



COMPOUND SEMICONDUCTOR

May/June 1997

Volume 3 Number 3

HBTs

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- Nitrides
- CDMA Update
- 980nm Laser News
- New MESFET products and process
- GaAs Forecast

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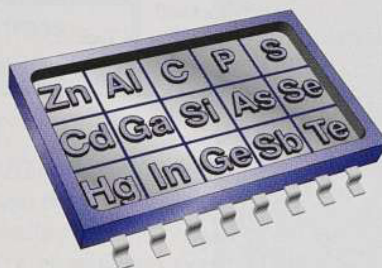
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False color SEM of a InGaP/GaAs HBT. The small blue "finger" (center, right) is the emitter (measuring $3 \times 10 \mu\text{m}^2$). The two adjacent fingers (pink) are the base contacts, and the two larger, outer fingers (green) are the collector contacts. A $2.5 \mu\text{m}$ Au evaporated airbridge emitter RF pad can be seen arching over the collector fingers. Image courtesy of the Semiconductor Research Group at the University of Illinois.

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and Laboratories appearing in this issue.

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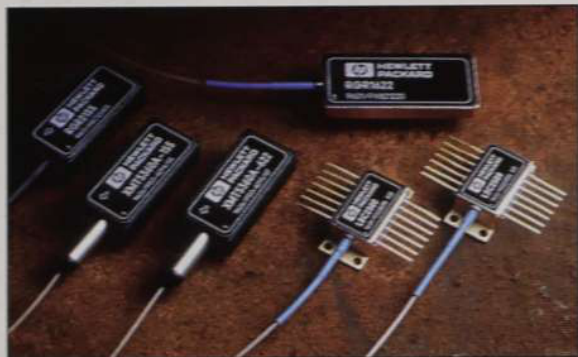
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Hewlett Packard

2.4 Gb/s Laser from Hewlett-Packard

Santa Clara, CA. Hewlett-Packard has introduced a directly modulated distributed feedback (DFB) 1500nm cooled laser for operation under ATM standards at speeds of 2.488 Gb/s, and capable of distances greater than 200km over single mode fiber. The range of applications includes telecommunications, fiber optic sensors, cable television and instrumentation. The laser features a -20°C to +65°C operating temperature range and is supplied in the industry-standard hermetic, 14-pin "butterfly package". The LSC2500 laser is based on InGaAs ridge waveguide multiquantum well structures fabricated using MOVPE, resulting in long lifetimes and modest threshold currents. The LSC2500 package includes a photodiode for monitoring the laser output, a thermistor for monitoring laser heatsink temperature and Peltier-effect thermoelectric cooler. It is priced at \$1,000 in 1,000 piece quantities, with samples available now.

Lucent GaAs IC for Fiber Networks

Allentown, PA. Lucent Technologies' Microelectronics Group has introduced a new GaAs IC for use in optical receivers, compatible with SONET/SDH transmission systems at 2.5 Gb/s. The LG1628A transimpedance amplifier is the latest member of Lucent's fiber-optic regeneration products, which include laser drivers and modulator drivers, clock and data regenerators and limiting amplifiers.

These devices can be used in a wide variety of applications that use data transmission over fiber such as local area networks and wide area networks. "With the addition of this amplifier, Lucent now offers a complete solution for fiber-optic regeneration applications," said Jim

Lucas, application engineer for Lucent Microelectronics.

The LG1628A is designed for low-noise, high-speed lightwave receiver applications when combined with an APD or PIN photodetector. It has a wide dynamic operating range with average photodiode currents from 4 micro amps to 3 milli amps when the on-chip overload circuitry is combined with an external dual operation amplifier. Amplifier operation is from a single -5.2V power supply with complementary 50 ohm outputs. It is available as a hybrid IC or as a single die. Pricing is \$75 each in quantities of 10,000. Samples and product are currently available.

Four Power FETs from Hewlett-Packard

Santa Clara, CA. Hewlett-Packard recently released four new internally matched power GaAs FETs for use in solid-state amplifiers, C-band satellite earth stations, and microwave point-to-point and point-to-multipoint communications transmitters. The new product family complements HP's series of 5.9 GHz to 6.5 GHz and 6.4GHz to 7.2GHz internally matched transistors introduced last year. (See CS 2(5) p. 8).

Class-A linear operation makes these FETs suitable for digital signals. They offer high power output - up to 32W - and power-added efficiency up to 42%, combined with ± 0.3 dB gain flatness and high linearity (-45dBc third-order intermodulation distortion at specified single-carrier level). All performance specifications are ensured at +25°C.

The performance of these transistors is expected to help communications-systems designers reduce the level of intermodulation distortion and harmonic spurious signals, resulting in higher-linearity power amplification. Internal 50-ohm input- and output-matching networks eliminate the need for RF-matching. The new FETs are offered in four frequency ranges: 3.6 - 4.2 GHz, 5.0 - 5.3 GHz, 5.2 - 5.9 GHz; and 6.4 GHz - 7.2 GHz. Pricing per unit ranges from \$194.00 for the 3.6 - 4.2 GHz model up to \$1,050.00 for the 6.4 GHz - 7.2 GHz model. All are currently available from stock.



Hewlett Packard

1 Watt Power Amp from Pacific Monolithics

Sunnyvale, CA. Pacific Monolithics recently introduced a new 2.4 GHz 1 Watt power amplifier. The PM2107, which uses an ultra-small 10-pin SOP plastic package, compliments the company's exiting line of RFIC power amplifiers covering the 800 MHz to 2.5 GHz frequency range. The PM2107 is a two stage amplifier that is off-chip matched to provide optimum performance for a variety of applications. Operating from a 5 V supply, it can produce 1 W of saturated output power with 45% typical efficiency. The new chip is available from stock.

New Products from NEC & CEL

Santa Clara, CA. California Eastern Labs has announced the availability of several new GaAs products from NEC. The list includes Ku- and X-Band power MESFETs for satellite applications, as well as a 1.9 GHz power MESFET in a low cost plastic package. Also available are four new heterojunction GaAs FET amplifiers for DBS applications in C- to Ku-band. These devices, packaged in plastic, are available in large quantities for as little as \$1.20.



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More Motorola GaAs



Motorola

Phoenix, AZ. Motorola continues to roll out GaAs chips. The most recent offering is a chipset of RFICs for wireless data in the 2.4 - 2.5 GHz Industrial-Scientific-Medical (ISM) band. These devices may be used in frequency hopping or direct spread-spectrum wireless data systems such as wireless local-area networks, wireless data links, RF identification or tagging systems, and cordless telephones.

The chipset includes four components. The MRFIC2405 GaAs transceiver integrates a two-stage power amplifier, an LNA, a downmixer, an antenna diversity switch and a transmit/receive switch housed in a 428-02 package. The MRFIC2406 device is an active GaAs upmixer with simple off-chip matching for maximum flexibility in a SO-16 package. The MRFIC2407 is a low-cost, two-stage Class A device designed to drive the MRFIC2405 transceiver, but can be used in a variety of amplifier applications from 2.0 - 3.0 GHz. It is also housed in an industry standard SO-16 package. The MRFIC2410 two-stage power amplifier is housed in a TSSOP-20 package and employs

Motorola's self-aligned planar MESFET technology for the best cost/efficiency tradeoff.

In quantities of 10,000, pricing for the MRFIC2405 transceiver is \$7.40 each, the MRFIC2406 upmixer is \$3.35 each, the MRFIC2407 amplifier is \$2.10 each, and the MRFIC2410 two-stage power amplifier is \$6.60 each. Samples and small quantities are available from stock; production quantities have an 8 week lead time.

Also new from Motorola is a 1.9 GHz GaAs MESFET power amplifier for European 1 Watt DCS1800 handheld radios. The MRFIC1818R2 is packaged in the PFP-16 power flat package which gives excellent thermal and electrical performance through a solderable backside contact while allowing the convenience and cost benefits of reflow soldering. The new chip is specified for 33 dBm output power with power gain over 30 dB from a 4.8 V supply and has 36 dBm output power with a 6 V supply. Pricing for the MRFIC1818R2 amplifier is \$18.95 in quantities of 1,500 units. Samples are now available.

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Anadigics Launches Volume Production of Dual Band Power Amplifiers

A single chip solution for flexible phones that can accommodate two different wireless standards

One of the significant trends in today's mobile communications market is the migration from cellular phones operating at 800-900 MHz to the more sophisticated 1.9 GHz digital personal communications services (PCS) handsets. PCS has many benefits over traditional cellular, including better service quality through use of digital technology, and enhanced service features such as seamless roaming, voice mail, caller identification, and paging. But there is still a massive installed base of cellular phone users (more than 125 million) - and their ranks continue to grow.

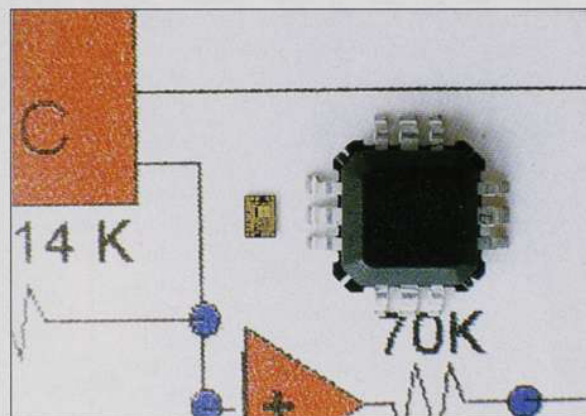
The easiest way to facilitate the introduction of PCS is to offer dual-band phones - handsets that will work with both cellular and PCS. Of course, such a handset would need a RF front end that accommodates both 800 MHz and 1.9 GHz transmission. In late March, Anadigics announced that was launching volume production of the first dual-band/dual-mode GaAs power amplifier for the cellular and PCS market. The new chip, the AWT919D, has been designed into Ericsson's PD398 cellular phone serving the dual-band DAMPS (also known as North American Digital Cellular or NADC) market.

"This is another example of Anadigics commitment to meeting the evolving needs of the cellular and PCS marketplace, with highly efficient GaAs IC power amplifier solutions," said Ron Rosenzweig, Anadigics President and Chief Executive Officer. "This power amplifier enables designers of telephone handsets to offer subscribers the ability to switch seamlessly between 800 MHz AMPS/DAMPS (cellular) and 1900 MHz (PCS) operation using one low-cost surface

mount integrated circuit. We are the first company to manufacture GaAs IC dual-band power amplifiers integrated into one package, giving our customers the best combination of reduced size and high efficiency."

Mr. Rosenzweig added, "According to Ericsson, worldwide cellular/PCS subscribers will grow from 137 million in 1996 to 590 million in 2001. Because of the combination of multiple standards and cellular and PCS frequencies, we believe many of the subscribers will be using dual-band/dual-mode phones by the end of the decade. The AWT919D is the first in a full line of dual-band products to be offered by Anadigics to cover all combinations of wireless standards and frequencies."

As we reported in a previous issue (see CS 3(1), p. 22), Anadigics believes that this application is a natural fit for GaAs's capabilities. Not only can it offer higher performance than Si at both 800 MHz and 1900 GHz, but also its semi-insulating substrate allows the integration of additional components without the need to isolate each item. According to Charles Huang, Vice President of Anadigics, "The more analog functions that the customer wants integrated onto the same chip, the more advantages that GaAs has."

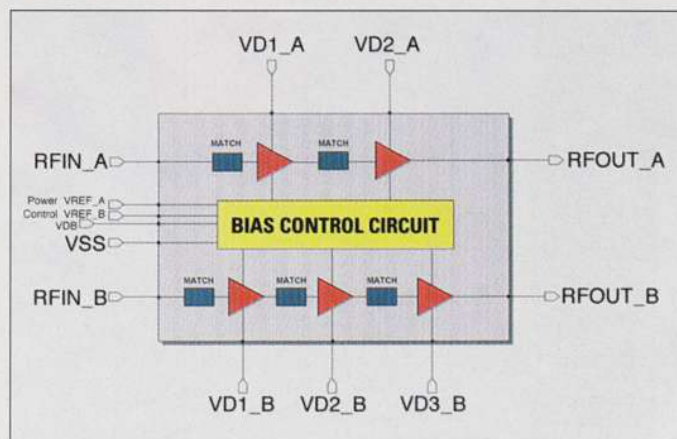


The Anadigics AWT919D power amplifier for dual-band wireless handsets that accommodate both cellular and PCS transmissions.

Dual Band Design

The AWT919D is a 5.8V dual input/output dual band power amplifier composed of two amplifier chains. One chain operates in the 824-849 MHz band and the other in the 1850-1910 MHz band.

The 800 MHz section is a two stage device that operates in two externally selectable modes. This allows it to meet the power and efficiency requirements of the U.S. AMPS analog standard as well as the power and linearity requirements of the U.S. DAMPS digital modulation standard. In the analog mode, class B operation, the AWT919D is capable of delivering an average output power of 28.5 dBm with typical gain of 24 dB and a typical power added efficiency of 45%. In the digital mode, class AB, it will deliver 31.5 dBm peak envelope power



Block diagram of the Anadigics AWT919D a dual input/output dual band power amplifier composed of two amplifier chains. One chain operates in the 824-849 MHz band and the other in the 1850-1910 MHz band.

with typical gain of 25 dB, a typical power added efficiency of 40%, and 3rd order intermodulation products greater than 24 dBc.

The 1900 MHz section is a three stage power amplifier operating in a class AB mode to achieve the linearity and adjacent channel power requirements of cellular phone transmitters utilizing the PCS 1900 MHz D-AMPS digital modulation standard. This power amplifier will deliver 31 dBm of peak envelope power with 25 dB typical gain, a typical power added efficiency greater than 30% and 3rd order intermodulation products greater than 24 dBc. An added feature of this new generation of multi-mode/multi-band amplifiers is that the quiescent operating currents can be externally controlled and lowered to reduce power consumption during low transmit power requirements. This translates into increased talk time and battery life.

"We expect this new class of dual band, low cost integrated power amplifiers will afford cellular and PCS dual band phone designers significant benefits. It is a cost-effective solution for substantially reducing the space requirements previously thought needed for dual band/dual mode cellular/PCS transmitters," said Osvaldo Lopez, Anadigics Product Development Manager.

In addition to reduced space requirements, these GaAs MMIC's are intended to provide an economic alternative to discrete and hybrid amplifiers. "The AWT919D is a low cost, reliable GaAs solution. It is attractive because it offers a high level of integration in a small package," Maoz said.

The ATW919D is packaged in a 28 pin thermally enhanced SSOP package. It is manufactured using Anadigics' high volume GaAs MESFET technology, in the company's ISO 9001 certified facility in New Jersey, and is 100% tested at DC and RF before shipping to maximize reliability.

The AWT919D is priced at \$10 in quantities of 100,000.

To date, Anadigics has delivered over 60 million GaAs ICs and was the first GaAs IC manufacturer to receive ISO 9001 Certification.



The Ericsson PD398 dual-band phone for the DAMPS standard. This handset uses the Anadigics AWT919D power amplifier.

Anadigics Ships Over One Million GaAs ICs for CDMA Handsets

In April Anadigics announced that it had surpassed the one million milestone in shipments of GaAs ICs for use in PCS telephone handsets that support the 1900 MHz CDMA digital PCS standard.

CDMA (Code Division Multiple Access) is an access method applied in digital cellular systems. The CDMA signal must be transmitted in a linear fashion to maintain phase-shift keying modulation and to prevent spectral regrowth into adjacent channels. Also, adjacent channel power rejection requires linear power amplifier operation at lower power levels while maintaining high DC to RF conversion efficiency to maximize battery life.

To optimize linearity, a high performance driver amplifier is critical.

The Anadigics GaAs ICs are used in the transmitter of the CDMA telephone handset and consist of a highly efficient power amplifier and a driver amplifier to provide gain control. They are being incorporated into handsets manufactured by Qualcomm Personal Electronics, a joint venture of subsidiaries of Qualcomm Incorporated and Sony.

"Qualcomm selected the Anadigics driver and power amplifier for our QPC-1900 CDMA digital PCS phone to meet the demands for large-scale roll-outs across the country," said Don Schrock, Vice President and General Manager of the ASIC Products Group for Qualcomm. "Our partnership with Anadigics proved to be instrumental in supporting the successful launches of our PCS customers, including PrimeCo and Sprint. Anadigics met our accelerated ramp-up and supplied more than 1 million parts in only four months, demonstrating their high volume leadership in the CDMA marketplace."

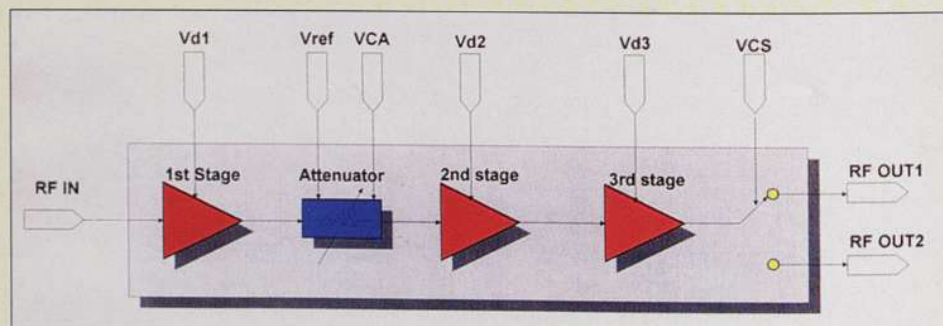
"Anadigics has been selected as a prime supplier in support of future generations of Qualcomm CDMA digital PCS single and dual band phones," Schrock said. The Qualcomm deal marked Anadigics' first foray into both the CDMA and the PCS market.

In a related announcement, Anadigics also recently announced the availability of a CDMA driver amplifier IC as a low cost, "off-the-shelf" part. The AWD1900 GaAs IC serves as a core active device building block for 1850 to 1910 MHz CDMA cellular phone transmitter functions. It is composed of a three-stage Class A GaAs MESFET cascaded amplifier, an output SPDT switch and an integrated one bit 15 dB attenuator. The AWT1900 features switchable dual outputs, a typical ACPR of 40 dBc at an output power of 10.5 dBm. The device also provides a stepped gain function of 32 dB/17 dB, and operates from a 5V supply while drawing less than 100 mA. The AWD1900 is available at \$5 in quantities of 100,000.



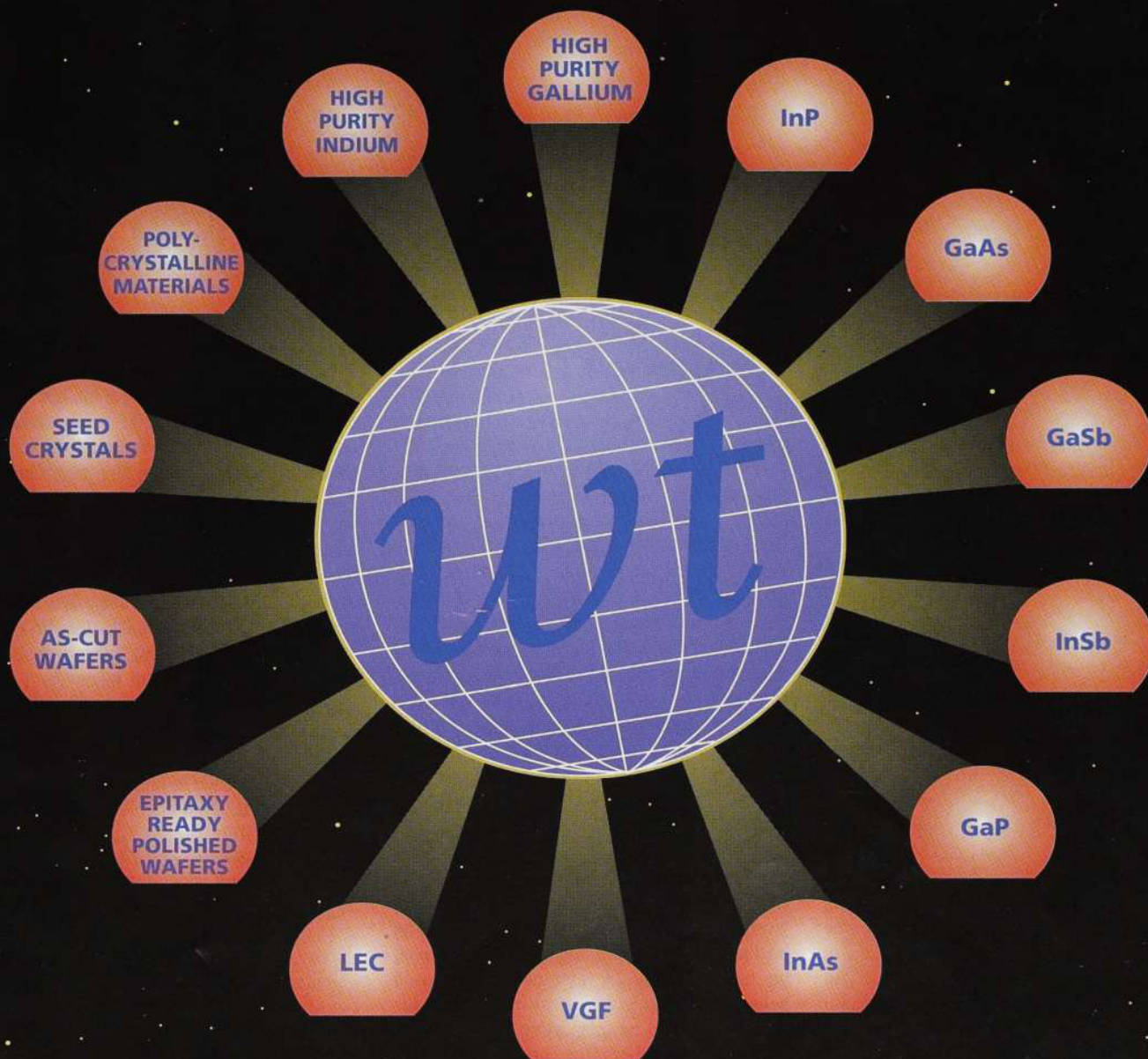
The Anadigics AWD1900 CDMA PCS driver IC.

For more on CDMA and GaAs power amplifiers, see page 38.



Block diagram of the Anadigics AWD1900, which consists of a three-stage Class A GaAs MESFET cascaded amplifier, an output SPDT switch and an integrated one bit 15 dB attenuator.

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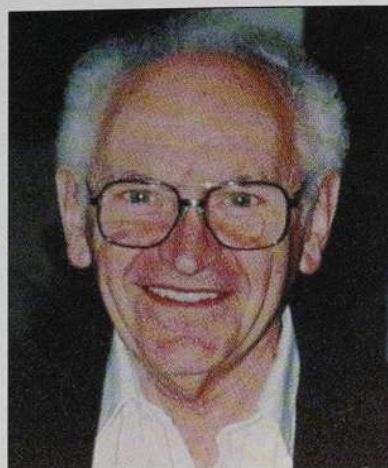


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Profile:

Jacques Pankove Inventor of the GaN LED

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This December at the Materials Research Society Meeting in Boston, the GaN community will gather to honor Prof. Jacques Pankove, widely considered the father of the GaN field, with a week long Symposium. Twenty-six years ago Prof. Pankove and colleagues at RCA Laboratories in New Jersey published a paper in the *Journal of Luminescence* entitled "Electroluminescence in GaN," which described the first GaN LED. Today Nichia Chemical derives \$200M of annual revenue from GaN LED products and Cree Research, Toyoda-Gosei, Toshiba, Sharp, Siemens, Hewlett Packard, Samsung and others are racing to catch up. A second race is underway to commercialize GaN laser diodes for optical storage, printing, display and other promising applications which may total an even larger market.

Prof. Pankove (originally Pantchechnikoff) was born in Russia in 1922, but when he was six months old his family moved to France where he was raised and attended the Lycee. In 1942 the Pantchechnikoff family moved again to California where they had relatives, and Pankove earned his Bachelor of Science degree in Electrical Engineering at Berkeley. Soon after, he was called into the army and assigned to the Pacific theater. Fortunately, the war ended before he saw combat, so his 13 months in Asia were spent working with communications equipment in Manila. The army wanted Pankove to learn Morse code, even sending him for a four-week intensive course. This unpleasant experience led to Pankove's first invention: a Morse code translator, which he further developed as his Master's project back at Berkeley. In 1948, Pankove was hired by the famous RCA Laboratories in Princeton, New Jersey.

Electron Devices & Lasers

The hot topic at the time was transistors, which had been invented only the year before at Bell Laboratories. While making Ge transistors, Pankove imagined and verified that devices with larger collectors than emitters would perform better and related this result to surface recombination. The RCA patent attorneys, in joking reference to Pankove's mesa structure transistor, called him "small dot, big dot Pankove". Further pursuing the Ge surface recombination problem, Pankove observed that SiO_2 was an effective passivant. That patent, which presciently claimed SiO_2 surface passivation for Si transistors also, earned RCA considerable royalties. In 1975 Pankove was awarded the IEEE J. J. Ebers Award "For Outstanding Technical Contributions to Electron Devices".

In 1956 Pankove earned a David Sarnoff scholarship to spend a year at the Ecole Normale Supérieure de Paris studying with the brilliant Prof. Aigrain. (Aigrain had received his tenure at only 28 years of age!) Aigrain believed a suitable 12 month project for his new man would be fabricating a diode laser. Pankove remembers the professor rapidly explained that a forward biased pn junction should create a population inversion and then derived the lasing threshold condition. After two weeks of hard work back in their office, Pankove and another student were finally able to reproduce and verify the calculation! Unfortunately the laboratory was not as well equipped as its leader's mind, but there was an excellent semiconductor spectroscopy system. Pankove busied himself with the luminescence and radiative recombination in germanium, studies he completed back at RCA to earn his Ph.D. in 1960.

At the time RCA was not interested in developing semiconductor lasers, but Pankove did manage to work on GaAs when he returned to New Jersey. In late 1961 Pankove succeeded in fabricating the first GaAs pn junction LED which emitted infrared light with high efficiency. When he presented his results at the APS meeting in January 1962, he remembers being surrounded afterwards by excited people from other labs. Later that year, when GE and IBM revealed the first diode lasers, RCA asked Pankove to try to make one. With a GaAs pn junction taken from a colleague at RCA, Pankove succeeded in reproducing their results in two weeks. Some years later, in collaboration with J. J. Tietjen, Pankove succeeded in fabricating a red GaAsP laser, one of the first visible diode lasers.

It was RCA policy that new hires with masters degrees were assigned to different groups for several months each. After several rotations, they would choose their career. In this way Paul Maruska came to work for Pankove and received an assignment to make some calculations on GaAsP. Around the time Maruska moved on, Pankove left to spend a year at Berkeley where he wrote his classic textbook "Optical Processes in Semiconductors". Upon his return to RCA he asked Maruska what he was doing and Maruska told him about GaN which had a wide bandgap of 3.4 eV. Maruska had been trying unsuccessfully to observe luminescence with Pankove's cathodoluminescence setup. They soon realized that no short wavelength visible light could penetrate the tin oxide window they were using. When the window was replaced with wire mesh, the UV cathodoluminescence emitted by the sample pegged the spectrometer meter!

Gallium Nitride

By doping GaN with various impurities, Pankove was able to produce luminescence of many colors, but attempts to make a GaN LED were frustrated by the inability to dope the material p-type. By 1969, "in desperation", Pankove tried an m-i-n structure comprising an In dot cold pressed onto insulating, doped GaN with undoped, n-type GaN beneath. Thus the GaN LED was born. This device was demonstrated to the Laboratory Head who stated, "Blue is very nice, but what we really need is a cheaper LED. If we have to use a sapphire substrate it will be expensive." As Nichia customers can attest, both observations were correct. His blue and green LEDs were so out of favor with RCA brass that they had to be hidden from the Vice President whenever he visited the lab, but Pankove continued his work through 1974 until his inability to solve the p-type doping problem persuaded him to move on.

By this stage of his career, Pankove had been made an RCA Fellow which allowed him the freedom, if not the funding, to pursue any problem he deemed interesting. Over the next ten years, Pankove focussed on three problems: superconductivity, electroluminescence in II-VI semiconductors and hydrogenated amorphous Si photovoltaics. Pankove discovered that doped ZnS luminesced brightly via a hot electron impact excitation mechanism, and that with tunnelling contacts, such devices could be operated efficiently at low voltage. These observations are the basis of commercial electroluminescent display technology. It is ironic that Pankove first realized and understood the role of hydrogen as a passivant of impurities and defects in amorphous Si and other semiconductors, because it was precisely hydrogen in GaN that had stymied his and others' attempts at p-doping! It would be years later that I. Akasaki and H. Amano at Nagoya University, building on work by G. V. Saparin of Moscow State University, finally realized p-type material using electron beam irradiation to remove residual hydrogen from GaN:Mg.

On to Academia & Entrepreneurship

By the mid 1980's, RCA was sold to GE, and as a result, staff reductions were undertaken at Princeton. Pankove was offered early retirement, which was agreeable to him. He had observed the changes around him, and also had an urge for an academic position which would permit him to work on GaN again. In academia he knew he would need funding, so he set about contacting various government organizations. When he spoke

with the Solar Energy Research Institute in Golden, Colorado, they said to him why not take a job with us? Pankove insisted that he wanted an academic position so a joint appointment with the University of Colorado in Boulder was arranged.

At UC Boulder Pankove, after several attempts, was finally able to restart his GaN research. At the time, it was easier to obtain GaN funding as a small business than at a university. Pankove was approaching emeritus age anyway, so by leasing some space at a local technology park, he founded Astralux Corporation, and Pankove became an entrepreneur at the age of 70. Eventually he moved his university laboratory over to Astralux where he has been working ever since. In 1995, Pankove in collaboration with Prof. B. Van Zeghbroeck of UC Boulder demonstrated a novel GaN/SiC heterojunction bipolar transistor. Because of the large valence band offset between the GaN emitter and SiC base, and the wide bandgap nature of both materials, the HBT exhibited the highest current gain ever achieved in a transistor and was able to function above 500°C, also a record. So, it appears that Prof. Pankove is not yet ready to rest on his laurels, although his work has come full circle back to HBTs.

At the conclusion of our conversation, I asked Prof. Pankove for his appraisal of GaN today. He is openly impressed at the work of Shuji Nakamura of Nichia in commercializing GaN LEDs of all colors, and pushing his laser diodes to 35 hours of room temperature cw operation so quickly. However, he feels that for GaN lasers to succeed, the defect density in GaN must be reduced. Since it will be a long time before GaN substrates are commercially available, there is still a lot of work to be done.

During the week of the Symposium two special events are planned. Prof. I. Akasaki will present the plenary lecture which will include his reminiscences about Prof. Pankove and GaN. On Thursday night a banquet is planned at which many of Prof. Pankove's colleagues and "friendly competitors" will be present to share their memories and stories about the first years of GaN.

For more information about the Fall MRS GaN Symposium, visit:

<http://www.zurich.ibm.com/pub/srt/mrssympd/index.html>
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Gallium Nitride and Related Materials Symposium D, MRS Spring Meeting

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The 1997 Spring MRS Meeting included a symposium focused on recent developments in GaN, InN, AlN and their related alloys.

The symposium was kicked off by Prof. S. P. DenBaars from UCSB who reported on advances in AlGaIn/GaN transistors with frequency performance metrics of 50 GHz for f_t and 92 GHz for f_{max} for a 0.2 mm gate length. These devices achieved power metrics of 2.8 W/mm at 8 GHz (1.7 W/mm at 10 GHz) that was limited by the poor thermal conductivity of the sapphire substrate. Improvements in the thermal management of this device are predicted to give power levels approaching 10 W/mm at these frequencies. Progress on electrically injected diode lasers from this group were also addressed, but appeared to still be limited by the low free hole concentration in the p-layers and contact failures at high current densities. Of course, these issues are not unique to this group. They appear to exist for everyone except Dr. S. Nakamura of Nichia Chemical who has reported the only electrically injected group-III-nitride laser, now with cw operation at room temperature for 35 hours.

LEDs and Detectors

Prof. S. M. Bedair discussed progress at North Carolina State University using atomic layer epitaxy to grow InGaIn layers. Prof. Bedair presented a new approach for white light generation by using stacked quantum wells at different In-compositions to potentially get an LED with dual wavelength emission that would appear as white light. Dr. W. Weeks of Cree Research gave an update on their work on GaN grown on 6H-SiC and presented some of the first public discussion of their conductive AlGaIn buffer with a low Al-composition that will allow vertical light emitting diode and laser structures. This approach allowed Cree to remove the shorting

ring used on earlier GaN/SiC light emitting diode (LED) structures that had a non-conducting buffer and thereby increase the light output by 20 to 50%. Prof. M. Shur of Rensselaer Polytechnic Institute summarized work on visible blind detectors that are now a viable product for flame monitoring and control. Significant progress has been made in pushing the detector cut-off frequency to shorter wavelengths and work is now focusing on improving the device speed.

Processing Challenges

Prof. S. J. Pearton of the University of Florida gave an excellent overview of the state of processing and future challenges with a particular emphasis on the technologies that will be required for realizing high power electronic devices in the group-III-nitrides. While the primary emphasis in these materials to date has been photonic devices (LEDs and lasers) and more recently high-frequency transistors, Prof. Pearton discussed equally attractive opportunities for the group-III-nitride materials for high-power (lower frequency) switches such as would be used in utility power distribution systems.

Dr. R. J. Shul of Sandia National Laboratories presented recent results for dry etching these materials in high density plasmas with etch rates up to 1 $\mu\text{m}/\text{min}$ and facet morphologies that should be applicable to laser facet formation or trench formation in power electronics. Q. Z. Liu of UCSD reported on thermally stable PtSi and NiSi Schottky contacts to GaN that appeared attractive for high temperature electronics. Advances in ion implantation doping of GaN were also reported by this author using annealing temperatures up to 1400°C with AlN-encapsulation to achieve n-type doping levels up to $\sim 3 \times 10^{20} \text{ cm}^{-3}$ with mobilities of 60 cm^2/Vs . This mobility is in the range reported for epitaxial GaN doped to such a high n-type level.

Quantum Dots

As was noted in the previous issue of this magazine (CS 3(2), p. 24), there is growing evidence that quantum dots may be an important part of the GaN story. The topic of In-segregation and quantum dot formation came up though out the meeting - and it should be noted that is an area that is not without controversy.

Dr. F. Ponce of Xerox PARC presented his latest understanding of the microstructure of heterostructures in AlGaIn/InGaIn/GaN structures with evidence of nanotubes extending through the quantum well regions. This ties in with reports that In-composition modulations in the quantum well gives rise to quantum dots that may enhance stimulated light emission in lasers (see below). Dr. J. Rosner of Hewlett-Packard showed convincing cathodoluminescence images from the edge of InGaIn quantum well structures demonstrating inhomogeneous emission. He also showed that nanotubes propagating through the quantum well region reduce the local growth rate and cause notching or non-planar growth fronts. This texturing was seen to re-planarize with additional GaN overgrowth.

Dr. S. Tanaka of RIKEN Semiconductor Laboratories presented exciting possibilities for the use of GaN quantum dots in laser structures to reduce the threshold current. Dr. Tanaka used tetraethylsilane as an anti-surfactant to cause three dimensional growth of GaN islands to form the quantum dots which were then clad in AlGaIn barrier layers. He reported stimulated emission at 3.48 eV at 21 K for optical pumping at 0.75 mW/cm^2 .

Some notable theoretical results were given by Dr. W. Chow of Sandia National Laboratories on the gain in laser structures. He suggested that the re-absorption in nonhomogeneous InGaIn quantum well layers (e. g. quantum dots) may cause an increase in the laser threshold currents. Significant discussion was generated by Dr. T. Yamanoto of Osaka University with his theoretical model for enhancing p-type doping in GaN by using oxygen co-doping with Be or Mg. He presented a model where Be-O-Be complexes would form a local cluster that would relax the ionic nature of the lattice and allow Be (and similarly for Mg) to form a high concentration of activated acceptors. This is an intriguing approach since increasing the p-type conductivity is a critical issue to reducing laser thresholds in this material.

Overall, the meeting left the attendees with an improved understanding of this intriguing materials system. However, much remains to be understood, and the presentation of significant device results at this and other recent conferences seems to suggest that the pace of progress in devices is currently outstripping the fundamental materials understanding.

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Electrochemical CV Profiling of Group III - Nitrides

The capacitance of a semiconductor device varies as a function of applied voltage, and the measurement of the capacitance-voltage (CV) characteristic is of considerable practical importance. An accurate CV profile has been described as "a window revealing the internal nature of the structure...[that] serves as a powerful diagnostic tool for identifying deviations from the ideal." [1]

For the mature compound semiconductors, such as GaAs- and InP-based structures, CV characteristics can be easily obtained using an electrochemical CV (ECV) profiler. [2,3] In fact, use of the ECV profiler probably qualifies as the "industry standard" for obtaining electrically active dopant concentration versus depth profiles in compound semiconductor layers.

But the convenience of ECV profiling has not been available to researchers working in the Group III-Nitrides field. Well documented difficulties in chemically (or electrochemically) etching GaN and related materials have been a formidable obstacle. In addition, the electrochemical etching process requires the generation of holes via illumination. However, standard ECV equipment uses a quartz halogen light source that does not emit sufficient energy in the UV region to create a photocurrent in GaN.

Solutions to these problems may be at hand. Bio-Rad Semiconductor Systems Division, which manufactures the ECV Profiler, have recently announced what is believed to be the first successful application of the ECV technique to GaN films, which should lead to more convenient ways to characterize GaN layers.

Operation of the ECV System

The operation of the ECV system entails placing the semiconductor sample in contact with a defined area of electrolyte. This electrochemical contact approximates a metal Schottky barrier so that, by analyzing the capacitance-voltage characteristics under reverse bias, doping profile information can be obtained. The electrolyte is chosen so that as well as providing suitable electrical contact, it also has a well-defined electrochemical dissolution reaction with the semiconductor material. The profiler can automatically remove thin layers (down to around 2nm if required) between measurements to build high resolution doping profiles through the sample.

To apply the ECV technique to GaN one must first determine how to make a controlled etch of a material that has such high chemical and mechanical stability. The answer appears to be the use of an aqueous solution of 0.5N Sulfuric acid. The electrochemical etching process alone does seem to generate nitrogen gas at the GaN/electrolyte interface, so it is necessary to add a suitable wetting agent to the electrolyte and to provide regular agitation at the sample to remove bubbles.

The etching rate for GaN is determined by Faraday's law, and the work done so far indicates that the dissolution number (the charge transferred per molecule) for GaN is 2 and is independent of etching current.

Profiling n- and p-type GaN

ECV profiling of n-type GaN requires another important modification - namely, replacing of the standard quartz halogen lamp with a UV light source capable of generating

the necessary photocurrent. A Si-doped GaN epilayer grown on sapphire, supplied by Paul Grudowski and Russell Dupuis of the University of Texas at Austin, was profiled using such a source. The current-voltage curves shown in Figure 1 demonstrate that saturated currents are observed and the photocurrent is directly proportional to the illumination density. The dark current is nearly zero confirming that the rate determining factor for dissolution is the availability of photogenerated holes at the GaN:electrolyte interface. The slight increase of photocurrent with reverse bias in the IV curve is due to improved carrier collection efficiency with increasing electric fields.

Figure 2 shows capacitance and C^{-2} versus voltage plots for the same electrolyte:GaN barrier. C^{-2} varies linearly with voltage giving a flat band potential of approximately 0.8V. From the IV and CV measurements, it is clear that the H_2SO_4 :GaN contact can be considered a Schottky barrier, rendering it suitable for use in the ECV system.

A typical ECV doping profile from the n-type GaN sample is shown in Figure 3 and a micrograph of the resulting etch hole in the epilayer is shown in Figure 4. The n-type free carrier concentration of this layer as measured by the Hall technique was $2.5 \times 10^{18} \text{ cm}^{-3}$. The average ionized impurity concentration measured by ECV is approximately $4 \times 10^{18} \text{ cm}^{-3}$ indicating that electrical activity of defects could be a factor in this material.

Etching p-type GaN electrochemically is a reasonably straightforward process that does not require illumination. However, ECV dopant profiling has generally been less successful than with n-type GaN because the CV curve gives very large flatband voltages which causes problems in the derivation of carrier concentration. These effects are probably due to dopant compensation and defect levels in the limited amount of material tested so far. It is hoped that as material quality improves, these problems will be overcome.

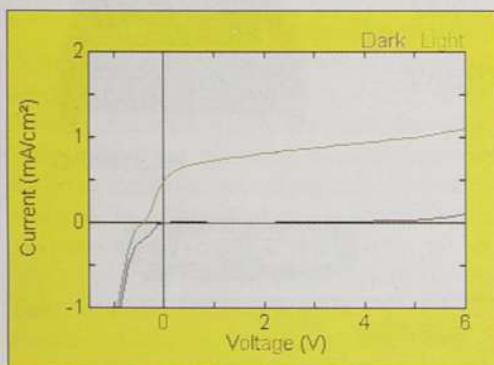


Figure 1. Current-voltage curves for n-type GaN under dark and illuminated conditions using sulfuric acid electrolyte.

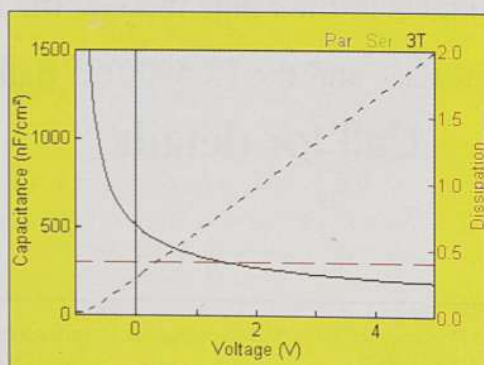


Figure 2. Capacitance (solid line) and C^{-2} (dotted) versus voltage for same sample.

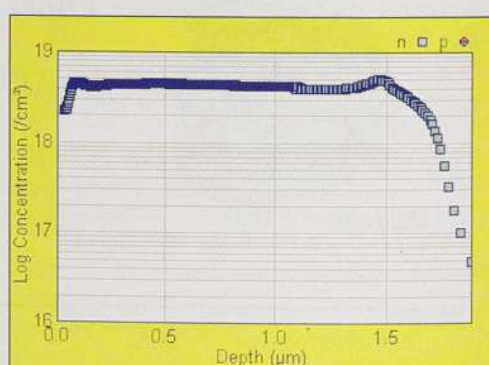


Figure 3. Doping profile obtained by ECV.

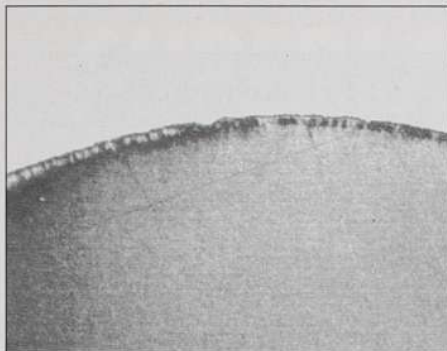


Figure 4. Confocal reflection image of etch hole in GaN. Note that the etch was stopped in the GaN epilayer, not the substrate.

Bio-Rad is currently developing a modified version of their ECV Profiler specifically for use with wide bandgap materials. Product announcements are expected later this year.

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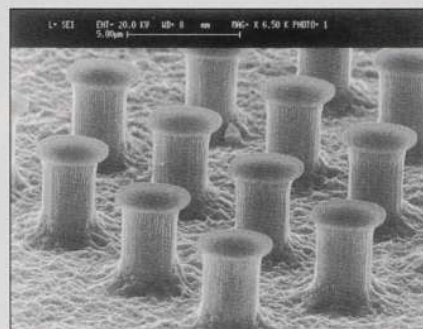
- [1] Robert F. Pierret, "Semiconductor Device Fundamentals" [Addison-Wesley Publishing, Reading, MA, 1996], p. 584.
- [2] Ambridge T and Faktor MM J.Appl. Electrochem. 4 (1974) 135 - 142.
- [3] P. Blood 1986 Semicond. Sci. Technol. 1 (1986) 7-27.

Etching of GaN

The development of effective processing methods for GaN and related materials is a necessary effort if commercial devices are to be realized. One area in need of exploration is wet-etching of nitride semiconductor layers, given that it may provide the solution to drawbacks associated with dry-etching, such as ion-induced damage.

Researchers at the University of Illinois and Cree Research recently reported progress in photoelectrochemical (PEC) etching. PEC is a technique in which the photogeneration of electrons and holes in a semiconductor enhances chemical etching of the material. Using KOH solution and broad-area Hg lamp illumination, they were able to achieve etch rates of 17-20nm/min for samples of n-type and not intentionally doped GaN grown on SiC substrates.

More significantly, no appreciable etching was observed for p-type GaN/SiC samples. This result suggests that the PEC technique may be useful for dopant selective etching of GaN layers. Preliminary



3.5 micron thick photoelectrochemically etched n-type GaN grown on SiC.

experiments carried out on p-n GaN heterostructures appear to confirm this conclusion.

However, many issues remain to be addressed. Among them is the need to improve the uniformity of the etching process over large areas - at present, the etching rate drops off sharply as the distance to the electrical contact is increased. The use of a backside contact to the SiC substrate is being explored.

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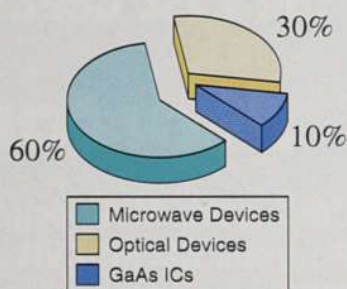
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Industry News

Fujitsu to Consolidate its Compound Semiconductor Activities

Fujitsu has announced that it will separate its compound semiconductor division to consolidate it into Fujitsu Quantum Devices (FQD), a compound semiconductor production subsidiary located in Yamanashi Prefecture. About 230 people now working in the compound semiconductor division at Fujitsu will be on loan to FQD, which will accommodate 1,300 employees from October. The aim is to consolidate manufacturing and sales into one body so as to quicken response time to demand. The division's gross sales of ¥44 billion (\$363.6 million)(see graph) will be automatically transferred to FQD, which is expected to achieve fiscal 1997 sales of ¥50 billion (\$413.2 mil). FQD will bolster overseas sales and set up development centers in an attempt to double sales to ¥100 billion (\$826.4 mil) in fiscal 2001.

1996 Sales, Fujitsu Compound Semiconductor Division



Source: Fujitsu

Dowa Mining Tends LED Business

Dowa Mining says that it plans to cultivate LED applications in order to cope with the rapidly expanding market for LEDs for use in wireless data transfer. The company, which first developed an AlGaAs LED in 1985, has already developed a 100MHz LED lamp. Dowa plans to continue focusing on red as well as infrared LED application development in order to maintain its edge over others.

NEC Planning to Expand its Satellite Business

NEC plans to increase the production of semiconductors for satellite receivers, based on forecasts for growth in demand for high performance antennae for data broadcasts in addition to digital satellite broadcasts. The total investment to increase production will be ¥50 million (\$406,504) - a relatively modest figure, because the company does not need to revamp preprocessing lines to reach its goal of 7 million units per month by October.

Central to the new strategy is a new GaAs MMIC low noise receiver chip, the NE32901. Fabricated using 0.17-micron electron beam processing technology, it features a noise factor of 0.35dB, down 0.1dB from its predecessor. Samples of the GaAs chip will become available from May 1997 at ¥200 (\$1.63).

Other NEC News

NEC has developed low-power multiplexer and demultiplexer LSIs for use in 10Gbps optical communications systems. The former multiplexes 1.25Gbps signals eightfold, and the latter separates 10Gbps signals into eight sets of signals. Each chip is based on a tree architecture with three levels, uses GaAs hetero-junction FETs and consumes 1.2W, less than 1/4 the power consumed by silicon bipolar LSIs. To achieve lower power consumption, the company has used SCFL (source connection FET logic) in high-speed and timing generation sections and DCFL (direct connection FET logic) in a low-speed section for processing less than 5Gbps signals.

NEC also recently announced the development of a Ka-band microwave amplifier that achieves an output of 150W, the world's highest. To be used in local multipoint distribution system (LMDS) base stations and gigabit/second-class satellite communications earth stations, the amplifier also achieves an amplifying efficiency of 40%, 60% higher than conventional devices, and can emit microwaves with little distortion. NEC anticipates that the market for LMDS will be driven by demonstrating that it is more cost effective than cable TV systems. The sample price for the amplifier is set at ¥5 million (\$39,370).

In Development

GaAs Chip with Single Electrode Drive

Toshiba says it has developed a GaAs chip powered by a single electrode. Using a proprietary processing technology called "P Pocket Self-Align", negative electrode layers comprising three different densities are formed on the positive electrode, making it possible to control threshold voltage freely and eliminating the need for a converter for the negative electrode. Toshiba says the new device consumes 35% less power than conventional GaAs devices. It plans to commercialize a PHS power amplifier LSI using the new technique in June of this year, and also plans to develop 1-3GHz versions for PCS and DECT applications.

Recent Results in High Speed Communications

NTT has succeeded in optical soliton communications over a distance of 10,000km at 100Gbps, which is 1/10 of the ultimate target speed of 1Tbps. The company has used a wavelength division multiplexing (WDM) system that bundles 20Gbps signals in five different wavelengths through an optical fiber. NTT explains long-distance soliton communications became possible by using as relays optical modulators capable of controlling wavelength distortion. KDD has also successfully transmitted 20Gbps optical signals in four different wavelengths over a distance of 5,000km, while Professor Hasegawa's group of Osaka University has developed a technique to transmit 100Gbps signals in a single wavelength over a distance of 5,000km.

New Optical Memory

The Toshiba Advanced Research Laboratory has developed optical memory capable of increasing recording density 200 times over a DVD. The new device uses as a recording medium a silicon substrate that is coated with organic molecules, a pigment material. The organic molecule coagulates into a quite fine drop as small as about 10nm in diameter, which functions as the smallest recording unit. Therefore, the lab claims that the new medium, if it takes the form of a 12cm-diameter optical disk, will be able to store about 1Tbyte of data, an equivalent of about 200 DVDs. The molecules emit yellow fluorescent light when a blue laser is emitted upon it. The technique uses an optical fiber to detect signals. Commercial versions may be available by 2010.

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Optoelectronics News From NEC

NEC has announced the development of a **laser for communications applications which does not require an isolator**, allowing users to build optical communications system inexpensively. The new laser can transmit data accurately without an isolator even when the highest possible 14% of the light emitted is reflected back to it. This has been achieved by using NEC's proprietary partial diffraction grating structure and optimizing device length and grating height. An experiment has found that degradation in receiving power at 622Mbps, equivalent to 9,700 phone lines, is less than 20%. NEC hopes to commercialize the new laser in 1998.

More evidence of the growing popularity of infrared data transmission: NEC says it will expand **infrared communications module** production. The company, which developed a 4Mbps FIR standard-compliant IrDA module in 1996, produces wafers for the module at NEC Kansai and entrusts assembly to Kumamoto-based Kyushu Electronics. NEC will raise Kyushu Electronics' production capacity threefold to 3 million units per month in the first half of fiscal 1997 in an attempt to achieve the economy of scale and expand its market share. NEC also plans to introduce a 5.0x13.2x5.0mm slim model and a 3V-class low-power model by the fall, targeting notebook computer and PDA applications.

In hopes of achieving **less expensive optical communications transmit/receive modules**, NEC has developed a technique to mount LEDs and photo detectors on T/R modules whose optical axes are unregulated. Capable of adjusting positioning at sub-1-micron precision three-dimensionally, the technique helps cut assembly costs to less than 1/5 those of modules with regulated optical axes. Regulating an optical axis accounts for 50% of module assembly costs. The technique involves highly precisely forming bumps and controlling the irregularity of the height of bumps.

NEC also recently announced the development of an **30mW-output DVD-RAM laser**. The 5.6mm-wide laser emits 657nm light and can continuously operate more than 10,000 hours at temperature as high as 60 deg C. The company says it has optimized the thickness and the refractive index of the laser's multi-quantum well layer in order to prevent edge surface destruction and threshold current deterioration. Plans call for bringing the laser to market by the end of 1997.

Other Opto News

Mitsubishi Electric has announced that it has developed a **980nm pump laser suitable for use in EDFAs**. The company says that the device achieves an average lifespan of over 100,000 hours when used at 50°C and generating 150mW. Mitsubishi plans to commercialize the laser in summer 1998.

Mitsubishi also recently announced the development of a **temperature insensitive laser diode for interactive cable TV systems**. The new laser operates over a wide temperature range of -40°C to 85°C and eliminates the need for cooling devices, helping reduce power consumption and component costs. The laser uses a distorted quantum well structure for the active layer and requires 1/3 the operating current of conventional lasers used in "node points" that send back signals from several hundred households to the interactive cable operator. Mitsubishi plans to ship ¥40,000 (\$317.46) samples from summer 1997, targeting the U.S. market where interactive cable systems are in wide use.

NTT says it has developed a **new optical wavelength filter** that is less susceptible to a change in the temperature. The optical wavelength filter is a key device for WDM systems. The new filter, which is made of two

compound semiconductor layers and has 30 waveguides to let lights pass through, features a wavelength fluctuation of less than 0.01nm/°C. It eliminates the need for a cooling device and can easily be integrated with other semiconductor devices such as a laser and a photo diode. NTT plans to put it into practical use for optical communications switching equipment and also apply it to optical integrated circuits.

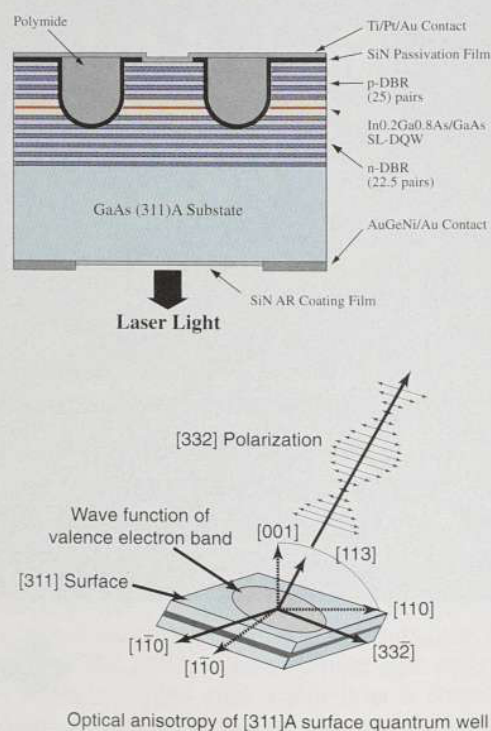
Sanyo Electric has developed a **more robust DVD laser**. The new laser is designed to generate less heat and operate at a lower threshold current (45mA) so that it can function stably at ambient temperatures of up to 80°C, 10°C higher than the limit for conventional DVD lasers. It is priced at about ¥1,000 (\$8.26) in quantities of 100,000 units. Subsidiary Tottori Sanyo Electric will produce tens of thousand units per month from May 1997, targeting car navigation system and DVD-ROM applications.

Hitachi has developed a **635nm red semiconductor laser** for laser levelers and markers. The HL6319G provides an output of 10mW and operates at up to 50°C. The company will ship samples of the AlGaInP MQW laser at ¥9,000 (\$71.43) from May 1997.

Polarization Control in VCSELs

VCSEL structures which are grown on conventional (100) substrates exhibit linear but random polarization states, and mode changes between the orthogonal polarization states easily occur. This characteristic is unsuitable for several potential applications for VCSELs, such as magneto-optic disk recording and coherent detection communications.

The ATR Adaptive Communications Research Laboratories, in collaboration with the Precision and Intelligence Laboratory of the Tokyo Institute of Technology, have announced the development of a VCSEL with stable and controlled polarization. The strained quantum well InGaAs laser structure was grown on (311)A GaAs. Because of the anisotropic in-plane gain distribution in the resulting structure, a stable polarization mode was exhibited along the [332] direction. This mode was maintained against injection current of 2.5 times the threshold over a temperature range of 25°C to 150°C.



Optical anisotropy of [311]A surface quantum well

News from Japan, con't

LiGaO Substrate for GaN

NTT reports that it succeeded in pulling lithium gallium oxide single crystal. This result could lead to the eventual availability of a substrate with a lattice mismatch with gallium nitride of just 0.9%. In comparison, the lattice mismatch between GaN and sapphire is over 14%. NTT says it is targeting electronic device applications for the new development.

Smallest Laser Diode

A research team led by Associate Professor Baba at Yokohama National University has developed a very small semiconductor laser. The new device features a disk-shaped GaInAsP emitter sandwiched between InP layers. The emitter is only 2 microns in diameter. The new laser has a threshold current of 0.2mA, down from 1mA required of other 1.55-micron lasers. The team will explore its potential as the light source for next-generation optical ICs that send data using light.

P-type Diamond

Associate Professor Ito's research group of the Engineering Science Department of the Graduate School of Osaka University reports that it has developed a p-type diamond semiconductor that achieves the world's fastest response speed, about four times faster than conventional p-type semiconductors. The fast response speed has been made possible by slashing nitrogen contamination of the ultra-pure methane gas used to form the monocrystal diamond thin film to less than 0.1ppm.

CONFERENCES

Preview of the 39th Electronic Materials Conference (EMC)

Fort Collins, Colorado, June 25-27, 1997

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For more conference information, see our report on the Nitride Symposium at the Spring MRS Meeting on page 12.

The Electronic Materials Conference traditionally covers a number of areas of relevance for compound semiconductors. Some of the features from this year's program include:

• **III-V Nitrides.** Four sessions at the conference will be devoted to the very active field of III-V nitrides.

Shuji Nakamura (Nichia Chemical Industries) will report on optical gain and emission characteristics of InGaN single-quantum well LEDs and multi-quantum-well laser diodes. James Speck (University of California, Santa Barbara) will present experimental results and models for the mechanisms of threading dislocation generation and reduction in GaN growth on sapphire; reporting that dislocation densities of order 10^8 cm^{-2} have been achieved. Jeff Rossner (Hewlett Packard Laboratories) will also address the development of extended defect structures in epitaxial GaN, relating the structure to the optoelectronic properties by using cathodoluminescence. Rossner finds evidence of non-radiative recombination at threading dislocations.

In addition, an entire session will be devoted to the recent realization of GaAsN, GaPN, and InPN alloys with nitrogen concentrations of up to 20%. The presenters will include W. G. Bi and C. W. Tu (University of California, San Diego), who have performed pioneering work with non-equilibrium MBE growth. These alloys will enable novel band-structure engineering as well as lattice matching to various substrates.

• **Silicon Carbide.** There will be presentations on many aspects of SiC epitaxy, processing, and devices. W. Shin and coworkers from Nagoya University will discuss their recent experiments on formation of porous SiC and the intense photoluminescence observed. V. Ramachandran

and collaborators (Carnegie Mellon University) will present formation of atomically flat surfaces of SiC using hydrogen etching. The formation of these large flat terraces is of interest for GaN heteroepitaxy. J. P. Henning and coworkers from Purdue University will present use of polysilicon on SiC for Schottky diode formation. This Schottky diode should be very stable since both polysilicon and SiC are inherently stable materials and the heterojunction should not be prone to react while the electrical properties are easily controlled by varying the doping of the polysilicon.

• **Epitaxy for Devices.** Researchers from Purdue University will report on increasing the cutoff modulation frequency of high efficiency GaAs LEDs to greater than 1 GHz with an output responsivity of 1.4 microwatts/milliamp. Using sophisticated materials science studies they have learned how to heavily dope GaAs with Be to decrease the radiative recombination lifetimes without producing nonradiative recombination centers which normally greatly reduce luminescence efficiencies. The Purdue diode efficiency at 1 GHz is almost a factor of 10 higher than the best previously reported results at this cutoff frequency.

Additional areas of relevance to compound semiconductors that will be covered at this year's EMC include:

- II-VI Structures: Self-assembled Quantum Dots and Heteroepitaxy
- Wide-Band-Gap Semiconductors: Surfaces and Emission
- Compound Semiconductor Oxides
- Defects, Defect Engineering, and Device Reliability.

More information about the Conference can be found at
<http://www.tms.org/Meetings/Specialty/EMC97/EMC97.html>.

Uniphase Acquires IBM's Laser Enterprise Unit

Also in this section:

- ▶ Cambridge Counts Electron Current - page 22
- ▶ Bell Labs Looks at Dopant Atoms - 24
- ▶ New GaAs Chip Companies - page 25
- ▶ TriQuint's New Process - page 26
- ▶ X-Ray Lithography Project - page 27
- ▶ GaAs Device Forecast - page 28

On March 10, Uniphase Corporation [San Jose, CA] announced the acquisition of the IBM Laser Enterprise business unit, based at the IBM Research Laboratory in Zurich, Switzerland. The business will remain in Zurich, although it will move out of the IBM facility, and will operate as a wholly owned subsidiary under the name Uniphase Laser Enterprise AG. The all-cash asset-based transaction was valued at \$45 million. Uniphase will also pay IBM \$27 million for patent and technology licenses, plus royalties on certain products.

Uniphase Corporation is an optoelectronics company active in the fields of laser subsystems, laser-based semiconductor wafer defect analysis equipment, and fiber optic telecommunications equipment. Total sales for the first nine months of 1997 were \$73 million. It employs approximately 500 people worldwide. Laser Enterprise employs approximately 50 people, including 14 Ph.Ds.

The Home of the 980nm Laser

Laser Enterprise is the repository of notable achievements made by IBM Zurich in the field of 980nm lasers for erbium doped fiber amplifiers (EDFAs). A team of scientists and engineers working under the leadership of Dr. Volker Graf has made major contributions towards an improved understanding of the degradation behavior of high-power AlGaAs lasers. As a result, IBM was able to dramatically improve high-power capabilities by developing a proprietary facet coating technology. This process, known commercially as "E2", has been shown to be capable of producing diodes with field lifetimes in excess of 50 million device hours and mean time to failure of 1,000,000 hours. (See CS 3(2), p. 16.) IBM has nearly 40 patents relating to the process.

Production at Laser Enterprise is based on MBE-grown strained-layer quantum well GaInAs/AlGaAs laser wafers which are processed into index-guided ridge waveguide lasers using wet chemical etching. In addition to the proprietary mirror coating, the company has also developed techniques for fully automated characterization of each laser diode.

Over the past six years IBM has delivered over 50,000 980-nm pump lasers to the telecommunications industry, and Laser Enterprise is estimated to have over 70% of the current market. Several other companies, including Hewlett-Packard FOC, Pirelli Cable, Lasertron, and Nortel, have licensed the E2 process from IBM. Of those, only Lasertron is believed to have qualified a device for release onto the open market. (See following.)

Commenting on the acquisition, Kevin Kalkhoven, Chairman and CEO of Uniphase cited Laser Enterprise's extensive patent portfolio and library of reliability data as two of the attractive features of the company. Speaking about Laser Enterprise's 980nm lasers, he said "they have demonstrated the longest lifetimes of any product in the world, and they are very well covered by patent protection. Other companies have been trying to find ways around these issues, including moving to aluminum free lasers, but so far none of them have got anywhere near the lifetimes that we have. So they are playing catch up with us."

Why did IBM sell the unit? According to Kalkhoven, it was not considered to be relevant to IBM's core of computing and storage technologies, but yet "they wanted to see the realization of the full commercial capabilities of the devices...and they felt it was a good thing for the scientists involved".

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The Future

Uniphase plans to invest \$15-\$20 million in building a new fab line for Laser Enterprise in the Zurich area. When it is completed, the existing operation will be moved out of the IBM Research Lab site.

There are several new products - including higher power 980nm lasers - already in the late development stages at Laser Enterprise. See chart. Uniphase will be offering a range of discrete devices, as well as complete modules. Uniphase currently sells EDFAs built by Nortel using IBM lasers. Kalkhoven says the company will now develop its own EDFA products.

The four companies mentioned earlier will retain their license rights to the E2 process, and thus could provide competition for Laser Enterprise. However, Kalkhoven points out that their licenses apply only to "the devices currently being manufactured, which are the 150 to 210 W devices. The higher power devices, which are currently in qualification, will be unique to our own designs."

Kalkhoven also reports that 1550 nm lasers will be forthcoming from Laser Enterprise, and that other telecommunications wavelengths are under evaluation as well. However, he says there are no plans to explore any of the applications for high power laser diodes at visible wavelengths at this time.

QUALIFIED	IN QUALIFICATION	IN DEVELOPMENT
980 nm L-N series (narrow stripe lasers) * 120mW (linear power) * 150mW * 180mW * 210mW	• 980 nm lasers for submarine (70mW) • 956 nm broad area lasers (0.5W)	• 980 nm narrow stripe laser (300 mW) • 920 - 1020 nm narrow stripe lasers (150 - 210 mW) • 910 - 980 nm broad area lasers (1W, 4W)

Part of the technology being transferred to Uniphase from IBM.

Other 980nm Laser News

Lasertron [Waltham, MA] reported that it has qualified its 980 nm pump fabrication process. "We are pleased to have achieved this important milestone," said Robert J. Hannemann, President of Lasertron. "We will commence shipment of modules incorporating our internally manufactured chip during the first quarter of 1997." Lasertron licensed the IBM "E2" 980nm laser process in 1994.

The company estimates that the 980 nm pump module market will be \$75 million in 1997 and that it will grow at a rate of 25-30% per year.

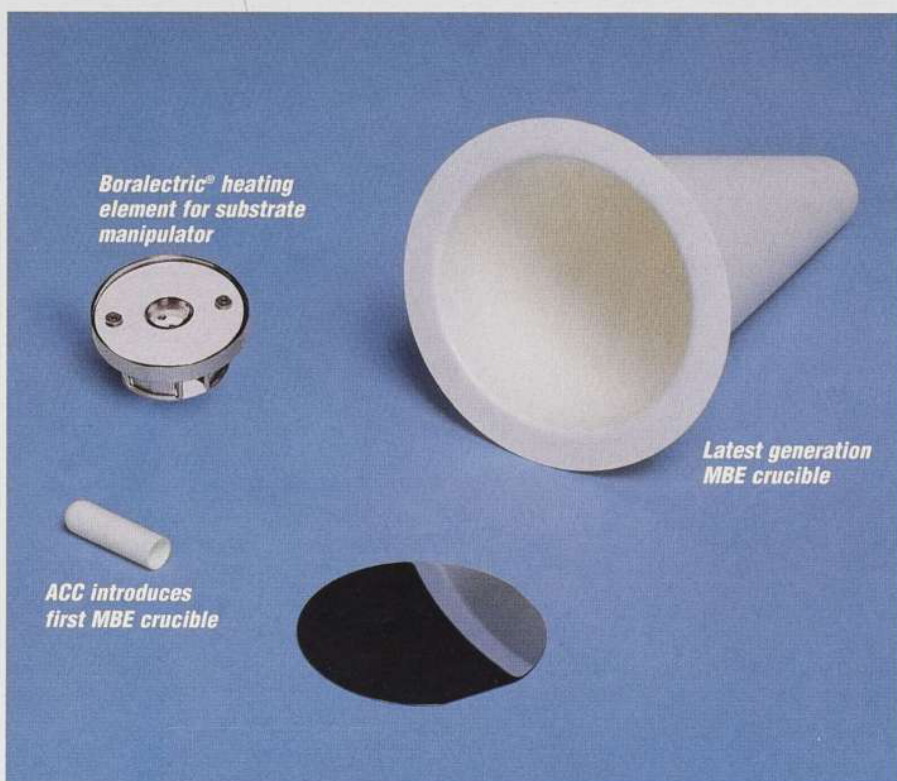
In late March **Ortel Corp.** [Alhambra, CA] announced what it called "a reduced manufacturing cost breakthrough" for its high power 980 nm pump laser module with output power ranging from 90 to 120 mW for erbium-doped fiber amplifier (EDFA) applications. The new development is said to enable a 20% price reduction for Ortel's pump lasers for use in fiberoptic communications networks and fiberoptic gyroscopes.

The company says it is increasing production capacity in anticipation of higher demand.

Funding for these cost reduction efforts was in part provided by the IFOG Flexible Manufacturability Program sponsored by the DARPA. Ortel is a member of a consortium headed by Honeywell, which uses Ortel's 980 nm lasers in its fiberoptic gyroscopes.

Ortel reports that their pump lasers use a proprietary non-absorbing window structure to achieve excellent device reliability. Devices have been qualified at up to 200 mW facet power levels. The company says high reliability is achieved from the hermetic laser welded package design, combined with advanced chip technology that has demonstrated less than 500 FITs during lifetests.

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Cambridge Counts Electron Current

Will $I=ef$ enter the next books next to $V=IR$?

MICHAEL KENWARD

A new quantum standard for electric current could be one outcome of recent research by Professor Michael Pepper and his colleagues in the semiconductor group at the Cavendish Laboratory in the University of Cambridge, England. The latest research coincides with the celebration of the discovery of the electron by J. J. Thompson 100 years ago, in the same laboratory. Researchers at the National Physical Laboratory (NPL), Britain's leading standards organization, are now looking into the possibility of using the Cambridge results as the basis for a new standard for current.

The Cavendish group carried out their experiments in a GaAs/AlGaAs heterostructure. This is a piezoelectric material, which means that a voltage can produce sound waves within the material. In their experiments, Pepper and his colleagues transmit high-frequency sound waves at a frequency of 3 GHz using aluminum transducer "fingers" with 1 micron spacings. See Figure One. The resultant surface acoustic waves (SAWs) travel along the surface at the GaAs/AlGaAs interface. The sound waves trap electrons into clusters of what Pepper describes as "buckets of charge" at the amplitude troughs of the sound waves.

The dimensions of the devices are such that electrons get together in their hundreds. With so many it is not possible to count them or to measure their charge, and hence the cur-

rent they carry. The Cavendish team overcame this obstacle by turning to the split gate, a device structure that it first produced in the early 1980s. See Figure Two. Since then the device has led to considerable progress in the understanding of the physics of electronics in semiconductors.

1-D Electron GaAs

A split gate restricts the current path and effectively turns a two-dimensional gas of electrons into a one-dimensional flow. "We squeeze the electron gas," says Pepper. As the 2-D electron gas is constricted into a line, there is less room for electrons, and some of them are "expelled" from the line. Eventually the flow reaches the level where a wave trough holds just one electron. By measuring the current flowing through the gate the Cambridge team can say exactly how much current is carried due to a flow of solitary electrons.

Other researchers have tried to devise ways of measuring the current of individual electrons with electronic devices using quantum dots. But this approach relies on a statistical phenomenon, inherently unsatisfactory to many scientists, and much less sensitive. Pepper estimates that by working with SAWs and split gates, the Cavendish team produces a signal that is three orders of magnitude stronger than is possible with quantum dots.

The robustness of the Cambridge group's approach shows up in the stability of its measurements as seen in graphs of current against voltage. There is a distinct plateau where the current remains constant over a range of SAW powers. The current, I , is equal to the product of the charge of the electron, e , and the wave's frequency, f . In the simplest case there is just one electron in the flow. "The flatness is a guarantee that no electrons are sneaking in or out," Pepper explains.

Since the Cavendish team first announced its results, the researchers have increased the number of electrons in each 'trough' to two. This increases the current to 2 times ef and makes it even easier to measure. Pepper hopes to increase the electron count to four or five per 'bunch'.

New Standard for Current?

The sensitivity of the Cambridge device has prompted the NPL to consider the idea for a new standard for current. The unit of current, the ampere, is now defined in terms of the physical force created between two straight parallel conductors. There are already quantum standards for voltage and resistance, based on the Josephson and quantum Hall effects respectively. "You can derive a quantum standard for current based on these indirectly," says Dr Tony Hartland of NPL, "but if you have a separate quantum standard you could complete the metrological triangle."

Earlier standards for voltage and resistance, for example, relied on standard cells and circuits made from materials that could vary. "Quantum standards are perfect standards," says Hartland, head of cryogenic metrology at NPL. "You will always get the same answer if you set them up properly."

NPL plans to work with devices produced by Pepper's group and to exploit its own ability to measure currents very accurately. Alternative approaches involve measuring currents of picoamps, by opening the door to a technique that produces nanoamps, the Cambridge work gives NPL a far easier target to reach. "It is still very difficult to do, but it is within the bounds of possibility," says Hartland.

Con't on page 24

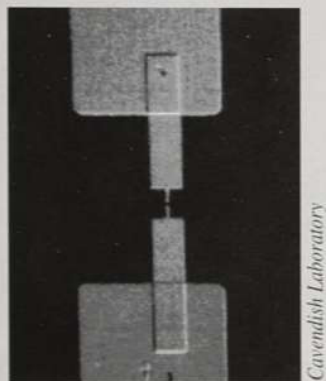


Figure One. Magnification $\times 15K$, shows the aluminum transducer fingers which set off the surface acoustic waves. The pattern is interdigitated, with like fingers 1 micron apart.

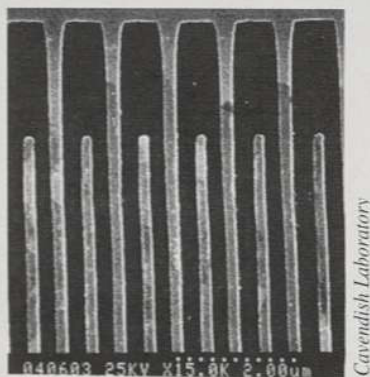


Figure Two. Magnification $\times 60$, the aluminum split gate is visible running from the top to the bottom of the image. The constriction just visible in the center of the picture measures 0.6×0.8 microns.

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- ▶ 3" in development

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- ▶ 2" undoped and S-doped

GaN in Development

American
Xtal
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Why GaAs?

The use of a piezoelectric material was obviously a key to the Cavendish group's approach. Equally important is the Cavendish group's ability to make and improve upon devices in its own laboratory. The next stage will be to use focussed ion beams alongside conventional molecular beam epitaxy. The group now makes devices where the features are around 0.05 micron apart. The ion beams should allow the group to fabricate devices with features just 0.01 micron apart.

Another important factor was that Cambridge was able to use MBE to produce extremely pure semiconductor materials to work from. In this type of work, "you are at the mercy of the odd impurity," Pepper explains. "But as the material gets better, you can start to look at more exotic phenomena." One possibility here is the interaction between electrons.

Pepper admits that much of this work is, in the first instance, mostly of interest to physicists, with limited device implications. To begin with, these devices have to be cooled to liquid helium temperatures. However, he does

not rule out the possibility of working with silicon-germanium or other materials that might work at room temperature. The important thing is to study the physics first in ideal systems. Only then is it possible to even start thinking of using the concepts as the basis for usable devices.

In addition to running his own unit at the Cavendish, Pepper is head of Toshiba Cambridge Research Centre. Toshiba has helped to fund the work, along with the UK Engineering and Physical Sciences Research Council.

Bell Labs Looks at Dopant Atoms

A group of researchers at Bell Laboratories is reporting the development a new instrument so sensitive it can image individual electric charges on and below the surface of semiconductor devices.

The instrument, known as the single-electron transistor scanning electrometer (SETSE), combines two other recent developments, the single-electron transistor (SET) and the scanning-probe microscope.

The SET, co-invented in the late 80's by Bell Labs researchers, is a cryogenic device of microscopic size whose electrical resistance is very sensitive to the electric fields emanating from nearby electric charges. The SET consists of two tunnel junctions, similar to diodes, interconnected by a minute metal "electron island" which senses the electric fields.

The second development, the scanning probe microscope, dating to the mid-80's and now in use in many forms, produces maps of physical properties of a surface on a scale comparable to that of electron-microscope images. The microscope uses a sharp tip as an ultra-small probe, which is brought gently into near contact with a material surface. A particular physical property, such as contact force, can be detected in the microscopic region below the tip. As the probe is scanned back and forth across the surface, images of this property can be captured by the microscope.

The probe used in the SETSE consists of a sharpened glass fiber, similar in size and shape to a small sewing needle but with a much finer tip that tapers down to a tiny, nearly flat area at the end. This flat area is only 100 nanometers wide. The SET is formed on this tiny area. The "electron island" covers

most of the area and the two tunnel junctions are at either edge of the island. Electrical connections extend from the junctions up the side of the needle to the detectors.

When brought close to a semiconductor or other surface, the SETSE probe picks up signals from all charges close to the island and measures the total charge to a small fraction of an electron. By scanning the SETSE probe back and forth, an "electric" picture emerges of the charge distribution on the surface. See figures, below.

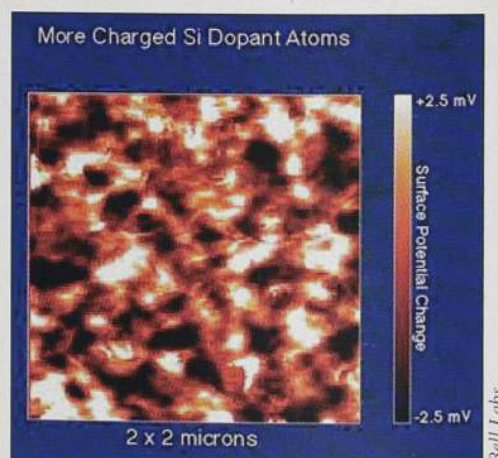
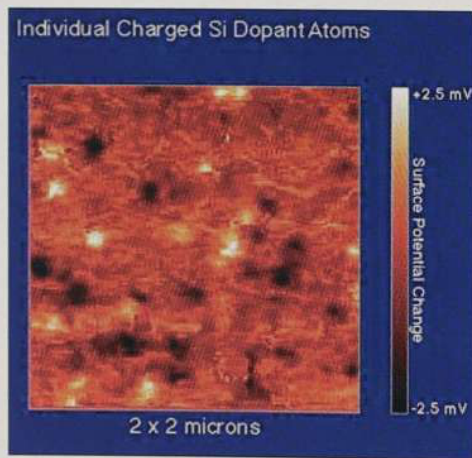
The authors have published an article, entitled "Scanning Single-Electron Transistor Microscopy: Imaging Individual Charges," in the April 25, 1997 issue of *Science*.

Speaking for the authors, Harald F. Hess noted that usually many electrical charges are sensed by the probe at once. "Typically there can be up to 300 electrons influencing the SET island at one time, which makes seeing individual electrons in the crowd a bit tricky," he said. "But, we were able to detect individ-

ual electrons by using light to move a very small fraction of them to different locations. By comparing the 'before' and 'after' picture, we can see individual spots where a new electron has arrived or where an old one has disappeared.

Hess said, "The day is not far away when only a handful of electrons will control a device's performance. The SETSE can help us locate where the electrons and charged dopant atoms are in a semiconductor material, such as gallium arsenide devices doped with silicon. The location and the amount of dopants and how they release electrons is critical to device performance. With the SETSE, we can image those charges with excellent sensitivity."

The SETSE device currently operates only at cryogenic temperatures. The authors expect that with time the device will be reduced in size, producing images with finer details, and will be made to operate at higher temperatures.



SETSE images of silicon dopant atoms in GaAs.

Korean, Taiwanese Entrants into the GaAs Chip Market

World's biggest GaAs fab reportedly under construction in Korea; meanwhile, Samsung begins shipping RF parts from its US plant.

Thus far, the GaAs industry has consisted almost entirely of Japanese, North American and European companies. But now the first Asian GaAs IC vendors outside of Japan are beginning to appear.

Hexawave

The first new company is Hexawave, based in the Hsinchu technology district in Taiwan. According to Vice President Kenneth Hsu, 1996 was a banner year for the six-year old company, with sales increasing 250% to \$8 million. He is forecasting similar growth for 1997, which would put the company in the \$20 million/year range.

Hexawave operates a 3" MESFET fab, and specializes in chips for wireless applications, especially 1.9 GHz PCS base stations and modules for wireless local loop transceivers. Hsu reports that their customers include Ericsson, Lucent and Philips. The company relies on MBE-grown epiwafers for many of its MESFET products, including power devices and MMICs. Hexawave has around 120 employees. There are publicly traded in Taiwan.

CTI

The other new entrant is CTI Semiconductor Corporation, which is based in Chungchong Province, South Korea. Korean newspapers are reporting that CTI plans to build the world's largest GaAs fab in Umsong. It is reportedly scheduled to become operational towards the end of next year, and will be capable of processing 10,000 six-inch wafers a month. Costs for the new plant are estimated at \$200 million.

CTI has reportedly obtained two contracts, valued at "\$5 million a month," to supply US companies with semiconductor chips for digital communications devices. The Korea Economic Weekly reports that CTI will deliver one million units of amplification converters for CDMA phones to Qualcomm Co. and five million units of chips for satellite arials to Raytheon each month. Lee Tae-Gil, senior managing director of CTI, is quoted as saying that the company expects its chip exports for this year to exceed \$80 million.

Company officials were not available for further comment.

Samsung Microwave

Meanwhile, Korean electronics giant Samsung has launched a line of RF products from its U.S. based Microwave Semiconductor operation, located in Milpitas, CA. These are the first products to come out of this fab since Samsung acquired it from Harris in 1993. The company has spent three years and \$20 million to transform the operation from a military to a commercial operation. The changes included upgrading from 3" to 4" GaAs wafer processing. In addition to GaAs, the fab has CMOS, BiCMOS, and power silicon capability.

The first products to be introduced are a low-noise amplifier and two voltage-variable attenuators. The SM-51501 is a high-intercept, low-noise amplifier (LNA) designed for wide dynamic range receiver applications. The device features low noise performance and uses low-cost surface-mount technology components to implement the input-matching network. It operates from a single 5-V supply and has a built-in DC blocking capacitor on the RF output. The device has a noise figure of 1.4 dB typical for 23 dB of gain over a frequency range of 2.1 GHz to 2.7 GHz. The LNA is available in an 8-lead plastic SOIC package costs \$4.70 in orders of 10,000.

The SM-515003 voltage variable attenuator operates from 300MHz to 3GHz and is intended for a range of applications including the ISM band, data-communications, and wireless communications. In volumes of 10,000 the price is \$2.40 per unit. The companion product, the SM-516003, is designed for ultralow power consumption and is available at the same price.

America's Confused Consumers

Many GaAs RF chip manufacturers would like to see digital cellular succeed (see page 34). But there may be an unexpected obstacle in the way. Market research firm MTA-EMCI reports that over 73% of current U.S. cell phone users believe they already have digital service. In reality, less than 5% of those phones are digital. MTA-EMCI is advising digital wireless companies to spruce up their marketing.

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TriQuint Aiming for Higher Levels of RF Integration

Introduces a new process designed for wireless handset transceivers

What is the optimum level of integration for the RF portion of a wireless handset? The most common current practice is decidedly *unintegrated*. Manufacturers build up the RF front ends of cellular phones by mixing and matching transmit/receive switches, low noise amplifiers, power amplifiers and up/down converters and other components.

Most everyone agrees that this phase will pass as the industry matures. But what will take its place? TriQuint Semiconductor recently relayed their vision of the future by announcing the availability of a new MESFET process designed to integrated transmit and receive functions in mixed-signal RF applications. Their goal is the realization of a single-chip RF front end, as shown in figure, below.

The company describes the new process, which is called the TQTRx (for TriQuint Transmit/Receive) as "the first commercially available true RF transceiver process". This is TriQuint's fourth proprietary GaAs foundry offering.

The Process

TQTRx is a 0.6 micron enhancement/depletion mode process with an integrated MESFET power amplifier. It supports RF applications up to Ku-band and supports mixed-mode applications up to LSI complexity. It uses three thick global metal interconnect layers that are encapsulated in a high-performance interlayer dielectric to allow a high degree of wiring flexibility and plastic packaging simplicity. Precision nichrome resistors and very high value MIM capacitors are included. Key figures of merit are given in the table, below. The new process requires 16 mask layers, which the company says is 2/3 the number required for comparable bipolar processes.

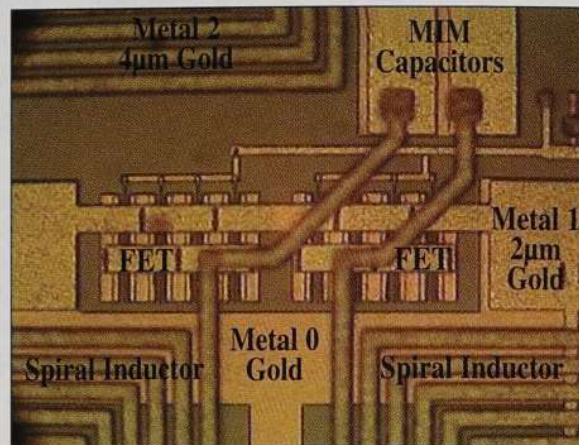
"The TQTRx realizes TriQuint's vision for a single GaAs technology that fully integrates the RF front end," said Rob Christ, TriQuint's Foundry Marketing Manager. "This is the first process that combines transmit and receive functions and it's the first to integrate power with small signal capability.

That makes it the first commercially available true RF transceiver process."

"As RF communications applications move away from discrete transistors, it's clear that GaAs is the most efficient and cost-effective way to integrate RF functions," adds Christ. "We expect the TQTRx process will have a very positive impact on RFIC design cycles, system costs and overall time to market for our foundry customers."

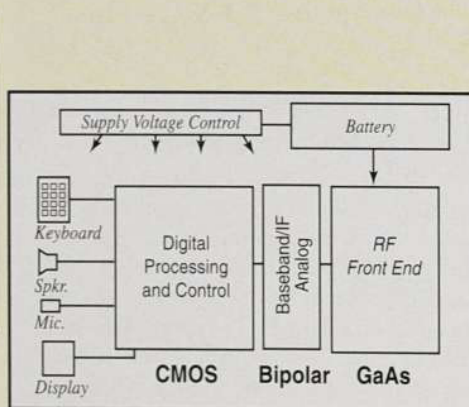
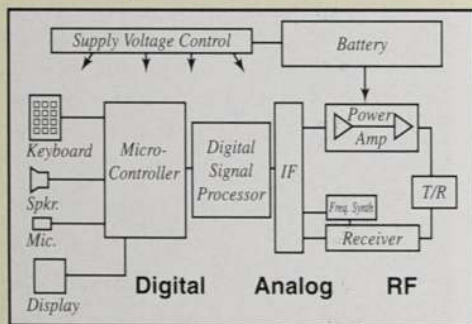
TriQuint offers three other GaAs MESFET contract fabrication processes. The QEDA is a 1-micron enhancement/depletion mode MESFET process used for RF and mixed analog/digital circuits, supporting RF applications up to X-band and digital circuits of LSI complexity. The HA2, a general purpose RF block process, is a 0.5 micron depletion mode MESFET featuring thick metals up to 6.3 microns. The TQHiP, is a high power extension of HA2 with FETs tuned for maximum linearity saturation current and power output.

All of TriQuint's processes are based on ion-implanted 4" wafers.



Photograph of circuit fabricated using TriQuint's new TQTRx process.

Mobile phones today. . .



... and TriQuint's vision of the mobile phone of the future.

Parameter	Units	Specs
MESFET Types	—	E, D, Power
E-FET V _{th}	V(e)	+0.15
D-FET V _p	V (D, Power)	-0.6, -2.2
Gate Length	Micron	0.6
Power Output	MW/mm	>300
f _t , f _{max}	GHz	20, >70
f _{min}	dB	<1
Avalanche Breakdown	V	>15
Interconnect	Total Layers	3
Inductor Quality	Q Factor	>17 at 1.9 GHz
MIM Caps	pf/mm ²	1200
Mask Layers	—	16

Key figures of merit for TriQuint's new TQTRx process.

Sanders to Develop X-Ray Lithography System for GaAs MMICs

Sanders Lockheed Martin [Nashua, NH] has been selected by DARPA to demonstrate a x-ray lithography system for the production of GaAs MMICs with fine linewidths at high throughput levels.

Under a \$10.5 million contract, Sanders Microwave Electronics Division will manage the development of a Point Source X-Ray Lithography System. The system includes an x-ray stepper, x-ray point source and beamline interface which connects the stepper and the source.

The Point Source X-Ray Lithography System will employ a dense plasma focus technique to generate x-rays that can create circuits with sub-0.15 micron linewidths. This is comparable to results currently available through electron beam lithography systems currently in use. But more importantly, the new system will allow much greater throughput levels than is possible with e-beam processing.

John Heaton, Sanders' program manager for this project, explains, "Until recently, x-ray lithography has remained in the realm of large silicon semiconductor manufacturers because of the high cost of synchrotron x-ray sources. Our approach is to use a point source technique to produce a commercially viable system for the fabrication of silicon and GaAs semiconductors on a smaller scale, and thereby realize a greater

volume of circuits at a lower cost."

According to Heaton, the ultimate goal is the demonstration of a system that is capable of processing five to ten 8" MMIC wafers per hour. The program will proceed in two phases: the first phase, of 15 months duration, will involve component development. The second phase, if funded, will last for 18 months, and will involve the construction and demonstration of a beta-site system.

High Frequency Applications

Heaton says that the x-ray lithography system, when applied to MMICs, should be quite capable of 0.1 micron resolution. The same linewidths are currently available with e-beam direct write systems, but at significantly lower throughput levels.

Does the industry need this capability? Many of today's high volume operations - Anadigics, TriQuint, M/A-COM, Raytheon and Rockwell, to name just a few - rely on MESFET processes with minimum linewidths of 0.4 - 0.5 microns (see CS 2(5), p. 12). Heaton explains that Sanders' interest is primarily for other types of FETs at higher frequencies. He said "We need 0.1 micron for the performance of both power and low noise devices at 60 GHz and 94 GHz, and some applications at 120 and 180

GHz." He points out that the previously mentioned commercial houses are currently making most of their high volume products for below 3 GHz. "Below 60 GHz you can get by quite well with 0.15 micron linewidths; below 20 GHz, quarter micron and half micron do the job."

Heaton describes Sanders' MMIC effort as "military oriented", but he also says that the company sees opportunities for high frequency devices in the commercial regime, because of increasing spectrum crowding. He predicts that "we will see some big communications systems, such as the Teledisc project, going up to the 20-30 GHz regime. To build those system we are going to need high throughput and dimensions below 0.25 micron to satisfy their requirements." Sanders does currently offer some 0.25 micron MESFET products, but Heaton says the x-ray lithography project will primarily involve GaAs PHEMT and InP HEMT circuits. "Even with the small dimensions, the MESFETs cannot provide the necessary performance," he says.

Sanders will serve as system integrator and will provide chip fabrication and development. Major subcontractors to Sanders include Suss Advanced Lithography (SAL) of Waterbury, Vt.; Science Research Laboratory (SRL) of Somerville, Mass.; and the Center for X-Ray Lithography (CXrL) at the University of Wisconsin at Madison.

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GaAs Market Heading Toward \$2 Billion

Continued global demand for communications will enable continued growth in the GaAs sector through the year 2000, according to a recently released report from Strategies Unlimited.¹ The worldwide market for GaAs devices is forecast to reach \$2.2 billion in 2000, up from \$1.3 billion in 1996. This equates to a compound annual growth rate (CAGR) of 15%.

Not surprisingly, analog devices are expected to lead the way. The report forecasts that analog IC sales will rise from \$655 million in 1996 to \$1.3 billion in 2000, a CAGR of 19%. Much of that growth is attributed to dramatic increases in the production of wireless telephones. Concurrently, the demand for high speed data communications is expected to push the market for GaAs digital ICs from \$115 million in 1996 to \$327 million in 2000, a CAGR of 30%.

A surprise in the report is the conclusion that North America led the world in the production of GaAs devices in 1996. The successful shift from military to commercial markets in the U.S. allowed North American companies to capture 47% of the worldwide market, with Japanese companies following closely behind with 44%.

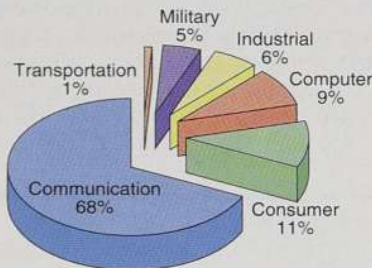
Strategies Unlimited finds that the North American companies are particularly strong in IC production, while Japanese producers such as Fujitsu, Matsushita, Mitsubishi and NEC continue to dominate discrete transistor production. But the report also forecasts stagnation in the discrete market. From 1996 to 2000 the ICs are expected to increase their market share from 60% to 75%, growing by more than 20% annually. But in that same period, the market for discretes is expected to grow at only 3% a year. Which leads to the conclusion that the Japanese producers will need to adapt a new strategy to remain competitive. The report also shows that European production continues to lag far behind, accounting for only 7% of total shipments.

GaAs Device Market 1996-2000

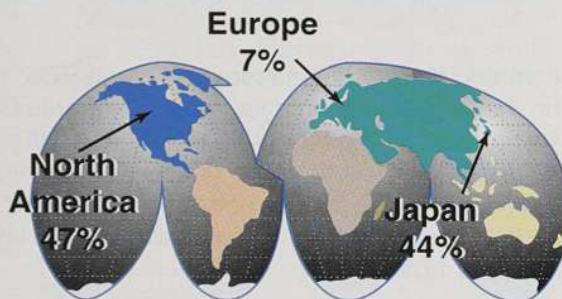


Worldwide market for GaAs ICs and FETs. With an overall annual growth rate of 15%, the market is forecast to grow from \$1.3 billion in 1996 to \$2.2 billion in 2000.

Applications for GaAs in 2000



Segmentation of the GaAs device market in the year 2000 according to application.



Production of GaAs devices in 1996 by geographic region. The remaining 2% of production is attributed to Asian companies other than Japan, most notably Korea and Taiwan.

Awards

The Optical Society of America (OSA) has established a new award honoring Nick Holonyak, Jr. The award will recognize individuals who have made significant contributions to optics based on semiconductor materials, including basic science and technological applications. The \$1,500 award will be presented annually beginning in 1998.

Holonyak, a professor at the University of Illinois Center for Advanced studies, is being honored for his career in quantum electronics, particularly his contributions to semiconductor light emitters. His early work involved breakthroughs in the preparation and application of compound semiconductors and extensive work on the optical properties of compounds. He also made the first usable semiconductor laser.

Holonyak did all of his academic work at the University of Illinois, completing his Ph.D. in electrical engineering in 1954. He worked briefly at Bell Labs and the U.S. Army Signal Corps, then spent several years with General Electric before returning to the University of Illinois as a professor in 1963. For his invention of the first light emitting diode, Holonyak has been cited as being responsible for one of the 45 most notable human achievements of the 20th century.

The award was made possible thanks to a gift from Donald and Carol Scifres and from Holonyak's former students. Scifres, who is president and CEO of SDL, Inc., was awarded the OSA Edwin H. Land Medal in 1996 for his pioneering scientific and entrepreneurial contributions to the field of high power semiconductor lasers.

Jerry M. Woodall, a Distinguished Professor of Microelectronics at Purdue University, will receive the Eta Kappa Nu Vladimir Karapetoff Eminent Member's award for 1997. The award recognizes inventions or discoveries that have had significant impact on society and have enhanced public welfare. Eta Kappa Nu is the national honor society for electrical engineers.

Woodall is being honored for his pioneering work in the use of liquid phase epitaxy to fabricate III-V semiconductors. According to the award citation, half of the compound semiconductor devices in use are based on fabrication methods and devices invented by Woodall.

Woodall was also recently elected the 1997 President-Elect of the American Vacuum Society.

¹ "GaAs IC and FET Market Review and Forecast 1996-2000", a 150-page report reviewing the applications, markets, technology and suppliers for GaAs RF, microwave, and digital devices. Price: \$3,950. For more information, contact Strategies Unlimited at TEL [1] 415 941 3438; FAX [1] 415 941 5120; Email strultd@ix.netcom.com; or via the WWW at <http://www.strategies-u.com>.

Vendor News

Picogiga Completes New Plant

Les Ulis, France. In late April, epitaxial wafer vendor Picogiga announced that it had completed construction of its new plant. Staff has been increased 40% to 35 people and new MBE systems were installed to expand production of GaAs epitaxial wafers for wireless communications and digital television semiconductors.

Commenting on this development, Dr. Linh Nuyen, President of Picogiga, said, "The new plant is an important step in the company's expansion program. It took a lot of time and energy. But this investment, which will strongly increase our production capacity, will respond to market demand and strengthen our leadership position."

Picogiga also announced that in the first quarter of 1997 their revenue reached FrF 13.9 million (US \$ 2.8 million), an increase of 16% over the previous year. The company reports that this result was achieved in spite of significant price decreases while demand remains in line with the quarter's production capacity.

Siemens Invests in Freiburger

Freiberg/Sachsen, Germany. Siemens AG has acquired a 12.5% stake in GaAs substrate vendor Freiburger Compound Materials GmbH. The interest was acquired from Federmann Enterprises Ltd., Tel Aviv, Israel.

Freiburger is the largest European-based supplier of GaAs wafers. The company is in the process of relocating its operations to a new facility that will allow them to expand their production capacity.

Epitronics Promotions

Danbury, CT. Epitronics Corp. recently announced three promotions.

Dr. Michael A. Tischler is now vice president of operations. Based at Epitronics manufacturing headquarters in Phoenix, Tischler is responsible for operations related to III-V (including gallium nitride) manufacturing and technology, and for planning and executing Epitronics' manufacturing capacity expansion. Dr. Timothy F. Murray is now director of sales and marketing, located at the Phoenix manufacturing facility. And Dr. George R. Brandes was named manager of research and development. He now manages research and production for SiC substrates and epitaxy, wide bandgap device processing, and flat panel display cathodes.

Three Companies Expanding III-V Gas Production

Morton International recently announced a multimillion-dollar purchase of land and facility in North Andover, MA to accommodate a planned expansion of its metalorganics production for the compound semiconductor industry. The new facility will allow for production advancements to meet the growing demand for high purity metalorganic aluminum, gallium and indium sources.

"The planned expansion of metalorganics production and research will enhance Morton's position as a leading supplier and demonstrates the company's ongoing commitment to this business," said Bob Stennick, market manager of Morton's metalorganics product line. "In addition to an increase in capacity, the facility will include significant advances in process quality control, research and development, and analytical capabilities."

Not far away, Epichem is finishing up a new manufacturing facility in Haverhill, MA, that will complement the company's existing facility in Bromborough, England. Epichem will also continue to use Air Products' facility in Hometown, PA where they have produced and transfilled select compounds for the past seven years.

And finally, Solkatrik Chemicals has begun construction on its second electronic gas production facility in Catoosa, OK. The first phase of the new plant, which is due to come on-line in the second quarter of 1997, will produce arsine, phosphine and dopant mixtures.

Briefly

Milton Keynes, UK. Wafer Technology has been awarded a Queen's Award for Export Achievement. The award is granted to selected British companies to mark three consecutive years of increased export sales. During the last three years WT increased exports by 90%.

Paris, France. Rhone-Poulenc has received ISO 9002 certification for its gallium activity.

Lowell, MA. M/A-COM has set up a web site dedicated to their GaAs semi-insulating substrate business. See <http://www.macom-gaaswafers.com>.

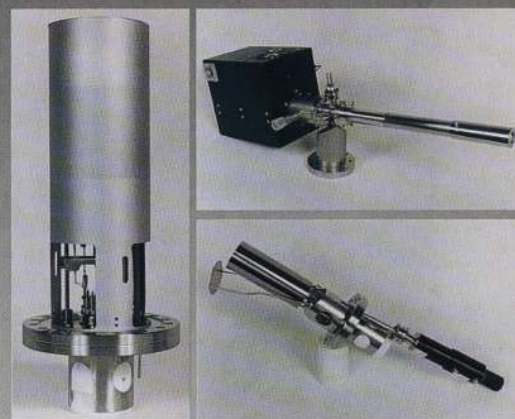
Aachen, Germany. Aixtron has established a web site describing their MOCVD business. See <http://www.aixtron.com>.

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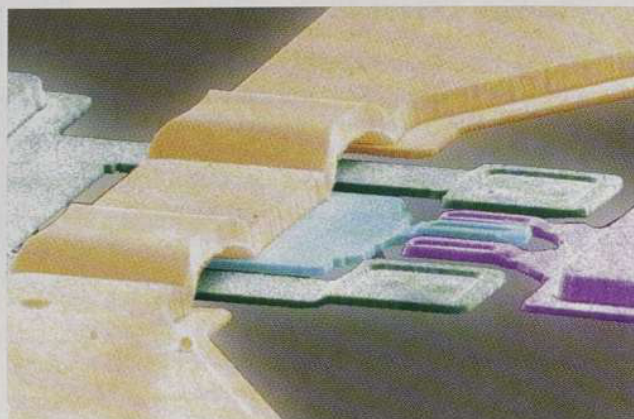


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Will HBTs be the Next Compound Semiconductor Success Story?

On the eve of their 50th anniversary, HBTs are moving into high volume production.

MARIE MEYER



The heterojunction bipolar transistor - the HBT - is nearly as old as the transistor itself. William Shockley described the basic concept in a patent application filed in 1948¹, which means that next year will be the 50th anniversary of the HBT's invention.

Of course, at the time of its invention, it was technologically impossible to produce what we recognize as an HBT. It was not until the late 1970's that the keys to removing what Herb Kroemer called "the heterostructure technology bottleneck" appeared, in the form of MOCVD and MBE reactors. Since 1982, when Kroemer published a review article that predicted that HBTs would someday challenge the "overwhelming dominance of the compound semiconductor device field by FETs,"² HBTs have been the object of intense and enthusiastic scrutiny.

But all of that effort failed to yield any significant applications outside of the defense/aerospace realm. There simply have not been many non-military systems or products that require the HBT's efficiency and linearity.

Now, however, it seems that wireless revolution is about to do for HBTs what it did for GaAs MESFETs - launch them into high-volume, ultra-cost-conscious competitive environments. Digital cellular phones will be the scene of much of the activity, but there are other potential markets as well, including both analog and digital circuits for fiber optic networks.

At this early stage it remains difficult to say what companies - and what kinds of HBTs - will be able to capitalize on these incipient opportunities. There are numerous different approaches to HBT design, especially with regard to material selection, and several competing options enjoy significant support. The following is a survey - by no means complete - of some of the most prominent commercial projects. Following that, beginning on page 40, are some of the highlights of current research (admittedly even more incomplete).

In the past two years, the compound semiconductor industry has seen the sudden emergence of some very profitable niches - for example, the rapidly expanding GaAs MESFET business, and the high brightness LED revolution. It looks like HBTs are poised to become the next "overnight success story" - a mere 50 years after their invention.

NEC's HBT Philosophy

HBTs offer a number of attractive features, but matching them to a particular application requires analysis of a number of factors. Kazuhiko Honjo and colleagues at NEC have created an elegant summary of the features of active devices and the suitable application fields for HBTs and two major competitors - HEMTs and Si bipolar transistors. See Figure One. As shown in the figure, HBTs excel in terms of low $1/f$ noise, high breakdown voltage, large power handling capability, low standard deviation for turn-on voltage, and high transconductance with high $f_{\max}$ and f_t .

NEC believes that this set of features suggests three major potential applications for HBTs. Low $1/f$ noise with high $f_{\max}$ is necessary for low phase noise microwave and millimeter-wave oscillators. The characteristics of high transconductance, low variation in turn-on voltage with high f_t and high $f_{\max}$ is suitable for high-speed digital circuits such as fiber optic communication ICs. And the feature of high breakdown voltage and large power handling capability with high $f_{\max}$ is attractive for power transistor applications.

These three fields offer excellent growth potential, which helps to reaffirm the image of the HBT as an exciting piece of technology. But before a semiconductor company can jump into product development, it first has to pick its material system - and there are several to choose from. Figure Two summarizes approximate calculations of intrinsic f_t and $f_{\max}$ for the most mature HBT material system, AlGaAs/GaAs; an alternative III-V system, InAlAs/InGaAs (or InP/InGaAs); and the most recent challenger, SiGe. Also shown are the figures for bipolar Si.

It is obvious from Figure Two that the III-V devices exhibit high f_t and $f_{\max}$, as well as a clear trade-off between these two features. This is not the case with SiGe, where the $f_{\max}$ remains essentially constant, regardless of f_t . This difference is due to the fact that the base resistance and base layer thickness impacts the base transit time in the III-V devices, whereas in SiGe, which has low electron mobility, there is no comparable relationship.

Which set of characteristics is most desirable? Kazuhiko Honjo, speaking on behalf of his colleagues at NEC, says, "when we consider microwave and millimeter-wave applications, $f_{\max}$ becomes

¹ US Patent # 02569347, filed June 26, 1948. Shockley did not use the phrase "heterojunction bipolar transistor". Instead, he described an n-p-n transistor "in which one of the separated zones is of a semiconductive material having a wider energy gap than that of the material in the other zones".

² H. Kroemer, Proc. IEEE 70, p. 78 [1982].

one of the most important figures of merit, and f_i matters little." In this case, the advantage lies with the III-V HBTs. In comparison, Honjo says that both f_i and f_{max} should be considered when evaluating digital IC applications. In this case SiGe can be more competitive, especially if it can live up to its promise of offering high performance at low cost.

HBTs for Cellular Phones

Of course this cost/performance relationship is also important for the III-V materials, especially if a company intends to pursue high volume markets. One of the perceived disadvantages of HBTs in comparison to GaAs MESFETs is that the HBT requires sophisticated epitaxial layers as a starting material.

NEC's solution to that problem is to make maximum use of that expensive real estate. The company recently announced that it has developed an AlGaAs/GaAs HBT power amplifier which satisfies the requirements of the Japanese Personal Digital Cellular Phones (PDC) standard in a chip area which is just one-fifth the size of a conventional GaAs power MESFET.³ This means that more chips can be obtained from each wafer. Moreover, the fabrication process, which is called the Hetero-Guardring Fully Self-Aligned Transistor (HGFST) technique, requires just twelve masks.

NEC has used the HGFST process to demonstrate operation at 3.4 V, which means that it can be used in handsets designed around a single lithium ion battery. A $2 \times 20 \mu\text{m}^2 \times 60$ emitters power

amp achieved a power added efficiency >60% with adjacent channel leakage power below -53 dBc at 50 kHz offset band for 950 MHz and 1.5 GHz at a CW-output power level around 31.5 dBm. NEC believes that this is the first device that has been able to operate on a single battery and meet CDMA specifications.

Because of the small size and the low number of processing steps, NEC believes that such a device can be produced in a cost-effective manner, leading them to conclude that "AlGaAs/GaAs HBTs have great potential in personal digital cellular systems operating at a low voltage".

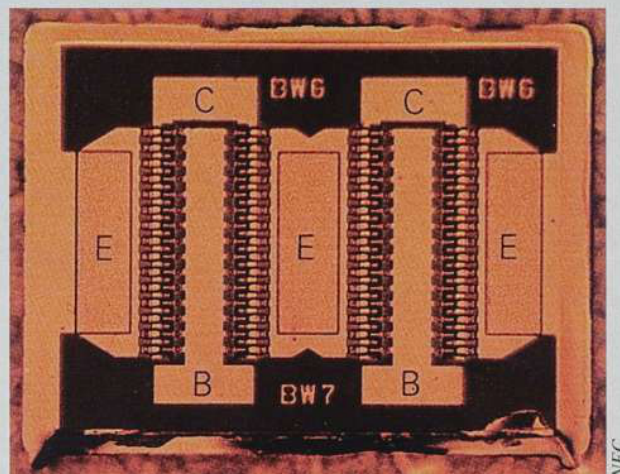


Figure Three. Chip photograph of the NEC HBT power amp with $2 \times 20 \mu\text{m}^2 \times 60$ emitters.

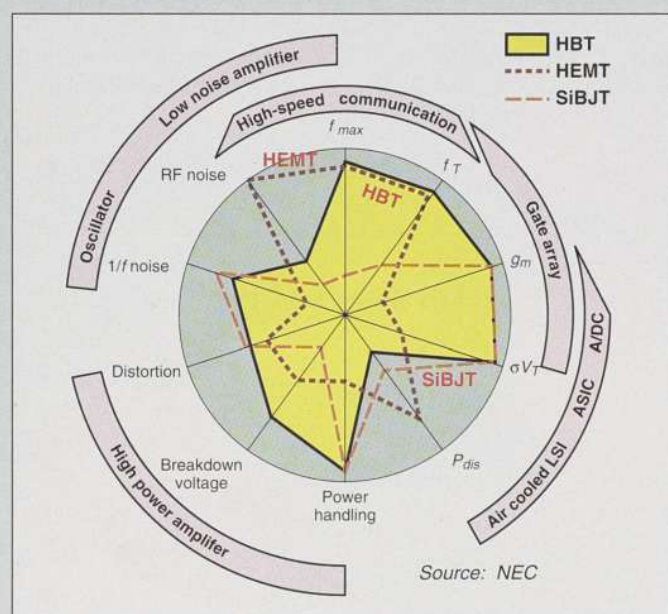


Figure One. Strengths and weaknesses and potential applications for three device types: HBTs, HEMTs, and silicon bipolar transistors. Ten features of active devices are listed (f_{max} , f_T , etc.). The circle periphery represents the best performance for each item. The center of the circle shows the poorest performance. Suitable applications are indicated outside of the circle.

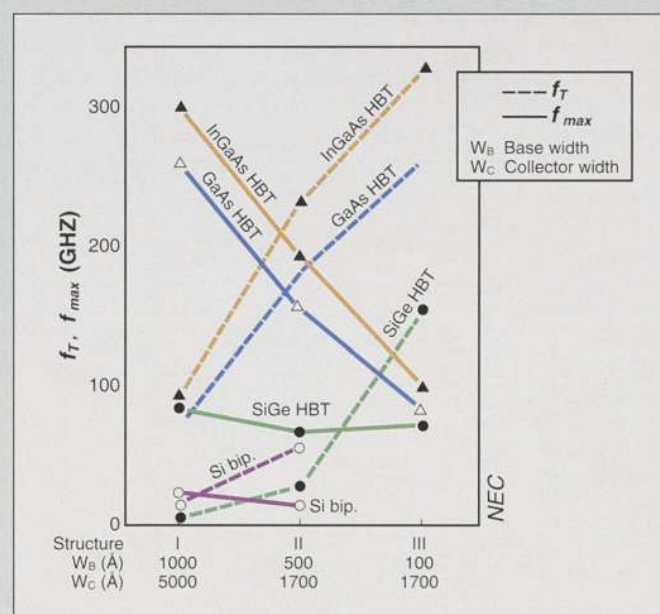


Figure Two. Comparison of intrinsic f_T and f_{max} among four types of bipolar transistors. The two III-V based HBTs exhibit high f_T and f_{max} , as well as a trade-off relation between these two factors. There is no such trade-off with SiGe; however, it has relatively low f_{max} values. NEC believes that for microwave and millimeter-wave applications, f_{max} becomes one of the most important figures of merit, and f_i matters little.

³ Nobuyuki Hayama et al, NEC Research & Development Vol 38 (1), page 10 [1997].

RF Micro Devices Introduces Wall Street to HBTs

RF Micro Devices seems destined to be known as "the HBT company". They are currently a "fabless" semiconductor vendor, offering GaAs HBT, GaAs MESFET and silicon bipolar transistor products. But HBTs are the core of their expertise, and they account for 85% of the company's current sales. And RFMD will soon lose its fabless status - it is building the world's first dedicated HBT fab in Greensboro, NC. To help raise funds for the expansion, the company will conduct its initial public offering (IPO) of stock, likely in May or June. Thus the company will join the ranks of Anadigics, TriQuint and Vitesse as a closely scrutinized flag bearer for the GaAs industry.

RFMD offers a broad array of products, including amplifiers, mixers and modulators/demodulators. As of March, 1997, the Company offered 63 products, and 40 additional products were said to be in development. In the past year the company has doubled employment to 131 employees.

The RFMD/TRW Alliance

The new fab will be the centerpiece of a strategic alliance between RFMD and TRW formed in 1996. The two companies have teamed up in order to develop TRW's HBT technology for high-volume applications in the wireless market. (See CS 2(2), 13). TRW will continue to produce HBTs for its own use and for its own customers, while RFMD will manufacture HBT circuits, under an exclusive license, for wireless applications below 10 GHz. TRW is RFMD's biggest shareholder. After the IPO, it will own 31.1% of the RFMD common stock. TRW is currently manufacturing all of RFMD's GaAs HBT products¹.

The new fab is a critical step in RFMD's progress. As sales have increased, the company has struggled to keep up with demand, and that has cost them at least one customer - Qualcomm recently switched to other suppliers because RFMD could not keep up with their requested delivery times and quantity requirements. This is a painful blow, as

Qualcomm was RFMD largest customer in the past year. In addition, other companies have been reluctant to rely on RFMD because of their perceived weakness in this area, and because of the lack of potential second sources. (There are believed to be only **two other commercial HBT suppliers at this time - Rockwell and TRW.**)

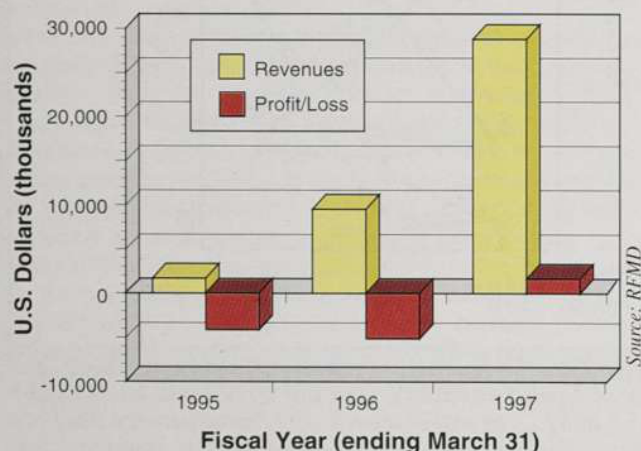
RFMD plans to source HBT wafers from TRW until the year 2000, but also plans to build up its own in-house supply at the new fab, using the MBE process licensed from TRW. The technology transfer could be tricky - for example, TRW's process is based on 3" wafers, but the new RFMD fab will be 100% 4". So in addition to replicating TRW's complex proprietary manufacturing processes, RFMD must also adapt to the larger wafers, which involves a number of technical hurdles including the development of new back-side wafer thinning processes.

The fab is scheduled to be developed in two phases, the first of which has a budgeted cost of \$40 million and the second of which involves an expansion of production capacity at a budgeted cost of \$30 million. The company expects to use approximately \$15 million of the net proceeds from the IPO to finance a portion of the first phase, and to finance the remainder of such phase with cash on hand and previously obtained financing commitments. RFMD plans to have the fab operating at commercial levels (~ 2,500 wafers per year) in the second half of 1998. Upon completion of the first phase of construction, the fab should have a capacity of 10,000 wafers per year, and when the second phase is complete that number will be raised to 25,000 wafers per year. (For a forecast of the combined TRW/RFMD production, see p. 36.)

The company currently uses five vendors located in Asia and one vendor located in the United States to package and assemble its products. RFMD tests 100% of its products for compliance with both DC and RF parameters at its facility in Greensboro, North Carolina.

For a report on the outcome of the RFMD IPO, see the "Portfolio" section of our next issue.

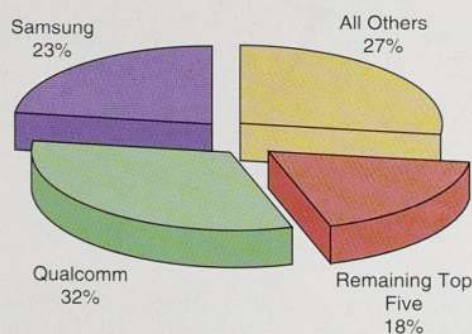
Growth at RFMD



RFMD has posted remarkable increases in sales over the past 3 years, reaching \$28.8 million in the year ended March 31, 1997. The company says it expects 100% annual growth for the next 3 years.

¹ RFMD's MESFETs products are fabbed by TriQuint and ITT.

RFMD Sales by Customer



In the past year the majority of RFMD's business came from Qualcomm and Samsung, who combined made up more than half of the company's sales. But RFMD recently announced that they do not expect any further orders from Qualcomm. The company says other major customers include Nokia, Hyundai, Motorola and LG.

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Rockwell Ramps Up

Over the past 16 months Rockwell has seen their HBT production explode. The company says it has shipped more than 2 million HBT chips, and monthly production has skyrocketed from just 10,000 units a month in early 1996 to 700,000 units a month today. Further increases, perhaps to as many as 2 million/month, are forecasted for the near future, and further escalations to perhaps as much as 5 million/month are considered possible in five years time.

Rockwell's production is completely merchant - all of their HBTs are being sold to outside companies. They offer a handful of HBT products, covering digital, mixed-signal, and analog applications.

The star of the product line, responsible for the large majority of sales, is the R12002, a power amplifier module for CDMA-based digital wireless communications. Rockwell's HBTs are being used in handsets sold by **Qualcomm, Samsung, Lucky GoldStar.**

2 Million and Gro3wing

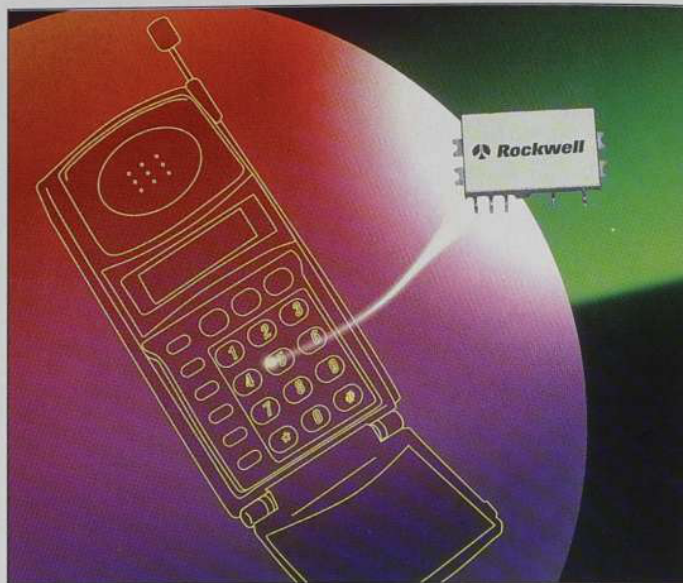
According to Deepak Mehrotra, Marketing Director of the Wireless Communications Division of Rockwell Semiconductor Systems, Rockwell shipped its 2 millionth HBT power amplifier in April.

Of course, there are a number of RF component manufacturers in the power amp business, and not all of them are choosing HBTs for CDMA (see page 8). Mehrotra explains that Rockwell, too, could have gone a different route. The company has internal capability for several semiconductor processes, including CMOS, Si bipolar, GaAs MESFET, as well as GaAs HBT. "Our designers were not constrained on what process technology to use to make the CDMA power

amplifiers" Mehrotra says. "But after trying out test circuits, trying out initial designs on different processes, we came to the realization that HBTs are the way to go for CDMA." The key factors he cites is the combination of efficiency and linearity. The former is important for extending talk time, while the latter is critical for the modulation scheme used in the CDMA standard.

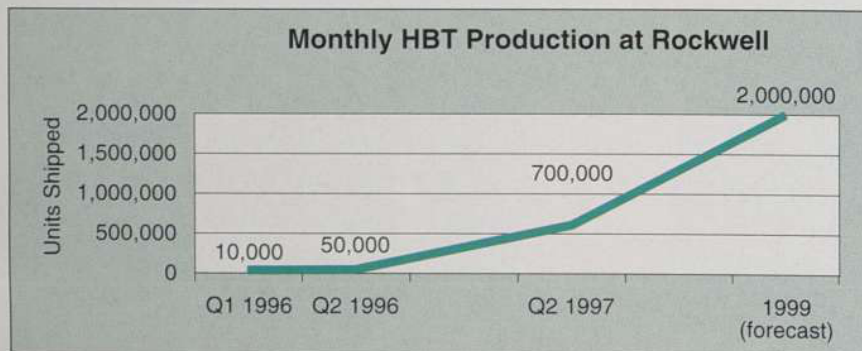
The majority of the Rockwell HBTs shipped to-date are used in 800 - 900 MHz digital cellular phones. But another opportunity is emerging with the roll-out of PCS at 1.9 GHz. (See page 38). Most observers believe that all of the PCS power amps will be GaAs. Silicon just cannot compete at this frequency at this time. This means that HBTs will be going head-to-head with MESFETs in this market.

MESFETs traditionally have the price advantage, but Mehrotra believes that Rockwell's HBTs provide critical performance advantages. "The biggest difference that our customers see is that get one additional hour of talk time with our HBT power amps compared to our MESFET competitors," he says. "In CDMA, the average output power is very low - usually 20 to 40 milliwatts - and so the efficiency of the power amp becomes very important." He says that in a stand-by mode, the HBT draws about 100 milliwatts less than a MESFET.



The Process

Rockwell's process is based entirely on C-doped AlGaAs grown on 100mm wafers, with the epi services being supplied by a combination of internal and external sources. Die sizes range from 15 mm² for some of the digital chips down to as small as 1 - 3 mm² for the RF parts. The lithography linewidths are typically 1.1 - 1.4 microns. The Rockwell process can produce f_t of up to 50 GHz, which is more than enough for the current high volume applications. However, there are more demanding requirements on the horizon. One example is digital chip sets for 10 Gb/s and higher data rates. (Rockwell is already selling HBT chipsets for 2.4 Gb/s systems.) Therefore the company is also experimenting with small lots done at 0.75 or 0.5 microns.



Characteristic	Symbol	Min.	Typ.	Max.	Unit
Operating Frequency Range	Fo	824		849	MHz
Gain @ Po=1dBm	G	26.75	28.5	30.25	dB
Gain @ Po=32dBm	Gls	26			
Noise Figure	NF		<6	8	dB
Analog Mode Output Power	Po	1.5			W
Analog Mode Power Added Efficiency	PAE	46	50		%
Digital Mode Output Power	Pod	831			mW
Digital Mode Efficiency	PAEd	26	32		%
Supply Voltage	Vcc	4.8	5	6.5	V

Electrical specifications for Rockwell's most popular HBT product - the R121002 CDMA/TDMA Power Amplifier.

The Pros and Cons of HBTs

HBTs are most frequently compared to their GaAs cousins, MESFETs. Here's a summary of the most frequently discussed issues.

Advantages of HBTs:

Efficiency — Efficiency is a measure of RF power output as a percentage of battery power consumed by the device. GaAs HBT power amplifiers are more efficient and use less power to transmit the same output power than comparable GaAs MESFET devices. Increased efficiency can translate into improved battery life and increased talk time.

Linearity — Linearity is a measure of the distortion of a signal as a result of the amplification of the signal. GaAs HBT products have higher breakdown voltages and smaller and more constant base-collector capacitance than comparable GaAs MESFET devices, which results in better linearity. Improved linearity can translate into a higher quality signal, which is important for wireless networks using digital air interface standards such as TDMA and CDMA.

Complexity — GaAs HBT transistors are bipolar devices that require only a single polarity power supply, while GaAs MESFET transistors generally require both a positive and negative power supply, which results in the need to include a negative voltage generator and other additional components or circuitry. As a result, GaAs HBT system architectures are simpler and easier to design, which can translate into reduced component costs and smaller equipment.

Die Size — GaAs MESFET devices have a lateral or horizontal design structure while GaAs HBT devices have a more vertical structure. GaAs HBT circuits can be made smaller than GaAs MESFET devices, enabling more die per wafer, which can increase manufacturing yields and translate into reduced costs.

Feature Size — The critical geometries of an HBT are formed by epitaxial growth. As a result, the HBT circuits have large feature sizes, and can be fabricated using 1 - 2 micron linewidths. This is much more manufacturable than the 0.25 - 1.0 micron gate geometries typically required by GaAs MESFETs.

MESFET Manufacturers respond:

*HBTs, unlike MESFETs, are based on **epitaxial layers**. This added expense can raise the total cost of the end device by as much as 2x, removing any economic justification for their use.

*The advantage of the single supply can be easily overcome by an **on chip charge pump** that takes very little space.

*The supposed **improved linearity** is only a **myth** when HBTs are compared to state-of-the-art high volume MESFET process.

***Long term reliability** can be an issue with HBTs. As a result, performance of commercial HBT processes has been compromised, reducing the competitive performance advantages they have over high speed silicon and GaAs MESFETs in laboratory comparisons.

*Since HBTs have a **very high turn on voltage** (V_{be}) the performance becomes severely impacted as power supplies move to ever lower voltages. At 3 V and below, HBTs can't match the high linearity, good gain and low noise characteristics of GaAs MESFETs. This is critical, because OEM manufacturers are relentlessly pushing to lower voltages.

Which side is correct?

This is one of those debates which is unlikely to be solved on paper. But, as the stories in this issue make clear, we won't have to wait much longer for a head-to-head match-up of these two technologies in the marketplace. Even still, it is unlikely that we will ever be able to say the one of these technologies is demonstrably superior to the other. The more important question will be which company is capable of delivering inexpensive RFICs in a timely fashion.

HBT data courtesy RFMD

The Future

One advantage of other technologies may be easier integration of multiple functions onto a single chip. But Mehrotra says that is not an issue in the current high volume markets. "The power amplifier, as far as we can see, will always be a separate function" he says. This is because it generates enough heat that it might degrade the performance of the

other functions on the die. "Our goal is to have a one-chip radio and a one-chip base band, but there will also be a one-chip PA." (For a differing opinion, see page 26.)

Given that Rockwell has several processes in-house, they could easily switch away from HBTs if they needed to. And given that the handset manufacturers revamp their product lines on a yearly basis, there is the need for constant re-evaluation. Mehrotra says

"We have to have migration plans that let us stick with our customers for the long term, and so we look at process technologies that allow us to do that. And possibly, what can be done with HBTs today might be possible with another process three years from now, and maybe we'll move to that."

But for now, he says, Rockwell is planning to stick with HBTs for at least the next two or three years for the CDMA market.

To Be, or Not to Be?

For HBT doping, that is the question. TRW explains why they chose Be.

There are a number of materials-related issues that will be debated in the next stages of HBT development. For example, there are three major materials systems - GaAs, InP and SiGe - under investigation, and, of course, there are many possible variants within each system (e.g. in GaAs, many companies will have to choose between basing their structures on AlGaAs or InGaP emitters).

Nevertheless, it should be clear from the foregoing pages that at least the first round of HBT circuits in production are all based on GaAs/AlGaAs. Yet even here there is some considerable debate regarding materials. At issue is the choice of p-type dopant. Much of the early HBT research was done using Be-doped structures - probably because most of that work was done using MBE-grown material, and virtually every MBE system comes equipped with a Be source.

As device designers began to push for higher doping levels in the base layer, questions arose about the reliability of Be-doped devices. There were concerns about Be diffusion in heavily doped layers during either the growth of subsequent layers, or during the fabrication process. As a result, C-doping, whether in MBE or MOCVD reactors, became more popular. Indeed, the work from NEC and Rockwell described previously is based on C-doped AlGaAs, as is most of the work being done elsewhere.

TRW (and, by extension, RF Micro Devices) stands out as an exception, because they have persisted with Be doping. And their views cannot be discounted, as they and Rockwell are the only companies that have announced a commercial HBT process.

One Million per Month and Climbing

Production of HBT materials has risen sharply at TRW over the past three years (see Figure One). They are currently shipping over 1 million HBT chips per month, and plan to raise that to 4 million/month by the end of the year - all based on Be-doped materials.

Obviously, the company is quite satisfied with its reliability data. They say they have performed over 10^6 device hours of bias-stressed, elevated-temperature reliability testing over the past five years. As part

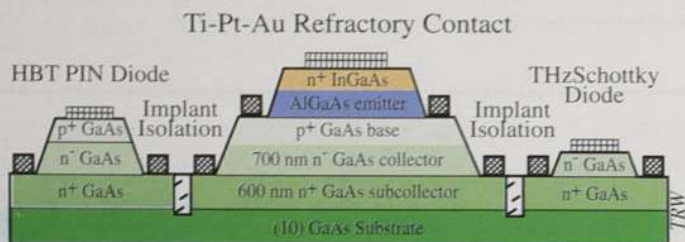


Figure Two. Schematic diagram of the HBT epitaxial profile used in the TRW comparison. The subcollector is highly doped for low R_c . The collector is relatively thick to provide high breakdown voltage. The base is doped at $1 \times 10^{19} \text{ cm}^{-3}$ for both the C-doped and the Be-doped HBT material to provide the optimum combination of reliability and performance.

TRW-RFMD HBT MMIC Production

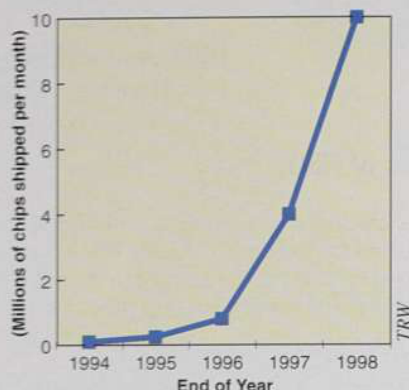


Figure One. Growth in production of HBTs at TRW, plus forecasted production (combined with RFMD's new fab).

of its subcontracting business, TRW has successfully qualified its HBT circuits for demanding military applications and for space flight. And TRW's partner, RF Micro Devices, has tested higher volume products for more commonplace uses. For example, RFMD recently announced a 900 MHz power amplifier (the RF 2155) which delivers 0.5 W at 3.6V with at 57% efficiency. At an ambient temperature of 85°C , and assuming a maximum junction temperature of 135°C under the full output power condition, the MTBF (mean time between failures) for this device is greater than 10^7 hours.

In an invited talk at this year's GaAs MANTECH Conference, TRW's Dwight Streit will present a direct comparison of lifetime data for C-doped and Be-doped material. For the structure shown in Figure Two, he will be reporting extrapolated lifetimes at 125°C junction temperature which are about 2×10^5 hours for C-doped material and 2×10^8 hours for Be-doped material.

Commenting on this result, Streit says "although carbon doping once seemed like a 'magic bullet' for HBT reliability problems, in reality it has taken nearly a decade of work to achieve reasonable device reliability with carbon base doping. And although early work with Be-doped HBTs did reveal reliability problems associated with interstitial Be diffusion, we now have a good understanding of the problem, and have it under control. As a result, we have been able to develop a robust

con't on p. 38

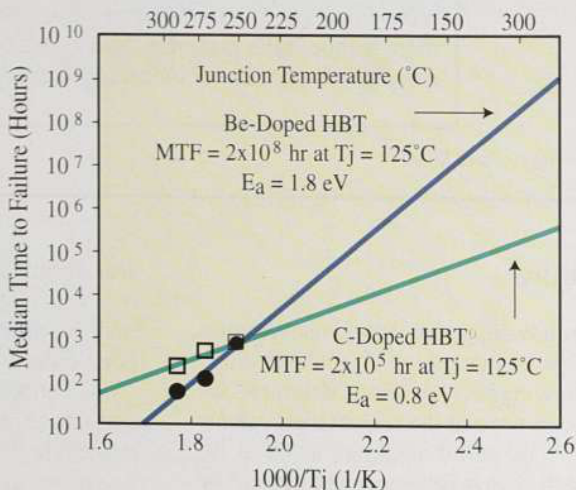


Figure Three. Be vs. C doped 3-temperature life test results. Nominally identical profiles processed and tested together.



8th International Conference on II-VI COMPOUNDS

25 -29 August 1997
Grenoble. France

FOREWORD AND GENERAL INFORMATION

The 8th International Conference on II-VI Compounds will be held in Grenoble, 25-29 August 1997. The conference will focus on fundamental aspects and on recent perspectives for applications of narrow and wide bandgap II-VI semiconductors. Areas of interest include: materials science, where many long-standing problems (particularly compensation) are still to be solved, low-dimensional physics including semi-magnetic heterostructures, and optoelectronic applications. The following main topics will be covered:

- *materials growth*: narrow and wide bandgap materials, substrates for devices, control of doping, epitaxial growth
- *fundamental properties and characterisation*: theory, electronic properties, surfaces, interfaces, defects, transport, electroluminescence, non-linear optics, photorefractive effects
- *low-dimensional systems* : quantum wells, wires and boxes, superlattices, nanocrystals
- *optoelectronic devices* : IR detectors, blue lasers, X- and g-ray detectors and other applications.

Other emerging subjects such as microcavities will also be highlighted. A special session on Wide Bandgap Lasers is scheduled for the Tuesday evening, 26 August 1997. It will be organised by Prof. Arto Nurmikko, Brown University, USA and Dr. Akira Ishibashi, Sony Corporation, Japan.

PRELIMINARY LIST OF INVITED SPEAKERS

J.P. Chatard, SOFRADIR, Chatenay-Malabry, France
Progress in HgCdTe homojunction infrared detectors.

T. Dietl, Academy of Sciences, Warsaw, Poland
Confinement effects in semimagnetic semi-conductors.

Y. Eisen, SOREQ NRC, Yavne, Israel
CdTe and CdZnTe materials for room temperature X-ray and g -ray detectors.

Sz. Fujita, Univ. Kyoto, Japan
p-type doping by MOCVD and MOMBE.

I. Galbraith, Univ. Heriot-Watt, Edinburgh, UK
Coherent exciton-biexciton interaction studied by femtosecond spectroscopy.

J. Gutowski, Univ. Bremen, Germany
Excitonic optical nonlinearities and dynamics in II-VI heterostructures and laser diodes.

S. Johnson, SBRC, Santa Barbara, California, USA
HgCdTe heterojunctions for infrared multispectral sensor applications.

P. Lavallard, Univ. Paris, France
Excitons in nanocrystals.

J.L. Merz, Univ. Notre-Dame, Indiana, USA
Self organized growth, " ripening " and optical studies of wide-bandgap II-VI quantum dots.

T.J. Miller, 3M-Company, St-Paul, Minnesota, USA
Beryllium-based II-VI blue lasers.

N. Nakayama, Sony Corporation, Yokohama, Japan
Recent progress in Se-based blue-green lasers.

A. Ohtake, JRCAT, Tsukuba, Japan
Characterization and control of II-VI / III-V heterovalent interfaces.

V. Savona, EPFL, Lausanne, Switzerland
Strong polariton coupling in microcavities: theory and applications.

A. Waag, Univ. Würzburg, Germany
Novel Beryllium-containing II-VI compounds: basic properties and potential applications.

Further invited papers will be scheduled following the submission of abstracts.

IMPORTANT DATES

Registration	10 July
Hotel	10 July
Late News	1 August

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Whither CDMA?

Earlier in this issue (page 8), CDMA handsets were discussed as a market for GaAs MESFETs. But CDMA phones are also a key test market for HBTs - both Rockwell and RFMD are pursuing this niche. Therefore it seems appropriate to query CDMA's status.

First, a review of the basics.

Everything is easier in analog - practically any analog phone will work with practically any analog cellular service on a given continent. But not so with the new digital services. There are two competing, and incompatible, digital standards: CDMA (code division multiple access) and TDMA (time division multiple access). If you buy a CDMA phone to use with a CDMA service, you won't be able to use it if you switch to a TDMA service provider or travel to an area where CDMA service isn't offered.

As if that were not confusing enough, we now have the new option of PCS (personal communications services). PCS is similar to digital cellular, except that it operates at 1.9 GHz instead of 800 - 900 MHz. And again, there are competing standards: GSM (global systems mobile) and CDMA.

CDMA uses direct sequence spread spectrum technology to provide more conversations for a given bandwidth. It requires very linear transmission to prevent spectral regrowth as well as high DC to RF conversion efficiency at low power levels. Overall, the performance specifications of the power amplifier is critical in a CDMA phone - which is very good news for GaAs.

CDMA is widely recognized as a technically superior standard. However, that alone will not guarantee success. After all, many people said the same thing about Betamax VCRs. CDMA is coming late to the party, and is very far behind its rivals, especially GSM. In addition, the current digital market is tiny in comparison to analog. See chart, above.

Never fear. The digital handset market is predicted to overtake analog in just a few years. Better yet, CDMA appears to be catching on. PrimeCo (a partnership involving AirTouch, Bell Atlantic, NYNEX and US West) is offering CDMA PCS services in 16 U.S. cities. Sprint also offers CDMA services in several cities.

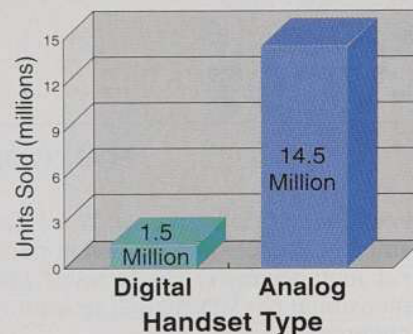
More importantly, CDMA is gaining momentum outside of the U.S. This is a critical because the non-North American market is currently dominated by GSM, a standard where GaAs is less competitive. GSM is currently the primary service for 90% of the digital wireless subscribers worldwide. Nevertheless, there are believed to be around a million CDMA phones in use in Korea and Hong Kong. And recent news from Japan, which is the world's fastest-growing cellular market, is extremely encouraging. In March, the Japanese Ministry of Posts and Telecommunications endorsed CDMA as a national standard, and Motorola landed a \$3 billion deal to build up a CDMA infrastructure capable of handling up to 20 million subscribers.

The overall handset market is forecasted to reach 150 million units by 2002. By that time, digital cellular and PCS will account for ~99% of all new handset sales. The Strategis Group predicts that 25% of the handset market - 34 million units - will be based on CDMA.

Of course, CDMA isn't the only standard that is good for GaAs. Most experts believe that the entire PCS market, with its higher operating frequency, will be supported by GaAs power amps. But CDMA is very nice because it also helps to improve GaAs's attractiveness at 900 MHz, where silicon is traditionally competitive. In short, whatever is good for CDMA is generally good for GaAs fabs, whether MESFET or HBT.

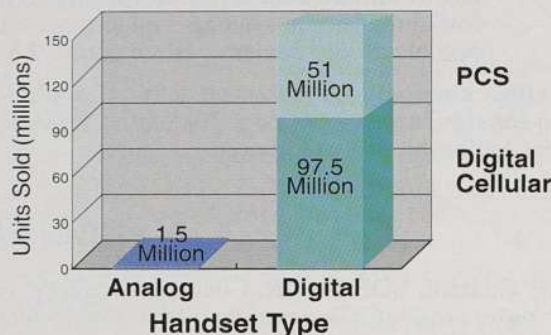
Remember that the next time you are shopping for a phone.

1996 Handset Sales by Type



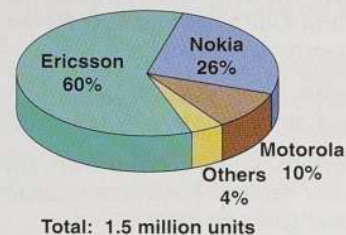
Source: The Yankee Group

2002 Handset Sales by Type



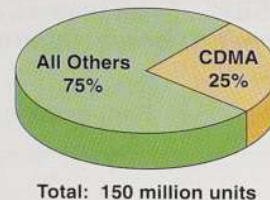
Source: The Strategis Group

1996 Digital Handset Sales by Manufacturer



Source: The Yankee Group

2002 Handset Sales by Standard



Source: The Strategis Group

process for Be-doped AlGaAs HBTs which consistently yields discrete devices with lifetimes greater than 10^8 hours and IC lifetimes greater than 10^7 hours." He goes on to say that "the current confusion in the literature regarding the relative reliability merits of C vs Be is due to the low activation energy of C-doped HBTs, which yields a longer device lifetime when tested at a single temperature above

about 250°C." He believes that when a full 3-temperature test is done, Be-doped material is not only comparable to C-doped material, it is actually superior.

TRW is so confident in its process that it is ramping up its production even further. They recently became the first company to commission a multi-wafer MBE system for HBT production (see CS 3(3), p. 32), and fur-

ther expansion is planned.

It remains to be seen whether other companies repeat TRW's results, or whether they will even try. With the exception of RF Micro Devices, it appears that most of the other companies, when faced with the "to Be, or not to Be" question, chose the latter. It is up to TRW, then, to suffer the slings and arrows - and, perhaps, the outrageous fortune.

A Growing Business

Merchant epiwafer vendors are increasing HBT wafer production to keep pace with demand

Not surprisingly, the rising demand for HBT circuits is also increasing demand for epiwafers. Some companies, like TRW and RF Micro Devices, seem to prefer to have in-house production. Others, like Rockwell, are known for doing substantial outsourcing. At least two merchant epiwafer vendors are increasing capacity to keep pace with anticipated further increases in demand for HBT epiwafers.

Epitronics

In late April Epitronics Corporation [Phoenix, AZ], a subsidiary of Advanced Technology Materials, Inc. (ATMI), announced that it had begun shipping 100 mm AlGaAs HBT wafers to selected customers.

Duncan Brown, President of Epitronics, said, "delivering 100 mm HBT wafers to our customers is an important step in our business plan. We've invested in advanced characterization tools, added to our technical staff, and will take delivery of the first of our high throughput multi-wafer production tools in Q3 1997. Looking forward, the financial strength of our parent, ATMI, should continue to give us access to the resources required to remain current in the market."

The multi-wafer tool he referenced is an Aixtron AIX 2600G3 MOCVD system. It features automatic cassette-to-cassette wafer handling and 76, 100, and 150 mm wafer capability. It can be upgraded to process up to eight 100 mm diameter wafers at one time. When completely configured, the new reactor will be capable of producing up to 2500 100 mm wafers per month.

As part of the purchase agreement, a suite of Epitronics'-developed MOCVD HBT growth processes will be qualified on the reactor prior to shipment.

According to Brown, "This investment is a significant commitment to ensure our customers a stable and growing supply of the enabling starting wafers for their rapidly growing businesses. We invested now so that we can support the ramp ups customers have forecast for 4Q 1997 and 1998."

Tim Murray, Director of Marketing and Sales, commented, "Epitronics has demonstrated competitive capability in all of the HBT materials systems. Our customers will want to produce even higher performance

devices in more complicated materials systems. We intend to support their development work and be a single source for current and future products

Kopin

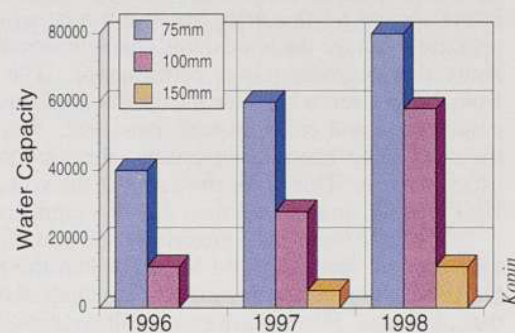
Kopin [Taunton, MA] has been working with HBT materials since 1989. They are probably most well known for their work with C-doped materials. The company says it was the first to offer a C-doped HBT wafer in 1991 - a time when many developmental efforts were struggling to control diffusion of the alternative p-type dopants, Be and Zn. (For more on this topic, see page 36.)

Kopin initiated high volume production of HBT wafers in September 1995. In 1996 they moved to a 7 day, 24 hour scheduled which tripled the number of wafers shipped. Shipments are expected to double again in 1997, to the equivalent of over 17,000 100 mm wafers. And the company is in the midst of installing and commissioning two new Aixtron MOCVD reactors with multiple 100mm wafer capability (See CS 3(2), p. 34.) These systems are expected to bring Kopin's capacity for 100mm wafers to the equivalent of 40,000 wafers/year in early 1998.

Rockwell is one of Kopin's major customers for HBT wafers. But they are not the only one. According to Kopin's Matt Micci, at this time the company has around 30 other customers in North America, Japan and Europe, ranging in size from "companies who are just testing the water to companies that are consuming very large amounts of material." Micci estimates that Kopin has around 90% of the merchant market for HBT wafers and that the "vast majority" of their shipments are 100mm wafers.

And, of course, the majority of Kopin's current shipments are AlGaAs wafers. But the company is also working on InGaP development. Based on input from their customers, Kopin anticipates that there will be demand for high volumes of InGaP HBT wafers beginning in early 1998. The company says that quality of its InGaP product, measured in terms of gain vs. base sheet resistance, is now directly comparable to the more mature AlGaAs products.

Wafer Capacity at Kopin



Annual capacity at Kopin, normalized to production of 75 mm, 100 mm or 150 mm wafers.

InGaP on the Way at GEC

If you follow the R&D announcements in the HBT field, it becomes clear that not everyone is going to base their first products on AlGaAs - especially among the companies that are looking at very high frequencies or very high performance. One such company is GEC-Marconi Materials Technology [GMMT, Caswell, UK]. We asked GEC's Bob Wallis to tell us why. Here is his reply:

"GMMT's earliest work in HBTs, like many other companies, used the AlGaAs/GaAs material system. But a review of the envisaged applications led in 1994 to the decision to develop a new process with much higher performance. A heavily C-doped base layer was seen as essential to achieve high f_{max} figures. It was also decided that this new process would use the InGaP/GaAs material system. It offered several advantages over AlGaAs, including ease of selective etching to contact the base layer and simpler layer

design since grading of the emitter composition was not required. The major risk at that time appeared to be the relative immaturity of the material system and the availability of commercial epitaxial material, although in practice these have not proved to be problems."

GMMT's basic 2 micron emitter stripe devices have f_t and f_{max} in excess of 50 GHz. Circuits fabricated to date include dividers toggling to 17 GHz, broad-band amplifiers with 12 dB gain from 0 to 8 GHz and power MMICs with 3W output power at X-band. There are plans to develop two variants of the core process: one for small-signal analog and high speed digital; and the other for high efficiency microwave power applications. Both are being developed initially in response to systems requirements at GEC, but they will likely also be offered commercially in standard products and foundry services.

Research Reports on HBTs

What will the next generations of HBTs look like? The current R&D literature may provide some clues. Here are a few of the recent highlights.

Power Performance at Low Voltage

T. Iwai et al, Jpn. J. Appl. Phys. 36, p. 648 [Feb 1997]

A constant theme in all types of electronic systems - especially wireless handsets - is the need for lower operating voltages. Researchers from Fujitsu Laboratories recently reported the first microwave power performance of InAlAs/InGaAs/InP double HBTs at an extremely low operating voltage - just 1.5 V.

The "double HBT" structure, commonly used in InP-based materials, has an additional sub-collector mesa not found in single HBTs. It was chosen for this work because it reduces offset voltage. As the operating voltage decreases, this characteristic becomes the dominant factor that degrades power performance. The offset voltage results from the difference between the conduction band discontinuities of the emitter-base and collector-base junctions. The double HBT reduces the conduction band discontinuity - meaning that it also reduces the offset voltage. This work showed that the voltage offset for a double HBT was six times lower than that of a comparable single HBT.

The InAlAs/InGaAs materials were chosen for this work because they provide lower turn-on voltages than the more commonly used GaAs-based materials, because the bandgap of InGaAs is smaller than that of GaAs. The lower turn-on voltage directly impacts the operating voltage.

The HBTs fabricated by Fujitsu exhibited f_t of 76 GHz and f_{max} of 157 GHz. Microwave measurements at an operating voltage of just 1.5 V showed output power of 20.6 dBm, with power added efficiency of 36.6% and a power gain of 8.5 dB biased for Class B-operation at 1.9 GHz.

The researchers at Fujitsu believe that these results are promising for future practical power and high-speed applications.

High Speed in a Small Package

T. Oka et al, Electronics Letters 33(10) p. 339 [13 Feb 1997]

InGaP/GaAs HBTs have many attractive properties compared to their AlGaAs/GaAs counterparts. The large valence band discontinuity at the InGaP/GaAs interface improves the carrier injection efficiency, and the high etching selectivity between the InGaP and the GaAs can greatly facilitate the fabrication process. In addition, the low surface recombination velocity of InGaP reduces the degradation of the current gain when the device is scaled down, which can enhance the prospects of achieving low-power circuits using small-area devices.

Many InGaP/GaAs HBTs with excellent high-frequency characteristics have been reported. But most of those devices have been relatively large, and have required large collector currents for high-speed operation. This leads to large power dissipation in integrated circuits.

So researchers from Hitachi set out to squeeze more performance into a smaller package. They recently reported devices with emitter-areas of just $0.35 \times 3.8 \mu\text{m}$. They were fabricated from a structure that had a heavily-doped (carbon, $1 \times 10^{20} \text{ cm}^{-3}$), relatively thin (300 Å) base layer designed to reduce base transit time and base resistance. A self-alignment technique was used to reduce the parasitic capacitance of the base-collector junction for the small emitter-area devices.

The devices exhibited f_t of 86 GHz and f_{max} of 120 GHz at a collector current as low as 1 mA. The peak f_t and f_{max} were 121 GHz and 149 GHz, respectively. The researchers at Hitachi believe that these results indicate that InGaP/GaAs HBTs are promising for high-speed and low-power integrated circuit applications.

A WDM Receiver Using InP HBTs

E. Sano et al, Electronics Letters 33(2) p. 159 [16 Jan 1997].

Wavelength Division Multiplexing (WDM) offers the prospects of fiber throughput as high as 1 Tb/s. But attaining that level will require improvements in many types of devices. One of the necessary components is a regenerative receiver such as the one shown in Figure One. Receiver packages with an operating speeds of 10 Gb/s have already been developed using GaAs MESFET and Si bipolar ICs. But researchers from NTT recently reported a HBT-based regenerative receiver which offers twice that speed, uses a smaller package, and dissipates less power.

The structure used was an InP/InGaAs double HBT. The fabricated IC - which included a preamplifier, post-amplifier automatic offset controller, PLL-based timing recover circuit, and D-type flip-flop - was just $1.6 \times 1.6 \text{ mm}$ in size. Error-free operation at 20 Gb/s was obtained for an input dynamic range of 13 dB. The power dissipation was just

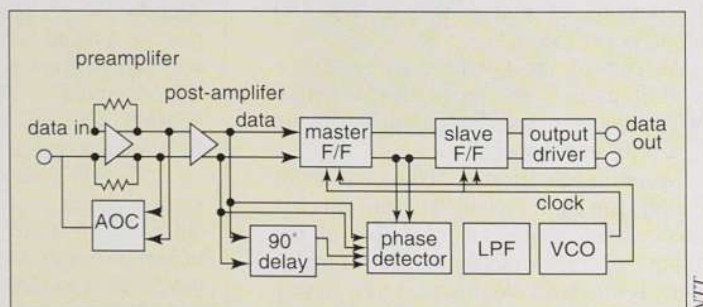


Figure One. Block diagram of a regenerative receiver IC for WDM.

0.6 W. The total power dissipation of a 10 Gb/s GaAs MESFET IC comparable to this one is 13 W. Therefore, the NTT team believes that their approach can lead to significant reductions in the operating energy of the WDM system.

Integrated Laser/HBT Structure

X. Li et al, *SPIE Proc. Vol. 3006, p. 126 [Jan 1997]*.

An ideal approach for OEICs for communications and optical interconnect applications might be to integrate HBTs and lasers onto the same chip. The typical approach is to create such a structure by some advanced processing technique, such as selective area epitaxial growth, etching and regrowth, epitaxial liftoff, and/or flip-chip bonding/substrate removal.

A recent paper from Columbia University shows a simpler approach. An AlGaAs/GaAs double HBT was integrated with an InGaAs quantum well laser. The quantum well of the laser was incorporated within the lightly doped GaAs collector region of the HBT while the p+ base and n+ region of the collector were used as the electrodes of the laser diode. See Figure Two. The epitaxial structure was grown in a single step, eliminating the need for selective epi or regrowth. In addition, the elimination of wire interconnects and the corresponding parasitics between the HBT collector and laser diode

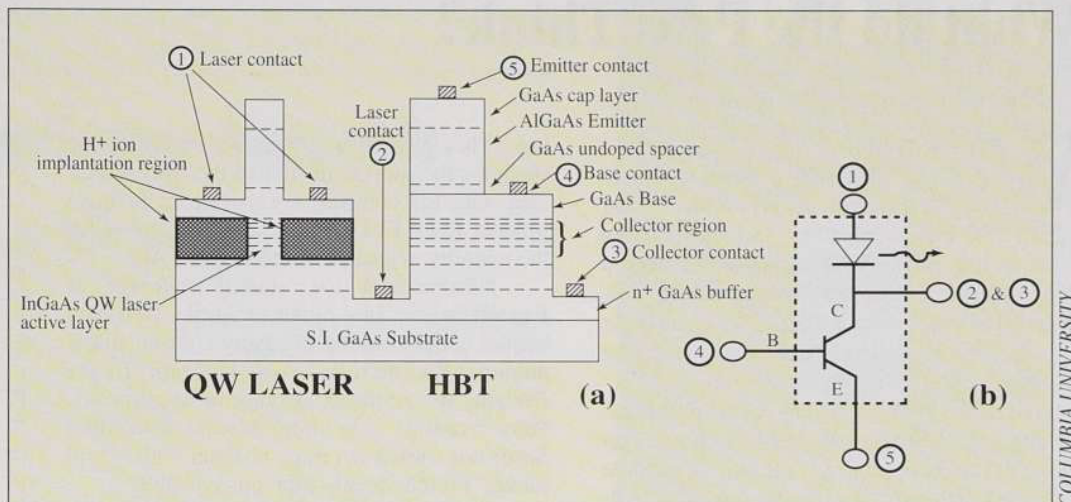


Figure Two. (a) Cross section of an integrated quantum well laser and HBT grown in a single step. (b) Corresponding circuit schematic with terminal assignments.

offers the potential to enhance the performance of the circuit. HBTs with current gains of 60 and lasers with threshold currents of 500 A/cm² were reported.

Planar Processing of HBTs

R. Driad et al, *Electronics Letters* 33(1), p. 85 [2 Jan 1997]

All of the HBTs discussed in this issue - and indeed, virtually all reports on HBTs to date - are based on mesa structures. But there are at least two disadvantages to this approach: one, the device topography presents step heights of >1 μm , which limits large scale integration; and two, it is impossible to simultaneously decrease the base resistance and the base transit time - hence a trade-off must be made on the base layer thickness and doping level.

Researchers at CNET in France recently reported what are believed to be the first high speed lightwave communications circuits based on a fully-planar InGaP/GaAs HBT technology. The epitaxial structures rely on regrowth of the extrinsic base and subcollector

layers. See Figure Three. Cutoff frequencies of 50 GHz and 70 GHz for f_t and f_{max} were reported for a device with a $9 \times 4 \mu\text{m}^2$ emitter-base junction area. High speed integrated circuits, including a 10 Gb/s decision circuit and an 18 GHz dynamic frequency divider, were successfully fabricated from these planar HBTs.

Among the advantages of the planar process is a reduction in base resistance, and the ability to form all of the ohmic contacts in a single step. The CNET team believes that this work has good potential for practical applications, especially in the area of complex high speed circuits.

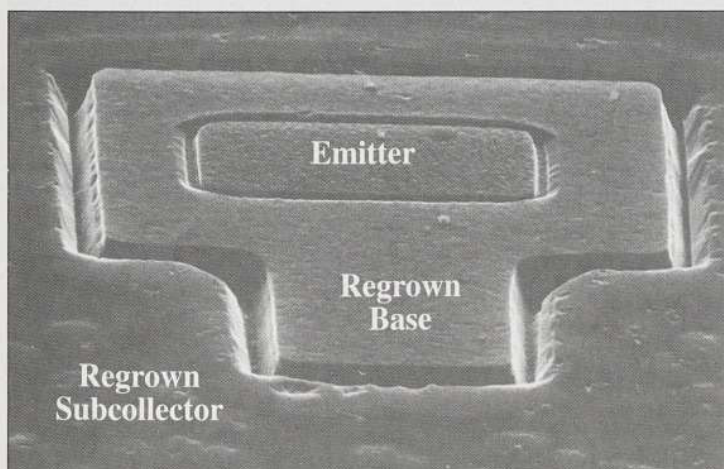


Figure Three. Scanning electron micrograph of a fully planar InGaP/GaAs HBT after base and collector contacts regrowths.

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What do the Pros Think?

Warren Buffet, who is famous in America for being a fabulously successful investor, once said that asking your stock broker whether you should buy stocks is like asking your barber if you need a haircut. One never knows where to turn for reliable advice in the stock market. Nevertheless, it is interesting to see what the analysts are saying about the stocks in our Portfolio.

Here are the most recent pronouncements. Note that several of our Portfolio companies do not attract professional coverage, and so they are not mentioned here. And in the right-hand column is a summary of the analyst ratings compiled by Zacks Investment Research. Again, some companies are missing, for lack of data.

The Pronouncements

In March, Rauscher Pierce Refsnes Inc. started coverage on **Anadigics** with a market outperform rating. In April, Goldman Sachs & Co. upgraded the company to its U.S. "recommended list" from its previous rating of "market outperform".

In early May Lehman Brothers initiated coverage of **Cree Research Inc.** with a buy rat-

ing. They also have a "venture" rating on the stock for the short term "due to the risks associated with the company's exposure to a single product (blue LED) and a single customer for the majority of that product (Siemens AG).

Needham & Co. started coverage of **Emcore** with a buy rating in April. Needham helped underwrite the company's recent initial public stock offering. Also in April, Tucker Anthony Inc. resumed coverage of Kopin with a "buy" rating. In late March Prudential Securities started coverage of Ortel with a hold rating. Further details were not available.

TriQuint has picked up a hat trick of sorts in the analyst department. On April 17, 1997 Cowen & Co. analyst Drew Peck said he upgraded his rating on TriQuint to "strong buy" from "buy." The next day Rauscher Pierce Refsnes Inc. initiated coverage on the company, with a "buy-market outperform" rating on the stock. The firm set a 12-month share-price target of \$32. And then on May 2 Morgan Stanley & Co. jumped on the bandwagon as well, initiating coverage of with an "outperform" rating.

And finally, on March 25 Montgomery Securities analyst Clark Westmont initiated coverage of **Vitesse Semiconductor Inc.** with a buy rating.

The Analysts' Opinions

	Buy	Hold	Sell
AHA	2	3	0
ANAD	8	0	0
ATMI	2	1	0
CLTK	1	0	1
CREE	1	1	0
EMKR	1	1	0
KOPN	2	0	2
ORTL	3	7	0
SDLI	1	0	1
TQNT	7	3	0
VTSS	10	2	0

Source: Zacks Investment Research

RFMD IPO Scheduled for Late May

As this issue went to press, underwriter Montgomery Securities reported that the RF Micro Devices IPO was scheduled for either the last week of May or the first week of June. Pricing is to be in \$9 - \$11 range. The company hopes to sell 2.5 million shares, leaving 14.8 million outstanding after the offering.

RFMD reported profit of \$1.65 million on sales of \$28.8 million for the year ended March, 1997.

Company	Symbol	Exchange	Last 52 Weeks		Closing Price		Change	Average Daily Volume	P/E Ratio	Market Cap (\$M)	% Held by Institutions
			Hi	Lo	April 30	Jan 2					
Alpha	AHA	AMEX	11 3/4	5 1/54	6 9/16	8	-18%	21,000	♦	74	41
Anadigics	ANAD	NASDAQ	37 5/8	14	28 1/4	25 1/3	+12%	356,000	30	451	36
APA Optics	APAT	NASDAQ	6 3/4	4 1/4	5 3/4	4 1/2	+28%	3,000	♦	48	2
ATMI	ATMI	NASDAQ	22	10 3/4	18	16 7/8	+7%	43,000	41	147	27
Celeritek	CLTK	NASDAQ	16 1/2	8 1/4	10 1/2	10 5/8	-1%	22,000	20	74	44
Cree Research	CREE	NASDAQ	21 1/2	8 1/4	12	10 5/8	+13%	83,000	92	148	27
Emcore	EMKR	NASDAQ	14 1/4	9 1/4	11 3/8	10 5/16*	+10%	14,000	♦	63	0
Int'l Semi Corp	ISSM	OTC	4	3/8	1/4	9/16	-56%	43,000	♦	3	na
Kopin	KOPN	NASDAQ	15 3/4	7	12	11 5/8	+3%	23,000	♦	115	12
Ortel	ORTL	NASDAQ	27	10 7/8	13	22	-41%	86,000	46	149	30
Power Spectra	PWSP	OTC	2 3/8	3/8	9/16	11/16	-45%	26,000	♦	10	17
SDL	SDLI	NASDAQ	32 3/8	8	13	24 5/8	-47%	227,000	39	173	78
SLI	SLIC	NASDAQ	11 3/8	4	5 3/8	7	-23%	22,000	♦	18	0
Spire	SPIR	NASDAQ	8	2 1/4	2 4/8	2 3/8	+89%	9,000	♦	14	10
TriQuint	TQNT	NASDAQ	37 7/8	15 5/8	29 3/4	27 3/8	+9%	239,000	42	285	40
Vitesse	VTSS	NASDAQ	37 7/8	11 1/8	31 1/2	28 1/8	+12%	718,000	52	1,168	75

* Closing price on first day of trading, 3/6/97

♦ = Loss in most recent 4 quarters.

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.

Compound Semiconductor Materials

Photoluminescence in Amorphous Si/SiO₂ Superlattices

B. T. Sullivan et al, Appl. Phys. Lett. 69 (21), 3149 [1996].

Silicon-based light emitting devices are attractive because they can be fabricated using standard Si processing techniques. Thick amorphous Si/SiO₂ superlattices were implemented with an automated radio frequency magnetron sputtering system developed at the NRC. The superlattice structure is formed by sputtering Si at a rate of 0.025 nm/s, after which the substrate is rotated away from the Si target, and oxygen is introduced in the chamber to form an oxidizing plasma that partially oxidizes the Si layer before the cycle is repeated for another period.

Room temperature photoluminescence measurements carried out on a 100-period superlattice sample with each period consisting of a 1.4 nm Si layer and a 1.2 nm SiO₂ layer (2.6 nm period) showed a pronounced light emission with a peak wavelength at 625 nm. The peak wavelength was found to shift to longer wavelengths as the period increased, but the PL was independent of the oxide thickness. PL was observed for a-Si/SiO₂ superlattices deposited on Si, quartz, glass substrates, and even on roughened Si substrates, indicating that no special substrate or smoothness requirement is required to observe luminescence in these superlattices. No PL was observed in the 460-850 nm range for thick a-Si and SiO₂ layers. Annealing the superlattices at a temperature of 1100°C in air for 30 min. resulted in a 40-times increase in the PL intensity of a 525-period sample when compared to the as-grown material. Work done at the National Research Council of Canada.

High-Quality 4H-SiC Bulk Material

M.E. Levinshtein et al., J. Appl. Phys. 81(4), 1758 [1997].

The 4H polytype of SiC has received much attention because of its suitability for high-power microwave devices. The electron mobility in 4H-SiC is about twice that in 6H-SiC, and the dopant activation energy is lower in 4H-SiC than in 6H-SiC. The bulk low-frequency noise characteristics of n-channel 4H-SiC junction field-effect transistors fabricated by Cree Research Inc. were recently measured. The JFETs under consideration had a gate length of $L = 5 \mu\text{m}$, and a gate width of $W = 1 \text{ mm}$. The doping densities for the channel and p+ epilayer were $N_D = 10^{17} \text{ cm}^{-3}$ and $N_A = 2.2 \times 10^{18} \text{ cm}^{-3}$, respectively. Previous work with GaAs FETs has shown that noise measurements carried out at low gate and drain voltages permit the evaluation of the bulk properties of the channel material. The electronic noise level in various materials is commonly characterized by the so-called Hooge parameter which provides a comparison of the relative merits of each material.

In the temperature range of 300 to 550 K, the spectral density of the bulk electrical noise was found to depend on temperature very slightly. The frequency dependence of the noise followed a $(1/f)^{1.5}$ law. At 300 K the Hooge constant was determined to be $(2-4) \times 10^{-6}$ at 20 Hz, and a $3/4 \times 10^{-7}$ at 1.3 kHz. These values are comparable to those reported for the best silicon FETs. According to criteria established for Si and GaAs, such small values of the Hooge constant indicate an extremely high degree of structural and electronic perfection of the 4H-SiC material. Work done at the A. F. Ioffe Institute and Cree Research Inc.

InAs/GaP Heterojunctions

E. H. Chen et al., Appl. Phys. Lett. 70 (12), 1551 [1997].

The growth of InAs on GaP to form an abrupt heterojunction with an 11% mismatch was performed in a solid source MBE system equipped with valved P and As crackers. After the growth of N- or P-type GaP layers on a GaP (100) substrate, the temperature was lowered to 350°C for the growth of InAs. A thin 2-20 nm InAs layer was deposited two dimensionally under slightly In-rich growth conditions. Under such conditions, the epilayer relaxes via the formation of an array of 90° type edge dislocations at the heterointerface and a relatively low density of threading dislocations can be found in the InAs layer. Despite the presence of some In droplets the resulting heterojunction system may be interesting for some device applications. Four different samples, which represent the four possible InAs/GaP isotype and anisotype heterojunctions, were grown and processed into diodes.

The resulting I-V characteristics have nearly ideal Schottky barrier-like forward bias characteristics. In forward bias, the characteristics showed an ideality factor n ranging between 1.04 and 1.10 over at least three orders of magnitude in current. In reverse bias, all diodes showed low leakage currents and breakdown voltages consistent with avalanche breakdown in the GaP. This near-ideal behavior was obtained despite the presence of a high density of dislocations in the plane of the InAs/GaP heterointerface. Work done at Purdue University.

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GaAs on Insulator Technology

Recently, the ability to oxidize AlAs and form highly insulating Al_2O_3 layers, has been used to laterally confine current transport through optoelectronic devices, especially VCSELs. But the availability of a "native oxide" could also be beneficial for electronic devices. For example, the ability to place a highly insulating layer under active regions could prevent substrate leakage, and thereby improve output resistances and perhaps lower $1/f$ and phase noise.

The use of oxidized AlAs layers has been implemented in a GaAs on insulator technology (GOI) by researchers at the University of California [Santa Barbara, CA]. Grown by MBE, a 50 nm AlAs layer is situated between a GaAs buffer and 10 nm $\text{Al}_{0.3}\text{Ga}_{0.7}\text{As}$ spacer layer. A 100 nm GaAs channel, which is n-type doped at a level of $3 \times 10^{17} \text{ cm}^{-3}$, is then grown directly above the $\text{Al}_{0.3}\text{Ga}_{0.7}\text{As}$ spacer layer. After mesa isolation, lateral oxidation of the AlAs layer takes place at 450°C in steam, such that an Al_2O_3 layer is formed beneath the active MESFET. Devices with the 100 nm channel exhibited degraded electrical characteristics, with a channel current of 60 mA/mm and a peak transconductance of 100 mS/mm, in which this poor performance was attributed to the back depletion of the channel charge at the insulator/channel interface. By increasing the channel thickness to 200 nm, in order to reduce this effect, the maximum current level was increased to 300 mA/mm and the peak transconductance increased to 185 mS/mm. The resulting $1.5 \mu\text{m}$ gate length devices exhibited an f_t of 9 GHz and an f_{max} of 45 GHz, values which are similar to those of devices which do not have the Al_2O_3 layer.

In another example of the use of the lateral oxidation of AlAs layers for electronic devices, researchers at Arizona State University [Tempe, AZ], want to utilize Al_2O_3 layers to isolate stacked devices - such as a VCSEL which might be grown directly above a MESFET. In order to test the feasibility of isolating stacked devices with oxidized layers of AlAs, a MESFET utilizing a 100 nm AlAs layer placed directly beneath a 150 nm thick GaAs channel which is doped at a level of $5 \times 10^{17} \text{ cm}^{-3}$ was fabricated, the GaAs substrate etched away, and the MESFET/ Al_2O_3 structure then bonded to a highly conductive Al coated Si substrate. Despite the presence of the highly conductive substrate, the Al_2O_3 layer successfully electrically isolated adjacent MESFETs.

See P.A. Parikh et al, IEEE Electron Device Letters, 18(3), 111 [March 1997], and C.B. Wheeler et al, IEEE Electron Device Letters, 18(3), 138 [March 1997].

Electronic Circuits and Devices

High Mobility InAlAs/InAs/InAlAs Pseudomorphic HEMT's

Albert Chin et al, IEEE Electron Device Letters, 18(4), 157 [April 1997]

It has been demonstrated both experimentally and theoretically that the RF performance of InP-based HEMTs using the InGaAs/InAlAs material system can be improved with increase in In content, with the greatest improvement expected for an InAs channel. However, the lattice mismatch between InAs and the InP substrate results in degraded material and device performance. By utilizing a multiple InAlAs/InAs monolayer superlattice buffer to increase the In content in the AlInAs buffer from 48 to 75%, a 7 nm thick InAs channel HEMT was fabricated which demonstrated a record room temperature mobility of $20,200 \text{ cm}^2/\text{V}\cdot\text{s}$, with a carrier concentration of $2.7 \times 10^{12} \text{ cm}^{-2}$. Using a $1.1 \mu\text{m}$ gate length, the device exhibited an f_t of 50 GHz and an extrinsic transconductance of 714 mS/mm. Work performed at the National Chiao-Tung University [Hsinchu, Taiwan, ROC], and at the Chung Hau Polytechnic Institute [Hsinchu, Taiwan, ROC].

High Voltage Power MOSFET's in 6H-SiC

Jayarama N. Shenoy et al, IEEE Electron Device Letters, 18(3), 93 [March 1997]

The high breakdown field (4 MV/cm) and large thermal conductivity ($4.9 \text{ W/cm}\cdot\text{K}$) of SiC make it ideally suited for high power and high temperature electronic device applications. Taking advantage of these characteristics, rapid progress has been made in the fabrication of Schottky-based SiC devices which operate in the kV range. However, SiC-based MOSFET structures, which have utilized a vertical trench-gated structure (U-MOS), have exhibited degraded high voltage characteristics due to high electric fields in the regions of the corners of the UMOS trench, and the inferior breakdown characteristics of oxides formed on the sidewalls of the trench. To avoid these limitations, a double implanted 6H-SiC power MOSFET has been fabricated in a $10 \mu\text{m}$ thick n⁺ epitaxial layer using n⁺ source/drain implants placed within p implanted wells. Using a 48 nm thick gate oxide, these devices show channel mobilities of up to $26 \text{ cm}^2/\text{Vs}$ (superior to UMOS devices), and blocking voltages of up to 760 V, which is nearly three times higher than reported by the best vertical devices. Work performed at Purdue University [West Lafayette, IN].

Low Voltage, High PAE, GaAs Spike-Gate Power FET's

Tsuyoshi Tanaka et al, IEEE Transactions on Electron Devices, 44(3), 354 [March 1997]

Low operating voltages and high power added efficiencies (PAEs) are crucial for mobile communication systems in order to lengthen the time between battery recharging. By utilizing a novel spike-gate structure, which effectively reduces the gate-length to near zero, a low on-resistance of 2.2 ohm/mm and a transconductance of 180 mS/mm were obtained in Si-delta doped ($4 \times 10^{12} \text{ cm}^{-2}$) MESFET. The device achieved an output power of 31.5 dBm with 70% PAE at a frequency of 900 MHz with a supply voltage of 1.5 V, while a PAE of 60% was obtained at a bias of 0.5 V - this representing the lowest reported operating voltage to date for this type of device. Work performed at Matsushita Electronics Corporation [Osaka, Japan].

High f_{max} n-type Si/SiGe MODFET's

M. Gluck et al, Electronics Letters, 33(4), 335 [13 February 1997]

II-V-based MODFETs have demonstrated superior device characteristics as compared to MESFETs, due to the confinement of the 2DEG at the heterointerface within the device, as well as to the separation of the carriers within the channel from the ionized donors which reside within the donor layers. In an analogous manner, the heterostructures available in the Si/SiGe material system can be used in the fabrication of Si-based MODFETs. A $0.18 \mu\text{m}$ gate length n-type Si/ $\text{Si}_{0.6}\text{Ge}_{0.4}$ MODFET is reported on which is fabricated on a relaxed $2 \mu\text{m}$ thick $\text{Si}_{0.6}\text{Ge}_{0.4}$ buffer. The device exhibits a large mobility of $1190 \text{ cm}^2/\text{Vs}$ with a charge of $1.9 \times 10^{12} \text{ cm}^{-2}$, accompanied with a transconductance of 270 mA/mm and a saturation current of 260 mA/mm. In addition, the device exhibits an f_t of 46 GHz and a record level f_{max} of 81 GHz under 1.5 V operation. Work performed at Daimler-Benz [Ulm, Germany] and at the University of Ulm [Ulm, Germany].

103 GHz f_{max} III-V Nitride HFET

Jinwook Burm et al, IEEE Electron Device Letters, 18(4), 141 [April 1997]

The RF performance of GaN-based FETs continue to rapidly improve. Utilizing a 100 nm thick n-doped GaN channel and a 30 nm thick n-doped $\text{Al}_{0.15}\text{Ga}_{0.85}\text{N}$ donor layer, a $0.12 \mu\text{m}$ gate length MODFET was fabricated using unannealed Ti/Au layers for ohmic contacts and Pt/Au layers for gate contacts. Despite a relatively high ohmic contact resistance of 10 ohm-mm , the device exhibited a transconductance of 80 mS/mm and record level RF performance as characterized by an f_t of 46.9 GHz and a f_{max} of 103 GHz. Work performed at Cornell University [Ithaca, NY], APA Optics [Blaine, MN], and Rensselaer Institute [Troy, NY].

Optoelectronic Devices

Another Material for Short Wavelength Lasers

D.M. Bagnall et al., Appl. Phys. Lett. 70(17), 2230 [28 April 1997]

Research efforts in the ZnSe-based and GaN-based material systems to produce green/blue/violet lasers have had a high profile in recent years. Recently BeSe-based materials have also produced short wavelength lasers (see CS 3(2), p. 28). Now yet another semiconductor material for short wavelength lasing can be considered - ZnO. Lasing in bulk ZnO, pumped by electron beam at cryogenic temperatures, was reported in the 1960's, but real life applications were remote. The practicality of ZnO took a big step forward with this most recent report, which demonstrated optically pumped lasing at room temperature in epitaxial ZnO. The material lased in the violet at 404 nm and is believed to be excitonic in nature. The excitation intensity at threshold, 240 kW/cm^2 , compares with that of GaN. The ZnO epitaxial layers were grown on (0001) sapphire substrates by microwave plasma-enhanced MBE, then cleaved into 300 - 1000 μm long cavities. Evidence of lasing include threshold behavior of optical output, line narrowing and polarization above threshold, and observation of longitudinal modes in the emission spectrum. Work performed at Tohoku University, Sendai, Japan.

Gain Coupled DFB Lasers

J. Robadey et al., Electronics Lett. 33(4), 297 [13 February, 1997]

M. L. Osowski et al, IEEE Photonics Techn. Lett. 9(4), 422 [April, 1997]

Diode lasers come in a variety of structures - cleaved-mirror Fabry-Perot's, vertical cavity surface emitters (VCSEL's), and grating-based structures such as distributed feedback (DFB) lasers. DFB's are the most difficult to fabricate, but provide superior modal properties such as narrow, stable linewidth and high side-mode suppression. Such properties are necessary in the important applications of optical communications and optical sensing. The conventional approach to DFB lasers, index coupling, uses a periodic variation of refractive index to accomplish mode selection. Such structures require a quarter-wave phase shift in the middle of the grating, a fabrication complication, to achieve single mode operation. A related DFB approach, gain coupling, does not require the phase shift in the grating, and is better than the index coupled approach in terms of linewidth, chirp, side-mode suppression, and immunity to reflections.

Gain coupling is accomplished by periodically varying either the gain or loss along the length of the cavity. Both approaches have been reported recently. One result used a periodic variation of the gain that was accomplished by building a quantum wire array. Each element in the array was spaced from its neighbor by a distance corresponding to the length of one wavelength in the semiconductor, 289 nm. After the growth of a lower $\text{Al}_{0.33}\text{Ga}_{0.67}\text{As}$ clad and the beginning of the GaAs waveguide, the MBE growth was stopped and UV holography and wet chemical etching was used to construct a saw-tooth grating. The surface was cleaned in a hydrogen radical beam and the regrowth was initiated with a GaAs / AlAs superlattice. The remainder of the lower GaAs waveguide was grown followed by an InGaAs active layer, which grew in the trenches of the grating to create a quantum wire array. The structure was finished off conventionally with the upper GaAs waveguide, upper AlGaAs clad and GaAs contact layer. The use of the superlattice to initiate the regrowth was found to lower the threshold by a factor of 14 to the value of 250 A/cm^2 . The side-mode suppression ratio was 40 dB. Work performed at the Swiss Federal Institute of Technology, Lausanne, Switzerland.

A second report achieved gain coupled DFB lasers by using the periodic loss associated with a metal grating. The grating was deposited on the surface of the wafer, thereby avoiding the need for re-growth. The epitaxial structure, consisting of AlGaAs cladding with a GaAs waveguide and an InGaAs quantum well, was conventional except for the fact that the upper clad was thinned to enable the optical mode to interact more strongly with the surface grating. The grating, like the above result, was second-order, i.e. it has a period equal to the wavelength in the semiconductor. The device exhibited single mode lasing with a side mode suppression ratio of greater than 30 dB. Work performed at University of Illinois, Urbana, Illinois.

High Speed 1.55 Micron Lasers

O. Kjebon et al., Electronics Lett 33(6), 488 [13 March 1997]

Y. Matsui et al., IEEE Photonics Techn. Lett. 9(1) [January, 1997]

High capacity data transmission over long optical fibers requires high speed lasers at 1.3 or 1.55 μm . Two different approaches were recently reported for pushing the modulation speed of 1.55 μm lasers to a record value of 30 GHz. The first group fabricated a diode laser consisting of two sections, one for gain and one containing a grating for optical feedback. The device was engineered to operate detuned from the grating reflection peak. This detuning alters the natural resonance frequency of the laser as well as the damping of the response above the resonance. The high frequency operation of the laser was attributed to this "detuned loading" effect. The second report of 30 GHz operation of a 1.55 μm laser diode employed a strain-compensated structure. Twenty periods of tensile-strained InGaAsP wells and compressive-strained InGaAs barriers were cladded with InP. The magnitude of the strain in each layer was 0.8 - 0.9%. This epitaxial structure has the benefits of large conduction band offsets and uniform hole injection. The researchers believe that reduction of series resistance may lead to a further increase in modulation frequency. Work performed at Royal Institute of Technology, Kista, Sweden and Femtosecond Technology Research Association, Ibaraki, Japan.

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HBTs

05610086 / 1997 03 11 / Hughes
05612551 / 1997 03 18 / Hughes
Liu, T.; Nguyen, C.; Matloubian, M.

AlPSb/InP HBT. An epitaxial structure and method of manufacture for a single HBT capable of being utilized in high-speed and high-power applications. Preferably, the epitaxial structure comprises an N-type collector made from InP, a P-type base made from InP, and an N-type emitter made from a semiconductor material of approximately 39 mole percent AlP and approximately 61 mole percent Sb.

05620907 / 1997 04 15 / Lucent
Jalali-Farahani, B. & King, C.A.

SiGe HBT. A heterojunction bipolar transistor in an integrated circuit has intrinsic and extrinsic base portions. The intrinsic base portion substantially comprises epitaxial silicon-germanium alloy. The extrinsic base portion substantially comprises polycrystalline material, and contains a distribution of ion-implanted impurities. An emitter overlies the intrinsic base portion, and a spacer at least partially overlies the emitter. The spacer overhangs the extrinsic base portion by at least a distance characteristic of lateral straggle of the ion-implanted impurities.

05625206 / 1997 04 29 / Lucent
Chandrasekhar, S. et al

High-Speed DHBTs. The total base-collector capacitance of a double-heterostructure bipolar transistor (DHBT) device is reduced by removing semiconductor material from the extrinsic regions and replacing the removed material with a relatively-low-dielectric-constant material. The base-collector capacitance is further reduced by using a composite subcollector structure that permits the extrinsic regions to be made thicker than the intrinsic region of the device.

05625205 / 1997 04 29 / NEC
Kusama, N.

HBT Circuit. The present invention relates to a bipolar transistor amplifier circuit of high efficiency and high output, suitable for use in a microwave band. In an NPN type bipolar transistor, by employing AlGaAs or InGaAs having greater band gap than silicon, for an emitter and a base, doping amount of the emitter can be made smaller than that of the base to permit improvement of reverse withstanding voltage between the base and the emitter. Therefore, B class or C class bias can be used in a microwave band to improve efficiency.

05614423 / 1997 03 25 / NTT
Matsuoka, Yutaka; Yamahata, Shoji

Method for Fabricating a HBT. A self-aligned HBT is disclosed which includes a semiconductor substrate having the (100) plane as a main surface, and at least a collector region, a base region, and an emitter region having a bandgap greater than the

base region. The emitter region has an under-cut mesa structure and its crystal orientation is defined in a direction other than that parallel to the [011] direction. In neither the [001] direction nor the [011] direction has the transistor any outwardly slanted structure that could cause leakage current between the emitter and base and, hence, the transistor has improved electric isolation between the emitter and base although it is self-aligned.

05608353 / 1997 03 04 / RFMD
Pratt, William J.

HBT Power Amplifier. An improved HBT power amplifier circuit providing an efficient and linear amplifier comprising: a first HBT having a base emitter voltage; a power supply; a power supply resistor connected to the power supply causing DC current to flow through the first HBT which develops a resultant voltage equal to the base emitter voltage of the first HBT; at least two manifold base resistors; at least two output HBTs, each of which receive the resultant voltage through its corresponding manifold base resistor; a RF signal input; at least two segmented capacitors, each coupled in parallel to receive the RF signal input and to the input of each corresponding output HBT; the segmented capacitors having a common input connected to the RF signal input and having individual outputs that are DC isolated from each other and which are connected to each output HBT; a RF output signal obtained from the parallel connection of the output HBTs; and provided that each HBT is connected to ground.

05624853 / 1997 04 29 / Sumitomo Electric
Shikata, Shinichi

Diamond/SiC HBTs. A pnp transistor is formed having a heterojunction of p-type diamond (or BP(x)N(1-x), 6HSiC) and n-type SiC (3CSiC). The transistor is formed such that a p+ SiC layer, a p SiC layer, an n+ SiC (3CSiC) layer, a p diamond (or BP(x)N(1-x), 6HSiC) layer, and a p.sup.+ -diamond (or BP(x)N(1-x), 6HSiC) layer are on a substrate, and a collector electrode, a base electrode. An emitter electrode is formed on and electrically connected to the p+ SiC layer, the n+ SiC layer, and the layer, respectively. This method produces a semiconductor device having a high resistance to various environmental conditions.

05616213 / 1997 04 01 / TI
Henderson, T.S.; Plumton, D.L.

Dry Etching InAlAs & InGaAs. This invention relates to a method of dry etching InAlAs as well as other Group III-V semiconductor compounds. By this procedure, functional InAlAs/InGaAs heterojunction bipolar transistors (HBTs) and HBT circuits can be fabricated using a dry etch. Also, self-aligned small geometry structures such as, for example, emitter HBTs and ring oscillator and comparator circuits composed of HBTs and both electronic and optical devices, such as lasers, can be fabricated using the above described procedures.

Other Microelectronics

05610410 / 1997 03 11 / Fujitsu
Imanishi, Kenji

InAlP Schottky Electrode. A field effect group III-V compound semiconductor device having a Schottky gate electrode including a gate electrode formed on a InAlP layer and forming Schottky contact therewith. A semiconductor device is provided with a Schottky electrode highly resistant to a current flow.

05622891 / 1997 04 22 / Fujitsu
Saito, Junji

Reduced Side Gate Effects. A silicon nitride film is formed on a GaAs substrate and patterned to selectively expose the substrate surface in uniformly distributed areas. When a semiconductor integrated circuit device is manufactured using this semiconductor substrate, side gate effect can be effectively reduced due to the existence of the silicon nitride pattern and the buffer layer.

05625323 / 1997 04 29 / Fujitsu
Tozawa, Norio

FET Gate Bias Circuit. An FET gate bias circuit having a Schottky barrier gate incorporated therein is provided which can prevent gate voltage variations and thus provide a high-performance, high-reliability GaAs FET amplifier. The FET gate bias circuit includes a PNP transistor having a collector connected to a negative power supply, an NPN transistor having a collector thereof grounded and an emitter connected to the emitter of the PNP transistor, a Schottky barrier gate FET having a source grounded and a gate connected to the node between the emitters of the PNP transistor and NPN transistor, and a base voltage applying circuit for applying predetermined base voltages to the respective bases of the PNP transistor and NPN transistor.

05616517 / 1997 04 01 / Hughes Aircraft
Wen, C.P.; Wong, W.; Gray, W.D.

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

05614739 / 1997 03 25 / Motorola
Abrokwah, J.; Lucero, R.; Rollman, J.

HIGFET and Method. A HIGFET utilizes an etch stop layer to form a gate insulator to be narrower than the gate electrode. This T-shaped gate structure facilitates forming source and drain regions that are separated from the gate insulator by a distance in order to reduce leakage current and increase the breakdown voltage.

Other Microelectronics, con't

05608239 / 1997 03 04 / NEC
Miyamoto, H.; Nakayama, T.

Heterojunction FET. A FET having a semiconductor layer with a higher composition ratio of In and thereby high electron mobility that is used for a channel layer so as to improve high frequency characteristics.

05621228 / 1997 04 15 / NEC
Ando, Yuji

HFET with Non-Alloy Ohmic Contacts. An InAlAs/InGaAs type heterojunction FET which can reduce the source and drain contact resistance through the InAlAs layer without lowering the sheet carrier concentration so as to form an ohmic contact without alloying.

05614740 / 1997 03 25 / Q-Dot
Gardner, D.; Linenbrink, T.; Galema, S.

High-Speed CCD Imager with GaAs FET Output. An improved CCD imaging array is disclosed which is capable of operating at 10,000 frames-per-second. The serial output registers are constructed from peristaltic CCDs, each having a GaAs FET output circuit bump-mounted to the silicon substrate.

05624860 / 1997 04 29 / TI
Plumton, D. & Yuan, H-T.

Vertical FET. A vertical field effect transistor and fabrication method with buried gates having gate sidewall crystal orientation the same as the substrate surface and a low index substrate crystal orientation without tilt to a higher index direction. The gate may have modulated doping along the channel, and the drain may have a lighter doping level than the channel which may be accomplished by an epitaxial overgrowth of the gates to form the channels.

05610085 / 1997 03 11 / TI
Yuan, H.; Kim, T.; Plumton, D.

Vertical FET on Ge Substrate. A vertical FET with buried gates is disclosed. The FET elements are made of III-V semiconductor compound grown on a Ge substrate, which has advantages including greater strength so thinner and larger substrates can be used which lowers series resistance and permits use of larger wafers during processing; and ohmic contacts are easier to form than to III-V compounds and Ge can be heavily doped to lessen series resistance.

05614743 / 1997 03 25 / Toshiba
Mochizuki, Masao

Microwave Integrated Circuit. MMIC elements are formed on the surface of a GaAs semiconductor substrate. Rectangular U grooves having V-shaped bottoms are formed on the bottom surface of the substrate up to the surface of the substrate under the electrode and ground terminals of the MMIC elements. MIM capacitors and coils are formed on the side walls of the grooves and the bottom surface of the substrate and are connected to the electrode and ground terminals. This arrangement provides the MIM capacitors with large capacitance and the coils with large inductance without increasing chip size.

05608255 / 1997 03 04 / U.S. Air Force
Martin, E. et al

FET Optical Receiver. A photo FET device having a large area backside optical energy reception surface is disclosed.

05623233 / 1997 04 22 / U.S. Army
Higgins, T. et al

MESFET Oscillator. An optically controlled MESFET semiconductor oscillator. In operation, the pulsed free running oscillation of the MESFET semiconductor can be injection locked to the intensity modulated optical signal delivered via the optical signal delivery system.

Quantum Devices

05608231 / 1997 03 04 / Sony
Ugajin, Ryuichi; Sameshima, Toshiyuki

Quantum Dot FET. A field effect transistor has a quantum dot array in its channel region composed of a plurality of quantum dots arranged adjacent to each other on a common plane. Each quantum dot may be made of heterojunction of compound semiconductors or junction of a semiconductor and an insulator.

05613140 / 1997 03 18 / Sony
Taira, Kenichi

Quantum Dot-Tunnel Device. A novel quantum dot-tunnel device having a revolutionarily faster processing speed and higher processing precision than conventional computer computation, which device has an array consisting of a large number of quantum dots which confine electrons three-dimensionally, with the coupling among quantum dots, that is, the tunnel transition probability, being defined by controlling the positional relationship and the shape of the quantum dots in accordance with an algorithm of predetermined information processing, so that the algorithm is expressed in solid state rather than by a conventional computer program.

05608229 / 1997 03 04 / Fujitsu
Mukai, Kohki; Ohtsuka, Nobuyuki

Quantum Box Device. Semiconductor devices having the quantum mechanical effects given by a quantum box structure which three-dimensionally confines a quantum. A semiconductor device having: a first semiconductor layer including: a first region of epitaxially grown III-V semiconductor; and second regions of group III-V semiconductor disposed and scattered in the first region, the second region having a different composition ratio from the first region, wherein lattice constants of the first and second regions in no strain state differ from a lattice constant of the substrate, and a difference between the lattice constant of the second region in no strain state and the lattice constant of the substrate is greater than a difference between the lattice constant of the first region in no strain state and the lattice constant of the substrate. A semiconductor device having a quantum box structure is provided capable of being manufactured by relatively simple processes.

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Semiconductor Lasers

05625636 / 1997 04 29 / None
Bryan; Robert P. et al

VCSEL Integration. A monolithically integrated optoelectronic device is provided which integrates a VCSEL and either a photosensitive or an electro-sensitive device either as input or output to the VCSEL either in parallel or series connection. Both vertical and side-by-side arrangements are disclosed, and optical and electronic feedback means are provided. Arrays of these devices can be configured to enable optical computing and neural network applications.

05617437 / 1997 04 01 / Fuji Photo Film
Fukunaga, Toshiaki

InGaAsP Semiconductor Laser. A semiconductor laser comprises an active layer, optical waveguide layers formed on opposite sides of the active layer, and cladding layers. The active layer is constituted of an InGaAsP type of compound semiconductor. Each of the optical waveguide layers and cladding layers is constituted of an InGaAsP or InGaAlAsP.

05621748 / 1997 04 15 / Fujitsu
Kondo, Makoto et al

Stripe Laser Diode. A method for fabricating a laser diode, comprises the steps of: forming a first stripe structure defined by a plurality of crystallographically distinct surfaces on a surface of a semiconductor substrate; forming an epitaxial layer of InGaAlP on the semiconductor substrate including the first stripe structure; wherein the InGaAlP layer is doped to the p-type by incorporating Mg.

05616177 / 1997 04 01 / Hewlett-Packard
Yamada, Norihide

II-VI Laser. A Group II-VI semiconductor laser based on MgZnSSe, CdZnSSe, and MgCdZnSSe, adsorption layers, and fabrication technique therefore.

05608750 / 1997 03 04 / Hitachi
Nakatsuka, S. et al

High Output Laser. Laser diode structure to prevent end surface optical damage, thereby permitting an increase in the output of the semiconductor laser.

05617435 / 1997 04 01 / Matsushita Electronics
Nagai, H. et al

Wavelength-Conversion Waveguide. This invention generally relates to a lasing system employing a wavelength-conversion waveguide within which semiconductor laser light is propagated while at the same time being converted into second-harmonic light. This invention has significant applications in optical recording/reproducing, laser printing, and laser instrumentation.

05621747 / 1997 04 15 / Matsushita Electric
Kitoh, Masahiro et al

MQW InP Laser. A multi quantum well semiconductor laser includes a multi-layered structure formed on the InP substrate, lasing at 1.29 to 1.33 micron wavelength.

05617439 / 1997 04 01 / Mitsubishi
Kakimoto, Syoichi

Semiconductor Laser Array Device. The present invention relates to a semiconductor laser array device in which a semiconductor laser and a photodiode having a light responsive surface on which the laser beam emitted from the semiconductor laser is incident are disposed on a same semiconductor substrate so that the light reflected by the light responsive surface of the photodiode does not return to the emitting point of the laser beam.

05608749 / 1997 03 04 / Mitsubishi
Kizuki, Hirotaka

Laser Diode with Plated Heat Sink. The present invention relates to a semiconductor laser diode including a plated heat sink electrode selectively buried in a substrate and a method of producing the semiconductor laser diode. The heat radiating characteristic is improved, especially at the laser beam emitting facet.

05608751 / 1997 03 04 / Mitsubishi
Shimoyama, K., et al

Low Threshold Laser. It has been found that by forming successively a first and second cladding layer on a III-V substrate by VPE; etching the second cladding layer to form a ridge; and forming a current blocking layer at the lateral side of the ridge by VPE with a small amount of HCl being added, a laser diode wherein the difference of refractive index in the transverse direction is sufficiently large and the threshold current is sufficiently small has been obtained.

05614436 / 1997 03 25 / NEC
Shim, Jong-In; Kitamura, Mitsuhiro

MQW DFB Laser. The invention relates to a multiple quantum well distributed feedback semiconductor laser device suitable for a coherent optical transmission system and a method for fabricating the same.

05608752 / 1997 03 04 / Sanyo Electric
Goto, Takenori et al

Laser Diode. A semiconductor laser device capable of reducing noises due to optical feedback of output laser light and a method of designing the same.

05610096 / 1997 03 11 / Sanyo Electric
Yodoshi, Keiichi et al

Laser with a Self Sustained Pulsation. The present invention relates to a semiconductor laser with a self-sustained pulsation in which the noises attributable to the optical feedback of a laser beam are reduced.

05621750 / 1997 04 15 / Seiko Epson
Iwano, Hideaki et al

Surface Emission Laser. A surface emission type semiconductor laser has insulation layers embedding separation grooves for partially separating the waveguide path in an optical resonator formed by a pair of reflecting mirrors, namely a distributed reflection type multilayer film mirror and a dielectric multilayer film mirror, and a quantum well active layer.

05625637 / 1997 04 29 / Seiko Epson
Mori, K.; Asaka, T.; Iwano, H.

SEL and Process. A surface emitting semiconductor laser, with a resonator cavity transverse to the planar extent of the deposited layers, is provided. In addition, a simple and reliable method is employed to fabricate the DBR mirror and other aspects, doping concentration is controlled through dopant gas flow control or is controlled through light and can be easily accomplished without using comparatively high temperature processing.

05623509 / 1997 04 22 / Seiko Epson
Iwano, H.; Yokoyama, O.; Nomura, H.

High Power Laser. A high-power semiconductor laser that is suitable as the light source for a distance measurement system or device, and a light-sensing device using this semiconductor laser. A semiconductor laser comprises AlGaAs-type semiconductor layers deposited on a substrate and a current constriction layer having at least one stripe-shaped current injection region.

05617446 / 1997 04 01 / Sony
Ishibashi, A.; Nakayama, N.; Kijima, S.

II-VI Surface-Emitter. A surface-emitting semiconductor light emitting device. The active layer has a single quantum well structure or a multiple quantum structure including ZnCdSe quantum well layers.

05625634 / 1997 04 29 / Sony
Ukita, M.; Ishibashi, A.

II-VI Semiconductor Laser. A semiconductor laser comprises: a first cladding layer of a first conduction type; an active layer stacked on the first cladding layer; and a second cladding layer of a second conduction type stacked on the active layer. II-VI compound semiconductors making the first cladding layer and the second cladding layer may be a ZnMgSSe compound semiconductor. A semiconductor laser using II-VI compound semiconductors and having the capability of continuous oscillation at high temperatures including the room temperature is provided.

05621746 / 1997 04 15 / Sony
Futatsugi, M.; Ando, K.; Yamamoto, T.

GaAs Laser Diode. A GaAs or AlGaAs active layer laser diode includes a semiconductor substrate and a laser diode region having a laser beam emission end. The semiconductor substrate has a front surface directly below said laser beam emission end, said front surface being retracted from said laser beam emission end. The front surface may be formed as an optically roughened surface as a side wall surface of a groove when the groove is defined in the semiconductor substrate by dicing. The front surface may further be optically roughened by etching or sputtering.

05617438 / 1997 04 01 / Toshiba
Hatano, Aiko; Ohba, Yasuo

Mg-Doped GaN Laser. The present invention relates to a semiconductor laser having a compound semiconductor layer using magnesium (Mg) as a dopant or a constituent element. A semiconductor laser having an oscillation wavelength of not more than 450 nm comprises a substrate, a lower

Semiconductor Lasers, con't

cladding layer containing a III-V Group compound semiconductor as a main component formed on the substrate, an active layer containing the III-V Group compound semiconductor as a main component formed on the lower cladding layer and an upper p-type cladding layer containing III-V Group compound semiconductor as a main component. Mg and Si are contained in the upper p-type cladding layer. A GaN series compound semiconductor is preferably used as the III-V Group compound semiconductor and the upper cladding layer contains preferably not less than $5 \times 10^{18}/\text{cm}^3$ of Si.

05615224 / 1997 03 25 / Univ. of Calif. Cohen, Daniel A.

Uncooled Lasers. A structure for stabilizing the wavelength and output power of uncooled diode semiconductor lasers using stress caused by differential expansion to counteract the effects of temperature fluctuation is realized by restraining the thermal expansion of the active region.

LEDs

05625201 / 1997 04 29 / Motorola Holm, P.M. & Gable, B.W.

Multiwavelength LED. A multiwavelength LED device including a first LED constructed to emit light of a first wavelength and a second LED constructed to emit light of a second wavelength. The first and second LEDs are stacked vertically on a substrate and positioned to both emit light in the same direction. One of the LEDs is transparent to light emitted by the other of the LEDs so that light from both LEDs is emitted through a single aperture and can be mixed in intensity to produce a variety of wavelengths. The LEDs are individually addressable.

05616937 / 1997 04 01 / Sharp Kitagawa, M.; Tomomura, Y.

II-VI UV Luminescent Device. This invention relates to a compound semiconductor luminescent device capable of emitting ultraviolet light. In a preferred embodiment, the II-VI group compound semiconductor is selected from the group consisting of ZnS, ZnSe, ZnSxSe1-x ($0 < x < 1$), and ZnSyTe1-y ($0 < y < 1$).

05610685 / 1997 03 11 / Sharp Aiba, Masahiko

LED Write Apparatus. A LED write apparatus wherein the arrangement step of LED chips is eliminated by constituting the LED head by a single LED chip composed of LEDs and electrical connection of the respective LEDs with driving.

05608234 / 1997 03 04 / Whitaker Corp Jiang, Ching-Long

Semi-insulating Edge Emitting LED. Light emitting devices are requiring greater switching speeds to achieve greater modulation bandwidths. The problems of intrinsic capacitance associated with conventional semiconductor heterojunction devices are reduced by the reduction of pn junction capacitance as well as the use of a semi-insulating blocking layer and a conductive substrate.

05614734 / 1997 03 25 / Yale Univ Guido, Louis J.

High Efficiency LED. The invention is an AlxGa1-xAs p-n junction light emitting diode, with a thin In_{203} current spreading layer, on the top-side, and an indirect band-gap $\text{AlAs-Al}_{0.6}\text{Ga}_{0.4}\text{As}$ distributed Bragg reflector, on the bottom-side. This structure yields a significant increase in electrical-to-optical power conversion efficiency, and a significant reduction in active region heating—in comparison with standard devices prepared and tested as controls.

05610412 / 1997 03 11 / Nippondenso Awano, Naomi

LED with Depletion Layer. This invention relates to a semiconductor device, and particularly to a light emitting device disposed on a Si substrate by way of a GaAs heterojunction.

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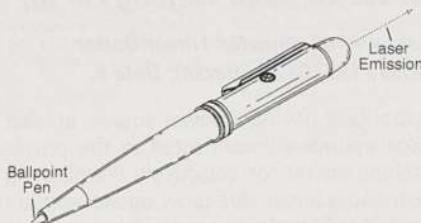
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Just What We've Been Waiting For (I)

Combination of Laser Pointer and Ballpoint Pen
05617304 / 1997 04 01 / Huang; Chaochi

A combination of laser pointer and ballpoint pen which includes a ballpoint pen mounting unit, which has a barrel and an ink cartridge inside the barrel, and a laser pointer mounting unit fastened to the barrel and turned relative to move the ink cartridge in and out of the barrel, the laser pointer mounting unit having a battery set and a semiconductor laser module on the inside, and a press button on the outside controlled to electrically connect the battery set to the semiconductor laser module, causing the semiconductor laser module to emit a laser beam through a transparent end cap at one end of the laser pointer unit remote from the ballpoint mounting unit.



Materials

**05616947 / 1997 04 01 / Matsushita Electric
Tamura, Akiyoshi**

MIS Structure. The present invention relates to a metal-insulator-semiconductor (MIS) type semiconductor device including a GaAs semiconductor substrate, an insulating layer which is made of material selected from the group MgS, MgSSe and CaZnS and is formed on the GaAs substrate, and a conductive electrode formed on the insulating layer.

**05622559 / 1997 04 22 / Mitsubishi Chemical
Goto, H.; Fujii, K.; Shimoyama, K.**

VPE Growth. The vapor phase growth method of the group III-V compound semiconductor thin-film, using hydrides and organic metals containing no halogen elements as a raw material for the growth, is disclosed. The method is carried out by alternately introducing group III organic metals raw material gas as well as halides gas and/or halogens gas into a growth chamber, and also by repeating the introducing to grow a thin-film. In accordance with the present invention, it is possible to obtain such high-quality crystal growth as the planarization of hetero junction interface, the improvement of surface morphology or facet, and no deposit of polycrystals on the mask in a wide range.

**05610098 / 1997 03 11 / National Science Council
(Taiwan)
Huang, W.; Lei, T.; Lee, C.**

N-InP Schottky Diode. A new Schottky diode structure, Pt/Al/n-InP, is disclosed in the present invention. Aluminum-oxide forms as the interfacial layer to improve barrier height. A method of preparing this Schottky diode structure is also.

**05612550 / 1997 03 18 / NEC
Gomyo, Akiko; Suzuki, Tohru**

Ordered Phase Alloy Layers. A heterojunction semiconductor device has a plurality of ordered phase alloy layers. Either the whole or a part of each of the ordered phase alloy layers has a crystal structure (triple-period structure) in which the ordered alloy is of a composition corresponding to the [111]A direction and an anion composition modulation period that is triple that of a disordered structure. The double-period structure may alternatively be used. The triple-period or double-period structure applied to the layer structure of the heterostructure semiconductor device results in a reduction of the bandgap.

**05625635 / 1997 04 29 / Sandia
Kurtz, Steven et al**

InAsSb IR Emitter. The present invention relates to a semiconductor infrared emitting device and method for use in a wavelength region from about 2 to 6 microns. The device comprises a III-V substrate upon which are grown a quantum-well active region having a plurality of quantum-well layers formed of a ternary alloy comprising InAsSb sandwiched between barrier layers formed of a ternary alloy having a smaller lattice constant and a larger energy bandgap than the quantum-well layers. The quantum-well layers are preferably compressively strained to increase the threshold energy for Auger recombination; and a method is provided for determining the preferred thickness for the quantum-well layers.

**05616178 / 1997 04 01 / Sony
Toda, Atsushi; Imanishi, Daisuke**

II-VI Semiconductors. A method for growth of II-VI compound semiconductors grows a p-type II-VI compound semiconductor such as a p-type ZnSe by vapor deposition such as metalloorganic chemical vapor deposition and molecular beam epitaxy using gaseous materials. The method uses as a p-type dopant an organic compound including at least one nitrogen atom and at least two groups of atoms each having a molecular weight larger than 12 and both combined with the nitrogen atom. One of such organic compounds is di-isopropylamine.

**05612014 / 1997 03 18 / Sumitomo Electric
Inoue, T.; Hagi, Y.**

Compound Semiconductor Crystal. A method which can prepare a compound semiconductor crystal doped with an impurity and having a prescribed carrier concentration with excellent reproducibility comprises the steps of melting a raw material for the compound semiconductor crystal in a crucible, and controllably cooling raw material melt, making thereby growing a crystal. The time required for cooling the raw material melt from the melting point T of the raw material to $2/3T$ is so controlled as to adjust the carrier concentration to a prescribed level.

**05620557 / 1997 04 15 / Toyoda Gosei
Manabe, K. et al**

Sapphireless Group III Nitride Semiconductor. A method of manufacturing two sapphireless layers at one time made of Group III nitride compound

semiconductor satisfying the formula $\text{Al}_x\text{Ga}_{1-x}\text{In}_y\text{N}_{1-x-y}$, and a LED utilizing one of the semiconductor layers) as a substrate includes the steps of forming two zinc oxide (ZnO) intermediate layers on each side of a sapphire substrate, forming two Group III nitride compound semiconductor layers satisfying the formula $\text{Al}_x\text{Ga}_{1-x}\text{In}_y\text{N}_{1-x-y}$, each laminated on each of the intermediate ZnO layers, and separating the intermediate ZnO layers from the sapphire substrate by etching with an etching liquid only for the ZnO layers.

**05625202 / 1997 04 29 / Univ. Central Florida
Chai, Bruce H. T.**

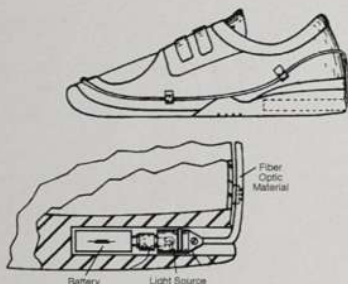
Substrates for III-V Nitrides. This invention relates to lattice matching crystals for epitaxial thin film growth, and in particular to methods of using modified oxide wurtzite compounds as substrates for growing wurtzite type III-V nitride compound semiconductor single crystal epitaxial films. The lattice matching substrates include Lithium Aluminum Oxide (LiAlO_2), Lithium Gallium Oxide (LiGaO_2), Lithium Silicon Oxide (Li_2SiO_3), Lithium Germanium Oxide (Li_2GeO_3), Sodium Aluminum Oxide (NaAlO_2), Sodium Gallium Oxide (NaGaO_2), Sodium Germanium Oxide (Na_2GeO_3), Sodium Silicon Oxide (Na_2SiO_3), Lithium Phosphor Oxide (Li_3PO_4), Lithium Arsenic Oxide (Li_3AsO_4), Lithium Vanadium Oxide (Li_3VO_4), Lithium Magnesium Germanium Oxide ($\text{Li}_2\text{MgGeO}_4$), Lithium Zinc Germanium Oxide ($\text{Li}_2\text{ZnGeO}_4$), Lithium Cadmium Germanium Oxide ($\text{Li}_2\text{CdGeO}_4$), Lithium Magnesium Silicon Oxide ($\text{Li}_2\text{MgSiO}_4$), Lithium Zinc Silicon Oxide ($\text{Li}_2\text{ZnSiO}_4$), Lithium Cadmium Silicon Oxide ($\text{Li}_2\text{CdSiO}_4$), Sodium Magnesium Germanium Oxide ($\text{Na}_2\text{MgGeO}_4$), Sodium Zinc Germanium Oxide ($\text{Na}_2\text{ZnGeO}_4$) and Sodium Zinc Silicon Oxide ($\text{Na}_2\text{ZnSiO}_4$).

**05608753 / 1997 03 04 / Xerox
Paoli, Thomas L.; Northrup, John E.**

Impurity Induced Layer Disordering. Novel semiconductor devices are monolithically defined with p-type and n-type wide bandgap material formed by impurity induced layer disordering of selected regions of multiple semiconductor layers. The devices are beneficially fabricated by simultaneously forming the n-type and p-type layer disordered regions with sufficiently abrupt transitions from disordered to as-grown material.

Just What We've Been Waiting For (II)

Footwear with Illuminated Linear Optics
05604999 / 1997 02 25 / Barker; Dale E.



Illuminated footwear having a power source, at least one light source operatively connected to the power source, a switching circuit for selectively illuminating the light source, and a linear side-glow optical conduit positioned exteriorly on the footwear so as to be visible when illuminated. The main features of the present invention are also incorporated into a self-contained portable illumination unit which can be easily attached to and removed from a wide variety of footwear.

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June 9-10, 1997 in Denver, CO
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June 8-11, 1997 in Berlin, Germany.
Contact: Dr. Wolfgang Richter
Technische Universität Berlin
TEL [49] 30 3142 2078 FAX [49] 30 3142 1769
Net or Web: richter@grit.physik.tu-berlin.de or
http://www.hhi.de

2nd European GaN Workshop

June 11 - 13, 1997 near Cannes, France.
Contact: Jean-Pierre Faurie
CRHEA-CNRS Sophia Antipolis
TEL [33] 4 9395 4220
FAX [33] 4 9395 4142
Net: jpf@arheal.unice.fr
Web: http://www.crhea.unice.fr/EGW-2/index.htm

1997 Electronic Materials Conference

Fort Collins, CO USA on June 25-27, 1997
Contact: TMS
TEL [1] 412 776 9000 x241
FAX [1] 412 776 3770
NET: csc@tms.org

7th Int'l Symp. On Si MBE

July 13-17, 1997 in Banff, Canada.
Contact: P. Lamoureux
National Research Council
Ottawa, ON K1A 0R6 Canada
TEL [1] 613 993 9431 FAX [1] 613 993 7250
NET: mbe97@nrc.ca
Web: http://www.nrc.ca/conf/serv/

19th Int'l Conf. On Defects in Semiconductors

July 21-15 in Aveiro, Portugal.
Contact: Dr. Maria Helena Nazare
Departamento de Física
Universidade de Aveiro
3810 Aveiro Portugal
FAX [351] 34 24965
Web: http://www.ua.pt/event/icds97/

Recent Advances in Microwave Technology

August 4 - 7 in Beijing, China.
Contact: Prof. Banmali Rawat
Univ. of Nevada, Reno
TEL [1] 702 784 1457 FAX [1] 702 784 6627
NET: rawat@ee.unr.edu

IEEE Summer Topical Meetings

August 11 - 15, 1997 in Montreal, Canada: GaN Materials, Processing, and Devices; Vertical-Cavity Lasers; Technologies for a Global Information Infrastructure; WDM Components Technology; and Advanced Semiconductor Lasers and Applications.
Contact: IEEE/LEOS '97
TEL [1] 908 562 3897 FAX [1] 908 562 8434

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

Eight International Conference on II-VI Compounds and Devices

II-VI '97 will be held August 25 - 29, 1997 in Grenoble, France. The conference will focus on fundamental aspects and on recent perspectives for applications of narrow and wide bandgap II-VI semiconductors. Areas of interest include: materials science, where many long-standing problems (particularly compensation) are still to be solved, low dimensional physics including semimagnetic heterostructures, and optoelectronic applications.
Abstract Submission Deadline: March 15, 1997
Contact: Le Si Dang
II-VI Conference Secretariat
Laboratoire de Spectrométrie Physique
Université J. Fourier - Grenoble I, BP 87
F-38402, Saint Martin d'Hères Cedex France
FAX: [33] 76 51 45 44
Net or Web: lesidang@spectro.grenet.fr

1997 Int'l Conf. On SiC and III-Nitrides

ICSCIII-N '97 will be held August 31 - September 5 in Stockholm, Sweden. This is the continuation of the series formerly known as the International Silicon Carbide Conference.
Abstract Submission Deadline: TBA
Contact: Prof. E. Janz'n
Linköping University
Dept. of Physics
Linköping S-581 83 Sweden
TEL [46] 13 281 797 FAX [46] 13 142 337
NET: erj@ifm.liu.se

III-V Nitride Materials and Processes Symposium

The III-V Nitride Materials and Processes Symposium will be held August 31 - September 5 in Paris, France. This symposium addresses recent experimental and theoretical advances in materials, substrates, processes, characterization, properties and modeling of BN, AlN, GaN, InN, ScN.
Abstract Submission Deadline: TBA
Contact: Electrochemical Society
10 S. Main Street
Pennington, NJ 08534-2896 USA
TEL [1] 609 737 1902 FAX [1] 609 737 2743
Net: ecs@electrochem.org
Web: http://www.electrochem.org/meetings/

5th European GaAs Applications Symposium

The 5th European GaAs and Related III-V Compounds Applications Symposium will be held September 3 - 5, 1997 in Bologna, Italy. The aim of the conference is to promote the discussion on recent developments and trends, and the exchange of scientific and technical information in the area of applications of GaAs and other compound semiconductors.
Abstract Submission Deadline: March 15, 1997
Contact: Prof. Vito A. Monaco
GaAs '97 Conference
University of Bologna
Viale Risorgimento, 2
40136 Bologna Italy
TEL [39] 51 644 3030
FAX [39] 51 644 3073
Net: gaas97@deis.unibo.it
Web: http://www.micrel.deis.unibo.it/~eletlc/

24th International Symposium on Compound Semiconductors

ISCS '97 will be held September 7- 11, 1997 in San Diego, CA. This meeting is a forum for papers on all aspects of compound semiconductors including growth, processing, devices, and ICs. Materials of interest include III-V compounds including nitrides; SiC; wide bandgap II-VI compounds such as ZnSe, ZnS; IV-IV materials such as SiGe; and others.
Abstract Submission Deadline: April 14, 1997
Contact: ISCS '97, IEEE/LEOS
445 Hoes Lane
Piscataway, NJ 08854 USA
TEL [1] 908 981 0060
FAX [1] 908 981 0027
Net or Web: http://luciano.stanford.edu/ISCS/

6th International Conference on Chemical Beam Epitaxy and Related Growth Techniques

ICCBE 6 will be held September 8-10, 1997 in Montreux, Switzerland. The scope of this meeting is the entire spectrum of CBE, MOMBÉ, GSMBE, as well as related growth technologies. Mechanisms and processes of growth and film properties directly related to the growth process are

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the main focal points, but relevant characterization techniques, physical properties and the relation between materials and device properties are equally addressed.
Abstract Submission Deadline: April 1, 1997
Contact: Dr. Alok Rudra
Swiss Federal Institute of Technology
Institute for Micro and Optoelectronics
CH-1015 Lausanne Switzerland
FAX [41] 21 693 54 90
Net or Web: rudra@eldp.epfl.ch

Microwaves, RF & Communications Technologies

The 1997 Microwaves, RF & Communications Technologies Conference will be held September 30 - October 2, 1997 at the Wembley Conference and Exhibition Centre, London, England. This is an annual international conference and exhibition for companies involved in RF, microwave and millimetre wave components and application technologies.
Contact: Debby Mitchell
Nexus Mtd Ltd.
Nexus House
Swanley, Kent BR8 8HY UK
TEL [44] 1322 660 070
FAX [44] 1322 661 257
Net: M+RF@nexusmedia.co.uk

16th North American Conference on Molecular Beam Epitaxy

NAMBE 16 will be held October 5-8, 1997 at the University of Michigan in Ann Arbor. Topics will include but are not limited to: advances in MBE, CBE, etc. growth techniques; in-situ measurement and control; deposition of new materials; heterostructures; patterned and selective area growth; devices and novel concepts; production MBE technology.
Abstract Submission Deadline: TBA
Contact: Pallab K. Bhattacharya
University of Michigan, Dept. Of EE & CS
1301 Beale Ave.
Ann Arbor, MI 48109 USA
TEL [1] 313 763 6678
FAX [1] 313 763 9324
Net or Web: pkb@eeecs.umich.edu

1997 IEEE GaAs IC Symposium

The 1997 IEEE GaAs IC Symposium will be held October 12 - 15 1997 in Anaheim, CA. Coverage embraces all aspects of the technology, from materials issues and device fabrication through IC design and testing, high volume manufacturing and systems applications.
Abstract Submission Deadline: May 2, 1997
Contact: Jaclene Berry
IEEE
445 Hoes Lane
Piscataway, NJ 08855 USA
TEL [1] 908 562 3875
FAX [1] 908 981 0538
Net: jberry@ieee.org
Web: http://www.eece.umich.edu/VLSI/GAASIC

2nd Int'l Conf. On Nitride Semiconductors

ICNS '97 will be held October 27 - 31, 1997 in Tokushima, Japan. This is the successor to two 1995 conferences: the Topical Workshop on III-V Nitrides held in Nagoya and the Int'l Symp. On GaN and Related Materials held in Boston. The objective of this conference is to provide a forum for active nitride researchers to exchange their knowledge by presenting their latest results and by carrying out in-depth technical discussions.
Abstract Submission Deadline: May 31, 1997
Contact: Dr. Sadafumi Yoshida
Electrotechnical Laboratory
1-1-4 Umezono
Tsukuba, Ibaraki 305 Japan
TEL [81] 298 54 5222
FAX [81] 298 58 5434
NET: icns-inquiry@eee.tokushima-u.ac.jp

1997 U.S. Workshop on the Physics and Chemistry of II-VI Materials

The 1997 II-VI Workshop will be held October 21-23, 1997 at the Red Lion Resort in Santa Barbara, CA. Areas covered include a broad range of disciplines: materials engineering, intrinsic and extrinsic defects including doping, surface science, manufacturing/processing, electrical, optical, and magneto-optical properties as well as interactions between them.

Abstract Submission Deadline: May 1, 1997
Contact: 1997 II-VI Workshop
Palisades Institute
201 Varick Street, Suite 1006
New York, NY 10014 USA
TEL [1] 212 620 3371
FAX [1] 212 620 3379
Net: jmorreal@newyork.palisades.org

44th National AVS Symposium

The 1997 AVS National Symposium will be held October 20-24, 1997 in San Jose, CA. AVS Technical Divisions include: applied surface science; nanometer-scale science and technology; surface science; vacuum metallurgy; electronic materials and processing; plasma science and technology; thin film; and vacuum technology.
Abstract Submission Deadline: May 1, 1997
Contact: Angela Mulligan
AVS
120 Wall Street
New York, NY 10005 USA
TEL [1] 212 248 0200
FAX [1] 212 248 0245
Net: angela@vacuum.org
Web: http://www.vacuum.org

1997 International Electron Devices Meeting

IEDM '97 will be held December 7 - 10, 1997 in Washington, DC. A special emphasis on RF devices is planned for this year's meeting. Papers are requested in all areas of quantum electronics and compound semiconductor devices. Other areas of interest are: CMOS devices and reliability; detectors, sensors and displays; device and interconnect technology; integrated circuits; modeling and simulation, and solid state devices.
Abstract Submission Deadline: June 30, 1997
Late News Deadline: September 17, 1997
Contact: Phyllis Mahoney
IEDM Conference Office
101 Lakeforest Boulevard
Suite 270
Gaithersburg, MD 20877 USA
TEL: [1] 301 527 0900
FAX [1] 301 527 0994
Net or Web: pvmahoney@aol.com
http://www.ieee.org/conference/iedm

1997 International Semiconductor Device Research Symposium

ISDRS '97 will be held December 11, 12, 13, 1997 in Charlottesville, VA (following IEDM in Washington, D. C.). The Symposium will emphasize fundamental concepts in novel devices and advanced processing technologies. Participation of students and foreign researchers is strongly encouraged. Original papers are solicited in the following areas: Novel Semiconductor Device Ideas and Concepts, New Material and Device Characterization Techniques, Microwave and Millimeter Wave Devices, Wide Band Gap (SiC, GaN, ZnSe, etc.) Devices, High Speed Electronics, High Power Semiconductor Devices, Nanoelectronics, Micro-electromechanical (MEMs) Devices, New Dielectric and Interconnect Approaches, SiGe/C) Devices and Circuits, Photonics and Optoelectronics, Simulation and Modeling, New Device Fabrication Technologies.
Abstract Submission Deadline: August 29, 1997
Contact: William C. B. Peatman, Program Chair
Department of Electrical Engineering
Thornton Hall
University of Virginia
Charlottesville, VA 22903-2442 USA
TEL: (804) 979-4103
FAX: (804) 979-2653
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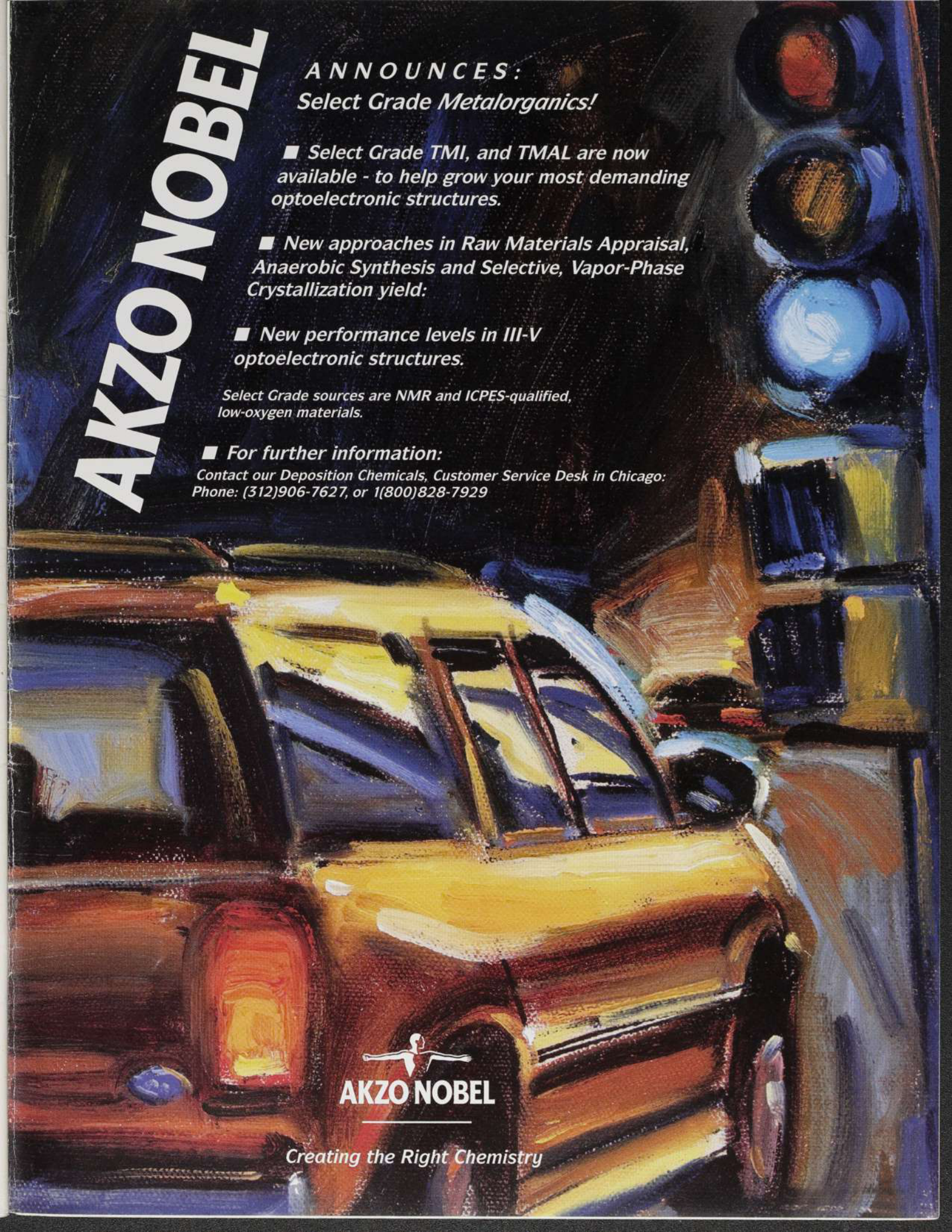
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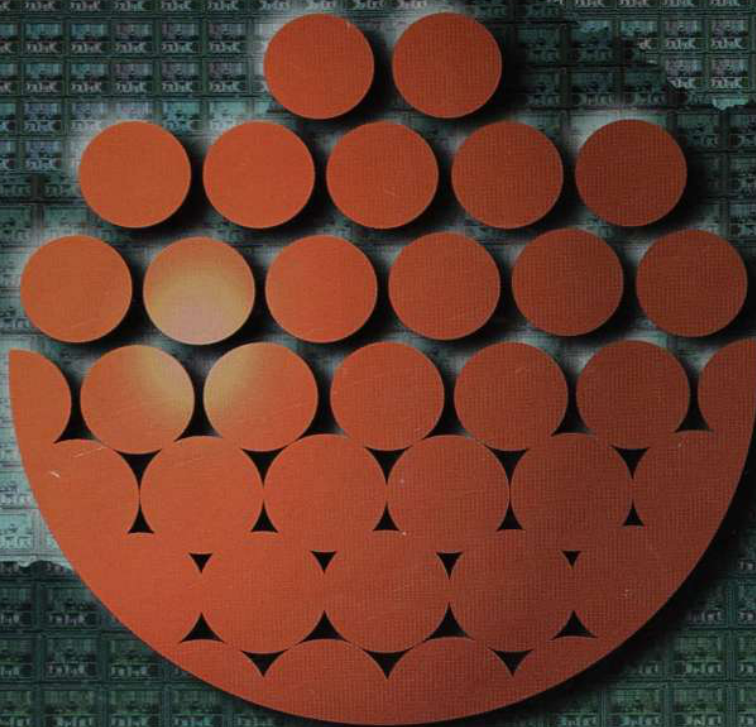
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