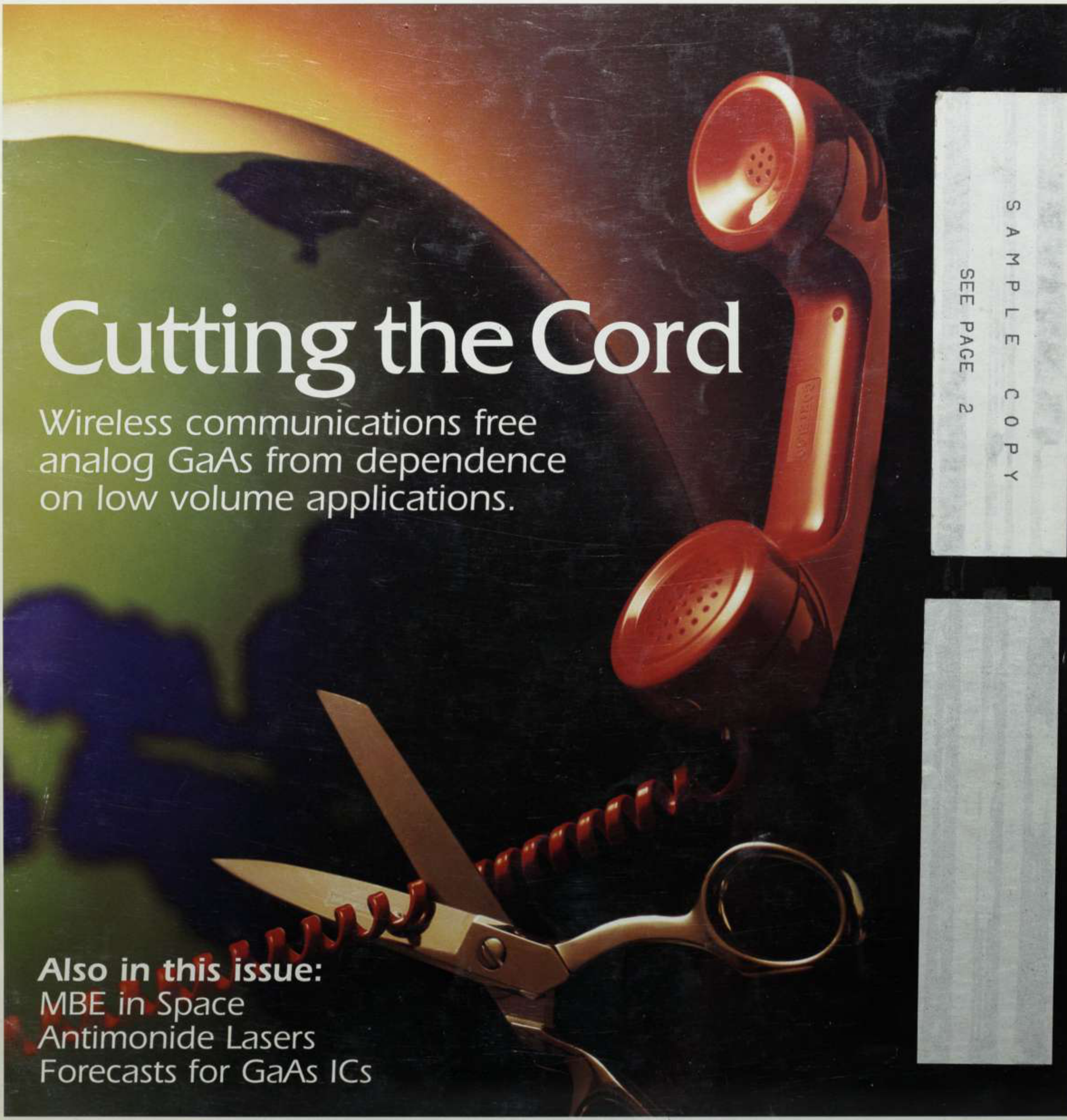
COMPOUND SEMICONDUCTOR

September/October 1995 *Volume 1 Number 2*



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Wireless communications free analog GaAs from dependence on low volume applications.

Also in this issue:
MBE in Space
Antimonide Lasers
Forecasts for GaAs ICs

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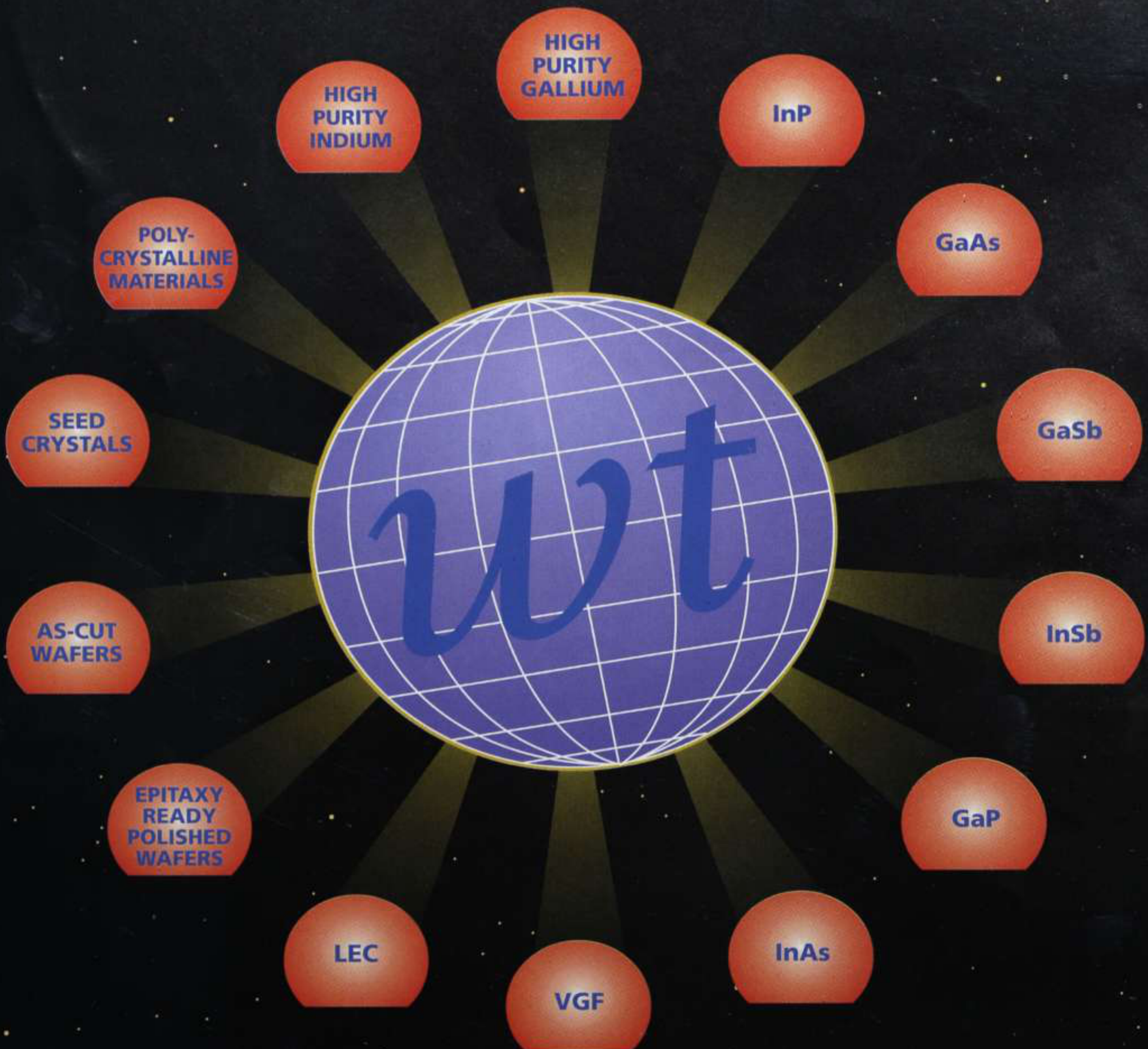

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SEPTEMBER/OCTOBER 1995 VOLUME 1 NUMBER 2

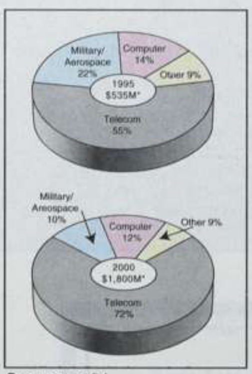
COMPOUND SEMICONDUCTOR

COVER STORY


See page 33


See page 37

OTHER FEATURES



See page 21

DEPARTMENTS


See page 6

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Wow - what a beautifully and professionally produced magazine! I got a lot of good info out of your premier issue. Can't wait for the next one. Congratulations.

Steve J. Noll
Ventura, CA USA

I just received the first issue of *Compound Semiconductor*. I found it to be very interesting and informative, and the story of the blue/green light emitting devices was particularly exciting. I look forward to the next issue.

Robert Grey,
The University of Sheffield,
Sheffield UK

I initially had misgivings about subscribing to *Compound Semiconductor* because I was afraid it would just be another trade magazine that would take up too much time to weed through with very little reward. I was very pleasantly surprised by the premier issue. It's very well done! I enjoyed the news articles, the Research Review section, the cover story, and the Tutorial section is a very good idea and well done.

D. Scott Katzer
Alexandria, VA USA

I commend you for the creation of *Compound Semiconductor*. Both the content and presentations are very good. The subjects covered cannot be found elsewhere. I appreciated in particular the story on Shuji Nakamura, which dispels some of the myths about Japanese industry.

Patrick Lautier
Toulouse, France

I really liked your premier issue: it is very professional. My kids think the pictures are cool, too. I hope you will be successful making III-V materials look exciting again.

Rob Christ
TriQuint Semiconductor
Beaverton, OR USA

I'm writing to tell you that I enjoyed reading your premier issue of *Compound Semiconductor*. It was good to see relatively impartial reporting on the II-VI industry without people introducing too many biases toward GaN or GaAs light emitting efforts or without having the ZnSe heteroepitaxy effort dominate the ZnSe articles as other news reports have. It seemed that the status of the ZnSe homoepitaxy effort was fairly represented without discounting the problems that exist.

David B. Eason, Ph.D.
Eagle-Picher Industries
Miami, OK USA

Your new magazine is GREAT! It provides us university types with info on what is happening in industry and will help keep our students up to date on new trends in the optoelectronics marketplace. Also, it is well written. Keep up the good work.

Gary Y. Robinson
Colorado State University
Fort Collins, CO USA

From the editor:

The above items are fairly representative of the mail that we received. Our primary editorial criteria is that everything we print should be "interesting" or "useful" or, preferably, both. Judging by the response we've received, we achieved that goal in our first issue. But I also detect a current of skepticism out there: more than one private communication inquired whether we would be able to maintain our standards. Of course our answer is "Yes!!", but you can have a look at this and future issues and decide for yourselves.

Frankly, I was a bit surprised that our cover story didn't provoke any criticism: I was expecting the GaN camp to accuse us of being too kind to ZnSe, and vice versa. Perhaps you were all letting us off easy since it was our first time out. Or perhaps the two technologies are actually equally balanced, as we suggested. Since we published that story there have been two important new papers, one each for GaN and ZnSe, suggesting an intriguing symmetry of progress in the field. See the "Research Review" section in this issue for more information.

There was another reoccurring theme in those private communications: "Why wasn't my employer mentioned anywhere in this issue?" There are three parts to the process of preparing an article. First we look for an idea, then we gather the news, and then we write the story. Given that we are a trade publication, we frequently rely on press releases as sources for ideas and facts (although we always write the stories ourselves). So if you would like to see news from your company in future issues, you can either contact us directly or ask your "Public Relations" or "Corporate Communications" department to include us on their distribution list for items relating to compound semiconductors. The appropriate address is given below.

I hope that you enjoy this issue of *Compound Semiconductor*, and I will look forward to hearing from more of you in the near future. Our address is given below.

Marie Meyer
Editor
Compound Semiconductor

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Press Releases & Letters to the Editor

We welcome all companies and organizations active in the compound semiconductor field to send us press releases and announcements regarding new developments that might be of interest to our readers. Information should be sent to: The Editor, Compound Semiconductor, c/o Franklin Publishing, 250 Selby Avenue, Suite 48, Saint Paul, MN 55102 USA. Items can also be FAXed to [1] 612 227 5499; or sent via E mail to: editor@compsem.com.

Looking Ahead

The cover story for our next issue is SiGe technology...we'll also have an interesting report on "rad hard" GaAs ICs, as well as our first optoelectronic device feature...also in the next issue: a retrospective on the MIMIC program (originally scheduled for this issue but "bumped" due to space constraints)...our first 1996 issue will focus on III-V epitaxy. If you are not already a subscriber, please complete the form provided on page 27 to insure that you don't miss a single issue.

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Device Feature

An in-depth look at a compound semiconductor product from a leading manufacturer

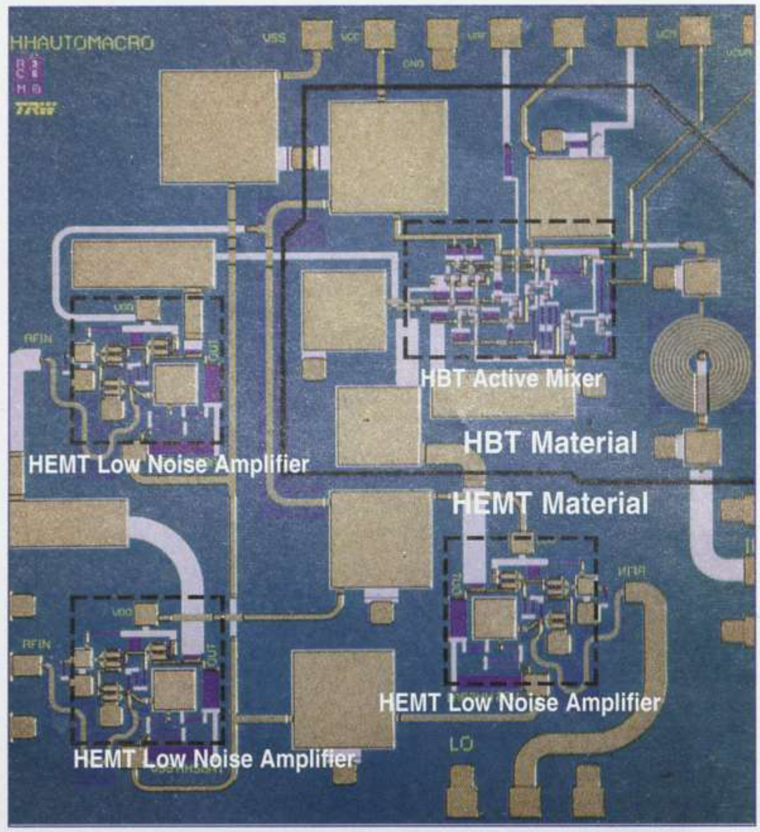
TRW's New Integrated HEMT/HBT Circuits

In late July TRW [Redondo Beach, CA] unveiled the first production ready MMIC to monolithically integrate both HEMTs and HBTs in the same microwave circuit. This new capability allows TRW designers to create a single chip solution which can handle both faint and strong signals by combining the low noise and high gain characteristics of HEMTs with the clean, accurate amplification capabilities of HBTs. "We've created a new family of chips which reduces the parts count for a typical integrated microwave assembly by a factor of 30 to 1," says Dave Vandervoet, vice president and general manager of TRW's Electronics Systems and Technology Division. "This breakthrough not only reduces our assembly costs, but also leads to significant improvements in the size, power consumption, and reliability of our customer's systems."

Monolithic HEMT-HBT integration was reported in our previous issue (*CS* 1(1), p. 22) as a highlight of TRW's research efforts. With this new announcement the company reveals that this technology is now commercially viable and that it has been moved into the production arena, where it is being used to fulfill the system requirements for in-house customers. At the moment, this technology is not available as part of TRW's foundry service, but Brooks McKinney, Manager of Public Relations, says that "discussions are currently being held regarding when and how this technology would be made available to commercial customers."

Selective Epi

The circuits are fabricated using selective MBE and a merged process technology which has been under development at TRW for the last three years. According to Dwight Streit, principal investigator for the project, "the technology has now matured to the point in which we have circuits which show clear advantages in microwave performance as compared to HEMT-only or HBT-only circuits which are then externally connected." The npn HBT profile is grown first by solid source MBE using Be p-type doping. The wafer is then removed from the MBE system, patterned with PECVD silicon nitride in the areas where HBTs will be needed, and the unpatterned areas wet etched back down to the substrate. The wafer is then reintroduced to the MBE system, and the GaAs/InGaAs HEMT is grown. The silicon nitride overhang created by the retrograde wet HBT etch provides a clean separation between the HBT island the HEMT region. The polycrystalline HEMT material and the silicon nitride layers are then removed. A merged device process is performed to fabricate the HEMT and HBTs, with ion implantation used for device isolation within islands, and air-bridges used for island interconnects.



Photograph of TRW's new integrated HEMT/HBT technology, impletmented as a low noise receiver chip.

A schematic of an integrated HEMT-HBT profile is shown in Figure 1. This example includes PIN and Schottky diodes which are easily been fabricated from the base-collector and collector region of the HBT. Potential applications for this new capability include single-chip transmit-receive circuits (using the HEMT to receive, the HBT to transmit, and PIN-diodes in switching functions); HEMT low-noise amplifiers that use HBT active feedback along with PIN-diode variable-gain control; and monolithic gain blocks that could combine HEMT low-noise front-ends with HBT high-linearity output stages.

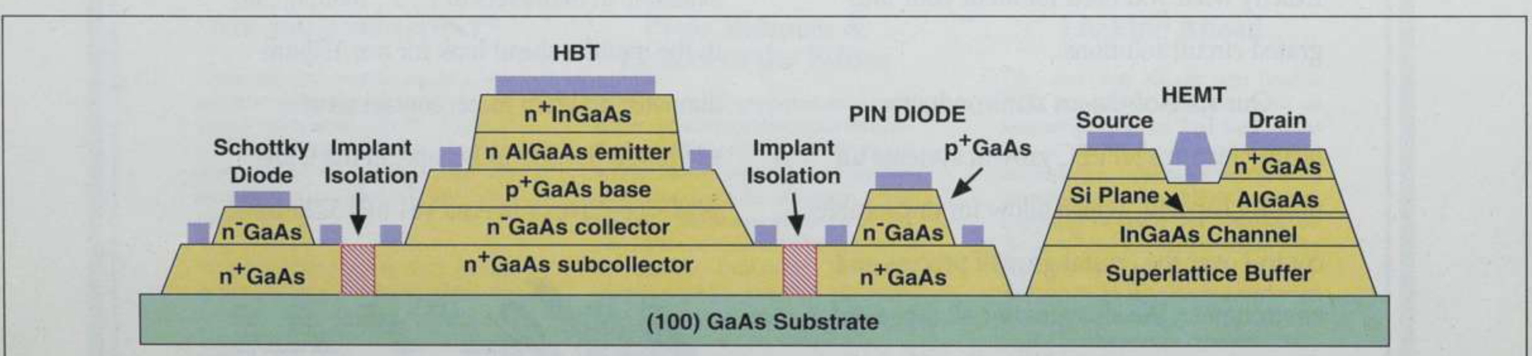


Figure 1. Schematic of integrated HEMT/HBT profiles, including PIN and Schottky diodes.

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New Devices

A summary of some of the new compound semiconductor and related devices recently announced by the manufacturers and distributors.

New "Super Bright" Blue LED from Cree

Cree Research, Inc. [Durham, NC] has announced a new high-output blue chip, more than 20 times brighter than Cree's previous blue products. The new chip has a typical radiant output of 500 microwatts measured at 20 milliamps with a peak wavelength of 430 nanometers, and it has been designed to conform to existing LED packaging standards, a feature which Cree says will facilitate its acceptance within the industry. The devices are fabricated using Cree's patented "G•SiC Technology™" which combines MOCVD-grown GaN with SiC substrates. The chips are available now, and a company spokesperson says Cree is expanding its manufacturing facilities to accommodate anticipated demand for the product.

980 nm Pump Laser Module from Mitsubishi

Mitsubishi is "leading the fiber optic industry migration to the 980 nm wavelength" with a recently announced 980 nm pump laser diode module. The module, which is offered by the Electronic Device Group (EDG) of Mitsubishi Electronics, America, Inc., is designed for use in long distance fiber optic telecommunications systems and cable television (CATV) applications based on the use of Er-doped fiber amplifiers (EDFA). Mitsubishi expects the 980 nm market to grow significantly. "As bandwidth and distance requirements for telecommunications and CATV applications continue to grow, use of EDFA will become more prevalent", said Mike Trapp, Mitsubishi EDG optoelectronics marketing manager. "We believe that 980 nm will be the preferred wavelength for the pump lasers required, and Mitsubishi is one of the first high-volume manufacturers in the market."

Mitsubishi reports that the new 980 nm module provides a lower noise pump source and that it has lower drive current requirements than the 1480 nm pump lasers now on the market. They also report that the MQW structure used in the new device results in lower threshold current and, therefore, higher efficiency than 1480 nm pump lasers, and that its high coupling efficiency (>60%) maximizes light coupled into the fiber. The new device is fabricated from InGaAs/GaAs using MOCVD. It features a hermetically sealed laser diode, with a built-in photodiode for monitoring optical output. The butterfly package has a built-in thermal electric cooler for temperature stabilization. It is available in two versions - one for 60 mW and one for 90 mW optical output power. Evaluation units are available now at $10,000 in single piece quantities.

New "Cost-Effective" 1300 nm Laser Diode

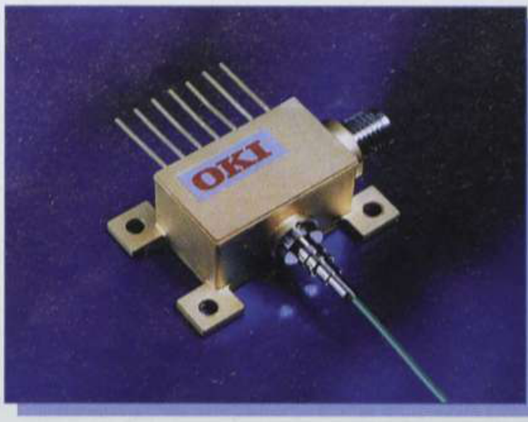
Mitsubishi has also announced a new 1300 nm laser product line which "offers a cost-effective solution for high-speed, optical communication systems." The new devices are intended to provide a highly reliable, stable light source for FitL (Fiber-in-the-Loop) and lower-speed SONET transmission applications. The new devices consist of two 1300 nm laser diodes (one with lens cap, one without) and a 1300 nm laser module, all fabricated from InGaAsP using FSBH (facet selected-growth buried heterostructure) multi-quantum well (MQW) active layers grown by MOCVD. Mitsubishi claims that the result of their designs and process technology is higher yields and lower costs compared to previous device versions, along with highly uniform electrical and optical characteristics. "Fiber optic networks are the infrastructure enabler for digitally-based, boadband interactive consumer and business communications on the information superhighway", said Mitsubishi's Mike Trapp. "Cost will be the market driver to move fiber deeper into telecommunications networks. What we've done is refine our optoelectronic process technology and further automate manufacturing to increase yields and, therefore, lower costs."

All three devices feature typical threshold currents of 10 mA and a typical operating current of 19 mA, and can operate over a wide temperature range (-40° to +85°C). The devices are designed to offer high-speed response for 155 Mb/sec and 622 Mb/sec transmission rates, and are qualifiable to the Bellcore reliability standards. The devices are available now. In quantities of 100, the price of the module is $175 and the laser diodes are $60 each. Higher volume pricing is available upon request.

New GaAs RF Devices from OKI

OKI Semiconductor has announced several new low-power GaAs microwave RF products operating from 850 MHz to more than 2 GHz for cellular, voice and data communications. The new products are high-efficiency, 3-V devices which are optimized and characterized to provide the necessary functions for portable UHF transceiver circuits in analog and low-distortion digital cellular radios, pagers and wireless LANs. The new products include MMIC amplifiers and drivers, broadband amplifiers, mixers, a digital prescaler, and power FETs. "With volume production in full swing, we're now able to fill requirements for most RF components", said Cliff Vaughan, OKI's RF/GaAs products manager. OKI began offering GaAs RF products in 1980. Today they operate two GaAs wafer fab facilities. They claim a unique distinction in the wireless arena - according to a company spokesman, it was an OKI subsidiary that placed the first cellular phone call in the US, in 1984.

New Laser Diodes Also Available



Four new distributed feedback (DFB) laser diodes for communications applications were recently announced by OKI Semiconductor's Electronics Components Group (ECG). These new devices are targeted for hybrid fiber/coax (HPC) broadband architecture network and trunking applications. Each is a multi-quantum well (MQW) design which includes built-in optical isolators to protect the transmission network from external optical feedback. "These products are just the tip of the iceberg" according to Yudhi Trisno, ECG fiber products manager. "As video and telephony converge on the information superhighway, it's apparent that fiber optics will play a much larger role in communications. We expect fiber to find its way into most of the next generation systems, including SONET or SDH, ATM for data communications, digital video transport, and telecom local loop access systems."

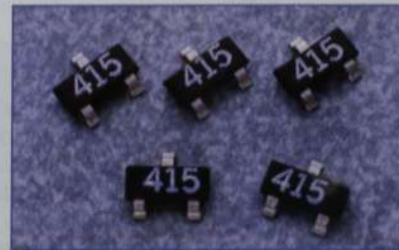
The first group of OKI laser diodes consists of two pigtail modules with wavelengths of 1300 nm and 1510 nm. These modules are rated for transmission up to 1.5 Gb/sec. In hybrid-fiber coax systems, typical minimum threshold current is rated at 20 mA and fiber output power at 1 mW. These units are currently in mass production, with standard delivery at 12 weeks, and prices at $2,000 per device in small quantities. The second group consists of thermal electric cooled (TEC) butterfly pigtail modules used in trunking applications, with wavelengths of 1310 nm and 1550 nm. Both are rated for 2.5 Gb transmission at 2 mW of output power, which makes them suitable for high-end transport. Other key specifications include minimum threshold current of 20 mA and a typical spectral half-width of 0.5 nm measured at 20 dB down. Engineering samples of these devices are available at $4,000 each.

New Devices from NEC, California Eastern Laboratories

NEC is offering several new GaAs devices. The new GaAs MESFET products include a power transistor designed for Ku-Band satellite communications. Also available are two new MESFETs which are designed to provide high efficiency for C-Band amplifier applications. Developed for 2.2 to 8.5 GHz operation, they feature internally matched input/output networks and SiO_2 passivated chips for power/gain stability under RF overdrive. In addition, NEC is now offering a new family of GaAs/AlGaAs heterojunction FET chips, which are designed for mm-wave Ka-Band transmitter applications. These new devices provide wide band performance up to 40 GHz, and deliver from 100 mW to 1/2 Watt of power. NEC's RF and microwave products are available in the US from California Eastern Laboratories.

New "Lowest Cost" 900 MHz Si Bipolar Transistor

Hewlett-Packard has introduced its lowest-cost 900 MHz silicon bipolar transistor. The devices are priced at $0.27 in quantities of 50,000 to 99,999, and they are in stock. This new product, which is a repackaged transistor now available in the SOT-23 three-lead surface-mount package, is targeted for applications such as cellular phones, WLANs, and direct-broadcast satellite receivers.



MBE in Space

The Wake Shield Facility is scheduled to fly its second mission; SVEC hopes to use the vacuum of space to grow epitaxial III-V's

A second go-around is planned for the Wake Shield Facility (WSF), a space-based MBE system developed by the Space Vacuum Epitaxy Center (SVEC) [Houston, TX] in the hopes of growing "the next generation of semiconductor and superconductor thin film materials" by capitalizing on the vacuum of space. The mission is planned for the next flight of the space shuttle Endeavor, originally scheduled for August 4, but delayed until late-August as this issue went to press.

During its first mission in February, 1994, the WSF demonstrated basic proof of the "MBE-in-space" concept by growing five homoepitaxial GaAs samples, but electrical interference problems curtailed the scope of the experiments. In this new mission the SVEC team hopes to demonstrate "free-flight" of the WSF facility and obtain full characterization of the "ultra-vacuum" created by the WSF, which they hope will be in the 10^{-14} Torr range. The growth experiments will concentrate on high purity, high mobility layers of GaAs and AlGaAs, with one HEMT, one p-n junction, and seven samples overall planned. Also on-board are TEGa and TMIn sources that will allow CBE-based experiments, looking at both the growth and the impact of the metalorganics on the growth environment.

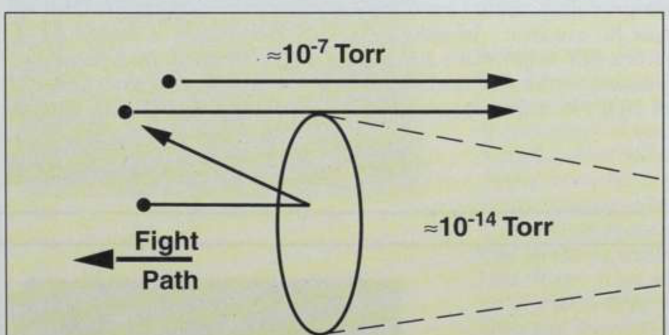
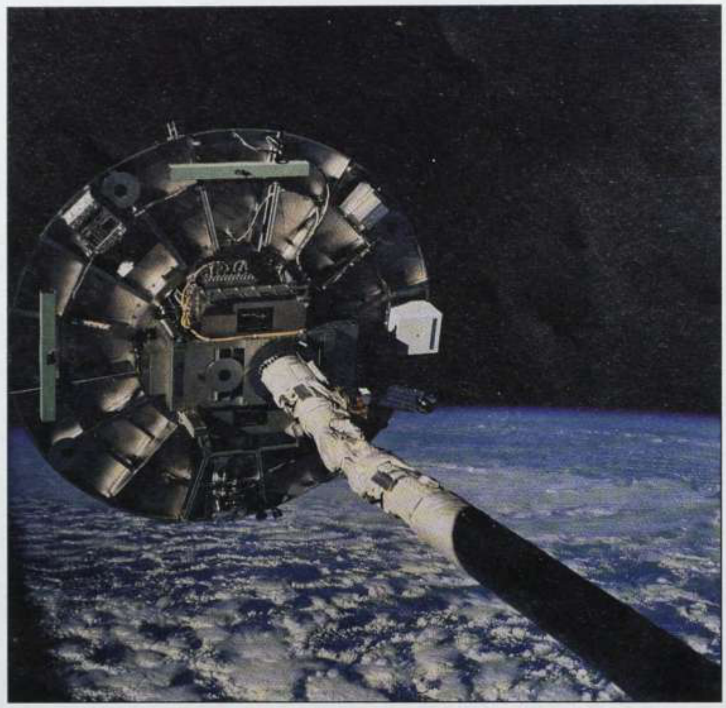


Figure 1. The wake formation concept in low earth orbit space. The vehicle (disc) velocity is ≈ 8 times the mean thermal velocity of the ambient gas atoms. As a result, the ambient atoms and molecules that do not collide with the disc have too few collisions per unit time to diffuse behind the disc, hence creating an ultra-vacuum region (a vacuum wake) behind the disc.



The Wake Shield Facility during its first mission in 1994.

Ultra-Vacuum

All earth-based MBE systems operate in the ultra-high vacuum (UHV) range, with base pressures of around 10^{-11} Torr. The vacuum in space varies from about 10^{-7} Torr in low earth orbit (LEO) to about 10^{-15} Torr halfway to the moon. Access to the higher orbits is severely limited, but LEO can be accessed via the space shuttle. SVEC engineers believe that the concept of wake formation can be used to improve the vacuum in LEO to levels unobtainable on earth. (See Figure 1)

The wake is generated by the WSF "free-flyer", a 12-foot dia. stainless steel disk looking somewhat like a large direct broadcast satellite dish. See Figure 2. The WSF first makes one orbit around the earth on the end of the shuttle's robotic arm with its wake side facing the flight path. This allows the atomic oxygen present in LEO to "scrub" the surfaces in the vicinity of the growth stage. The WSF is then released, and it becomes a fully equipped spacecraft in its own right, with a cold gas propulsion and a momentum bias attitude control system. The WSF maneuvers ≈ 40 nautical miles away from the shuttle [a first for any payload] and positions itself to create the "ultra-vacuum". The MBE components are then powered up, using on-board silver-zinc batteries (solar panels are planned for future flights), and the growths begin. The campaign for this flight is scheduled to last for 3 days. After the growths are completed the shuttle crew recovers the WSF for the return to Earth.

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Room to Grow

Fantastic baseline vacuum pressures are not the only advantage to be gained by growing in space, according to Alex Ignatiev, SVEC's director. For example: although earth-based MBE systems may be able to achieve 10^{-11} Torr while idling, the pressure rises by orders of magnitude during growth as the evaporants fill the chamber. The WSF, however, benefits from a semi-infinite pumping speed. In addition, there is no vacuum chamber on the WSF, and therefore there is less opportunity for the evaporant species to flake or desorb off the chamber walls and contaminate either the growth surface or the sources. Ignatiev also points out that the absence of chamber walls and the semi-infinite pumping speed allows one to "think big" when contemplating multi-wafer growth. He foresees processing dozens of wafers at a time. He also envisions incorporating in-situ processing, including lithography and regrowth. And, finally, Ignatiev hopes to take advantage of the atomic oxygen in the LEO environment for the growth of crystalline oxide films, including high temperature superconductors and insulating layers for semiconductors.

First Flight

The first WSF mission - WSF-01 - flew in February, 1994. The WSF was deployed on the shuttle's robotic arm, but could not be released because the attitude control system malfunctioned. Had the WSF been released in that state, it would have orbited in a slow tumble, preventing wake formation. Vacuum measurements were conducted and growths were performed with the WSF on the robotic arm, but both sets of experiments were compromised by the large amount of water vapor contamination produced by the shuttle.

The failure to free-fly is what most people remember about that first mission. Nevertheless, says Ignatiev, "we still did about 85% of what we wanted to do. We formed a wake vacuum, measured it [it was found to be $\approx 10^{-10}$ Torr despite outgassing from the shuttle], and grew crystalline thin films." He acknowledges that there is still work to be done, especially when it comes to convincing people: "We still have to prove the basic science aspects of the vacuum environment and develop thin-film technology in space. We want to prove not only that we can make better materials, but in quantities that will make industry take notice."

What Lies Ahead?

One has to admire the ambition of the WSF team. Here is a look at what they hope to achieve in their next several missions. WSF-03 and WSF-04 are already schedule to go up in 1996 and 1997; their success or failure may determine the future for WSF-05 and beyond.

*WSF-03 (1996) - add capacity through the addition of solar panels for continuous power generation; multi-wafer capacity approaching 50 samples; direct ground communications for autonomous operations of the WSF through ground stations; materials grown primarily under recipe from industry; small runs of samples that could be processed into test devices in industrial fab lines.

*WSF-04 (1997) - increase number of substrates processed to 300; significant industry participation both in the support of the flight and in receipt of finished wafer products from the flight.

*WSF-05 (proposed) - increase mission time to 60-90 days (put in orbit by one shuttle, retrieved by another) and thereby maximizing economic efficiency

*WSF Mark II (proposed) - a five year orbiting platform, capable of processing up to 3,500 wafers per year, serviced robotically to harvest finished wafers and to replenish raw materials, with service support from the shuttle.

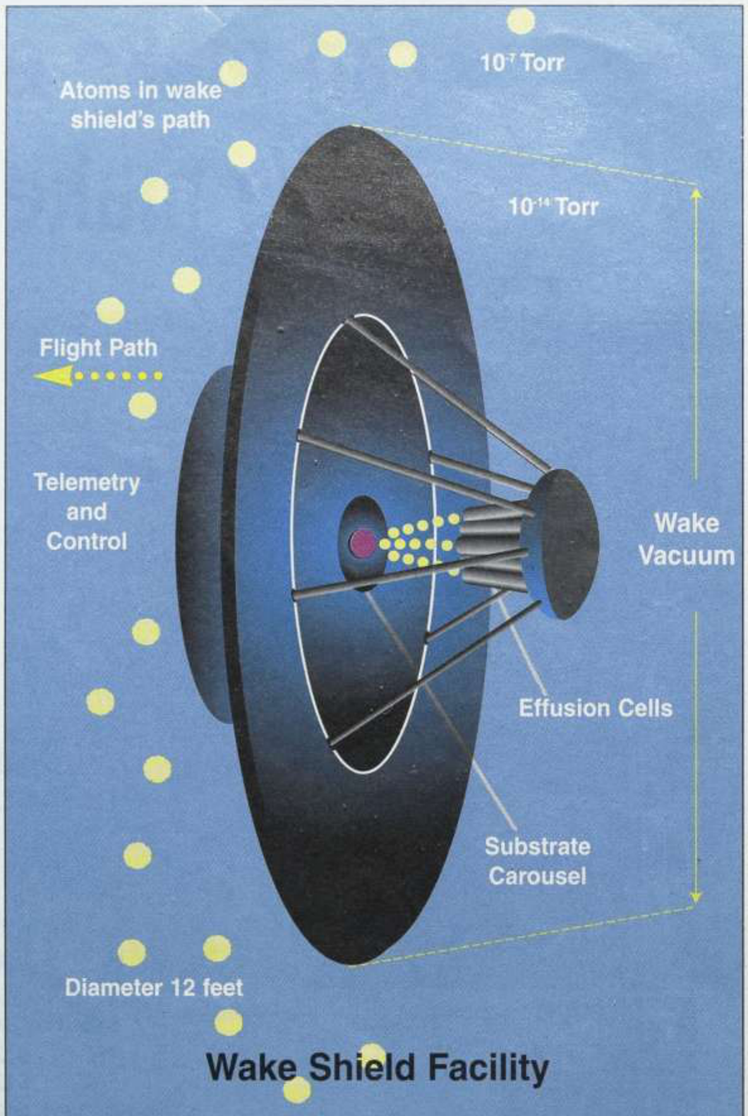


Figure 2. A schematic of the Wake Shield Facility. The "ram" side - that which faces the direction of travel - houses avionics and some auxiliary, non-vacuum-related payloads. The "wake" side houses the MBE equipment.

For this mission the WSF is equipped with eight effusion cells - two each for As, Ga and Al, one each for Si and Be. Seven substrates are carried in a carousel assembly. After each growth the carousel is rotated to expose the next substrate for growth. The WSF is also equipped with a 10 kV RHEED system with a video display attachment which will relay the RHEED data to the shuttle crew and ground personnel. Also included: three mass spectrometers (one high sensitivity magnetic sector unit for ultra-vacuum measurement, and two "time of flight" units, one which is used as a beam flux monitor (BFM) and one which is used to monitor wake environment and pressure); three cold cathode gauges (one used as a BFM, two for vacuum measurement), and an optical pyrometer.

With apologies to Star Trek...

SVEC's unofficial mission statement:

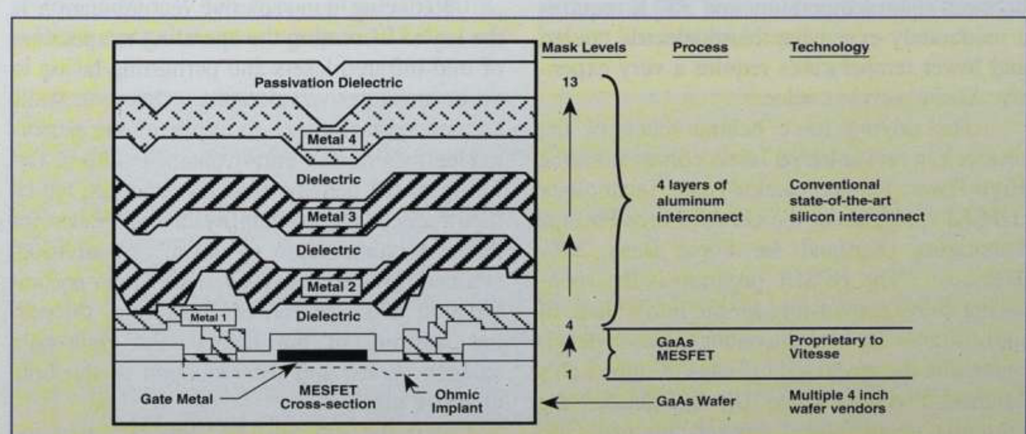
"To boldly grow where no man has grown before"

Vitesse Announces New GaAs Process

Vitesse Semiconductor Corporation has unveiled its latest VLSI GaAs process for digital ICs. This fourth generation process, designated H-GaAs™ IV (the "H" stands for "High Integration"), is capable of combining million transistor integration with microwave performance, and is intended to enable implementation of high performance systems for telecommunications, data communications and test-instrumentation at price levels far below ECL and BiCMOS technology. "H-GaAs IV continues a series of GaAs process technology breakthroughs made at Vitesse that bring H-GaAs™ technology to market as the commercial mainstream technology of choice for high-performance systems" says Lou Tomasetta, President and CEO of Vitesse. "Vitesse has focused on reducing process cost through improvements in density and manufacturability. The result is a technology that offers a low-cost, higher-performance alternative to CMOS."

H-GaAs IV is a 0.5 µm gate length scaled version of the H-GaAs III process currently in production. Chip density has been doubled compared to the previous 0.6 µm gate length technology by reducing the pitch of the first and second levels of metal by a factor of two. According to Chris Gardner, Marketing Director, "when H-GaAs IV is applied to gate arrays, not only is the gate array density doubled, but the power requirement drops to 1/2 to 1/4 of that required for the GaAs III process." By doubling gate density, the new Vitesse family of gate arrays, called the GLX-family, can support upwards of 900,000 gates in a 1.5 x 1.5 cm^2 chip. However, according to Gardner "we find that the market dictates that gate counts in the 150,000 to 200,00 level are what is needed for telecommunications, data communications and ATE/instrumentation applications. As a result of the softening of the CPU market, these applications have become very important to us, now comprising some 80% of our business as compared to only 30% three years ago. H-GaAs IV permits us to fabricate much smaller chips, which translate into more die per wafer, and thereby reduce the cost per chip."

H-GaAs IV implements refractory metal self-aligned gate transistors, one layer of local interconnect, and four layers of standard aluminum global interconnect (see figure). Polyimide dielectrics and planarization are used to reduce interconnect capacitance and improve routing density. This 0.5 µm gate length MESFET exhibits a transistor cutoff frequency, f_t, in excess of 35 GHz and a delay-power product of less than 6 femto-Joules (fJ), resulting in unloaded gate delays of less than 70 ps. Power dissipation is below 0.1 µW/MHz/gate at clock frequencies above 600 MHz. By comparison, BiCMOS and CMOS processes achieve gate delays of 200-300 ps, and can not support clock rates above 200 MHz. H-GaAs IV supports supply voltages from 1.2 to 3.3 V with less than a 20% change in gate speed. Clock frequencies on VLSI designs up to 200K gates using Direct-Coupled-FET-Logic (DCFL) can exceed 800 MHz. For MSI circuits, using Source-Coupled-FET-Logic (SCFL), 10 GHz clock rates can be obtained for broadband telecommunication applications. Initial products utilizing the H-GaAs IV process will be announced later this year.



Vitesse Semiconductor Corporation.

Schematic of Vitesse's new H-GaAs™ IV process.

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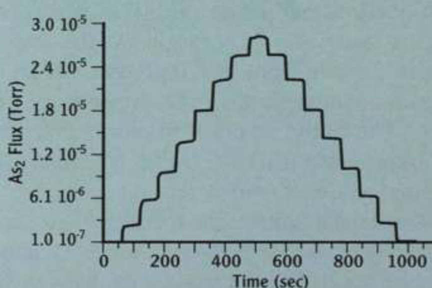
Arsenic

The EPI Valved Cracker for arsenic – the "VC-As" – is the key to maximizing the performance of any III-V MBE system. It provides all the advantages of a gas source – rapid and reproducible flux modulation, easy on-off switching – without the drawbacks of safety and health hazards. It works equally well as a source for As_2 or As_4. And it offers a very large useful capacity – either 500cc or 2000cc. Automated valve positioning for precise remote control over flux density is available as an option. Standard and custom models are offered to fit all types of systems. The EPI VC-As is a proven effective source, with more than 200 units currently in use at facilities around the world. If you are using arsenic, the VC-As is for you.



One example of the flux modulations provided by the EPI VC-As.

Several application notes detailing the performance of the VC-As are available. For more information, please call EPI.

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A Progress Report on Antimonide-Based Mid-Infrared Lasers

Mid-IR lasers are needed for the next generation of atmospheric monitoring systems. Some impressive engineering efforts are moving the III-Sb materials system closer to the goal.

Antimonide-based mid-infrared semiconductor lasers could be the key to the next generation of atmospheric monitoring devices. Many important atmospheric molecules - both industrial pollutants as well as green-house gases - have strong absorption lines in the mid-infrared between 2 and 5 µm, with overtones at shorter, near-infrared wavelengths. See Table 1. For example, the absorption of 3.3 µm light in CH_4 is two orders of magnitude stronger than the overtone at 1.65 µm. Currently, many emission-monitoring techniques use LIDAR (light detection and ranging) systems, which rely on scattering of light from particulates in the air. This technique can be used to determine total concentrations of particulates or pollutants, but can not differentiate between molecular species. Differential absorption LIDAR (DIAL) systems are intended to address this shortcoming, and the key to implementing DIAL is the laser source.

Key Absorption Lines

CO	2.38 mm
HF	2.52 mm
CH_4	3.3 mm
HCl	3.47 mm
CO_2	4.25 mm
N_2O	4.5 mm
O_3	4.73 mm

Table 1. Key absorption lines for several important atmosphere species.

The concept behind DIAL is that two mid-infrared laser beams are used, one operating on the absorption line of a molecule of interest, and one at a slightly displaced frequency at which absorption will not take place. When these two laser beams are transmitted through a sample containing the molecule of interest the laser beam which is resonant with the molecule will be absorbed more than the off-resonant beam. The difference in signal strength between the two laser beams can then be used to determine the amount of the molecule of interest. From a practical, economic consideration, room temperature operation of the mid-infrared laser is desired. Operation between room temperature and 200 K requires a moderately expensive thermoelectric cooler, and lower temperatures require a very expensive Stirling-cycle cooler.

The driving force behind much of the research in mid-infrared lasers comes from the High Power Semiconductor-Laser Technology (HPSLT) program of the US Air Force Phillips Laboratory (Kirtland Air Force Base, New Mexico). "The HPSLT program is the sponsoring entity responsible for the lion's share of mid-infrared III-V semiconductor laser development in the world today," says Phillips Lab's Michael Prairie. Three US laboratories are currently being funded through this program: 1) Lincoln Laboratory, Massachusetts Institute of Technology (Lexington, MA), 2) David Sarnoff Research Center (Princeton, NJ), and 3) Hughes Research Laboratories (Malibu, CA). According to Prairie, "the major objectives of this program are to obtain high power, long wavelength lasers (1 W operating over 2-5 mm) and to get these lasers operating at high temperature - ultimately room temperature."

The Technical Challenge

In a perfect laser, every charge carrier supplied would result in a stimulated emission. But there is no such thing as a perfect laser. Nonradiative recombination is the reason why the maximum room temperature operation of a mid-infrared laser is currently no higher than 2.78 µm. Prairie explains, "the two principal nonradiative mechanisms impacting mid-infrared lasers are monomolecular and Auger processes. Monomolecular recombination results from carriers interacting with defects. Reduction of these defects generally come about by improvements in material growth, especially at heterojunction interfaces. Auger recombination involves collisions between carriers which then scatter to different energy states, thereby non-radiatively depleting some inverted carriers which would otherwise be available for radiative recombination. This recombination mechanism can be reduced by bandgap engineering. The reason that nonradiative recombination limits the operating temperature of the device is because of local heating which takes place as electrons and holes recombine nonradiatively. If this excess heat cannot be transported away from the active region quickly enough, then the temperature-dependent losses will increase. The laser will then require more current to reach threshold, which further heats the device, resulting in a thermal-runaway situation."

Reducing non-radiative recombination is the key to increasing the operating temperature of mid-infrared lasers and permitting lasing to occur at longer wavelengths. Quantum wells are now typically used to improve laser performance, where this improvement is due to tailoring of the density-of-states function, which then reduces the availability of final states for Auger recombination to occur. In addition, strained QWs are used to reduce Auger recombination and free carrier absorption, through the splitting of the heavy- and light-hole valence bands, and the reduction of the hole effective mass.

It is the strained QW approach that the David Sarnoff Research Center has used in

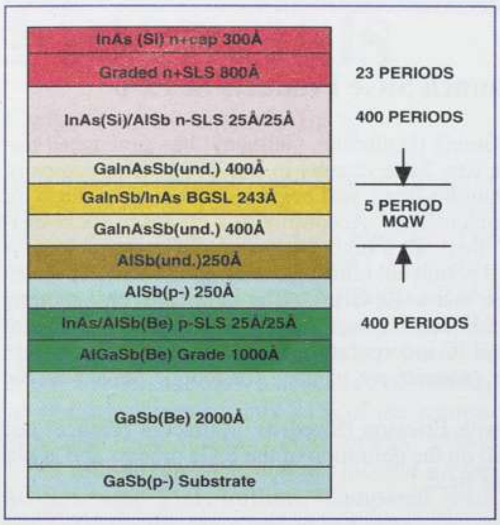

Figure 1. Schematic layer sequence diagram for GaInSb/InAs superlattice-based diode laser structure. Courtesy of Tom Hasenberg, Hughes Research Laboratories (Malibu, CA)

obtaining room temperature 2.78 µm laser operation. This MBE-grown laser on a GaSb substrate incorporates an active area consisting of 4 $In_{0.24}Ga_{0.76}As_{0.16}Sb_{0.84}$ QWs and 5 $Al_{0.25}Ga_{0.75}As_{0.02}Sb_{0.98}$ barriers. The QWs are under 0.2-0.3% compressive strain. Pulsed operation for this laser was observed at 15°C, at a threshold current density of 10 kA/cm², producing a maximum power output of 30 mW.

In a similar approach, but using slightly different materials, researchers at Lincoln Laboratories have fabricated an MBE grown laser on a GaSb substrate which incorporates an active area consisting of 10 $InAs_{0.85}Sb_{0.15}$ QWs and 11 $In_{0.9}A_{0.1}As_{0.9}Sb_{0.1}$ barriers, and emits at 3.9 µm. As in the David Sarnoff Research Center approach, these QWs are under compressive stress. Broad stripe lasers using this active region exhibit pulsed operation up to 165 K, with a threshold current density of 78 A/cm² at 80 K. A maximum cw power of 30 mW/facet was obtained at 80 K, with cw operation occuring up to 123 K.

The most aggressive approach, from the perspective of MBE growth, has been that taken by the Hughes Research Laboratories (Malibu, CA). They have fabricated a structure on GaSb substrates in which the active layer consists of a 5 or 6 period multiple quantum wells (MQW) with $Ga_{0.75}In_{0.25}As_{0.22}Sb_{0.78}$ barriers and type-II (broken-gap) $Ga_{0.75}In_{0.25}Sb$/InAs superlattice wells. The cladding layer surrounding the active layer consists of a 400 period n- or p-type InAs/AsSb(25Å/25Å) superlattice. See Figure 1. The unique aspect of this work is in the use of the superlattices. By tailoring constituent layer thicknesses in the superlattice wells, laser emission wavelengths ranging from 3.28 µm (maximum operating temperature 170 K) to 3.90 µm (maximum operating temperature 84 K) are obtained under pulsed conditions. The broken-gap band alignment between $Ga_{1-x}In_xSb$ and InAs allows superlattice energy gaps smaller than those of any bulk III-V alloy, opening the possibility to very long wavelength lasers (>4 µm). Tom Hasenberg of the Hughes Research Laboratories says, "GaInSb/InAs superlattices hold a number of significant potential advantages relative to GaInAsSb (or InAsSb) alloys as QW materials for 2-5 µm lasers, including reduced threshold carrier densities, suppression of Auger processes, and favorable band offsets for hole and electron confinement."

The future trends for all these approaches will continue to center on improving MBE growth, and optimizing the active area bandstructure in order to increase both the temperature of operation and lasing wavelength. For many of these systems, the band offsets between alloys are only known to the order of 50-100 meV, while changes as small as 10 meV can have a major impact on the confinement of electrons and holes. As a result of this, antimonide-based mid-infrared laser work will continue to be very experimentally intensive, requiring the grower to attempt a wide range of alloy contents, and to then experimentally determine how those changes in alloy content impact laser performance.

Detailed information regarding the approaches discussed above can be found in:

1. "Demonstration of 3.5 µm $Ga_{1-x}In_xSb$/InAs Superlattice Diode Laser", T.C. Hasenberg et al, Electron. Lett. 31(4), 275 [16 February 1995].

2. "InAsSb/InAlAsSb Strained Quantum-Well Diode Lasers Emitting at 3.9 µm", H.K. Choi and G.W. Turner, Appl. Phys. Lett. 67(3), 332 [17 July 1995].

3. "Room-Temperature 2.78 µm AlGaAsSb/InGaAsSb Quantum-Well Lasers", H. Lee, et al, Appl. Phys. Lett. 66(5), 1942 [10 April 1995].

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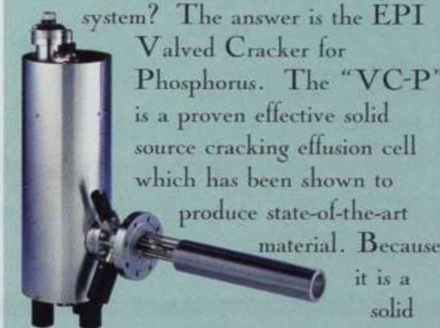
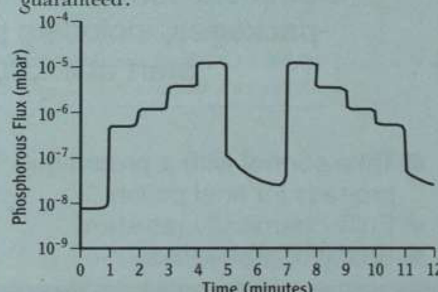
Phosphorus

How can you equip an MBE system for the growth of phosphides without incurring the expense and hazards of a toxic gas handling system? The answer is the EPI Valved Cracker for Phosphorus. The "VC-P" is a proven effective solid source cracking effusion cell which has been shown to produce state-of-the-art material. Because it is a solid source, no hazardous gases are required; and because it is a valved source, rapid and reproducible flux modulations and easy on-off switching are provided. Other features include a large useful capacity (500cc) and optional automated valve positioning. Best of all, it is from EPI, the authorities on MBE sources, which means that your satisfaction is guaranteed.





Example of the P_2 flux modulation made possible by the VC-P.

For more information, please call EPI and request a copy of our new brochure, "Epitaxial Phosphides by Solid Source MBE", which includes a bibliography of results achieved using the EPI VC-P.

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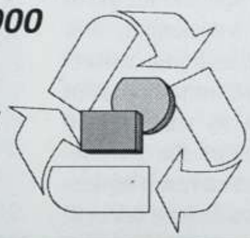

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TEMIC Plans to Launch SiGe Products in 1996

TEMIC Telefunken GmbH [Heilbronn, Germany] has announced that it will begin marketing its first SiGe circuits in late 1996. The company, which is a subsidiary of Daimler-Benz, will begin by sampling products for the wireless communications market. According to a company spokesperson, the development of their ultra-high frequency SiGe technology is almost complete, and it will permit cut off frequencies up to 50 GHz, "focusing on the operating range below 10 GHz". The devices, with operating voltages up to 5 V, will be fabricated using a 1 µm process. Among the products planned are a front-end IC incorporating a low noise amplifier, mixer, VCOs and buffers. Other products are planned for mobile phones on the GSM and DCS standards.

TEMIC is working with Ericsson (Sweden), Matracom (France) and Northern Telecom (Canada) on the definition of the SiGe process and applications in the mobile phone field.

Murata to enter GaAs IC business

Murata Manufacturing Co., Ltd. [Kyoto, Japan] has announced that it plans to enter the GaAs IC business. According to a company spokesperson, Murata has developed GaAs semiconductor circuit design application software and using the software they have developed an ultra-small microwave MCM power amplifier for use in PHS (personal handy phone system) handsets. The devices are integrated onto the company's proprietary multi-layered ceramic substrate. Murata claims that the software enables GaAs IC development time to be slashed by 2-5 months and allows them to lower production costs. Murata plans to supply the amplifier to domestic PHS handset makers and export it for use in cellular phones.

Major Reorganization at ITT

In June the board of ITT Corp. approved a plan to spin-off its diverse range of businesses to shareholders to form three separate publicly held corporations. The three new companies will be: ITT Industries, which will consist of the electronics, defense, automotive, and fluid technologies businesses of the current ITT; ITT Hartford, consisting of ITT's present insurance business; and the "new" ITT Corp., which will include the "old" ITT's entertainment and hospitality holdings.

The ITT GaAs Technology Center [GTC] in Roanoke, VA will continue as a business unit of ITT Defense and Electronics, one of the business that will be owned by ITT Industries. GTC was originally formed to supply GaAs ICs for ITT's military operations, but over the past few years it has been transforming itself into a supplier for commercial wireless markets. The reorganization may improve its situation. As a company spokesperson put it: "Overall, the spin-off will allow ITT Defense and Electronics to better determine its own destiny. Our proposals for capital expenditures and funding will no longer have to compete with proposals for acquiring hotels, or investments like Madison Square Garden [a property recently acquired by ITT's hospitality area]". He went on to say that the company believes that the outlook for the GTC is "bright", given the overall demand for GaAs devices, and the capabilities of the center. Several proposals for upgrading or expanding the facility are said to be under consideration.

Lockheed Martin Announces Microwave Products Business

The Lockheed Martin Corporation has announced that it will establish a Microwave Electronics "Center of Excellence" at its Sanders Facility in Nashua, NH. It will include work previously performed by the Electronics Lab in Syracuse, NY, which Martin-Marietta acquired from GE prior to its own merger with Lockheed. That facility is scheduled to be phased out by late 1996. Microwave and millimeter wave R&D capabilities from the company's Baltimore laboratories will also be included. This announcement comes as part of a company-wide $1.7B consolidation plan which is aimed at eliminating duplicative facilities

Financials

GaAs Boosts Alpha's 1st Q

New orders, sales, and revenue were all up for Alpha Industries [Woburn, MA] in the first quarter of its fiscal year, ended June 30. The company's president and CEO, M.J. Reid, cites "particularly strong" demand for Alpha's GaAs MMICs as the reason. The company claimed a "significant increase in new orders from the major wireless OEMs", and states that military contracts represented only 21% of the company's total new orders. New orders totaled \$26.3 million, up 24%, and net income for the quarter was \$1.1 million, compared with \$603,000 for the same period last year.

Anadigics Reports Record 2nd Q

Anadigics [Warren, NJ] reported record net income of \$1.4 million for the 3 months ended June 30, 1995. Net income for the same period in 1994 was \$171,000. The company posted a gross profit margin of 53.7% for the quarter. Anadigics' President and CEO Ron Rosenzweig said, "Sales of cellular telephone ICs were very strong and represented approximately 30% of second quarter 1995 as compared to minimal sales in the second quarter of 1994. In addition, CATV ICs were at record levels, beating a previous record set one year ago." The cellular IC sales included power amplifier and receiver front ends for the analog AMPS cellular phones, and power amplifier ICs for the analog ETACS and digital DAMPS units. The increase in CATV IC sales was driven by increasing shipments of the company's new 50-860 MHz chipset for use in new broadband CATV settop boxes.

Cree Shows Progress, Announces Stock Split

Cree Research Inc. [Durham, NC] announced revenues for their fourth quarter of \$3,398,000, up 60% over the previous year's fourth quarter. Increasing revenues resulted in a fourth quarter net profit of \$207,000, compared with a loss of \$118,000 for the same period last year. For the fiscal year ended June 30, 1995, Cree posted a loss of \$17,000, compared with a loss of \$431,000 in 1994. In announcing the results for 1995, Cree's President Neal Hunter remarked "this is the first full fiscal year that product sales represented a larger percentage of total revenues than contract research sales. This trend should continue with the increased production of our new superbright blue LED." He added that "Cree expects to produce between 1 and 1.5 million super bright chips during the first quarter as our manufacturing

ramp continues. We are adding epitaxial and fabrication capacity in the first quarter to increase our output. During this fiscal year we expect significant capacity enhancements from larger wafer diameters, smaller chip sizes, and higher yields." Cree also announced on August 1 that their Board of Directors had authorized a 2 for 1 stock split, to take effect on August 15.

SDL Reports Record 2nd Q

SDL Inc. [San Jose] announced record revenues and earnings for their second quarter, ended June 30, 1995. Revenues were \$12.5 million and net income was \$1.4 million, compared to revenues of \$7.8 million and net income of \$0.5 million in the second quarter of 1994. This represents a 61% increase in revenues and a 204% increase in net income as compared to the prior year.

TriQuint Files for Public Stock Offering

TriQuint Semiconductor [Beaverton, OR] announced on August 4 that it had filed for a public offering of 1,500,000 shares of Common Stock. TriQuint is currently traded on the Nasdaq National Market, and will have 7,270,536 shares outstanding after the offering.

Vitesse Announces 3rd Q Results

Vitesse Semiconductor Corp. [Camarillo, CA] reported revenues in the third quarter of fiscal 1995 of \$11 million, an increase of 20% over same period in 1994. Net income was \$762,000, compared with \$128,000 for the third quarter of 1994. These results represented a rebound from a tough second quarter, during which the company posted a net loss of \$1 million, due largely to a \$1.4 million write-off of receivables and work-in-progress inventories for Cray Computer, which filed for bankruptcy.

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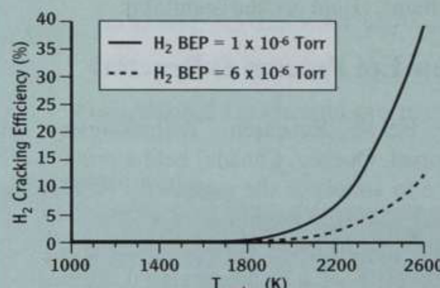
Hydrogen

Atomic hydrogen has many potential applications in solid source MBE.

It allows oxide desorption from GaAs and InP substrates at lower temperatures than conventional methods. It has also been shown to improve the quality of epitaxial layers, and it can be used as a surfactant to suppress island formation. The EPI Atom-H Source generates atomic hydrogen by thermal cracking. It is similar in size to a small effusion cell, which means that it is easy to install on virtually any UHV system. The Atom-H source is simple to operate, offers high cracking efficiency at low power consumption, and is significantly less complex and expensive than ECR or plasma sources.



Measured cracking efficiency for the EPI Atom-H Source.

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News from Semicon West '95

Among the 2,700 booths, a few compound semiconductor items.

It is a good time to be a semiconductor equipment supplier - especially if your *forte* is silicon. This year's Semicon West Exposition, held July 11-13 at San Francisco's Moscone Center, was the biggest ever (2,700 booths, 1,200 exhibitors, 45,000 attendees), and it was, of course, dominated by silicon. The mood among the vendors was extremely upbeat. They are saying amongst themselves "if you can't turn a profit in these market conditions, then you probably never will!" The only complaint seems to be that the backlogs are too big: delivery for some capital items is reported to be out to 18 months.

Mixed in with all that silicon were a few interesting compound semiconductor and related items. Here are the highlights.

New Epi Process & Reactor

F.S.F. Research Technologies, Inc. [Dorval, Quebec, Canada] held a press conference to announce the availability of their new "solid phase epitaxy" (SPE) reactor. According to F.S.F. President Fareed Sepehry-Fard, SPE is a fundamentally different epi growth technique which his company has developed and patented. It uses all solid source materials, and operates at atmospheric pressure, thereby eliminating both hazardous chemicals and the complications associated with vacuum environments.

The source material in SPE is a crystalline or polycrystalline "source wafer" of a composition similar to that which is to be grown - for example, GaAs for GaAs homoepitaxy, or AlGaAs for AlGaAs/GaAs heteroepitaxy. The "target" substrate - the one which will be deposited on - can be virtually any material and, according to Sepehry-Fard, "we are practically unlimited in terms of the size of the substrate we can accommodate." He adds that the key to controlling the stoichiometry of the deposited film is ultra-precise temperature control for both the source and target, as well as "a lot of proprietary know-how that is built into the reactor". F.S.F. claims that its in-house reactors have been used to grow 18 different semiconductor materials, including GaAs, AlGaAs, InGaAs, InP, CdTe, and HgCdTe.

F.S.F. believes that the SPE process will be competitive with MBE and MOCVD in terms of material quality, and that it will be much more cost effective, reducing the cost of processing GaAs epi wafers "by a factor of 10 to 1." They cite their primary cost advantages as higher growth rates (up to 2 μm/minute is claimed), and greater simplicity in the equipment design. The company is targeting both optotelectronic and wireless device manufacturers. No SPE reactors are currently in use outside of F.S.F., but the company says that it will be placing the first units "very soon".

ATMI Introduces SiC Wafers and Epitaxial Services

Advanced Technology Materials Inc. [ATMI, Danbury, CT] announced the availability of single crystal SiC wafers and SiC epitaxial growth services. It also announced the signing of an agreement to distribute Nippon Steel's SIMOX wafers in North America.

ATMI is entering the SiC wafer market with 1" dia. wafers, and plans to increase to 2" as soon as possible. Both 4H and 6H polytypes are available, with a micropipe defect density spec of <200 cm^{-2}.

New ALE Reactors

Advanced Thin films [Saratoga, CA] announced the availability of a new family of Atomic Layer Epitaxy (ALE) reactors manufactured by Microchemistry Ltd. [Espoo, Finland]. A company spokesperson said that the reactors are based on a proven proprietary process that has been used to manufacture CdTe solar panels and ZnS electroluminescent displays for several years.

Balzers + Leybold = One Very Big Vacuum Company

It is now official: the Swiss holding company Oerlikon-Buhrle, which owns Balzers (Liechtenstein), announced that it had completed the acquisition of Leybold AG (Germany), creating the world's largest vacuum engineering company, with combined 1994 worldwide sales of $1.1 billion. The new company will be called Balzers and Leybold, and it will operate as eight autonomous business units: Balzers Thin Film Components, Balzers Instruments, Balzers Process Systems, Balzers Wear Protection, Leybold Vacuum, Leybold Coating Technologies, Leybold Didactic, and Leybold Materials.

Other Semicon News

The compound semiconductor standards meeting scheduled for July 12 was canceled in favor of relocating to the GaAs IC Symposium in October....the exhibitors included Bio-Rad Microscience [Hemel Hempstead, UK], who were conducting the North American Launch of their new PL9000 Series Fourier Transform Photoluminescence Series....also exhibiting was Emcore Corporation [Sommerset, NJ], exploring the market for advanced CVD applications and demonstrating their 300 mm wafer-handling capability....this was the 25th Semicon West Exposition. Next year's meeting will be held July 16-18 at the Moscone.

Marie Meyer

Sensors Unlimited [Princeton, NJ] has released a new family of near-infrared line scan cameras which rely on InGaAs photodiode arrays. The cameras are sensitive to the 0.8 to 2.2 μm wavelength band, and are for use in scanning moving objects such as assembly line items.

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News from Japan

Matsushita announces red laser for SD DVD

Matsushita Electric Industrial Co., Ltd. has developed a self-oscillating GaInP/AlGaInP red laser to read SD (super density) DVD (digital video disk) data. SD is the next generation of DVD, and it requires very low noise pick-ups. The new Matsushita product has a 650nm wavelength with 5 mW of output power at 60°C., and a noise level of approx. 130 dB - around 1/10 that of conventional devices. The company plans to begin volume production next spring.

NEC develops prototype surface-emission laser array capable of oscillating beams with different wavelengths

NEC has developed a prototype surface-emission laser array capable of oscillating beams with different wavelengths. NEC researchers have incorporated a masking shutter onto an MBE system, allowing them to change a mask for each growth step, enabling a desired thickness of a layer to be formed in a desired area. In an experiment, NEC used two mask shutters with 250μm-wide stripes and applied twice selective crystal growth using them so that the stripes crossed each other to create a surface-emission laser with four different wavelengths.

Fujitsu Labs develops technique to deposit metal crystal on compound semiconductor substrate

Fujitsu Laboratories has developed a technique to deposit metal crystal on a compound semiconductor substrate. The technique uses MBE to deposit nickel and InAl layers on an InP substrate to form Niinal (nickel indium aluminum) crystal. Researchers have arranged the ratio between indium and aluminum so that the crystal's lattice constant is just half that of the substrate. In an experiment, the company grew crystal 30nm thick. The company says that the technique can be used to build metal electrodes and wires into semiconductor devices and increase integration density.

Other News

The Nikkei Weekly (6/26/95) reports that Showa Denko plans to cut yen-denominated export prices of its compound semiconductor products in reaction to the weak dollar. They report that "the move is being made because the firm believes that if it fails to reduce yen-denominated prices, foreign clients will start employing liquid crystal displays and other display units not using LEDs".... Shin-Etsu Handotai will open a new GaP wafer plant in Taiwan in January, 1996. The location was chosen because "Taiwan is becoming the LED chip supplier to the Pacific Rim".... Takenaka Electronics of Kyoto has developed a blue LED-based photoelectric sensor. The sensor incorporates a blue LED featuring a high luminance of 1,000mcd and a short wavelength of 450nm. The new sensor will likely be 3,000-4,000 yen ($33.33-44.44) more expensive than conventional models that cost about 15,000 yen ($167). The company wants to launch volume production by year end.

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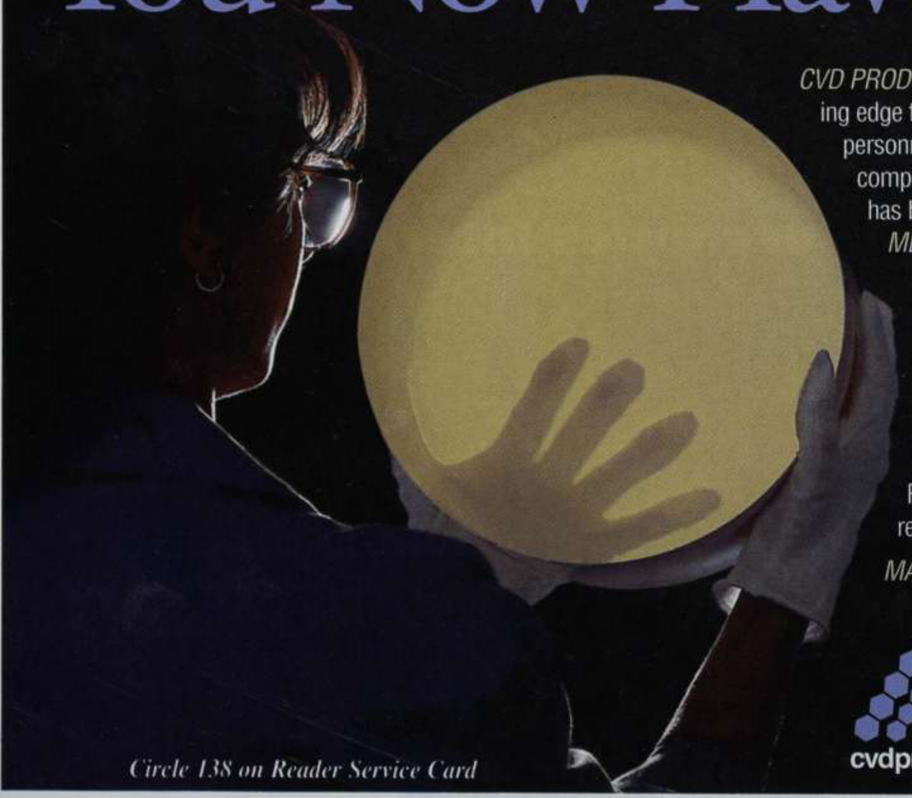

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FOOF! There it goes...

Researchers demonstrate effective etching of SiC using dioxygen difluoride.

How does one etch SiC, a material which is nearly as hard as diamond? Researchers at the University of California, Berkeley have tackled the problem using dioxygen difluoride, also known as "FOOF". In a recent paper [Appl. Phys. Lett. 66(25), 3480 (1995)] they demonstrate efficient, room temperature etching of SiC at rates comparable to or exceeding those of elemental Si etching by halogens.

The authors describe FOOF as a potent fluorinating agent which has been previously used for , among other things, volatilizing plutonium at low temperatures. One of the major challenges for this work was to develop a process for synthesizing sufficient quantities of the compound to make a practical demonstration. To this end they built their own FOOF generator, which was then coupled to a modulated beam mass spectrometric system wherein the reaction between FOOF and SiC was analyzed. Large reaction ratios were observed, with approximately 1 in 20 FOOF molecules reacting with SiC at room temperature. A 5.8 μm thick epitaxial SiC sample was etched to a depth of 1.9 μm during an 18 minute exposure. Epitaxial and polycrystalline samples were also etched and then examined by AFM. In terms of roughness and morphology the etched samples were virtually indistinguishable from unetched samples. The authors believe that their process is suitable for commercialization, and that it has the potential to reduce the cost and increase the availability of SiC microelectronic circuitry.

JM Claims Demonstration of the Superiority of Pd-Purified Hydrogen in MOCVD

Johnson Matthey has announced a study comparing carrier gases used in MOCVD which it claims demonstrates that palladium (Pd)-purified hydrogen results in devices with significantly lower oxygen-related impurities or deep traps, as compared to samples grown using hydrogen which is purified using lithium or other materials. The study was conducted at the University of Maryland Baltimore County, and results from it were presented at the Spring MRS meeting. According to a company spokesperson this work demonstrates that the deep impurity density of AlGaAs samples grown using Pd-purified hydrogen is consistently lower, by two orders of magnitude, and that the samples showed superior optical properties.

Congratulations

Vitesse Semiconductor has received the AT&T Network Systems "Supplier Excellence" award for the second year in a row. Vitesse supplies chipsets for AT&T's highest end SONET fiber optic network transmission system.....Hiden Analytical has received ISO 9001 certification for its design, development, sales and manufacturing facility in Warrington, England.

TRANSACTIONS

Cree Signs Distribution Deal with Sumitomo and Shin-Etsu

Cree Research, Inc. [Durham, NC]. has announced the signing of a three-year distribution agreement for its blue LED chips and SiC wafer products for the Japanese market. Shin-Etsu Handotai Co.'s Compound Semiconductor Division and Sumitomo Corporation's Electronic Materials and Equipment Department will act as distributors of the products in Japan. Sumitomo Corporation of America will act as the exporter.

Ryuichi Hiraishi, Director of Shin-Etsu's Compound Semiconductor Division state, "Cree's superbright blue LED is revolutionary. Their new superbright blue technology will give use two benefits. The first is access to the missing color for high performance LED displays. The second is our anticipated future business success. In addition, the use of SiC as a substrate gives our customers distinct advantages over other technologies."

Neal Hunter, Cree's President, commented that "The agreement is a continuation of a strong relationship we've developed over the past five years. Our team includes the world's largest supplier of semiconductor materials (Shin-Etsu) and the world's top trading company (Sumitomo). We're optimistic about the potential market impact of our products in Japan."

Kyosuke Takaishi, General Manager of Sumitomo's Electronic Materials and Equipment Department stated: "A superbright blue LED is the product that Japanese customers have sought for many years. We believe that this new product will be a driving force in expanding the full color LED display market. Our strong relationship with Cree and Shin-Etsu may lead to the establishment of a joint venture for production in Japan."

According to Calvin Carter, Cree's Director of Technology, there are several unique features in Cree's products that make them attractive for the Japanese market. For example, Cree is able to deliver its GaN/SiC blue LEDs as die instead of packaged parts, because the company can perform 100% wafer testing, eliminating the need for burn in of individual devices. This provides more flexibility for end users such as display manufacturers. Of course price and availability are also critical factors, and Carter says Cree LEDs are available in large quantities at low prices - around $0.75 per piece. In addition, the new LEDs offer greatly improved levels of performance - see page 6. As far as the SiC wafers are concerned, Carter says "to my knowledge, there is not a domestic Japanese supplier of SiC wafers at this time."

EPI, SVT Merge, Report Expansion Beyond MBE

EPI MBE Products [Saint Paul, MN] and Superior Vacuum Products (SVT) [Eden Prairie, MN] have completed a merger agreement. The new company will take the EPI name and will operate from its facility in Saint Paul. The transaction leaves EPI as the sole remaining manufacturer of MBE equipment in the US. EPI acquired the former Varian MBE operation from Intevac in 1993, and SVT was founded as the spin-off of Physical Electronics' MBE operation.

According to a company spokesperson, EPI's motivation for the transaction was the acquisition of SVT's expertise in Si and IV-IV epitaxial growth. In addition, the merger provides financial resources for the further development of SVT's UHV flat panel probe tool, which is used for on-the-wafer inspection of field emission display circuits.

New Distributor for GaAs IC CAD System

CN Software, Inc. [Rochester, MN] has obtained the world-wide distribution rights to the MagiCAD system developed by the Special Purpose Processor Development Group at the Mayo Foundation. MagiCAD supports the design of advanced semicustom ICs and electromagnetic modeling, and is targeted for high performance technologies such as GaAs MESFETs and HBTs. According to a CN spokesperson, most commercial CAD systems are targeted at one million gate VLSI CMOS. To achieve design integrity in these complex circuits much effort is expended on "bullet-proofing" the design process, which drives up price and code maintainance costs. In contrast, MagiCAD is intended for use with the lower integration levels which are more common in GaAs designs, although it also supports the rapid adoption of new IC technology. CN reports that the software is currently available and is fully operational outside of the Mayo facility.

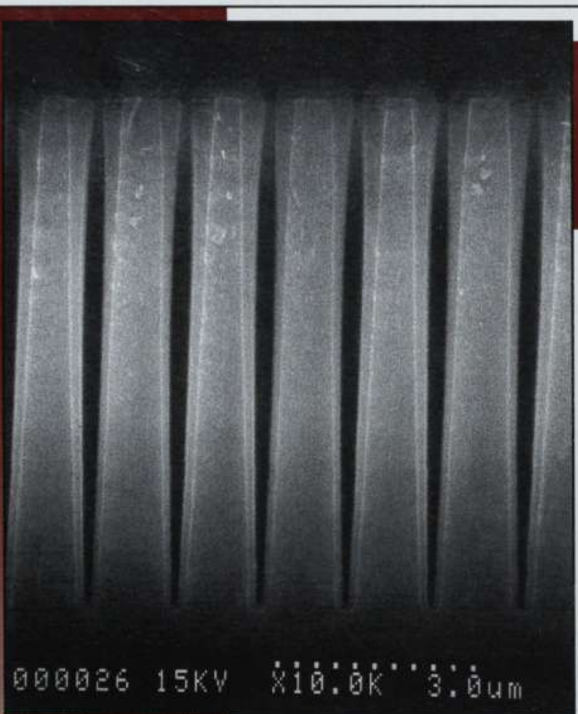
Aixtron Success in Asia

Aixtron have announced the sale of three new MOVPE systems in Asia. United Epitaxy Company (UEC) of Taiwan have ordered an AIX 2000 system for 7 x 2" MOVPE of ultra-high brightness LEDs. This is the third system of this type ordered by UEC. Also announced is the sale of an AIX 200 system to the Korean Advanced Institute of Science and Technology (KAIST) for the development of AlGaAs/GaAs VCSEL structures. Aixtron have also announced their fourth recent sale in China - an AIX 200 system for NEDI in Nanjing.

Emcore Announces MOCVD Installation, New Collaboration

Emcore and Spectrolab, a Hughes Electronics Subsidiary, have announced the delivery and installation of three Emcore Enterprise 400 MOCVD processing chambers at Spectrolab's Sylmar California location. Spectrolab will use the new systems to produce solar cells on germanium wafers. According to an Emcore spokesperson, the Spectrolab setup is "the world's highest-throughput manufacturing capability for solar cells of this type". Each of the new systems is capable of handling up to nine 100mm, four 150mm or one 300mm wafer per deposition cycle.

Emcore also reports the sale of a Discovery 125 MOCVD system to Dr. Manejeh Razeghi at the Center for Quantum Devices at Northwestern University [Evanston, IL]. Emcore and Dr. Razeghi have entered into a "comprehensive" collaboration agreement aimed at process and system development for the growth of III-V and nitride materials.



SiO_2 step coverage from TEOS/Ozone at 280 Torr using MKS DLI System

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The Forecast for GaAs Integrated Circuits

Four market research firms offer their views on growth in the GaAs IC market by the year 2000

Anyone who remembers the too-good-to-be-true 1980's predictions for GaAs is likely to approach the subject of forecasting with a bit of trepidation. But professional market forecasting can be indispensable, and even the biggest skeptic may have his curiosity stirred by the fact that several consulting firms are once again painting a rosy picture for GaAs's future. Is it time to shrug off the previous bad experience and start looking at the bar charts and graphs again? The theme for this issue's cover story is that high-volume, consumer-driven applications for GaAs ICs have arrived. If you agree that is true, then you may also believe that quantification of market growth is useful as a planning tool.

We recently had the opportunity to discuss the forecast for the GaAs IC market with four US market research firms. The following is a brief summary of their views. Each firm has addressed the topic differently, and therefore their results should not be compared or contrasted. But if you look at the subject as a whole, what emerges is picture of industry which is poised to enjoy growth in the coming years, although opinions about the extent of that growth vary, ranging from "solid" to "spectacular".

Readers who would like more information about the reports and services mentioned here are invited to contact the participating firms directly. Addresses and phone numbers are provided on page 24-25.

$1 Billion by '98

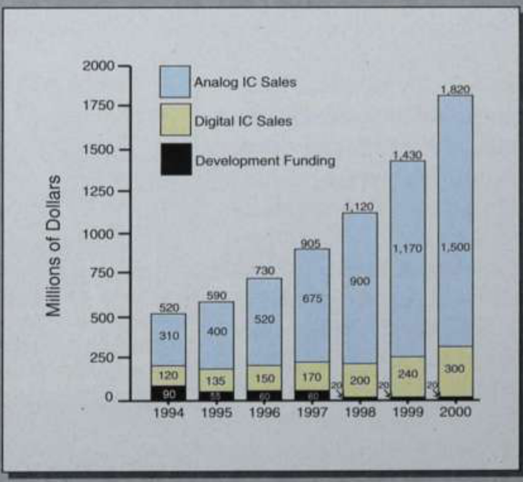
Integrated Circuit Engineering Corporation (ICE) evaluates the GaAs IC market as part of its annual "Mid-Term" report on the status and forecast of the entire IC industry. Their figures are derived by analyzing both external sales and internal consumption for the merchant fabs. In contrast, all of the production from the captive fabs is excluded. For these purposes, a "captive" fab is defined as any company which delivers less than 25% of its production to the open market. While there are not many companies which fall into this category, those that do are notable - Hewlett-Packard and IBM are good examples.

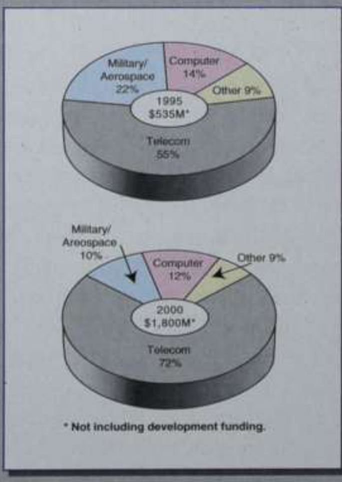
ICE expects the worldwide GaAs IC market to reach $535 million in 1995, with more than 75% of the production coming from ten firms. They predict that it will pass the $1 billion mark in 1998, and will reach $1.8 billion by 2000. ICE calculates a 23% compound annual growth rate (CAGR) for the GaAs IC industry between 1994 and 2000, with most of that growth driven by analog ICs (30% CAGR, compared to 17% for digital).

ICE's Bill McClean cites the "booming" market for communications equipment as the driving force behind GaAs's growth. He believes there is reason "considerable" concern about the demand for digital GaAs ICs, but he thinks that high volume use of analog GaAs ICs in 2 GHz and higher wireless communications is "almost guaranteed". McClean goes on to say that "analog GaAs ICs have even done fairly well at penetrating 800 MHz-type applications", and continued success at lower frequencies is one factor in ICE's calculations.

ICE includes developmental funding - such as the MIMIC and MAFET programs - in its definition of the market. However, that portion of the market will decline significantly beginning this year. ICE also predicts a declining role for military and aerospace applications among end users, with the difference to be made up by telecommunications.

	1995 Sales ($M, FCST)		
Company	Analog	Digital	Total
Fujitsu	60	36	96
Anadigics	50	--	50
Vitesse	3	46	49
Thomson-CSF	44	--	44
TI	30	5	35
TriQuint	13	20	33
Philips	32	--	32
Oki	27	4	31
Rockwell	22	5	27
NEC	25	--	25
Others	94	19	113
Total	400	135	535





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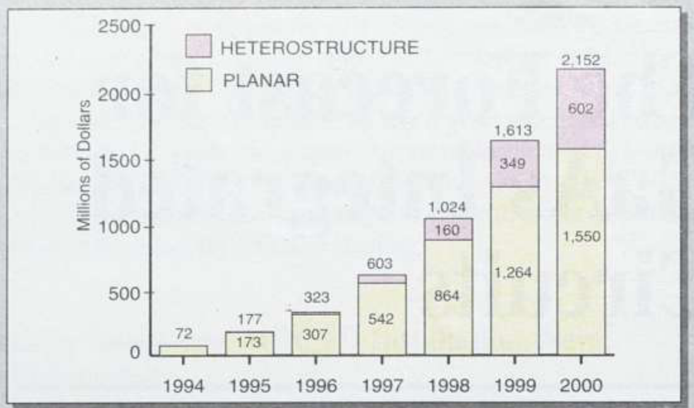
Left: Top ten GaAs IC sales leaders in 1995. Center: ICE's forecast for the worldwide merchant GaAs IC market. Right: Breakdown of the merchant GaAs IC market by application. Source: Integrated Circuit Engineering.

Digital Wireless

Kenneth W. Taylor & Associates specializes in strategic information for the digital wireless communications (DWC) industry. They track GaAs ICs only insofar as they are used in DWC; digital GaAs ICs and analog GaAs ICs used in analog communications are not included in their forecasts. Company president Ken Taylor believes this approach is appropriate for his opportunity-identification-based consultancy because "DWC is going to be the most important growth sector for the GaAs industry". Both captive and merchant GaAs IC production for the DWC are included.

Taylor calculates that the market for GaAs ICs in DWC will more than double this year, growing from $72 million in 1994 to $177 million in 1995, and reaching an estimated $2.2 billion in the year 2000. See Figure 4. This corresponds to an impressive 76.2% CAGR. Figure 4 also predicts that the market will be dominated by "planar" structures (JFETs, MESFETs), but "heterostructure" circuits (HFETs, MODFETs, HEMTs and HBTs) gain ground toward the end of the forecast period.

According to Taylor, his firm's methodology focuses on "total business forecasting". When preparing their forecast they first analyzed 17 major applications of the DWC industry as a whole, and then calculated GaAs's role within it. Given their robust forecast for GaAs, it is not surprising to learn that the firm believes that the entire DWC industry has reached the "take-off" point. They predict that the number of DWC terminals in operation worldwide will increase from 34.5 million in 1994 to 585 million by 2000. Taylor's firm believes that there are key DWC applications other than telecommunications that will fuel demand for GaAs circuits. For example, he predicts that the largest of all DWC applications will be radio frequency identification (RFID) transponders, accounting for 47.2% of all DWC terminals in the year 2000. RFID applications include security, toll collection ("smart highways") and industrial process controls.



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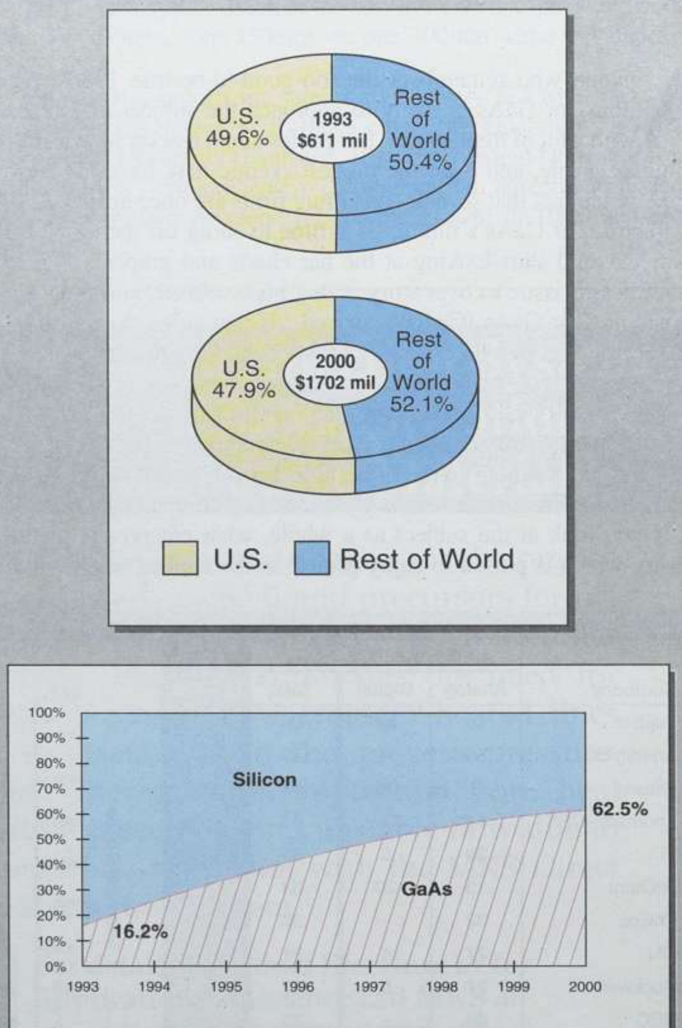
The forecast for the worldwide digital wireless communications GaAs IC market. Source: Kenneth W. Taylor & Associates

GaAs for Mobile Communications

Another view on the wireless market is provided by Electronic Tend Publications, an independent market research firm specializing in computer, semiconductor and telecommunications markets. They recently analyzed the semiconductor content in a number of mobile communication products, including pagers, analog and digital cellular phones, analog and digital cordless phones, and WLANs. They forecast that the total market for all RF/IF circuits (GaAs and Si) for these applications will increase from $611 million in 1993 to $1.7 billion in 2000 (a CAGR of 15.8%).

What does that mean for GaAs? Forecasting is by nature an inexact science, at best. Not surprisingly, Electronic Trend acknowledges that when one moves beyond asking "how much RF?" and begins to ask "how much GaAs?", the margin for error increases. As Murray Disman, Electronic Trend's chief investigator on this project, says: "the markets for the RF/IF functions can be defined fairly accurately. However, partitioning these functions into specific types of semiconductors and ICs is highly dependent on a number of different factors. There are numerous ways to partition the circuitry for the same application, and the selection of either bipolar silicon or GaAs IC technology is not always a clear or obvious choice. The key deciding factors should be, as always, total cost of manufacture, size, and power consumption. However, the experiences and prejudices of the equipment designer and the capabilities and overall directions taken by the semiconductor producer are also important factors in this decision."

Disman goes on to explain that in his view the primary drawback to the use of GaAs, as compared with Si, has been the high cost resulting



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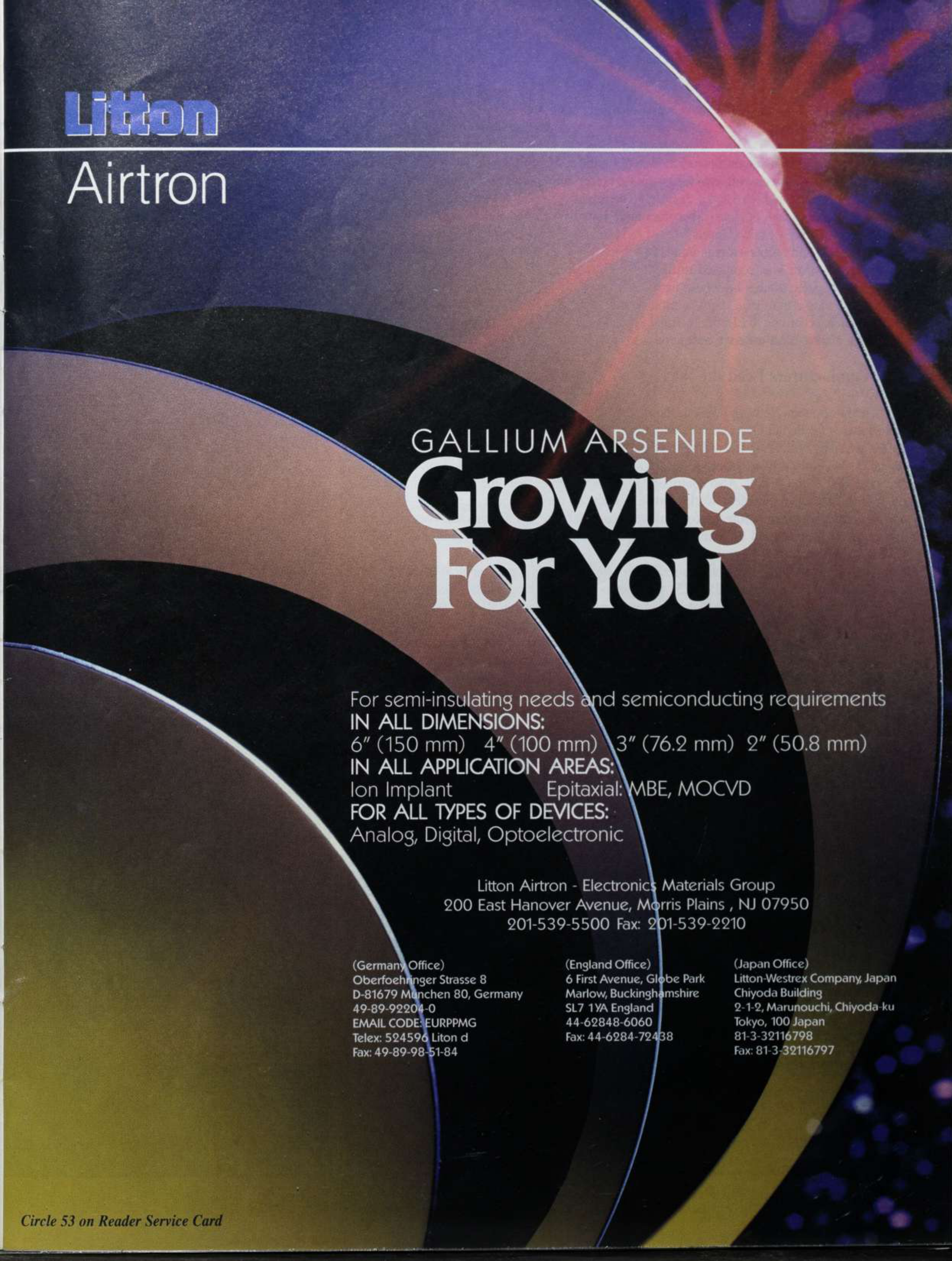
Top: Forecast of the market for all RF/IF Circuits (GaAs and Si) for mobile communications applications. Bottom: Segmentation of the market for MMICs in moblie communications between GaAs and Si. Source: Electronic Trend Publications.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from lower yields and the high cost of wafer material. "But both of these factors become less important for smaller-size chips. In this case, a large part of the cost is determined by assembly, packaging, and testing. The cost of integrated RF functions in GaAs is therefore not significantly more than the bipolar silicon equivalent, except for the power amplifier. But in this case, GaAs is often a clear winner on performance, as GaAs power amplifiers are generally more efficient than silicon devices, and have better linearity. The disparity in efficiency grows as the operating frequency increases and, obviously, becomes more important to the total power budget in applications requiring higher power levels."

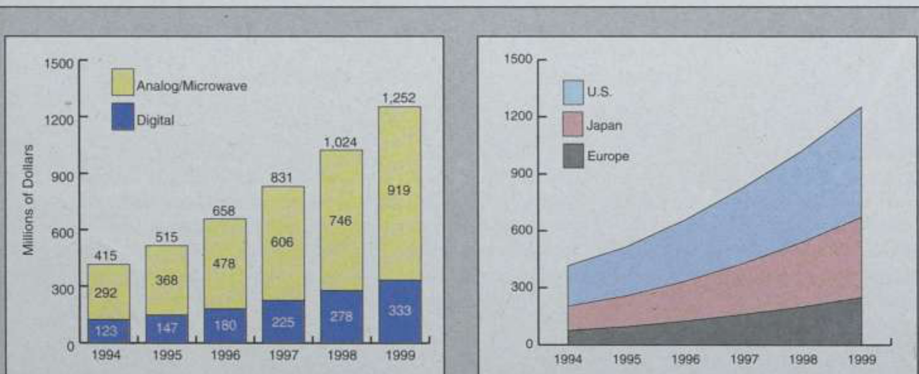
With these and other factors in mind, Electronic Trend has ventured an estimate of the market for GaAs MMICs as compared to Si in mobile communications. For this purpose power amplifiers and T/R switches have been included in the MMIC category, since these parts contain more than a single transistor. GaAs's projected market share by the year 2000 is estimated at 62.5%, which, according to Electronic Trend, should have a value of approximately $600 million. That same market is estimated to be approximately $75 million for 1995.

US Manufacturers Lead the Way

The Information Network [Williamsburg, VA] predicts that the worldwide market - merchant and captive - for digital GaAs devices will grow from $123 million in 1994 to $333 million in 1999 - a CAGR of 22.1%. According to Robert Castellano, the firm's president, the market for digital GaAs will be driven by fiber optic telecommunications and data networking in applications such as SONET and FDDI. Also contributing will be demands from the computer industry for use in high-end supercomputers, workstations, and general purpose compute engines. Growth of a more impressive nature is forecast for analog/microwave GaAs ICs. Their value - both merchant and captive - is forecasted to increase from $292 million in 1994 to $919 million in 1999 - a CAGR of 25.8%.

The Information Network has also analyzed the market on a geographical basis. The US commanded the largest share in 1994 (51.1%), and it is predicted to hold the lead throughout the forecast period. Castellano notes that in the recent past military applications have accounted for the bulk of the US market, but now that position has decreased to around 25%, and will continue to shrink. He sees telecoms, the new driving force in the US, as moving along three fronts: GaAs ICs for long haul technologies over fiber; the ever-expanding wireless market, including cellular, set-top boxes, and LANs as well as ID tags, tolls, and GPS; and the demand for GaAs in direct-broadcast satellite. Castellano goes on to say that the driving force in the development of GaAs ICs in Japan will come from communications and consumer applications. The same trends will be evident in Europe, with some contributions from the weapons industries in France and Britain. Although these markets will remain smaller than the US's, they will grow at a faster pace: a CAGR of 22.3% is predicted for the US, as compared to 27.1% for Europe and Japan. This due to the early emergence of the American market, as well as generally high demand for the new technologies which utilize GaAs.

Marie Meyer



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Left: The Information Network's forecast for the worldwide GaAs IC market. Right: Breakdown of the GaAs IC market by geographic area. Source: The Information Network

For More Information

The following is a brief profile of the four firms that participated in this article. Readers who would like more information about their products and services are invited to contact the firms directly, or use the Reader Service Card provided on page 29 to request more information.

Integrated Circuit Engineering

Integrated Circuit Engineering was formed in 1964 to help its clients participate in the growth of the electronics industry. They offer a broad range of products and services, including consulting services, analytical lab services, market research publications and seminars, and technical publications and seminars. Their GaAs IC forecast was prepared as part of their annual "Mid-Term Report on the Status and Forecast for the IC Industry". The 1995 Mid-Term Report, which was released in July, illustrates IC product market trends, market share, trends by technology, the top ten worldwide IC suppliers and their expenditures, and more. Over 300 charts and figures are included.

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E Mail 73512.304@compuserve.com

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Kenneth W. Taylor & Associates

Kenneth W. Taylor & Associates was established in 1985 as an electronics industry research and corporate strategic planning consulting organization. Among their offerings is the Digital Wireless Communications Strategic Industry Information Service, which provides report, inquiry, and private oral presentation deliverables in the areas of technologies, applications, market, competition, potential strategic partnerships and recommended strategic action. The firm's founder earned MBA and BSEE degrees from Stanford University. He has been active in RF, microwave, and optical wireless communications for more than 30 years, and he has been forecasting semiconductor markets since 1965.

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Electronic Tend Publications

Electronic Tend Publications is an independent market research firm specializing in computer, semiconductor and telecommunications markets More information on the market for semiconductors in wireless applications is available in Electronic Trend's new study, Opportunities in Mobile Communications Semiconductors. This 177-page report contains a detailed discussion of and forecast for requirements for semiconductors in the rapidly growing wireless equipment industry. Topics covered include: 1) wireless equipment design considerations, which includes access methods (for example, FDMA v. TDMA v. CDMA), voice coding, modulation techniques, and spread spectrum technology; 2) the various categories of wireless equipment (phones, pagers, and WLANs) with their respective semiconductor requirements, including block diagrams from several semiconductor manufacturers; 3) analysis of and forecast for the IC market, including baseband and RF/IF circuits, and GaAs and Si devices; 4) a database of semiconductor consumption by equipment type for the years 1993-2000; and 5) brief profiles of 173 equipment/component manufacturers. For those interested in more information about equipment, a companion report, Opportunities in Mobile Communications Equipment, is also available.

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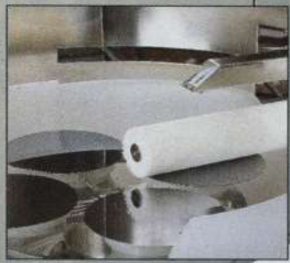

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Research Review

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

Optoelectronic Materials and Devices

New Developments in Intersubband Semiconductor Lasers and LED's

Last year a new type of semiconductor laser was announced that lases on a transition between two subbands of the conduction band of a multiple quantum well structure. A potential advantage of this laser is the ability to use wide gap materials such as AlGaAs/GaAs and AlInAs/GaInAs to operate over a wide range of wavelengths in the mid-IR. These wide gap materials are more stable and easier to grow and process than the small gap materials that are conventionally used for mid-IR emitters. The initial work reported a device that operated at a wavelength of 4.3 μm. Recently a similar device was reported that lases at 8.4 μm. It consists of an 11-well active region, and produces a peak power of 10 mW at a temperature of 130K. Work performed at AT&T Bell Laboratories [Murray Hill, NJ]. See "Quantum cascade laser with plasmon-enhanced waveguide operating at 8.4 μm wavelength", C. Sitori, et al, Appl. Phys. Lett. 66, 3242 [18 June 1995].

A simpler 2-well structure for producing mid-IR emission was recently proposed and demonstrated. A key aspect of this new approach is the engineering of the coupled well structure so that the lower level of the radiative transition is one phonon's energy above the ground state. This feature enables rapid emptying of the lower radiative state, facilitating the establishment of a population inversion. This structure produced emission at a wavelength of 1.4 μm, and uses the AlGaAs/GaAs material system. Work performed at CNRS [Orsay, France]. See "Observation of infrared intersubband emission in optically pumped quantum wells", Z. Moussa, et al, Electron. Lett. 31(11), 912 [25 May 1995].

Optical Upconversion Using a Quantum Well Intersubband Photodetector and LED Integrated in AlGaAs/GaAs

A quantum well intersubband photodetector (QWIP) and near IR LED have been integrated by epitaxially growing one on top of the other. Mid- or far-IR is absorbed in the QWIP causing a photocurrent to flow into the LED where near IR is emitted. The proposed application of this optical upconverter is in two dimensional focal plane arrays for imaging of mid- to far-IR with standard near-IR silicon detector arrays. This would avoid the difficulties associated with hybrid bonding of InSb or HgCdTe detector arrays to silicon chips, which is the standard approach. Work performed at National Research Council [Ottawa, ON, Canada]. See "Integrated quantum well intersub-band photodetector and light emitting diode", H.C. Liu, et al, Electron. Lett. 31(10), 832 [11 May 1995].

Integration of Vertical Cavity Laser Diodes with GaAs Microlenses

Beam collimation and focusing of vertical cavity laser diodes was recently achieved by the integration of the lasers with GaAs microlenses etched on to the back side of the substrate. Original beam divergence of 6.5 degrees was reduced to 1.9 degrees or increased to 12.3 degrees with lenses with focal lengths of 220 microns and 60 microns, respectively. The lenses were fabricated by the reflow of photoresist into a lens shape and transfer of the shape into the GaAs substrate by reactive ion etching. Work performed at University of California [Santa Barbara, CA]. See "Monolithic integration of vertical-cavity laser diodes with GaAs microlenses", E.M.Strzelecka, et al, Electron. Lett. 31(9), 724 [27 April 1995].

Low Threshold Distributed Bragg Reflector Diode Laser

Distributed Bragg reflector (DBR) lasers have the desirable attributes of narrow linewidth, tunability and integration capability. Recently a new record for DBR laser threshold was reported. By using "aluminum-free" materials, i.e. GaAs/GaInP, DBR lasers with thresholds as low as 7 mA have been obtained. The aluminum-free materials alleviate the difficulties with epitaxial regrowth that plague the GaAs/AlGaAs material system. Work performed at Hyundai Electronics Industries Co., Ltd. [Kyoungki-do, Korea]. See "InGaAs/GaAs/InGaP Distributed Bragg Reflector Buried Heterostructure Strained Quantum Well Lasers", Y.K. Sin and H. Horikawa, Jpn. J. Appl. Phys. 34, L892 [15 July 1995].

New Developments in Blue, Green and Yellow Light-Emitting Diodes

High efficiency LED's have been available in red region of the spectrum for several years, and more recently have also become available in the blue. However, similar efficiency LED's are not yet available for the middle region of the spectrum, the greens and yellows. The conventional approach in this spectral region employs the indirect gap material, GaP, and therefore has efficiencies of only 0.1%. Furthermore the color is yellowish green (555 nm wavelengths), not pure yellow or pure green. Other traditional approaches include AlGaInP materials that can produce higher efficiency in the yellow-green but cannot reach the green with high efficiency, and the II-VI materials that can produce high efficiency in the green but have not been commercialized because of limited device lifetimes.

Researchers at Nichia have recently reported progress in the middle region of the spectrum through the use of InGaN strained quantum wells grown by MOCVD on sapphire substrates. The typical green LEDs had a peak wavelength of 525 nm and external quantum efficiency of 2.1%. Their luminous intensity (4cd) was about 40 times higher than that of GaP LEDs. Typical yellow LEDs had a peak wavelength of 590 nm and external quantum efficiency of 1.2%.

See "High-Brightness InGaN Blue, Green and Yellow Light Emitting Diodes with Quantum Well Structures", S. Nakamura, et al, Jpn. J. Appl. Phys. 34, L797 [1 July 1995]. Work performed at Nichia Chemical Industries, Ltd. [Tokushima, Japan].

Much of the current interest in blue, green and yellow LEDs is being driven by the market for full color displays. Color purity is an important specification for this application. If high purity LEDs are not available, some type of compensation for color distortion due to the white background may be required. Researchers at 3M recently reported the first high color purity short period superlattice II-VI blue LEDs. The MgZnSSe structure, characterized by room temperature electroluminescence, showed only a single strong peak at 460 nm, with a FWHM of 13 nm. In contrast, SiC and GaN blue LEDs exhibit FWHM of ≈ 70 nm. See "Short period superlattice II-VI blue light emitting diodes", B.J. Wu, et al, Electron. Lett. 31(12), 1015 [8 June 1995]. Work performed at the Photonics Research Laboratory, 3M Company [Saint Paul, MN].

Electronic Materials and Devices

InGaAs/InP Composite-Channel HFET's

Attempts to improve electron mobility in InGaAs/InP HEMTs by increasing the In content in the channel have come at the cost of increased impact ionization, which often results in the kink phenomena and low breakdown voltages. An alternative approach has been to use InP channels, since electrons in InP have a high drift velocity at high electric fields, and the impact ionization coefficients of InP are much lower than those of InGaAs. However, InP-channel HFETs reported to date have exhibited inferior characteristics compared to InGaAs HEMTs, possibly due to the low electron mobility of InP and the small conduction band discontinuity between InP and InAlAs. This work presents an approach to HFET channel design using both InGaAs and InP layers, where this structure exploits the high mobility of InGaAs at low electric fields and the high drift velocity and low impact ionization coefficients of InP at high electric fields. It was found that the doping density of the InP subchannel is a key parameter in realizing the advantages of the composite channel. For the composite channel utilizing an undoped InP subchannel, a very high transconductance of 1.29 S/mm and a current gain cutoff frequency of 68.7 GHz were obtained, where the average velocity of electrons in the composite channel is $2.9x10^7$ cm/s. These devices exhibit no kink phenomena in their I-V characteristics, possibly due to low impact ionization in the InP subchannel. Work performed at NTT LSI Laboratories [Kanagawa, Japan]. See "Design and Characteristics of InGaAs/InP Composite-Channel HFET's", Takatomo Enoki, et al, IEEE Transactions on Electron Devices, 42(8), 1413 [August 1995].

InAlAs/InGaAs HFET's on GaAs

In addition to the problems associated with high indium content in the channel regions of pseudomorphic HEMTs, in which impact ionization is increased (see above), the thickness of the channel is typically limited so that the strain generated from the lattice mismatch between the substrate and the high indium content channel does not exceed the critical thickness limit, which would lead to dislocation generation in the channel. A different approach is taken here, in which a graded InAlGaAs buffer is used to accommodate the large lattice mismatch between the substrate and the channel. A 0.15 µm gate length $In_{0.70}Al_{0.30}As/In_{0.80}Ga_{0.20}As$ HFET grown on this graded buffer exhibited a f_t of 140 GHz and a f_{max} of 200 GHz, where this is the highest value of f_{max} reported to date for an InAlAs/InGaAs HFET lattice mismatched on a GaAs substrate. Work performed at Chalmers University of Technology [Goteborg, Sweden]. See "DC and rf performance of 0.15 µm gate length $In_{0.70}Al_{0.30}As/In_{0.80}Ga_{0.20}As$ HFETs on GaAs Substrate", N. Rorsman, et al, Electronics Letters 31(15), 1292 [20 July 1995].

Self-Aligned 6H-SiC MOSFETs

Conflicting requirements arise in the fabrication of a self-aligned 6H-SiC-based MOSFET due to the high temperature implant anneal (1200-1500°) required for the activation of source/drain ion implantations, which can also degrade the integrity of the polysilicon gate and underlying gate oxide. A surface-channel n-MOSFET in 6H-SiC is described using n^+-polysilicon gates on 80 nm thick gate oxide in a self aligned process. A peak channel mobility of 40 cm²/V-s and a subthreshold slope of 500 mV/decade are obtained. These MOSFET's exhibit a saturation drain current of 18 mA/mm at 340°C when the gate is 9 V above threshold. This saturation drain current is three times higher than the best reported to date. Work performed Purdue University [West Lafayette, IN]. See "Self-Aligned 6H-SiC MOSFETs with Improved Current Drive", J.N. Pan, et al, Electronics Letters 31(14), 1200 [6 July 1995].

An L-Band Ultra-Low-Power Consumption Monolithic LNA

In order to both reduce cell phone weight (where the battery can be the largest and heaviest single component in the handset), while increasing talk time, it is critically important to reduce the power consumption of the cellular phone's components. A low power consumption, variable gain, low-noise amplifier (LNA) based on a cascode connection between an enhancement-mode GaAs MESFET and a depletion-mode MESFET is described. This LNA exhibits a noise figure of 2.0 dB, a gain of 12.2 dB and an IP_3 of 5.1 dBm at 1.9 GHz. This performance is obtained at the ultra-low power consumption of 2.0 mW (1 mA at 2V). Work performed at NTT Wireless Systems Laboratories [Kanagawa, Japan]. See "An L-Band Ultra-Low-Power-Consumption Monolithic Low-Noise Amplifier", Masashi Nakatsugawa, et al, IEEE Transactions on Microwave Theory and Techniques 43(7), 1745 [July 1995].

W-Band High Efficiency InP-Based Power HEMT

The implementation of compact monolithic amplifiers incorporating W-Band power transistors has the potential for significantly reducing the cost or enhancing the capability of many military and commercial systems, spanning the range from radar front ends for missile seekers and aircraft systems to automotive collision avoidance radar and local area communication networks. At 94 GHz, GaAs-based PHEMTs have demonstrated single device output powers in the 45-63 mW range and power gains of 3-4 dB, with PHEMT based MMICs limited to approximately 100 mW and power added efficiencies (PAEs) of 5-13%, where these limitations have been due primarily to the performance of the PHEMT devices.

Researchers at Lockheed Martin Electronics Laboratory have recently described a W-Band HEMT based on the InAlAs/InGaAs/InP material system which exhibits output power comparable to PHEMTs, but with significantly higher PAEs and power gain. This HEMT utilizes a 200 Å pseudomorphic InGaAs channel with a 68% indium mole fraction, and planar doping both above and below the channel, to yield an electron sheet charge density of $3.1x10^{12}$ cm^{-2} with a room temperature mobility of 10,500 cm²/V-s. Using a 0.1 µm T-gate with a total periphery of 200 µm, these HEMTs were fabricated both as discrete devices and embedded in single-stage MMICs to facilitate on-wafer testing at W-Band. Circular via holes formed by wet etching were placed on each side of the device's active region for source grounding and airbridge interconnect, and the completed wafers were thinned to 50 µm both to improve thermal properties and to obtain low via inductance in order to produce high gain. This HEMT exhibits a maximum dc transconductance, g_m, of 980 mS/mm, and a maximum frequency of oscillation, f_{max} of 600 GHz - the highest f_{max} reported to date for any transistor. The device generates 58 mW output power and 6.4 dB power gain with 33% PAE. At comparable output powers, this InP-based HEMT exhibits a factor of two improvement in PAE as compared to the best GaAs-based PHEMTs, and shows a significantly higher power gain.

See "W-Band high Efficiency InP-based power HEMT with 600 GHz f_{max}", P.M. Smith, et al, IEEE Microwave and Guided Wave Letters, 5(7), 230 [July 1995]. Work performed at Lockheed Martin Electronics Laboratory [Syracuse, NY].

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Cutting the Cord

Wireless communications are freeing analog GaAs from reliance on low-volume military markets.

ROBERT A. METZGER

Since the creation of the first radar systems in the mid-1930's the microwave and millimeter wave fields have been dominated by military and large industrial needs. But now a massive RF market is taking shape which will be driven by the needs of consumers in search of wireless communications.

Evidence of the exploding market for wireless communications equipment is readily available in almost any urban area - just look at the number of people talking on cellular phones, or wearing pagers. There is also a plethora of other types of wireless equipment: cordless phones, direct broadcast satellite (DBS) TV, wireless local area networks (WLANs), global positioning systems (GPS), mobile computing, etc., to name just a few. How big is the market? One research firm, Electronic Trend Publications [San Jose, CA], estimates that almost 91 million units of wireless communications & computing devices will be shipped this year, and that this figure will rise to more than 175 million units by the year 2000.

The wireless world is, at present, a jumble of competing technologies and standards, making generalizations risky. But for the most part there is agreement that some of the potentially very large wireless applications, such as WLANs and other two-way data transfer systems, will operate at high frequencies (2.4 GHz and above) that are well suited to GaAs's capabilities. For now, however, the most interesting areas are cellular and cordless telephones, which operate at frequencies <2 GHz, where Si is more competitive. The huge demand for cellular services is quickly filling up the 800-900 MHz frequency range - so the companies that provide cellular services in the US recently spent over $7 billion at the FCC Broadband Auctions for the right to use the PCS frequency band (1800-2000 MHz) for future cellular/data communications services.

One of the more interesting contests currently being waged is not between GaAs and Si, as one might expect, but between discretes and MMICs - and some of the more sophisticated manufacturers are trending toward discrete solutions.

Every one of the millions and millions of consumer-oriented handsets requires RF or microwave components. While there are many different types of wireless equipment, each with their own specifications for operating frequency, output power, etc., all share certain fundamental building blocks in the RF "front end" portion. It can generally be divided into four sections: 1) the receiver, which amplifies the incoming signal through a low noise amplifier (LNA); 2) the transmitter, which amplifies the outgoing signal through the power amplifier (PA); 3) the downconverter, which takes the incoming signal from the LNA, reducing it to the IF, and then passing it along to the non-RF portion of the phone, as well as the upconverter, which receives the IF from the non-RF portion of the phone, increases it back to the RF frequency, and then passes it into the PA; and 4) a transmit/receive switch to control incoming and outgoing signals. (See the Tutorial on page 42 for more information about the basics of RF front-end design.)

The RF/IF components used in today's wireless phones range from GaAs and Si MMICs to GaAs and Si discretes. Device types used include Si-BJTs and Si-CMOS, while GaAs-based devices include MESFETs, HBTs and HEMTs. At the moment, Si-based discrete devices dominate the RF/IF market, but that fact does not help explain where the market is going. Depending on the type of wireless device, its capabilities, its niche in the market place (high-tier or low-tier), and the quantity of the product being produced, each device type offers unique advantages and disadvantages. One of the more interesting contests currently being waged is not between GaAs and Si, as one might expect, but between discretes and MMICs - and some of the more sophisticated manufacturers are trending toward discrete solutions.

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Natural Place

"GaAs has its natural place and silicon has its natural place. GaAs must compete head-to-head with Si only where their capabilities overlap," says Joe Skovron, marketing manager of TriQuint Semiconductor (Beaverton, OR), a GaAs-based MMIC fabrication house. At the moment, there is not one best set of RF components for a cell phone, and there will not be one as long as the requirements and capabilities of the phones themselves are as varied as they are in the current marketplace. But by using the guideline of finding the "natural" place for a component - matching the phone's needs with a device's capabilities - a design approach can be established. For example, performance requirements will vary depending on the type of phone (high-tier or low-tier, analog or digital). The capabilities of the phone manufacturer are also important. Smaller companies may not be able to afford large numbers of designers to optimize a discrete solution, and will therefore often opt for the MMIC solution, whereas the larger and more sophisticated manufacturers with more design resources may prefer to wring every last drop of performance out of their phones by assembling more complex solutions based on discrete devices. Of course, the availability or lack thereof of in-house discrete or MMIC capability is also important.

Each electronic device also has its own unique set of capabilities, which may or may not make it compatible with a specific phone. For example: there is widespread agreement that GaAs is a natural choice for PAs. But what kind of GaAs? Depletion mode MESFETs and HEMTs provide the best power added efficiencies (PAEs) (approaching 80% at 3V operation), making them suitable in the PAs of many high-tier phones where long talk time is needed. However, these devices require a negative power supply which adds to the cost of the phone, and in the case of HEMTs, require sophisticated epitaxial growth capability. Enhancement mode MESFETs and HEMTs do not require a negative supply, and they provide excellent PAEs for PA applications, but there are limits to their maximum output power. HBTs require no negative supply, have very competitive PAEs, and exhibit excellent linearity, but they also require sophisticated epi. And there are silicon alternatives as well. Silicon bipolars require no negative power supply and are relatively low cost, but they have inferior RF integration capabilities due to the lossy silicon substrate and have poorly-competitive PAEs (40-50%), making them ill-suited for high-tier phone applications. RF MOSFETs require no negative supply and they suffer from the same inferior RF integration as silicon bipolars, but exhibit competitive PAEs (60-70%) and are very low cost. These different characteristics make all these devices applicable to some phone applications and inappropriate for others.

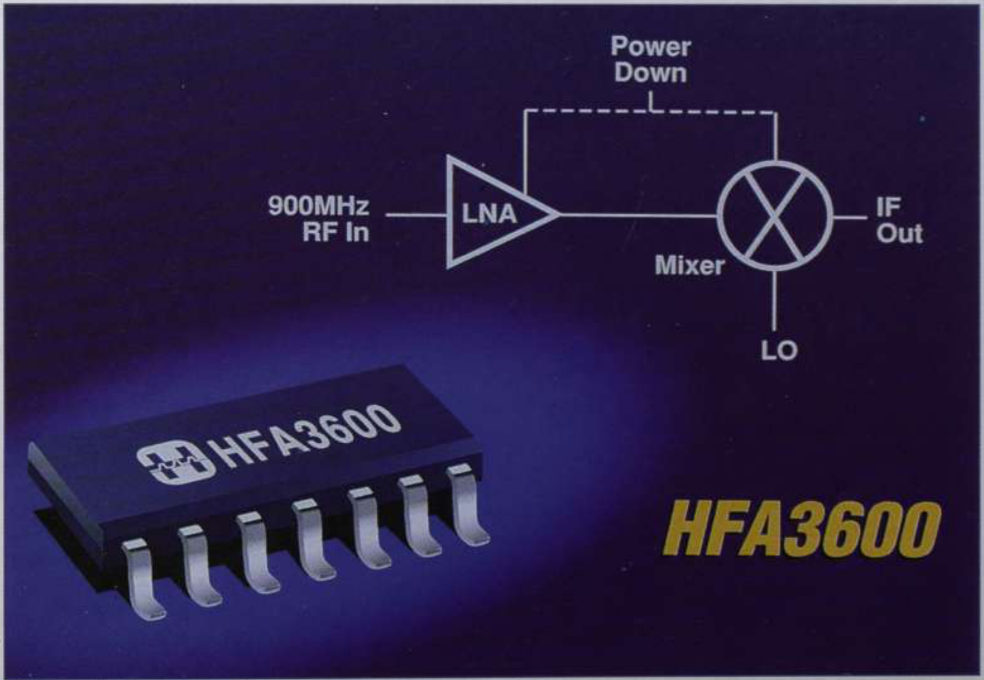
Discrete vs. MMIC

Major GaAs producers such as TriQuint and Anadigics (Warren, NJ), supply a full range of GaAs-based RF MMICs for cellular phone applications. According to Jerry Miller, sales manager of Anadigics "we are currently shipping over 100,000 power amplifiers for 900 MHz applications (AWT0900-series - PAEs of 55%) a month. What we find is that our real competition is not from Si MMICs, but from both Si and GaAs discretes. Customers add up the price of the discretes and ask if can you meet the price - if not, then they'll go for the discrete solution."

While MESFETs are the mainstay of Anadigics and TriQuint, HEMTs are being commercially produced by other companies. Hewlett Packard Communication Components Division (Newark, CA) offers an integrated LNA/mixer, as well as the LNA and mixer alone, all based on MBE-grown PHEMTs. This part requires 8 mask layers, E-beam written gates, as well as a gate recess etch. Henrick Morkner of Hewlett Packard says, "because we have been running this part in high volume for the last three years, we have established a very stable, manufacturable process - in which we are running small enough die so as to get 20,000 LNA per 3 inch wafer. Despite the complexity of the process, we can sell a PHEMT LNA in volume quantities for under $1." Morkner has found that some customers actually prefer building blocks in which the LNA and mixer are sold separately, thereby giving them more design latitude.

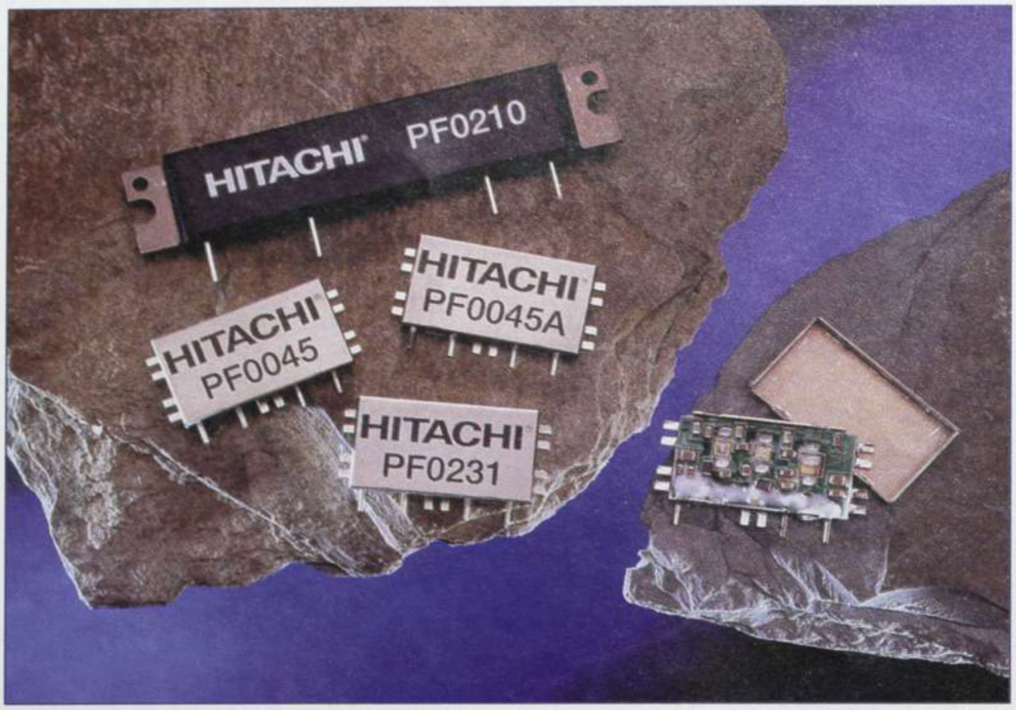
Jack Di Bartolo of Pacific Monolithics (Sunnyvale, CA) also finds that the best marketing strategy is not to overly integrate their GaAs-based MMICs. "We don't want to be too applications specific," he says. "If we over-integrate a device so it meets one phone manufacturer's need, then we will not be able to sell that chip to another manufacturer who has slightly different needs."

GaAs houses are not the only MMIC producers to experience stiff competition from discretes. Harris Semiconductor offers a Si-BJT-based LNA/Mixer - the HFA-3600. Using a wafer bonded process so that the entire bipolar sits on SiO_2, this configuration cuts down on the high frequency parasitics which are normally present in Si-based MMICs. "Discretes are the chief competition and will probably dominate for years," says Wes Kilgore of Harris. "For the LNA/Mixer, we are competing against discretes which a good designer can put together for $0.60-0.80. The advantage that we have is that we feel the MMIC approach is more manufacturable, since you



Harris Semiconductor

Harris Semiconductor's HFA-3600 LNA/Mixer MMIC based on Si-BJT devices.



Hitachi

Hitachi's RF MOSFET-based power modules.

don't have to worry about matching discretes which vary from lot to lot."

Once a part meets operational specifications, all that matters is cost. When it comes to cost, it is very difficult to beat a MOSFET. Hitachi (Brisband, CA) offers a wide spectrum of two and three stage MOSFET-based power modules. These devices operate at 4.8 V, and can deliver up to 1.2 W at 50% PAE. Because of these characteristics, Paul Patterson, Senior Product Marketing Engineer, says that "we have obtained a dominant position is GSM systems." However, Patterson says that he is the first to recognize that MOSFETs do not represent "the best solution to all the customers needs." But even though MOSFETs might not meet the needs of every customer, Patterson feels that Hitachi's product line as a whole can do the job.

Plenty for All

What companies like Hitachi, Siemens, M/A-COM, Motorola, Hewlett Packard, and Texas Instruments offer is not a single technology, i.e. GaAs MMICs, Si-bipolar, or MOSFET modules, but a full range of technologies and device types. Andreas Nitschke of Siemens (Iselin, NJ) says that "we offer several alternatives to design. Depending on the customer's approach, we can offer discretes in both GaAs and Si as well as GaAs and Si MMICs. We see a lot of 3 V requirements going to GaAs-based parts, while 5 V applications seem to go to Si. But even this is not always true, especially since we introduced our SIEGET bipolar process which can operate down to 1 V. MMICs have the advantage of requiring less design and are already input and output matched at 50 ohm, but some customers prefer to do their own designs with discretes."

For these manufacturers, the device type or material used does not really matter. All that matters is that business is growing. According to Nitschke, 'business is occurring at an unforeseen growth rate - it is booming!" And Siemens is not the only company turning in good results. RF MicroDevices (Greensboro, NC) has seen phenomenal growth over the last three years. The fabless facility, which sells only RF MMIC devices, has seen bookings climb from $1.9 million in 1993 to $9 million in 1994 to projected bookings of $18-20 million in 1995. Jerry Neal, marketing manager of RF MicroDevices says, "growth is absolutely explosive. We're experiencing sales that are more than doubling every year and we will need to double our head count from the present 50 to 100 by the end of the year in order to keep up with demand." RF MicroDevices offers a wide range of MMIC technologies, including HBT-based circuits from TRW, MESFETs from TriQuint Semiconductor and ITT, and Si-based parts from IBM. Of the 5 million ICs they project selling in 1995, 60% of their sales will be due to GaAs-based MMICs with the remaining 40% due to Si-based MMICs.

Things are also looking good in the GaAs-only camp. Like Anadigics, TriQuint is having a very good year. They are currently running more than 10,000 4" wafers per year, and are predicting sales in 1995 of $45 million, up by $15 million from 1994. TriQuint's most popular RF part, the TQ9203, an LNA/Mixer for cellular phone operation in the 800-1000 MHz range, has recently surpassed the 3 million production level point. TriQuint believes that this growth is tightly coupled to their 1.0 µm, 13 mask layer E/D MESFET process, which they think is competitive in performance with the most aggressive bipolar process (which, with trench isolation, is typically a 21 mask layer process), and just as competitive in price.

GaAs Phone Home

Even though Si-discretes currently dominate the RF/IF market, this trend is beginning to give way to GaAs-based MMICs. The current predominance of both discretes and low levels of integration are a direct consequence of the literally hundreds of different models of cellular phones, and the more than a dozen different operating standards which currently exist. MMIC manufacturers find that they can not over-integrate their chips, or they will become too application-specific to a given phone, which may not have the sales volumes to warrant spending the resources to develop such a chip. When a given phone model can be produced in the hundreds of thousands of unit quantities, then it can make economic sense to spend the resources on designing and fabricating a specific chip set for that phone, where the volume of production will drive down costs, allowing the MMIC approach to not only compete, but to beat the discrete approach. Evidence of this trend is seen in two cellular phones which have just entered the market place - the QCP-800 from QualComm and the PocketTM by Kyocera. Both of these phones are entering into large production runs, and both phones exclusively use GaAs-based MMICs for their entire RF section. See our next story for more information.

The GaAs industry has learned from hard experience that it should always mix some caution in with its optimism. Nevertheless, when one looks around the cellular, cordless, and general wireless fields, it is easy to believe that the days of reliance on low-volume applications are over for good.

Top Cellular Acronyms

AMPS - Advanced Mobile Phone Service
IS-54 (TDMA) - Time Division Multiple Access
IS-95 (CDMA) - Code Division Multiple Access
GSM - Groupe Special Mobile
DCS-1800 - Digital Communication Services at 1.8 GHz
ISM - Industrial, Scientific, and Medical Bands
DECT - Digital European Cordless Telecommunications
BPSK - Binary Phase-Shift Keying
FSK - Frequency Shift Keying
QPSK - Quadrature Phase-Shift Keying
DPSK - Differential Phase Shift Keying
DQPSK - Double Quadrature Phase-Shift Keying
OQPSK - Offset Quadrature Phase-Shift Keying
FDD - Frequency Division Duplex
TDD - Time-Division Duplex
I/Q - In-Phase/Quadrature Phase

Understanding Cellular Nomenclature

FDD systems are those in which the receive and transmit signals are on two different frequencies, while TDD systems use a single frequency, with the receive and transmit channels assigned unique positions in time. Duplex offset is the frequency difference between the received and transmitted frequencies in FDD systems. TDMA (IS-54) is an access method in which the individual channels are assigned unique positions in time on each RF carrier. CDMA is another access method utilizing spread spectrum techniques, where a number of users with different codes, which are embedded in the transmission, can utilize the same radio carrier. Frequency modulation of the RF carrier by the voice signal is used in the analog systems, while phase modulation is used in the digital approaches. GMSK is the phase-modulation technique used in the European GSM standard. TDMA-based systems use p/4DQPSK phase shifting, while CDMA-based systems use OQPSK in the mobile units and QPSK at the base station.

Two Phone Lines

Digital cellular looks like the wave of the future. The TDMA & CDMA access systems are two reasons why people who work at GaAs houses should know phones.

The widespread insertion of MMICs (Microwave Monolithic Integrated Circuits) into cellular phones has been hampered by the lack of a specific phone model which requires the superior RF capabilities of GaAs MMICs and is produced in large volumes. The later factor is crucial, because it is only through large production runs that the cost per chip can be driven down and the investment in the design and development of highly application specific MMICs can be recovered.

Phone manufacturers and cellular service providers are currently under a great deal of pressure to provide more effective utilization of the available cellular bandwidth in order to accommodate more consumers. An example of this is taking place in North America over the 824-894 MHz region, where currently, analog cellular systems (AMPS) use frequency division multiple access (FDMA) to divide the available band into smaller fixed-frequency bands which are referred to as carriers. The AMPS system can support 832, 30 kHz carriers in a 25 MHz band, within a given cellular region. Driven by the need for increased capacity within a given cellular region, new digital systems with increased capacity are currently being developed, and will see widespread implementation within the next 1-2 years. This could be good news for manufac-

PCSI

The Pocket™ Japanese Personal Handyphone manufactured by Kyocera, utilizing a chip set manufactured by PCSI. This TDMA-based cordless phone offers 6 hours of talk time and 1 week of standby.

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turers of GaAs MESFETs and HBTs, because of the high power added efficiencies for both devices and good linearity in the case of the HBTs, which is critical for digital applications.

There are two primary access methods in digital cellular: TDMA and CDMA. TDMA (time-division multiple access) improves upon the AMPS system by further segmenting each carrier into three time slots, with plans to go to six time slots. This approach would allow up to six users to share a common carrier. CDMA (code-division multiple access) is a more sophisticated digital system in which separate users are not distinguished by individual frequency carriers (or time segments on a given carrier), but by using correlative codes to distinguish between users which are all using the same operating frequency. CDMA systems use up to 64 different codes with each carrier. Unlike AMPS and TDMA, CDMA permits the reuse of the same carriers in adjacent cells, which potentially increases the number of carriers per cell by a factor of seven. Overall, CDMA-based systems may be expected to increase service capacity by a factor of 10-20 as compared to AMPS systems. (See Table 1 for the detailed characteristics of these three systems, plus other major systems being used throughout the world.).

Given that these two systems look likely to take over the cellular market, it is critical that GaAs find a home within them. Happily, large production volumes of GaAs MMIC-based digital phones, using both TDMA and CDMA approaches are now entering the marketplace.

TDMA

Pacific Communication Sciences, Inc., (PCSI) (San Diego, CA), a wholly owned subsidiary of Cirrus Logic Inc., has chosen TriQuint to produce a pair of custom RF chips, which are coupled with PCSI's TDMA baseband and IF Si chips and sold to Japanese manufacturers, including DDI Corporation and Kyocera, for insertion into the Japanese Personal Handyphone System (PHS). The PHS phone system, which just became operational on July 1, 1995, is primarily focused on residential cordless and public telepoint applications.

Joe Skovron, marketing manager of TriQuint explains that "what the customer looks for is what GaAs can do, not that it is GaAs. At TriQuint we want to use a technology that is natural - not wanting to inflict cost, reliability and manufacturability issues on the customer with a technology that may not be suitable for their applications - so we apply a technology which is natural for the application." TriQuint reports that they are currently fabricating the RF chip set in quantities of tens of thousands per week. PCSI's custom 2.7 V RF chip set, operating in the 1900 MHz range, consists of two chips built in GaAs, two in BiCMOS and one in CMOS. The two GaAs-based MMIC chips are:

1. PC11601 - This MESFET-based MMIC contains all up/down converter functions. Precise output power is obtained in the transmitter chain with an analog gain adjustment. Transmit/Receive selection is done via integrated RF switches providing common usage of an external IF SAW filter.

2. PC11301 - This MESFET-based MMIC includes a power amplifier, low noise amplifier, and a transmit/receive switch.

When the TriQuint-built RF portion is combined with PCSI's CMOS baseband processor, BiCMOS IF IC, and BiCMOS frequency synthesizer, the chip set produces a system which is capable of 6 hours of talk time and 1 week of standby. Ed Egan, Director of Semiconductor Product Operations of PCSI says, "the first order for our chip set to the Japanese has been filled, consisting of several hundred thousand sets, and we are now starting on the second order." Over 10 different manufacturers are involved in utilizing the PCSI chip set, using it in the fabrication of various lightweight PHS phones which weigh from 95-130 gms. An example of one of these phones is the Pocket™ by Kyocera. Egan goes on to say, "probably the most amazing aspect of this program is not just the fact that we use such an extensive amount of GaAs-based circuitry in the phone, but that US manufacturers are supplying these components for Japanese commercial products."

CDMA

Besides offering various MMICs suitable for a wide range of wireless applications, RF MicroDevices is also offering an RF chip set specifically designed for CDMA operation in the 800-900 MHz range. RF MicroDevices has entered into a collaborative effort with TRW (Redondo Beach, CA), where the MBE-grown, HBT-based, RF chip set is fabricated, and with QualComm (San Diego, CA), which has both aided in the design of the RF chip set, as well as supplying the CDMA-based baseband circuitry required to complete the phone. In 3-4 months time, Neal projects that RF MicroDevices will be producing 100,000 of the chip sets per month. The 3.6 V chip set consists of:

1. RF9906 - CDMA/FM Low Noise Amplifier/Mixer - This circuit contains an LNA, a double-balanced Gilbert cell mixer, dual IF output buffer amplifiers for CDMA and FM outputs, LO buffer amplifier, and an LO output buffer amplifier for providing the buffered LO signal as an output.

2. RF9907 - CDMA/FM Receiver AGC Amplifier - This circuit is a complete AGC (automatic gain control) amplifier designed for the receive section of CDMA/FM cellular applications. It is designed to amplify IF signals while providing 90 dB of power control.

3. RF9908 - CDMA/FM Upconverter - This circuit contains an IF amplifier, a double-balanced mixer stage and an output buffer amplifier stage. Figure 3 shows a photo of this device.

4. RF9909 - CDMA/FM Transmit AGC Amplifier - This circuit is a complete AGC amplifier designed to amplify the IF signal while providing 84 dB of power control.

5. RF2103 - Although not a specific part of this chip set, this medium power linear amplifier is often used as the power amplifier to complete the RF portion of the phone. This amplifier delivers up to 750 mW of output power with 26 dB of gain.

	Cordless Telephone Standards					Cellular Telephone Systems				
System Name	CT-1	CT-1/CT-1+	DECT	CT-2	PHP	AMPS	IS-54	IS-95	GSM	DCS1800
Regions of Use	N. Amer.	Europe	Europe	Europe	Japan	N.Amer.	N. Amer.	N. Amer.	Europe/Other	Europe
Transmission Method	Analog	Analog	Digital	Digital	Digital	Analog	Dual-Mode	Dual-Mode	Digital	Digital
Frequency Range (MHz)	46/49	800/900	1880-1900	840-844	1895-1907	824-894	824-894	824-894	890-966	1710-1880
Access Method	FDD	FDD	TDMA/ TDD	TDD	TDMA/ TDD	FDD	TDMA/ TDD	CDMA/ TDD	TDMA/ TDD	TDMA/ TDD
Modulation	FM	FM	GFSK	GFSK	π/4DQPSK	FM	π/4DQPSK	OQPSK/ QPSK	GMSK	GMSK
Power Output (MW)	7.5	10	250 PEAK	10	80	600-3,000	600-3,000	600	1,000	250-1,000
Carriers	10	40/80	10	40	TBD	832	832	20	125	375
Channels/Carrier	1	1	12	1	4	1	3,6	20-60	8	8

Table 1: Cordless and Cellular Telephone Systems

One of the major customers for this RF chip set is that of QualComm and the QualComm QCP 800 digital cellular phone which is built in collaboration with Sony. Rick Kornfeld, Vice President of Engineering of QualComm says, "that by running large volumes of the RF chip set, this brings down costs. When this decrease in costs is then coupled with the advantages of putting specific CDMA functions within the MMIC chip sets, there is no reason why these GaAs MMICs can not compete against Si MMICs or discretes." In addition to the HBT-based RF chips, QualComm supplies two BiCMOS-based baseband chips to complete the telephone: the QUALCOMM BBA-2 baseband analog ASIC, and the QUALCOMM MSM mobile station modem ASIC. This high-tier CDMA-based phone has an extremely long talk time of 5 hours and standby time of 3 days. This long battery lifetime is due to a combination of factors. For example: the cell basestation controls the power to insure that excess power is not transmitted from the phone; the phone transmits only when people are speaking; and the vocoder reduces the data rate from the normal 8 kb/s to 1/8 rate when speech is slow. QualComm has licensed their CDMA technology with over 30 other companies. Kornfeld says, "that many of those that we have licensed are using RF MicroDevices RF chip sets, and we encourage them to do so. The larger the number of chip sets RF MicroDevices produces, the lower will become the costs, and the more widespread and economically attractive the technology will become."

These two examples illustrate that GaAs-based MMICs have found their way into diverse phone systems - both TDMA-based and CDMA-based, for both cordless and cellular applications, and for operational frequencies at 900 and 1900 MHz. As different as these two systems may appear to be, they do in fact share many commonalties - both of them being digital systems which require extremely long battery lifetimes, high efficiency PAs, and large production volumes. It is these commonalties which have led phone manufacturers to choose the GaAs-MMIC approach to implement the RF portion of their phones, and it is these very same commonalties which will continue to see future growth in the cellular marketplace.

QualComm

The QualComm QCP 800 Digital Cellular Phone utilizing RF MicroDevice's HBT-based RF CDMA chip set. This CDMA-based cellular phone offers 5 hours of talk time and 3 days of standby.

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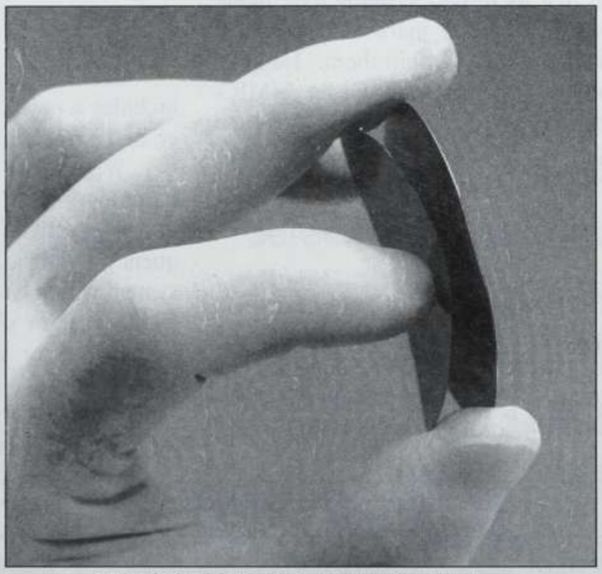

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SYSTEM	FREQUENCY	SYSTEM	FREQUENCY
Advanced Mobile Phone Services (AMPS)	~860 MHz	North American Digital Cellular (NADC)	~860 MHz
Total Access Communication System (TACS)	~900 MHz	Global Systems for Mobile Communication (GSM)	~925 MHz & ~1800 MHz
Nordic Mobile Telephone (NMT)	~450 MHz & ~920 MHZ	Japanese Digital Cellular (JDC)	~425 MHz
		Personal Digital Cellular (PDC)	~890 MHz & ~1460 MHz

Table 1: Cellular Telephone Systems

From the 1940s through the early 1980s, military, space and other government related low-volume applications were the primary drivers for the microwave community. Today, however, a large consumer cellular telephone market has dramatically shifted the emphasis for microwave business.

Cellular applications have brought unique challenges to the microwave device circuit designer. These multi-user consumer systems are as complex as their military counterparts, but their design cannot be approached in the same way. The cellular business is defined by low cost, high volume and rapid product development constraints. In terms of technical specifications, cellular subscriber phones are small, lightweight, highly reliable radios with regulated narrow bandwidths and maximum allowable power levels.

The Cellular Radio

Several distinct cellular systems are in existence or are emerging around the world today. Table 1 lists many of these systems along with the frequency where each one operates. Each system is allocated a transmit band of between 5 and 33 MHz and an associated receive band of identical bandwidth. The center frequency of the transmit band is typically offset from the receive band by 45 to 55 MHz. Analog systems are comprised of 200 to 2000 channel separations of 12.5 to 30 kHz. The resulting analog system manages to accommodate between 15 and 40 users per MHz of allotted bandwidth. In digital systems, the number of channels is determined by the multiple access method used to code the signal. This scheme also determines the number of users per channel. The end result is that digital systems make more efficient use of the bandwidth than their analog counterparts by factors ranging from 3 to 20.

Although the systems listed in Table 1 are each uniquely specified, they share many common requirements. All of the systems are cell based. System base stations (cells) are separated by distances on the order of miles. The subscriber phone transmits and receives signals from the nearest base station which is connected to the local telephone network. The cell system continually poles each subscriber and hands off the call as a subscriber moves from one cell to the next. As a result of the similarities in the systems, the rf portion of the radios are often very comparable. Figure 1 illustrates a block diagram of a typical cell phone detailing the rf portion of the unit. Architectures sometimes vary slightly from that shown in the figure in terms of the number and location of the filters in the rf path. Some phones also include an rf switch at the antenna to allow use of an external antenna, and some include an isolator on the output of the PA. The transmit and receive signals share a common antenna and due to the frequency separation of the two bands can be distinguished via a duplex filter.

On the receive side, the signal is amplified (LNA) and mixed down to the IF (Intermediate Frequency). Signal level control is sometimes used to avoid saturation of the LNA when the base station signal is strong. Cost is the primary driver determining the technology of choice in these front-end circuits. For that reason, Silicon BJTs in plastic packages dominate in these slots. Also for cost reasons, minimal levels of integration are observed in current products. Silicon bipolar transistors are likely to continue to dominate until the frequency allocations are increased to well beyond 3 GHz.

On the transmit side the signal is upmixed and then boosted via two to three stages of amplifiers before being transmitted. Gain control is required in the output stage to conserve the battery when low transmit powers are capable of reaching the base station. Maximum output power requirements vary from system to system, but are generally in the 1 to 3 Watt range. In addition to low cost requirements, a premium is sometimes paid for high efficiency amplifiers in these applications — provided all other specifications including power, gain and ruggedness are met. Digital systems require greater linearity while tolerating slightly reduced efficiency compared to the analog systems.

Another feature which distinguishes the technologies used in a particular phone is the target consumer. Phones range from minimum cost low-tier radios to full-featured, compact, lightweight, high-tier radios. The philosophy behind the low-tier phone is to provide the lowest cost option with acceptable size, weight and performance, while the high-tier philosophy is to provide the highest possible performance, minimum size, and minimum weight with an acceptable cost. These subtle differences, result in use of very different components for critical elements in the radios. For example, GaAs MESFETs have found their way into many high-tier telephone power amplifiers but tend to be replaced by less expensive Silicon MOSFETs for low-tier applications.

System Trends

Low cost, high volume and rapid product development are the primary features of the cellular radio design environment. Key technical drivers include size, weight and battery lifetime. There is also a strong desire from base station providers to satisfy the maximum number of customers with the allocated bandwidth.

In order to reduce the size and weight of hand-held cellular phones, designers have worked diligently to reduce the system's operating voltage from the previous standard for mobile radios of 12 volts, to an emerging industry standard of 3 volts. Lowering this operating voltage enables manufacturers to reduce the number of battery cells. Because batteries are often the largest, heaviest and one of the most costly components in a cellular phone, any reduction in the battery weight and volume will result in a lighter, smaller and less expensive unit. Reduction in the number of battery cells, however, must not come at the expense of battery lifetime or electrical performance of the radio. Battery lifetime requirements translate into low-current, low voltage and high efficiency demands unparalleled in military or space applications. GaAs device designers have exploited these severe requirements for low voltage, high efficiency power amplifiers to displace Silicon devices in most high-tier phones. Competition from Silicon rf MOSFETs has not subsided, however, and GaAs parts have not been able to penetrate the lower-tier radios.

High-volume, high-yield manufacturing requirements create new demands on microwave device and circuit designers. Experience with a technology is invaluable in achieving necessary volume and yield specifications. In the absence of experience, accurate and efficient simulation of the manufacturability, as well as the performance, must be relied upon. Design for manufacturability is as critical to success as design for nominal electrical performance. Even package and test practices which are acceptable for devices and circuits of a mature process may need to be altered if the material or assembly technologies are changed. The high volumes associated with this business often justify the development of entirely new devices, circuits, packages and assembly procedures for each new application. Such development must consider reliability and manufacturability from the onset.

Extremely short design cycle-time requirements demand that first pass success be realized and that an uncompromising emphasis be placed on deadlines. It is almost always more acceptable for a working solution to be available on time than for an optimized solution to be available one day late. Again, experience and accurate simulation are the most valuable tools in meeting these requirements.

One of the trends that is observed in emerging cellular phone systems is the move from analog to digitally encoded systems. As mentioned previously, these systems offer greater efficiency in the use of the available bandwidth. Digital systems also alter the PA requirements of the phone significantly. Since digital systems are pulsed on and off with short duty cycle, amplifier efficiency is slightly less critical than in the case of an analog phone. In contrast, linearity requirements for these phones is significantly more stringent. At this time, there is no obvious winner among the technologies in the race for these applications.

The Cellular telephone business is changing the face of the microwave industry. Microwave designers that embrace cost, schedule, manufacturability and reliability as critical design constraints will thrive in this new environment.

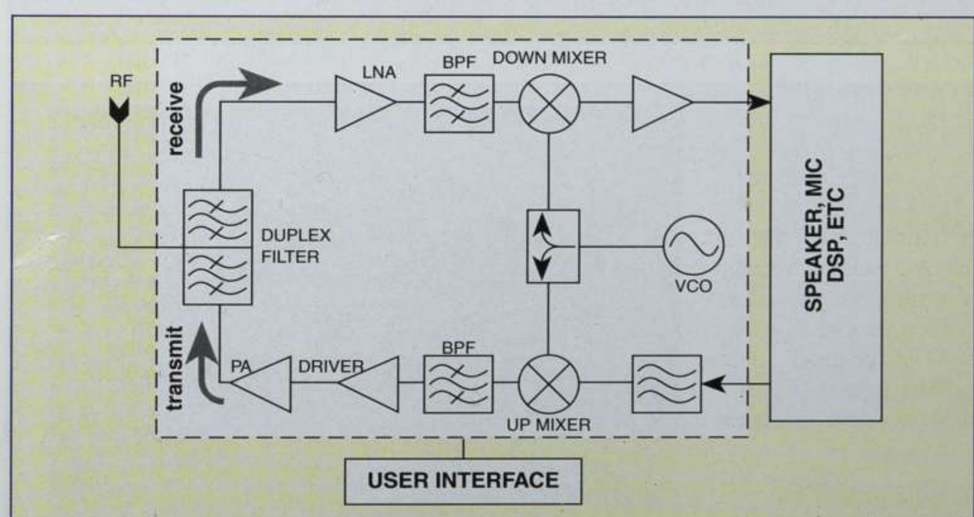

Figure 1: Block diagram of a typical cell phone detailing the rf portion of the unit.

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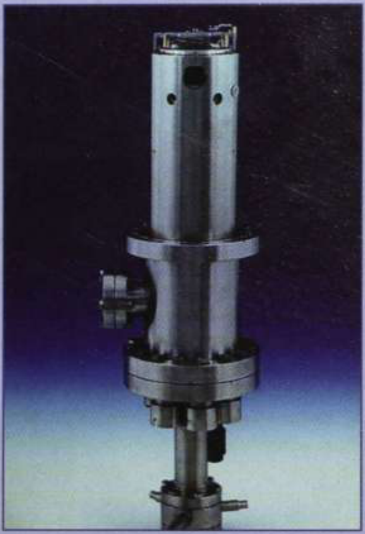
Balzers Introduces Compact Gauges and Controllers

Balzers [Hudson, NH] has expanded its line of compact gauges and controllers to include capacitance and Piezo compact gauges for absolute pressure measurement independent of gas type. The Balzers Compact Gauge series also includes the Pirani, cold cathode and FullRange™ gauges. The Full Range gauge combines two gauges in one compact housing to measure from atmosphere to UHV. The compact capacitance gauge has a full scale range from 1 to 750 Torr. Ceramic construction offers corrosion resistance for most semiconductor processes. Excellent long-term stability of better than 0.01% of reading per degree C is assured. The compact Piezo gauge offers a less expensive alternative for accurate pressure measurement from 1 mbar to 50 bar. All compact gauges offer an output voltage that is easily converted to any pressure measurement unit by one simple formula. Balzers also offers both the SingleGauge™ and DualGauge™ full function controllers for its line of compact gauges. These units form a complete and easy-to-use pressure measurement and control system. ***Circle 118 on Reader Service Card.***



New UHV Photoemission Electron Microscope from Omicron

Omicron has introduced its FOCUS IS-PEEM, a new photoemission electron microscope for surface analysis. With an ultimate resolution better than 40 nm, its performance approaches that of conventional SEM's. The IS-PEEM is based on image contrast, which results from spatial variations of the secondary electron yield, which in turn is dependent on both local work function and surface topography. Electron emission is commonly initiated with UV light, thereby avoiding possible e-beam induced damage as seen in SEM's. An electrostatic lens system focuses electrons emitted from the surface directly onto a screen, producing a real-time image. A key feature of the new Omicron product is its integral sample stage. By fixing it to the microscope, mechanical vibrations are suppressed, allowing high resolution imaging. The sample stage is Piezo-driven, and offers remote-controlled sample positioning over a range of 5x5 mm^2. The microscope contains both adjustable iris and contrast apertures (with optional in-situ exchange) and a stigmator/deflector. The detector is a single-crystal YAG plate, which provides for high brightness, low noise images. The IS-PEEM comes complete with 6" OD mounting flange and comprehensive control system. ***Circle 124 on Reader Service Card***

High Vacuum Venturi Pumps

A new line of venturi vacuum pumps is being introduced by Vaccon Company, Inc. [Medfield, MA]. Vaccon HIGHVAC Venturi Vacuum Pumps feature a straight-thru design and operate from any compressed air or gas with pressure from 60 to 80 psi. Suitable for applications requiring a vacuum down to 3 Torr, these clean, quiet (<70 db) and compact pumps are a maintenance-free alternative to liquid ring roughing pumps. The new pumps are constructed from aluminum, stainless steel, or plastic, and come in three models: 1.3 cfm; 3.0 cfm; and 6.0 cfm.
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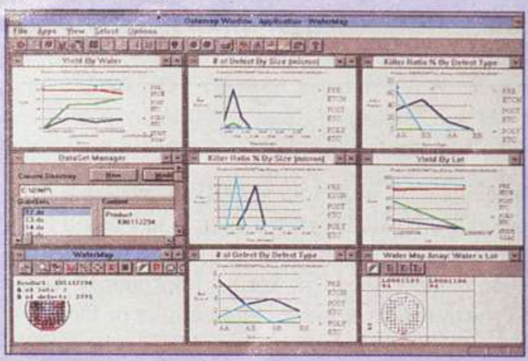


Software for Unattended, Automated Reporting of Yield Data

Knights Technology [Sunnyvale, CA] has released YieldBook™, a new module of their YieldManagerTM semiconductor yield enhancement software. It offers an automated, paperless approach for organizing, analyzing, and reporting yield data. YieldBook's user-defined data selection routines and unattended reporting function produce statistically rich graphical analyses of yield data immediately or at specified intervals. Engineers can create custom electronic notebooks, based upon their individual reporting needs, that contain everything from wafer maps and charts to analysis reports and defect images. ***Circle 91 on Reader Service Card.***

New SIMS System from Oryx

Oryx Technology Corporation [Fremont, CA] has introduced a new transportable, small-footprint SIMS system that is optimized for support of the semiconductor and other thin-film industries. The TTS-2000 can hold samples up to 200mm and includes multi-element depth profiling, extremely sensitive trace-element detection, negative and positive ion detection, remote operation, and an operator-oriented, Windows™ based control system. All of these features make checking surfaces for composition and contamination and monitoring profiles both readily available and practical.

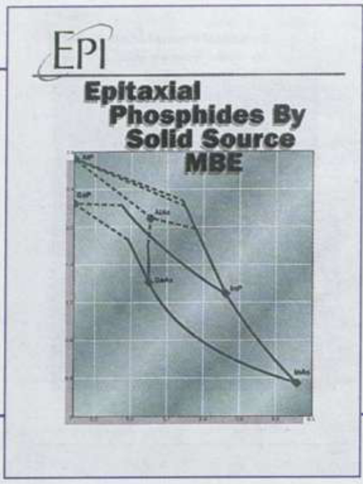
The TTS-2000 is a sector, double-focusing spectrometer with a unique electrostatic and magnetic field configuration. Spectra can be acquired in minutes; mass resolution extends to 3,000 (FWHM); mass range is 1-700 AMU; the 1 mm to 25 micron diameter ion beam is raster-gated for high-quality, elemental depth profiling; and the ion beam operates from 3-5 kV and delivers 10 to 1,000 nanoamps of beam current. Both argon and oxygen ion sources are available. ***Circle 48 on Reader Service Card.***

Sapphire Smart Head Residual Gas Analyzer from Vacuum Generators

"Sapphire" is a new range of residual gas analyzers from Vacuum Generators [Hastings, East Sussex, UK] based on "smart head" technology. All the drive electronics are housed in a compact, lightweight module that connects directly to the quadrupole analyzer. Furthermore, by incorporating several microprocessors within Sapphire, any software changes can be detected by the Smart Head which then automatically upgrades the firmware. This allows new features to be added while avoiding the need to change eproms. The new units cover mass ranges from 1 to 300 amu and include a charge integrating signal amplifier for sub-ppm gas identification. Close coupling the analyzer and electronics improves noise immunity. Likewise, the autotuning RF ensures that Sapphire automatically operates at peak performance with no user set-ups or tricky adjustments necessary. For optimum performance, VG offers an optional triple filter version in addition to the standard single mass filter model. All analyzers are mounted on a 70mm OD (2.75") conflat flange. ***Circle 52 on Reader Service Card.***

New Beam Imaging Systems from Colutron Research

Colutron Research [Boulder, CO] has introduced the new BIS and BVS high resolution beam imaging systems, which can be used to measure two or three dimensional intensity distributions of ion, electron and neutral beams as well as X-rays. The systems form an image by using a microchannel plate in combination with a phosphor screen, and record the image with a CCD camera. Applications include real time image analysis, single particle position sensitive detection, beam line diagnostics, X-ray spectroscopy, and beam profile analysis (beam tuning). ***Circle 15 on Reader Service Card.***



Epitaxial Phosphides by Solid Source MBE

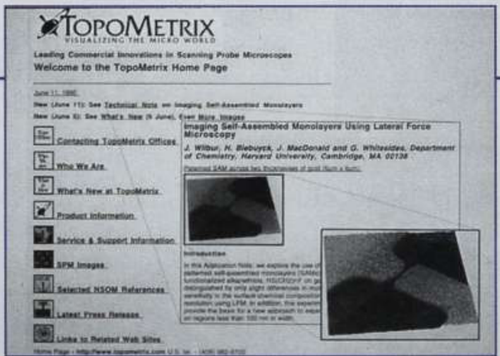
A new brochure describing the growth of epitaxial phosphides by solid source MBE is available from EPI [Saint Paul, MN]. Epitaxial InP and its related materials are usually grown using a gas-based technique, such as MOCVD, GSMBE, or CBE, because of the hazards traditionally associated with the use of solid phosphorus. EPI has developed a new MBE source, the Valved Cracker for Phosphorus, which eliminates those hazards. This brochure describes the growth results achieved at a number of facilities, demonstrating that it is now possible to grow state-of-the-art phosphide layers in any MBE system without the use of toxic gases. ***Circle 29 on Reader Service Card.***

New Vacuum Accessories Catalog from Balzers

Balzers [Hudson, NH] has published a new catalog offering a comprehensive line of vacuum accessories. Included are over 800 new produces featuring fittings, flanges, construction components, compact gauges, residual gas analyzers and valves. In-stock items are shipped within 48 hours from receipt of order via toll-free telephone or fax numbers. Visa and Mastercard are accepted.
Circle 117 on Reader Service Card.

New Brochure from Wavemat

Wavemat, Inc. [Plymouth, MI] has published a new brochure describing the MPDR 610i microwave plasma ECR source. This retrofittable MBE component can be used in the fabrication of blue LEDs from GaN or nitrogen-doped ZnSe, as well as advanced microwave components and high speed/high temperature microelectronics. The MPDR 610i was the first fully-UHV compatible ECR plasma source and it has been a proven success in applications from nitride thin film growth to plasma cleaning of compound semiconductors. Its low ion energy (10-30 eV), wide operating range (10^{-2} to 10^{-5} Torr) and high atomic content ensure rapid, low-damage processing in virtually all current MBE, GSMBE and MOMBE systems. ***Circle 56 on Reader Service Card.***



WWW Site for Scanning Probe Microscopy

TopoMetrix [Santa Clara, CA] now has a WWW site with over 30 pages of colorful scanning probe microscopy (SPM) images and technical information. The mission for this new Web page is to provide both technical information about the SPM technique and its applications and product information. Technical information available on the site includes a copy of the most recent application note produced by TopoMetrix; latest product and technical offerings; several full-color images of the latest SPM applications, NSOM references, and more. Site address: http://www.topometrix.com

UHV Catalog on the Web

Vacuum Generators [Hastings, East Sussex, UK] is putting their entire 1995/96 UHV catalog onto the WWW. The new catalog provides a comprehensive range of products for UHV, Residual Gas Analysis, and Surface Science. Categories include flanges and accessories, linear/rotary drives, manipulation, pumps and traps, transport and transfer devices, UHV chambers, RGAs, synchrotron components and surface system. There is also a new-products update page which details some of the latest VG products.
Site address: http://www.surface.fisons.co.uk/vacgen/

Internet "Mailing List" for SPM

Digital Instruments [Santa Barbara, CA] has begun an Internet "mailing list" for scanning probe microscopy (SPM). The list is intended to be an open and unedited forum for discussing and exchanging technical information, views, issues, and applications of SPM with the goal of expanding knowledge of SPM and bringing the SPM community closer together. Persons who wish to subscribe should send a line similar to the following to majordomo@di.com: subscribe spm <your email address>

New Home Page for Granville-Phillips

Granville-Phillips [Boulder, CO] has introduced its new WWW home page, allowing customers world-wide on-line access to a variety of information and customer services. The site also includes general company information, product specifications, newsletters, press releases, and tutorial information. In addition, the home page will be used as a tool for GPC to receive customer feedback and requests.
Site address: http://www.aescon.com/granvill/

Substrates for Epi Nitride Thin Films

A new brochure is available from Materials Technology International Corporation (MTI) [El Cerrito, CA]. MTI manufactures and supplies high quality single crystal substrates for epi nitride thin films, such as Al_2O_3, $MgAl_2O_4$, MgO, ZnO 6H-SiC, GaSb, InP and InSb etc. MTI uses a special polishing technique and makes substrate surface roughness less than 15 Å. MTI also fabricates epi substrates with special orientation and edge alignment upon customer request. ***Circle 200 on Reader Service Card.***

1996 International Conference on GaAs Manufacturing Technology

First Call for Papers

GaAs MANTECH Goes Global!

Following ten years of service to GaAs manufacturing in the United States, the executive committee of the GaAs MANTECH Conference has unanimously decided to open the conference to the world-wide community. The first International GaAs MANTECH Conference will be held at the Hotel Del Coronado in San Diego, CA from April 28 to May 2, 1996.

The success of MANTECH has been, and will continue to be, the result of outstanding technical work done by the participants and, subsequently, shared with their peers at the Conference. In keeping with this year's theme, "Manufacturing Challenges in a Growing Global Market", papers are sought in the following areas:

DESIGN: Novel devices for improved manufacturability; MCA design methodology, power amplifiers, power device thermal management.

PROCESSING: Yield enhancement solutions, multilevel interconnect, HBT passivation.

MANUFACTURING: CIM, module manufacturing, development in a manufacturing environment, cycle time reduction, quality success stories, low cost and plastic packaging.

TESTING/RELIABILITY: Low cost testing, high speed testing, novel test structures.

APPLICATIONS: MMIC commercialization, future government and commercial applications, phased array radar chip sets, broadband applications.

And, in addition to the traditional MANTECH topics, the program committee encourages the submission of papers on manufacturing equipment and facilities as applied to GaAs.

ABSTRACTS

Abstracts should clearly state: a) the purpose of the work; b) how manufacturing technology was advanced; and c) what specific results were obtained. Manufacturing equipment abstracts should include supporting data from equipment users, and if the paper describes related work in government of University centers, the abstract should describe the realization of the results in the manufacturing environment.

Authors wishing to submit abstracts should send the original and thirty-five (35) copies to:
Jim Oakes
Raytheon, ADC
362 Lowell Street
Andover, MA 01810

Abstracts are due by November 3, 1995

Abstracts may be up to four pages in length, including graphics, pictures, charts, etc. The extended abstract must be typewritten on one side of each page with one inch margins. The abstract must also include the title, author(s), organization affiliation, mailing address and telephone number. Abstracts become the property of the MANTECH Conference, so it is the author's responsibility of obtain any required company or government clearance prior to submission of the abstracts.

Visit our WWW Site at http://www.ee.wustl.edu/GaAs/
E mail can be sent to: gaas@ee.eustl.edu
Other inquires: Neal Mellen, Conf. Chair, Motorola, 4800 Alameda NE, Albuquerque, NM 87113 USA
TEL [1] 505 822 8801 x 236 FAX [1] 505 822 8812

53rd Annual Device Research Conference

Charlottesville, Virginia June 19-21, 1995

Reports of decreasing dimensions and novel geometries, for FETs and HBTs at this year's DRC

ROBERT A. METZGER

11 Sessions
4 Rump Sessions
Presentations: 71
Attendance: 400

This years Device Research Conference, once again lived up to its name, where the focus of this conference was clearly on device work, including Si MOSFETs, III-V FETs, III-V HBTs, Wide Band Gap Devices, Quantum Devices, Detectors, Modulators and Lasers. Fundamental improvements in device operation were obtained by the continuing shrinkage of device dimensions, as well as by the utilization of novel device geometries. These improvements were especially evident in the areas of FETs and HBTs.

FETs and HEMTs

Due to high power added efficiencies (PAEs), GaAs-based FETs are finding wide use as power amplifiers in cellular phones, where the high PAEs result in lower power consumption and therefore longer talk time between battery charging. Takuma Tanimoto from Hitachi's Central Research Laboratory (Tokyo, Japan) reported on a dual gate ion implanted MESFET utilizing 0.35 µm gates, where a large gain FET is used for the first gate to improve the power characteristics of the device, while the distance from the second gate to the n - implantation region is lengthened in order to increase the FETs breakdown voltage. Using this structure, an extremely high PAE of 78% was obtained at 1.9 GHz operation using a 3 V supply. These characteristics make this MESFET ideally suited for both the Japanese Personal Handy Phone (JPHP) and the Digital European Cordless Telephone (DECT) system which operate at 1.8 GHz, as well as being applicable for future operation in the US PCS band of 1.8-1.9 GHz.

One of the most important factors in determining the noise performance of a HEMT is the parasitic gate resistance. Jin-Hee Lee of the Electronics and Telecommunications Research Institute (Taejeon, Korea) addressed this issue by developing a wide head T-gate fabricated by using dose split electron beam lithography and selective gate recess etching. He described a AlGaAs/InGaAs pseudomorphic HEMT grown by MBE in which the gate head length (1.35 µm) to gate footprint (0.13 µm) is greater than a factor of ten - this ratio being twice as large as a conventional T-shaped gate. See Figure 1. The maximum frequency of oscillation, f_{max}, and the cut-off frequency, f_t, of this 0.13 µm gate length device are 207 and 82 GHz, respectively. A minimum noise figure of 0.31 and 0.45 dB were obtained at 12 and 18 GHz, respectively. These are the lowest noise figures ever reported for passivated GaAs-based HEMTs operating at these frequencies.

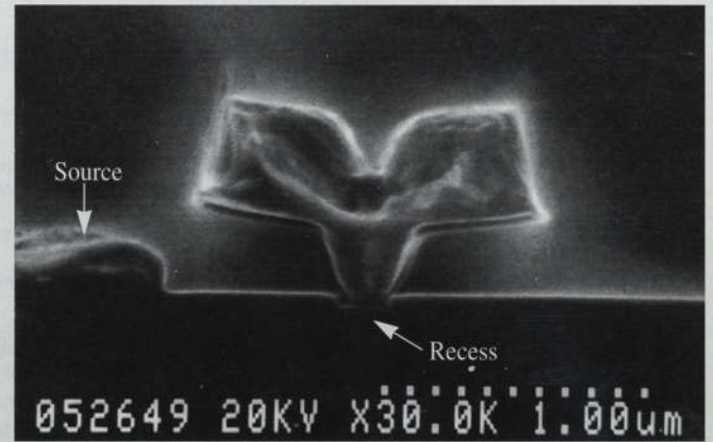


Figure 1. Cross-Sectional SEM of a wide head T-gate MESFET fabricated by split E-Beam lithography. The footprint and top width of the T-gate are 0.13 µm and 1.35 µm, respectively. SEM courtesy of Jin Hee Lee, ETRI (Taejeon, Korea)

As MESFET geometries scale down, both drain induced barrier lowering (DIBL), and narrow channel effects (NCE), which limit the current I_{on}/I_{off} ratio, speed, and logic voltage scaling, degrade device operation. Bill Peatman of the University of Virginia (Charlottesville, VA) described the scaling of a novel two dimensional AlGaAs/InGaAs/GaAs MESFET in which sidewall Schottky Barriers

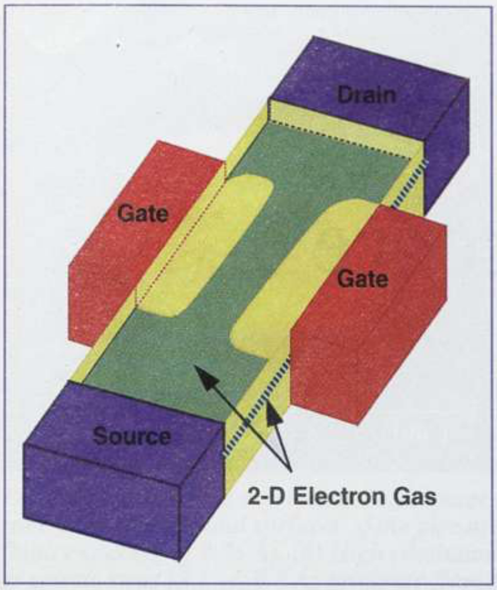


Figure 2. 2-Dimensional MESFET showing lateral gate depletion of the 2-Dimensional electron gas channel. Courtesy of Bill Peatman, University of Virginia (Charlottesville, VA)

are placed on the sides of a very narrow 2-D electron gas channel (See Figure 2). This geometry is used to eliminate both NCE and DIBL effects. It was experimentally shown that by reducing the gate length from 1.0 to 0.8 µm and the spacing between lateral Schottky barriers from 1.0 to 0.5 µm, that the output conductance of the MESFET was reduced from 40 mS/mm to less than 1 mS/mm, as knee voltages where reduced from 0.75 V to 0.25 V. Source-Drain breakdown voltages of over 10 V, and a I_{on}/I_{off} ratio of over 10^5 were achieved. Simulations show that DCFL (Direct Coupled Field Effect Transistor Logic) circuits utilizing this novel 2-D MESFET geometry should be able to achieve power delay products lower than 0.1 pJ with a propagation delay of 40 ps per stage using a power supply voltage of only 0.8 V.

Advances were not only being made on III-V based FETs, but also on SiC-based FETs. Scott Allen of Cree Research (Durham NC) presented the results of joint work performed with Motorola Corporate Research Laboratories (Tempe, AZ), in which 0.4 µm gate length MESFETs were fabricated on high resistivity 4-H SiC. These FETs produced an f_{max} and f_t of 30.5 and 14.0 GHz, respectively - the highest RF values yet reported for a SiC-based MESFET. S. Sriram of Westinghouse Science & Technology Center (Pittsburgh, PA), using 6-H SiC, demonstrated a 0.5 µm gate length MESFET which delivered 3.5 watts, with 45.5% PAE, at 6 GHz operation and a 40 V drain bias. This performance represented a power density of 1.75 W/mm - a value twice that normally attained in GaAs-based MESFETs.

GaAs and InP HBTs

Selective growth of a heavily doped extrinsic-base structure was utilized by Minoru Ida of NTT LSI Laboratories (Kanagawa, Japan) in an MOCVD-grown InP/InGaAs-based HBT in order to reduce base resistance. Good selectivity of InGaAs growth was obtained at a low temperature of 400°C (typical selective growth occurs at growth temperatures above 600°C), where this low temperature is needed in order to minimize Zn-diffusion from the heavily doped ($4x10^{19}$ cm^{-3}) base region during regrowth. The regrowth of the heavily doped extrinsic-base structure reduced the base resistance from 134 to 75.4 ohm, where this reduction in resistance produced an improvement in f_{max} from 90 to 141 GHz. However, due to a preheating step of 500°C prior to the InGaAs regrowth at 400°C, Zn diffusion from the base to the emitter took place, resulting in degradation of f_t from 142 to 93 GHz. Ida plans additional optimization of the regrowth temperature sequence in order to further minimize Zn diffusion.

Low power applications require reduction in device current which can be obtained by using reduced junction areas. Madjid Hafizi of the Hughes Research Laboratories (Malibu, CA) described an AlInAs/GaInAs, InP-based fully self aligned HBT in which the emitter area has been reduced to 0.3 $µm^2$ - representing a greater than one order of magnitude reduction in emitter area from their current baseline HBT process, and the smallest emitter geometry HBT in any III-V material system. See Figure 3. This device utilizes 1 µm vias and a single metalization step for Emitter/Base/Collector contacts. This HBT exhibits an f_{max} and f_t of 102 and 70 GHz, respectively, and under high speed operation with a power consumed per gate of 9 mW, operates at 4.75 ps. This speed is 5 times faster than Hughes' standard 2x2 $µm^2$ HBT operating under the same power consumption conditions.

High breakdown voltage, which is a key requirement for devices operating at high power, is a challenge for InP-based HBTs utilizing small bandgap InGaAs as the collector material. Two approaches were presented which demonstrated how breakdown voltages can be improved. Chanh Nguyen of the Hughes Research Laboratories (Malibu, CA) reported on the use of a 50 nm short period AlInAs/GaInAs MBE-grown chirped superlattice (CLS) placed at the base-collector junction. The larger bandgap AlInAs rich region of the CSL is placed at the base-collector junction interface where the electric field is highest, and thereby inhibits breakdown. The remainder of the collector consists of 350 nm of GaInAs. The CSL is then coupled with a pair of acceptor and donor delta doped sheets with the same carrier concentration ($4x10^{11}$ cm^{-2}) which creates a dipole that cancels out the conduction band offset at the interface. This HBT exhibits a breakdown voltage, BV_{CEO} of 18 V and an Early Voltage, V_A of 300 V. John Cowles of TRW (Redondo Beach, CA), reported on replacing the entire GaInAs collector of a AlInAs/GaInAs, InP-based HBT with 540 nm of $In_{0.53}Ga_{0.24}Al_{0.23}As$ (where the introduction of Al increases the bandgap of the collector from 0.75 to 1.1 eV) which is lattice matched to InP. This modified HBT with a quaternary collector, showed no degradation in DC gain or RF performance, while exhibiting an increase in BV_{CEO} from 10 to 20 V, and an increase in V_A from 7 to 250 V.

Once again the DRC presented results on HEMTs and HBTs which exhibited higher speeds, higher breakdown voltages, smaller geometries, lower noise figures, and less power consumption than were reported on the year before. It is impossible to guess what specific breakthroughs might be reported in next years DRC, but it is safe to assume that the trends exhibited this year will likely continue on into the next.

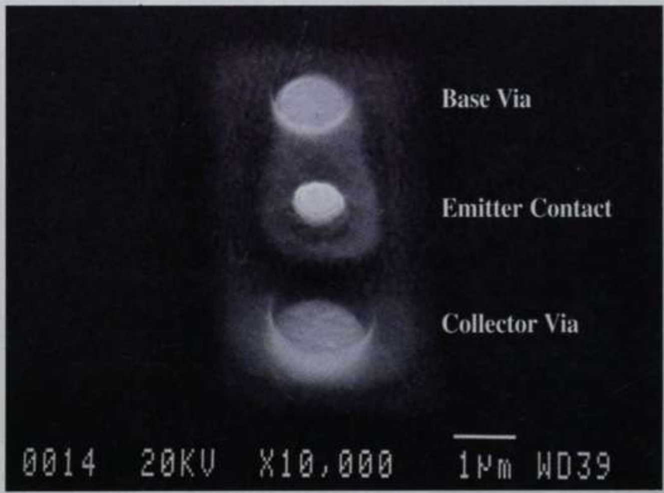


Figure 3. SEM of a fully self aligned AlInAs/GaInAs, InP-based HBT with 0.3 $µm^2$ emitter. SEM courtesy of Madjid Hafizi, Hughes Research Laboratories (Malibu, CA).

37th Annual Electronic Materials Conference

Charlottesville, Virginia June 21-23, 1995

Nitride materials and the search for suitable substrates were the highlight of this year's EMC

ROBERT A. METZGER

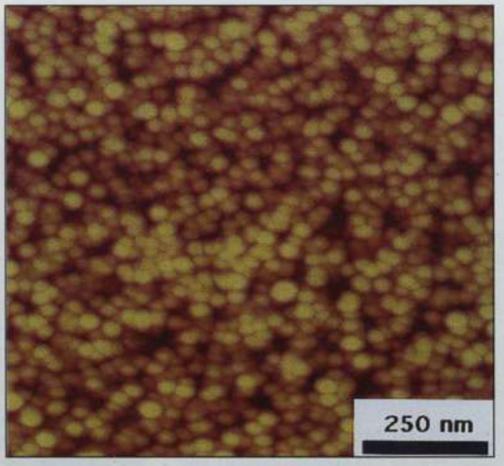
27 Sessions
Presentations: 226
Attendance: 500
Exhibit: 30 Vendors

A wide spectrum of materials work was presented at this years EMC, including investigations in the III-V, II-VI, SiGe and SiC material systems, as well as the more exotic epitaxial and conducting oxides, and transparent conductors. Growth techniques described included both MOCVD and MBE, with device applications including FETs, HBTs, Quantum Wires and Dots, and Photovoltaics. One of the highlights of this conference dealt with the rapid advances being made in the area of nitride growth, this activity being driven by the recent commercialization of blue LEDs from Nichia Chemical Industries (Tokushima, Japan) and Cree Research (Durham, NC), and the pursuit of nitride-based blue lasers.

Growth on Sapphire

Because of the large lattice mismatch between sapphire and GaN (14%), it has been found necessary to first grow a low temperature buffer (500-600°C) which acts as a nucleation layer, before the initiation of high temperature (1000-1100°C) GaN growth. The understanding of initial GaN nucleation and its impact on subsequent film growth and morphology are of critical importance in improving material quality. Dave Kapolnek of the University of California at Santa Barbara reported on Atomic Force Microscopy (AFM) observations of GaN nucleation layers grown at low temperature by MOCVD. He finds that substantial structural evolution of the GaN buffer layer occurs as the substrate temperature is increased from that used in the low temperature regime during buffer deposition (600°C) to the high temperature regime (1080°C) in which a 1.2 µm thick GaN layer is grown. Figure 1 shows AFM images of a 19 nm thick GaN nucleation layer which was grown at 600°C, in which the GaN grain size has increased from 33 to 77 nm as a result of the buffer layer being annealed at 1080°C for 8 sec. Despite the obvious three-dimensional nature of the nucleation layer, AFM observation of the resultant 1.2 µm thick GaN film shows two-dimensional step flow growth with a surface roughness that has been reduced by roughly a factor of 50 as compared to that of the initial low temperature buffer layer. Further studies are being pursued to investigate how the transition between two and three-dimensional growth occurs.

Further structural analysis of GaN films grown on sapphire was performed by Weida Qian of Carnegie Mellon University (Pittsburgh, PA) in collaboration with the Naval Research Laboratory (Washington DC). Like Kapolnek, he observed that the initial growth of the low temperature GaN buffer was highly three dimensional, and that grain-like structures were formed in the film during coa-



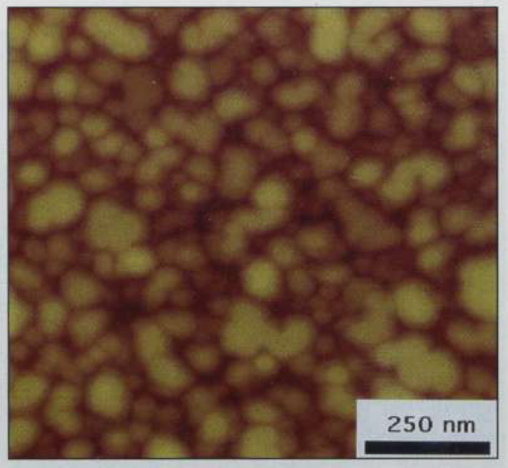


Figure 1. Atomic Force Microscopy (AFM) images of 19 nm thick GaN layers grown on sapphire at 600°C. Temperature quenching at the end of 19 nm growth produces an average grain size of 33 nm (A), while an additional 8 sec anneal at 1080°C prior to quenching produces an average grain size of 77 nm (B). Courtesy of Dave Kapolnek, University of California at Santa Barbara.

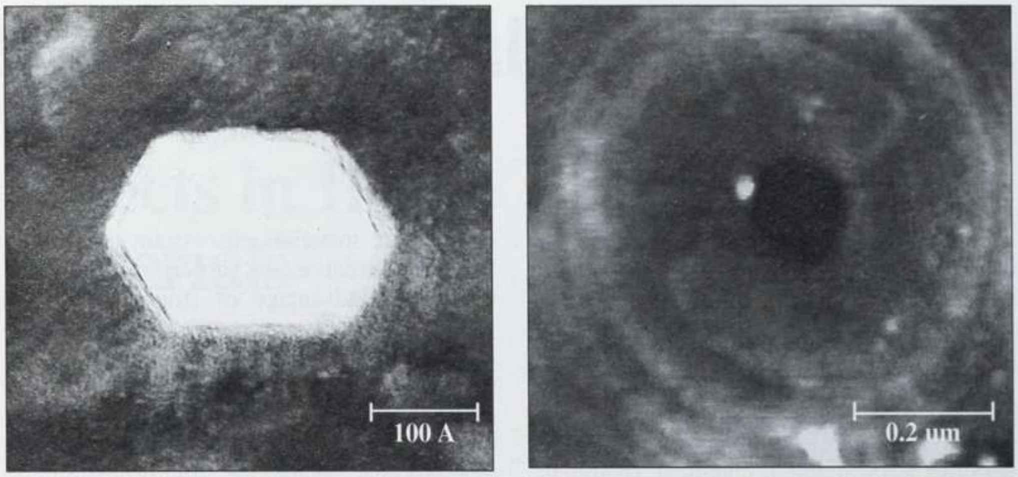


Figure 2. (a) Atomic resolution TEM image of a nanopipe in GaN obtained with the [0001] zone axis. The internal surfaces of the pipe are formed by six close-packed {1100} prism planes (lattice spacing of 2.76 Å). (b) High resolution AFM image of a nanopipe. A pair of monolayer spirals steps (3.1 +/- 0.8 Å) originate from the pipe and propagate outwards, indicating that the nanopipes are the open-cores of screw dislocations. Courtesy of Weida Qian, Carnegie Mellon University (Pittsburgh, PA).

lescence of islands. The grain sizes ranged from 50 to 500 nm, with inplane misorientation of the islands being less than 3° and corresponding to a dislocation density of 10^{10} cm^{-2}. It was shown that lower dislocation densities ($1x10^{9}$ cm^{-2}) were possible by controlling the nucleation stage of growth. However, because these were perfect edge threading dislocations, there was no appreciable annihilation of the defects with increasing GaN layer thickness, suggesting that controlling these dislocations through commonly used buffer and superlattice schemes might be very difficult. In addition to the edge dislocations, a second type of defect was observed - long hollow pipes 7 to 60 nm in diameter, oriented along the c-axis with densities of 10^{5} to 10^{7} pipes/cm^{2}. Qian has called these defects nanopipes. Located at the centers of growth hillocks, these hexagonally shaped tubes exhibit monolayer growth spirals around the perimeter of the tubes. See Figure 2. It is believed that these nanopipes are formed by open-core screw dislocations generated under thermodynamic equilibrium.

Despite the large lattice mismatch between the sapphire and GaN film, which result in dislocations on the order of 10^{10} cm^{-2}, p-n junctions have been fabricated, with commercially available GaN-based LEDs delivering brightnesses of 400-1000 mcd. Chong Yuan of EMCORE Research Laboratory (Somerset, NY) with collaborators from Rutgers University (Piscataway, NJ), NCSU (Raleigh, NC) and the University of Florida (Gainesville, FL), reported on the growth of p-type GaN on sapphire in a multi-wafer-rotating-disc MOCVD reactor. Grown at 1040°C, these p-type GaN layers are used in the formation of light emitting p-n junctions. P-type GaN layers using Cp_2Mg as the precursor, produced carrier concentrations as high as $5x10^{18}$ cm^{-3} with mobilities as high as 20 cm^2/V-s after annealing the Mg-doped films in a N_2 ambient at 700°C. SIMS analysis of the p-type layers indicated that approximately only 1% of the Mg had been activated by the annealing process. Homojunction LEDs were fabricated from Mg doped p-layers grown on n-type layers, where despite defect densities of $8x10^{9}$ cm^{-2} (see Figure 3), electroluminescence was observed at 380 nm. In addition, Yuan reported on the growth of $In_xGa_{1-x}N$, with In content as high as 60%, producing photoluminescence far into the green region of the spectrum at 553 nm, a region that has been difficult for InGaN to reach due to the strain introduced by the large In content.

Other Substrates

Due to the problems associated with growth of nitrides on sapphire (lattice mismatch, thermal expansion mismatch, only insulating substrates available), other substrates are being investigated as possible replacements. Q. Chen of APA Optics (Blaine, MN) in conjunction with JPL (Pasadena, CA), reported on the growth of GaN on (100) and (111) spinel (MgA_2O_4), which has a 10.9% lattice mismatch to GaN. They found that growth on (100) spinel showed faceted features, with elongation along one of the two (110) directions, while growth on (111) spinel resulted in smooth films with n-type conductivity and room temperature carrier concentrations of $6x10^{17}$ and mobilities of 50 cm^2/V-s. Mark Johnson of North Carolina State University (Raleigh, NC), reported on the growth of ZnO (with close lattice match and thermal expansion coefficients to GaN) by MBE on both sapphire and SiC, using a standard Zn effusion cell and a plasma source to convert molecular oxygen into atomic oxygen. GaN layers were then successfully grown on the ZnO layers. Johnson also reported on the MBE growth of GaN on 3.0 μm GaN films which had been grown by MOCVD on SiC substrates by Cree Research (Durham, NC). SiC is an attractive alternative to sapphire, being more closely lattice matched, exhibiting a closer thermal expansion coefficient, higher thermal conductivity, and availability of both conducting and resistive substrates. TEM analysis revealed dislocation densities as low as 10^{6} cm^{-2} in both the MBE grown GaN layer as well as the underlying MOCVD grown buffer layer. The most novel substrate proposed for GaN growth at the EMC was that presented by Rod Beresford of Brown University (Providence, RI), using a metal Hafnium substrate which is perfectly lattice matched in the basal plane to GaN, and has a thermal expansion coefficient which differs by only 4.3%. Strain annealing methods were used to form small diameter single crystal Hafnium substrates (4-5 μm grain size). After an in situ Ar ion sputter was used to clean the Hf surface, GaN growth was initiated. Initial growth experiments were able to produce polycrystalline GaN films up to 1 μm thick, which exhibited some photoluminescence response.

As evidenced by this conference, rapid progress is being made on the growth and analysis of nitride based materials. However, many questions have yet to be fully answered. What are the optimum conditions for buffer growth? How can defects levels be reduced? How do these defects impact the optical and electrical properties of films and devices? What is the best substrate for nitride-based growth? Undoubtedly, next years EMC will have much more to report on in this area.

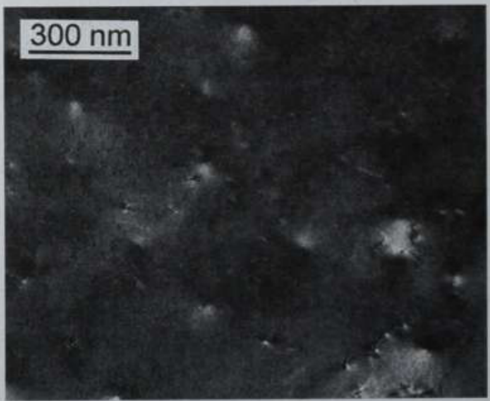


Figure 3. Plane-view TEM of a GaN p-n junction exhibiting a defect density of $8x10^{9}$ cm^{-2}. Courtesy of Chong Yuan, EMCORE Research Laboratory (Somerset, NY)

7th Int'l. Conf. on InP and Related Materials

JOE LORENZO, ROME LABORATORY

The purpose of the annual IPRM Conference is to offer its delegates the entire "food chain" of InP technology. This year's conference, held in Sapporo, Japan, fulfilled its task by offering important reports from all areas, ranging from from bulk material to processing and epi, and on up to optoelectronic and electronic devices. The increased attendance at this year's confternece was an indicator of the pent up demand and interest in advanced InP-based technology. Without reservation, the technical quality of the contributed and invited papers was excellent, a gauge of the preeminent role of IPRM as a full spectrum, III-V forum.

Bulk Growth

While the number of researchers is small, bulk growth remains and important topic since it provides the foundation for all other advances in InP technology. One primary goal in this area is to achieve stable semi-insulating (SI) material, and several groups at this year's IPRM reported the reproducible preparation of lightly Fe-doped/undoped SI InP. A new model based on the complex defect, In-vacancy-hydrogen, has been proposed as the mechanism of SI behavior. Progress in developing 3 inch diameter InP substrates was also reported, along with demonstrations that high resolution characterization methods such as double crystal x-ray diffraction (DCD) mapping, scanning photoluminescence (SPL), noncontact resistivity mapping (NRM) and scanning infrared polariscopy (SSIP) can be practical and effective characterization tools. Advances in a multicomponent zone melting method have been applied as a crystal growth technique, which has high potential for growing bulk ternary InGaAs and other III-V bulk crystals. Given the increasing demand for higher quality and larger diameter InP substrates due to the development of the multi-media area, it can be concluded that as a whole, researchers in the bulk area will remain active at a variety of institutions across the globe.

Processing

It was strongly evident that the processing area is experiencing a resurgence of research related to the understanding, passivation and control of surfaces and interfaces. A common goal of many researchers is the development of in-situ processing. In one instance the long-lived problem of a strongly pinned Fermi level at the InP surface was analyzed and addressed by an in-situ electrochemical etching and metalization process, thus enabling unencumbered Schottky barrier formation on an unpinned surface. Another simple but effective technique reported by Rome Laboratory passivates the surface and controls pinning with a low temperature CdS-thiourea chemical treatment. This process effectively removes native oxides, provides a barrier to oxide regrowth, and forms III-S bridge bonds, thereby reducing traps due to P-vacancies.

Epi

Epitaxial growth and characterization continues to dominate as a major topical area, comprising about one third of the total contributed papers. Advances in the controllability, uniformity, planarization and the formation of smooth edges and vertical surfaces using selective growth techniques received the most attention. Delegates reported growth techniques which incorporate partly masked and non-planar substrates as part of the regrowth process. Quantum wire and dot formation stood out as a prominent, though problematic, research topic. A focus of many research groups was growth using self-organization phenomena in the strained material systems. Strained layers continue to offer an additional degree of freedom in band-gap engineering to the device designer. Demonstrations of the advantages of strain-compensated MQW structures were reported by several groups. For example, experimental evidence indicates that increasing the number of MQW periods results in enhance optical gain and the reduction of threshold current density.

Devices

The optoelectronics area boasted nearly 50 papers, underling the high visibility and interest in InP-based optical devices and applications. A driving force for optical technologies is the promise of speed and bandwidth in network applications. To this end, various wide temperature range semiconductor lasers operating at 1.3 µm were fabricated and tested for applications to access networks. In order to improve temperature characteristics, the conduction band difference between the active layer and cladding layer was enlarged by employing various combinations of heterostructure materials, also strain compensation was introduced in barrier layers to fully exploit the advantage of strained quantum wells. Significant progress in waveguide-type photodetectors and electro-absorption modulators devices attracted much attention. These devices displayed wide bandwidth above 100 GHz. Some waveguide photodetectors utilized low voltage avalanche multiplication to enhance the gain. InP-based electro-absorption modulators were shown to be polarization insensitive while maintaining low-drive voltage requirements.

The electron devices area provided illustration of the competition between HEMT and HBT devices. Well-designed HEMT MMICs based on deep submicron technology were reported. A three stage InAlAs/InGaAs HEMT-based amplifier with a gain of 33 dB at 20 GHz was optimized by Hewlett-Packard using a low temperature buffer layer. Daimler-Benz reported the first demonstration of a low cost approach for 60 GHz coplanar waveguide low noise amplifiers with a gain of 15 dB using HEMT technology. NTT demonstrated alignment techniques for 40 Gb/s InP HEMT ICs. The effort included circuits such as baseband/limiting/preamplifier for future monolithic OEIC technology.

HBT device technology is already commercially acceptable for microwave applications - nevertheless, research in this area continues to progress, achieving even higher performance standards. Novel self-aligned InP/InGaAs HBTs with submicron emitters achieving f_t=120 GHz were described by Hitachi. NTT fabricated collector-up HBTs which were designed with low base/collector capacitance for high-speed applications. A monolithic HEMT/HBT using a 2DEG in the base-emitter interface was demonstrated by AT&T.

And, finally, the nanostructure device technology presentations presented a glimpse of what may lie in the future. Contributions in this area targeted new functional devices, covering a wide technological range from analysis of physical phenomenon to circuit demonstrations. Resonant tunneling (RHET), multi-emitter RHET, quantum dot tunneling HET and quantum functional bipolar transistors were discussed as potential successors in the evolution of electron devices.

The 1996 IPRM conference will be held at Schwaebisch Gmuend, Germany, April 22-25, 1996.

Purification, Doping and Defects in II-VI Materials

R. TRIBOULET, CNRS

This year's E-MRS Meeting included a symposium entitled "Purification, Doping and Defects in II-VI Materials". It was divided into several sessions covering the following topics: growth; doping and purification; defects; transition elements in II-VI compounds; photorefractivity; and compensation. It consisted of 13 invited lectures, 21 shorter oral presentations, and 23 poster presentations.

Bulk Growth

In spite of some remaining controversies concerning some of its basic properties, CdTe appears more mature than ZnSe, in both crystal growth and characterization aspects. As an illustration, the only communications dealing with ZnSe were related to its growth, either from the vapor phase, according to the Markov-Davydov technique (Y.V. Korostelin, Lebedev Institute, Moscow, reported 60 mm dia. ZnSe crystals), or more generally by high pressure Bridgman, with or without oriented seed. The difficulty in growing twin-free crystals by this last technique has been stressed. Hommel, et al. (Bremen, Wurzburg, Berlin and Frankfurt Universities) experimentally demonstrated the advantage of homoepitaxial growth of ZnSe layers on high quality ZnSe substrates, to reduce the density of dislocations appearing at the GaAs/ZnSe interface that are thought to be partially responsible for the short lifetimes of the ZnSe

While the search is still on for the most appropriate growth technique for ZnSe, in the CdTe area the Bridgman method, or gradient freeze technique, in either vertical or horizontal configuration, is more generally adopted. In this frame, the spectacular growth by the vertical gradient freeze technique of 100 mm diameter (111) oriented CdZnTe single crystals with a dislocation density of $<10^5$ cm^{-2} was reported by T. Asahi from Japan Energy.

The phase equilibria and subsequent determination of the homogeneity field of CdTe have been revisited by several authors. Using a novel approach to probing the non-stoichiometry in crystals, called vapor pressure scanning, the P-T-X phase equilibria of CdTe has been investigated and the solidus surface reconstructed. (J.H. Greenberg, Jerusalem University). Some very significant features such as congruent melting position on the Te-side, maximum melting temperature on the Cd-side, maximum deviations from stoichiometry of approx. 1.5×10^{-2}% and approx 4×10^{-3}% on the Te- and Cd-sides respectively have been reported, in disagreement with previous high temperature Hall effect measurements giving lower deviations. In contradiction to those results, Cd and Te solubilities exceeding 10^{20} cm^{-3} have been found by Y. V. Ivanov (Moscow Institute of Steel and Alloys) from a special mass spectrometric method coupled with optical vapor density measurements. Two successive solid phase transformations, near 1250K and 1180K, separating three different phases, were also found using these measurements together with In diffusion experiments. These phase transformations significantly complicate the production of crystals with perfect structure, and should be taken into account by the crystal growers.

Doping

The important questions of doping and compensation have been reexamined in several communications. The respective role, in doping and compensation, of native defects, residual impurities and lattice relaxation around impurities has been stressed. Phase diagrams and band structures have been shown to be key parameters in compensation (Y. Marfaing, CNRS, Meudon, France). The actual role of native defects in compensation has been elegantly demonstrated by transmutation doping (Wienecke et al., Humboldt University). Isolectronic radioactive isotopes (Cd, Se) have been implanted in CdTe, ZnTe and ZnSe where they occupied normal sites, and then transmuted via a radioactive decay into relevant dopants (Ag, In, As). The doping efficiencies reported have been shown to be close to 100% under such conditions. MBE deposited CdTe and ZnSe have been shown to by efficiently doped with Group V elements like As using a novel plasma cracker (Lugauer et al., Wurzburg University). Doping has also been achieved in CMT by extremely fast electromigration of silver atoms at room temperature (I. Lyubomirsky et al., Weizman Institute of Science). A p/n junction created in such a way can spontaneously recover its characteristics lost after thermal or electrical disturbance.

To summarize, this Symposium clearly demonstrated the vibrant and increasing interest and high quality research now associated with these compounds, especially on the crucially important materials issues. Many exciting results were reported and discussed, covering topical scientific areas. II-VI compounds, a family of semiconductor materials so rich in possibilities, appear now to be more and more mature and closer to actual industrial developments. In this frame, such a conference dealing specifically with materials science aspects, which are the key for any industrial application, has proved to be not only extremely fruitful but quite essential for the community.

Compound Semiconductors at Upcoming Spring MRS Meeting

A number of compound semiconductor-related symposium are scheduled for the Spring Meeting of the Materials Research Society, to be held April 8-12, 1996 at San Francisco, CA.

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Symposium B:
Defects and Interfaces in Lattice-Mismatched Semiconductor Heterostructures

•

Symposium C:
Compound Semiconductor Electronics and Photonics

•

Symposium D:
Rare-Earth Doped Semiconductors

•

Symposium E:
III-Nitride, SiC, and Diamond Materials for Electronic Devices

•

Symposium F:
GeSi and Related Compounds

•

Symposium G:
Semiconductors on Insulators - Fundamentals and Technology

•

Symposium J:
Thin Films for Photovoltaic and Related Device Applications

•

The Abstract Deadline is November 1, 1995.

For more information, contact:

Materials Research Society
9800 McKnight Road
Pittsburgh, PA 15237-6006 USA
TEL [1] 412 367 3004
FAX [1] 412 367 4373
E mail: INFO@MRS.ORG

As always, a major exhibit will be held in conjunction with the meeting. Companies interested in exhibiting should contact Ms. Mary E. Kaufold at the above address.

Microwaves and RF 1995

Microwaves and RF '95 will be held Oct. 10-12, 1995 in London, England. This is an international conference of invited presentations addressing topical issues of concern to both commercial and military microwave and RF sectors. One of the special topics for this years meeting is a session on "SiGe vs. GaAs".
Proceedings: Nexus Media, Ltd.
Abstract Submission Deadline: NA
Contacts: Gillian Shinar, Conference Coordinator
Nexus Information Technology
Nexus House, Swanley, Kent BR8 8HY, UK
TEL [44] 1322 660 070 FAX [44] 1322 661 257
Vendor Exhibit? Yes - contact Beverly Lucas
Nexus Information Technology
Nexus House, Swanley
Kent BR8 8HY, UK
TEL [44] 1322 660 070 FAX [44] 1322 661 257

3rd Int'l Symposium on Atomically Controlled Surfaces & Interfaces

ACSI-3 will be held Oct. 12-14, 1995 at Raleigh, NC, USA. This conference's goal is to further, on the atomic scale, our understanding and control of the formation of surfaces, interfaces, nanostructures, etc. through a combination of theory and experiment.
Proceedings: Applied Surface Science
Abstract Submission Deadline: Passed
Contact: Prof. D.E. Aspnes
NC State University, Dept. of Physics
Raleigh, NC 27695-8202 USA
TEL [1] 919 515 4261 FAX [1] 919 515 1333
E mail aspnes@unity@ncsu.edu
Vendor Exhibit? No

42nd American Vacuum Society National Symposium

This year's AVS meeting will be held October 16-20, 1995 at Minneapolis, MN, USA. It will feature 100 technical sessions and 10 poster sessions, presenting over 1000 papers. Areas of interest include electronic materials and processing; vacuum technology and metallurgy; thin films; surface science; plasma science and technology; nanometer-scale science and technology; manufacturing science and technology; biomaterials interfaces; and applied surface science.
Proceedings: J. Vac. Sci. Technol.
Abstract Submission Deadline: Passed
Contact: AVS National Symposium
American Vacuum Society
120 Wall Street
New York, NY 10005-3993 USA
TEL [1] 212 248 0200 FAX [1] 212 248 0245
E mail avsnyc@vacuum.org
Vendor Exhibit? Yes - contact the AVS.

1995 IEEE GaAs IC Symposium

The 1995 GaAs IC Symposium will be held Oct. 29-Nov. 1 in San Diego, CA, USA. For the past 17 years this conference has been the preeminent international forum on the most recent advancements in integrated circuits using GaAs, InP and other compound semiconductor devices. Subject matter includes all aspects of the technology, including materials, device fabrication, IC design and testing, volume manufacturing, and systems implementation.
Proceedings: IEEE Publishing
Abstract Submission Deadline: passed
Contact: Ellisa Sobolewski
Advanced Research Projects Agency
3701 N. Fairfax Ave.
Arlington, VA 22203-1714 USA
TEL [1] 703 696 2254 FAX [1] 703 696 2203
E mail lsobolewski@arpa.mil
Vendor Exhibit?: Yes - contact Harry Kuemmerle III
VIP Meetings & Conventions
1515 Palisades Drive, Suite 1
Pacific Palisades, CA 90271 USA
TEL [1] 310 459 4691 FAX [1] 310 459 0605

8h IEEE Lasers and Electro-Optics Society Annual Meeting

LEOS 8 will be held Oct. 30 -Nov. 2, 1995 in San Francisco, CA. This is the annual meeting of the LEOS society, covering a broad spectrum of topics of interest to the laser and electro-optic communities.
Proceedings: IEEE Publishing
Abstract Submission Deadline: Passed
Contact: Samantha Phillips, Conf. Manager
IEEE/LEOS
445 Hoes Lane, PO Box 1331,
Piscataway, NJ 08855-1331 USA
TEL [1] 908 562 3894 FAX [1] 908 562 8434
E mail s.phillips@ieee.org
Vendor Exhibit? Yes - contact Samantha Phillips

3rd IEEE International Workshop on High Performance Electron Devices for Microwave and Optoelectronic Applications

EDMO '95 will be held November 27, 1995 at King's College, London, UK. Two related events will also be held in London that same week - see below. The purpose of this workshop is to bring together scientists and engineers in the area of compound semiconductor devices applied to microwaves and optoelectronics, to discuss systems requirements and advances in semiconductor materials, device processing and circuit design. Topics include: HBTs for microwave and optoelectronic applications; microwave and mm-wave devices; new optoelectronic devices and OEICs; power & high temperature application of III-V devices; and CAD and modeling advances.
Proceedings: Available for attendees.
Abstract Submission Deadline: Passed
Contact: Ali A. Rezazadeh
King's College London, EEE Dept.
Strand, London WC2R 2LS UK
TEL [44] 171 873 2879 FAX [44] 171 836 4781
Net or Web: A.Rezazadeh@bay.cc.kcl.ac.uk or http://www.eee.kcl.ac.uk
Vendor Exhibit? Yes - contact Dr. Rezazadeh

IEE Tutorial Colloquium on MMIC's

MMIC's '95 will be held on Tuesday, November 28, 1995 at London, UK. This event is timed to coincide with the events described above and below. This year's theme is "how to design and layout circuits for manufacture in GaAs foundries". The presenters include representatives from three European GaAs foundries, and the program will cover sessions on design processes, communication with the foundry, and future GaAs foundry services.
Proceedings: Available from IEE
Abstract Submission Deadline: Passed
Contact: Allison Dewhurst
IEE Electronics Division
Savoy Place, London WC2R 0BL UK
TEL [44] 171 344 5423 FAX [44] 171 497 3633
Net or Web: adewhurst@iee.org. uk or http://www.iee.org.uk
Vendor Exhibit? No

IEE Workshop on Microwave and Millimeter Wave Communications - "The Wireless Revolution"

This workshop will be held on Wednesday, November 29, 1995 at London, UK. It is timed to coincide with the two events described above. This workshop provides those involved with microwaves, RF engineering and radiocommunications an update on the exciting developments surrounding mobile radio, wireless LANs, satellite systems and vehicular systems.
Proceedings: Available from IEE
Abstract Submission Deadline: Passed
Contact: Allison Dewhurst
IEE Electronics Division
Savoy Place, London WC2R 0BL UK
TEL [44] 171 344 5423 FAX [44] 171 497 3633
Net or Web: adewhurst@iee.org. uk or http://www.iee.org.uk
Vendor Exhibit? No

1995 Fall Meeting of the Materials Research Society

The 1995 MRS Fall Meeting will be held November 27-December 1, 1995 in Boston, MA, USA. This conference includes 30 different symposia on topics ranging from beam-solid interactions and fullerenes to laser processing, GaN, and low-cost manufacturing of materials.
Proceedings: MRS Proceedings Series
Abstract Submission Deadline: Passed
Contact: M. Geil, Dir., Meeting Activities
Materials Research Society
9800 McKnight Road, Pittsburgh, PA 15237 USA
TEL [1] 412 367 3004 FAX [1] 412 367 4373
E mail info@mrs.org
Vendor Exhibit? Yes - contact Mary Kaufold, Exhibit Mgr.
Materials Research Society
9800 McKnight Road, Pittsburgh, PA 15237 USA
TEL [1] 412 367 3036 FAX [1] 412 367 4373
E mail kaufold@mrs.org

1995 Defect Recognition and Image Processing in Semiconductors

DRIP VI will be held Dec. 3-6, 1995 at Estes Park, CO. This is an international conference devoted to furthering understanding of defect inhomogeneitites in semiconductor materials and devices. Topics include, but are not limited to, 1) optical, electrical, and acoustical substrate defect imaging techniques as applied to semiconductor substrates, epilayers, nanostructures and devices for electronic, optoelectronic and optical applications; 2) techniques for processing the quantities of data coming from automated defect testing methods; and 3) correlation of device performance with defect density and distribution.
Abstract Submission Deadline: Sept. 1, 1995
Contact: Prof. Alan R. Mickelson
University of Colorado, ECE Dept.
Campus Box 425, Boulder, CO 80309-0425 USA
TEL [1] 303 492 7359 FAX [1] 303 492 2758
E mail mickel@boulder.colorado.edu

1996 IEEE Int'l Solid State Circuits Conference

ISSCC '96 will be held February 8-10, 1996 at San Francisco, CA. The theme for this year's conference is "Systems on a Chip". Papers targeting monolithic system integration in the following areas will be presented: analog; communications; digital; sensors, imagers, & neural networks; memory; signal processing; and technology directions.
Proceedings: Available from IEE
Abstract Submission Deadline: Passed
Contact: Diane Suiters
Courtesy Associates
655 Fifteenth St., NW, Suite 300
Washington, DC 20005 USA
TEL [1] 202 639 4255 FAX [1] 202 347 6109
Net or Web: diane+la+rcourtesy_associates@mcimail.com
Vendor Exhibit? No

Int'l Symp. on Blue Laser and Light Emitting Diodes

ISBLLED will be held March 5-7, 1996 at Chiba, Japan. The objective of this symposium is to provide a forum for bringing together specialists from both the ZnSe and GaN community at one place for stimulating discussions so that the direction for solving common problems can be derived. The symposium will consist of invited talks and oral/poster presentations of contributed papers. Original quality papers as well as papers whose subjects have been reported elsewhere but are suitable for this symposium will be considered for inclusion. Papers from the following areas are encouraged: substrates; epitaxy and doping; characterization; processing, including contacts; devices; device degradation mechanisms; and new materials.
Abstract Submission Deadline: Dec. 1, 1995
Contact: Prof. M. Kobayashi
Secretary, ISBLLED
Chiba Univ., E&EE Dept.
1-33 Yayoi-cho, Inage-ku, Chiba, Japan 263
TEL [81] 43 290 3330
FAX [81] 43 290 3360
E mail isblled@semi.te.chiba-u.ac.jp

3rd Int'l Conf. on the Physics of X-Ray Multilayer Structures

The 3rd International Conference on the Physics of X-Ray Multilayer Structures will be held March 3-7, 1996 at Breckenridge, CO, USA. This conference focuses on the interaction of x-ray and extreme ultraviolet radiation with multilayer structures, as well as multilayer growth, structures, and properties
Abstract Submission Deadline: Nov. 10, 1995
Contact: Ms. Marty Benson, Admin. Asst.
Univ. of Arizona, Dept. of Physcis
PAS #81, Tucson, AZ USA 85721
TEL [1] 520 621 2878 FAX [1] 520 621 4356
E mail pxrms-info@nanook.div111.att.com
Vendor Exhibit?: Yes, contact Ms. Marty Benson

1996 Spring Meeting of the Materials Research Society

The 1996 Spring MRS Meeting will be held April 7-11, 1996 in San Francisco, CA, USA. This conference includes 30 different symposia on semiconductor materials and processing, polymers, amorphous silicon, microwave processing, ceramics, and other topics.
Proceedings: MRS Proceedings Series
Abstract Submission Deadline: TBA
Contact: M. Geil, Dir., Meering Activities
Materials Research Society
9800 McKnight Road
Pittsburgh, PA 15237 USA
TEL [1] 412 367 3004 FAX [1] 412 367 4373
E mail info@mrs.org
Vendor Exhibit? Yes - contact Mary Kaufold, Exhibit Mgr.
Materials Research Society
9800 McKnight Road
Pittsburgh, PA 15237 USA
TEL [1] 412 367 3036 FAX [1] 412 367 4373
E mail kaufold@mrs.org

8th Int'l Conf. on Indium Phosphide and Related Materials

IPRM '96 will be held April 22-25, 1996 at Schwabisch-Gmund, Germany. Papers are requested in the following areas: optolectronics, electron devices, processing, epitaxy, bulk crystal growth, characterization and control.
Abstract Submission Deadline: Nov. 10, 1995
Contact: Volker Schanz
ITG/VDE
Stresemannaliee 15
60590 Frankfurt Main, Germany
TEL [49] 69 6308 360
FAX [49] 69 9631 5217
Vendor Exhibit? Yes - contact ITG/VDE

3rd Int'l Workshop on Expert Evaluation and Control of Compound Semiconductor Materials and Technologies

EXMATEC '96 will be held May 12-15, 1996 at Freiburg, Germany. The goal of this conference is to bring together research and development specialists involved in compound semiconductor material physics, process technology and device fabrication to address issues such as improvement of yield, reliability, performance, reproducibility and lifetime of micro- and optoelectronic devices and circuits through optimization and control of materials and process.
Abstract Submission Deadline: December 1, 1995
Contact: Dr. W. Jantz
Fraunhofer IAF
Tullastr. 72
D-79108 Freiburg I. Br.,
Germany
TEL [49] 761 5159 510
FAX [49] 761 5159 423
Vendor Exhibit? Yes - contact Dr. Jantz

8th Int'l Conf. on MOVPE

ICMOVPE 8 will be held on June 9-13, 1996 in Cardiff, Wales. This conference seeks to bring together specialists in growth, characterization and device applications of MOVPE and to present a forum for discussion of recent progress and the latest achievements in the field of both fundamental and applied research. Topic area include: precursors; process design/communication issues; developing applications of MO compounds; growth technologies; advances in devices by MOVPE; and characterization.
Proceedings: Journal of Crystal Growth
Deadlines: Abstracts - December 1, 1995
Late news - On-site, June 9
Contact: Glenda Bland
Global Meeting Planning, GMP 22 Plas Taliesin
Portway Village Marina, Penarth,
South Glamorgan CF64 1TN, Wales
TEL [44] 1222 700 053 FAX [44] 1222 700 685
E mail 100416.1402@compuserve.com
Vendor Exhibit? Yes - contact Prof. Colin Whitehouse
Univ. of Sheffield, EE Dept.
Mappin Street, Sheffield, S1 4DU UK
TEL [44] 1142 825 254 FAX [44] 1142 726 391

1996 Electronic Materials Conference

EMC '96 will be held June 26-28, 1996 at Santa Barbara, CA.
Abstract Submission Deadline: TBD
Contact: TMS, Meetings Dept.
420 Commonwealth Dr.
Warrendale, PA 15086 USA
TEL [1] 412 776 9000
FAX [1] 412 776 3770
Vendor Exhibit? Yes - contact TMS

Ninth Int'l Conf. on Superlattices, Microstructures, and Microdevices

ICSMM-9 will be held July 14-19, 1996 at Liege, Belgium. The scope of this conference includes novel phenomena in semiconductor superlattices and quantum wells based on IV-IV, III-V, & II-VI compounds, as well as microstructures and superlattices based on other materials such as porous silicon, nitrides, metal/magnetic/semimagnetic materials, and semiconductor/metal microstructures. Also of interest are: nanostructures and low dimensional systems with strong emphasis on novel phenomena in quantum wires and quantum dots including dot-dot interaction; novel fabrication and probing techniques of quantum structures, including self-organized systems, ordered granular systems, and chemistry of nanoscale systems; STM, ATM, and novel technologies; photonic band gap materials and microcavities; and novel nanoscale devices including Si, SiGe, and SiC devices.
Proceedings: Will be published
Abstract Submission Deadline: March 15, 1996
Contact: Prof. Jean-Pierre Leburton
Univ. of Illinois
Beckman Institute, Urbana, IL 61801 USA
TEL 217 333 6813 FAX 217 244 4333
Net or Web: leburton@ceg.uius.edu
Vendor Exhibit? Undecided

23rd Int'l Conf. on the Physics of Semiconductors

ICPS-23 will be held July 21-26, 1996 at Berlin, Germany. All aspects of semiconductor physics including organic and inorganic materials and devices will be covered and highlighted by plenary and invited talks as well as contributed papers.
Abstract Submission Deadline: Feb. 19, 1996
Contact: Dr. Axel Hoffmann, Secretary
Institut fur Festkorperphysik
PN 5-1, TU Berlin
Hardenbergstr. 36
10623 Berlin, Germany
Vendor Exhibit? Yes

Ninth International Conf. on Molecular Beam Epitaxy

MBE-IX will be held August 5-9, 1996 at Malibu, CA. This conference will cover the full spectrum of MBE-related topics. Subjects covered will include MBE growth of semiconductors, metals, insulators, and superconductors, as well as novel growth techniques , in situ control and characterization, and device applications of MBE technology.
Proceedings: Will be published in J. Vac. Sci. Techn. B
Abstract Submission Deadline: March 15, 1996
Contact: Dwight Streit
TRW
R6-2373, One Space Park, Redondo Beach,
CA 90278 USA
TEL [1] 310 814 1722 FAX [1] 310 812 4378
Net or Web: dwight.streit@trw.com
Vendor Exhibit? Yes. Contact David Grider
2060 Avenue Los Arboles, Suite 342,
Thousand Oaks, CA 91362 USA
TEL [1] 310 317 5007 FAX [1] 310 492 6262
Net or Web: rgrider@aol.com

1996 GaAs MANTECH Goes International

Here is another sign that the Cold War is really over: The next GaAs MANTECH Conference will be open to attendees from all countries. The conference, which focuses on improving the manufacturability of GaAs, was launched in the mid 1980's, at time when GaAs was considered to be a "strategically important" material. Therefore attendance was restricted to US citizens and resident aliens. But the MANTECH Executive Committee recently reached a unanimous decision to open the conference to the world-wide community.

The next MANTECH meeting will be held April 28 to May 2, 1996 at San Diego, CA. For more information see page 47.

Would you like your conference to be included in future issues of *Compound Semiconductor*? Send the following information by E mail to calendar@compsem.com, or by FAX to [1] 612 227 5499, attention **"Calendar"**

* Full name of conference, plus acronym or abbreviation
* Dates and location
* Brief description of content, focus, or goals
* Whether the proceedings will be published, and, if so, in what journal
* Abstract submission and late news deadlines
* Primary contact name, address, phone, FAX and E mail
* Whether there will be a vendor exhibit, and, if so, contact name, address, phone, FAX and E mail

Contributions must be received by October 6 to appear in our next issue.

An Integrated Circuitous Argument

The Gallium Arsenide industry has come full circle

PAUL JAY
DIRECTOR OF TECHNOLOGY AND ENGINEERING
NORTHERN TELECOM MICROWAVE MODULES GROUP
OTTAWA, ONTARIO, CANADA

It seems as if the Gallium Arsenide community has been, from some years, the object of focused aggression and resentment from their colleagues in the silicon industry. However, family psychologists will tell us that such types of "sibling rivalry" are not uncommon, and that ultimately the older offspring will come to accept and even value the younger upstart that has created such a distraction within the semiconductor family.

This change of attitude is now beginning to happen as GaAs technology is establishing itself as an authority in certain applications areas, and as the silicon protagonists realize that the new technology challenges only certain niche areas, as opposed to undermining the whole basis of the silicon economy. Indeed, it is becoming apparent that certain aspects of technology developed to cope with the particular issues facing GaAs are also useful in Si processing.

However there are many lessons to be learned from the difficult upbringing of this new technology, and in particular, those with long memories (brain cells, that is) may question where all the original promised performance of GaAs has gone, when comparing the claims of a few years ago to the devices in commercial manufacture now. Uniformity and a sound statistical base of process data are major assets of the silicon world, and only now as GaAs chips are enjoying the millions per year demands driven by wireless applications can the III-V technologists begin to have a similar authority. A clear lesson evident from this hindsight is that the designers had to expend some valuable performance advantage to guarantee that the circuits would work across the range of process and materials variations.

The true advantages of scale will now start to emerge as GaAs fabs are scaling up to 4 inch and 6 inch lines, and handling thousands of wafers per week rather than handfuls of substrates. Since the GaAs industry has remained rather insular by comparison with silicon, (perhaps because there isn't a "Silicon Valley" within which process engineers migrate back and forth between different fabs) there has been very little homogenization of processes, and even after a couple of decades the GaAs community is still represented by pockets of ethnic diversity. This lack of standardization slows down the convergence of substrate requirements, of processing equipment, of metallisation schemes and gate structures, and altogether fragments the body of collected data into groups that cannot be so easily compared. As a whole this holds back the maturing of the process control, and so limits the improvements in yield, uniformity and thereby reduction in cost, where silicon always wins.

Still, as we like to say, "this is not a problem but an opportunity"! Digital GaAs in particular has had a long struggle, trying to develop larger areas of high uniformity devices, usually in very direct competition with an entrenched silicon insertion (which had frequently already set the boundary conditions), and will surely benefit from the improved material and process uniformity that the industry is now developing as it deals with these new high volumes of small microwave circuits. Many suppliers into the expanding wireless market (recent projects suggest a $2.5 billion worldwide market for GaAs by the year 2000) are currently expanding their capacity, upgrading from 3" to 4", and even looking at "liaison agreements" with other GaAs producers. This last element has a powerful potential develop some commonality of process approach among clusters of GaAs producers. This will be a reassuring aspect for the customers, who are still somewhat wary of the new technology with all its complicated process steps and poisonous undertones.

> ***Come on GaAs; tighten up those yields, standardize those substrates, shrink those die, improve that testability, and remember how that allowed Si to squeeze out a few more dB of performance.***

Following closely behind, and leaning substantially from the experience of the GaAs MESFET introduction, are new technologies such as HBTs offering high speed, improved power performance and linearity, as well as some of the low noise technologies such as pseudo-morphic HEMT, etc. Now the GaAs developers may experience some of the concerns of market erosion that Si manufacturers felt several years ago!

Returning to the family metaphor, the next phase of growing up for GaAs is to understand how to deal with the promise of SiGe technology snapping at its heels. Should GaAs gracefully cede some applications opportunities to a lower cost medium or is SiGe not yet up to the performance? This sort of pressure helps to focus the attention of GaAs manufacturers on how to reduce their costs and maintain the performance advantage, somewhat reminiscent of the challenge to Si a few years ago of how to improve their performance and yet maintain the cost advantage! Si rose to that challenge, so come on GaAs; tighten up those yields, standardize those substrates, shrink those die, improve that testability, and remember how that allowed Si to squeeze out a few more dB of performance.

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