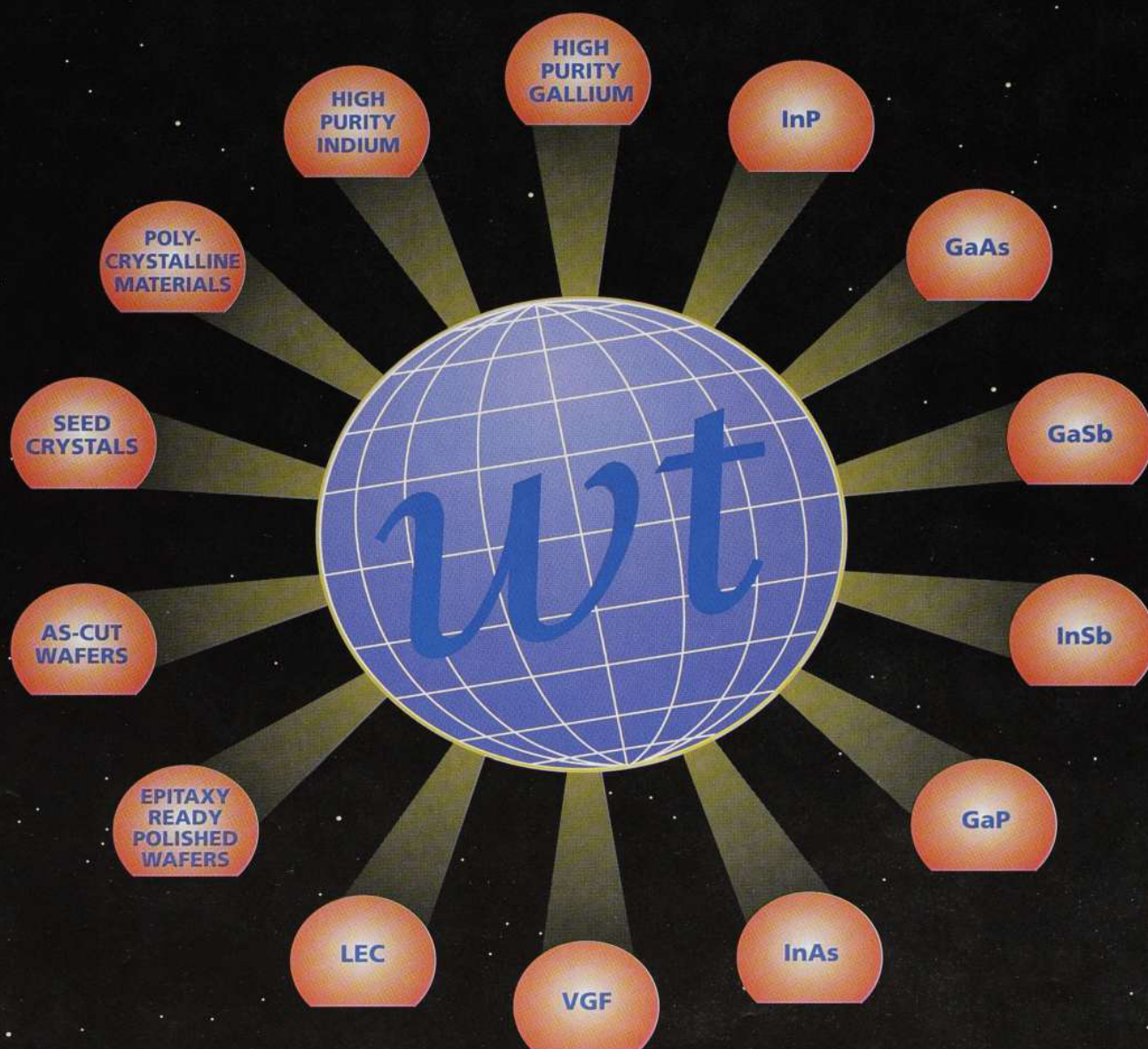


Figure 2: A cross-sectional bright field TEM image of a 6500 Å thick InSb film grown on (a) a GaAs bulk substrate; and (b) a CU substrate.

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Wide Bandgap Materials

The preparation of wide bandgap materials was the focus of much activity in 1997, both for II-VI compounds (see page 24) and for nitrides alike. Since bulk GaN substrates are not likely to be available any time soon, and since the most popular alternative, sapphire (Al_2O_3), has a large lattice mismatch (approximately 14%) to GaN, there is a great deal of interest in finding other materials which would be acceptable substitutes.

One of the most interesting reports of reduced lattice-mismatch to GaN came from Y. Tazoh and co-workers from the NTT System Electronics Laboratories in Japan, who demonstrated epitaxial growth of GaN on nearly lattice-matched (001) LiGaO_2 substrates grown by the Czochralski pulling method⁴. Smooth GaN epilayers with a thickness of 0.4 μm grown by MBE on LiGaO_2 substrates were characterized by an XRD FWHM of 260 arcsecs, which is roughly 7 times smaller than for GaN films grown on {0001} sapphire substrates. These new substrates may eventually prove to be a viable alternative to sapphire substrates for GaN-based thin films. Once major difficulty with LiGaO_2 substrates is that they tend to grow in a multi-domain fashion (with only one domain type suitable for epitaxy). Fortunately, it appears that single-domain substrates can be made.

G. Gaska and colleagues of APA Optics also provided some excitement in the area of alternative substrates for GaN epitaxial growth by taking advantage of the higher thermal conductivity of 6H-SiC substrates (which is 10-20 times higher than that of sapphire) to demonstrate AlGaIn/GaN heterostructure field-effect transistors (HFETs) grown on SiC substrates with much higher thermal breakdown thresholds. The maximum dissipated DC power at room temperature was 0.6 MW/cm^2 —three times higher than in similar devices grown on the conventional sapphire substrates⁵.

Readers of this magazine will likely be aware that in July Cree Research and Fujitsu Laboratories both reported the successful fabrication of GaN/InGaP laser diodes on SiC substrates. (See CS 3(5), p. 10 & 12.) These results suggest that SiC substrates may find a niche in laser production, and the APA Optics result makes SiC appear to be very attractive for power devices requiring good heatsinking. Nevertheless, sapphire still appears to be the substrate of choice for LED implementations driven by manufacturing costs.

New Designer Alloys: The Leading Edge

GaAsN is a direct bandgap material that can be lattice-matched to Si for a nitrogen concentration of ~20% and is thus potentially useful for the integration of optoelectronic devices such as light emitters with conventional Si electronics. Unfortunately, it has proven difficult to incorporate high nitrogen mole fractions without phase-separation because of the large size mismatch between As and N atoms. Bi and Tu from the University of California (San Diego) were able to increase the N concentration to nearly 15%, and they determined that the alloys are characterized by a direct energy gap⁶. Interestingly, nitrogen incorporation is found to decrease the alloy energy gap—in sharp contrast to what would intuitively expect in light of the widegap nitride alloys.

It was shown by Bellaiche and co-workers from the National Renewable Energy Laboratory (Golden, CO) that simple approximations like the virtual crystal approximation, the use of high-symmetry small ordered structures to mimic random alloys, or the neglect of relaxation cannot properly describe the band gaps versus composition dependence in GaPN and GaAsN random alloys⁷. This is due to the fact that such calculations misrepresent the band-edge wave function localization in these alloys. Fully relaxed, large supercell calculations

of epitaxial GaPN and GaAsN alloys differ considerably from the corresponding bulk results, but reproduce the measured band gaps well for epitaxial alloys.

The TlInGaP (thallium indium gallium phosphide) alloy is a new III-V material system with potential uses in active layers for optoelectronic devices with wavelengths ranging from 0.9 μm to 10 μm . With its widely tunable energy gap, TlInGaP is of interest for optical devices such as laser diodes in the 1 μm range, and for mid-infrared devices with $\lambda > 2 \mu\text{m}$. This new material system is promising because the complete wavelength range can be covered while retaining lattice-matching conditions with InP substrates, and thus provides an alternative to both antimonide structures grown on GaSb or InAs substrates, and to the growth of complex multilayer devices such as quantum cascade laser structures. The material can also be lattice-matched to GaAs over the wavelength range from 0.65 μm (InGaP) to 1.24 μm (TlGaP). Because the alloy uses only one group V element, straddling band line-ups are expected in this system, thus allowing the confinement of electrons and holes in the same active layers for enhanced optical recombination efficiencies.

Another potential advantage of the TlInGaP system is that the alloy is expected to exhibit a temperature independent energy gap of 0.7-0.8 eV while lattice-matched to InP substrates, with the value of the energy gap being tunable by As or Al alloying, and/or by the formation of quantum well structures. Such a temperature independent energy gap would prove useful in low-loss, high-capacity 1.55 μm wavelength division multiplexing (WDM) fiber systems which currently require Peltier systems to temperature compensate InGaAsP/InP laser diodes.

H. Asahi of Osaka University reported the successful GSMBE growth of TlInP and TlInGaP layers on InP substrates by using elemental Tl (5N purity), In, and Ga sources, and thermally cracked phosphine as the group V source⁸. Following a thermal cleaning of the substrates in phosphine and the growth 0.1 μm thick InP buffer, TIP, TlInP, and TlInGaP epitaxial layers were grown at substrate temperatures of 400-450°C. RHEED patterns showed a (2 x 4) phosphorus stabilized surface reconstruction, and samples exhibited mirror smooth surfaces. A $\text{Tl}_{0.073}\text{In}_{0.732}\text{Ga}_{0.195}\text{P}$ layer was grown and the composition was found to be in a rough agreement with the expected value inferred from the beam fluxes. Potential problems in the use of the thallium metal are its ease of oxidation, and a high toxicity.

References

1. F. E. Ejeckam et al., "Lattice engineered compliant substrate for defect-free heteroepitaxial growth," *Appl. Phys. Lett.* 70 (13), 1685 (1997).
2. F. E. Ejeckam et al., "Dislocation-free InSb grown on GaAs compliant universal substrates," *Appl. Phys. Lett.* 71 (6), 776 (1997).
3. V. Umansky et al., "Extremely high-mobility two dimensional electron gas: Evaluation of scattering mechanisms," *Appl. Phys. Lett.* 71 (5), 683 (1997).
4. Y. Tazoh et al., "GaN thin film growth on LiGaO_2 substrate with a multi-domain structure," *Jpn. J. Appl. Phys.* 36 (Part2, 6B) L746 (1997).
5. G. Gaska et al., "High-temperature performance of AlGaIn/GaN HFET's on SiC substrates," *IEEE Electron Dev. Lett.* 18(30), 492 (1997).
6. W. G. Bi et al., "Bowing parameter of the band-gap energy of $\text{GaN}_x\text{As}_{1-x}$," *Appl. Phys. Lett.* 70 (12), 1608 (1997).
7. L. Bellaiche et al., "Band gaps of GaPN and GaAsN alloys," *Appl. Phys. Lett.* 70 (26), 3558 (1997).
8. H. Asahi, "New semiconductors TlInGaP and their gas source MBE growth," *J. Cryst. Growth*, 175/176 (1/2), p. 3558 (1997).

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TRW Acquires MilliWave Technologies, Continues To Develop GaAs Markets

On October 6 TRW announced it had agreed to acquire MilliWave Technologies Corp., a privately held Diamond Springs, CA, firm that specializes in the design and manufacture of multi-chip electronic modules used in high-capacity wireless communications systems.

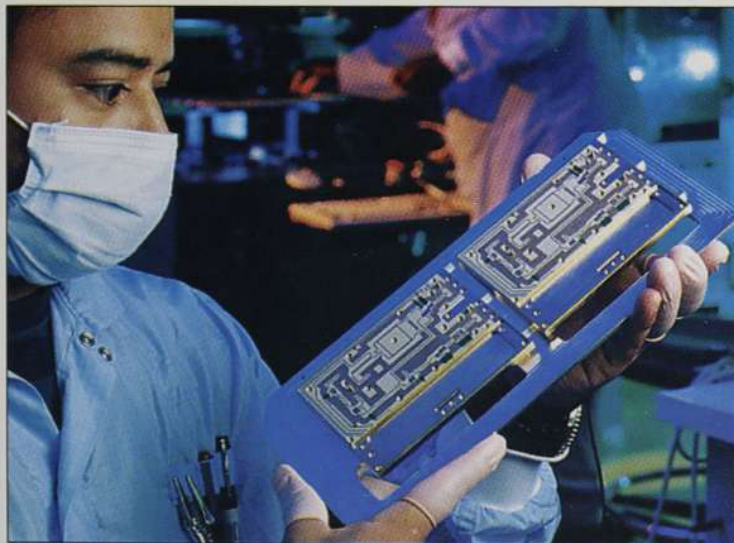
The transaction is intended to expand TRW's role in the commercial telecommunications industry from being not only a high-volume supplier of low-cost GaAs ICs, but also a high-volume supplier of more highly integrated multi-chip modules based on those circuits.

"This acquisition of MilliWave Technologies represents another key milestone in TRW's strategy to exploit its gallium arsenide integrated circuit technology in commercial telecommunications markets," said Timothy W. Hannemann, executive vice president and general manager, TRW Space & Electronics Group. "It also allows us to take a significant step up the value chain."

The new company will be known as TRW MilliWave Inc. Financial details of the transaction, which was completed on September 30, were not disclosed.

John Rosenberg, president of MilliWave Technologies commented: "This agreement integrates TRW's expertise in the design and fabrication of MMICs with MilliWave's high-volume assembly, integration and testing capabilities. By merging our corporate strengths, we have solidified our ability to deliver millimeter wave, multi-chip modules to commercial telecommunications markets in high volume at very competitive prices."

MilliWave currently produces millimeter wave modules that operate between 18 and 60 GHz. One of their largest markets is in microwave "links" - line-of-sight, point-to-point communications systems used to augment installed wire line and fiber optic networks. TRW and MilliWave Technologies both currently produce millimeter wave modules used in these industrial digital radios. The modules are also critical for insertion into emerging "point-to-multi-point," terrestrial broadband communications systems.



TRW continues to fill in the blanks. Shown is a bare multi-chip module produced by Milliwave, a company which TRW acquired in October to exploit their GaAs MMIC capability.

The MilliWave acquisition is the third deal in 18 months designed to find a partner to help TRW exploit its GaAs IC technology in telecommunications markets. In March 1996, TRW formed a strategic alliance with RF Micro Devices to supply GaAs HBT chips in high volume for wireless telecommunications systems operating at frequencies less than 10 GHz. TRW is also helping RFMD duplicate the TRW process in RFMD's new fab, which is currently under construction in Greensboro, NC. And in July 1997, TRW formed a strategic alliance with Santa Monica, Calif.-based Multilink Technology Corp. to provide GaAs chips for optoelectronic modules used in high-speed, fiber-optic telecommunications networks. While the RFMD and MilliWave deals will involve analog chips, the Multilink arrangement calls for mixed-signal and digital circuits, operating at speeds ranging from 622 Mb/s to 2.5 Gb/s with the current technology, and extending to 10 Gb/s in the future.

Raytheon Closing in on Hughes Deal

In early October the U.S. Justice Department tentatively approved Raytheon's acquisition of Hughes Electronics Corp.'s defense operations from General Motors. As expected, the agreement requires Raytheon to divest itself of certain businesses to avoid anti-trust conflicts. Raytheon said it would sell off its Dallas, TX-based IR sensor business, recently acquired from Texas Instruments, as well as the ground electro-optical systems business located in El Segundo, CA, and La Grange, GA, that it had proposed to buy from Hughes. The units are believed to account for about \$100 million in revenue.

Commentators say the Justice Department was concerned that, without the divestitures, Raytheon would have nearly 80% of the market for focal-plane arrays. Hughes's electro-optics operations are the industry's largest, and include ground-based radar systems, forward-looking infrared radar used in airplanes' cockpits, and night-vision and laser range finders.

Watkins-Johnson Hangs on to GaAs

Watkins-Johnson has agreed to sell its defense electronics and microwave components and subsystems business for \$103 million to Mentmore Holdings Corporation. Included in the deal are WJ's guided-missile subsystems, YIG-tuned devices and military components business located in Palo Alto, CA. However, the company says it is holding on to its Palo Alto-based GaAs IC foundry as well as its commercial subassemblies and components products for telecommunications infrastructure applications.

"This agreement is truly advantageous to both parties," said W. Keith Kennedy, Jr., president and CEO of Watkins-Johnson. "It provides Mentmore Holdings Corporation with proven, superior technology and a reputation for excellence in the vital defense-electronics market, and it enables WJ to complete its transformation to a company tightly focused on only two high-technology business areas: semiconductor manufacturing equipment and wireless-infrastructure products." He said that the proceeds from the sale would allow WJ to make additional investments to take advantage of the exceptional growth opportunities seen in the company's core technical disciplines.

Developments at Vitesse

Vitesse Semiconductor has opened a design center in Portland, OR which will be responsible for developing high performance telecommunications ICs.

"Growth in the telecommunications market creates strong demand for Vitesse's high bandwidth integrated circuits," stated Bill Woodruff, director of telecommunications products. "Continuing to provide innovative products to meet this demand requires that Vitesse rapidly expand its design capability. In today's growth climate, hiring additional highly-skilled engineers is a challenge throughout the electronics industry. Establishing design centers where the designers are has proven to be an effective strategy for Vitesse," continued Woodruff.

Gary McCormack, formerly an engineering manager with TriQuint, will serve as director of the Portland Design Center.

Vitesse also has a design center at its Camarillo, CA, headquarters; as well as in Santa Clara, CA; Richardson, TX; and a recently opened center in Colorado Springs, CO, which will be in the same facility as Vitesse's new 6" GaAs fab, which is targeted for full-scale production in mid-1998.

In other news, Advanced Micro Devices - one of the largest merchant suppliers of Ethernet chips - recently launched a new Gigabit Ethernet physical-layer device based on Vitesse's GaAs process. The AM79761 GigaPHY operates at 1.25 Gbit/s and is capable of driving fiber-optic modules that support both single-mode and multimode fiber-optic cables. It can also directly drive 25 meters of duplex twinax copper cable, making it suitable for switch-to-switch and server-to-switch connections. The device is manufactured by Vitesse and marketed by AMD - a strategy which AMD reportedly adopted because its own 0.35 μm CMOS process can't support gigabit speeds. However, the company plans to introduce its own products next year, after it moves to a 0.25 μm process. In the meantime, the AMD/Vitesse chip will sell for \$23 in small-volume orders of 1,000.

Lasertron Releases 980nm Laser to Production

Lasertron recently announced that it has released 980nm laser chips into full production. The lasers are based on a license of the "E2" design developed by the IBM Research Lab in Zurich, Switzerland. The E2 technology, which played a key role in enabling the use of erbium-doped fiber amplifiers (EDFAs) based on 980nm pump lasers, was acquired by Uniphase Corporation earlier this year (CS 3(3), p. 20).

Previous 980nm laser products from Lasertron were based on laser chips purchased from IBM, and, later, Uniphase Laser Enterprise (ULE). The chips were then packaged and processed at Lasertron's facility in Bedford, MA. But with this new announcement Lasertron indicates that it is now capable of processing its own chips, including the mirror passivation steps which are a critical part of the E2 process. (See CS 3(2), p. 16). The Lasertron chips will be obtained from laser wafers purchased from ULE. However, according to Lalit Goel, Lasertron's Product Manager for 980nm Pump Modules, the company will eventually become a completely vertically integrated manufacturer of 980nm lasers.

Lasertron is a subsidiary of Oak Industries. The company was founded in 1980, and currently employs 285 people.

ZnSe Substrates

Eagle-Picher of Miami, OK says it is now shipping single crystal ZnSe substrates. Available in 1" diameter, the substrates are produced by seeded physical vapor transport. The standard product has <100> orientation with double-sided polish, but other options are available by request. These are believed to be the first ZnSe substrates produced by an American company.



Eagle-Picher

More IPOs

Aixtron, QED and C3 are all planning initial public offerings of stock in the November - December time frame. MOCVD equipment manufacturer Aixtron will be listed on the Frankfurt Neuer Markt exchange. The company was founded in 1983 as a spin-off of RWTH Aachen, and it claims to have a 30% share of the MOCVD equipment market. 1996 sales were \$25.5 million.

In America, epiwafer vendor QED plans to list on the NASDAQ. The company, which had 1996 sales of just under \$7 million, hopes to raise \$18 - \$20 million to fund expansion. The company, which was founded in 1988, was the first U.S. merchant epiwafer company.

Also in the works is an IPO from C3 Inc. As we reported in our last issue, this company is working closely with Cree Research to develop a SiC-based diamond substitute which is superior to cubic zirconium. (See CS 3(5), p. 21.) The 2-year-old company hopes to raise around \$25 million and list on the NASDAQ.

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Looking Forward to 40 Gb/s

**1997 GaAs IC Symposium
October 13-15, Anaheim, CA**

MARIE MEYER

Crews are hard at work around the world installing new fiber optic networks that will have data rates of 10 Gb/s.¹ But in the R&D labs, the engineers are pushing toward higher rates. Reports discussing circuits for 40 Gb/s optical data systems were especially noticeable at this year's GaAs IC Symposium, which was held October 13-15 in Anaheim, CA.

HBT Circuits for High Speed Optical Transmission Systems

Hitachi and Rockwell both presented two papers each demonstrating a wide variety of HBT-based ICs for fiber optic systems. Rockwell announced a 40 Gb/s 4:1 multiplexer, a >30 Gb/s 1:4 demultiplexer, a DC-26 GHz VGA, and a 26 GHz bandwidth pre-amplifier. All were fabricated from C-doped AlGaAs/GaAs epiwafers purchased from a

merchant supplier. The MUX circuit was especially interesting, as it is believed to be the fastest ever reported. The transistors in the IC had a peak f_t of 60 GHz and f_{max} of 125 GHz.

The Hitachi ICs were fabricated from a InGaAs/InP HBT process which yields an f_t of 147 GHz and an f_{max} of 210 GHz. A chip-set for 40 Gb/s transmissions was reported, including both digital ICs (a modulator driver, a D-type flip-flop at 20 Gb/s, and a 2:1 selector at 40 Gb/s) and analog ICs (a 5-section cascode distributed amplifier, a transimpedance amplifier, and a 2-stage differential amplifier).

Hitachi also presented a paper on even more advanced InGaAs/InP HBT technology, which may also applied to 40 Gb/s ICs in the future. This more experimental process has an f_t of up to 235 GHz. The structure uses an InGaAs collector with an InP subcollector to suppress thermal runaway.²

Big Numbers

A group from Rockwell and UCSD reported a 12 x 12 cross-point switch designed for use in a 40 Gb/s WDM network. Based on AlGaAs/GaAs HBT technology, the circuit operated with a per channel data rate of 10 Gb/s - giving an aggregate data rate of 12 Gb/s, which is one of the highest ever reported.³ The completed switch, which contained ~4600 transistors, measured 4.8 mm x 5.1 mm, and dissipated 7.4 W. To avoid possible localized hot spots, the circuit design spread out functions such as output drivers which require the greatest power.

Even 40 Gb/s is not good enough for some companies. Researchers at NTT say they are pushing toward 100 Gb/s. As a milestone along the way, they report a 2:1 multiplexer (MUX) circuit based on InP HEMT technology that provided an 80 Gb/s operating rate in on-wafer testing. See

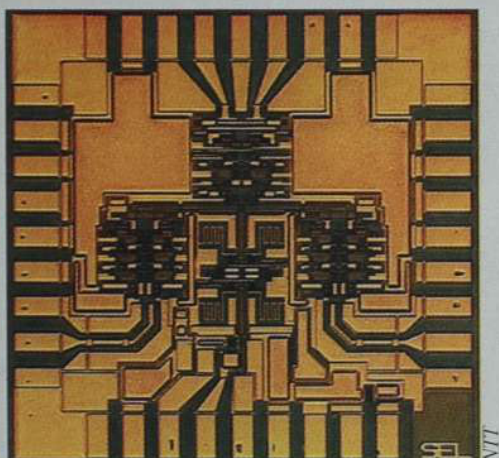


Figure One. Microphotograph of a 2 mm x 2 mm 80 Gbit/s 2:1 selector-type MUX IC based on InP HEMT technology reported by NTT.

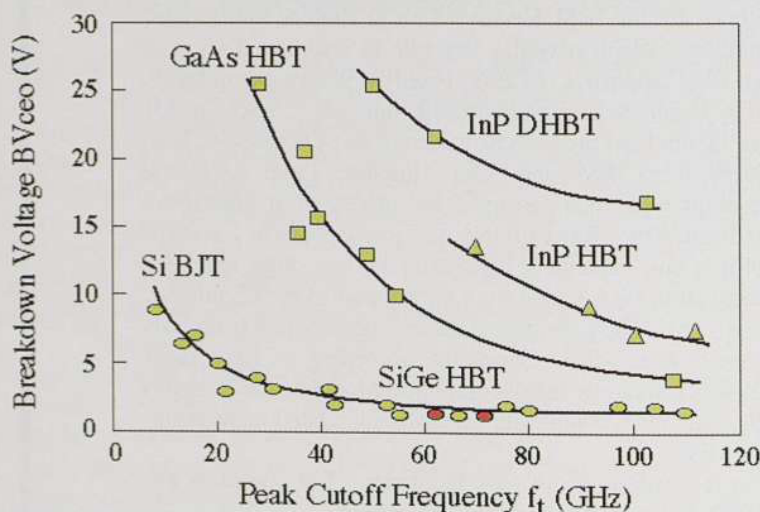


Figure Two. Comparison of representative breakdown voltages vs. peak cutoff frequencies for the major competing RF IC technologies.

Figure One. The previous best result for a MUX, which was reported by this same group, was 64 Gb/s on-wafer and 52 Gb/s in a packaged module. The 0.1 μm process yielded 48% good die (determined by the eye opening) on the best 3" wafer.

InP HBTs Going to Production?

Among the GaAs fabs reporting at this year's conference, slightly more than half discussed HBT circuits. See Table. Roughly 1/3 of all of the papers presented involved HBTs.

One of the most interesting was an invited talk from Dwight Streit of TRW. Earlier this year TRW had released some details about transitioning their 2" InP program to a 3" manufacturing line.⁴ But in this talk, the company discussed their specific plans for volume production of InP devices for the first time, indicating that they anticipate that "InP circuits will follow the same demand curve as demand for GaAs-based HBTs in three to five years" - which means they are planning for production volumes of as many as 10 million InP circuits a month sometime shortly after the turn the century.

The baseline process at TRW produces devices with breakdown voltage $BV_{CEO} = 8\text{V}$ and $BV_{CBO} = 13\text{V}$, and dc current gain ~ 25 . The advantage that InP has in breakdown voltage compared to competing technologies is illustrated in Figure Two. The fully self-aligned process yields f_t and f_{max} of 88 and 140 GHz at $I_c = 60 \text{ KA/cm}^2$ and collector bias of 2V. This is a factor of two increase in frequency performance compared with TRW baseline 1 μm GaAs HBT process, while operating a lower voltage. Nevertheless, these are certainly not records for InP performance. But Streit says that is by design, because "profile changes that can improve f_t and f_{max} performance, such as thinner collector layers and higher base doping, also degrade device breakdown characteristics, linearity and device reliability." Therefore the TRW structure uses relatively thick 700nm collector, and Be base doping of $N_A = 3 \times 10^{19} \text{ cm}^{-3}$.

TRW predicts that demand for InP HBTs will be driven by requirements for lower battery voltages for wireless products. InGaAs-InAlAs-InP HBTs have the natural advantage of a base bandgap of 0.75 eV compared to 1.42 eV for GaAs HBTs. This in turn gives InP HBTs a turn-on voltage $\sim 0.7\text{V}$ compared to $\sim 1.3\text{V}$ for GaAs HBTs. InP HBTs also have superior transport characteristics compared to GaAs HBTs, which allows improved performance at reduced collector bias and current density. Streit reported low-voltage InP HBT power amplifiers with 50% power-added efficiency at 950 MHz with only 1.5V collector bias, and 68% power-added efficiency and 20 dB gain at 1.9 GHz with 2.7V bias. He also discussed prototype MMICs that are currently being sampled by prospective customers that achieve 32 dB gain and 2 watts output power at 950 MHz with a single 3V power supply.

Obviously a major obstacle standing in the way of successful high volume commercialization is the supply of InP sub-

¹ For example, in our last issue (CS 3(5), p. 20), we reported on the construction of the first coast-to-coast 10 Gb/s network in North America.

² The thermal resistivity of InP is 15 to 20 times lower than that of InGaAs.

³ Earlier this year there was a report of a 16 x 16 10 Gb/s crosspoint switch, also based on GaAs/AlGaAs HBTs, from Nortel. See CS 3(5), p. 43.

⁴ See "InP for the Information Society" (1997 IPRM Conference), CS 3(4), p. 8).

Who is Doing What?

Major GaAs Fabs at the 1997 GaAs IC Symposium

France Telecom	InP double HBT for 40 Gb/s optical data transmission systems
Fujitsu	5 GHz A-D converter using HEMTs
Hewlett-Packard	• Deep UV lithography of a 0.15 μm MHEMT; • Parallel optical links for high data rate communication
Hitachi	• InP HBTs for 40 Gb/s optical transmission; • 77 GHz MMIC chipset for automotive radar
Hughes	Highly integrated low power InP HBT ICs for fiber optics
Lucent	III-V MOSFETs using Ga_2O_3
Matsushita	• 1.9 GHz 3 V single-supply normally-off MODFET; • 1.9 GHz receiver die shrink by microbump bonding
Mitsubishi	X-band PHEMT passivation
Motorola	Complementary GaAs for enhancement mode RF amps and rad hard digital processors for space applications
NEC	• 0.1 μm HFET for ultra-high speed ICs; • Low power 10 Gb/s 8:1 Mux/Demux; • 50 GHz bandwidth HBT amps for 40 Gb/s networks; • Low power HFET prescaler IC
Northrup-Grumman	• HBT Reliability; • Microwave & millimeterwave device arrays
NTT	• SiO_2 on GaAs for 19 GHz FET switches; • 80 Gb/s Multiplexer IC using InP HEMTs
Oki	1.9 GHz MMIC upconverter
Raytheon	• HBT modeling; • 1.4 Watt Q-Band PHEMT MMIC amplifier
Raytheon/TI Systems	• Resonant tunneling diodes (RTDs) & circuits; • ESD effects on HBTs; • RTDs & HFETs for A-D converters
Rockwell	• Track-and-hold amp for high speed A-D converters; • 10 Gb/s 12x12 crosspoint switch; • Timing interface unit; • ICs for 40 Gb/s optical communications (All of the above using HBTs)
Sharp	• 1.9 GHz HBT MMIC amplifier; • 60 GHz HBT MMIC VCO
Siemens	• High frequency PHEMT gate design; • 3V 1.8 GHz HBT MMIC with 62% PAE
Toshiba	Single supply 2.4V MESFET amplifier for 1.9 GHz PHS
TriQuint	• RFIC Packaging; • 64 x 33 crosspoint switch
TRW	• Superconductive ICs complimentary to III-V's; • InP HBTs for commercial applications; • PHEMT reliability; • HBT LNAs; • 5.5 GHz HBT fractional frequency synthesizer IC

strates. A steady - though expensive - supply of 2" InP is available, but TRW believes that 3" is the absolute minimum for economically feasible manufacturing. The company is currently participating in several programs to improve the quality and availability of larger diameter semi-insulating InP. While there is clearly much work to be done, Streit reported that "increased demand, higher production volumes, and careful material analysis of 3" InP substrates has yielded lower costs and significant improvements in InP substrate quality".

Next year's GaAs IC Symposium will be held November 1 - 4 in Atlanta, Georgia.

Organic LEDs vs III-V's: Basics, Status and Outlook

Hot on the heels of recent revolutionary developments in semiconductor LEDs, organic LEDs are promising to make a dramatic impact on several applications.

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WALTER RIESS

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In the past five years we have witnessed not one but two dramatic developments in semiconductor LED technology: the commercialization of high brightness LEDs based on the quaternary system InAlGaP (led by Hewlett-Packard), and the rapid emergence of GaN-based blue and green LEDs (led by Nichia Chemical Industries).

There is a new development just now emerging from the laboratory, and it has to potential to be equally dramatic. Organic LED (OLED) technology has seen a wave of interest since the first demonstration of efficient electroluminescence (EL) at Kodak in 1987¹, and the first polymer LED at Cambridge University in 1990². Like semiconductor LEDs, the organic LED technologies now provide efficient operation across the full visible spectrum, and there have been recent reports of lifetimes in excess of 50,000 hours³, which suggests that the commercialization of OLEDs is not far off.

We examine here the potential of OLEDs against the backdrop of existing semiconductor LED technology. While similar at first glance, the underlying physics of OLED operation is quite different from that of semiconductor LEDs. By understanding these differences and the limitations they place on each technology, the applications for which each LED type is best suited become clear.

Basic OLED Operation

Organic LEDs look and function much like conventional semiconductor LEDs.

Figure 1 (a) shows a typical cross-section. OLEDs are generally fabricated on glass

substrates coated with a patterned, transparent, conductive indium-tin-oxide (ITO) anode layer. The organic layers are deposited by sequential evaporation in vacuum (small molecules) or via spin-coating from solution (polymers). Some commonly used organic EL compounds are pictured in Figure 1 (b).

Organic and semiconductor LEDs are based on injection luminescence which is illustrated schematically in Figure 2. Under forward bias: 1) electrons and holes are injected from the contacts, 2) drift or diffuse towards each other, 3) form electron-hole pairs, and 4) recombine radiatively (and non-radiatively).

Despite the similarities, fabricating OLEDs is much simpler. Foremost, deposition occurs on unheated, inexpensive, and arbitrarily large glass or other "low-tech" substrates. Because the organic films are amorphous and Van der Waals bonded, there is no lattice matching constraint on material selection. The OLED emission color is determined by the materials and dopants used in the active region. By changing the active layer dopant e.g., the emission from a blue OLED can be varied across the full visible spectrum. Due to the ease of fabrication, OLED production is considerably less expensive than semiconductor LEDs.

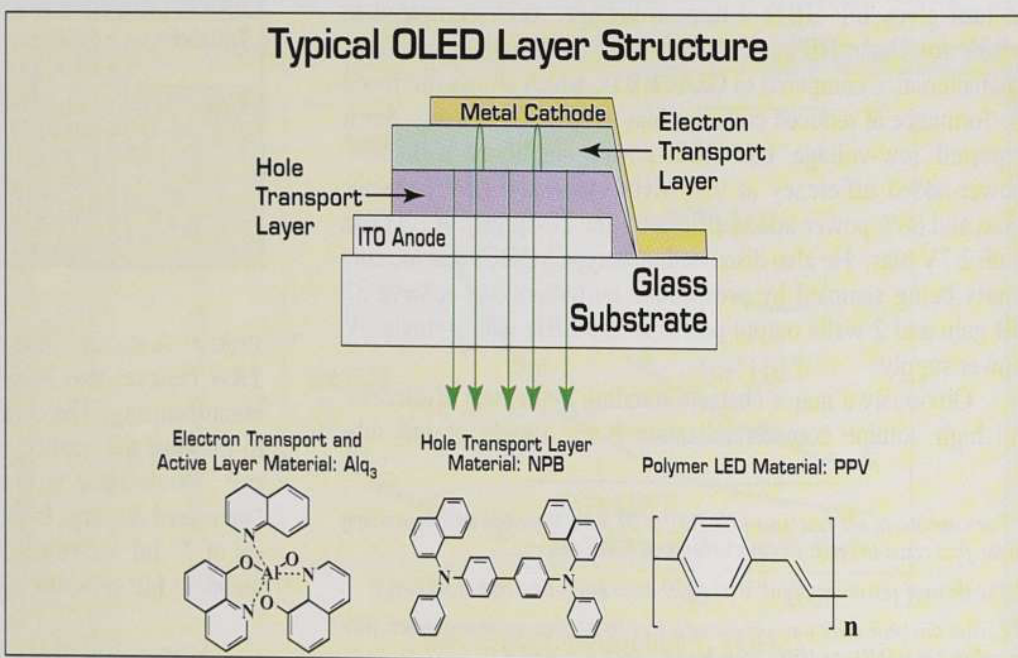


Figure 1. (a) Typical OLED cross section, and (b) Structures of common organic EL materials, Alq₃: tris(8-hydroxy-quinoline)aluminum, NPB: (N,N'-di(naphthalene-1-yl)-N,N'-diphenylbenzidine, PPV: poly-p-phenylene vinylene.

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Basics of Organic and Inorganic LEDs

The fundamental difference between organic EL materials and classical LED semiconductors is the relevant length scales in which the physics of luminescence occurs. This is in turn given by the nature of charge transport in each material class. By understanding these differences, which are tabulated in Table 1, one can understand and derive the performance advantages and limitations of each technology.

Inorganic Luminescence

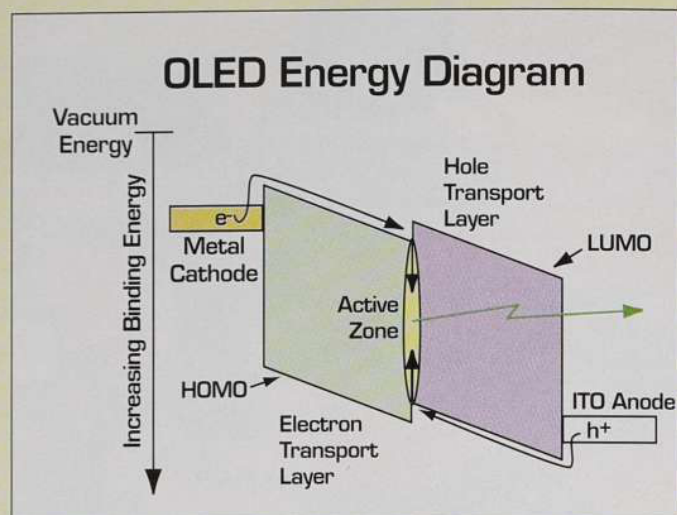
Semiconductor LEDs are characterized by high mobilities ($10^1 - 10^3 \text{ cm}^2/\text{Vs}$) and long radiative lifetimes ($\sim 10 \text{ ns}$) which produce carrier diffusion lengths and mean free paths as large as $1 \text{ }\mu\text{m}$ and $100 \text{ }\mu\text{m}$, respectively. Equivalently, the charge carriers have delocalized wave functions spread over many atoms at a time. Efficient EL requires that injected carriers encounter few or no defects while traversing the crystal, and therefore that the semiconductor lattice have a high degree of perfection. For example, an AlGaAs LED loses half its efficiency at a dislocation density of 10^5 cm^{-2} and barely emits light at 10^6 cm^{-2} (one dislocation per μm^2). GaN is an exception to this rule, but defects are still important, such that high quality GaN LEDs are still only fabricated in a few laboratories. To minimize the defect density, semiconductor LEDs are epitaxial single crystals deposited under ultra-clean, high temperature growth conditions on expensive crystalline substrates.

Organic Luminescence

On the other hand, charge carriers in organic systems are localized on a single molecule or a polymeric functional group at a given time. In the presence of an electrical field, charge transport occurs via a low mobility ($10^{-3} - 10^{-7} \text{ cm}^2/\text{Vs}$) hopping process to adjacent molecules or functional groups along the polymer backbone. The fact that a charge carrier's environment is overwhelmingly dictated by the molecule or functional group on which it resides is responsible for the relative insensitivity of organic EL to defects and impurities. Carrier localization also compensates for the low mobilities by permitting much thinner ($\sim 50 \text{ nm}$), less resistive transport and emitting layers in OLEDs. The balance achieved in organic EL is that carriers are sufficiently mobile to transport charge and recombine radiatively, but not so mobile that they explore an unduly large volume before recombination. Efficient OLEDs may therefore be fabricated at room temperature on nearly any substrate in much less costly environments than semiconductor LEDs.

Figure 2. Energy diagram of an OLED which illustrates the three processes: injection, transport and recombination, needed for efficient OLED operation.

Since organic materials are difficult or impossible to dope, tunnelling ohmic contacts, which are used for semiconductor LEDs, cannot be formed. Therefore choice of the electrode materials which have work functions matched to the energy of the adjacent molecular orbital is critical to minimize the energy barrier over which the carriers must be injected. ITO is a popular anode not only for its transparency, but because its work function is only slightly lower than the highest occupied molecular orbital (HOMO) of common OLED hole transport materials.



The choice of a cathode metal is more problematic since low work function metals are highly reactive and corrode quickly in atmosphere. Cathodes containing Mg, Ca or Li are presently favored for both their low work function and the stability of their interface with the organic electron transport material.

Table 1. Comparison of semiconductor and organic LED carrier mobilities.

LED Type	Electron Transport Layer	Typical Electron Mobility	Hole Transport Layer	Typical Hole Mobility
Inorganic Semiconductor	n-AlGaAs n-InAlGaP n-AlGaIn	$10^2 - 10^3 \text{ cm}^2/\text{Vs}$	p-AlGaAs p-InAlGaP p-AlGaIn	$10 - 50 \text{ cm}^2/\text{Vs}$
Small Molecule OLED	Alq ₃ Oxadiazoles	$10^{-5} \text{ cm}^2/\text{Vs}$	aromatic diamines: TPD, NPB	$10^{-3} \text{ cm}^2/\text{Vs}$
Polymer OLED	PPV	$10^{-7} \text{ cm}^2/\text{Vs}$	PPV	$10^{-5} \text{ cm}^2/\text{Vs}$

Table 2. Comparison of semiconductor and organic LED performance.

LED Type		
Characteristic	Semiconductor LED	Organic LED
Brightness	Usable peak brightness: $10^7 - 10^8 \text{ Cd/m}^2$	Usable peak brightness: $10^2 - 10^4 \text{ Cd/m}^2$
Color Quality	Pseudomorphic QW FWHM $\sim 20 \text{ nm}$	Phonon and disorder broadened EL FWHM $\sim 100 \text{ nm}$
Areal Cost	$\$10^2 - \10^3 cm^{-2}	$\$1 - \10 cm^{-2}
Luminous Efficiency	Blue: 10+ lumens/Watt Green: 30+ lumens/Watt Amber: 60 lumens/Watt Red: 20 lumens/Watt	Blue: 6 lumens/Watt Yellow-Green: 14+ lumens/Watt Orange-Red: 3 lumens/Watt
Lifetime and Reliability	Typical $10^5 - 10^6$ hours operation to 80% brightness	Best value 6×10^4 hours to 50% brightness (green), highly dependent on device encapsulation

Comparison of Semiconductor and Organic LED Performance

Semiconductor LEDs operate more efficiently than OLEDs. This is attributable to internal quantum efficiencies approaching 100% realized through optimized crystal growth, quantum well active regions which promote radiative recombination by confining injected carriers together, and considerable efforts optimizing light extraction. Furthermore, tunneling ohmic contacts into heavily doped semiconductor contact layers and highly conductive, doped transport layers insure that little efficiency is lost to Joule heating. Organic compounds are not easily doped, so the resulting Schottky contacts have barriers to injection of hundreds of meV. Low voltage electron injection requires a cathode material having a low work function (see Figure 2). The low work function metals and alloys commonly used (Mg:Ag, Ca and Al:Li) are reactive and oxidize readily which introduces complications in device handling, and encapsulation is required for long term stability. Further ohmic losses can result from the

low mobility within the charge transport layers. Although many organic compounds have near unity quantum efficiencies for photoluminescence, their EL is fundamentally limited to internal quantum efficiencies $\leq 25\%$ because quantum mechanical selection rules allow radiative recombination only in the singlet exciton variety. Further optimization of OLED materials and contacts will narrow, but not eliminate, the efficiency gap between semiconductor and organic LEDs.

Strong covalent bonding, the ability to dope, and the better thermal conductivity of inorganic semiconductors means that these LEDs can be driven at higher current density (i.e. brightness). Semiconductors favored for LEDs have bond energies larger than their emitted photons which minimizes photoactivated defect creation by self-absorption. In contrast, OLEDs often exhibit Coulombic degradation (i.e. EL decay proportional to integrated drive current) which implies that recombination and aging are related (although less for doped active regions). Furthermore, organic materials, especially the hole transporting small molecule compounds, have poor thermal and chemical stability which can

lead to degradation from device heating, poor encapsulation, and reactions with impurities emanating from the contacts.

Semiconductor EL arises from a narrow linewidth (FWHM ~ 20 nm) band-to-band recombination and can therefore produce highly saturated colors ideal for full color displays (FCD), while OLED recombination is considerably broadened (FWHM ~ 100 nm) by phonon interactions and disorder. However, to tune the color of a semiconductor LED, a new active zone alloy composition must be substituted while maintaining precisely lattice matched conditions in the overall device structure, and for larger wavelength shifts a whole new materials set is needed. On the other hand, the lack of lattice matching constraints permits an OLED to be tuned by replacing the active region organic material or dopant. Therefore, an OLED FCD could be fabricated by depositing different active layers through shadow masks into otherwise identical vertical organic layer stacks. This approach is unthinkable for inorganic semiconductors whose FCD applications are presently limited to architectures comprising numerous discrete semiconductor LEDs.

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Applications of OLEDs

OLEDs can find wide use in applications where they compare favorably with semiconductor LEDs, especially those utilizing the ability to deposit OLEDs inexpensively over large areas. At the low end, inexpensive lighting is an attractive opportunity, provided that high brightness is not required. Applications such as automobile overhead lamps or customized, disposable signs are being considered. But first, the temperature stability of OLEDs will have to be improved to meet rather demanding specifications.

Low information content passive matrix OLED displays can be fabricated simply by a grid of ITO/glass rows and metal columns sandwiching the organic stack. Such OLED displays are envisioned for automotive dashboard displays and navigation systems, or dot matrix displays for electronic equipment. Pioneer Corporation has developed particularly impressive dot matrix OLED displays (see Figure 3) for these applications⁴.

Other research groups are aiming at the higher information content Flat Panel Display (FPD) market. Much underlying FPD technology developed for LCDs can be inexpensively adapted to OLEDs. A common approach is to fabricate an array of amorphous or polysilicon Si thin film transistors with ITO contact pads on a glass substrate, followed by the OLED layers. This approach substitutes OLEDs for the backlight, polarizers, and liquid crystal light valve increasing the overall efficiency and potentially the color quality. One complication is that Si circuitry must be altered to drive a constant current as opposed to the constant voltage needed for LCDs.

Achieving full color at high pixel density with OLEDs is still problematic, but several approaches have emerged for color patterning at the <100 micron pitch required. Shadow masking becomes technically difficult at such small pitches, especially since it must be one in the UHV OLED deposition environment. To avoid shadow masking altogether, a group at Princeton⁵ sequentially deposits blue, green and red LEDs in a vertical stack structure. This process is being commercialized by Universal Display Corp.

An approach pioneered at Hitachi and Bell Labs is to deposit a white emitting OLED onto a distributed Bragg reflector (DBR) which is selectively etched back. The DBR and the top OLED metal, creates an array of Fabry-Perot cavities with three distinct lengths, each able to extract one primary color, while inhibiting EL at the other wavelengths.

Another approach is to fabricate a monolithic white OLED structure onto a color filter array (CFA), similar to the CFAs used in LCD technology. This approach eliminates much of the OLED efficiency gains since at least ~3/4 of the white light is absorbed in each CFA, but is straight forward to implement. TDK has announced such an OLED display. An improved approach, pioneered at Idemitsu Kosan, is to replace the CFAs with color converter arrays (CCA), and the white OLED with a more efficient blue one. Via the same process by which dye lasers operate, CCAs down convert blue photons to red or green with efficiencies of 90% or more. Idemitsu Kosan has recently demonstrated a very impressive 5" quarter VGA (320x240, 90 μm x 300 μm pixels) OLED FCD capable of video rate images with 256 gray scales (see Figure 4). These results, coupled with widespread and growing industrial interest in Japan, the U.S. and Europe, bodes well of a bright future for OLEDs.

References

- ¹ C. Tang and S.A. VanSlyke, *Appl. Phys. Lett.* 51 (1987) 913.
- ² J.H. Burroughes, et al, *Nature* 357 (1990) 539.
- ³ C.W. Tang, *Information Display Vol. 12, no. 10* (1996) 16.
- ⁴ T. Wakimoto, et al, *SID International Symposium San Diego, May 12-17 (1996)*; H. Nakada, and T. Tohma, in *Inorganic and Organic Electroluminescence EL 96*, ed. by R.H. Mauch and H.E. Gumlich, p. 385.
- ⁵ Z. Shen, P.E. et al, *Science* 276 (1997) 5321.

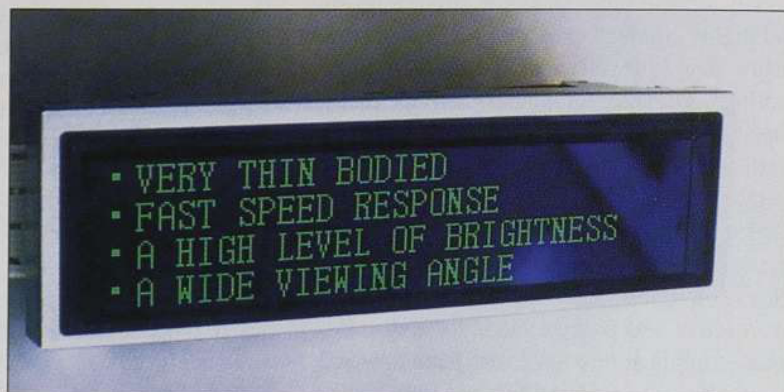


Figure 3. The Pioneer Electronic Corporation OLED dot matrix monochrome display. Specifications: luminance: 100cd/m², pixel count and size: 256x64, 0.34x0.30mm, contrast ratio: > 100:1. (photo courtesy Dr. Tetsuo Tohma, Pioneer Electronic Corp).



Figure 4. An Idemitsu Kosan full color quarter VGA OLED display (photo courtesy Dr. Tadashi Kusumoto, Idemitsu Kosan).

Contributions Welcome!

We welcome contributions which discuss technology or applications of interest to our readers. Inquiries or submissions should be sent to

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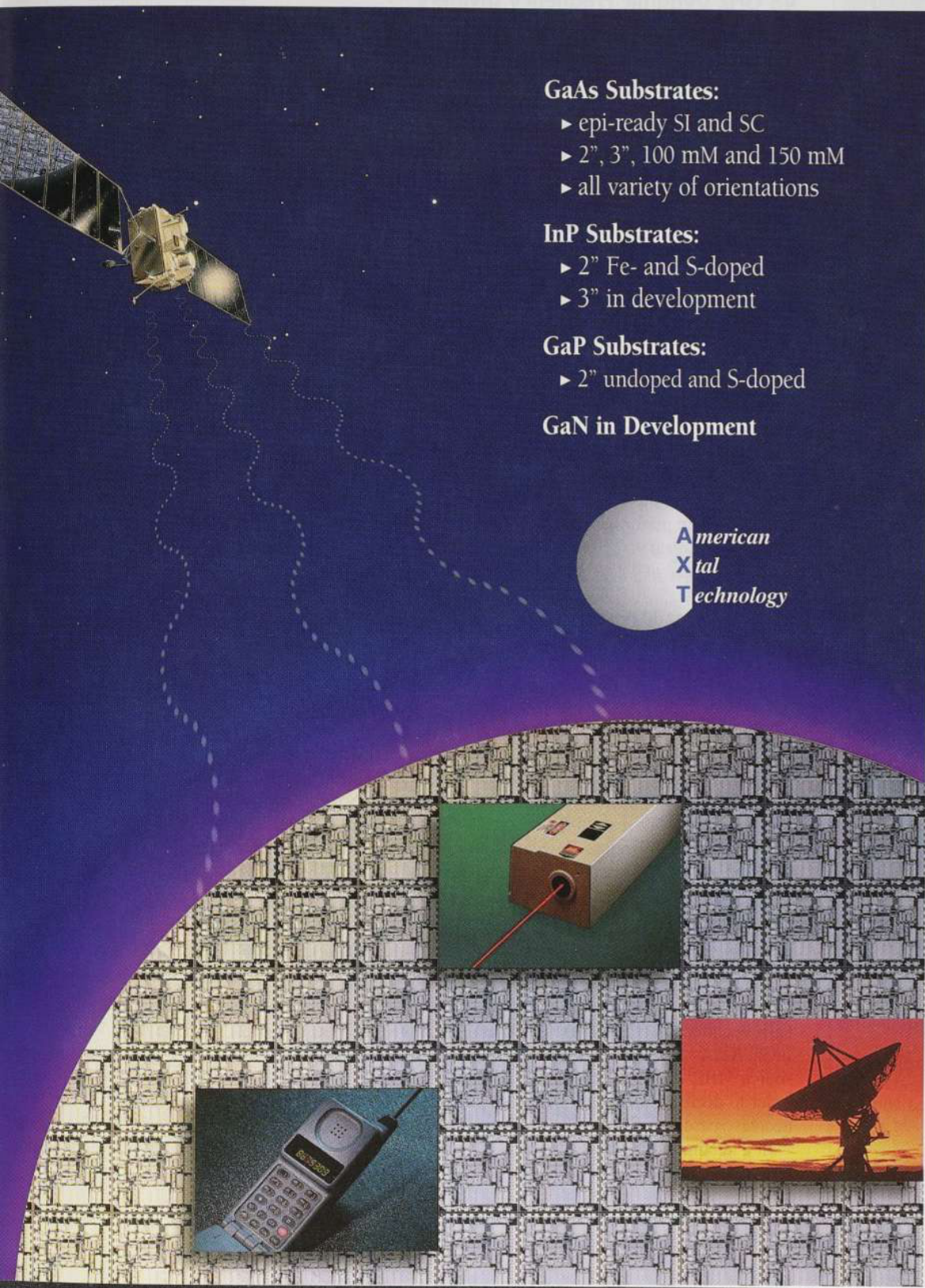
- ▶ 2" Fe- and S-doped
- ▶ 3" in development

GaP Substrates:

- ▶ 2" undoped and S-doped

GaN in Development

American
Xtal
Technology



High Power HBTs with Reduced Base-Collector Capacitance

There is growing demand for power HBTs in X through K band (8-26 GHz) applications. Their high power densities, operating voltages, efficiencies, and high degree of linearity make them ideal replacements for travelling wave tubes which have historically supplied RF power for this frequency range. This is especially true for satellite communications systems in which the HBT's smaller size and lower cost are particularly advantageous. Traditionally, improvements in HBT performance have come about by either more refined epitaxial structures, or by using InP instead of GaAs. But as these devices and materials systems mature, further device performance improvements are typically obtained through reduction of parasitics. In the case of the HBT, a major limitation to RF device performance is due to the collector-base capacitance. Two different groups have recently reported on the reduction of collector-base capacitance in HBTs, and the RF performance obtained as a result of this reduction.

Researchers at the Hughes Research Laboratories report on the modification of the collector-base structure in AlInAs/InGaAs/InP DHBTs by the use of selective wet etching to create a micro-airbridge base connection, and to remove the extrinsic collector material from under the base material. As a result, the base-collector capacitance is reduced by 80%. For Class B operation at 18 GHz, an eight-finger $2\text{ }\mu\text{m} \times 30\text{ }\mu\text{m}$ power cell achieved 1.17 W output power (or 4.88 W/mm power density), with 54% PAE and 7.3 dB gain, which are the best combination of PAE and output power reported for this power density at K-band frequencies.

In a similar approach, researchers at Texas Instruments placed two AlGaAs etch stop layers in the collector and sub-collector layers of an AlGaAs/GaAs HBT, and used a BCl_3/SF_6 RIE plasma to selectively remove the extrinsic GaAs collector material from between the two AlGaAs etch stop layers. This approach resulted in a 50% reduction of base-collector capacitance. Operating at 10 GHz, a $10 \times (2.8 \times 50)\text{ }\mu\text{m}^2$ HBT unit cell delivered 2.09 W output power (or 4.18 W/mm power density) with a 62.2% PAE and 7.13 dB gain. When the transistor was tuned for maximum efficiency, a record PAE of 74.2% was obtained at an output power of 1.36 W and a gain of 7.32 dB.

See Robinder S. Virk et al, IEEE Microwave and Guided Wave Letters, 7(10), 323 [October 1997], and Hin-Fai Chau et al, IEEE Microwave and Guided Wave Letters, 7(9), 288 [September 1997].

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

48 GHz Dynamic Frequency Dividers

Zhihao Lao et al, IEEE Journal of Solid State Technology, 32(10), 1556 [October 1997].

High speed frequency dividers are key components in measurement equipment, microwave, and satellite communication systems. Static and dynamic frequency dividers (both 2:1 and 4:1) based on enhancement and depletion mode $0.2\text{ }\mu\text{m}$ gate length AlGaAs/GaAs HEMTs with f_s of 60 and 55 GHz, respectively, were fabricated. The static frequency dividers which use master-slave toggle flip-flops, operate up to 35 GHz, the fastest speed yet realized in HEMT technology, while the dynamic frequency dividers operated at 48 GHz, the fastest speed reported for AlGaAs/GaAs HEMT technology. The power consumption is 250 mW for the 2:1 dividers and 350 mW for the 1:4 dividers which use two supply voltages of 4 and -2.5 V. Work performed at the Fraunhofer Institute [Freiburg, Germany].

A 50 MHz to 55 GHz InP-Based HBT Amplifier

K.W. Kobayashi et al, IEEE Microwave and Guided Wave Letters, 7(10), 353 [October 1997].

Distributed amplifiers are finding more applications for high data rate ($>40\text{ Gb/s}$) lightwave communications due to their inherently high bandwidth capabilities. Distributed amplifiers have been fabricated utilizing a $1\text{ }\mu\text{m}$ InAlAs/InGaAs/InP-based HBT technology in which devices exhibit f_s and f_{max} of 80 and 200 GHz, respectively. The distributed amplifier exhibited a 50 MHz to 55 GHz bandwidth, these values representing both the widest bandwidth and highest frequency of operation for a bipolar amplifier. Key to this wide bandwidth was the use of active load terminations used on both the input and output distributed amplifier transmission lines, which extended the low-frequency gain performance down to baseband. Consuming only 82 mW of dc power, the amplifier exhibited a gain of 7.6 dB at 50 MHz, 5.7 dB at 30 GHz, 5.8 dB at 50 GHz and 3.1 dB at 55 GHz. Work performed at TRW [Redondo Beach, CA]. (146)

AlGaIn/GaN MODFETs with 1.7 W/mm at 10 GHz

Y.-F. Wu et al, IEEE Electron Device Letters, 18(9), 438 [September 1997].

Improved high frequency characteristics of an AlGaIn/GaN MODFET was achieved by reducing the donor layer thickness to $200\text{ }\text{\AA}$, which increased the gate-source capacitance and improved f_t . $0.2\text{ }\mu\text{m}$ gate length devices were fabricated from an epi structure with sheet carrier density of $8 \times 10^{12}\text{ cm}^{-2}$ and a mobility of $1200\text{ cm}^2/\text{Vs}$. This device exhibited a record level f_t of 50 GHz, and high channel saturation current and transconductance of 800 mA/mm and 240 mS/mm , respectively. At 10 GHz operation, this device exhibited a CW output power density of 1.7 W/mm , exceeding the previous record for a solid-state HEMT. Work performed at the University of California [Santa Barbara, CA], the Hughes Research Laboratories [Malibu, CA], Wright State University [Dayton, OH] and Wright Laboratory [Wright-Patterson AFB, OH].

InGaP/GaAs Ballistic Collection HBTs

K. Mochizuki et al, Electronics Letters, 33(18), 1584 [28 August, 1997].

Ballistic collection HBTs use a bandgap designed electron launcher at the base-collector interface, which decreases electron transit time and increases f_t . However, these devices typically utilize narrow collectors ($<200\text{ nm}$), which result in large base-collector capacitances which degrade f_{max} . InGaP/GaAs ballistic collection transistors with 150 nm thick collectors have been grown by gas source MBE which incorporate a high resistivity poly-GaAs on SiO_2 beneath the base electrode in order to decrease the base-collector capacitance, and a heavily carbon doped base ($1 \times 10^{20}\text{ cm}^{-3}$) to decrease base resistance. The resulting device exhibited both f_t and f_{max} values of 170 GHz, along with a maximum stable gain that was increased by 2.3 dB as compared to transistors which did not incorporate the polycrystalline GaAs. Work performed at Hitachi [Tokyo, Japan].

Compound Semiconductor Materials

Schottky Barrier Heights and Conduction-band Offsets of InGaAsP Lattice-Matched to GaAs

J.-K. Lee et al, Appl. Phys. Lett. 71 (7), 912 [1997].

The Schottky barrier heights of Au/In_{1-x}Ga_xAs_{1-y}P_y contacts have been determined as a function of y by capacitance-voltage and temperature dependent current-voltage measurements. The barrier height is observed to increase as y is increased for both n - and p -type materials, with a more rapid increase for the p -type material. The compositional variation of the barrier heights for Au/In_{1-x}Ga_xAs_{1-y}P_y is found to be identical to that of the conduction-band offsets in In_{1-x}Ga_xAs_{1-y}P_y/GaAs heterojunctions. A possible cause for this phenomenon is discussed. Work done at Seoul National University (Korea) and Northwestern University, Evanston, IL.

Ti-Gate Metal and pHEMT Degradation in Hydrogen

P. C. Chao et al, IEEE Electron Dev. Lett. 18 (9), 441 [1997].

Accelerated life tests in hydrogen reveal that the Ti metal in Ti/Pt/Au gate pHEMTs can also cause a degradation of the device performance by reacting with hydrogen gas in the ambient. The degradation is significantly smaller than with Pt and, since Ti is not a hydrogen catalyst, the hydrogen sensitivity indicates that no catalytic reaction is required for hydrogen degradation to take place. The data show that the Ti-H₂ degradation is of a similar nature to that from the Pt-H₂ interaction, and suggest that eliminating the Pt gate metal in pHEMTs to solve hydrogen degradation problems does not address the root of the problem. Work done at the Lockheed Martin Co.

Ohmic Contact Formation in AlGaIn/GaN Heterostructures

Q. Z. Liu et al, Appl. Phys. Lett. 71 (12), 1658 [1997].

The contact formation process of Ti/Al and Ti metallizations on AlGaIn/GaN heterojunction field effect transistors (HFETs) was investigated. The Ohmic contact formation arises because of the low work function of the Ti contacting layer and the formation of a TiN phase at the Ti/nitride interface. Contact resistances as low as 1 Ω -mm or less can be obtained on appropriately doped AlGaIn/GaN HFET samples and on n -GaN with a carrier concentration of 1.5×10^{18} cm⁻³. The Ti/Al bilayer contact scheme is superior to pure Ti contacts due to a surface Al₃Ti layer in the bilayer contact, which may reduce the oxidation problem during high temperature annealing cycles in nitrogen. The Ti/Al contact scheme yields sufficiently low HFET contact resistances for microwave applications. Work done at the University of California, San Diego, and APA Optics Inc. (Blaine, MN).

Bandgap Bowing in Epitaxial AlGaIn Alloys

H. Angerer et al, Appl. Phys. Lett. 71 (11), 1504 [1997].

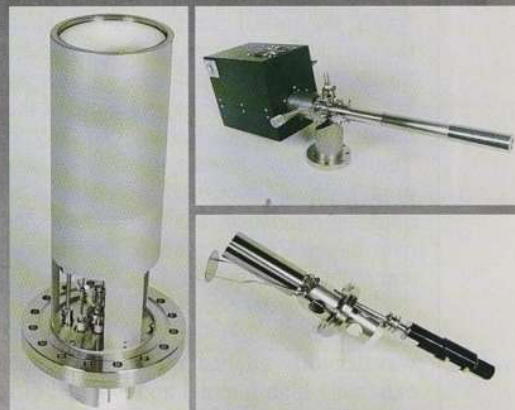
Al_xGa_{1-x}N alloys were grown on c -plane sapphire by plasma-induced molecular beam epitaxy. The Al content x was varied over the full composition range ($0 < x < 1$). The Al molar fraction was deduced from x-ray diffraction and by elastic recoil detection analysis. The composition of the alloys calculated from the lattice parameter c underestimates x . This is due to a deformation of the unit cell. The exact Al mole fraction and the biaxial strain of the alloys can be calculated by an additional determination of a , using asymmetric reflections. The results obtained by x-ray diffraction and elastic recoil detection provide evidence for the validity of Vegard's law in the AlGaIn system. In addition, the deviation of the band gap from a linear dependence on x was investigated. A downward bowing with a bowing parameter $b = 1.3$ eV was found to lead to a maximum deviation of approximately -0.3 eV with respect to the linearly interpolated energy gap for AlGaIn. Work done at the Walter Schottky Institut, and the Technische Universität, München, Germany.

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Broad-Waveguides Lasers for High Power Operation

Researchers from David Sarnoff Research Center, together with collaborators from University of Wisconsin-Madison and from Princeton, have recently set several records in high power lasers using broad-waveguide designs. The idea is to build edge emitting quantum well lasers with waveguides that are many times thicker than those conventionally used. This single design change produces several effects that can improve the high power performance.

The first effect is simply the spreading of the power over a larger thickness, allowing a smaller power density for a given amount of total power. The smaller power densities alleviate the problem of catastrophic optical mirror damage (COMD). A second effect is related to the fact that narrow waveguides tend to "push" the optical mode into the cladding layers, where the optical loss is high due to free carrier absorption. So the broad-waveguide design decreases the optical loss of the lasers by keeping more of the optical mode out of the clads. Losses are typically lowered by 4X. The lower loss, in turn, enables longer cavities to be used without excessive degradation in differential quantum efficiency. Longer cavities spread the current over larger areas, producing reduced current densities and reduced heating for the same total current.

Last year the Sarnoff group reported broad-waveguide lasers at 0.81 μm , 0.97 μm , 1.5 μm and 2.0 μm wavelengths- all had record low optical losses and extremely high internal and external differential quantum efficiencies. Over the past few months, they have reported power records at 0.97 - 0.99 μm and 1.43 μm wavelengths. In the shorter wavelength band, 14.3 W of quasicontinuous output power was obtained, a record for any type of wide stripe diode laser. These devices were constructed of aluminum-free materials on GaAs substrates. Other impressive numbers for these devices: 1 cm⁻¹ optical loss and COMD at 22.5 MW/cm². At a wavelength of 1.43 μm , broad-waveguide devices produced continuous and quasicontinuous power records of 5.2 and 10 W, respectively. The epitaxial materials were InGaAsP/InP on InP substrates. An advantage of the materials used for lasing wavelengths greater than 1.1 μm is the absence of COMD. The output power of these devices is limited by thermal considerations, rather than COMD.

In addition to the high power and low loss characteristics of the broad waveguide lasers, both the 0.97 μm and 1.43 μm lasers exhibited excellent mode characteristics. The modulation of the near field was less than 10% and the far field pattern was single-lobed. These observations suggest that filamentation is not a problem in these devices throughout the entire range of operation.

See D.Z. Garbuzov et al, *Elec. Lett.* 33 (17), 1462 [14 August 1997]; A. Al-Muhanna et al, *Appl. Phys. Lett.* 71 (9), 1142 [1 September 1997]; D.Z. Garbuzov, *Elec. Lett.* 33 (19), 1635 [11 September 1997].

Optoelectronic Devices

Interband Cascade Laser with Differential Quantum Efficiency Greater than 100%

R.Q. Yang et al, *Appl. Phys. Lett.* 71 (17), 2409 [27 October, 1997]
C.L. Felix et al, *IEEE Photonics Techn. Lett.* 9 (11), 1433 [November, 1997].

Quantum cascade lasers are constructed to enable electrons to traverse multiple active regions. In each active region, electrons have the possibility of emitting photons. So it is theoretically possible for many photons to be emitted for each injected electron, i.e., to have a differential external quantum efficiency of greater than 100%. This characteristic makes quantum cascade lasers quite distinct from conventional diode lasers that may approach 100% differential external quantum efficiency, but never exceed it. The original version of the quantum cascade laser operates on intersubband transitions in the conduction bands of quantum wells. These transitions suffer stiff competition from non-radiative, phonon-assisted energy relaxation, and as a result have low quantum efficiency. A newer version of the quantum cascade laser avoids this non-radiative competition by operating on interband, type II transitions. These transitions occur from the conduction band of an InAs quantum well to the valence band of a GaInSb quantum well. Recent improvements in material quality of such structures have enabled University of Houston and Naval Research Laboratory scientists to break the 100% mark for the first time, obtaining differential quantum efficiencies of 130%, which corresponds to 6% per active region. The devices lase at 3-4 μm wavelengths, operate at temperatures up to 225K, and emit powers up to 430 mW.

370 GHz Bandwidth Photodetector

Yi-Jen Chiu et al, *Appl. Phys. Lett.* 71 (17), 2508 [27 October, 1997].

An ultrafast photodetector was recently reported by researchers from University of California at Santa Barbara. The key aspects of the device are the use of low-growth-temperature (LT) GaAs and an edge-coupled traveling wave p-i-n photodetector (TWPD) design. The LT-GaAs was used because of its short carrier lifetime. The TWPD design is an advantage over conventional vertical structures, which can only obtain high speed at the expense of low quantum efficiency. When excited with a 800 nm optical pulse of 100 fs duration, an electro-optically determined response of 1.1 ps was measured. The Fourier transform power spectrum of the measured signal shows a 3dB bandwidth of 370 GHz. This is the highest reported bandwidth for any p-i-n photodetector. The external quantum efficiency was measured to be 8%. The UCSB researchers expect that the design should be able to be optimized to achieve sub-picosecond response times with quantum efficiencies over 20%.

Temporal Characteristics of Violet Lasers

S. Nakamura et al, *ICNS'97 Conference*, Tokushima, Japan [30 October, 1997].

The recent Nichia InGaN laser result, which used epitaxial lateral overgrowth to obtain an extrapolated room temperature lifetime of 10,000 hours, is the biggest recent news in diode lasers (see article on page 4). In addition to the impressive lifetimes, these devices exhibited interesting temporal characteristics. At drive currents above 1.3 times threshold, self pulsating operation is observed. The frequency of the pulsation is 3.5 GHz. Self pulsation has been seen in other types of laser diodes and is usually caused by a saturable absorber in the laser cavity. In the InGaN laser, the saturable absorber may be the InGaN buffer layer, or may be related to the indium composition fluctuations of the InGaN active layer, which have been reported previously.

Red Lasers from Toshiba

Irvine, CA. In late September Toshiba announced the U.S. availability of three new visible (650 nm) laser diodes for use in bar code scanning and alignment type applications, as well as DVD ROM and DVD players.

The TOLD9442M is based on Toshiba's DVD laser technology but is modified for bar code scanning and alignment applications. The TOLD9450MC, featuring low noise and self-pulsation, is designed for DVD player applications. The TOLD9441M, which offers high operating temperatures and high power, is suitable for DVD players and DVD-ROM applications.

All three diodes come in of 5.6 mm dia. packages. Sample pricing for the TOLD9442M is \$10.00 each, the TOLD9450M is priced at \$25.00 each and TOLD9441M is priced at \$19.00. All are in full production.



Toshiba

Part Number	TOLD9442M	TOLD9450M	TOLD9441M (self-pulsating)
Wavelength (typ.)	650nm	650nm	650nm
Output Power (max)	5mW	5mW	7mW
Threshold Current	30mA	75mA	40mA
Operating Current	35mA	85mA	50mA
Beam Divergence:			
Parallel	8 degrees	8.5 degrees	8 degrees
Perpendicular	28 degrees	33 degrees	28 degrees
Monitor Current	0.25mA	.03mA	0.25mA
Operating Temp.	-10 to +60°C	-10 to +60°C	-10 to +70°C
Feature	High Visibility	Low Noise	High Temp

New 980nm Pump Module from SDL

San Jose, CA. SDL has announced the availability of a new high power 980 nm pump module for the 1.5 μ m erbium doped fiber amplifier (EDFA) market. This product is a higher power version of the standard SDL-21 00 series pump module which offers 125 mW of power. The new SDL-2100-150 delivers 150 mW of kink free optical power. SDL says the 20% increase in power is a result of continuous improvements in both chip and coupling efficiency performance.

This module was developed to meet the need for more power in the next generation of dense wavelength division multiplexing (DWDM) systems. Donald R. Scifres, chairman and chief executive officer, noted, "The performance benefits of this new module show SDL's commitment to lead the market for high power, reliable pumps which in turn enables our customers to lead in the development of new systems. This new product employs SDL's patented fiber Bragg grating stabilization technology which ensures power and wavelength stability in these demanding applications."

SDL also recently announced the introduction of the 8610-1550, a high-power, fiber-coupled tunable laser system. This single-frequency laser is tunable over a 70 nm wavelength range centered between 1540 nm and 1560 nm. The laser system offers a fiber-coupled output of +8 dBm and an extremely low relative intensity noise of less than -160 dB/Hz.

This system is one member of a new family of system level products from SDL designed for the telecommunications industry. The 8610-1550 is intended for both the R&D and OEM communications markets, in applications such as LIDAR, satellite communications, cable television, DWDM, and nonlinear studies.

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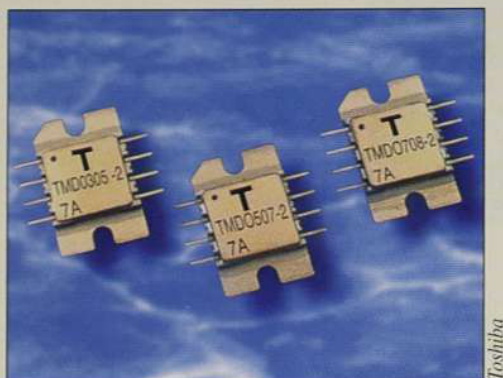
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C-Band MMIC Modules from Toshiba

Irvine, CA. Toshiba recently introduced three new GaAs C-Band MMIC modules with frequencies ranging from 3.7 - 5.1, 5.1 - 7.2 and 7.1 - 8.5 GHz. Designated TMD0305-2, TMD0507-2 and TMD0708-2, the modules are targeted towards satellite, military and wireless communications, as well as point-to-point radio. According to the company, because the new MMIC modules can operate at a wider range of frequencies, a single MMIC module replaces the multiple narrow-frequency modules previously needed.

Pricing in 100 piece quantities is \$124. Full production is now in progress.



C-Band MMIC Product Specifications

Part Number	TMD0305-2	TMD0507-2	TMD0708-2
Frequency	3.7-5.1GHz	5.1-7.2GHz	7.1-8.5GHz
P1dB (dBm) (typ)	33.0	33.0	33.0
G1dB (dB) (typ)	22.0	22.0	22.0
IDD (A) (typ)	1.6	1.6	1.6

Analog Optoelectronic Amps from Vitesse

Camarillo, CA. Vitesse has introduced four new transimpedance amplifiers for use in Synchronous Digital Hierarchy (SDH) optoelectronic telecommunications systems. The VSC7902 and VSC7903 are designed for 155Mb/s operation, while the VSC7911 and VSC7912 are for 622Mb/s data rates. Two amplifiers are offered at each data rate to meet both single-ended and differential output configurations. All of the amplifiers are designed for use with commercially available long-wavelength optical detectors.

This series of transimpedance amplifiers is intended to provide highly integrated solutions for converting the current produced by a photodiode into a voltage suitable for digital data recovery.

SDH specifications place stringent demands on high-bandwidth optoelectronic amplifiers. According to Vitesse, the availability of these amplifiers has been

limited because only specialized microwave analog GaAs technologies have been capable of meeting the required performance, and these technologies "are typically low-yielding". But, according to Ray Milano, director of Analog Product, "through the last decade, Vitesse has developed a robust digital and mixed-signal GaAs IC technology that is now being used to fabricate analog optoelectronic components. With this process, fabricating digital communications ICs with a million transistors is common practice. Our high-yielding VLSI process is now being used to deliver these new analog optoelectronic circuits in volume and at a price that substantially undercuts other optoelectronic GaAs products."

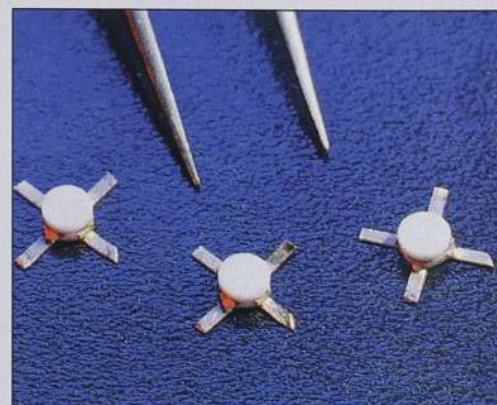
Pricing per unit for 10,000 units is \$8 for the VSC7902 and VSC7903, and \$25 for the VSC7911 and VSC7912. Samples are available now.

Celeritek GaAs FET

Santa Clara, CA. Celeritek has introduced a new, low-noise, high dynamic range GaAs FET intended for in receivers in cellular and PCS base stations and industrial data networks. It produces less than 1 dB noise figure across the 0.8 to 2.0 GHz frequency range, with 34 dBm 3rd order intercept point. The CFB0301 is a GaAs MESFET with 600 (m gate width and 1/4 (m gate length. According to Celeritek, the low noise figure and high intercept point of this device makes it well suited for use as the low-noise amplifier of the base station receiver in PCS, Japanese PHS, AMPS, GSM and other communications systems. It comes in an industry-standard 70 mil package. Samples are available from stock. Quantities of 100,000 are priced at \$3.50 per unit.

Celeritek also recently announced the availability of a new low-cost 3V power amplifier for PCS handsets. The Model CMM1330 is intended for both TDMA and CDMA amplifier applications. A 3-stage device, it produces greater than +30 dBm TDMA digital output power from a standard +3 volt supply, with 40% linear power efficiency and 30 Db of gain. The same device produces 28 dBm CDMA digital output power at 35%. It comes in a surface mount SO-8 power package. Samples are available from stock. Quantities of 1,000 are available 30-45 days ARO and are priced at \$18.00 per unit.

Also new from Celeritek is a new 5 V power amplifier for 1.8 -1.9 GHz PCS handsets. The Model CMM1321 features 28.5 dBm CDMA output power with 30% PAE and 24 dB of gain. Quantities of 100,000 are priced at \$5.50 per unit.



Quite a Fall

Like stocks everywhere, the Compound Semiconductor Portfolio looks more volatile after the events of October

MARIE MEYER

The last two weeks of October will not be soon forgotten by anyone who watches the stock market. Stocks plunged on every exchange around the world. Not surprisingly, decliners exceeded advancers in the Compound Semiconductor Portfolio as well, with TriQuint suffering the worst - see next page. However, the majority of Portfolio companies are still up by more than 20% since the first of the year.

As this issue went to press, there signs of a rebound in the overall markets. Whether this will impact the Portfolio stocks remains to be seen.

Ironically, several of the Portfolio companies reported good results for the quarter which ended in September. But the good news seemed to get lost in the turmoil. Consider, for example, Vitesse, which has been the undisputed leader in the compound semiconductor related stocks. On October 21 they reported they had increased revenues by 61%, and more than doubled their profits. The market's response? Three days later, Vitesse's share prices hit their lowest point in five months, indicative of a bearish mood in the market.

Shareholder Lawsuit Against Cree Dismissed in Landmark Case

On October 20 Cree Research announced that class action lawsuits brought against the company and its directors and officers last year have been dismissed. The suits, filed in October and December 1996, had been consolidated and were pending before a U.S. District Court in North Carolina. The plaintiffs alleged that public statements about Cree's anticipated blue LED production had artificially inflated the value of its shares. In a ruling issued October 17, 1997, the court granted the defendants' motions to dismiss, finding that the company's statements were immune from liability under the safe harbor provisions of the Private Securities Litigation Reform Act of 1995.

Neal Hunter, Cree's President and CEO, commented: "The decision vindicates the integrity of our organization and the named individuals. We maintained that the litigation was without merit and are pleased the court has agreed."

Legal experts said that this is the first case to be dismissed in its entirety on the basis of the controversial "safe harbor" law, which is designed to shield companies from lawsuits. It protects companies from liability from securities fraud when forward-looking statements don't materialize, as long as those statements are accompanied by "meaningful cautionary language."

It is not yet known whether the plaintiffs will appeal or seek other relief from the dismissal, which was without prejudice.

Company	Symbol	Exchange	Last 52 Weeks		Closing Price		Change	Average Daily Volume	P/E Ratio	Market Cap (\$M)	% Held by Institutions
			Hi	Lo	Jan 2	Oct 31					
Alpha	AHA	AMEX	19 7/8	5 1/2	8	15 7/8	98%	101,000	◆	162	44
Anadigics	ANAD	NASDAQ	54 1/5	20	25 1/3	37	46%	330,000	30	578	61
APA Optics	APAT	NASDAQ	9 1/4	4 1/4	4 1/2	8 5/8	92%	8,000	◆	70	2
ATMI	ATMI	NASDAQ	42 1/4	12 1/4	16 7/8	26 7/8	59%	109,000	55	272	42
Celeritek	CLTK	NASDAQ	18 3/8	9 3/16	15 1/2	15 1/2	0%	70,000	30	108	48
Cree Research	CREE	NASDAQ	27 3/4	8 7/8	10 5/8	25 1/8	136%	305,000	■	347	27
Emcore	EMKR	NASDAQ	25 1/4	9 1/4	10 5/16*	19 1/4	87%	65,000	◆	111	18
Int'l Semi Corp	ISSM	OTC	1 1/8	1/32	9/16	1/32	-94%	41,000	◆	0.3	na
Kopin	KOPN	NASDAQ	29	7 1/4	11 5/8	21 1/4	83%	108,000	◆	231	14
Ortel	ORTL	NASDAQ	25 5/8	10 7/8	22	23 3/8	6%	127,000	36	271	25
Power Spectra	PWSP	OTC	1 3/8	3/8	11/16	7/8	27%	20,000	◆	12	na
RF Micro Devices	RFMD	NASDAQ	23 3/4	11 5/8	15 5/16*	14 7/8	-3%	89,000	◆	226	15
SDL	SDLI	NASDAQ	29	8	24 5/8	18	-27%	116,000	◆	243	73
SLI	SLIC	NASDAQ	9 3/4	3 1/4	7	3 5/8	-48%	45,000	◆	12	0
Spire	SPIR	NASDAQ	24 3/4	2 1/4	2 3/8	17 1/8	621%	53,000	■	55	9
TriQuint	TQNT	NASDAQ	45 1/2	16 7/8	27 3/8	24 1/2	-11%	497,000	31	221	57
Vitesse	VTTS	NASDAQ	56 1/2	20 3/8	28 1/8	43 3/8	54%	752,000	50	1,608	78

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

◆ = Loss in most recent 4 quarters.

■ = More than 100

Bad News

Probably no one was happier to put October behind them than the folks at **TriQuint**. Even before things got nasty in the overall market, shareholders in this company saw their investment lose one-third of its value in very heavy trading on September 30 and October 1. See below.

The sell-off was sparked by an announcement from the company that third quarter earnings would be lower than expected, due to delayed new product introductions by some of their wireless OEM customers. Unfortunately, the company flubbed the release of the announcement, allowing major institutional shareholders to dump their holdings before the rest of the market received the information. And while the company says that their long-term outlook remains positive, they have given themselves a black eye with their mishandling of this situation. The Dow Jones wire service reports that the bad news caught many analysts off guard and raised issues about the credibility of TriQuint's management, since there had been no previous indication that the company was experiencing problems.

When the actual results were announced a few weeks later, they revealed revenues for the quarter of \$17.6 million, just a 16% increase over the year-ago period. Net was sharply lower: \$1.3 million a 29% decrease from the \$1.9 million reported a year ago.

Another disappointment, though much less extreme, was **RF Micro Devices**. The company reported revenue for the quarter of \$9,158,000, an increase of 52% or \$3,147,000, over the corresponding quarter last year. But net income was just \$816,000, compared to \$604,000 for the fiscal 1997 second quarter.

The decline in gross margin was attributed to what RFMD described as "a slightly less favorable product mix". Earlier in the

period the company had warned of lower-than-expected earnings for the period, due to problems in obtaining a sufficient supply of HBT wafers from its venture partner, TRW. Commenting on the results, David Norbury, President and CEO of RFMD, stated, "Regarding our supply of GaAs HBT wafers, it continues to be tight. We are working closely with our supplier to expand their output as quickly as possible, and construction of our own GaAs HBT fabrication facility is on schedule and on budget...We continue to expect commercial output in the second half of 1998."

Emcore's quarterly results were not available as this issue went to press, but on September 9 the company warned that results for the quarter would be negatively impacted by the delayed shipment of four MOCVD production systems. The four orders, which are bound for Asia, represent total revenues of approximately \$4.7 million. Recognition of the revenue from these orders will be recorded later in the year.

Good News

But not everything was gloomy in September and October. Here is a summary of the best of the good news:

- **Alpha** showed net income for of \$2.3 million for the 3rd quarter, compared with a net loss of \$4.7 million in Q3 '96. Net sales were \$28.6 million, compared with \$20.1 million for the year-ago period. According to the company, "widespread customer acceptance of [Alpha's] RF semiconductor products, especially GaAs integrated circuits, is driving the growth in orders and sales".

- **Anadigics** reported 3rd quarter revenue increased 57% to a record \$26.7 million, compared to \$17.0 million in same period of 1996. Net income increased to \$4.0 million. The company said the increase in net "was primarily attributable to a greater than twofold rise in integrated circuit sales for cellular and PCS wireless applications". The company also reported that their gross margin for the quarter increased to 48.8% from 34.5% in the third quarter of 1996. This was attributed to improved production

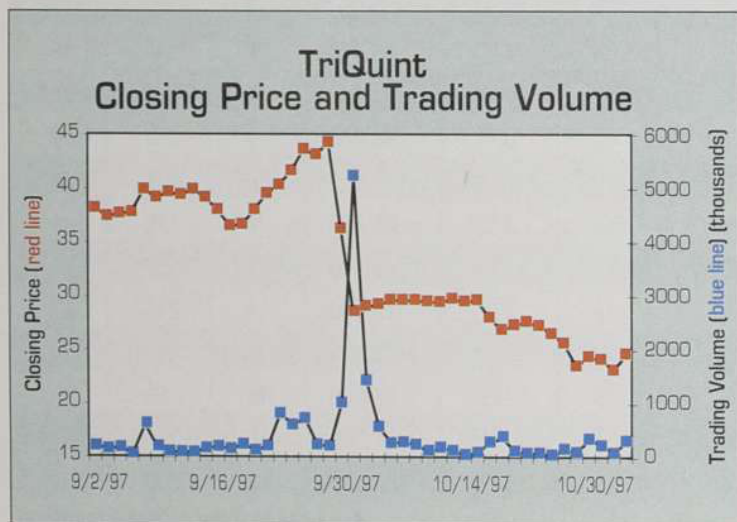
yields and manufacturing efficiencies resulting from higher production volume and the conversion from 3" to 4" wafers.

- There was more good news for **Cree Research** (see previous page). The company reported record quarterly revenues of \$10,207,000, a 46% increase over the \$6,989,000 reported in the year-ago period. Net income of \$1,169,000, compares with net income of \$1,906,000 or \$0.15 per share for first quarter 1997. However, the year-ago period included recognition of a one-time license fee of \$2,615,000; excluding that, earnings for the quarter reflect a substantial improvement in operational profitability over the year-ago period. According to the company, revenue growth for the quarter was driven by increased product sales and includes no license fees. Cree reports that "wafer sales, sales of the Real Color Module™ product and contract revenues all contributed to the growth, with the bulk of the increase in the company's blue light emitting diode (LED) sales".

- **SDL** reported revenue of \$24.0 million compared to revenue of \$19.4 million in the year-ago period. Net income rose 160% to \$2.5 million, compared to \$0.9 million or reported the same period in 1996. "We are encouraged by our return to revenue growth in the third quarter which resulted from continued strong customer demand for 980 nm pump modules generated by our new product offerings," said Donald R. Scifres, chairman and chief executives officer. "This progress is also due to our focus on increasing our front end wafer manufacturing capacity over the past 12 months."

- As mentioned earlier, **Vitesse** continues to impress. The company reported revenues of \$30.8 million, an increase of 61% over the \$19.1 million in the year-ago period. Net income was \$10.1 million, compared with \$4.5 million for the same quarter in 1996. This quarter was also the end of Vitesse's fiscal year. Total revenues for fiscal 1997 were \$104.8 million, an increase of 59% over the \$66.0 million for fiscal 1996. Net income for the year was \$32.9 million, or 86 cents per share, compared with \$12.6 million, or 42 cents per share, for fiscal 1996.

Vitesse President and CEO Lou Tomasetta said, "Fiscal year 1997 was an excellent year. We exceeded our annual goals in revenue, profit and bookings. We executed extremely well in manufacturing and design. All three of our core focus businesses — telecom, datacom and test equipment - showed significant revenue growth and ended the year with a strong backlog."



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

Electronic Circuits & Devices

05668022 / 1997 09 16 / ETRI (Korea)
Cho, D et al

SiGe HBT. A Si/SiGe bipolar transistor fabrication method employs a metallic silicide film as an extrinsic base electrode to reduce resistance of the extrinsic base electrode, and to increase a maximum oscillation frequency and cut-off frequency due to its self-aligned structure.

05682046 / 1997 10 28 / Fujitsu
Takahashi, T et al

InGaP Emitter HBT. A HBT has a support substrate, a collector layer formed on the support substrate, a base layer formed on the collector layer containing arsenic, a first emitter layer formed on the base layer, containing phosphorus, and having a band gap wider than the base layer, an emitter passivation layer formed on the first emitter layer made of semiconductor having a function of passivating the surface of the first emitter layer, and a base electrode forming an ohmic contact with the base layer.

05670804 / 1997 09 23 / Hitachi
Usagawa, T; Sawada, A; Tominaga, K

PN-Junction Gate FET. This invention relates to a semiconductor device having a PN-junction gate FET, particularly a semiconductor device capable of offering a high-performance MMIC and a high-performance power amplifier. The invention is effective for an enhancement type PN-junction power FET using compound semiconductors such as GaAs and capable of running with a single power supply and for a semiconductor device integrating the enhancement type PN-junction power FET and a high-frequency low noise amplifier monolithically.

05663583 / 1997 09 02 / Hughes Aircraft
Matloubian, M; Liu, T; Nguyen, C

AlGaPSb/GaInAs/GaAs HEMTs. The present invention relates to a novel material system for a MODFET, HMET or PHEMT capable of low-noise and power applications. Preferably, the epitaxial structure includes an N-type barrier layer comprising a wide-gap AlGaPSb semiconductor material.

05670801 / 1997 09 23 / Mitsubishi
Nakano, H

HBT Process. As a result of the disclosed process a minute emitter electrode is produced without employing vacuum evaporation and lift-off techniques that can cause burrs on the emitter electrode. Since a refractory metal can be employed as the emitter electrode material, a highly-reliable emitter electrode is produced with high stability.

05675159 / 1997 10 07 / Mitsubishi
Oku, T & Kasai, N

Recessed Gate FET. A semiconductor device includes a compound semiconductor body having a recess, the recess having a bottom and a hollow,

and a refractory metal gate electrode having a lower portion within the hollow. The invention avoids an unwanted reduction in the control speed in the channel layer due to the charging and discharging of carriers in traps in the depletion layer produced at the interface between the active layer and a passivation film.

05677574 / 1997 10 14 / Mitsubishi
Hisaka, T

Airbridge Wiring Structure for MMIC. An airbridge wiring structure includes a substrate having a surface; a first wiring layer disposed on the surface of the substrate; and a second wiring layer disposed partially on the surface of the substrate and including an airbridge wiring layer crossing the first wiring layer, the first and second wiring layers being electrically insulated from each other and separated by an air gap wherein the airbridge wiring layer includes at least one longitudinal groove.

05682045 / 1997 10 28 / Mitsubishi
Hayafuji, N; Yamamoto, Y

Method of Improving HEMT Reliability. A Si-doped AlInAs layer and an intrinsic AlInAs layer are successively grown on InP by MBE. The sample is then heat-treated in a nitrogen ambient at so that electrical characteristics of the sample are deteriorated because of the infiltration of fluorine into the Si-doped AlInAs layer. The sample is then placed in the MBE chamber and reheat-treated and the fluorine is removed. The result of the process is that electrical characteristics of the Si-doped AlInAs layer can be made hard to be deteriorated.

05672890 / 1997 09 30 / Sumitomo Electric
Nakajima, Shigeru

FET with Lightly Doped Drain. It is an object of the present invention to provide a structure of a FET, which effectively suppresses a leakage current from a source/drain region to a substrate side without increasing a parasitic capacitance, and a method of manufacturing the same.

05680280 / 1997 10 21 / TI
Seabaugh, A & Frazier, G

Magnetic Field Sensor Using HBTs. A magnetic sensor using heterojunction transistors for detecting magnetically recorded data. The sensor has a pair of heterojunction transistors connected in a differential circuit disposed on a substrate. The substrate is carded on the free end of a suspension arm at a distance D from the surface of a disk having magnetically recorded data thereon. The transistors are disposed a distance apart which is selected with D so that the magnetic field direction at one transistor is generally perpendicular to the disk and the magnetic field direction at the other transistor is generally parallel to the disk when a magnetic transition occurs immediately adjacent the magnetic sensor.

05681766 / 1997 10 28 / TI
Tserng, H & Saunier, P

Integrated High Power/Low Noise FET. An integrated circuit is disclosed for a single-chip solution to the needs of high-power and low-noise amplification and switching at state-of-the-art performance levels is made possible. In addition, the processing and material growth is simpler than in prior art solutions, because no regrowth of epitaxial material is required. All epitaxial material growth is done prior to processing. In a first preferred embodiment of the invention, a low-noise FET and a power FET are constructed of a common epitaxial material structure.

05672522 / 1997 09 30 / TRW
Streit, D; Lammert, M; Oki, A

Selective Subcollector HBTs. A method for fabricating an HBT in which the subcollector-base junction, which contributes to the base-collector capacitance of the device, is reduced by using a selective subcollector. In particular, subcollector areas of the device that do not contribute to collector resistance reduction are eliminated, thereby reducing the subcollector area, which, in turn, reduces the base-collector capacitance. As such, the maximum power-gain frequency f_{max} is increased.

05663075 / 1997 09 02 / U.S.A.F.
Robinson, G.

Photo FET. A photo FET device having a large area backside optical energy reception surface is disclosed. The photo FET device is fabricated in the source gate and drain upward configuration and then inverted onto a new permanent substrate member and an original surrogate substrate member removed in order to expose the active area backside optical energy reception surface. Fabrication of the device from GaAs and utilization for infrared energy transducing in a number of differing electronic applications are also disclosed.

05665618 / 1997 09 09 / U.S. Navy
Meyer, J; Hoffman, C; Bartoli, F

Interband Lateral Resonant Tunneling Transistor. This invention describes a nanometer scale interband lateral resonant tunneling transistor, and the method for producing the same, with lateral geometry, good fanout properties and suitable for incorporation into large-scale integrated circuits. The transistor is of a single gate design and operation is based on resonant tunneling processes in narrow-gap nanostructures which are highly responsive to quantum phenomena. Such quantum-effect devices can have very high density, operate at much higher temperatures and are capable of driving other devices. The electronic material forming the transistor is AlSb-InAs-GaAs or a modulation-doped HgTe-CdTe single quantum well.

Laser Diodes

05663980 / 1997 09 02 / None

Adachi, Yoshi

Laser with Changeable Wavelength & Polarization Mode

This invention relates to semiconductor lasers and more particularly to a method and means for providing a choice of a plurality of collimated beam lasers having specific qualities for a multiplicity of applications requiring specific attributes of wavelength, polarization, and beam shape characteristics including expanded or reduced circle and broad or thin line characters. A choice of a plurality of focused beam lasers is also provided.

05665612 / 1997 09 09 / ETRI (Korea)

Lee, Jung-Kee, et al

Planar Buried Heterostructure Laser Diode. The present invention relates to a method for fabricating a laser diode having planar buried heterostructure capable of modulating at high speed. By the disclosed method, a leakage current induced in an interface between the active layer and the first current blocking layer can be reduced in proportion to a distance between the active layer and a second current blocking layer formed on the first current blocking layer, and therefore performance of the laser diode can be enhanced.

05680411 / 1997 10 21 / France Telecom

Ramdane, A; Devaux, F; Ougazzaden, A

Integrated Monolithic Laser-Modulator with MQW Structure

This invention includes an InP substrate, a laser formed from a stack of semiconductor layers epitaxially on the substrate, including an active and absorbent layer and a periodic Bragg grating fixing the emission wavelength of the laser to a value slightly above an optimum wavelength of the laser gain peak. An electrooptical modulator is formed from the same stack of semiconductor layers, with the exception of the Bragg grating, the active layer of the laser and the absorbing layer of the modulator being formed by the same epitaxial structure having several constrained or unconstrained quantum wells, the modulator functioning according to a confined Stark effect.

05675600 / 1997 10 07 / Fujitsu

Yamamoto, S et al

Laser Diode Driver. The present invention relates to a laser diode driver system having an electrical circuit in an optical modulator, which modulates an electric signal to an optical signal with the use of a laser diode.

05666375 / 1997 09 09 / Furukawa Electric

Yokouchi, N; Yamanaka, N; Kasukawa, A

Low Threshold Current Density Laser

The present invention gives rise to a 1.3 micron tensile-strained quantum well laser having a InGaAsP quantum well active layer with a tensile stress between 1.0 and 1.5% and which can be fabricated without any substantial phase-separation between InP and GaAs. Threshold current density is less than 0.2 kA/cm².

05675599 / 1997 10 07 / Hitachi

Abe, H & Takai, A

Laser Driving Circuit. An optical transmission device which is used for a short range optical data

link or an optical communication system for subscribers and more particularly requires no automatic optical power control minimizes the turn-on delay time of a laser diode and allows unformatted optical signal transmission by fixed level decision receiving system.

05682398 / 1997 10 28 / Kodak

Gupta, M

Frequency Conversion Laser Devices

A frequency converting laser device is disclosed which includes a laser diode adapted to produced an output laser beam and an optical fiber coupled to the output of the laser diode and including a built-in grating in the optical fiber arranged so as to provide a beam having a specific wavelength and to reflect a small portion of such beam back into the laser diode while transmitting the beam so that the laser diode will produce a beam of that wavelength.

05665637 / 1997 09 09 / Lucent

Chand, N

Passivated Facet. In a preferred embodiment, the passivation layer is a ZnSe layer (e.g., 5 nm), formed on an essentially contamination-free laser facet. More generally, the passivation layer comprises at least one of Mg, Zn, Cd and Hg, and at least one of S, Se and Te. Typically, the facets are formed by cleaving in vacuum, immediately followed by in-situ deposition of the novel passivation layer material on the facets.

05668049 / 1997 09 16 / Lucent

Chakrabarti, U et al

Dry Facet Coating. In a method of making a GaAs-based semiconductor laser, a fully processed wafer is cleaved, typically in the ambient atmosphere, into laser bars, the laser bars are exposed to a H₂S plasma. Following the exposure, the cleavage facets are coated with a protective dielectric (preferably SiN) layer. The method can be practiced with high through-put, and can yield lasers (e.g., 980 nm pump lasers for optical fiber amplifiers) capable of operation at high power.

05675592 / 1997 10 07 / Lucent

Dragone, C & Kaminow, I

Rapidly Tunable Integrated Laser. Disclosed is a monolithically integrated laser which is rapidly tunable over a wide optical frequency range. It comprises a frequency router formed in a semiconductor wafer (typically an InP based material such as InGaAsP) defining a tuned cavity. A control circuit applies electrical energy to predetermined controllably transmissive waveguides connecting the frequency routing device with reflective elements defined in the wafer. This tunes the laser to a desired one of a plurality of optical frequencies. Application of such electrical energy creates frequency selective pathways through the wafer able to support selected lasing frequencies. This laser is economical to construct and is useful in high capacity, high speed optical communications networks.

05663974 / 1997 09 02 / Matsushita Electric

Tsujimura, A et al

II-VI Laser. A semiconductor laser of the present invention includes: a ZnCdSe active layer, a pair of

optical confinement structures, and a pair of cladding layers, wherein an energy band gap of the optical confinement structure monotonously increases as a distance from the active layer increases. The invention makes possible a blue-green laser having an improved optical confinement factor.

05677923 / 1997 10 14 / McDonnell Douglas

Rice, R; Ruggieri, N; Shanley, J

Vertical Cavity Electron Beam Pumped Semiconductor Lasers

According to this invention a single crystal active gain layer can be formed on a substrate by epitaxial deposition techniques to increase the performance and reliability of an electron beam pumped semiconductor laser.

05668822 / 1997 09 16 / Mitsubishi

Tada, H

Integrated Semiconductor Laser Device. A method of fabricating an integrated semiconductor laser device includes preparing a polygonal heat sink having side surfaces, and die-bonding semiconductor laser chips to the side surfaces of the heat sink. Therefore, the semiconductor laser chips are accurately arranged at such positions that laser beams emitted from these laser chips are parallel to each other and partially overlap each other. The complicated process of die-bonding a laser chip on another laser chip is dispensed with.

05675597 / 1997 10 07 / Mitsubishi

Shigihara, K

Laser & Photodiode. The present invention relates to a semiconductor laser device including a semiconductor laser chip and a photodiode used as a light source in optical communication and for an optical disc. Disclosed is a method whereby the return light which returns the monitor photodiode is reduced and the controllability of the APC control can be enhanced.

05675601 / 1997 10 07 / Mitsubishi

Karakida, S; Miyashita, M; Mihashi, Y

980nm Pump Laser. The present invention relates to the structure of a semiconductor laser device used for optical communication and a fabricating method thereof. The laser has a wavelength of 900 to 1200 nm, and is suitable for use as a pump laser for EDFAs. Disclosed is a semiconductor laser device in which generation of large mode hops is suppressed, the generation of kinks is reduced, and stable and high power output laser beams are produced.

05677922 / 1997 10 14 / Mitsubishi

Hayafuji, M; Motoda, T

Semiconductor Laser with Crystalline Window Layer

This invention relates to a semiconductor laser that produces high power light output and a method of manufacturing the semiconductor laser. Disclosed is a semiconductor laser which includes a compound semiconductor substrate having a surface with a first crystalline orientation; crystalline semiconductor layers including a first cladding layer, an active layer, and a second cladding layer successively disposed on the surface of the semiconductor substrate and including first and second window surfaces transverse to the surface of the

Laser Diodes, con't

semiconductor substrate and having a second crystalline orientation; a doped crystalline semiconductor window layer disposed on the window surfaces; and electrodes respectively disposed on the crystalline layers and the semiconductor substrate.

**05665982 / 1997 09 09 / NEC
Torikai, M**

Eliminating Stray Light. A semiconductor laser emitting device has a semiconductor laser emitting diode mounted on a heat sink attached to a side surface of a heat conductive stem accommodated in a package; and a top surface of the stem is oblique with respect to the optical path of a laser beam, roughened and topographically coated with an anti-reflecting film so as to drastically decrease a stray light.

**05668047 / 1997 09 16 / NEC
Muroya, Y**

InP Diffraction Grating and DFB Laser. A method for fabricating an InP diffraction grating for a DFB semiconductor laser includes electron beam exposure such that the incident electron doses are made larger at a center portion than at portions towards two sides of the diffraction grating. Due to the proximity effect, the resist patterns after development will have a lower height and a narrower width at portions at which the incident electron doses are increased. The method enables to fabricate a low distortion distributed feedback laser for analog modulation having non-uniform diffraction gratings.

**05673349 / 1997 09 30 / NEC
Kosugi; Tomonari**

Semiconductor Laser Module. The present invention relates to a semiconductor laser module used in, for example, optical communication or optical information processing, and in particular, to a semiconductor laser module in which an optical beam emitted from a semiconductor laser is coupled to an optical fiber and the temperature of the semiconductor laser is regulated by a cooling element.

**05678935 / 1997 10 21 / NEC
Sakata, Yasutaka**

Semiconductor Optical Waveguide. The present invention relates to a semiconductor optical waveguide for a DFB laser diode integrated electro-absorption (EA) modulator and a method of fabricating the same by using a selective growth on an n-InP substrate. Disclosed is a structure of the semiconductor optical waveguide comprising a window structure region in which the reflection of the guided light is small is provided with good controllability and reliability and with high yield.

**05663976 / 1997 09 02 / Northwestern
University
Razeghi, M**

Buried-Ridge Laser Device. A buried-ridge structure of the quaternary/tertiary structures of InGaAsP/InGaP are grown on a GaAs substrate by Low Pressure MOCVD in a two-step process. The process comprises steps of growing and doping the requisite epitaxial layers, etching these layers so

that stripes or mesas of material remain and then regrowing the material by gas molecular beam epitaxy (GSMBE). The structures are then processed into devices.

**05674779 / 1997 10 07 / Philips North America
Tijburg, R.; Haberern, K; Flamholtz, S**

Ridge-Shaped Laser in a Channel. A method for manufacturing a ridge in a channel laser diode in II-VI materials by etching grooves to form an active mesa flanked by support mesas. The method involves using certain etchants for certain compositions of the II-VI layers so that the grooves can be formed by wet chemical etching using only a single photolithographic process.

**05677920 / 1997 10 14 / SDL, Inc.
Waarts, R. et al**

Upconversion Fiber Laser. The present invention relates to optical fiber lasers which are pumped to an excited state by means of an upconversion process, and in particular relates to diode-laser-pumped upconversion fiber lasers.

**05677924 / 1997 10 14 / Sharp
Bestwick, Timothy David**

Resonant-Cavity Optical Device. A resonant-cavity optical device, eg a VCSEL, has a substrate upon which are provided a Bragg reflector multilayer bottom mirror, a semiconductor lower spacer region, an active region, and a dielectric region which surrounds the bottom mirror, the active region and the lower spacer region. An upper spacer region and a top mirror are provided on top of the active region. The top mirror has a window in which a metal terminal is provided. The terminal is in direct contact with the upper spacer region which is formed of a transparent electrically conducting oxide, eg indium tin oxide.

**05663975 / 1997 09 02 / Sumitomo Electric
Yoshida, I; Katsuyama, T; Hashimoto, J**

Multi-Beam Semiconductor Laser with Separated Contacts. This invention relates to art of improving the reliability of semiconductor lasers, and the stability of the laser output, mainly to a multi-beam semiconductor laser including a plurality of light emitting regions which are formed on one and the same semiconductor substrate and can be driven independently from each other. As a result, laser beams of uniform output levels can be supplied to the printing unit of a laser printer.

*The full text of any of these
patents can be obtained by
e-mail from MicroPatent
for \$1.50 each.*

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

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October 12 - 16, 1998

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ISCS'98 Secretary

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**05680007 / 1997 10 21 / Hamamatsu
Niigaki, M et al**

Compound Semiconductor Photocathode. A photoelectric emission surface which is excellent in stability and reproducibility of photoelectric conversion characteristics and has a structure capable of obtaining a high photosensitivity is provided.

**05675685 / 1997 10 07 / Hitachi
Fukuda, K et al**

Optical Semiconductor Array. The present invention is used, for example, in optical fiber communications, inter-computer communications, asynchronous transfer mode (ATM) exchanges, etc., and relates to an optical semiconductor array module provided with a semiconductor laser diode, LED array device, a semiconductor photo diode array device, and an optical fiber array optically coupled to these devices, a method of fabricating the optical semiconductor array module, and an external board mounting structure of the optical semiconductor array module.

**05682122 / 1997 10 28 / Imperial College
Toumazou, C & Vanisri, T**

Optoelectronic Transconductors. A transconductance device particularly suitable for use as a high frequency active filter has an input stage including at least one FET arranged to drive a laser diode and an output stage including at least one photodiode optically coupled to the laser diode. The output stage is preferably provided with a high impedance bias current supply circuit. In an alternative arrangement particularly useful as an operational amplifier, a differential input stage includes a pair of laser diodes optically coupled to respective pho-

todiodes connected in series, the output being taken from the junction of the two photodiodes.

**05679964 / 1997 10 21 / Matsushita Electric
Kobayashi, Y & Matsuda, K**

VCSEL-based OEIC. Disclosed is an OEIC which includes a VCSEL formed on a substrate, a phototransistor stacked over the VCSEL, for driving the VCSEL, and a semiconductor buffer structure interposed between the VCSEL and the phototransistor.

**05675602 / 1997 10 07 / Mitsubishi
Takemoto, A**

OEIC and Driver. An optical integrated circuit device includes a compound semiconductor substrate whereupon a semiconductor laser, a waveguide, and an amplifier are grown as a single layer. The optical integrated circuit device is easily fabricated, and an absorption loss in the waveguide is suppressed by applying a voltage across a common electrode and the waveguide electrode to inject current into the waveguide.

**05663581 / 1997 09 02 / Motorola
Holm, P & Gable, B**

Implanted LED Array. A method of fabricating an LED array including 1) epitaxially growing a conductive layer, a first carrier confinement layer, an active layer, a second carrier confinement layer, and a conductive cap; 2) selectively etching the cap to provide exposed surface areas defining row and column areas with a matrix of diodes; 3) implanting a first impurity to form surface contacts to each diode; 4) implanting a second impurity to form an

isolating resistive volume around each diode; and 5) implanting a third impurity to form an isolating resistive volume between each row of diodes.

**05682455 / 1997 10 28 / Nortel
Kovacic, S & Ojha, J**

Semiconductor Optical Waveguide. A channel waveguide structure which can be incorporated into VLSI (very integrated circuits) uses a SiGe alloy core and Si top and bottom cladding layers. The core may consist of only a SiGe alloy layer or it may be formed as a superlattice containing Si layers alternating with SiGe alloy layers. LOCOS (locally oxidized silicon) regions are formed on the top cladding layer at spaced locations thereby defining lateral boundaries of channels in the core.

**05668395 / 1997 09 16 / Northwestern
University
Razeghi, M**

InSb and GaAs on Si Photodetectors. An intermetallic compound semiconductor thin film comprises thin film made of either InSb or GaAs heterostructure on a silicon substrate. Preferably, the thin film is grown by a Molecular Beam Epitaxy method.

**05665985 / 1997 09 09 / Ricoh Company
Iwata, H**

Edge Emitting LED. The present invention relates to light-emitting diodes, light-receiving devices, and arrayed light sources which can be used as light sources or light-receiving devices for optical communication using optical fibers, for optical fiber illumination, for optical printers printing on a photo-

10th International Conference on Indium Phosphide and Related Materials

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Contacts: Program Chair, Hajime Asahi, Osaka University, Osaka, Japan (E: asahi@sanken.osaka-u.ac.jp); Exhibition Chair: Toshio Fujii, OITDA, Tokyo, Japan (F:81-3-5632-7725); Publicity Chairs: Joe Lorenzo, Rome Laboratory, Bedford MA, USA (F: 617-377-6765), I. Mito, NEC, Japan (E: mito@optd.cl.nec.co.jp).



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sensitive material, etc. Disclosed is a semiconductor device includes a semiconductor substrate, and a plurality of semiconductor layers formed on the semiconductor substrate and forming a concave lateral surface, the semiconductor layers including an active layer for either emitting light or receiving light, wherein the concave lateral surface is used as either a light-emitting surface or a light-receiving surface.

05674778 / 1997 10 07 / Samsung Electronics
Lee, K; Shur, M; Jones, S

OEIC including HBT, Laser and Photodetector.

An optoelectronic integrated circuit furnishes a monolithic integration of high-speed transistors, lasers and photodetectors for optoelectronic communication applications. The monolithic device integrates an InP/InGaAs emitter-down HBT with an InP/InGaAs quantum well laser and modulator, and a metal-semiconductor-metal photodetector.

05663564 / 1997 09 02 / Santa Barbara
Research Center
Radford, W

Photovoltaic Detector. An integrated photovoltaic detector includes a reference photovoltaic detector and an active photovoltaic detector in a series connection. The reference detector produces a dark current that opposes the active detector's dark current. The active detector effectively masks the reference detector from incident illumination so that the active detector produces photocurrent but the reference detector does not. The band gap of the reference detector is preferably matched to the active detector so that their dark currents are substantially matched over a temperature range. As a

result, the current read out of the integrated detector at the series connection is approximately equal to the photocurrent generated by the active detector. This improves the detector's SNR, signal resolution, and useful operating temperature range.

05670797 / 1997 09 23 / Sharp
Okazaki, Jun

Surface Mount LED. The present invention relates to a surface mount LED and its manufacturing method, which is used as a light source for various display panels, a backlight for liquid crystal displays and a light source for lighting switches. In particular, the present invention concerns LED chips of small size that have high tolerance to external stress, and its manufacturing method.

05665984 / 1997 09 09 / Showa Denko
Hasegawa, K; Kabe, I

Si-doped GaAlAs LED. The present invention relates to a light-emitting diode for use as a light source in a photocoupler, remote control or other such application requiring high-output infrared light. A light-emitting diode comprises a first layer of Si-doped N-type GaAlAs, a second layer of Si-doped P-type GaAlAs and a third layer of P-type GaAlAs, in that order, in which the first and third layers have a higher Al concentration than the second layer. Light emission is via the first layer. Selecting appropriate growth temperatures makes possible the continuous formation of an N-type GaAlAs layer and a P-type GaAlAs layer using a single solution. The reason for this is that at a high temperature Si enters the GaAlAs single crystal at a group III element site, while at a low temperature the entry takes place at a group V element As site.

05665977 / 1997 09 09 / Sony
Ishibashi, A et al

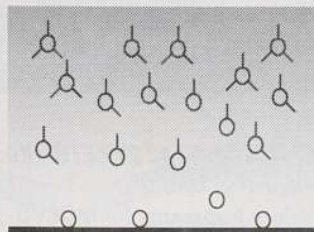
II-VI Light Emitter with Superlattice Structure.

This invention relates to a semiconductor light emitting device comprising II-VI compound semiconductors including a superlattice structure. By making the superlattice structure in a part or the entirety of the cladding layer, a self-compensating effect can be suppressed. It can also serve as a multiquantum barrier. Also, by making the superlattice structure between the substrate and the active, growth of defects such as stacking faults generated at the interface between the substrate and the II-VI compound semiconductor layer can be suppressed.

05666376 / 1997 09 09 / Univ. of New Mexico
Cheng; Julian

VCSEL-Based OEIC. The present invention to an electro-optical device including a substrate carrying a vertical cavity surface emitting laser electrically cascaded to be responsive to a heterojunction phototransistor or photothyristor on the substrate. Disclosed is an electro-optical device that includes a vertical cavity surface emitting laser, a heterojunction light emitting device and heterojunction phototransistor on a semiconductor substrate. Layers of the heterojunction phototransistor and the heterojunction light-emitting device are electrically and optically coupled so there is regenerative optical and electrical feedback between them. Layers of the heterojunction light-emitting devices are proton implanted to control the feedback. Plural such devices are electrically and optically coupled together to perform logic functions, such as EXCLUSIVE OR, in response to optical signals.

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Nitrides and SiC

05663580 / 1997 09 02 / ABB Research Ltd Harris, C & Bakowski, M

Optically Triggered SiC Device. A semiconductor device comprises a semiconductor layer of SiC having an active area through which the device is adapted to be triggered by light incident thereon and means for generating and emitting light with an energy exceeding the bandgap, being the energy difference between the conduction band and the valence band, of the SiC-layer of the active area.

05680008 / 1997 10 21 / ATMI Brandes, G & Miller, J

Low-Noise Dynodes. This invention relates to electron emitting semiconductor materials for use in dynodes, dynode devices incorporating such materials, and methods of making the dynode devices. In particular, the invention relates to emissive materials having an electron affinity that is negative and which have low resistivity. The secondary electron emitters of the present invention comprise wide bandgap semiconductor films such as diamond, AlN, BN, GaAlN and (AlN)_x(SiC)_{1-x}. The films are preferably single crystal or polycrystalline.

05677538 / 1997 10 14 / Boston University Moustakas, T; Misra, M

Photodetectors Using III-V Nitrides. A photodetector using a III-V nitride and having predetermined electrical properties is disclosed. The photodetector includes a substrate with interdigitated electrodes formed on its surface. The substrate has a sapphire base layer, a buffer layer formed from a III-V nitride and a single crystal III-V nitride film.

05672889 / 1997 09 30 / General Electric Brown, D

Vertical Channel SiC MOSFET. An object of the present invention is to provide a method of fabricating a SiC MOSFET which avoids the need for precision alignment of contact layers, and to provide a device which has minimal parasitic resistances. The invention uses the vertical device approach, which has an advantage because the current is evenly distributed across the whole area of the contact, thereby eliminating current crowding at a single edge.

05677230 / 1997 10 14 / Motorola Weitzel, C; Fisk, E; Pack, S

Method of Making Wide Bandgap Semiconductor Devices. A method of planarizing wide bandgap semiconductor devices selected from a group including SiC, GaN and diamond having a mesa defined thereon by a trench with a depth of 1 to 2 micrometers and a width of 2 to 10 micrometers. A layer of dielectric material is deposited on the substrate overlying and surrounding the mesa, to a height approximately equal to the height of the mesa and the dielectric material is

etched from atop the mesa and from a surrounding area. Layers of spin on glass are deposited to fill the surrounding area and etched to achieve a planar surface including the mesa and the layer of dielectric material.

05670798 / 1997 09 23 / NCSU Schetzina, J

Integrated Heterostructures of Group III-V Nitrides (I). An integrated heterostructure of Group III-V nitride compound semiconductors is formed on a multicomponent platform which includes a substrate of SiC and a non-nitride buffer layer of ZnO. The ZnO may be formed by MBE using an effusion cell containing Zn, and a source of atomic oxygen, such as a plasma source which converts molecular oxygen into atomic oxygen. An ohmic contact for a semiconductor device formed of Group III-V nitride compound semiconductor materials including a layer of AlN or AlGa_{0.5}N, includes a continuously graded layer of AlGa_{0.5}N and a layer of GaN or an alloy thereof on the continuously graded layer. The continuously graded layer eliminates conduction or valence band offsets. A MQW may also be used instead of the continuously graded layer where the thickness of the layers of GaN increase across the MQW. The ohmic contacts may be used for Group III-V nitride laser diodes, LEDs, electron emitters, bipolar transistors and field effect transistors.

05679965 / 1997 10 21 / NCSU Schetzina, J

Integrated Heterostructures of Group III-V Nitrides (II). An n-on-p integrated heterostructure device of Group III-V nitride compound semiconductor materials is formed on a substrate of p-SiC and includes a buffer layer of p-AlN or p-AlGa_{0.5}N on the substrate. The n-on-p integrated heterostructure includes continuously graded layers of AlGa_{0.5}N to reduce or eliminate conduction band or valence band offsets. A MQW may also be used instead of the continuously graded layer. The n-on-p integrated heterostructure device may include lasers, LEDs and other devices. A p-type negative electron affinity (NEA) photoelectron emitter device may also be provided, including a p-SiC substrate, a layer of p-AlN or p-AlGa_{0.5}N, a continuously graded layer of AlGa_{0.5}N and a layer of p-AlGa_{0.5}N. A surface enhancement layer may be located on the layer of AlGa_{0.5}N. A MQW may be used instead of the continuously graded layer of AlGa_{0.5}N. An ultraviolet-sensitive NEA device may thereby be provided.

05681762 / 1997 10 28 / NCSU Baliga, B

Buried SiC Conduction Layers. A SiC semiconductor device includes a SiC substrate, an active layer in the substrate and a SiC buried layer which provides a conduction barrier between the substrate and at least a portion of the active layer. The

buried layer is preferably formed by implanting second conductivity type dopants into the substrate so that a P-N junction barrier is provided between the active layer and the substrate. In particular, lateral SiC-on-insulator enhancement and depletion mode FETs can be formed in accordance with the present invention.

05665986 / 1997 09 09 / Sumitomo Electric Miura, Y et al

GaN LED on GaAs Substrate. The present invention relates to a GaN LED employing a substrate of GaAs, GaP, InAs or InP and a method of preparing the same. The LED includes a GaAs substrate, a buffer layer consisting of GaN, having a thickness of 10 nm to 80 nm, which is formed on the substrate, an epitaxial layer consisting of AlGa_{0.5}N which is formed on the buffer layer, an incommensurate plane which is located on the interface between the buffer layer and the epitaxial layer, a light emitting layer which is formed on the epitaxial layer, and a cladding layer which is formed on the light emitting layer. The buffer layer is formed by organic metal chloride vapor phase epitaxy at a first temperature, while the epitaxial layer is formed by organic metal chloride vapor phase epitaxy at a second temperature which is higher than the first temperature. The light emitting layer preferably consists of InGa_{0.5}N which is doped with Mg.

05675028 / 1997 10 07 / Univ. of Texas Neumayer, D; Lakhota, V

Group III Bisamido Azides as Precursors for Nitride Films. There are disclosed bisamido azides of gallium, aluminum or indium which when pyrolyzed in accordance with the invention, produce metal nitride films on a substrate. A representative example of a bisamido azide is bisdimethylamido-gallium azide, (CH₃)₂N₂GaN₃.

Other Materials

05679164 / 1997 10 21 / ETRI (Korea) Baik, J-H & Lee, B

Auxiliary Apparatus for MOCVD. The present invention relates to an auxiliary apparatus for providing uniform growth of an epi layer of a semiconductor, such as GaAs or InP and related material by MOCVD method. It comprises a means for guiding the source gas supplying the reaction chamber deposition apparatus to uniformly deposit on the substrate surface, and means for attaching this means to the reaction chamber.

05668048 / 1997 09 16 / Fujitsu Kondo, M; Anayama, C; Shoji, H

C-Doping Utilizing Crystal Orientation. It is an object of the present invention to provide a technique of manufacturing a novel semiconductor device by using a group III-V compound semiconductor substrate containing As and having a surface crystal orientation other than a (100) plane as well as a step, a groove, a ridge, or other uneven surface. By selecting a proper crystal orientation, carbon can be incorporated as a dopant or suppressed.

*The full text of any of these patents can be obtained by e-mail from MicroPatent for \$1.50 each.
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and select the "PatentWEB™" option.*

05682040 / 1997 10 28 / Fujitsu

Imanishi, K

HEMTs and HBTs with Improved Interfaces. The present invention relates to compound semiconductor devices such as HEMTs and HBTs having a reduced resistance at a cap layer interface. Disclosed is a fabrication process wherein the depletion of carriers at a heterojunction interface is successfully compensated for.

05679179 / 1997 10 21 / Kubota Corporation

Hiyamizu, S; Shimomura, S; Okamoto, Y

GaAs/AlGaAs Heterostructure. A primary object of the present invention is to provide a method for forming GaAs/AlGaAs layers with an improved heterointerface, thereby resulting in improved optical and electrical properties. The GaAs/AlGaAs heterostructure is formed by a method which includes the steps of preparing a GaAs substrate having a (411)A-oriented surface and setting the GaAs substrate inside a growth container with the (411)A surface being disposed as a surface to be deposited. The pressure inside the growth chamber is reduced and the GaAs substrate is heated up to a predetermined temperature to cause epitaxial growth of Ga, Al, As on the (411)A substrate and forming a GaAs/AlGaAs hetero-structure on the (411)A-oriented GaAs substrate.

05663639 / 1997 09 02 / MIT

Brown, E; Smith, F

Photomixer Based on LT GaAs. The present invention is directed to a photomixer which overcomes the limitations of the prior devices to provide useful levels of continuous-wave power over a

very wide operating bandwidth. In one embodiment, the active layer is created by low temperature epitaxial growth. In another embodiment, the homogeneous crystal lattice structure is grown on the substrate by conventional techniques. Then, in a subsequent step, the column V defects are introduced by ion implantation.

05677565 / 1997 10 14 / Mitsubishi

Funaba, S

Monocrystalline Compound Semiconductor

Wafer. A method of fabricating a semiconductor wafer includes preparing a semiconductor wafer of a monocrystalline compound semiconductor. Since the semiconductor wafer includes a non-monocrystalline part at the side surface including the corners, even when a crack is produced in the non-monocrystalline part, unwanted cleaving of the wafer from the crack does not occur.

05679603 / 1997 10 21 / Mitsubishi

Kimura, T; Ishida, T; Sonoda, T

MOCVD of AlInAs. The conventional high resistance AlInAs layer is obtained by MBE or by MOCVD while adding Fe as a dopant. Disclosed in the present invention is a method of growing AlInAs by MOCVD wherein the high resistance layer includes p type impurities having a concentration that positions the Fermi level of the compound semiconductor approximately at the center of the band gap of the compound semiconductor. Therefore, it is possible to produce a high resistance AlInAs layer that has less impurities that are diffused into an adjacent compound semiconductor layer.

05681975 / 1997 10 28 / Rutgers

Brennan, J; Cheng, Y

IV-VI Metalorganic Precursors. The present invention relates to the preparation of novel metal organic precursor compounds comprising at least one metal from Group IV and at least one element from Group VI of the Periodic Table. More specifically, these novel compounds are useful as single source metalorganic tellurium, selenium, sulfur, germanium, tin or lead containing precursors in the preparation of semiconducting materials having precisely defined elemental ratios.

05679963 / 1997 10 21 / Sandia

Klem, J & Zolper, J

Semiconductor Tunnel Junction with

Enhancement Layer. The incorporation of a pseudomorphic GaAsSb layer in a tunnel diode structure affords a new degree of freedom in designing tunnel junctions for p-n junction device interconnects. Previously only doping levels could be varied to control the tunneling properties. This invention uses the valence band alignment band of the GaAsSb with respect to the surrounding materials to greatly relax the doping requirements for tunneling. Potential applications include multijunction photovoltaic solar cells.

05679151 / 1997 10 21 / Seiko

Ohmoto, S et al

Method for Growing Single Crystal ZnSe. The present invention relates to a method and machine for growing a single crystal of ZnSe or another material which makes a phase transition when a single crystal grown from a melt is cooled.

Call for Papers

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Abstract Submission Deadline
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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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1998 Conference on Optical Fiber Communication

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

Contact: Ms. Lisa Myers

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IRPS '98 will be held Mar. 30-Apr. 02, 1998 at the Reno Hilton Hotel in Reno, NV.

Contact: Ms. Ann N. Campbell

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Integrated Photonics Research Topical Meeting

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

Abstract Submission Deadline: December 1
Contact: OSA

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The 1998 GaAs MANTECH Conference will be held April 27 - April 30, 1998 in Seattle, Washington. Papers that deal with manufacturing "how to" in the following subject areas will be covered: manufacturing; processing; test & reliability; device technologies; materials; packaging; optical devices (integration with GaAs or InP, process simplification); and the future of GaAs (business outlook, trends, competition, new applications).

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The 193rd ECS Meeting will be held May 3-8, 1998 at the Sheraton San Diego Hotel & Marina in San Diego, California. Symposia include: E1 - Third International Symposium On Low And High Dielectric Constant Materials (covering all aspects of low and high dielectric materials in silicon and compound semiconductor); F3 - First International Symposium On Environmental Issues With Materials And Processes For The Electronics And Semiconductor Industries (including III/V semiconductor materials and processes); I2 - State-Of-The-Art-Program On Compound Semiconductors (SOTAPOCS XXVII); K1 - Light Emitting Devices For Optoelectronic Applications
Abstracts Submission Deadline: January 2
Contact: The Electrochemical Society

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Abstract Submission Deadline: November 25
Contact: IPRM '98

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22nd Workshop on Compound Semiconductor Devices and Integrated Circuits

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

are kept short and focused on the main results and new ideas presented by the participants. The Workshop is open to European and world wide participation.

Abstract Submission Deadline: February 16
Contact: Joachim Würfl

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FAX [1] 253 657 8903

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

ICMOVPE IX will be held May 30 - June 4, 1998 at the Sheraton Grande Torrey Pines in LaJolla, CA. Topics of interest include precursors, process design/communication issues; developing application of MO compounds; growth technologies; advances in devices by MOVPE, and characterization.
Abstract Submission Deadline: January 15

Contact: Barbara Laitwood

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

1998 MTT-S International Microwave Symposium

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

Contact: Mr. Steven Stitzer

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

1998 IEEE Radio Frequency Integrated Circuits Symposium

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

Contact: Dr. Vijay Nair

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

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

EXMATEC 98 will be held June 22-24, 1998 in Cardiff, Wales, UK. This conference aims to bring together research, development, and production specialists involved in compound semiconductor material physics, chemistry, process technology, and device fabrication. Central issues to be addressed are the improvement of yield, reliability, performance, lifetime and reproducibility of electronic and optoelectronic devices and circuits through characterisation, optimisation, and control of materials and processes. Papers on investigations ranging from perfection of crystal growth and improvement of intermediate processing steps to device lifetime testing are solicited. Material systems to be discussed include wide band gap (GaN, ZnSe, SiC ...), intermediate band gap (GaAs, InP, SiGe ...) and narrow band gap (HgCdTe ...) compound semiconductors.

Abstract Submission Deadline: December 1
Contact: Cherrie Summers

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

1998 Device Research Conference

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

Abstract Submission Deadline: March 2

Contact: Emmanuel Crabbe

Tel: [1] 914 892-2056
Fax [1] 914 892-2568
Net or Web: crabbe@watson.ibm.com

1998 Electronic Materials Conference

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

Abstract Submission Deadline: February 6
Contact: Barbara Laitwood

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

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 December 22 to appear in our next issue.

OE Expo '98

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

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

ICCG-12 & ICVGE-10

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

Abstract Submission Deadline: November 1
Contact: Conference Secretariat
ICCG-12 / ICVGE-10
International Travel and Congresses Ltd.
P.O. Box 29313, 9 Rothschild Blvd.
Tel Aviv 61292 ISRAEL
TEL [972] 3 5102538
FAX [972] 3 5160604
NET or WEB
100264.2432@compuserve.com
or <http://www.technion.ac.il/~iccg12>

1998 Custom Integrated Circuits Conf.

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

Contact: Melissa Winderkehr
CICC
101 Lakeforest Boulevard
Gaithersburg, Md. 20877 USA
TEL [1] 301 427 0902
FAX [1] 301 527 0994
Net or Web: cicc@his.com or
<http://www.ieee.org/conference/cicc/>

10th Int'l Conference on Molecular Beam Epitaxy

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

Abstract Submission Deadline: March 15
Contact: Prof. Jean-Pierre Faurie
CRHEA-CNRS Sophia Antipolis
Rue Bernard Gagnepain

F 06560 Valbonne France
TEL [33] 4 9395 4220
FAX [33] 4 9395 4142
NET or WEB: org@mbe-x.unice.fr
<http://www.crhea.unice.fr/mbe-x>

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

CLEO EUROPE/EQEC will be held Sep. 13 - Sep. 18, 1998 at the Scottish Exhibition & Conference Center in Glasgow, Scotland.
Contact: Ms. Melissa K. Estrin
IEEE/LEOS
445 Hoes Lane
Piscataway, NJ 08855-1331
TEL [1] 908 562-3896
FAX [1] 908 562-8434
Net or Web: m.estrin@ieee.org
<http://www.ieee.org/leos/meet.htm>

1998 IEEE Bipolar/BiCMOS Circuits and Technology Meeting

BBCTM '98 will be held Sep. 27 - Sep. 29, 1998 in Minneapolis, MN.
Contact: Ms. Janice V. Jopke
CCS Associates
6611 Countryside Dr.
Eden Prairie, MN 55346
TEL [1] 612 934-5082
FAX [1] 612 934-6741
Net or Web: jjopke@aol.com

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

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

Abstract Submission Deadline: May 15
Contact: Prof. F. Hasegawa
University of Tsukuba
Institute of Materials Science
1-1-1 Tennodai
Tsukuba, Ibaraki 305 Japan
TEL [81] 298 53 5287
FAX [81] 298 55 7440
Net or Web:
hasegawa@mat.ims.tsukuba.ac.jp
or <http://www.etl.go.jp/etl/divisions/material/isblled2/isblled2.html>

1998 IEEE/LEOS Semiconductor Laser Conference

The 1998 IEEE/LEOS Semiconductor Laser Conference will be held Oct. 5, 1998 - Oct. 10, 1998 at the Nara Public Hall in Nara, Japan. The scope of the meeting includes semiconductor laser physics; materials and processing; design and modeling; long & short wavelength laser; high power & high speed laser; VCSELS, novel laser structures; and integration and packaging.

Abstract Submission Deadline: May 8
Contact: Ms. Elsie L. Vega
IEEE/LEOS
445 Hoes Lane
Piscataway, NJ 08855-1331

TEL [1] 732 562-3897
FAX [1] 732 562-8434
Net or Web: e.vega@ieee.org
<http://www.ieee.org/leos/is/c.htm>

European Microwave Week (Including GAAS '98)

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

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

25th Int'l Symp. on Compound Semiconductors

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

Abstract Submission Deadline: May 18, 1998
Contact: Kimiyoshi Yamasaki
NTT System Electronics Laboratories
3-1 Morinosato Wakamiya, Atsugi,
Kanagawa, 243-01 Japan
TEL [81] 462 40 2500
FAX [81] 462 40 2872
Net: kyama@aetl.ntt.co.jp
Web: <http://www.ieice.or.jp/es/iscs98.html>

3rd Int'l Workshop on Novel Index Surfaces

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

Abstract submission deadline: May 15
Contact: Mariano Gonzalez
ETSI Telecomunicacion-UPM
Ciudad Universitaria
28040-Madrid, Spain
FAX [34] 1 336 73 23
Net or Web: mariano@die.upm.es

1998 IEEE GaAs IC Symposium

The 1998 IEEE GaAs IC Symposium will be held Nov. 01 - Nov. 04, 1998 at the Westin Peachtree Plaza in Atlanta, GA.
Contact: Dr. William Stanchina
Hughes Research Labs., RL61
Plasma Physics Lab.

3011 Malibu Canyon Rd.
Malibu, CA 90265
TEL [1] 310 317-5089
FAX [1] 310 317-5483

194rd Meeting of the Electrochemical Society

The 194rd ECS Meeting will be held November 1-6, 1998 at the Sheraton Boston Hotel & Tower in Boston, Massachusetts. Symposia include: G1 - Dielectric Science And Technology/Electronics Joint General Session; H1 - Interconnect And Contact Metallization: Materials, Processes And Reliability; I1 - III-V Nitride Materials And Processes; J1 - Fifth International Symposium On Quantum Confinement: Nanostructures; N1 - Compound Semiconductor Power Transistors; N3 - Sixth International Symposium On Long Wavelength Infrared Detectors And Arrays; Physics And Applications; N4 - State-Of-The-Art Program On Compound Semiconductors (SOTAPOCS XXVIII); P1 - Photovoltaics For The 21st Century
Abstracts Submission Deadline: June 1
Contact: The Electrochemical Society

10 South Main Street
Pennington, NJ 08534-2896 USA
TEL [1] 609 737 1902
FAX [1] 609 737 2743
NET or WEB: ecs@electrochem.org or
<http://www.electrochem.org>

45th National AVS Symposium

The 1998 AVS National Symposium will be held November 2-6, 1998 at the Baltimore Convention Center in Baltimore, MD. AVS Technical Divisions include: applied surface science; nanometer-scale science and technology; surface science; vacuum metallurgy; electronic materials and processing; plasma science and technology; thin film; and vacuum technology.

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

1998 IEEE International Electron Devices Meeting

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

Conf. on Optoelectronic and Microelectronic Materials and Devices

COMMAD '98 will be held December 16-18, 1998 in Perth, Australia.
Abstract Submission Deadline: August 31
Contact: Lorenzo Faraone
Univ. of Western Australia
EEE Department
Nedlands, WA 6907 Australia
TEL [61] 8 9380 3104
FAX [61] 8 9380 1095
Net or Web: faraone@ee.uwa.edu.au
<http://www.ee.uwa.edu.au/~COMMAD98>

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The FBH is a public research institute supported by the country of Berlin and the Federal Republic of Germany. Its mission is application-oriented research and, in close cooperation with industrial partners, product-oriented development in the fields of microwave technology and optoelectronics based on III-V semiconductors. The activities in microelectronics center around design and fabrication of HBTs and MMICs while the focus is on high-power laser diodes in the field of optoelectronics.

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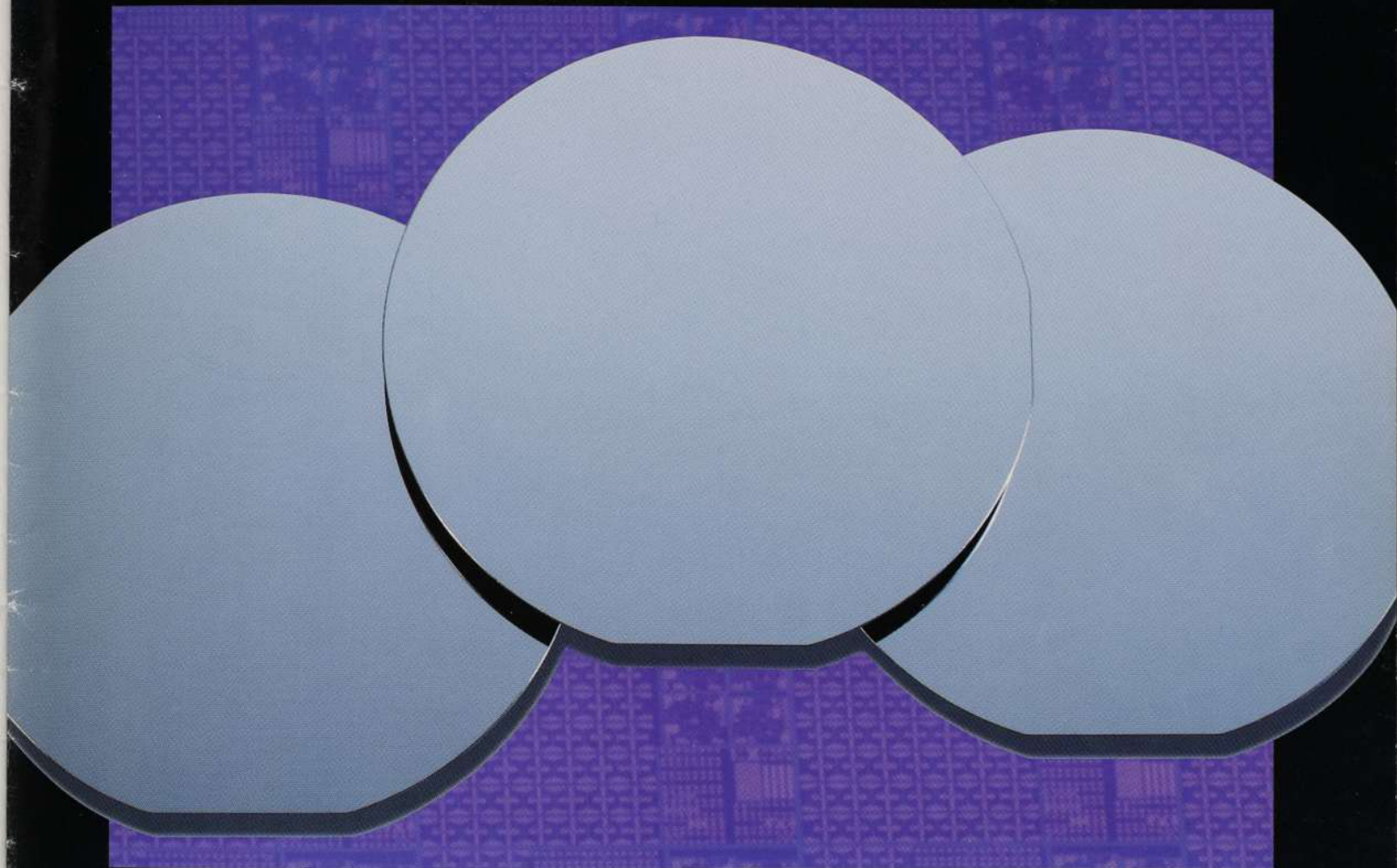
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For further information please contact Dr. Markus Weyers
(weyers@fbh-berlin.de)

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