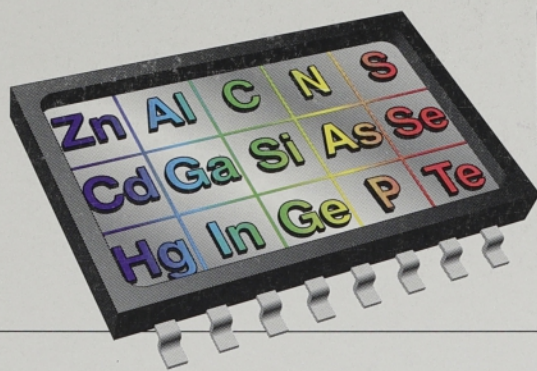




COMPOUND

SEMICONDUCTOR

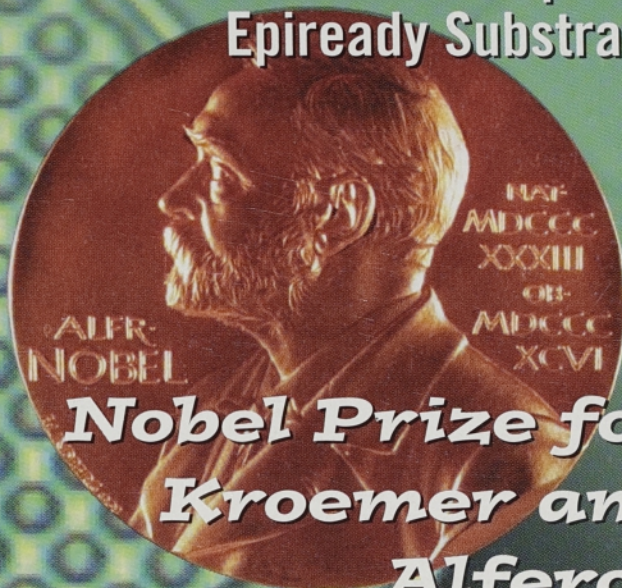
www.CompoundSemiconductor.net

November 2000

Volume 6 Number 8

Special Reports:

Epitaxy Equipment
Fabless GaAs Companies
Epiready Substrates



**Nobel Prize for
Kroemer and
Alferov**

Agilent Gets Busy
Investors Tune Into Agility
Osram's Blue LEDs

Reports from the GaAs 2000,
European SiC and Semiconductor
Laser Conferences.



Equipment Engineers

Process Engineers

Shift Engineers

MOCVD Engineers

MBE Engineers

grow with the best

With International Headquarters based in Cardiff and manufacturing sites in the UK and the USA, IQE has evolved into the highest valued Welsh public company and a FTSE250 listed multinational organisation. Formed over 10 years ago, the group has established itself as the largest compound epi-wafer foundry worldwide with a reputation for quality that is second to none.

We are the leading supplier of epi-wafers worldwide. Our products, manufactured using both MOCVD and MBE techniques, provide the key enabling technology behind many of today's electronic and opto-electronic based applications such as components used in optical fibre telecommunications, data storage systems such as CD, DVD & Minidisc and LEDs for display technologies.

Demand for the group's products for both the electronics and opto-electronics sectors has soared. Fuelled largely by growth in internet usage and mobile telephony, many large multinational blue chip companies have turned to IQE as a specialist contract supplier of these key materials.

In order to meet the increasing demands for our materials, major expansion plans have been put into place. To support our planned rapid expansion, we now seek to recruit highly motivated engineers at both our UK and USA manufacturing sites.

For the right candidates, we offer a competitive salary and benefits package, including stock options. If you have two years or more relevant engineering experience and a solid academic background, then we want to hear from you.

If you have what it takes to join a fast growing world-leader, send your CV to:

Gail Cole, IQE (Europe) Ltd, Cypress Drive, St. Mellons, Cardiff, UK CF3 0EG.
Tel: +44 (0) 29 2083 9470. Fax: +44 (0) 29 2083 9471. E-mail gcole@iqep.com
or Lorraine Ball, IQE Inc, 119 Technology Drive, Bethlehem, PA 18015, USA.
Tel: 610 861 6930. Fax: 610 861 5273.

Alternatively, visit our stand at MRS, Boston on the 28th - 30th November.

www.iqep.com

EMPLOYMENT ADS

Recruitment is one of the biggest issues in the compound semiconductor industry today. Therefore, we have reorganized our Employment Section to make it more useful. And, for a limited time, we are also offering a free tie-in to the Employment section on our web site, CompoundSemiconductor.net (please note this is a dot-net, not a dot-com, address).

We have subscribers at more than 850 compound semiconductor facilities around the world, including virtually every fab and R&D center in the compound semiconductor field. We deliver a very targeted audience that you won't be able to reach using any other publication.

If you are interested in advertising your compound semiconductor-related job openings in this space in our next issue, we need to hear from you by November 21. The deadline for the subsequent issue is January 5. Interested parties should contact:

Marie Meyer
Managing Editor
COMPOUND SEMICONDUCTOR Magazine
163 Cabot Street
Beverly, MA 01915
TEL [1] 978 927 9994
FAX [1] 978 927 9893
mmeyer@compsem.com
<http://www.compoundsemiconductor.net>



AOI

Applied Optoelectronics, Inc.

See the World in a New Light

MBE Scientist

- Ph. D. & experience in MBE of III-V opto devices
- Broad knowledge and management skills a must
- Experience in material characterization required

Packaging Engineer

- 3+ years experience in packaging of semiconductor lasers and photodetectors
- TE-cooled and fiber pigtailed components

Processing Engineer

- 5+ years experience in both back and front-end processing
- Strong troubleshooting/process development skills

Applications/Sales Engineer

- 2 Years sales experience in opto industry
- Willingness to travel

Applied Optoelectronics is a rapidly growing semiconductor laser/photodetector manufacturer located near Houston, TX. Please fax resume to: Human Resources Manager, 713-743-3496, or e-mail jobs@ao-inc.com.

www.ao-inc.com

MBE Field Service Engineer (USA)

VG Semicon, the world's largest supplier of production Molecular Beam Epitaxy systems, is seeking engineers to enhance its US Field Service team and to meet the challenges of the industry's rapid expansion. Applicants will need a solid background in electronics, mechanical engineering and computing. Experience working with Ultra High Vacuum systems would be an advantage. After training in the US and UK, duties will include system maintenance, customer training and installation of upgrades. A significant level of travel is required. Self motivation and the ability to work with minimal supervision is critical.

Interested parties should respond in writing to

VG Semicon
100 Cummings Center
Suite 451G
Beverly MA 01915
e-mail: sales@vgmbe.com



VG Semicon
The MBE Company

Join...

...as a Service Engineer (Electrical Engineering)

About AIXTRON

- It's a high tech company in a rapidly growing market
- Market leader for MOCVD equipment within the compound semiconductor industry
- Successfully listed on the Frankfurt Stock Exchange, New Market
- Annual growth rate of 50% p.a.
- Stock option plan for all employees
- Competitive salaries & attractive benefits
- Young & enthusiastic team

The Position

- Join one of our local service teams in Taiwan, Japan, Europe/Wales
- Technical start-up & service of CVD systems on customer site
- Handle international service orders
- Develop & optimize the local service organization
- Support the international network of service centers

Your Profile

- Degree in electronic engineering
- Mechanical skills & relevant practical experience
- Skilled in working in a multi-cultural environment
- Capable of training & coaching employees
- Building up a good customer relationship
- Self-motivated & disciplined
- High degree of responsibility

About Yourself

Are you looking for a challenging position within a dynamic and successful organization?

Then please send your CV under reference 2000/44 to:

AIXTRON AG
Human Resources
Kackertstr. 15-17
D-52072 Aachen
Germany
Phone: +49 (241) 89 09-0
E-mail: wei@aixtron.com
www.aixtron.com

JOIN THE PHILIPS ANALYTICAL TEAM

Let's make things better

POSITION LOCATED IN PHOENIX, AZ

PHILIPS is a blue chip multinational company with sales over \$40 billion worldwide with operations in over 70 countries. Its North America Corporation is a fortune 100 company and Philips Analytical is one of the fastest growing business units within Philips. We develop, manufacture, sell and service hi-tech scientific analysis equipment for use in industry and research.

If you or someone you know is interested in the below vacancy, please forward a resume by email joanne.perloff@Philips.com, fax to (508)647-1113, or mail to 12 Michigan Drive, Natick, MA 01760.

Application Specialist:

Compound Semiconductor Materials Characterization

Philips Analytical offers a wide range of analytical instruments for materials characterization in the semiconductors market. We are looking for an applications specialist to support our pre-sales and after-sales activities. Responsibilities include demonstrating our products to potential customers and providing training and support to existing customers. Candidates should have a BS, MS or PhD in a relevant scientific discipline. Previous experience of the use of x-ray diffraction to collect rocking curve measurements or photoluminescence measurements in a laboratory or industrial environment is strongly preferred. Effective written and verbal communication skills are essential. Extensive travel (upwards of 50%) is required.

Let's make things better.



PHILIPS

Engineering Career Opportunities

Spectrolab, Inc., the world's leading manufacturer of space and terrestrial photovoltaic systems, has career opportunities in its photonic devices division.

■ **III-V Materials Growth Engineer** Epitaxial film deposition and characterization of III-V materials. BS required. Experience with MOVPE systems and materials characterization desirable.

■ **III-V Solar Cell Project Engineer** Device design of III-V multijunction solar cells. PhD +1-2 yrs. or MS + 5 yrs. experience required. Must have strong understanding of physics of photovoltaic cells or detectors. Project management and proposal writing experience desirable.

■ **Sensor Product Engineer** Design, fabricate and test III-V detectors, plus process documentation and proposal/report writing. BS required, MS preferred, plus 3-4 yrs. experience in III-V detectors required.

■ **HBT Device Engineer** Develop III-V microelectronic devices (HBTs and HEMTs). Must be knowledgeable in electrical characterization and device processing. BS, MS, or PhD in EE, MatE, Physics, or related fields plus 1-2 yrs. experience required.

■ **Laser Diode/Light Emitting Diode Device Engineer** Develop III-V Compound Semiconductor light emitting products. Work with crystal growers and wafer processing engineers for producing devices that meet both internal R&D and customer requirements. Must characterize materials and device performance. Should have a Ph. D. or M.S. in electrical engineering or physics.

Please specify the **position category** to which you are responding.

We offer an attractive salary and an outstanding benefits package.

SPECTROLAB

A BOEING COMPANY

12500 Gladstone Ave.
Sylmar, CA 91342
Fax: 818.898.7534
www.spectrolab.com

Equal Opportunity Employer

What do you want the Internet to be?SM

Optical Internet

You've never been one to accept the status quo. And we wouldn't have it any other way. We're Nortel Networks. And we know it takes daring ideas like yours to change the way people work, learn, and communicate. Today, we're building the new high-performance Internet. And we're counting on you to help set a new global standard for speed, reliability and security. How's that for radical thinking?

Nortel Networks is a global leader in eBusiness, data, telephony and wireless solutions for the Internet. Today, we're creating the high-performance Internet that is more reliable and faster than ever before. Nortel Networks is the recognized global Optical Internet leader. More than 75% of North American and 50% of European backbone Internet traffic travels across our Optical networking equipment. Our competitive advantage in 10 gigabit systems is due in part to our leadership in components.

We have exciting employment opportunities for experienced process engineers in our new and recently expanded GaAs wafer fabs which produce volume HBT ICs for the Optical Internet.

Engineering:

- Yield Engineer
- Device Physicist
- Implant Process Prime
- Process Integration Specialist
- PCM Test Engineer
- Device Reliability Engineer

Management:

- Engineering Manager, Etch, Dielectric Deposition and Implant

Exceptional compensation and excellent benefits are just part of what you can expect from this world-leading, \$21-billion (US) company. So come together, right now, with Nortel Networks, and make the Internet whatever you want it to be. Please e-mail a detailed resume to gfindlay@nortelnetworks.com or apply online at:

nortelnetworks.com/careers

NORTEL
NETWORKSTM

III-V EPITAXY OPPORTUNITIES

ATMI, Inc., with revenues nearing \$300M/yr, is recognized for its innovative thin-film semiconductor materials technology. Our Services Division is a leading epitaxy provider to the wireless communications industry. New plant expansion has created the following needs for talented professionals:

CHARACTERIZATION ENGINEER...requires a BS/MS in Electrical Engineering, Materials Science or Physics with 1-3 years' closely related semiconductor industry experience. Using diverse test engineering practices, will develop protocols/SOPS for characterizing specialty III-V wafers.

PRODUCTION ENGINEER...must possess a BS/MS in Electrical or Chemical Engineering and 3-5 years' hands-on experience in III-V MOCVD growth technology. Will spearhead programs for yield improvement and process efficiency enhancement.

We offer an attractive compensation/benefits package featuring profit sharing, stock options, discounted stock purchase, company-matched 401(k) savings and tuition reimbursement plans along with PTO starting at 17 days/yr. Relocation assistance is provided. To expedite consideration of your candidacy, please include cover letter and salary history with your resume. *We will reply only if mutual interest exists.* EOE.

HR Manager – ATMI/Services Division
21002 West 19th Avenue, Suite 5
Phoenix, AZ 85027 Fax: (623) 581-3415
www.atmi.com

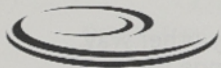


EMCORE Corporation offers the complete spectrum of compound semiconductor products for the broadband and wireless communications and solid state lighting markets. The Company's integrated solutions philosophy embodies state of the art technology, material science expertise and a shared vision of our customer's goals and objectives to be leaders and pioneers in the rapidly growing world of compound semiconductors. We are seeking candidates for the following positions:

- InP Scientist
- Test & Reliability Scientist
- LED Device Scientist
- GaAs Based Staff Scientist
- Production Software Engineer
- Electrical Engineer
- Development Engineer

EMCORE offers a competitive salary and benefits package. If interested, mail, fax or e-mail your resume, including the position of interest to:

Joan Thomas
EMCORE Corporation
145 Belmont Drive
Somerset, NJ 08873
Fax: (732) 271-9686
E-mail: Joan_Thomas@emcore.com



EPIWORKS™

THE OPPORTUNITY IS NOW

EpiWorks, Inc. is an advanced MOCVD technology company supplying epi-wafers to the communications industry.

We are adding highly motivated **managers** and **engineers** who can have immediate impact. If you are ready to make an upward career move, thrive in a challenging environment, want the potential of a pre-IPO company and have a background in compound semiconductor manufacturing, please send us your resume. We are looking to hire the following immediately:

VP Sales: Develop and lead sales organization. Over 5 years experience in sales w/proven track record. Background in management and compound semiconductors or communications desired. B.S. or MBA desirable.

MOCVD Process Manager: Develop and manage processes for multi-wafer MOCVD systems in high-volume environment. At least 5 years experience in MOCVD manufacturing, including transferring processes from development to production, bringing multi-wafer systems on-line, and developing manufacturable processes. A strong understanding of devices and materials, and a Ph.D. in E.E. or related field is desirable.

MOCVD Production Manager: Manage high-volume MOCVD production line. At least 5 years experience in MOCVD manufacturing, including the ability to establish processes transferred from Engineering, ramp to volume, perform SPC and sustaining engineering. A strong understanding of MOCVD, high-volume manufacturing, throughput and yield are desirable.

R&D Engineer: Research next-generation products, develop processes and transfer processes to Engineering. The ability to interact with applications engineers and manage R&D projects

is critical. A strong understanding of crystal growth, materials and devices, and a Ph.D. in E.E. or related field is desirable.

Test Manager: Responsibilities include management of small fabrication line and device test/analysis, including a staff of engineers and technicians. Other duties include implementation of ISO qualified procedures, SPC and documentation, data analysis, and developing and implementing tests to meet customer specifications. Candidates must be team oriented with excellent communication, interpersonal and technical skills. A Bachelors Degree in Electrical Engineering or related field with five years experience required. Experience with, IC fabrication, automated test and characterization are desired.

MOCVD Engineer: This position offers a ground floor opportunity to bring a new MOCVD system online and into production. Responsibilities include, maintaining MOCVD reactors to meet uptime, performance and throughput targets, performing troubleshooting, maintenance and materials characterization such as Hall, PL, and Leighton C-V doping profiling. Other duties include development, improvement of manufacturing methods and maintaining SPC for product and process requirements to optimize yield and throughput. Candidate must have proficiency with database, graphing, process flow and office communications software. A Bachelors Degree in Electrical Engineering, Chemical Engineering, Materials Science or related field required. Three years in manufacturing and SPC experience is desired.

EpiWorks is located in Champaign, Illinois. Employees receive **significant** stock option compensation and a competitive salary/benefits.

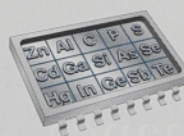
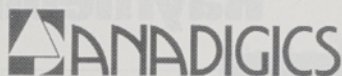
Fax resumes to EpiWorks, Inc at 217-373-1591.

Sr. Design Engineer

ANADIGICS, through rigorous design, engineering and testing in a niche market, is a top contender on the RF circuit. Our newest 6-inch GaAs manufacturing line builds our capacity for speed, and we've got engineers rolling out more RF and microwave products than ever. Our Senior Design Engineer will take a leadership role.

You will be responsible for the design/characterization/initial production of high speed and ultra-high speed fiber optic devices and components; interact with key customer accounts to enable smooth transitions of designs to field applications; and collaborate with customers/marketing/manufacturing in transitioning the development to a viable product. Requirements include a BS degree and 8-10 years of related RF IC and MMIC design experience. Preferred candidates will possess an MSEE and 5 years' experience or a Ph.D and 2 years. SPICE and ADS design tool skills are desired, along with background in RF microwave design and knowledge of RF test measurement techniques and equipment.

See www.anadigics.com for details about this opportunity and others. Please send your reply to hr@anadigics.com or ANADIGICS, Inc., Human Resources/CS, 35 Technology Drive, Warren, NJ 07059. FAX: 908-412-5942. An EOE



COMPOUND

Position Available

If you have excellent communication skills and are knowledgeable about the compound semiconductor industry, we want to hear from you! Part-time and work from home applications will be considered.

Assistant Editor

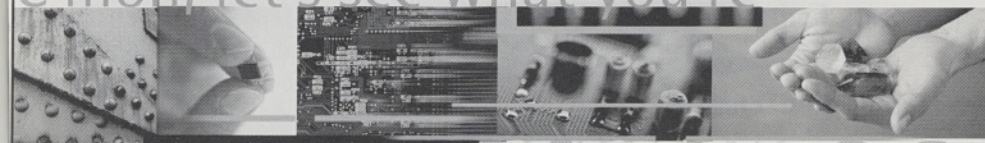
The Assistant Editor will be responsible for writing feature articles and editing news items for print and Internet publication. Applicants should have excellent writing skills, knowledge of compound semiconductor technology, and an interest in both scientific and commercial developments.

Please send your resume to:

Marie Meyer
Franklin Publishing
163 Cabot Street
Beverly, MA 01915 USA
FAX: [1] 978 927 9893,
Email: mmeyer@compsem.com



C'mon, let's see what you're



If you're ready to see what you're made of, get in on our ground floor and find out. Founded in 1999, Nitronex is commercializing materials and devices based on a revolutionary new semiconductor—Gallium Nitride (GaN)—that offers faster, more efficient, and greater density data storage and communication. Our kind of challenge is hard-hitting; our kind of day is fast-paced; and our kind of style is quick-thinking. We're hard at work stirring up phenomenal opportunities that are revving up dramatically exciting careers. If you're smart, ambitious, and ready to put yourself to the test, then you're made of the right stuff. So c'mon. It's time.

Director, Device Fabrication

This position, reporting directly to the CEO, will be responsible for setting up a pilot production wafer fab for the development of Gallium Nitride RF devices in a cost effective and timely fashion. Initial focus will be on GaN specific fabrication processes. Ideal candidate will have minimum of 8 years of progressive engineering management experience with an emphasis on device engineering, along with an MS in Materials Engineering, Chemical Engineering or Electrical Engineering.

Semiconductor Engineers

Responsibilities of these positions include operating, maintaining and process development for various semiconductor growth and processing equipment. Ideal candidates will have experience with UHV manufacturing systems and/or mechanical and electronic troubleshooting skills. Electrical Engineering, Mechanical Engineering, or equivalent experience preferred. 1st and 2nd shift positions available.

Applications Engineer

This dynamic position calls for a multi-talented individual who combines RF/Microwave design experience and knowledge of wireless communication standards and trends, as well as excellent customer interface skills. Functions include identification and development of design slots in wireless and broadband communication systems using GaN based microwave devices developed at Nitronex. The ideal candidate will possess a graduate degree in EE or Physics specializing in microwave engineering; 3 plus years of experience in microwave circuit design or fabrication is preferred, as well as proven experience in developing customer relationships.

You'll like our generous compensation/benefits package that includes an excellent incentive stock option plan. Relocation package also available. Please send your resume to: Human Resources, Nitronex Corporation, Dept: CS08, 628 Hutton Street, Suite 103, Raleigh, NC 27606; E-mail: hr@nitronex.com Diversity drives us to success. EOE

E-mail: hr@nitronex.com Diversity drives us to success. EOE

RF Test/Amplifier Engineer

This position will be responsible for setting up a complete state-of-the-art measurement lab for characterizing high-power microwave devices and circuits. Building upon standard DC and S-parameter measurements using parameter and vector network analyzers, the RF Engineer will specify additional equipment for a range of measurements including IMD, power sweeps, load pull, and noise figure. Paralleling the lab measurements, the RF Engineer will prototype amplifier circuits utilizing the latest microwave CAD tools. The ideal candidate will have 2-3 years of RF testing and design experience, and practical experience with test equipment, such as Agilent. MSEE or PhD preferred.



Photolithography Engineer

The Photolithography Engineer will develop a state-of-the-art lithographic process to support current development of sub-micron AlGaIn/GaN heterojunction FET's. Previous experience with compound semiconductor mushroom gate processes involving multi-layer polymer photoresists such as PMMA and MMA is required. Cross-functional knowledge in associated areas such as metalization and plating is highly desirable. The candidate will combine an academic background in EE, Chemistry, or Physics with a minimum of three years of experience in a compound semiconductor photolithography lab.



NITRONEX

CORPORATION

Inspiring High-Performance.



At Raytheon RF Components, high-performance is critical to our success. As a leader in cutting-edge products for satellite communications, Wireless LAN, and mobile phone handsets around the globe, we strive to outperform the competition, and hire the most talented people in the industry. We're breaking the mold in everything from GaAs MMIC power amplifiers, to "catalog" amplifiers, to outstanding wideband and millimeter-wave technology. It's an incredible performance—and one that relies on the most inspiring talent in the industry: You.

SENIOR DESIGN ENGINEER

Responsible for design of next generation high-efficiency microwave and millimeter-wave MMIC power amplifiers, LNAs, phase shifters and switches using various device technologies, including pHEMT, metamorphic HEMT and wideband gap semiconductors. Requires a BS and 6 years of directly related experience; MSEE preferred. Previous experience with MMIC design tools (Libra, Momentum, Cadence layout) is also required.

DEVICE DESIGN ENGINEER

Responsible for the design and fabrication of next generation microwave and millimeter-wave compound semiconductor devices. Duties include the design and implementation of material, process and device development, and characterization experiments. Requires a BS and 3-7 years of directly related experience. Experience with III-V compound semiconductors is desirable.

PRINCIPAL EE DESIGN ENGINEER

Responsible for GaAs IC or RF component designs used in commercial applications such as cellular telephones and base stations. Work closely with an integrated team of professionals from layout, wafer processing, packaging and testing to take designs from concept through pre-production phases in an environment where time-to-market is of critical importance. Requires a BSEE and 5+ years of experience in MMIC or RF hybrid circuit design using linear and non-linear simulators. Demonstrated experience with HP Libra or similar design tools, pHEMT, or HBT-based power amplifiers is highly desirable.

Raytheon offers outstanding benefits and compensation and paid higher education. To explore these and other opportunities, please send your resume to: **E-mail: cooljobs@rfc.raytheon.com; Mail: Raytheon RF Components, Attn: Employment Manager, RF Components Career Center, 362 Lowell Street, Andover, MA 01810; Fax: (978) 684-8790.**

The reason is

Raytheon

For more information on Raytheon RF Components, visit our website at:

www.raytheon.com/micro

SPECIFICATIONS FOR EMPLOYMENT ADS

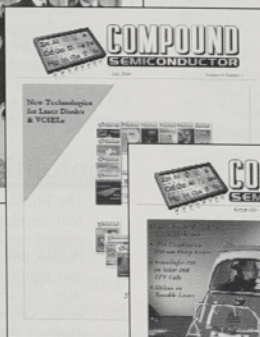
RATES

Full page, one time: \$2,678
Full page, three or more times: \$2,544
Half page, one time: \$2,110
Half page, three or more times: \$2,006
Quarter page, one time: \$1,078
Quarter page, three or more times: \$1,019

SPECIFICATIONS

B&W or 2 color, second color cyan, only. No bleeds. We cannot accept film or camera-ready art, as we use a "straight to plate" printing process. We prefer that you submit your ad as a high resolution (300dpi) PDF file. Please include the fonts. If you do not have an ad, we can prepare one for you. Simply email us your text and a copy of your logo.

Full page, Inches: 8 3/8" × 10 7/8"
Full page, Metric: 212.75mm × 276.5mm
Half page, Inches: 8 3/8" × 5"
Half page, Metric: 212.75mm × 127mm
Quarter page, Inches: 3 1/2" × 5"
Quarter page, Metric: 89mm × 127mm



DEADLINES

Issue 9 (Dec.)

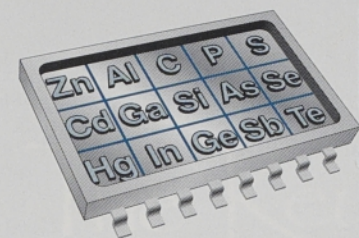
Orders due November 21
Materials due November 28
Publication Date: December 15

Issue 1 (Jan.)

Orders due January 5
Materials due January 12
Publication Date: January 26

For more information, contact:

Marie Meyer
Managing Editor
COMPOUND SEMICONDUCTOR
Magazine
163 Cabot Street
Beverly, MA 01915
TEL [1] 978 927 9994
FAX [1] 978 927 9893
mmeyer@compsem.com
<http://www.compoundsemiconductor.net>



COMPOUND

SEMICONDUCTOR



SPECIAL REPORTS

- 7 Nobel Prize**
A profile of two pioneers in the compound semiconductor field, Herbert Kroemer and Zhores Alferov, who share half of this year's Nobel Prize in physics.
- 37 Growing Demand for Epi Equipment**
Major manufacturers of MOCVD and MBE equipment have full order books this year—and all have expansion plans in the works.
- 66 Reflections on a Semiconductor Crystal Surface**
Nigel Mason and co-workers discuss epi-ready GaAs substrates.

GaAs ICs

- 19 GaAs ICs News**
New fab news . . . Hexawave expands, develops new processes . . . and more
- 44 European Microwave Week Report**
- 49 Fabless GaAs Companies Feature Prominently in the Latest Rounds of Financing Activity**
- 57 Improved InGaAs/InP DHBT Technology for 40 Gbit/s Optical Communications Circuits**

NITRIDES

- 11 Nitride News**
Cree doubles LED brightness, announces blue laser results . . . and more
- 75 The 3rd European Conference on SiC and Related Materials**
- 81 Developments in InGaN-on-SiC LEDs and Lasers at Osram**

OTHER FEATURES

- 16 Agilent Gets Busy**
Agilent has reorganized its fiber-optic networking activities, announced strong semiconductor sales and a new 6-inch GaAs fab to make E-mode PHEMTs.
- 34 Investors Tune into Agility**
Agility Communications' recent \$70M funding windfall should hasten the introduction of its first tunable laser products.
- 72 17th IEEE Semiconductor Laser Conference Report**

This issue's cover shows GaN-based interconnected microdisk LEDs, which have demonstrated much higher emission efficiencies than conventional devices—see page 14 for details. Photo courtesy of Jingyu Lin and Hongxing Jiang, Kansas State University (Manhattan, KS, USA). Also inside, beginning on page 7, is a feature article about the winners of this year's Nobel prize for physics, Herbert Kroemer and Zhores Alferov.

NEWS

- 14 LED News**
Interconnected microdisk LEDs promise higher emission efficiencies . . . LumiLeds wins order for emergency lighting . . . and more
- 21 News from Japan**
Sony shows blue laser DVD recorder . . . Toyoda Gosei targets ¥60B in LED sales by 2003... and more
- 22 Opto News**
TRW acquires Cutting Edge Optonics . . . Opto Power focuses on Telecom lasers . . . and more
- 25 Fiber-Optics News**
Money flows in fiber-optic funding season . . . Corning buys Pirelli's optical components business . . . Nortel plans to sell shares in its fiber-optics business . . . and more
- 39 Materials and Equipment**

DEPARTMENTS

- 2 Index**
- 88 Silicon Update**
- 63 Portfolio**

www.compoundsemiconductor.net

Compound Semiconductor

is published nine times yearly by

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

Editor

Tim Whitaker
tim.whitaker@compsem.com

Managing Editor

Marie Meyer
mmeyer@compsem.com

Assistant Editor

Richard Dixon
rdixon@compsem.com

Editorial Board

Colombo Bolognesi

Simon Fraser University (Canada)

Steven DenBaars

University of California at Santa Barbara (USA)

Andrew Johnson

Defense Evaluation and Research Agency (UK)

Robert Metzger

Georgia Institute of Technology (USA)

Rodney Moss

Agilent Fiber Optic Components (UK)

Shuji Nakamura

University of California at Santa Barbara (USA)

Dwight Streit

TRW (USA)

Toby Srite

JDS Uniphase (UK)

Jacob Tarn

Epistar (Taiwan)

Gary Tomkins

Nortel Networks (Canada)

Andreas Waag

University of Ulm (Germany)

Gary Wicks

University of Rochester (USA)

Peter Zory

University of Florida (USA)

©Copyright 2000 by Franklin
Publishing - all rights reserved.

POSTMASTER

Send address changes to:
CS Subscriptions
163 Cabot Street
Beverly, MA 01915 USA

Organization Index

Company/Organization

Page

ABB	78, 80	Multilink	49, 53-55
ACREO AB	75	n&k Technology	40
Advanced Wireless Semiconductor	19	NEC	30, 47-48, 72
Agilent	11, 16-19, 63	Nichia Chemical	11, 73
Agility Communications	34-35	Nitres	11
Aixtron	37, 39, 76, 63	Nokia	50, 53, 55, 63
Alcatel Optonics	31-32, 63	Nortel Networks	25, 64
Allied Business Intelligence	49	Nova Crystals	27
Alpha Industries	44-45, 63	Novalux	27
AMCC	54	NTT	54
Anadigics	21, 39, 45, 49, 63	Oki Electric	48
Applied Optoelectronics	22	Okmetic	75
Atmel	12	ONR	13
ATMI	13, 39, 63	OPTO+	57
Audi	81	Opto Power	23
Avnet	49	Ortel	25
Bell Labs	10, 22	Osram Opto	11, 81-82, 84, 86-87
Bio-Rad	69	Palomar Technologies	41
BMDO	13	Philips	16, 44
Boeing	15	Picogiga	30, 37, 63
Brush Wellman	41	Picolight	27
Celeritek	19, 53, 63-64	Pioneer	19, 21
Ciena	31, 54	Pirelli	25
Cisco Systems	25, 27	PIRI	25
Coherent	30, 63	PTI	41
Conexant	21, 63	Qtera	54
Corning Lasertron	25	Qualcomm	21
CyOptics	27	Raytheon	15, 45, 53
Daimler-Chrysler	12	RCA	7, 10
EiC	45	RF Micro Devices	64
Emcore	13, 37, 39, 63-64	Riber	37, 39, 63
Endwave	49-51, 53-54, 63	Rohm	41
EPI MBE Products	37	S-SENCE	80
Epichem	41	Samsung	55, 63
Epigress	76	SDL	25, 31, 72, 63
Epistar	41	Sharp	48, 64
Ericsson	53, 55, 75, 63	SiCED	75, 78
France Telecom	57	Siemens	34, 63, 78
General Electric	8	Sony	21, 73
GiGa	54	Spectra-Physics	23
Gore	72	Spectrolab	15
Hexaware	19	Stanford Microdevices	49-50, 63
Hitachi	30	Steag	40
Huawei Technologies	25	StratEdge	41
Hughes Electronics	15	Strategies Unlimited	32
IBM	7-8, 10, 54	Sumitomo Electric	39
Infineon	27, 44, 78, 81	TDI	13
Infineon Technologies Ventures	27	Tecstar	15
Intel	27, 54	Tegal	40, 63-64
Intel Capital	27	Teledesic	15
IntelliEPI	37, 39	Temic	12, 49
IQE	63	Texas Instruments	8
JDS Uniphase	16, 54, 63	Thomson-CSF	53, 75, 78
JPL	15	Toyoda Gosei	21
Kawasaki Res. Center	48	Trikon	63-64
KDF	40	TriQuint	21, 54, 63-64
Kopin	39, 63-64	TRW	22, 40, 49, 51, 53-55
Kyma Technologies	13	Tutcore	30
Kyoto University	78	Ultra RF	49
Lasertron	25	UMS	45, 47, 54
Lawrence Livermore	72	University of Illinois	88
Lucent	16, 22, 25, 53-55, 72	University of New Mexico	73
Lumera Corp.	23	University of Texas	7
LumiLeds Lighting	17	VG Semicon	37
Luminent	32	Vishay Intertechnology	12
Marconi	20	Vishay Telefunken	12
Microvision	23	Vitesse	19, 27, 54, 63-64
Milliwave	51	Wafer Technology	65-66
MIT Lincoln Labs	8, 64	Watkins-Johnson	55
Mitsubishi	63	WIN Semiconductors	19
Modulight	30	WJ Communications	20, 55
Motorola	15, 19, 21, 63	Xerox	73
MRV	32		

The Key Conference

Compound Semiconductors in Communications

Key West, Florida
March 5-6, 2001
www.keyconference.com

Sponsored by:

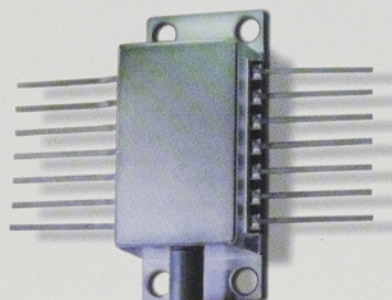


Compound Semiconductors for Communications: What Lies Ahead?

The communications market is of paramount importance to the compound semiconductor industry. Join us in Key West this March for an opportunity to hear how the major producers and consumers of compound semiconductor devices plan to meet the chal-

lenges ahead. More than 20 companies will offer

Presented By:

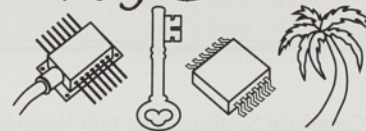


their views on topics involving both "wired" and "wireless" communications. All of the speakers are hand-picked by the sponsors for their knowledge about the forces that will shape the future of the compound semiconductor industry

in the global communications market.



The Key Conference



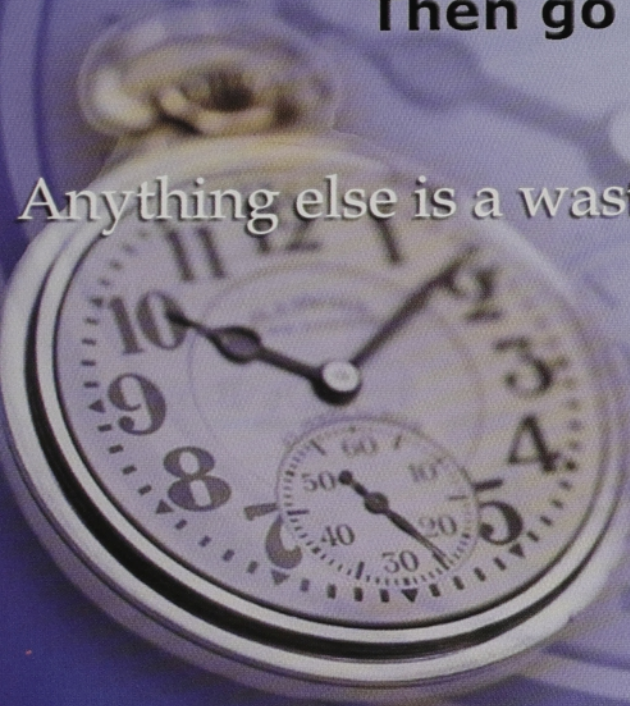
www.keyconference.com

For more information visit our website at
www.keyconference.com

Looking for compound semiconductors on the Net

Then go to CompoundSemiconductor.Net

Anything else is a waste of time.



To find
Compound Semiconductor magazine
on the net, go to
CompoundSemiconductor.net

Advertiser Index

Accent	28, 29	Lake Shore	6
Aeronex	80	Maintech	87
Aixtron	5	Mochem	59
Akzo Nobel	33	Omicron	12
Applied Epi	OBC	Raboutet	41
Arconium	35	RF Nitro	87
Atlantic Metals	51	Riber	26, 73
AXT	36	Rohm & Haas	30, 62
Bruker	20	Solkatronic	79
Centrotherm	23	ST Systems	18
Charles Evans & Associates	10	Sterling Semiconductor	77
DCA	56	Strategies Unlimited (Conference)	24
Dynatex	22	Struers Logitech	13
Eagle-Picher	15	Super Epi	13
Emcore	9, 38, 71	TDI	83
Epigress	65, 67	Tegal	52
Epitaxial Technologies	17	Thomas Swan	85
Hitachi Cable	55	Union Miniere	61
Honeywell Electronic Materials	74	United Epitaxy Company (UEC)	IBC
IntelliEPI	51	VG Semicon	42, 43
IQE	IFC, 46, 47	Wafer Technology	68
Key Conference	3		

The CVD Engineering Company



IT'S A FACT

that no other MOCVD company in the world offers you the **unique, versatile, and constantly high quality** technology you're assured of from AIXTRON, whether you're producing LED's, Lasers, Detectors, HEMTs, HBTs, OEICs...
...And we can prove it!

FACT!

No other company in the world offers you a complete MOCVD reactor line, based on a proven scaling concept, from R & D up to full-scale production [1x2" up to 95x2" wafers or equivalent 3", 4" wafers].

FACT!

AIXTRON is the only company in the III-V epitaxy field offering proven processes from mono layer thickness up to more than 200µm/h.

FACT!

AIXTRON was the first MOCVD company worldwide to receive the ISO 9001 Certification - the internationally recognized quality symbol.



WHAT BETTER GUARANTEE OF OUR

Commitment to AIXcellence

AIXTRON

European Headquarters
Aachen, Germany
AIXTRON AG
Kackertstr. 15-17
52072 Aachen
Germany

Phone: +49 (241) 89 09 - 0
Fax: +49 (241) 89 09 - 40
e-mail: info@aixtron.com

US Headquarters
Chicago, Illinois
AIXTRON Inc.
1670 Barclay Blvd.
Buffalo Grove
IL 60089, USA

Phone: +1 (847) 215 - 7335
Fax: +1 (847) 215 - 7341
e-mail: usinfo@aixtron.com

AIXTRON Taiwan
Hsinchu, Taiwan
Challentech International Corp.
Pateh Road No. 1, Lane 9
Hsinchu, 300
Taiwan R.O.C.

Phone: +886 (3) 5614 - 211
Fax: +886 (3) 5614 - 194
e-mail: hotoon@challentech.com.tw

Sales and Service
Tokyo, Japan
Moritani & Co., Ltd /AIXTRON
4th Section, 12th Machinery Dept.
2nd Business Group
1-4-22 Yaesu, Chuo-Ku
Tokyo 103 - 8680, Japan
Phone: +81 (3) 3278 - 6131
Fax: +81 (3) 3278 - 6121
e-mail: mike@moritani.co.jp

The Ideal Tools for Semiconductor Characterization

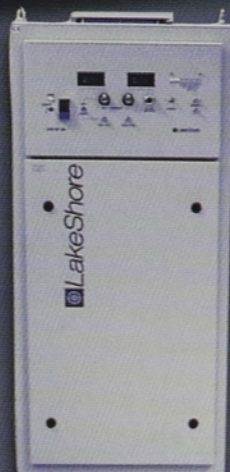
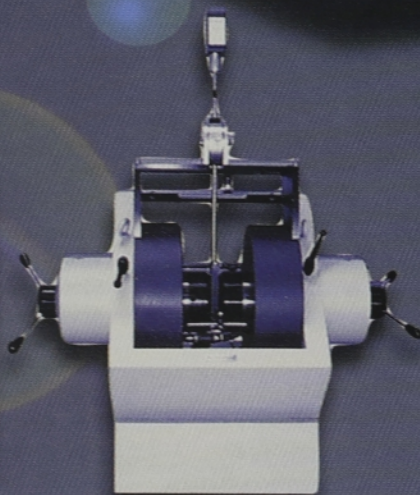
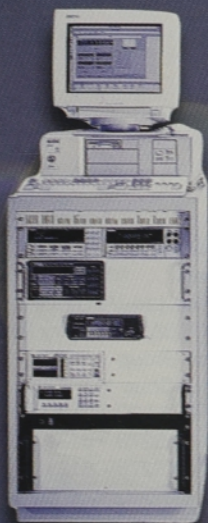
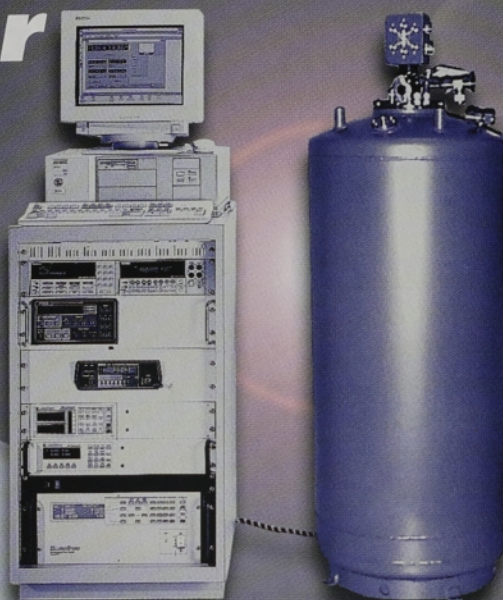
Lake Shore's Hall Effect Measurement Systems (HMS) are the most comprehensive tools available for the characterization and analysis of semiconductors.

Lake Shore Hall systems characterize all types of conducting and semiconducting materials:

- Semiconductors including Si, SiGe, GaAs, GaN, InP, GaAlAs, and HgCdTe
- Heterostructure devices including HEMTs, HBTs, FETs, quantum wells, and LEDs
- MR, GMR, and CMR devices
- Other organic and inorganic materials

Features include:

- Measurements of Hall voltage, resistance, magnetoresistance and I-V characteristics
- Calculations of Hall coefficient, resistivity, carrier mobility and carrier density
- Variable field, variable temperature and time-dependent measurements
- Robust and easy to use fully-automated Windows™-based control software
- Unique Quantitative Mobility Spectrum Analysis (QMSA) software for multi-carrier devices



LakeShore

Lake Shore Cryotronics, Inc.

575 McCorkle Boulevard
Westerville, Ohio 43082-8888 USA

Telephone (614) 891-2244

Fax (614) 818-1600

sales@lakeshore.com

www.lakeshore.com

Kroemer & Alferov Awarded Nobel Prize

WILLIAM R. FRENSLEY
University of Texas at Dallas

Two of the leading researchers in the compound semiconductor field, to Zhores I. Alferov and Herbert Kroemer, will share one half of the 2000 Nobel Prize in physics. The other half goes to the father of the integrated circuit, Jack S. Kilby. Although the three men worked independently of each other, the Nobel committee has grouped them together because they did the work "that has laid the foundation of modern information technology, particularly through their invention of rapid transistors, laser diodes and integrated circuits."

Alferov and Kroemer are being cited "for developing semiconductor heterostructures used in high-speed and opto-electronics." Out of the many chemical elements and compounds that form semiconducting crystals, only a few combinations form heterojunctions that are good enough to be useful in semiconductor devices, and all but one involve compound semiconductors.

Herb Kroemer was the early and persistent advocate of the use of heterojunctions in devices. The common theme that runs through his work is the search for more effective ways to control the electrons and holes that carry electrical currents in semiconductor devices. Kroemer's earliest device invention (1953) was the drift transistor. The idea behind this device is best understood by examining the "energy-band profile," which is a graph of the conduction- and valence-band energies versus depth into the semiconductor wafer (see Figure 1). To visualize how electrons and holes move through a device, think of the electrons as little balls rolling around on top of the conduction band curve, and holes as bubbles trapped under the valence band curve. In a homojunction device the shape of the band profile is entirely due to the dopants introduced into the semiconductor and the voltages which are applied to the terminals. The idea of the drift transistor is to continuously grade the doping density in the base to create an electric field which will push the electrons (in an NPN transistor) through the base and on into the collector. This electric field appears in Fig. 1 as the downward slope of the energy bands through the base. In conventional transistors in the early 1950s, the base doping was uniform, and the bands were flat through the base. Electrons in conventional transistors had to find their way through the base by random motion, and only a fraction of them did so.

The drift transistor had improved speed and gain over conventional transistors. IBM's first high-speed scientific computer was built using such devices, and they permitted the use of tran-

sistorized circuits at the higher radio frequencies, in products like television receivers. We do not hear about drift transistors today, because the double-diffused planar process (the standard technique for making silicon bipolar transistors for the past 35 years) naturally produces the graded base doping of the drift structure.

The next conceptual advance in bipolar transistors was the idea of the heterojunction emitter structure, but this device took much longer to come to fruition. William Shockley, who won the Nobel Prize in 1956, was issued the original patent on the bipolar transistor in 1951. His application included a claim that described a heterojunction emitter, but no one followed up on this idea at the time. Kroemer did a more thorough analysis of the advantages of the heterojunction bipolar transistor (HBT) while working at RCA in 1957. The HBT structure is shown in Figure 2. It solves another problem of transistor design, increasing the emitter efficiency. The electron current out of the emitter and through the base is what provides the amplification in a transistor. But, current can also be carried by holes moving from the base into the emitter. This latter current must be minimized in a

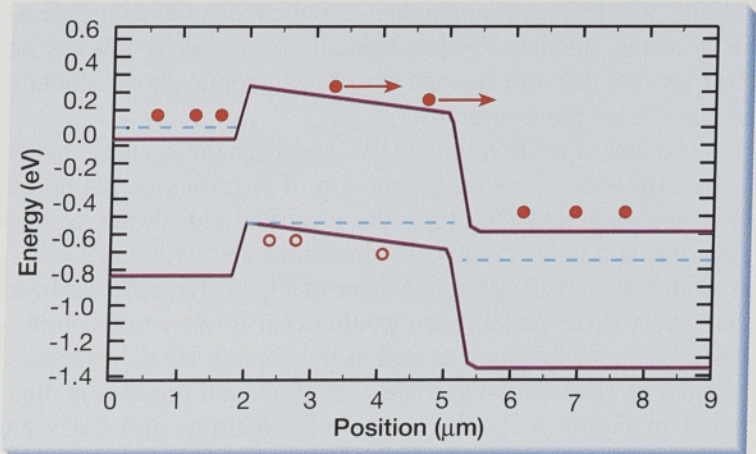


Figure 1. The energy-band profile of a germanium drift transistor. Electrons (filled circles) must remain above the conduction-band edge while holes (open circles) must stay below the valence-band edge. Changing the doping density in the base creates a slope to the conduction-band edge which pushes electrons through the base, resulting in faster electrical switching.

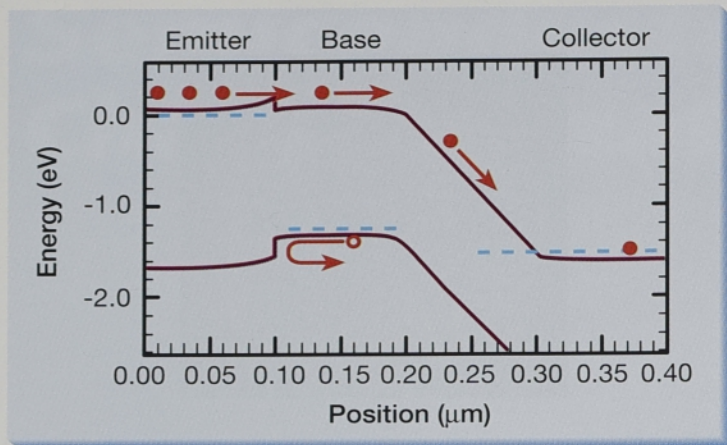


Figure 2. The energy-band profile of an AlGaAs heterojunction bipolar transistor. The wider bandgap in the emitter confines the holes in the base. With this parasitic hole current blocked, several aspects of the device design can be changed to increase the speed and power of the HBT.

high-performance transistor. The wide-bandgap emitter in the HBT provides an extra energy barrier to block the hole current. This permits a number of design refinements to be made which enhance the frequency response and power performance of the transistor.

It took many years for production technology—especially epitaxial growth techniques—to develop to a point where the inherent advantages of HBTs could be capitalized upon. Nevertheless, Kroemer predicted all the way back in 1982 that HBTs would eventually dislodge FETs from their then-dominant position in the compound semiconductor field. And indeed, beginning in 1997, HBTs began to gain wide acceptance in high volume wireless communications applications, moving MES-FETs to the sidelines. Today, virtually every GaAs fab has an HBT process line and the majority of new mobile phones contain an HBT-based power amplifier.

The heterojunction in the HBT improves the device because it has different effects on the motion of electrons versus holes. In a homojunction structure, the electric field always pushes electrons and holes in opposite directions and with equal force, as in the base of the drift transistor of Fig. 1. Kroemer realized that a very different situation would occur if one could continuously grade the bandgap as well as the doping. He published the concept of “quasi-electric fields” in 1957, and the idea is illustrated in Figure 3. In this case, both electrons and holes are pushed in the same direction, toward the narrow-gap material. In the same paper, he suggests that the bandgap in the base of an HBT could be graded, building in a better drift field for electrons because it would not act on the holes. This idea has become an important part of silicon-germanium HBT technology. This is the aforementioned exception to the rule stated above that all interesting heterostructures are compound semiconductors, as SiGe is, strictly speaking, an alloy of elemental semiconductors, not a compound semiconductor.

Heterostructures in Optoelectronics

Active pursuit of semiconductor optoelectronic technology began in 1961 with the invention of the GaAs light emitting diode (LED) by Baird and Pittman at Texas Instruments, and by mid-1962 most of the major semiconductor laboratories had reported results on these devices. In an LED electrons and holes are mixed into the same region of the diode under forward bias. The electrons recombine with the holes, producing photons of light. Since the ruby laser had been demonstrated in 1960, researchers quickly focused attention on converting the LED into a laser by obtaining stimulated emission. R.N. Hall and others from General Electric reported the first results in late 1962, followed quickly by reports from IBM and MIT Lincoln Labs. These devices required enormous currents to lase, and so they could operate only in a short pulse mode and had to be operated at very low temperatures. The problem is that the electrons and holes spread over too large an area, making it difficult to get the high densities of electrons and holes in the same area that is required for lasing.

The solution to making a low-threshold-current laser is to confine the electrons and holes to the same region of space using heterojunctions (an application of the quasi-electric field concept). The structure that does this is the double-heterostructure (DH) laser, which was proposed by Kroemer in 1963 in the U.S., and by Alferov and R.F. Kazarinov at St. Petersburg’s famed Ioffe Institute. The DH laser principle is shown in Figure 4. The optically active region is the narrow gap region in the center of the device. Electrons and holes are injected from either side of this region, but they are confined in this region by the energy barriers created by the heterojunctions. The very high carrier densities needed to achieve lasing are obtained with much lower currents in DH structure. The double heterostructure also forms an optical waveguide, which confines the photons as well.

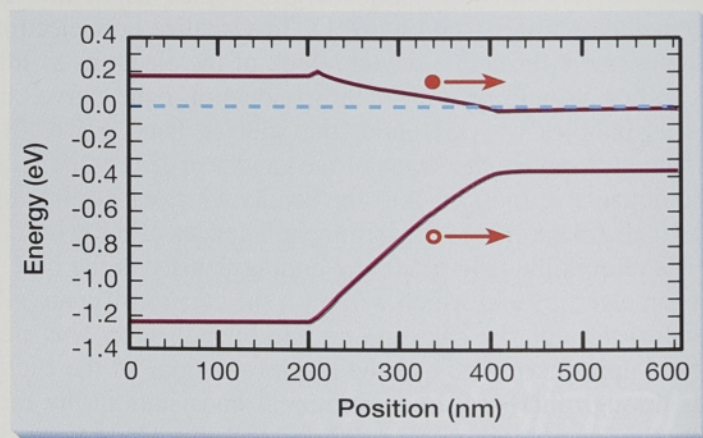


Figure 3. A structure which is continuously graded from GaAs to InAs illustrates the idea of the “quasi-electric field.” A normal electric field pushes electrons and holes in opposite directions with equal force. A quasi field in a graded heterostructure, on the other hand, can affect the carriers differently and even push them in the same direction.



**With EMCORE's
New SpectraGaN
MOCVD Tool,
the Gas is Always
Half Full**

- Improving upon EMCORE's renowned SpectraBlue tool, which also produces both blue and green LEDs, the SpectraGaN maximizes efficiency and increases growth rates
- Significantly improves ammonia cracking and alkyl efficiency in the MOCVD process to greatly reduce overall gas consumption costs
- Up to double the growth rate of all other commercially available tools
- Produces high quality materials with excellent thickness, composition and doping uniformity
- Outstanding temperature uniformity; easy to set up with multiple clean pyrometer ports

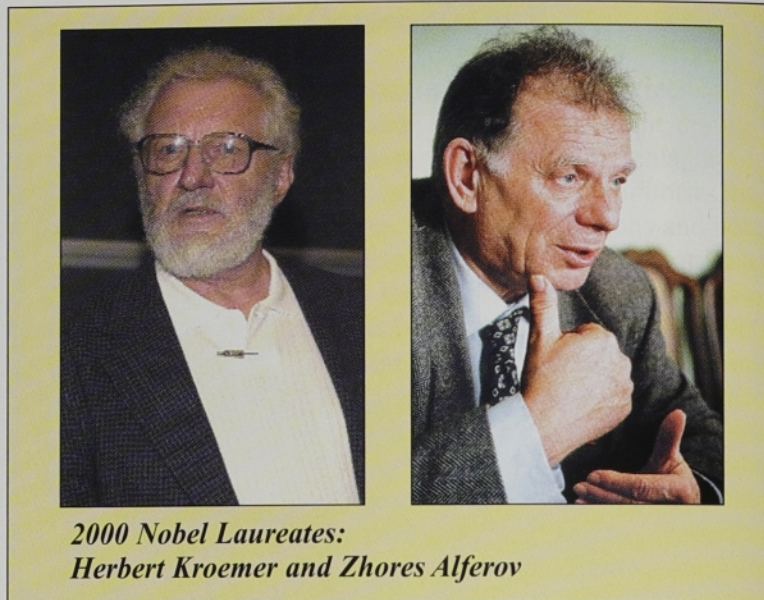
**EMCORE's SpectraGaN is the Most Advanced Tool
Available for the Production of High Brightness
Blue and Green GaN-Based LEDs**

For more information, please contact sales at EMCORE - 732-271-9090.



In the mid 1960s there was not an established heterojunction technology. Early attempts to fabricate and characterize heterojunctions were made by R.L. Anderson at IBM (1962) and by Arthur Milnes and co-workers at Carnegie Tech throughout the mid-1960s. This work necessarily involved the semiconductors that were known at the time, so combinations like Ge-GaAs and GaAs-ZnSe were investigated. (It was recognized very early that good heterojunctions required matching the lattice constants of the semiconductors. This drastically reduced the number of viable material combinations.) We now know that such chemically mismatched combinations (mixing group IV, III-V, or II-VI semiconductors) do not produce good heterojunctions (at least without employing some very sophisticated materials techniques). A really viable heterostructure technology required the development of alloyed semiconductor technologies such as AlGaAs. The development of these technologies was led by Alferov's group at the Ioffe institute and by workers at Bell Labs, IBM, and RCA in the U.S. The use of alloys has greatly extended the number of heterojunction combinations we can use in devices.

The signal that heterojunction technology had arrived was the demonstration of continuous room-temperature operation of a DH laser in 1970. This was achieved almost simultaneously by Alferov's group in Russia and by M.B. Panish and co-workers at Bell Labs. The DH laser has been continuously improved over the years, most notably by the introduction of quantum-wells into the active region, and by the development of the vertical-cavity sur-



face-emitting laser. Both of these ideas use a large number of heterojunctions to achieve their effect.

Alferov is currently the director of the Ioffe Institute, where he has worked since 1953. He is also Vice President of the Russian Academy of Sciences. He was born in 1930 in Vitebsk, Russia, and received his doctorate degree in physics and mathematics in 1970 from the Ioffe Institute.

Herbert Kroemer was born in 1928 in Germany, and received his doctorate degree in physics in 1952 at the University of Göttingen. Since 1976 he has been a professor at the University of California at Santa Barbara where he has played a pivotal role in turning the ECE and Materials Science Departments into the leading institutions in their fields.

The total prize amount is 9 million Swedish Krona, or approximately \$895,000. Alferov and Kroemer are to share one half and Kilby will receive the other half.

Evans Expertise™

Industry Standard in
Materials Analysis of:

- MOCVD, MBE, CBE
- GaAs FET, HBT, HEMT
- InP MISFET, HBT, HEMT, PHEMT
- AlGaAs laser, LED
- AlInGaP laser, LED
- GaN LED

CHARLES EVANS & ASSOCIATES®
SPECIALISTS IN MATERIALS CHARACTERIZATION

ISO 9002 Certified

810 Kifer Road
Sunnyvale, CA
94086

tel 408.530.3500
info@cea.com
www.cea.com

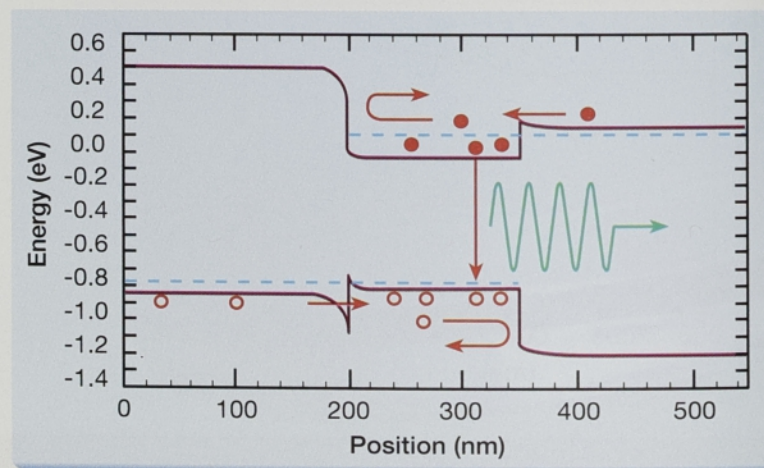


Figure 4. The energy-band profile of an InP-InGaAs double-heterostructure laser. The narrower bandgap region in the center is the optically active layer. Electrons and holes are injected from the right and left, respectively, and confined within the active layer by the band discontinuities. This achieves the very high densities needed for lasing.

Cree Doubles Brightness of Blue and Green LEDs

Cree has introduced a new range of blue and green LEDs that have twice the brightness of the company's current InGaN-on-SiC devices. The advance is made possible using a proprietary chip shaping technique to produce angled facets and increase light extraction from the chip. Cree says the new ultra-bright (UB series) LEDs are intended to close the brightness gap between its own devices, which are grown on SiC substrates, and competitors' devices grown on sapphire. The company is currently offering evaluation and qualification samples, and volume production will start in January 2001.

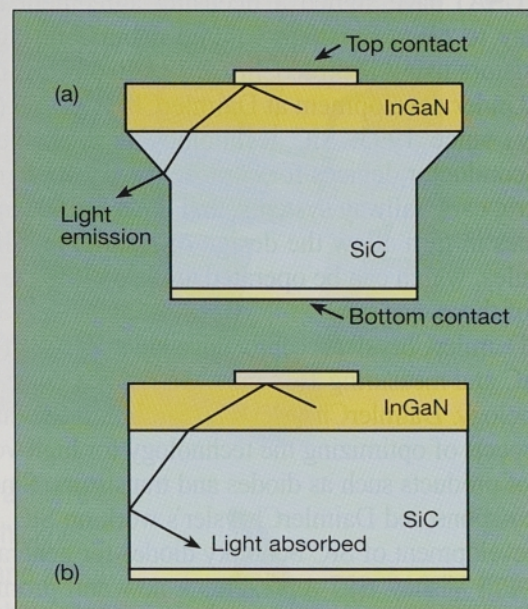
The chip shaping approach uses inclined facets to reduce the occurrence of total internal reflections, leading to a significant increase in light extraction compared to Cree's standard chip [see Figure]. A similar chip-shaping approach has been used by Agilent/LumiLeds to achieve 100 lm/W AlInGaP LEDs [see CS 6(1), p. 93].

"These new LED devices, offered in both blue and green, provide significantly

enhanced performance and are expected to compete in applications that require a higher brightness intensity, such as full color outdoor displays," says Mike Dunn, Cree's general manager of Optoelectronics.

Available at operating wavelengths of 470 nm for the blue LED and 525 nm for the green device, the new InGaN-on-SiC LEDs feature a junction area of $240 \times 240 \mu\text{m}^2$, and utilize the company's standard top and bottom contact design that allows vertical current flow. Cree's UB series device produces a flux of 0.4 lumens for the blue LED and 1.4 lumens for the green emitter at a typical forward voltage of 3.5 V.

According to company literature, Cree shipped over 50 million nitride-based LED chips during July 2000, making it one of the largest volume suppliers in the world.



Cross-section of Cree's new patent-pending InGaN-on-SiC LED design (top) showing the new chip shape compared to a standard LED (bottom). The device geometry is optimized to reduce total internal reflection, which limits the light extraction efficiency of standard LED devices. The result is a 2× increase in light emission. The new chip design has a top area of $300 \times 300 \mu\text{m}^2$ and a bottom area of $200 \times 200 \mu\text{m}^2$.

Cree Reports Blue Laser Results...

Cree has reported CW lifetime results in excess of 100 hours for its nitride-based blue laser device grown on SiC. The output power was 1–3 mW. "We believe we now understand the fundamental key to long life continuous wave operation of blue lasers based on SiC, and we expect future progress to occur at a rapid pace," says Cree's Chairman and CEO Neal Hunter. "The performance reported allows us to begin initial design work with systems manufacturers."

The company has also demonstrated up to 100 mW of CW power from a single laser, which exceeds the 30–40 mW level presently required for read/write optical storage applications. Cree says its commercial challenge is to further increase device lifetime and to reduce fabrication costs.

Although this is good news for Cree, the company remains a long way behind its rival Nichia, which 3 years ago reported a lifetime of 10,000 hours for its blue laser diodes. Among Nichia's blue laser products—the only ones commercially available today—is a 30 mW device with an estimated life of 500 hours at 60°C.

Feature Articles on Wide Bandgap Devices and Materials

Page 75 –

Report from the European Conference on Silicon Carbide.

Page 81 –

Developments in InGaN-on-SiC LEDs and Lasers at Osram Opto Semiconductors.

...and Hires a New Researcher

Cree's CEO Neal Hunter stated in the company's recent earnings conference that Shuji Nakamura, formerly of Nichia Chemical Industries, is now a part-time employee of Cree. Nakamura left Nichia to take an academic post at the University of California at Santa Barbara. The announcement by Cree comes as no surprise—earlier this year, the UCSB spin-off Nitres Inc. became Cree Lighting [see CS 6(4), p. 7], and at least one other UCSB professor is also employed by Cree.

Vishay and DaimlerChrysler Sign SiC Technology Transfer Agreement

DaimlerChrysler and Vishay Intertechnology (Malvern, PA, USA) have signed a licensing agreement that will enable Vishay to carry out high-volume manufacturing of diodes and transistors using DaimlerChrysler's silicon carbide technology.

Under development at DaimlerChrysler AG (Frankfurt, Germany) since 1993, SiC technology enables the fabrication of semiconductor devices for compact power conversion systems in electric cars, railway systems, and other mobile applications. SiC devices in turn allow the design of smaller and lighter converter modules, which can be operated at the elevated temperatures typical of these systems.

DaimlerChrysler recently unveiled a 50 A Schottky diode built on SiC and measuring 16.8 mm²—a record device size for the new technology. DaimlerChrysler's research into SiC has encompassed all aspects of optimizing the technology for high-volume manufacture of products such as diodes and transistors. Since 1997, Vishay has co-sponsored DaimlerChrysler's work on SiC, with a focus on the development of SiC Schottky diodes for general applications.

"For Vishay, SiC represents a new and promising key technology with substantial market potential," says Felix Zandman, Chairman of Vishay Intertechnology. "DaimlerChrysler, on the other hand, profits from the semiconductor experience of this partnership and will also gain access to a SiC foundry." The location of Vishay's manufacturing site has not yet been determined, but R&D work is being carried out at Vöcklabruch, Austria.

Vishay and DaimlerChrysler have a long and involved history: Vishay Telefunken, now a Vishay subsidiary, was originally part of the semiconductor unit of Temic, a Daimler-Benz subsidiary. Daimler-Benz sold the semiconductor part of Temic to Vishay, which kept the Telefunken business and other units. The remaining capabilities, including the SiGe effort, were sold to Atmel Corp. Vishay Telefunken manufactures diodes, rectifiers and transistors along with a wide range of optoelectronic components including LEDs, IR emitters and optocouplers.

SiC Schottky diodes combine high breakdown voltages (up to 2000 V) with a low forward voltage drop and negligible switching times. Comparable devices cannot be achieved with conventional silicon technology, so a key application for the new SiC devices will be the replacement of fast Si *pin* rectifiers.

As an additional feature, SiC devices can be operated at much higher junction temperatures compared to silicon devices without compromising their electrical performance. This feature can be used for SiC device miniaturization or to allow device exposure to higher ambient temperatures, opening the door for completely new fields of applications in which SiC devices are located in the direct vicinity of heat sources such as engines or electrical generators. The packaging of SiC Schottky diodes will be based on existing surface-mount techniques as well as Sinter-glass packaging technology, which is already used in many high-temperature applications.



AES
AFM
ARUPS
CITS
ESCA
HREELS
ISS
LEED
MBE
MFM
PEEM
RHEED
SAM
SEM
SEMPA
SNOM
SPA-LEED
SPEED
STM
STS
UPS
XPD
XPS

www.omicron-instruments.com
and
www.omicron.de

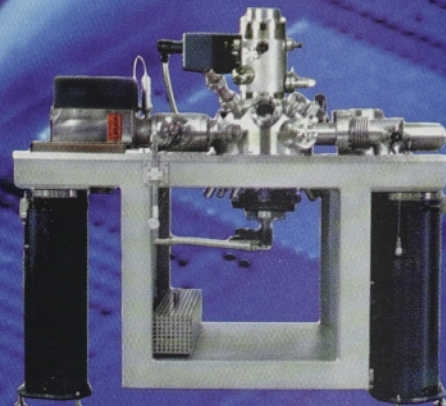
UHV NANOPROBE

Multi-Point Measurement Tool for Nano-devices

Up to 4 independent probes
SEM assisted positioning
True UHV operation
STM imaging capability
Nanostructuring
50 K to 500 K



UHV NANOPROBE stage



System Solution with UHV SEM

Headquarters:
OMICRON VAKUUMPHYSIK GmbH
Tel./Fax +49 (0) 6128 9 87 - 0 / - 185
E-mail: info@omicron.de

USA:
OMICRON Associates
Tel./Fax (412) 831-2262 / -9828
E-mail: info@omicronUS.com

 **OMICRON**
INSTRUMENTS FOR SURFACE SCIENCE

Substrates for Nitride Growth

The search continues for the ideal substrate on which to grow nitride-based devices. Commercial blue LEDs and lasers use sapphire or SiC wafers—both materials that have a large lattice mismatch with respect to GaN. While GaN itself obviously provides ideal matching of the thermal coefficient of expansion and lattice parameters, large area wafers are not commercially available due to the difficulty of producing bulk GaN crystals. AlN is also a potentially suitable material, which is under development by a number of companies, including TDI, Crystal IS and Cermet. Recently, ATMI (Danbury, CT) announced internal investments in the development of 2-inch GaN development, while Kyma Technologies (Raleigh, NC) announced the availability of samples of 2- and 4-inch AlN substrates.

ATMI has developed and patented processes that allow the manufacture of high purity GaN wafers of 2-inch (50-mm) diameter and larger. As a result, the company is committing significant additional funding for continued development and pilot manufacturing capacity. ATMI has been working to develop free-standing GaN films using hydride vapor phase epitaxy (HVPE) for the past two years, and has recently been awarded contracts totaling nearly \$4 million from the Office of Naval Research (ONR) and the BMDO to further develop GaN wafers for electronic and optoelectronic devices.

"High crystalline quality GaN wafers will enable high device density and improved device performance," said Bob Vaudo, GaN wafer project manager. "ATMI's patented HVPE process produces large area, low defect density GaN wafers that permit simplified device structures, improved heat dissipation and lower device defect density."

Kyma Technologies, a 2-year old spin-off from North Carolina State University, is sampling 2- and 4-inch AlN substrates and intends to provide pilot production quantities early next year. The company grows free-standing AlN films on a variety of substrates to a thickness of 300 μm using a proprietary high transport rate physical vapor deposition (PVD) process.

According to chief scientific officer Jerry Cuomo, the availability of larger wafer sizes could offer considerable manufacturing cost advantages. "Scaling to bigger diameter wafers is not a limiting factor," said Cuomo. "We are mainly testing 2-inch AlN because that's what the majority of the GaN device industry is equipped for." At present, four companies are performing quality assessment of Kyma's AlN substrates, including Emcore, which intends to begin growing devices in the next few months.

Kyma has been funded by BMDO STTR contracts to develop AlN materials, and separately to grow large diameter GaN substrates and co-develop solar blind UV photodetectors with Emcore. The company operates from a 7,500 sq.ft. R&D facility in the Research Triangle Park of North Carolina, and has plans to move to a larger manufacturing facility by the middle of next year.

PM5 Auto-lap Precise Wafer Backthinning

Sub-micron
sample flatness



Confidently achieve
consistent thickness
uniformity and a high
quality polish on **GaAs**
and **InP** substrates.

LOGITECH
A Division of Struers Inc.
810 Sharon Dr. • Westlake, OH 44145
440-871-0071 • 800-321-5834
info@logitech-us.com

SUPER EPI

Super Epitaxial Products, Inc.

~ a devoted MOCVD products supplier ~

Super EPI provides the best quality MOCVD epitaxial wafers

(Multi-wafer MOCVD reactors, 2", 4" and 6" wafers capability)

- AlGaInP/GaInP
- AlGaAs
- GaInAsP
- GaN

for high performance
devices:

- Light Emitting Diodes
- Laser Diodes
- Photo-Detectors
- HBTs
- high brightness
AlGaInP LED Chip



Tel: (410) 772-0078

Fax: (410) 772-0079

http://www.superepi.com

e-mail: info@superepi.com

Interconnected Microdisk LEDs Promise Higher Emission Efficiencies

GaN-based technology has changed the landscape of visible solid state light emitters forever by making bright, high efficiency emitters operating in the UV, blue, and green wavelength regions. Hongxing Jiang and Jingyu Lin's group at Kansas State University (Manhattan, KS) has found a method that can further enhance LED emission efficiency by as much as 60%. The novel approach is based on interconnecting hundreds of microdisk LEDs, as shown in Figure 1.

The group has fabricated interconnected microdisk LEDs from InGaN/ GaN single quantum wells grown by low-pressure MOCVD. These interconnected microdisk LEDs fit into the same device area taken up by a conventional broad-area LED. The performance characteristic of the novel devices, including I-V and L-I characteristics, as well as electroluminescence spectra, were mea-

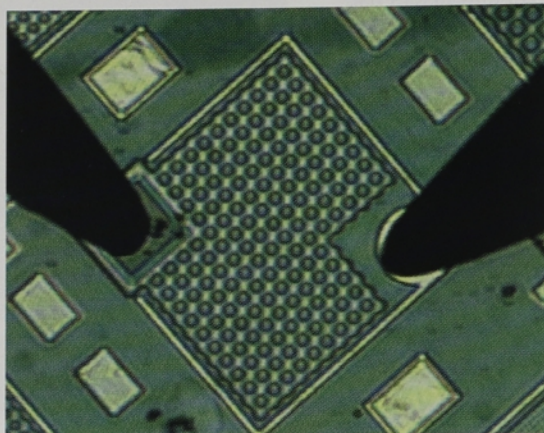


Figure 1. Optical microscope image of KSU's interconnected microdisk LEDs. After fabricating the individual microdisk LEDs, a p-type Ohmic contact was deposited on each microdisk, and a transparent p-type film was then deposited over the whole structure to connect the devices.

sured and compared with those of the conventional broad-area LEDs fabricated from the same LED wafers [see Figure 2]. For interconnected microdisk LEDs, while the forward biased voltage

(V_F) was slightly higher at 20 mA, the emission efficiency was increased by as much as 60% over the conventional LEDs for a fixed device area.

The results suggest that by replacing a conventional broad-area LED with an interconnected microdisk LED, the external quantum efficiency can be significantly enhanced. There are believed to be several reasons for the enhanced emission efficiencies, the first of which is improved photon confinement within the individual microdisk LEDs. Secondly, there is thought to be more efficient usage of the injected current in individual microdisk LEDs than in the broad-area LEDs i.e. the current spreading is better. The third (and probably dominant) effect is the enhanced extraction efficiency in interconnected microdisk LEDs—more light can escape from these devices than from the broad-area LEDs.

Finally, the processes used to fabricate these violet/blue/green interconnected microdisk LEDs are almost the same as those used for conventional broad-area LEDs. It is thus expected that the total yield of these novel microdisk LEDs will be the same as the conventional devices.

The present method of using interconnected microdisk LEDs to improve the brightness of LEDs is also believed to be applicable to other semiconductor LEDs as well as polymer and organic LEDs.

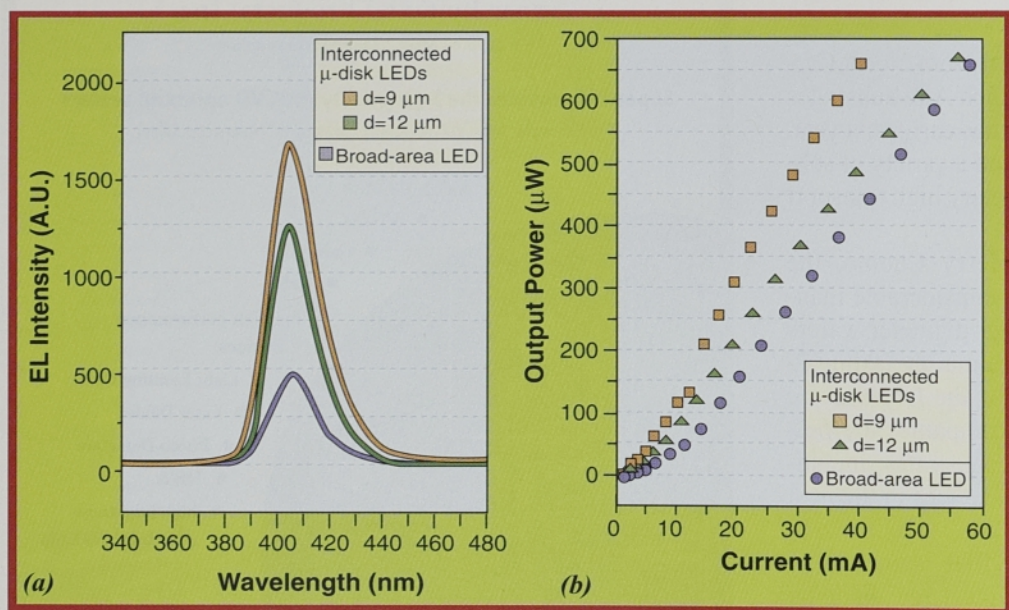


Figure 2. Comparison of (a) electro-luminescence (EL) spectra and (b) L-I characteristics of interconnected microdisk LEDs and conventional broad-area LEDs fabricated from the same InGaN/GaN QW wafer. Spectra were measured on the top surface of unpackaged chips at a current of 20 mA.

For more information, contact Hongxing Jiang at jiang@phys.ksu.edu. The group's paper entitled "InGaN/GaN Quantum Well Interconnected Microdisk Light Emitting Diodes" by S. X. Jin et al. is to be published in *Applied Physics Letters* in November.

LED Technology Licensed for Dental Curing Light Source

Dental/Medical Diagnostic Systems (DMDS), a developer of dental equipment based in Deurle, Belgium, has signed a worldwide license agreement with GC Corporation for DMDS' patented LED-based high-speed curing technology. GC is a leading manufacturer of dental supplies and equipment based in Japan. The LED source was

optimized for fast polymerization curing using DMDS' patented lens system, which allows curing of fillings in around 6 seconds compared to upwards of 40 seconds per layer in systems with traditional light sources. DMDS says dentists (and patients) will also benefit from the lighting source reliability and absence of heat from the curing probe.

LumiLeds Wins Power LED Order for Emergency Vehicle Lighting

LumiLeds Lighting has been awarded a multi-million dollar order to supply "Power LEDs" to 911EP (St. Cloud, Minnesota), a provider of LED-based emergency lighting for the emergency and service vehicle markets. LumiLeds' Power LED is currently used in red traffic signals to reduce the number of LEDs required from 80 standard 5 mm LEDs to just 18 high flux devices. "The LumiLeds power LED source allows us to innovate, while at the same time providing a high quality, reliable product that's mandatory in the emergency vehicle lighting market," said 911EP's John Pederson.

In more news, British Petroleum (BP) has awarded LumiLeds a global purchase agreement for its Chipstrip Lighting System, an LED-based lighting system designed to replacing existing neon in contour lighting used on the edge of buildings. The deal is part of BP's recently announced re-branding project, in which its retail sites will feature new services, designs and colors. BP expects to convert over 20,000 retail sites to the new image over the next 4 years.

BIRDWATCHING

Boeing Completes Spectrolab Acquisition

Spectrolab, one of the leading manufacturers of GaAs-based solar cells, is now part of Boeing Satellite Systems after being acquired from Hughes Electronics along with two other Hughes businesses. Boeing also acquired the Hughes Electronics share of HRL Laboratories (Malibu, CA), which was formerly jointly owned by Hughes and Raytheon. David Lillington has been named as Spectrolab's new president.

Motorola Quits Teledesic Program

Teledesic and Motorola have ended their agreement under which Motorola was to have built satellites for the Teledesic system, a broadband satellite communications network. Teledesic has merged with New ICO, which is building a separate multi-satellite network to provide personal communication services.

Tecstar and JPL Develop a "Space Ball"

Tecstar and the Jet Propulsion Laboratory (JPL) are working to develop a "space ball" featuring Tecstar's solar cells, which will be used to return soil samples from the surface of Mars during missions planned in the next 3-5 years.

Discover the Advantage

EAGLE P ICHER
SUBSTRATES

ZINC OXIDE



ZnO

Single Crystal
Water Clear

6 N's Sputtering Targets
Contact Us for NEW Pricing

GERMANIUM



Ge

Zero EPD

2"-6" Capability

Solar Cell, LED, or
Device Applications

1-800-331-3144

visit our website <http://www.epi-tech.com>



The Solution Center

Eagle-Picher Technologies, LLC
200 B.J. Tunnell Blvd. • Miami, OK 74354
email: rdbrown@epi-tech.com

CS-MAX

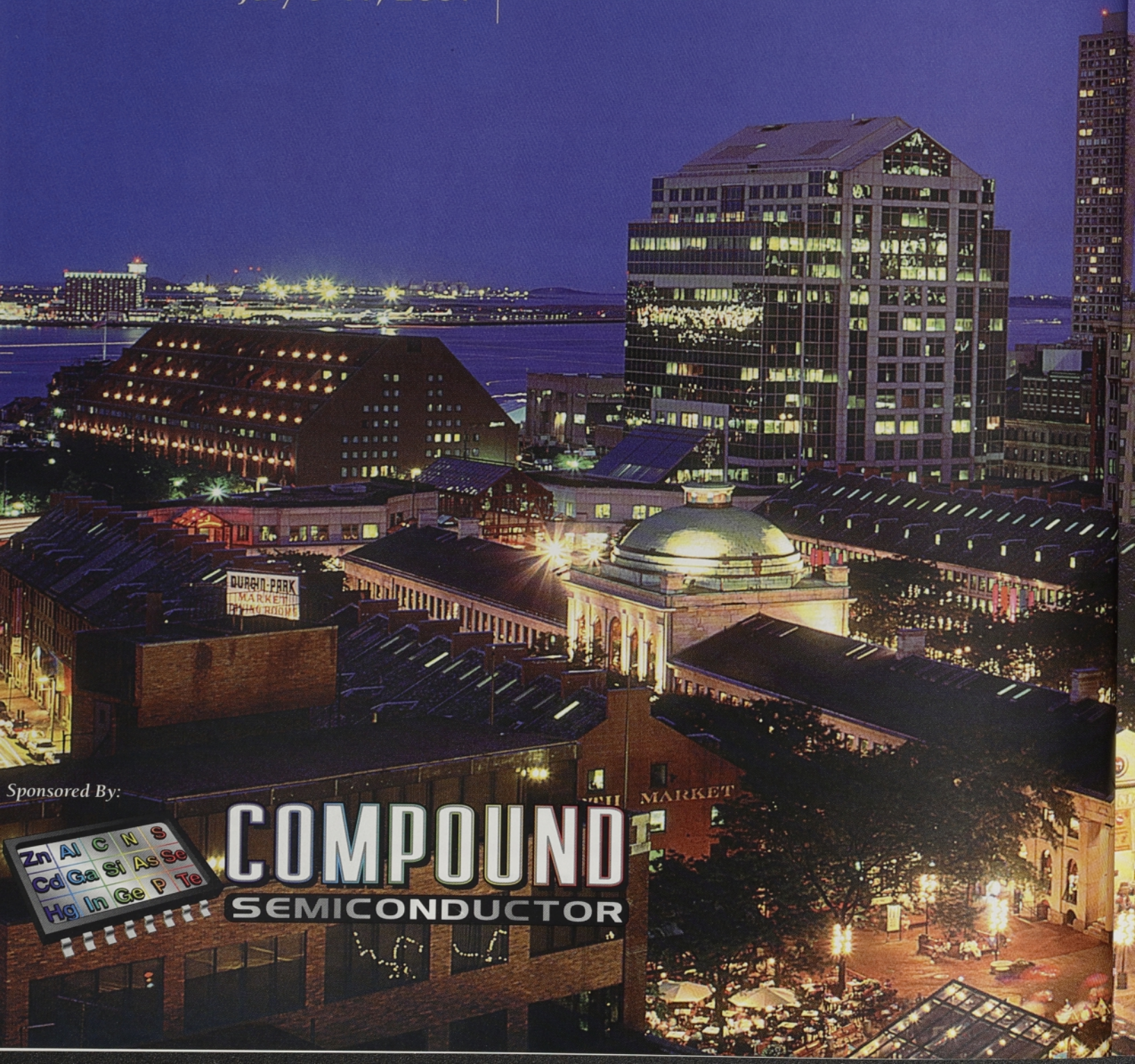
COMPOUND SEMICONDUCTOR
MANUFACTURING EXPO

July 9-11, 2001

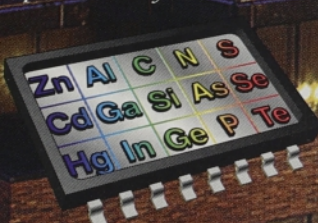
*Plan now to attend the 1st conference designed
for fab managers and engineers engaged in high
volume manufacturing of compound semiconductor
optoelectronic and microelectronic devices.*

GaAs ICs • LEDs • InP ICs • Laser Diodes

SiC ICs • III-V Detectors • Solar Cells



Sponsored By:



**COMPOUND
SEMICONDUCTOR**



Boston, MA USA

www.CS-MAX.com

It's like Semicon West without all the silicon!

Compound
Semiconductor
Manufacturing
Expo

CS-MAX

Agilent Gets Busy

In a flurry of recent activity, Agilent Technologies has reorganized its fiber-optic networking activities, announced strong results from its Semiconductor Products Group, and revealed plans for a new 6-inch GaAs fab in Colorado to make E-mode PHEMTs.

TIM WHITAKER

Agilent Technologies, headquartered in Palo Alto, CA, has combined its fiber-optic communications and integrated circuit business divisions to form a new unit focused on the high-speed networking market. The new Networking Solutions Division (NSD) plans to integrate the company's fiber-optic and IC technology to deliver complete networking solutions with the lowest cost-per-bit in the industry.

"By combining the world's leading fiber-optic transceiver operation with expertise in high-speed networking products and million-gate ASICs, we have assembled a very powerful division," says

Dick Chang, who will head the new group. "There are few, if any, companies in the world that have as much expertise in as wide a range of communications disciplines as Agilent has," says Bill Sullivan, general manager of Agilent's Semiconductor Products Group (SPG), which oversees the activities of the newly formed NSD.

Semiconductor Products is one of four groups within Agilent, the others being Test and Measurement, Healthcare and Chemical Analysis. As shown in Figure 1, Semiconductor Products contains five divisions, several of which have a significant interest in compound semiconduc-

tors. As well as fiber-optic components and transceivers, discussed below, Agilent manufactures GaAs-based wireless products and is planning to open a new 6-inch fab in Colorado (see box). The company also manufactures a wide range of discrete optoelectronic components, including visible LEDs, IR emitters and pin photodiodes, and optocouplers. Furthermore, Agilent is involved in LumiLeds Lighting, a joint venture with Philips Lighting, which is a leading manufacturer of high brightness AlInGaP and InGaN LEDs.

The Semiconductor Products Group had revenues of \$1.72 billion in 1999, and has already reached \$1.53 billion in the first three quarters of its 2000 financial year (November 1999 to July 2000, inclusive) [see Figure 2].

Fiber-Optic Components

Because Agilent is not yet a major player in the long-haul market, its fiber-optic component activities are often overshadowed by competitors such as JDS Uniphase, Lucent and Nortel. However, Agilent is certainly a major supplier, and dominates many enterprise networking markets such as Gigabit Ethernet datacom networks and Fibre Channel storage area networks. The company ships 2.4 million fiber-optic devices per month, along with 1.0 million fiber-optic transceivers. Furthermore, the company recently announced that it would spend more than \$175 million to expand its FOC manufacturing

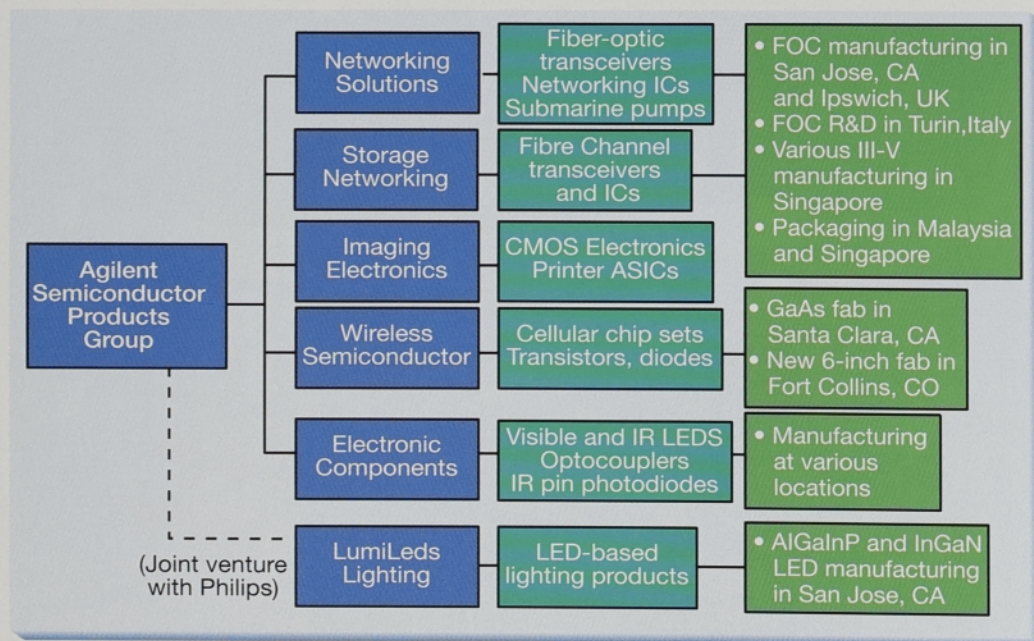


Figure 1. Organizational structure and products of Agilent's Semiconductor Products Group, showing the locations of the company's main manufacturing sites related to compound semiconductors.

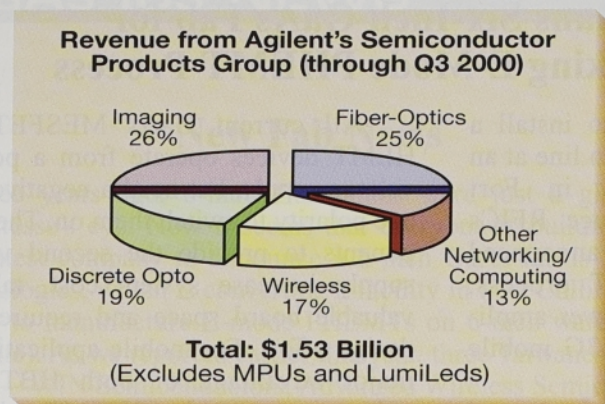


Figure 2. Agilent's Semiconductor Products Group generated revenues of \$1.53 billion in the first three quarters of its 2000 financial year (November 99 through July 2000). Wireless includes GaAs-based products, Discrete Opto includes visible LEDs, IR emitters and detectors, and optocouplers. Figures exclude microprocessor units and revenues from LumiLeds Lighting.

capacity in San Jose, Ipswich, Singapore and Malaysia [see CS 6(5), p. 19].

Agilent is easily the largest supplier of Gigabit Ethernet transceivers, and shipped 370K units in the second quarter of 2000 (February–April), which the company claims was equivalent to a market share of 63%. These shipments include VCSEL-based products operating at 850 nm, as well as 1310 nm transceivers containing edge-emitting lasers. The company is also developing products for next-generation 10-Gigabit Ethernet systems, as described below.

Agilent is also striving to increase its presence in the metro access network (MAN) market, where the worlds of short-range, low cost datacom products and expensive long-haul telecom systems are coming together. Products include fiber-optic transceivers and ports at data rates up to 2.5 Gb/s (OC-48)—the company reports that single mode transceiver shipments grew to 287K units in the third quarter of 2000. Agilent is also a supplier of submarine pump lasers at 980 nm and 1480 nm.

10 Gb/s Ethernet Transceiver Samples Shipped

Agilent recently reported the shipment of first engineering samples of its 10 Gb/s Ethernet (10 GbE) fiber-optic transceiver, to address the demand for more bandwidth in enterprise and metropolitan area networks.

Agilent is using a wide WDM (WWDM, also known as coarse WDM) approach, with an array of four uncooled 1300 nm DFB lasers each running at 3.125 Gb/s. The lasers are mounted side by side on a ceramic submount and aligned to a low cost silica waveguide combiner. In WWDM systems, the spacing between wavelength channels is relatively wide at around 25 nm, so there is no interference between adjacent channels even when the wave-

lengths drift with temperature. In dense WDM, the channels are closely spaced (0.8 nm separation on the 100 GHz ITU grid), so temperature control of the sources is required. As well as the advantage of uncooled operation, WWDM technology provides an economical implementation of 10 GbE, as it allows for transmission on currently installed fiber-optic cable. The transceivers support transmission of up to 300 m on standard 62.5- μ m/125- μ m multimode fiber, and up to 10 km on single mode fiber.

"This is an exciting first for Agilent [and] shows that an economically attractive, high-volume implementation of 10 GbE is possible," says Dick Chang of Agilent's new Networking Solutions Division.

Agilent is also developing solutions to meet other proposed IEEE 10 GbE standards, including 10 Gb/s serial laser technology attained in the acquisition of the Optical Technology Center from Telecom Italia. The 10 GbE standard is still in the formation stage and approximately 70 companies have been discussing 10 GbE technology since March 1999 in the IEEE 802.3 Higher Speed Study Group. In January 2000, the IEEE 802.3ae task force was officially sanctioned to develop an industry standard for Ethernet at 10 Gb/s. A draft standard is expected in 2001, with a full ratification of this standard expected by the spring of 2002. Agilent plans to provide pre-standard products in 2001, and to provide a compliant offering as soon as the standard is ratified.

EPITAXIAL WAFERS



Epitaxial Technologies offers standard and highly challenging epitaxial layers on GaAs, InP, GaSb, InSb and InAs.

Wafers that meet your needs

- High quality, low cost, fast turn-around

Wireless and RFICs

- GaAs MESFET, p-HEMT & HBT

Infrared Sensors

- GaAs, GaInAs & Sb-based QWIPs

Optoelectronics

- VCSELS, MSM, PD & APD

Advanced Device Technologies

- InP- & Sb-based FET, HEMT, HBT & RTD

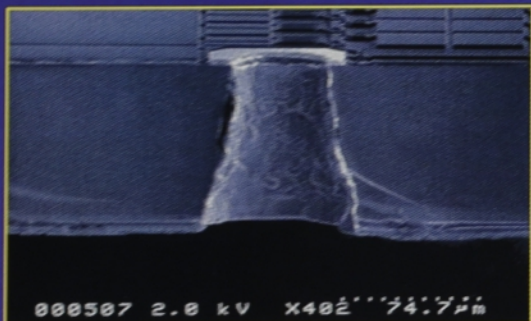


Tel: 410-455-5594
Fax: 410-455-5595
e-mail: epiwafers@erols.com

1450 South Rolling Road, Baltimore, MD 21227

Helping You Grow Your Business!

Production-Proven GaAs Via Etch For MMIC Device Manufacture



Via hole etched with smooth 80° positively sloped metalized profile

The Process

- Sidewall angle control of between 75° and 85° with clean process chemistries
- Robust, high throughput processing with etch rates of up to 4µm/min on 100mm and 150mm diameter wafers
- Industry leading process reproducibility

The Platform

- True cluster format with industry standard Brooks robotics
- Flexible architecture allows independent use of twin loadlocks
- Extended Mean Time Between Cleans and rapid clean capability
- Optimized clamp design eliminates damage to fragile wafers and stops wafers sticking to clamp assemblies
- Compatible with sapphire wafer carriers

The Support

- 12 Worldwide Service Centers
- Over 50 experienced Service and Process Engineers with a reputation for rapid and reliable response

STS - setting a new benchmark for compound semiconductor processing

For further details about STS' compound semiconductor etch or PECVD processes, please contact STS through your local sales office:-

- U.K. Tel: +44 1633 652400 Fax: +44 1633 652405
- Japan (SPP) Tel: +81 3 3213 5828 Fax: +81 3 3213 5867
- USA Tel: +1 650 569 3655 Fax: +1 650 569 3663
- Germany Tel: +49 731 921 7781 Fax: +49 731 921 7875
- France Tel: +33 1 6990 0991 Fax: +33 1 6990 0757
- Italy Tel: +39 02 90093082 Fax: +39 02 9052778
- Korea Tel: +822 5784271/3 Fax: +822 5784274
- Hong Kong/PRC Tel: +852 2881 0555 Fax: +852 2577 6660
- Taiwan Tel: +886 35 614211 Fax: +886 35 614210



SURFACE TECHNOLOGY SYSTEMS

www.stssystem.com

Agilent Plans Six-Inch GaAs Fab for Groundbreaking E-Mode PHEMT Process

Agilent Technologies is to install a six-inch GaAs fabrication line at an existing company facility in Fort Collins, Colorado, to produce RFICs using the company's recently announced enhancement-mode PHEMT process. Production will focus on power amplifiers for CDMA, GSM and 3G mobile handsets.

The first phase of the fab is planned to be in full production by the end of 2002, and is expected to initially produce 48,000 six-inch wafers per year. Until (and after) the new fab goes into production, Agilent plans to produce E-PHEMT devices at its current 4-inch GaAs fab in Santa Clara, California.

The first phase of the project will include 15,000 sq.ft. of cleanroom, and Agilent will have the option to expand to 45,000 sq.ft. in the existing Class 100 cleanroom facility. The company plans to create "mini-environments" within the larger cleanroom that will achieve particle levels better than Class 1 in order to realize very high quality and yields.

"This fab will allow us to keep pace with the large demand that we anticipate for our high-efficiency handset power modules, based on initial customer interaction," says Dave Allen, VP and general manager of Agilent's Wireless Semiconductor Division. "The Fort Collins facility was a logical choice because our existing high-volume silicon fab facilities and experienced talent pool will allow us to quickly ramp this new process."

The E-PHEMT Process

As well as stepping up capacity, Agilent is also implementing a production process for enhancement-mode PHEMTs, also known as E-PHEMTs. The company believes this process can successfully compete for power amplifier sockets with the current champion, the HBT.

All current GaAs MESFET and HEMT devices operate from a positive voltage supply, but need a negative voltage polarity to switch them on. The components to provide the second voltage supply increase system cost, take up valuable board space and require extra design effort. For mobile applications, a major advantage of both HBTs and enhancement-mode PHEMTs is the requirement for only a single positive power supply.

In addition, Agilent claims that its E-PHEMT process promises power-amplifier modules that will improve CDMA mobile phone battery life by up to 15%, or allow smaller batteries that will make room for new features. The company expects its E-PHEMT power amplifiers, currently under development, to offer higher performance than existing and future products based on HBT technology [see Figure 3].

Agilent's first product using this process will be a high dynamic range transistor, scheduled for introduction in November 2000. In the first quarter of 2001, the company plans to introduce E-PHEMT power modules into its CDMA Advantage RF chipset. Agilent is also developing a series of amplifiers for the GSM standard, planned for introduction in the first quarter of 2001, and anticipates that E-PHEMT performance will create rapid growth for the technology in GSM phone applications.

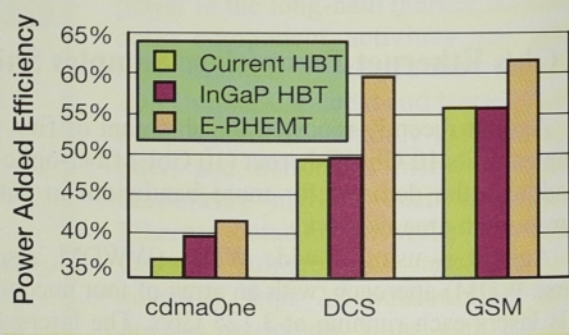


Figure 3. Agilent's new E-mode PHEMT process offers significantly enhanced power-added efficiency for different wireless communication formats.

New Fab News

Three years ago, 6-inch GaAs fabs were just a gleam in Vitesse's eye. Now it seems that everyone is building one. The latest company to announce a 6-inch GaAs fab is Agilent Technologies, which is converting a facility in Fort Collins, Colorado, to manufacture E-mode PHEMTs on 6-inch wafers (see opposite). As we reported earlier this year, three Taiwanese companies—WIN Semiconductors, Advanced Wireless Semiconductor Co. (AWSC), and Global Communication Technology (GCT)—are all building new 6-inch fabs. As if that wasn't enough, at least three other 6-inch fabs are being planned in Taiwan, and a new HBT foundry, CSMC, will soon begin production.

Compound Semiconductor Manufacturing Corp. (CSMC)

The development of Taiwan's GaAs industry continues at a rapid pace, and new companies seem to emerge every month. Compound Semiconductor Manufacturing Corp. (CSMC) was founded in July of this year, and is currently installing equipment in its factory in Hsinchu. The company intends to offer foundry services for GaAs devices, including HBTs and PHEMTs, which will be initially fabricated on its 4-inch GaAs line. Capability for 6-inch manufacturing will also be developed. CSMC will initially focus on fabricating HBT power amplifiers for wireless applications, and will also have the capability to manufacture optoelectronic devices based on GaAs. Installation is scheduled to be complete by March 2001, with pilot production beginning shortly afterwards. The foundry should be fully operational by June of next year. "Through an OEM business relationship with CSMC, major GaAs manufacturers and design houses worldwide can double their turnover and save the cost of expansion," says CSMC's Amy Hsu.

Broadband Wireless Access Sales to Reach \$15.2 Billion by 2010

Pioneer Consulting (Cambridge, MA) is predicting sizeable market opportunities for broadband wireless access equipment suppliers and service providers. According to the study, *Broadband Wireless Access: LMDS, MMDS and Broadband Wireless Systems Markets Worldwide*, sales of broadband wireless access equipment will grow from \$0.2 billion in 2000 to \$15.2 billion in 2010. Worldwide service revenue during the same period is projected to increase from \$100 million to \$35.6 billion.

"Our model predicts that the largest opportunities for broadband wireless access equipment sales and service revenues will be in North America, followed by Europe, Asia Pacific and Latin America," said Pioneer's Paul Kellett. "We are also predicting that broadband wireless access technologies operating over 10 GHz will achieve a wider acceptance in world markets, generally, than below 10 GHz."

Hexawave Expands, Develops New Processes

Hexawave was founded in 1991 as Taiwan's first GaAs manufacturer. Having recently completed an expansion of its facilities, which increased the total clean room area from 3,500 sq.ft. to 8,500 sq.ft., the company has also built a 4-inch wafer manufacturing line. The previous 3-inch line remains in operation. These enhancements have provided Hexawave with sufficient additional capacity to begin to offer foundry services.

Hexawave's main products are discrete GaAs MESFETs, which are supplied in chip form or in ceramic or plastic packages, along with GaAs MMICs and power modules. These products are directed towards L-, S- and C-band applications for cellular and PCS base stations, wireless local loops, wireless local area networks (LANs) and MMDS (multi-channel, multi-point distribution service) systems. Hexawave is currently one of the leading suppliers of 1-3 W power modules for L- and S-band applications, as well as being a leading source of MMDS down-converters operating in the 2.5–2.66 GHz range. Previously, Hexawave was also involved in sub-system manufacturing but most of this business has now gone to low cost packaging and assembly houses in mainland China.

According to Yie-Der Shen, executive VP of Hexawave, the company is currently seeing a great deal of interest in power amplifier modules for 3.5 GHz wireless LAN applications. Another area generating interest, especially among attendees at the recent MTT-S meeting in Boston, is the 5-6 GHz ISM (industrial, scientific and medical) band. To address the latter market and other higher frequency applications, Hexawave is poised to bring a 0.5- μ m PHEMT process into production (using purchased epiwafer material), and is also developing HBT-based products.

Celeritek Reports Production Contracts

Celeritek (Santa Clara, CA) has received several new production contracts worth \$17 million, including a \$5.2 million order for 3.0 V InGaP HBT CDMA power modules from a major US handset manufacturer, believed to be Motorola. These amplifiers will be used in CDMA handsets and are expected to begin shipping in the last quarter of calendar 2000.

"Previously announced design wins for our TrueTriangle 50-W HBT modules are now moving into production," said Bill Hoppin, VP of sales and marketing. "Our portfolio of customers and design wins now exceeds 20, across multiple major manufacturers and supporting WCDMA, 1X CDMA and TDMA access technologies."

The company also received several initial production orders for GaAs-based subsystems for receive and transmit functions for the satellite communications and high capacity radio markets. Delivery is expected to begin in the last quarter of calendar 2000.

Alpha's GaAs MMICs Selected for Bluetooth System

Alpha Industries is to provide GaAs MMIC switches to Digianswer for incorporation into Bluetooth radio modules. Bluetooth is the 2.4 GHz frequency standard being adopted by a consortium of companies for low-cost short range radio links between laptops, mobile phones and other portable devices.

"Over the past year Alpha has extended its wireless leadership into the Bluetooth market, capturing key design and production contracts with some of the world's largest personal computer OEMs," says Chris Conlin, Alpha's director of worldwide sales and marketing.

The recent order addresses two applications in the radio, one for an antenna diversity switch and the other for a T/R switch. Very aggressive radio cost targets and integration goals have been set for

Bluetooth. Because of this, says Alpha's Ron Cavalieri, silicon will dominate and offers the best solution for a single chip, low power radio. However, high performance GaAs switches could have a role to play. "If the all-silicon radio solution cannot meet existing receiver-to-transmitter isolation requirements, then a viable alternative would be the use of off-chip GaAs switches, as in the Digianswer module," says Cavalieri.

Alpha Purchases Test and Assembly Facility

In more news, Alpha is expanding its test and assembly facilities following the acquisition of an existing 125,000 sq.ft. manufacturing and office facility based in Haverhill, MA for \$8.75 million. Alpha expects to refit and commence operations at the new site in January 2001. Primary operations will include silicon device assembly, plastic packaging and RF and

DC testing. GaAs manufacturing and processing will continue to be performed at Alpha's Woburn site, which is currently undergoing a transition to 6-inch GaAs manufacturing.

Marconi Orders Transceivers from WJ

WJ Communications, Inc. (formerly Watkins Johnson) is to provide GaAs-based RF transceivers for Marconi's Digital Multi-point System (DMS) product line. Valued in excess of \$3 million, the initial order is for five thousand 26 GHz DMS transceivers, which will be used in broadband wireless access systems employed across Germany. WJ Communications expects to deliver these units, which will be assembled at the company's facilities in San Jose, California, during the fourth quarter of 2000 and first quarter of 2001.

QUALITY QUESTIONS?

- Surface Roughness
- Layer Thickness
- Lattice Mismatch
- Chemical Composition
- Film Density
- Dislocations

Worldwide:
Tel. (+49) 721/595-2888
Fax (+49) 721/595-4587
<http://www.bruker-axs.de>
E-mail: info@bruker-axs.de

USA and Canada:
Tel. (+1) 608/276-3000
Fax (+1) 608/276-3006
<http://www.bruker-axs.com>
E-mail: info@bruker-axs.com

**find out
what's inside**

**OUR SOLUTION:
D8 DISCOVER THIN FILM ANALYZER!**

BRUKER ADVANCED X-RAY SOLUTIONS



RFMD Ships One Million MCMs

RF Micro Devices recently shipped its one millionth PA multi-chip module (MCM), and expects module sales to account for an increasing percentage of its total revenues. The company also reported that its CDMA PA module has been fully qualified by Qualcomm and that volume production shipments have begun.

In more news, RFMD will become an associate member of the Bluetooth Special Interest Group, and expects the first products—silicon-based transceivers—to be available later this year. RFMD has also opened a new engineering design center in Pandrup, Denmark to focus on high efficiency PAs and RF ASIC designs, in addition to a new test facility in Greensboro (NC) designed to enable a 5× increase in test rate.

New Devices

- **Conexant's** new family of tri-band GaAs HBT PAs operate at 900, 1800 and 1900 MHz and are designed as a single amplifier package for operation world-wide using the GSM standard.
- **Anadigics** has introduced the first in a new family of 3 V, InGaP HBT PAs. The AWT6107 delivers dual band (GSM/DCS) operation as well as GPRS data services in a single integrated module. Anadigics also announced a new cable modem RF data tuner (the AIT1000M6 "PicoTuner") that represents a single-chip drop-in alternative to current single conversion tuner boxes and IC-based double conversion tuner solutions.
- **Motorola** has developed a GaAs PHEMT for broadband wireless access infrastructure applications operating at 3.5 GHz. The MRFG35010 is an unmatched 10 W discrete transistor operating at 12 V, available in a non-hermetic package and suitable for use as the driver stage in base station amplifiers.
- New low-cost, highly integrated upconverter (MD59-0039) and downconverter (MD59-0043) ICs from **M/A-COM** are designed to meet the stringent linearity and low current requirements of CDMA and TDMA handsets. These converters each integrate an IF amplifier, a mixer, a LO buffer, and various other components into a small, plastic package.
- **RFMD** has developed a new complete GaAs HBT receiver front end for W-CDMA, PCS and general applications up to 2.5 Gb/s. The RF2469 integrates the LNA and mixer and provides 24.5 dB of maximum cascade gain, with a noise figure of only 2.5 dB and -9.5 dBm IP3.
- **TriQuint** has unveiled two high power 18-32 GHz MMIC PAs for point-to-point or point-to-multipoint radios, satellite communication and spacecraft payloads. Based on a 0.25-μm gate length PHEMT process, the TGA1135B is a two-stage amplifier providing 1 W of output power and 14 dB of small signal gain. The TGA1172 amplifier is a three-stage design providing 0.8 W and 18 dB of small signal gain.

Sony Shows Blue Laser DVD Recorder

At a recent technology exhibition in Japan, Sony unveiled a prototype DVD recorder that uses a 405 nm blue laser source. The system is capable of writing 22.5 GB of data on a 12 cm disk, which is enough to record about two hours of HDTV digital broadcasting. This is about five times the capacity of current single-sided DVDs. The specifications are still being ironed out, but commercial systems could become available as soon as next year. Sony's "DVR-Blue" machine was designed in cooperation with Pioneer; Sony developed the optical components and Pioneer contributed the disc technology.

Toyoda Gosei Targets ¥60B in LED Sales by 2003

Toyoda Gosei's President, Tokio Horigome, has announced plans to boost sales in the company's LED division to as much as ¥60B (~US\$545M) by 2003. Thanks to expansion of automobile LEDs and backlights for mobile phones, the LED division grew 2.3 times to ¥14.8B (~US\$135M) in the fiscal year ending March 2000. LEDs are expected to generate sales of ¥22.5B (US\$205M) this year, and the market is expected to continue growing at a 20–40% annual rate. Toyoda Gosei plans to invest ¥8 billion (~US\$72M) to expand production capacity this year.

Horigome also commented on the company's ongoing patent litigation with Nichia Corp., reiterating Toyoda Gosei's position that it has been a pioneer in the field and that its products do not infringe on Nichia's patents.

X-Ray Technique Measures InGaAsP Composition

NEC Corporation and the Himeji Institute of Technology have developed a method to measure the composition of InGaAsP quaternary material in stripe widths as narrow as 1.7 μm. Researchers measured the lattice constant of quantum well layers with approximately 100 times greater accuracy than had been previously achieved, with the aid of a high-resolution microbeam X-ray diffraction technique employing a powerful synchrotron radiation source.

The method allowed accurate compositional control of InGaAsP MQW layers grown by selective area MOVPE within narrow mask stripes. The InGaAsP composition (specifically the ratio of the group-V elements) is almost entirely dependent on the width of the stripe, but until now it has proved impossible to measure accurately the composition of material grown in regions measuring only a few microns across. The team used the X-ray measurements to adjust the mask stripe widths and therefore to accurately control the emission wavelengths of the lasers being fabricated. Luminescent efficiencies were improved by approximately 40% [see Applied Physics Letters, August 28th].

SAWING DOESN'T CUT IT

When separating compound semiconductor die, sawing can't match the accuracy, throughput and yield of dry process dicing from Dynatex.

Our automated scribe & break wafer dicing systems deliver:

- Higher die density
- Chip free results
- Full programmability
- No toxic water discharge
- Up to 10" per second scribing
- Dice the most fragile substrates
- Dice 4" (GST-100) and 6" (GST-150) wafers



ICs

MMICs

Diode Lasers

MEMS



dynatex[™]

INTERNATIONAL
semiconductor dicing equipment and materials

HBTs

FETs

5577 Skylane Boulevard • Santa Rosa, CA 95403

Phone: 707•542•4227 Fax: 707•579•8599 Email: sales@dynatex.com

OPTO NEWS

TRW Acquires Cutting Edge Optronics

TRW has purchased Cutting Edge Optronics (CEO), a vertically integrated designer and manufacturer of lasers based in St. Louis, MO, for around \$24 million. CEO's products include high-power laser diodes, fiber-coupled arrays and direct-diode laser arrays and subsystems for industrial, medical and scientific uses.

CEO will become a wholly owned subsidiary of TRW and merge its low-cost laser design and high volume manufacturing capabilities with TRW's expertise in high-power, solid-state lasers and extreme ultraviolet (EUV) technology. EUV is an emerging laser-based technology for semiconductor photolithography applications.

"TRW's leadership position in EUV technology combined with Cutting Edge Optronics' low-cost laser manufacturing capabilities gives us a significant head start in inserting EUV light sources into next generation photolithography equipment," said Richard Walker, president and CEO of the new subsidiary. "TRW's additional solid-state laser intellectual property and capital investments in Cutting Edge Optronics also will allow us to address new solid-state laser business opportunities."

QC Laser Wavelength Extended to 20 μm

Scientists at Bell Labs have reported a Quantum cascade (QC) laser that operates at a wavelength of almost 20 μm , emitting up to 15 mW of peak power at -124°C. This is claimed to be the longest wavelength semiconductor laser ever made from standard semiconductor materials. The new laser may be used for very sensitive chemical analysis and diagnostic applications.

"Such lasers could be used to detect minute traces of pollutants in the stratosphere and in medical and combustion diagnostics," says Federico Capasso, physical research VP at Bell Labs and a co-inventor of the QC laser. "They could detect chemical concentrations of a few parts per billion." Recently, Lucent licensed its QC laser technology to Applied Optoelectronics of Sugarland, Texas.

Opto Power Focuses on Telecom Lasers

Spectra-Physics has realigned its business units to support growth in telecommunications and other strategic markets. Spectra-Physics is a supplier of high-power multimode semiconductor lasers and solid-state laser systems, with operations in Mountain View and Oroville in California, and at Tucson, Arizona through its high-power laser diode subsidiary, Opto Power.

The company's new management infrastructure now includes three operating groups: the SP Passive Telecommunications Group, SP Active Telecommunications Group and the SP Lasers Group, which will be responsible for all laser business in the industrial, OEM and research markets.

The SP Active Telecommunications Group will contain the Opto Power and Active Telecom Systems business units. Opto Power's products include 915 and 975 nm multi-mode pump lasers, which

are coupled to fiber lasers to produce high power single-mode sources for pump laser applications.

Spectra Physics CEO, Patrick Edsell, told *Compound Semiconductor*, "We believe that the new infrastructure increases our focus on high-growth passive and active telecommunication opportunities, while ensuring that we maintain our leadership position in the semiconductor-based laser markets.

"In particular, we hope to leverage the strong position that Opto Power has in multi-mode high power laser diodes used in materials processing and other industrial applications to access markets for telecommunications pump lasers. We already have prototype samples undergoing Telecordia qualification, and expect to be shipping multimode lasers for pumping applications by the middle of next year."

Microvision to Develop Electro-Optic Polymer Materials

Microvision (Bothell, Washington) has launched a subsidiary company, Lumera Corp., to develop active and passive components for optical networks based on proprietary electro-optic polymer materials. These materials, the result of research by Microvision and the University of Washington, are engineered at the molecular level to enable active components, such as electro-optic modulators, that feature a combination of the fastest switching speeds with the lowest drive voltages and optical losses in the industry. The company is also developing novel waveguide amplifiers, low-loss passive devices, ultra-fast photonic packet switches and a variety of integrated devices featuring both planar (single layer) integration and unique multi-layer structures.

Prototype devices based on materials developed by Lumera's research team have already achieved record-setting bandwidth (in excess of 100 GHz) and operating voltages (below 1 volt) in demonstrations at commercial and government research labs. Lumera expects to make prototype devices available to customers for testing during 2001 with commercial production scheduled to begin during 2002.

Lumera will target optical systems providers who are seeking a competitive edge in the emerging market for 40 Gb/s transmission. The company claims that devices based on lithium niobate or GaAs have difficulty achieving the required data rates without requiring prohibitively high operating voltages, and are also not well suited to higher levels of device integration.

"Lumera has the best way to deliver the right combination of performance and cost for 40 Gb/s systems," says Todd McIntyre, VP for business development. "We intend to be the first company to successfully commercialize polymer-based electro-optic devices, and we think our leadership in materials will keep us way out in front."

For news on fiber-optic component manufacturers including Corning, Alcatel and Agility, see the Fiber-Optics News section starting on page 25.

centrotherm

thermal dynamics

Quick Link to IrDA

Add powerful advantages to your production process by implementing centrotherm systems and technologies for Liquid Phase Epitaxy. With the field-proven FEA-V we offer a production tool for IrDA components providing optimum productivity at best CoO.

-  Space saving due to vertical design
-  Low running costs
-  Easy process handling
-  High yield and high throughput 50 wafer/day
-  High output power 30mW to 40mW
-  Fast switching time 30ns to 10ns

North America:
centrotherm LP
Atlanta, GA
Tel 404-869-6295
Fax 404-869-6296
info@centrotherm-intl.com

Europe, Asia:
centrotherm Elektrische Anlagen GmbH+Co.
Blaubeuren, Germany
Tel +49-7344-951-0
Fax +49-7344-951-333
www.centrotherm-intl.com

STRATEGIES IN LIGHT 2001

Lighting the Future with LEDs

February 8-9, 2001 • Hyatt Regency San Francisco Airport • Burlingame, California

Following the success of the first-ever international business conference devoted to high-brightness LEDs, Strategies Unlimited will host the second annual STRATEGIES IN LIGHT conference in February 2001. The conference will provide an unequalled opportunity for those in the LED community and those involved in lighting and other emerging LED applications to gain insight into the markets, issues and technologies that characterize the rapidly growing high-brightness LED (HB-LED) industry.

STRATEGIES IN LIGHT 2001 will deliver presentations on:

UPDATED MARKET TRENDS and forecasts directly from Strategies Unlimited, the world's premier market research firm in optoelectronics

APPLICATION DETAILS and market potential from international suppliers and users of HB-LEDs, including:

- Full-Color Signs
- Illumination
- Traffic Management
- Backlighting for Displays
- Automotive Lighting
- Machine Vision

TECHNOLOGY ISSUES and timeframes for HB-LED development, including solid-state lighting

BUSINESS AND FINANCIAL ISSUES associated with the emerging HB-LED industry

CONFERENCE HIGHLIGHTS include:

- 1-1/2 day focused agenda
- Unique access to presenters, including panel discussions
- Ample opportunity for informal discussions during breaks and receptions
- Located at the elegant Hyatt Regency San Francisco Airport, just minutes from downtown San Francisco

ACT NOW to reserve your place at this unique industry event.

For program and registration information, contact Strategies Unlimited at (650) 941-3438 (voice) or (650) 941-5120 (fax), or e-mail info@strategies-u.com. Also, check the company's web site at www.strategies-u.com for conference updates and registration materials.



Strategies Unlimited

201 San Antonio Circle, Suite 205
Mountain View, CA 94040

www.strategies-u.com

Corning Buys Pirelli's Optical Components Business

In the latest mega-acquisition in the fiber-optic components industry, Corning has acquired Pirelli's optical components and devices business, based in Milan, Italy, which manufactures lithium niobate modulators, 980 nm submarine pump lasers, specialty fibers and fiber gratings. Corning is to pay around \$3.6 billion in cash for Pirelli's 90% stake in the business. Cisco Systems currently owns the remaining 10%, and will exchange its shares for Corning shares. The deal comes just months after Corning ended talks to buy Nortel Networks' optical networking components business.

Corning gains access to 980 nm submarine pump laser chips and modules, directly complementing Corning Lasertron's 980 nm terrestrial pump capabilities, based in Bedford, MA. Pirelli's unit also adds lithium niobate modulator technology and specialty fiber capacity to Corning's portfolio. Both parts of the acquisition are expected to close by the end of 2000.

Nortel Plans to Sell Shares in its Fiber-Optics Business

Nortel Networks has announced plans to sell shares in its fiber-optics components unit, which would allow the fast-growing business to acquire other essential technologies. A recent Bloomberg News report quoted Nortel's CEO, John Roth, as saying that an IPO would occur in summer 2001.

The unit was valued at \$100 billion during failed merger discussions with Corning earlier this year [see CS 6(6), p.8]. Roth stated that the Corning deal did not go through because Nortel wanted to keep control of the components business; Nortel is expected to retain a stake of at least 85% in the unit following the planned IPO. In contrast, Lucent plans to spin off its Microelectronics Group to shareholders following an IPO in the first quarter of 2001.

Nortel recently announced investments totaling \$1.2 billion that will more than triple its production capacity for fiber-optic components, and expects sales of \$2.5 billion this year, around 80% of which go to internal customers.

SDL to Supply 980 nm Pump Modules To Huawei Technologies

SDL (San Jose, CA) is to supply Huawei Technologies, a Chinese telecommunication equipment manufacturer, with 980 nm pump modules and arrayed waveguide grating (AWG) modules for Huawei's DWDM systems. Huawei supplies switching/routing, DWDM transmission and optical access network products. The supply agreement, which will run through to the end of 2001, is expected to be worth more than \$20 million. SDL's 980 nm pump modules and AWG components are used in both long distance fiber optic networks and metro DWDM systems. AWGs are passive components designed and manufactured by SDL PIRI that enable the routing of individual wavelength channels in fiber optic systems.

"The acquisition of Pirelli's active component technologies and products significantly adds to our capabilities in the transmission segment of the optical layer," says Corning's chairman and CEO, Roger Ackerman. "Pirelli is currently in the final stages of qualifying its [980 nm] submarine chip and is beginning qualification of a packaged 980 nm pump module. In the near term and while Pirelli's products are being qualified, Corning will use the extra capacity to manufacture 980 nm terrestrial pumps."

To date, Pirelli's sales have been exclusively to its internal customers, Pirelli and Cisco, and Corning will continue to supply these two companies with submarine pump lasers. "Part of the deal is a long term supply contract with Pirelli Submarine Devices, but we'll need to do a lot of work over the next 6 to 9 months to enter the submarine market," said Gerald Fine, VP of Corning Photonic Technologies. "We think an advantage will be the ability to supply not only submarine 980 nm pump chips, but also modules."

Lucent Expands Optoelectronic Component Facilities

Lucent Technologies Microelectronics Group is spending \$65 million to expand its optical component manufacturing at its sites in Pennsylvania, Texas and Mexico. "Our expansions involve investments in facilities, semiconductor fabrication equipment, and assembly automation technology, as well as in developing a highly skilled workforce," said Chuck Mattera of Lucent's Microelectronics Group. "This will help us meet increasing demand through more production capacity, higher product yield, and faster order fulfillment time."

Lucent will add a new 120,000 sq.ft. office and laboratory facility at its Optoelectronics Center at Breinigsville, PA, planned for occupancy by late spring of 2001. At the same time, Lucent will outfit existing space with additional manufacturing capacity at a cost of about \$14 million. Lucent will also invest \$11 million in a leased 125,000 sq.ft. space in Upper Macungie Township in Pennsylvania to house fiber amplifier manufacturing. In Matamoros in Mexico, construction has started on a new 80,000 sq.ft. manufacturing facility that will begin to manufacture transmitters, receivers, transponders and fiber amplifiers during the first quarter of 2001.

DWDM Spacing Reduced to 12.5 GHz

Ciena has announced plans to enhance the capacity of its optical networking systems by reducing DWDM channel spacings. The company has developed fiber Bragg gratings that allow systems to operate with 25 GHz and 12.5 GHz channel spacings, corresponding to wavelength separations in the fraction of a nanometer range. The products will be available in 2001.

ENGINES OF GROWTH

For over a decade, RIBER has consistently delivered the state-of-the-art in production MBE equipment: first 3x4" (1988), first 4x4" (1996), first 4x6" (1998), first... (to be continued).

Our MBE 49 and MBE 6000 epitaxial reactors provide the:

highest **Throughput.**

highest **Uptime,**

best **Cost Effectiveness,**

and... **Peace of Mind.**



Best-in-class MMIC and laser epiwafers are produced daily on our systems fueling the growth of the information age.

R I B E R

Products and Services for the Compound Semiconductor Industry

Money Flows in Fiber-Optic Funding Season

Despite recent stock market turbulence, the fall season saw several emerging fiber-optic component (FOC) manufacturers secure healthy rounds of funding. Venture capital firms have been happily opening their check books, along with established fiber-optics industry names such as Cisco Systems, Corning and Vitesse, who are anxious to bring forward the next generation of technologies.

Company	Location	Products	Latest Funding Round
Novalux	Sunnyvale, CA	Surface-emitting lasers	\$109 million
CyOptics	Burlington, MA	40 Gb/s components	\$57 million
Agility*	Santa Barbara, CA	Tunable lasers	\$70 million
Nova Crystals	San Jose, CA	LEDs, VCSELs	\$31.25 million
Picolight	Boulder, CO	VCSELs	\$38.9 million
Funding for FOC manufacturers announced during September and October.			
*For more information on Agility, see page 34.			

CyOptics

CyOptics, a developer of optoelectronic components for 40 Gb/s and ultra-long-haul transmission, has raised an additional \$57M of equity financing, bringing the company's total financing to over \$77M. The money will be used to fund product development and accelerate expansion of the company's manufacturing facilities.

Cisco Systems led the funding round, which also included Corning, Intel Capital, and Vitesse Semiconductor, as well as all the original investors. "CyOptics' products address a market of vital interest to Vitesse, namely, 40 Gb/s optical transmission," says Lou Tomasetta, President and CEO of Vitesse. "Their optical components are synergistic with our high performance semiconductor devices."

"The Internet continues to grow at an exponential rate, and innovations such as 40 Gb/s optical components and components for ultra-long haul transmission will be a necessary development to keep pace with this growth," commented Tom Willis, director of optical investments at Intel Capital. Intel Capital, Intel's strategic investment program, focuses on making equity investments and acquisitions to grow the Internet economy in support of Intel's strategic interests.

CyOptics, founded in early 1999, is headquartered in Burlington, MA, with offices in Los Angeles and R&D facilities in Israel. The company has full optoelectronic component manufacturing capability, including InP wafer fabrication, regrowth, and characterization, as well as microelectronic packaging, test & qualification facilities.

Nova Crystals

Nova Crystals raised \$31.25M in its latest funding round, which will be used to expand the company's VCSEL chip-making capability and increase capacity. An established LED manufacturer, Nova Crystals demonstrated the world's first practical, electrically pumped, 1.3- μ m VCSEL with the highest power reported to date in August 2000 [see CS 6(6), p. 12]. The device is plug-compatible with the standard Gigabit Ethernet and SONET/SDH transceiver modules that presently use Fabry-Perot edge-emitting lasers, while offering superior characteristics and new functionality.

"As an investor in several top tier optical systems companies, we see Nova Crystals as one of the leading companies that can provide breakthrough optical components for next-generation optical networks," says Andrew Kau, general partner of Walden International. Ridgewood Capital led the investors, which also included Intel Capital and Infineon Technologies Ventures.

Novalux

At the end of September, Novalux Inc., an FOC manufacturer based in Sunnyvale, CA, closed a \$109M round of equity financing. New investors included Cisco Systems and Intel Capital.

The investment allows Novalux to immediately expand manufacturing capacity for its proprietary surface-

emitting laser technology, known as the NECSEL. The company will be able to meet the demand for its first family of pump laser products, with a focus on newly designed, automated methods of packaging, assembly and testing. The funding will also be used to assemble independent design teams to develop other photonic products such as tunable transmitters.

"This financial support brings us one step closer to fully realizing the advantages of the NECSEL platform in performance, manufacturing, assembly, packaging and testing," says Malcolm Thompson, CEO of Novalux.

Picolight

VCSEL manufacturer Picolight of Boulder, CO has received \$38.9M in its third and largest round of funding. The proceeds will enable the company to further ramp manufacturing of its VCSEL-based, 1.3 Gb/s fiber-optic components. Picolight also plans to accelerate and expand its research program, and develop and supplement marketing.

The funding round includes new investment from Cisco Systems and Corning, and brings the total investment in Picolight to more than \$53M.

Picolight designs and manufactures VCSEL-based, fiber optic transceiver components and subsystems that provide multi-Gigabit bandwidth to manufacturers of telecom switch, storage area network (SAN) and enterprise network equipment.

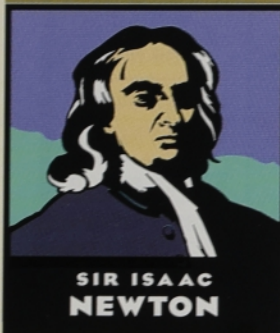
1688 John Worgan opens his shop for the sale of mathematical instruments.

1703 The first telescopic level is created for Sir Isaac Newton.

1714 A mechanical model of the solar system, called an "orrery" after the Earl of Orrery for whom it was created, is shown to His Majesty George I.

1795 The equatorial telescope is created for the Armagh Observatory.

1809 Edward Troughton refines the dividing engine, an important contribution to the development of astronomical instruments.



Scientist.
Mathematician.
Customer.

Considered by many to be history's greatest scientist, Newton studied the nature of light, devised the first reflecting telescope, developed calculus, and discovered the law of universal gravitation after, it is said, observing the fall of an apple.

SIR ISAAC NEWTON, one of our predecessor's earliest customers, changed the way people understood the laws of physics. Not to be outdone, we changed our name. Of course, there have been other changes during our history. Technology has advanced. Our tools have evolved. Sir Isaac Newton is found in science books instead of our lobby.

THE NAME HAS CHANGED.



www.accentopto.com

Through it all, we've continued to provide innovators with the tools they need to create, discover, and succeed. Today, we supply both compound and silicon semiconductor manufacturers throughout the world with process control and measurement tools, helping fuel, amongst others, the rapidly growing optoelectronics, wireless communications and internet industries. Like our customers, we have a history of changing things. A legacy based on commitment, fueled by drive. Built on the shoulders of giants. . . .

1848 An innovative transit circle is built for the Greenwich Meridian, defining longitude.

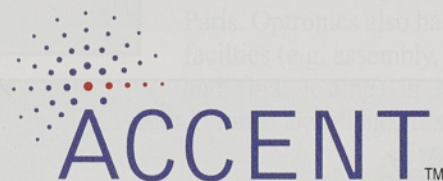
1912 Robert Scott reaches the South Pole using the lightweight theodolites for sub-zero conditions created for the British Antarctic Expedition.

1988 High-precision measuring apparatuses and laser rangefinders are distributed worldwide.

2000 Bio-Rad Semiconductor Systems Division becomes Accent, a global company that supplies process control tools to optoelectronic and semiconductor industries throughout the world.

BIO-RAD SEMICONDUCTOR SYSTEMS DIVISION HAS BECOME ACCENT OPTICAL TECHNOLOGIES.

The laws
of physics,
we've pretty
much left alone.



THINK FASTER.

ACCENT OPTICAL TECHNOLOGIES, INC.

China • France • Germany • Israel • Japan • Korea
Singapore • Taiwan • United Kingdom • United States

www.accentopto.com

sales@accentopto.com

Think Faster.

NEC and Hitachi to Jointly Develop Optical Transport Systems

In an attempt to compete with leading suppliers such as Nortel Networks, NEC and Hitachi have agreed to pursue the joint development of next-generation optical transport systems, targeting the US market. The agreement will include DWDM systems, 10 Gb/s and 40 Gb/s SONET/SDH optical transmission systems, ultra-long haul repeater systems, optical cross-connect systems and network management systems. The first products of the joint development will be rolled out during the middle of 2001.

NEC Sets DWDM Transmission Record of 6.4 Tb/s

NEC has set what it believes to be a new industry record in high-density DWDM capacity transmission by successfully transmitting 6.4 Tb/s over a single 186 km fiber. The high capacity was achieved using 40 Gb/s data rates over 160 channels. NEC says this capacity is the equivalent of simultaneously transmitting one million motion pictures over a single fiber. The company developed several new technologies to achieve the result, including new mux/demux components and 40 Gb/s receivers employing ICs based on GaAs HBTs.

Picogiga Invests in Modulight

Picogiga (Paris, France), which supplies MBE-grown epiwafers for microwave applications, has purchased a 40% stake in Modulight, Inc., a newly formed manufacturer of optoelectronic components for telecommunications. Based in Tampere, Finland and formed in May 2000, Modulight is a spin-off from the Optoelectronics Research Center (ORC) at Tampere University of Technology. The university has spawned two previous companies: Tutcore, a manufacturer of high power laser diodes that was acquired by Coherent, and Nordic Epitaxy, which supplies epitaxial wafers.

Modulight describes itself as a manufacturer of optoelectronic semiconductor components for modern fiber-optic communication networks, and provides services ranging from epitaxial structure design to device chip fabrication.

"This capital investment allows us to ramp up our production capacity and set up a high quality R&D site," says Petteri Uusimaa, Modulight's President & CEO. "It is a vote of confidence in the bright future of Modulight during a period of considerable market turbulence."

Stable

Consistent

Rock-Solid Vapor Delivery Technology.

Tired of unstable flow from solid sources and not satisfied with packing rings or solution alternatives? Then consider the Uni-Flo cylinder with your next purchase of TMI_n, (Cp)₂Mg or CBr₄ for stable flow through

90% depletion. If you prefer the purity of solids but don't want the headaches of growing epi wafers from unstable sources, ask for the Uni-Flo cylinder available only through Rohm and Haas Metalorganics.

Contact us today or visit our website at metalorganics.com.



THE UNI-FLO™ CYLINDER
(patent pending)



ROHM AND HAAS COMPANY 60 WILLOW STREET NORTH ANDOVER MA 01845

Tracking the Fiber Optic Components Market

Alcatel offers the public an interest in its Optronics Division

MARIE MEYER

Despite adverse market conditions, on October 20 Alcatel successfully sold 16.5 million shares of "tracking stock" for its Optronics division at 85 euros each, valuing the division at 8.1 billion euros or \$6.9 billion. The new "Class O" shares rely on separate financial statements that Alcatel has created to segregate the Optronics division from the rest of the company. They will be traded on both the Paris Bourse and the NASDAQ.

Alcatel Optronics produces optical components for use in terrestrial and submarine fiber optic networks. Virtually all of its products are active components, especially lasers, laser modules, and laser-based sub-systems (see Figure 1 for an explanation of these categories). The major product lines are as follows:

- Discrete Modules, which include DWDM lasers;
- Pump Modules for both terrestrial and submarine networks;
- Optical Amplifier Sub-systems, which combine the pump, the fiber and passive devices such as filters;
- Optical Interface Sub-systems, which combine all the required equipment to

transmit and/or receive signals; and

- Passive Components, such as fiber Bragg grating filters, a new product line launched in early 2000.

Optronics has been selling lasers on the open market since 1995, but historically all of the other products were cap-

deployments outside of North America. The company has enjoyed steady revenue growth, despite the rapid decrease in selling prices that are characteristic of their industry—see Figure 3.

The Optronics division operates a 6,100 sq. meter chip fab in Nozay, France which is currently being expanded so as to roughly double its size by the end of this year. The fab is located so as to facilitate interaction with Alcatel's well-known research center, just outside of Paris. Optronics also has back-end facilities (e.g. assembly, packaging and final testing) in Nozay and Lannion, France and Plano, Texas.

Alcatel estimates that total market for DWDM components alone will grow from \$2.5 billion in 1999 to approximately \$11.3 billion in 2003

tive to Alcatel's own operations. In late 1999 the company changed course and began offering its entire product portfolio to outside customers, who now account for 20% of Optronics' sales. See Figure 2 for a breakdown of sales by product type. Their major external customers include ADVA, Ciena, Corvis, Fujitsu and Sycamore. 43% of Optronics's sales are made to the Alcatel Submarine Network division; 16% are made to an Alcatel division addressing the terrestrial market in North America; and another 23% are made to another Alcatel division for terrestrial

About that Valuation

The intense interest in the Optronics offering is a testament to the strength of the fiber optic components sector. Alcatel, one of the world's largest and most well known companies, had 1999 sales of just over \$23 billion, and its current market capitalization¹ is over \$70 billion. In

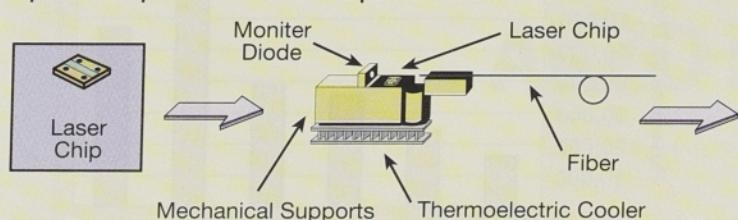
that same year Optronics accounted for just 1% of Alcatel's total sales and less than 3% of their total profits. But yet Alcatel received \$1.2 billion for just 17.4% of the Optronics division.

While that may seem like a lot, recall that JDSU's acquisition of SDL was valued at \$41 billion. Despite the possibility of some short-term slowdowns,

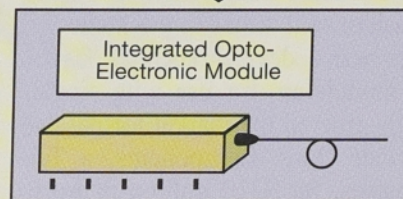
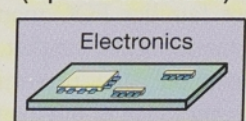
Figure 1.

Optical Chip

Optical Module



Optical Sub-system (Optical Interface)



the long term forecast remains excellent. Based on industry sources including RHK, Electroni-cast and Strategies Unlimited, Alcatel estimates that total market for DWDM components alone will grow from \$2.5 billion in 1999 to approximately \$11.3 billion in 2003 (including both active and passive components).

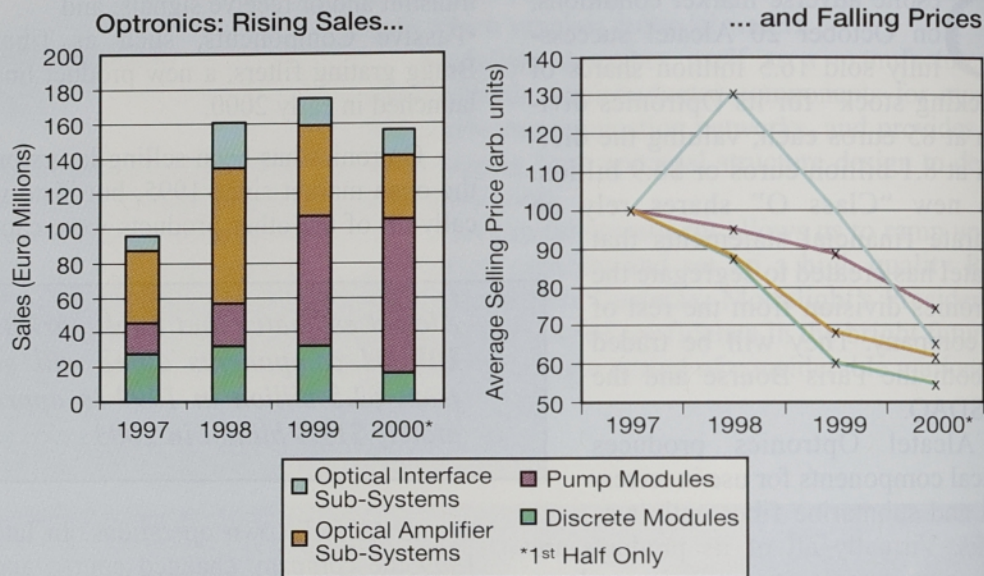
And Alcatel Optronics is well positioned in that market. They are the largest European supplier, and are probably the #4 supplier over-all, behind Nortel, JDSU and Corning (for more on market shares, see CS 6(6), page 6).

Even so, the IPO was a bit unusual, to say the least. Tracking stocks are fairly uncommon in the U.S. and a real rarity elsewhere. In fact, Alcatel believes that they are the first French company to do it. Which raises the issue of whether or not they may be subject to adverse treatment under French law. The Optronics would undoubtedly be even more valuable if it were spun out as an independent entity. But that is unlikely to happen, as Alcatel management seems keen on participating in the up-side in this market for the long-run.

Figure 2. Breakdown of Sales by Product Type

Product Line	Sales, 1 st Half 2000	Change Since 1999	% Merchant Sales
Discrete Modules	\$17.6m	+22%	69%
Pump Modules	\$87.3m	+312%	7%
Optical Amplifier Sub-Systems	\$36.7m	+68%	29%
Optical Interface Sub-Systems	\$14.7m	+84%	9%
Passive Components	\$3.5m	--	0%

Figure 3.



Luminent & the Metro Market

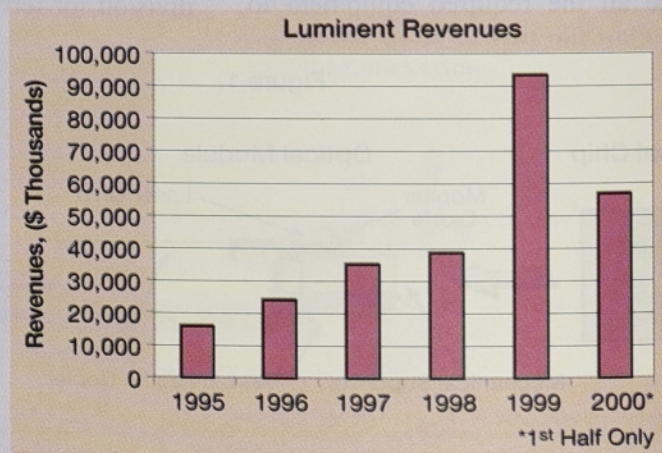
Another IPO waiting in the wings is the spin-out of Luminent from its parent company, MRV Communications. Both companies are located in Chatsworth, CA. MRV is a manufacturer of network equipment that has run a low-profile fiber optic component (FOC) operation for several years. MRV will retain a 92% stake in Luminent after the IPO, which will then be distributed to MRV's shareholders.

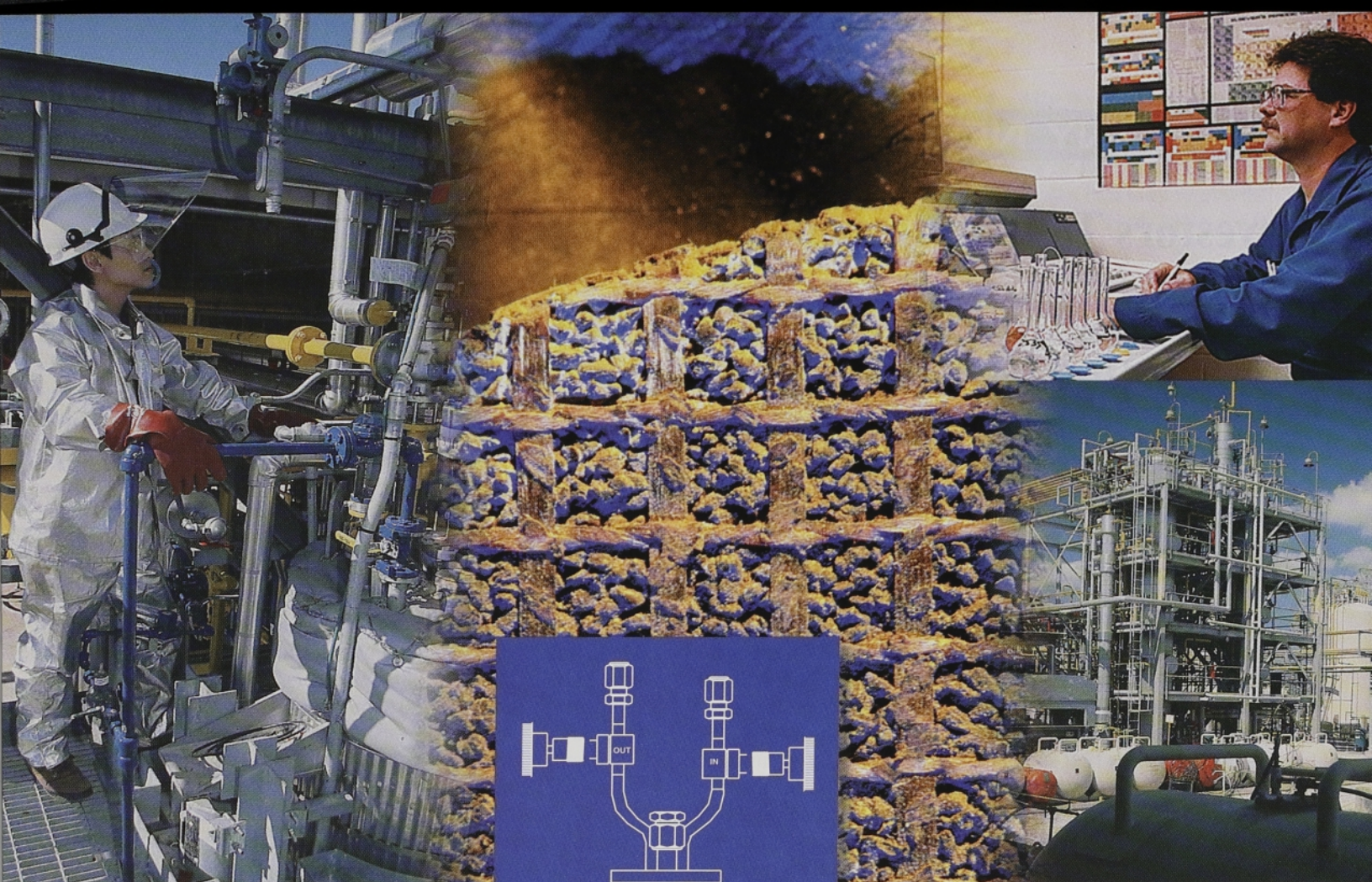
Luminent differs from the more familiar FOC manufacturers in that it is focused on the metropolitan market. This gives it a few advantages. For example, the performance requirements are generally less stringent those in the long-haul market. It is also expected to be the fastest growing segment of the FOC market—although there is some disagreement about the timing of the long-awaited push toward “fiber-to-the-home”.

Luminent manufactures active devices such as lasers, transmitters, receivers, and modulators for use with single-mode fiber. They also recently entered the market for passive devices, having acquired Fiber Optic Components, a Taiwanese manufacturer of passives, for \$310 million in April. The company says that its objective is “to become the leading supplier of single-mode fiber optic components for the

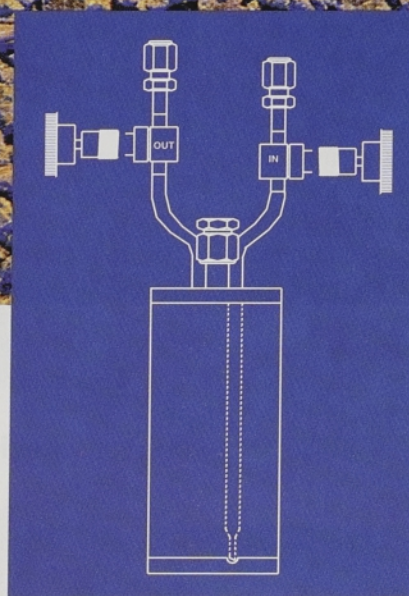
metropolitan and access networks”. Sales for the first half of 2000 reached \$56.7 million (see Figure), and active components accounted for >80% of the total.

Luminent's two biggest customers in 1999 were Marconi (40% of sales) and Cisco (6% of sales). The company has 645 full-time employees, and operates manufacturing facilities in Chatsworth, CA and Hsinchu, Taiwan.





Trimethylindium
Trimethylgallium
Trimethylaluminum
Trimethylantimony
Dimethylzinc



Triethylindium
Triethylgallium
Triethylaluminum
Diethylzinc
(Bis)cyclopentadienylmagnesium

"Supplying Metalorganics to Epitaxy Leaders Since 1971"



For a quote or more information on Akzo Nobel Select Grade low-silicon, low-oxygen sources, please call **1-800-828-7929** or e-mail us at metalorganics@AkzoNobel.com.

Investors Tune In to Agility

Tunable laser specialist Agility Communications has received \$70 million in its second round of funding. Its first products are expected soon.

TIM WHITAKER

Agility Communications, a developer of tunable lasers for next-generation optical networking systems, has received \$70 million in its second round of funding to add to the \$15 million it raised one year ago. The company, a spin-off from the University of California at Santa Barbara (UCSB), expects to release its first product in November of this year. This will be a tunable sampled grating DBR laser capable of producing 4 mW at any of 100 ITU channels across the entire C-band (1530-1565 nm) – the industry's first such product. Agility plans to introduce a transmitter module incorporating control software for the laser.

Tunable lasers are seen as key components in helping communications providers to increase network capacity and maximize existing network resources. These devices allow networks to dynamically provision bandwidth: in other words, they eliminate the problem of having some network channels under-utilized, while others are overloaded. They will also be widely used in all-optical networking functions. "Tunable lasers are critical to our next-generation systems," says Luis Llovera of Mustang Ventures, the corporate venture arm of Siemens Information and Communication Networks. "We're confident that Agility will provide the kind of widely tunable, high-power lasers that our optical networking customers need."

Agility was founded in October 1998 by Larry Coldren, a professor at UCSB, and one of his former students, Greg Fish.

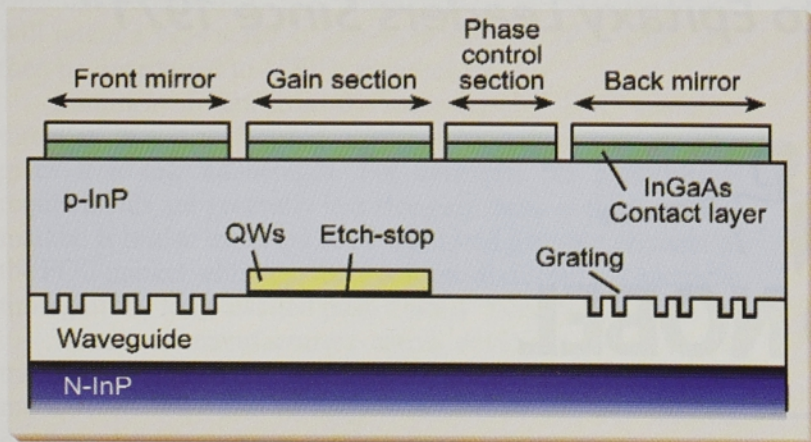
The company has a fab in Santa Barbara that carries out epitaxy and chip manufacturing, as well as a high volume packaging facility in Allentown, PA. "Our first round of funding was used to set up the two facilities," says Arlon Martin, Agility's VP of Marketing. "After only nine months, both are operational and we have parts in beta test with customers." The company has grown rapidly and now has 160 employees, compared to about 20 in February.

Demand for fiber-optic components is extremely high at present, and the tunable laser market is especially hot, with a number of start-ups competing with established FOC suppliers. "Given the market conditions, we realized we had to add capacity and add it fast," says Arlon Martin. "We will use this second round of funding to rapidly expand our wafer fabrication and packaging capabilities, and to accelerate our high-volume, automated assembly process."

A Technological Edge

Agility's position in the tunable laser market is strengthened by a group of patents licensed from UCSB, in particular a patent covering multi-section sampled grating DBR lasers that dates back to 1990. "There are a lot of companies chasing the tunable market with a lot of different technologies," says Martin. "Our architecture is a standard InP design, which is manufactured in the same way as today's long-haul and metro access source lasers." Martin feels that the more complex technologies used by some of Agility's competitors will increase the time it takes to bring these products to market in volume. "In contrast, we have a straightforward and robust method of manufacturing, the device reliability can be readily understood, and customers can have confidence in our ability to ramp to high volumes," he says.

Some competitive approaches use temperature tuning, and have tuning ranges that peak at 4-5 channels. Electrically tuned approaches have faster tuning and are usually limited to 10-20 channels. Agility's proprietary approach uses two mirrors to create an optical vernier effect, allowing rapid tuning across more than 100 channels. The new products are specified at 10 ms, but the laser itself can switch wavelengths much more quickly. The ability to tune across the full C-band sim-



Cross-sectional view of Agility's tunable four-section sampled grating DBR laser.

plifies control software – and the architecture can also work in the L-band, simply by using different QWs in the gain region.

The sampled grating DBR approach also allows Agility to integrate either modulators or semiconductor optical amplifiers (SOAs) onto the same chip, thus minimizing space requirements and cutting costs. Components under development include single-chip wavelength converters, and attenuators that allow the power to be turned up or down on a channel by channel basis.

Widely Tunable, Sampled Grating DBR Lasers with Integrated SOAs or Modulators

The sampled grating (SG) DBR laser design developed at UCSB and now manufactured by Agility consists of four sections, namely the gain and phase sections and two DBR mirrors, each driven by a separate current. The architecture (see figure) allows the integration of modulators or semiconductor optical amplifiers (SOAs) [1,2]. The DBR gratings have comb-like reflection spectra with different peak intervals, and can be tuned differentially across a very wide range covering both C- and L-bands.

The structure requires a relatively straightforward two-step MOCVD growth, the first stage being the growth of a quaternary waveguide layer and a multi-quantum-well active region separated by an InP etch-stop layer. In standard laser structures the QWs are located within the waveguide; here, the QWs are offset, and this

allows the active and passive sections of the device to be readily fabricated without the need for a complex butt joint regrowth.

The QWs are removed in passive sections of the device (mirrors, phase section, modulator) and retained in the active regions (gain section, SOA). Sampled gratings are defined holographically and etched into the waveguide layer in the mirror sections. Lateral confinement is achieved by etching through the waveguide; the resulting ridge is then buried with a thick p-InP cladding layer and an InGaAs cap.

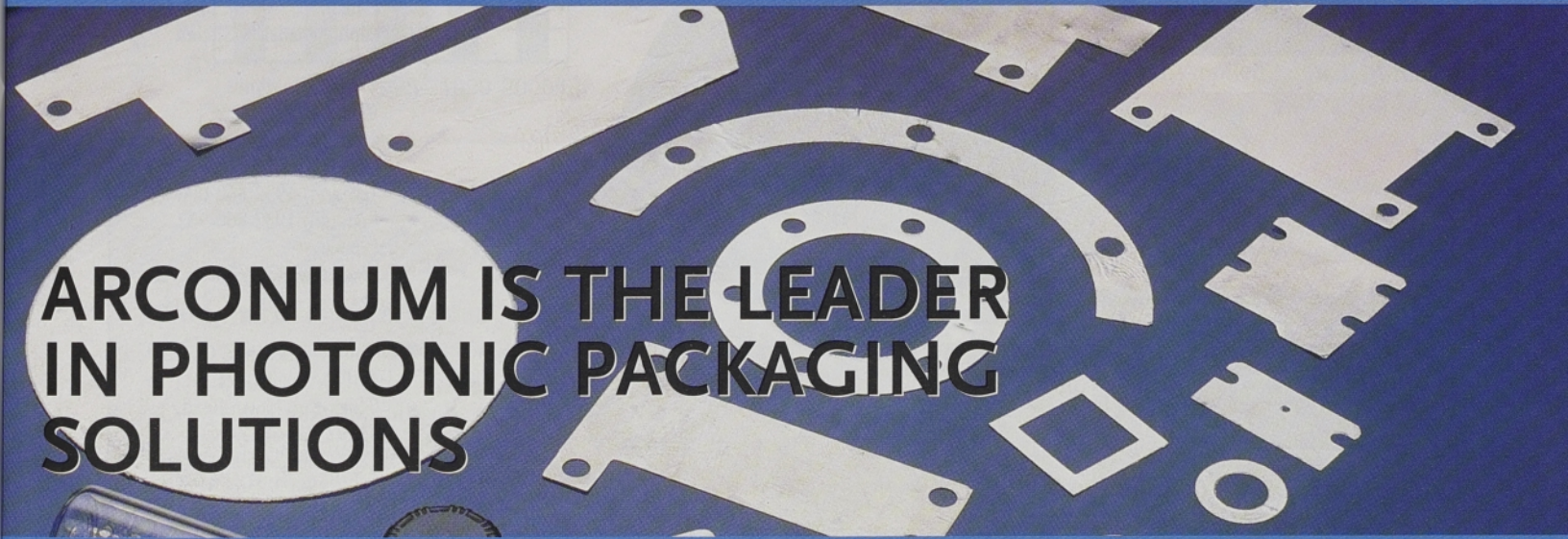
External modulators provide high bandwidth and reduce chirp in data transmission systems. Integrating the modulator with the laser can reduce cost, complexity and insertion losses, as demonstrated by commercial laser-modulator sources with fixed wavelengths. A paper by UCSB [1] describes a tunable laser with an integrated modulator demonstrating more than 22 dB of optical extinction over the entire tuning range of 41 nm, equivalent to 51 channels at 100 GHz spacing.

Integrated SOAs are used to compensate for increased absorption loss in the mirrors at high tuning currents, increasing the output power from the tunable laser. The Agility/UCSB collaboration has demonstrated a quasi-continuous tuning range of over 50 nm with peak output powers of +8 dBm for an integrated SG-DBR laser and SOA [2].

[1] B. Mason et al., *IEEE Photonics Tech. Lett.* 1999, 11(6), p. 638

[2] B. Mason et al., *IEEE Photonics Tech. Lett.* 2000, 12(7), p.762

ARCONIUM



ARCONIUM IS THE LEADER IN PHOTONIC PACKAGING SOLUTIONS

You may think of Arconium as the leader in specialty solders for photonic devices. What you actually get is the added value of more effective and efficient solder selection and innovative process development expertise that will make you more productive and more successful. To get the highest performance and throughput in solder preforms, thermal management, solder paste, and semiconductor grade indium, call 1-800-343-0282 or visit our web site at www.arconium.com

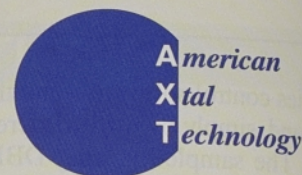


Alpha-Fry Technologies

A COOKSON ELECTRONICS COMPANY

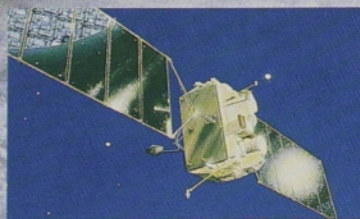
50 Sims Avenue, Providence, Rhode Island 02909 • Phone: 1-800-343-0282 • Fax: 401-421-2419

The Core of Advanced Communication Technologies



Call Us Today For:

- ▶ Up to 150mm GaAs Substrates
- ▶ Up to 100mm InP Substrates
- ▶ Up to 100mm Ge Substrates
- ▶ Low-EPD Epi-Ready Substrates
- ▶ Uniform Ion-Implant Ready VGF Substrates
- ▶ High-Volume LED Substrates
- ▶ High-Mechanical Strength VGF Substrates
- ▶ Ultra-Thin VGF Substrates



USA Head Office

American Xtal Technology
4311 Solar Way
Fremont, CA 94538
Tel: 510-683-5900
Fax: 510-683-5901
Email: sales@axt.com
Website: www.axt.com

Japan

AXT-Japan
302 Urban Plaza Izumi
2-26-4 Myojin-cho
Hachioji, Tokyo 192-0046, Japan
Tel: (81) 0426-56-2032
Fax: (81) 0426-56-6885
Email: axtajapan@cg.netlaputa.ne.jp

France & Germany

SO.FRA.S.I.L
109 Rue De Javel
75015 Paris, France
Tel: (33) 1-4554-4000
Fax: (33) 1-4554-4004
E-mail:
ralph_hananel@CSI.com

United Kingdom

West Associates
46 Leigh Road, Cobham, Surrey
United Kingdom, KT11 2LD
Tel: (44) 1932-868-006
Fax: (44) 1932-860-932
E-mail:
mwest@westassociates.co.uk

Taiwan

Conary Enterprises Co., Ltd.
10 F-2, No. 33, Sec. 2
Chien-Kuo North Road
Taipei, Taiwan, ROC
Tel: (886) 2-2509-1399
(886) 2-2509-3174/5
Fax: (886) 2-2501-6279
E-mail: conary@top2.ficnet.net.tw

Korea

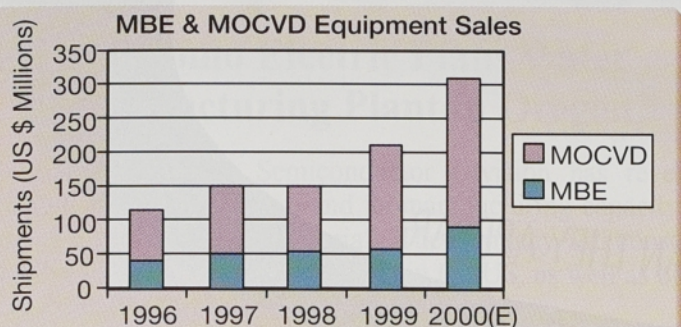
Dong Kyung Electronic Industry
Co., Ltd.
#302 Daegun Bldg.
677-1 Ryeoksam Dong
Kangnam-Gu
Seoul 135-080, Korea
Tel: (82) 2-569-6723/5
(82) 2-568-5261/2
Fax: (82) 2-561-1185
E-mail:
dkekorea@nownuri.nowcom.co.kr



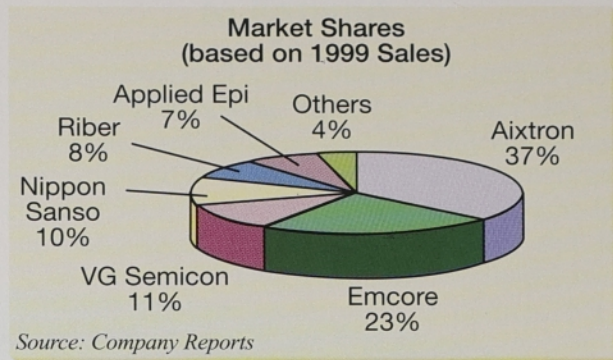
Growing Demand for Epi Equipment

Reports from the major manufacturers indicate that sales of RMBE and MOVCD equipment will likely top \$300 million this year. While LPE and VPE remain important growth techniques for producing conventional LEDs in very high volumes, the more sophisticated MBE and MOVCD growth techniques are crucial elements in the production of almost all other compound semiconductor devices, including high brightness LEDs, laser diodes, solar cells, HEMTs and HBTs.

Over the past four years the market for MBE and MOVCD equipment has grown at a compound annual growth rate of 42.5%, despite the fact that sales were stagnant in 1998, due to the Asian financial crisis. MBE equipment sales for 2000 will be up an estimated 55%, and MOVCD sales will be up an estimated 45%. The figures for this year would likely be even higher if the major suppliers had more manufacturing capacity. Conversations with several of the companies indicate that their order books are completely full through the 2nd quarter of next year. All have expansion plans in the works.



Source: Company Reports



Source: Company Reports

MOVCD equipment accounts for ~70% of the total market, buoyed by complete dominance in HB-LED production. Aixtron, the largest MOVCD equipment manufacturer, captured 37% of the total reactor market in 1999, followed by their arch-rival Emcore with 23%. VG Semicon, the largest MBE equipment manufacturer, captured 11% of the reactor market.

The two other major manufacturers of MBE equipment, Ribier and Applied Epi (formerly EPI MBE Products) are taking a cue from Aixtron and Emcore and turning to the equity markets to finance expansion. Ribier raised \$33 million by floating on the Nouveau Marche of the Paris Bourse in May. And Applied Epi filed for an IPO in late September. No offering date or share price has been announced. The company plans to use the proceeds to set up an applications lab and to enter into the MOVCD market in the second half of 2001. Competition will be fierce, but if they can pull this off, Applied Epi will be their first company to participate successfully in both the MBE and MOVCD markets.

More Reactor Sales

VG Semicon says orders for its MBE systems for the first nine months of 2000 were a record \$42.9 million, more than double the total for the same period during 1999 (\$19.4 million) and already exceeding orders for all of 1999 (\$38.3 million). The company has installed more than 60 multiwafer GaAs production systems worldwide.

Ribier has announced multiple orders for its MBE 6000 and 7000 production reactors, bringing the total of orders for these systems to date to 19.

The company has received the first order for three of its new MBE 7000 production machines from Picogiga. The MBE 7000 is a 7 × 6-inch reactor that increases capacity by 75% compared to the MBE 6000 4 × 6-inch model. Delivery of the systems is scheduled for 2001.

IntelliEPI has ordered a Ribier MBE 6000 production system as part of a recently announced expansion of the

company's merchant epiwafer capacity. Two Ribier MBE 49 (multiple 4-inch) production systems are already in operation at IntelliEPI's facility in Richardson, Texas.

The Naval Research Laboratory (NRL) has placed order with Ribier for a Compact 21 reactor, a 3-inch, single-wafer MBE research system.

Picogiga has also ordered three new GEN2000 production MBE systems from **Applied Epi**. The systems are scheduled for delivery in 2001.

"We purchased the new GEN2000 systems in anticipation of strong demand for HBTs," says Lihn Nuyen, chairman and CEO of Picogiga. "We chose Applied Epi's new systems because they can simultaneously process seven 6-inch wafers within a footprint that's much smaller than any other multi 6-inch production MBE system."



SOLUTIONS ARE CLOSER THAN THEY APPEAR

EMCORE is the only company in the industry with the technology and resources to offer the full spectrum of compound semiconductor solutions.

- MOCVD Tools
- Epitaxial Materials for Wireless Communications and Lighting Applications
- Integrated Magnetic Sensors
- Solar Cells
- VCSELS
- VCSEL Arrays

EMCORE Corporation

394 Elizabeth Avenue
Somerset, NJ 08873 USA
Tel: +1 (732) 271-9090
Fax: +1 (732) 271-9686
<http://www.emcore.com>



Anadigics Orders PHEMT and HBT Epiwafers from Emcore

Emcore has received an order worth \$10.7 million from Anadigics to supply 6-inch GaAs HBT and PHEMT epiwafers. These will be used by Anadigics to manufacture power amplifier ICs for GSM, TDMA and CDMA multi-band wireless handsets, in addition to high-speed digital ICs used in 10 Gb/s data communication applications.

"We have placed this order based on demand for HBT wireless products and PHEMT broadband products," says Bruce Diamond, senior VP of Operations at Anadigics. "We are impressed with Emcore's ability to provide high volumes of 6-inch GaAs HBT and PHEMT epitaxial wafers, while at the same time meeting our requirements for high performance and yield."

Emcore reported significant growth in shipments of InGaP epiwafers over the last year due to increased demand for wireless communications devices—more than half as a result of sales of 6-inch epiwafers.

Sumitomo Electric Plans Wafer Manufacturing Plant in Oregon

Sumitomo Electric's Semiconductor Division has revealed details of its plans to expand its manufacturing capacity for compound semiconductor materials. The company will construct a plant in Hillsboro, Oregon, its first in the US, as well as opening new facilities in Japan and Taiwan.

Production at the Oregon facility will initially focus on 150 mm GaAs wafers, while expansion into the production of large diameter InP wafers is also planned.

Construction on the Oregon site is scheduled to begin in November 2000 and the facility is projected to be in test production by August and in full production by the end of 2001. The total investment for the first phase of the project will be \$20 million. Sumitomo Electric will have an 80% stake in the venture and Mitsui & Co. will have 20%.

"There is a strong increase in demand for our products in the wireless communications industry, and the need to move quickly was a key factor in making this investment," says Kenichi Yoshida, Sumitomo Electric's managing director.

Sumitomo Electric has been manufacturing compound semiconductor materials in its Itami and Osaka facilities in Japan for more than 30 years. The company is currently converting an existing building in Yokohama, Japan to produce compound semiconductor materials, and also plans to build an additional factory in Kobe, Japan.

Meanwhile, a factory in Taiwan is already under construction. A wholly owned subsidiary of Sumitomo Electric will produce and sell GaAs wafers, supplying local semiconductor manufacturers.

New Funding Allows IntelliEPI to Expand

IntelliEPI (Richardson, TX) has raised \$25 million during a recent round of fund raising, which the company says will be used to expand its manufacturing capacity. This will include the addition of 22,000 sq.ft. of clean room space and offices, and the purchase of four 6-inch production MBE systems for the growth of GaAs-based and InP-based HEMTs and HBTs. IntelliEPI will install the first system in November, with the additional reactors scheduled for delivery during 2001. Two Riber MBE 49 (4 × 4-inch) systems are already in operation at the Richardson site for GaAs and InP production.

"The four new systems are part of a capacity ramp-up for a total of ten reactors over the next three years," said Yung-Chung Kao, the company's president and CEO. "In addition, IntelliEPI intends to consolidate volume production of InP HBT epiwafers, and epitaxial structures for lasers used in data communications and fiber optic networking."

Kopin Acquires Super Epitaxial Products

Kopin (Taunton, MA) has acquired Super Epitaxial Products (SEP), a supplier of MOCVD-grown epiwafers used in the manufacture of high brightness LEDs, high power laser diodes, VCSELs, LEDs and photodetectors. SEP, based in Columbia, Maryland, was bought by Kopin with an exchange of stock worth \$25 million.

"As a cornerstone of our plans to broaden the scope of Kopin's optical communications business, SEP dovetails with our GaAs technology and wafer manufacturing capabilities," says John Fan, Kopin's president and CEO.

ATMI Announces Major Expansion

ATMI is expanding its GaAs epiwafer capacity with the addition of a new 50,000 sq.ft. facility in Phoenix, Arizona. The company says this is currently being outfitted to accommodate 11 Aixtron MOVPE production reactors, with space planned for a further 8 reactors.

"We believe that the analog GaAs market will grow at rates well exceeding general semiconductor industry growth rates," said Phil Yin, president of ATMI Services. "One of the key drivers for this growth is the telecommunications industry including mobile handsets and other complementary wireless devices. These devices will require GaAs-based epitaxial products for HBT applications."

Etching and Processing

TRW Orders Temescal Evaporation Systems

TRW has ordered several of Temescal's new electron beam evaporation systems for its new high-volume InP production line, the world's first. "These load-locked evaporators incorporate all of Temescal's latest technology improvements for e-beam lift-off metallization and wafer handling," said Gregg Wallace, Temescal's business manager. The FCE-2700A evaporation systems being installed at TRW are capable of processing 4-inch InP wafers and contain patented wafer clips designed specifically for delicate or thin substrates.

"We are equipping our InP production line with the most advanced semiconductor processing equipment, and Temescal's FCE-2700A evaporation system gives us the latest technology," said Dwight Streit, TRW's VP of Advanced Semiconductors. "We expect to be producing volume quantities of InP chips beginning in the second half of 2001."

Mattson Acquires Part of Steag

Mattson Technology, a leading supplier of processing equipment for the silicon industry, is to acquire the semiconductor equipment division of Steag Electronic Systems AG. Steag, based in Germany, is the leading supplier of rapid thermal processing (RTP) equipment in the GaAs industry. The deal, which is due to be completed in November, will make Mattson (Fremont, CA), which supplies equipment for photoresist strip/etch, chemical vapor deposition, silicon epitaxy and RTP, a top 15 supplier in the silicon industry.

Send Us Your News!

Our magazine and web site are the ideal places to tell the rest of the industry about your company or research group.

We cover all aspects of the compound semiconductor industry, and are interested in your news about the following:

- Contracts and orders
- Technical breakthroughs
- New products
- Research results

In addition, we are available to discuss ideas for longer feature articles or company profiles, and we welcome suggestions for suitable subjects.

For further details or to submit information, please contact the

Editor

Tim Whitaker

[tim.whitaker@compsem.com]

New Taiwanese Fab Buys Tegal Etchers

Tegal has received an order for series 6500 etch and 900 plasma etch systems from Compound Semiconductor Manufacturing Co. (CSMC), a new Taiwanese foundry company that provides GaAs HBT PA foundry services [see page 19]. Scheduled for installation in January 2001 at CSMC's Hsinchu-based facility, the tools will be used to process GaAs and InP devices used in the wireless telecommunications market.

KDF Sells First 4-Target Batch Sputtering System

KDF (Rockleigh, NJ.) has sold the first of its new 4-target batch sputtering systems to a leading European telecommunications company. The 954NT is PVD batch sputtering system for both front and backside deposition of GaAs and other compound semiconductors.

Metrology Tool Orders for n&k Technology

A company based in San Jose, CA, n&k Technology, has received orders in excess of \$2.4 million for its high throughput metrology tool. The orders were placed by three undisclosed customer primarily for use in the manufacture of GaAs ICs. n&k's family of analyzers employ a fast, non-destructive, patented spectrophotometric method of determining material properties and are ideally suited for integration into the manufacturing environment.

New Products

ASML (Veldhoven, The Netherlands) has introduced the PAS 5500/150, a new i-line lithography system optimized for high-volume 0.35 μ m line resolution production. The new stepper has a throughput of more than 110 wafers per hour for 150 mm wafers—10% higher than its predecessor—and will begin shipping during the first quarter of 2001. "We expect this product to be very popular with customers who are transitioning to sub-0.5- μ m manufacturing, and for those interested in adding additional i-line capacity at 0.35 μ m," said ASML's Eduard Hoeberichts.

L-Tech Corporation (Mountain View, CA) has introduced a new substrate drying system that removes the hazards associated with residual isopropyl alcohol (IPA) vapor, which is typically condensed on the substrate to displace moisture. The new AVID IPA system uses ultrasonic frequencies to atomize the IPA directly above the water surface into micro-sized droplets. The substrate subsequently dries by differential surface tension, avoiding the

need for IPA heaters and vapor safety equipment. The system can dry GaAs wafers up to 150 mm in size.

Rohm and Haas Introduces New Cylinder for Solid Sources

Rohm and Haas has introduced the Uni-Flo™ cylinder for solid MOVPE sources, which provides extremely stable vapor concentration with a standard deviation of ± 0.001 . The cylinder is a suitable packaging technology for trimethylindium, bis-(cyclopentadienyl) magnesium, and carbon tetrabromide. The new design does not have the dip-tube used in conventional bubblers, and provides complete saturation over a wide range of temperature, pressure and carrier gas flows.

In other news, Rohm and Haas has opened a warehouse in Hsin-Chu, Taiwan, and will install capabilities for analytical and film growth verification by the end of 2000. The company has appointed Harris Liao, formerly with Epistar, to the position of Technical Sales Manager for its Metalorganics business in Greater China and Korea.

Isonics and Epichem Develop Isotopically Pure Gallium

Isonics Corporation (Golden, CO) and Epichem, Inc. (Allentown, PA) have entered into a Joint Development Program to commercialize isotopically pure gallium compounds for the semiconductor and optoelectronic industries.

"This jointly funded, two year program will demonstrate cost effective isotope separation techniques for gallium compounds and determine the benefits of higher thermal conductivity on GaAs, GaN, and GaP based devices such as semiconductor lasers, LEDs, and high frequency ICs," says Stephen Burden, Isonics' VP for Semiconductor Materials. "We believe that improved thermal conductivity provided by isotopically pure

gallium can be a cost effective way to increase the performance and reliability of these devices."

Packaging

StratEdge (San Diego, CA), a manufacturer of ceramic packages and stripline filters, has acquired **Package Technologies Inc.** (PTI) of Taunton, MA. PTI designs and manufactures hermetic glass-to-metal seal, flat pack, plastic equivalent packages and metal packages for telecommunication applications. The acquisition expands the company's range of post-fired ceramic packages used in communications applications up to 50 GHz. In addition, PTI's facility doubles StratEdge's existing clean room space to 30,000 sq.ft. StratEdge uses a post-fired, hardened ceramic to avoid the inherent instability associated with co-fired ceramic packaging, which it says has had limited success at millimeter-wave frequencies above 20 GHz.

Palomar Technologies (Vista, CA) has introduced a microelectronic packaging tool kit aimed at microelectronics engineers wanting to design and package devices operating at high frequencies. Palomar supplies process and equipment solutions for automated assembly of optical, RF and microelectronic packages, including eutectic solder or epoxy, precision ball and wedge bonding processes, and dispensers, placement stations, ovens, cleaners and wire bonding products. The new Telecom Tool Kit assists with high frequency package design by reducing the IC/package size, increasing the power driven through the circuit, and reducing insertion and return losses.

Brush Wellman's Powder Metal Group (Tucson, AZ) has been awarded a U.S. patent for functionally graded material (FGM) flanges used in microelectronic and optoelectronic packaging. These Cu-W metal matrix composite flanges are used as heat sink mounts or sub-mounts for laser diodes, sensors and detectors, and in microelectronics power packages used in cellular base stations. Brush Wellman says its new flanges feature a high effective thermal conductivity of 320 W/m.K.

Manufacturer
of Molybdenum
Components for MBE.

Specialized Cleaning
& Degassing available



...
RABOUTET S.A.

250, av. Louis-Armand - Z.I. des Grands-Prés
B.P. 31 - F 74301 CLUSES Cedex - FRANCE
Tel. : 33 (0)4 50 98 15 18 - Fax 33 (0)4 50 98 92 57
e-mail : info@raboutet.fr - http://www.raboutet.fr

Representative office in : BOSTON
Component Sources Int'l, Inc.
Steve DOODY - Tel. (508) 485 - 5999
e-mail : steved@compsources.com

Reading this ad only takes 3 minutes. But it will save you weeks of downtime.

When it comes down to it, what do you really want from high volume epitaxy equipment? You want to get the largest number of shippable wafers at the lowest possible cost.

At VG Semicon we know that better than anyone. Our V100 system is the industry standard for HBT and PHEMT technology. So when it comes to finding ways to improve yield, nobody does it better than us. That's why you'll find our V150 system full of features that ensure you more throughput, higher yield and at the same time save you money.

HERE ARE THE FACTS

Our V100 is the most successful MBE product in the history of MBE technology. It enabled a generation of PHEMT and HBT based devices, which have found wide use in a variety of wireless products.

When it came to developing the next standard in production MBE equipment the industry looked to us and we had a choice: simply scale up the V100 or evolve the technology to provide significant enhancements to benefit our customers. We chose the latter.

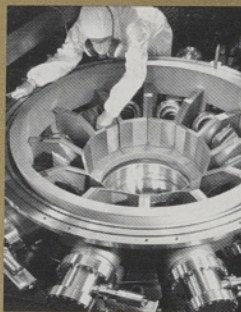
The V150 was developed by the same team of engineers who designed the V100 so we had a good starting point. Our aim was to increase throughput by scaling the system geometry, reduce downtime by increasing reliability, decrease turn round time and increase productivity by making the process more stable. So what does this mean in technological terms?

RAPID INSTALLATION

The V100 already has a reputation of being the fastest production MBE system to install. With this in mind, we designed the V150 so it can be up and running in less than a third of the time needed for competitive systems. Part of this is due to the highly efficient bake system used by all VG Semicon products. The V150 has a bakeout enclosure that surrounds the whole system so it can be quickly and efficiently baked at 200°C with no cold spots. Our competitors cannot fully bake their systems. They use a makeshift collection of inefficient flexible bakeout covers, tapes and foil coverings. Since any bake is only as good as the coldest part of the system, you'll probably be amazed to hear that parts of their systems are never heated. It's no wonder they take three times longer to bake than the V150.

RAPID TURN ROUND

MBE system turn round involves venting the system, cleaning the deposition chamber, reloading source material, pumping down and baking. With a reliable system it doesn't have to be done too often, but minimizing the time taken is still vital for improving system throughput. VG Semicon's unique and exclusive chamber seal technology means the V150 is the first production MBE system ever that allows easy removal of the entire source



assembly. This gives you unprecedented access to the entire source area and growth chamber walls, for faster source replenishment and easy clean up.

Our competitors, on the other hand, rely on individual source replenishment and awkward chamber clean up through small ports. With reloading and cleaning done in a fraction of the usual time, the V150 source flange is simply re-attached and the chamber pumped down - no time-consuming and complicated bolt sequence to worry about. Combine this with the V150's rapid bake and its no wonder the V150 can be turned around in 30% of the time it takes our competition. In a high volume application this can increase overall productivity by more than 10%!

HIGH STABILITY

Open conical sources of Ga and In suffer from variation in flux over time. Simply stated, the flux drops because of material depletion as the source is used. For standard MBE processing this predictable behavior necessitates routine recalibration to ensure constant growth rates. VG Semicon's ThermoCell™ range was designed to dramatically reduce the requirements for calibration. In fact our Ga ThermoCell™ is ten times more stable than our competitors' conical cell design and it virtually eliminates shutter-related flux transients.

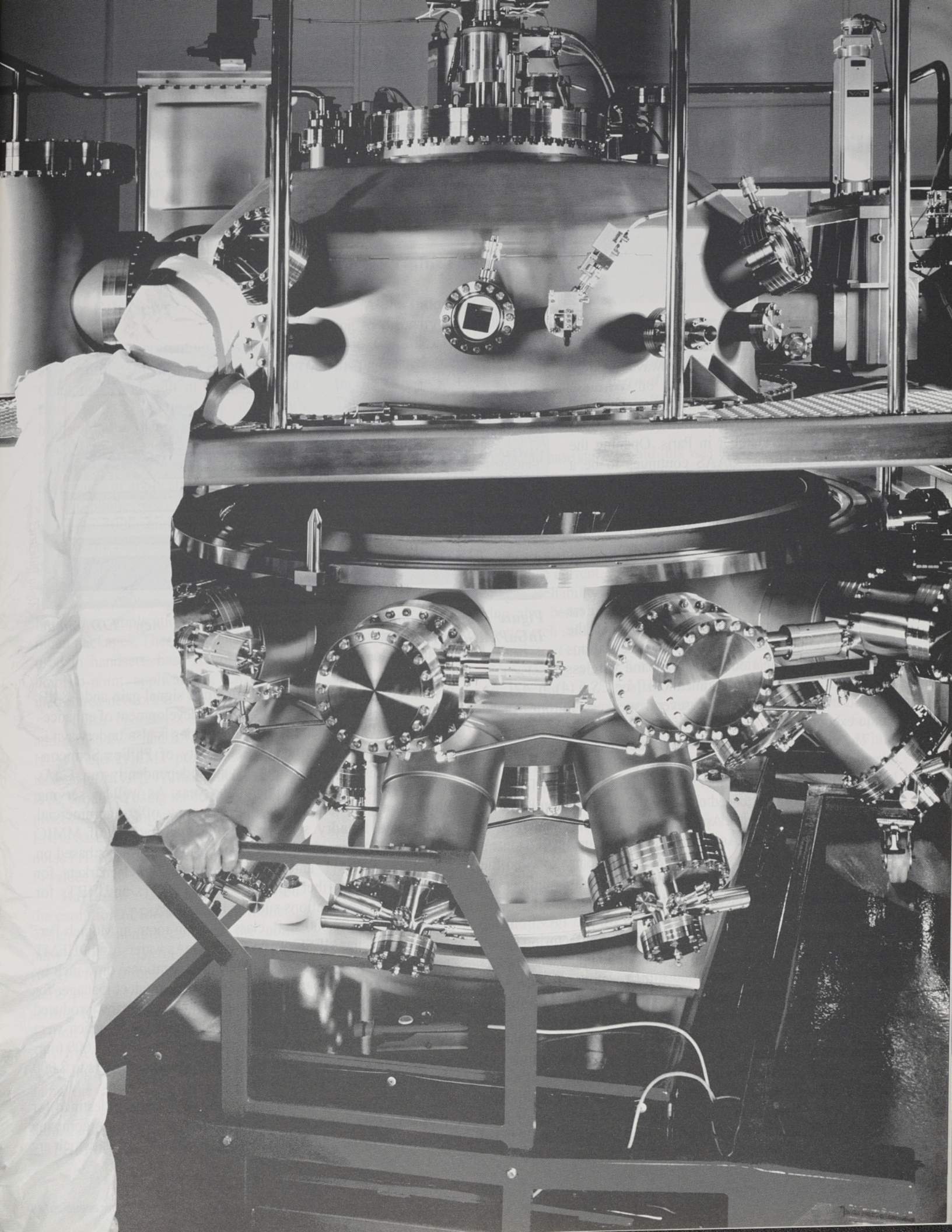
The V150 is designed to be more reliable, more stable and more productive than any other system on the market. It's no wonder we're market leaders. We're making the engineering choices to ensure that you're ahead of the game.

TALK TO VG SEMICON THE MBE COMPANY

UK	(44) 1342 325011
USA	(1) 800 888 7007
	(1) 978 922 1865
Japan	(81) 3 3639 9652
France	(33) 1 6092 3610
Korea	(82) 2 548 2983
Taiwan	(88) 63 535 9771
Benelux	(31) 184 490909

 **VG Semicon**
The MBE Company

VG SEMICON IS A THERMO ELECTRON COMPANY.



European Microwave Week

PARIS, FRANCE
October 2–6, 2000

RICHARD DIXON

This year's European Microwave Week incorporating the European Microwave Conference, European Conference on Wireless Technology and Gallium Arsenide and Other Semiconductors Application Symposium (GAAS 2000) took place in early October in Paris. Opening the technical presentations, GAAS continues to be a popular event for the gallium arsenide community, with attendance up to 414 from 380 last year. Some of the week's highlights are presented below.

Developments at Europe's Fabs

Worldwide, many GaAs device manufacturers are undertaking capacity ramp-ups to meet the demand for components for handsets, base stations and emerging applications for broadband wireless access and fiber-optic communications [see CS 6 (4), p. 42]. As outlined in the presentations of several speakers, European fabs are no exception.

The rate of progress at **Filtronics**' new 6-inch GaAs fab has been very rapid since it acquired Fujitsu's silicon DRAM plant at Newton Aycliffe in September 1999 [CS 6 (4), p. 43]. The first sample, a MMIC LNA based on a single heterojunction PHEMT structure, was produced in April this year. In his presentation on very high volume GaAs MMIC manufacturing, Filtronics' Christopher Snowdon described how the company speeded the installation process by adapting existing 6-inch Si equipment to accommodate 6-inch GaAs substrates wherever possible. Filtronics is already sampling PHEMT-based MMIC PAs from the new fab, which consists of a 100,000 sq.ft. manufacturing space. The company is capable of a throughput of 30,000 6-inch wafers per year and has plans for 50,000 6-inch wafers by 2003. Ultimately, said Snowdon, the capacity of the plant could be extended to over 150,000 six-inch wafers per year.

Filtronics intends to produce the majority of its epitaxy requirements in-house, having recently acquired two 6-inch production MBE reactors, and will outsource around 15% of its epi-wafer requirements. The company also has design and full front and back end processing facilities. The first iterations of a 1.9 GHz MMIC handset PA, which is based on a 0.5 μ m PHEMT

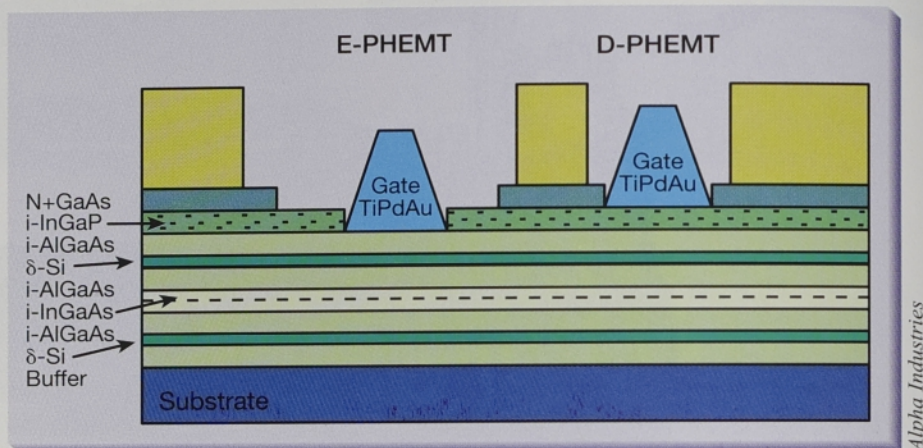


Figure 1. Schematic diagram showing Alpha's new E/D mode InGaP/AlGaAs PHEMT.

process, typically provide 25 dB of small signal gain and -8 dB of insertion loss. Snowdon says that the development of enhancement mode PHEMT and HBT technologies is also underway.

OMMIC, the former GaAs facility of Philips Semiconductors, has been operating as an independently-run GaAs foundry since the beginning of the year. As well as serving Philips on a contract basis, the company offers commercial design and foundry services for the manufacture of MMIC LNAs and PAs, in addition to 4- and 6-inch epiwafers based on MESFET, PHEMT and HBT structures. Target markets for OMMIC include fiber optic ICs and PHEMTs and HBTs for high volume applications such as handset PAs.

Infineon's 22,600 sq.ft. class 10 clean room in Munich-Perlach is producing MESFETs on 6-inch GaAs wafers, and PHEMT and HBT processes should also be fully operational on 6-inch by the middle of next year, says Markus Behet, product manager for GaAs projects and wireless products. The company produced around 80 million devices in 1999, around 50% of which were MMICs. According to Behet, last year Infineon started 1,000 four-inch wafers per week, and there are plans to increase this to 2,000 per week by the end of 2001.

A large proportion of Infineon's GaAs PAs are destined for handsets, Bluetooth and WLAN applications, and the company described its new InGaP/GaAs emitter HBT products, which are

commercially available in flip chip and thin shrink small outline (TSSOP) type packages. These devices operate from a 3.2 V supply, with an output power of 23 dBm and PAE of 50%. The unpackaged flip chip device occupies an area of just 0.56 mm², compared to 14.5 mm² for the TSSOP 10 pin variant, and is designed for leadless package production using re-flowed SnAu bumps.

Other Fab News

Speakers representing fabs from outside Europe also gave presentations. Chandra Khandavalli of **Fujitsu Quantum Devices** described the company's high volume manufacturing activities. According to Khandavalli, Fujitsu manufactures up to 4 million MMICs a month for a range of applications, including PAs for cell phones, and has a throughput of between 4000 and 8000 wafers per month. The company sells chips and also plastic and metal packaged MMICs, in addition to a new surface mount package. It also manufactures MMIC modules for high power applications using traditional metal packages. These products are being used in handsets, base stations, VSATs, point-to-point applications, LMDS and metro area networks.

Fujitsu operates a FET process, in addition to 0.25 and 0.15 μm gate length HEMT and PHEMT processes. Products include an 18 GHz PA that provides 68.5% PAE, produced using its 0.25 μm PHEMT process. The company also manufactures LNAs based on a 0.15 μm gate length low noise PHEMT (the H8 series) process with f_t values of 90 GHz and f_{max} of 200 GHz.

Raytheon's Dave Leyton discussed the evolution of Raytheon's RF products, which are manufactured at the company's 4-inch GaAs line in Andover (MA) with a throughput of 30,000 wafer starts per year. One of Raytheon's best selling RF products with more than 15 million chips sold is a Direct Broadcast Satellite (DBS) TV downconverter operating at 10–13 GHz, manufactured using the company's 0.5 μm MESFET process. Leyton says these products are soon likely to be phased out in favor of its PHEMT PAs, which are based on

0.5 μm , 0.25 μm and 0.15 μm gate length processes. PHEMTs offer higher power and lower noise performance, he said, and enhancement/depletion (E/D) mode PHEMTs were increasingly in demand for mixed-signal MMIC applications.

InGaP Gains Ground

Alpha Industries is continuing to diversify its product portfolio. Gene Tkachenko described the company's new E/D mode InGaP/AlGaAs PHEMT process. This structure replaces original AlGaAs-based PHEMT process and is designed for high power PAs used in wireless handsets and base stations, with operation voltages ranging from 2 to 7 V. The substitution of an InGaP layer leads to a number of advantages, including the higher valence band discontinuity at the InGaP/AlGaAs hetero-interface, which leads to lower leakage current and higher breakdown voltages. Reliability and ease of manufacturing also benefit: one of the reasons is the better etch selectivity of InGaP with respect to GaAs, which allows the use of a selective wet chemical etch for the recess process.

The new 0.8 μm gate length device employs an MOCVD-grown double delta-Si doped epitaxial structure with an InGaP ledge (see Figure 1). The D-mode PHEMT is a single recess device with a TiPdAu gate grown on InGaP, while the E-mode PHEMT is a double-recessed device with an InGaP ledge and TiPdAu gate grown on the AlGaAs. The changes represent only minor modifications to the conventional AlGaAs process. Operating at a voltage of 7 V, PAE results of 85% and output of 630 mW/mm for the D-mode PHEMT, and 82% PAE and 340 mW/mm for the E-mode device are the best for any competing single supply technology, said Tkachenko.

Frank Chau of **EiC** described the conversion of the company's AlGaAs emitter HBT into an InGaP emitter structure, affected easily by minor modifications to just one processing mask. Chau

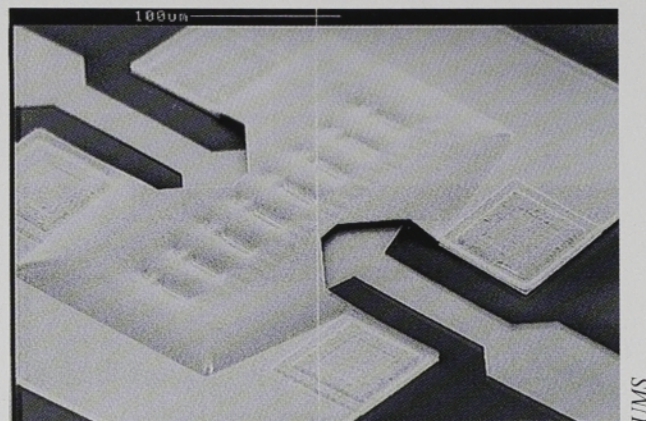
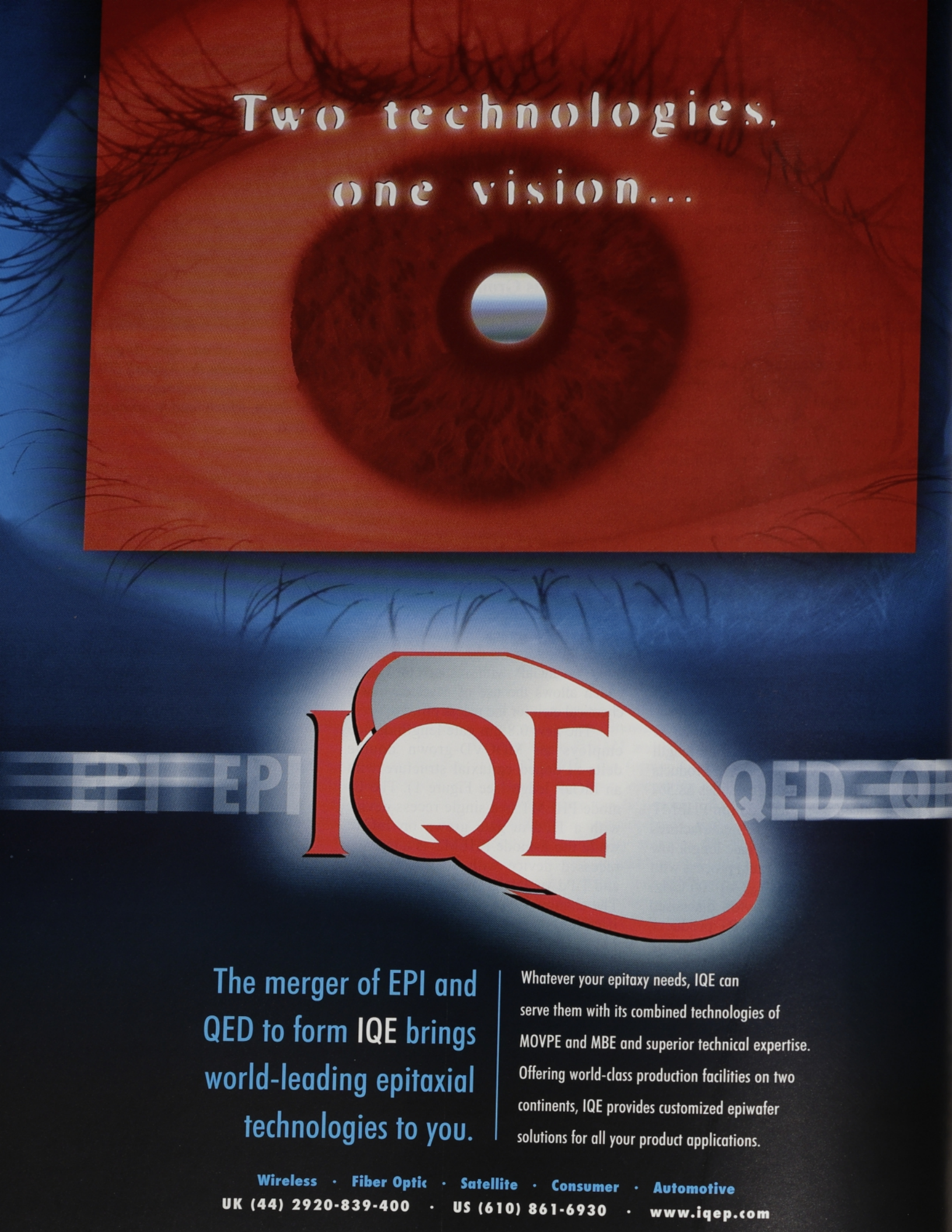


Figure 2. SEM image of an eight-finger power HBT from UMS for use in the X-band (10 GHz). The power transistors feature integrated resistors and a thermal drain, which lead to an output of 1 W and 60% PAE.

said this was important in order to maintain the transparency of the manufacturing process for its customers, which amount to around 30% of EiC's contract manufacturing services. The company maintains a 44,000 sq.ft. 4-inch GaAs facility in Fremont (CA), where it undertakes 1,000 wafer starts per week.

Using identical designs and comparing the performance of the original AlGaAs-based emitter HBT with the new InGaP structure for PA applications at 836 MHz, EiC's non-optimized InGaP HBT power amplifier exhibited 32.7 dB versus 30 dB for the AlGaAs-based HBT. Supply currents were also very similar. While overall performance gains were quite small, the AlGaAs epilayer could be replaced relatively easily without major redesigns of circuits. InGaP offered several advantages for HBTs, he said, including better reliability, as much as an order of magnitude improvement in transistor lifetime, the ability to handle higher currents and the potential for a reduction in die size. For the same epitaxy and processing cost structure, Chau believes these additional advantages make the InGaP emitter HBT process the "dominant HBT IC technology in the near future".

Anadigics was also among those introducing new HBT products. The company announced an HBT power amplifier for GSM/DCS and GPRS data-enabled handsets using its new multi-chip module (MCM) capability [see CS



Two technologies,
one vision...



The merger of EPI and
QED to form IQE brings
world-leading epitaxial
technologies to you.

Whatever your epitaxy needs, IQE can
serve them with its combined technologies of
MOVPE and MBE and superior technical expertise.
Offering world-class production facilities on two
continents, IQE provides customized epiwafer
solutions for all your product applications.

Wireless • Fiber Optic • Satellite • Consumer • Automotive
UK (44) 2920-839-400 • US (610) 861-6930 • www.iqep.com

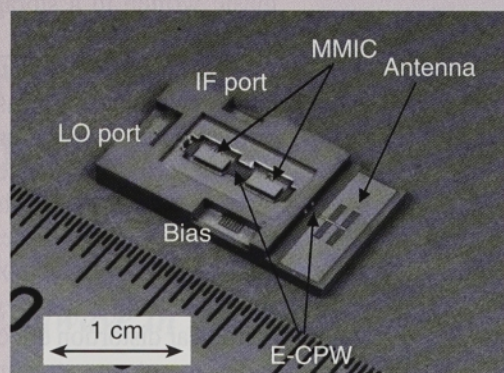


Figure 3. A 60 GHz MCM from NEC integrates MMICs, co-planar waveguides and antennas using multi-layer low-temperature co-fired ceramic (LTCC) substrate technology.

Daembkes also noted that cheaper manufacturing could be realized if the MMICs do not require further tuning after assembly into the module. This is achieved by self-biasing, and UMS has demonstrated a GaAs MMIC LNA with as many as 9 external biasing circuits and no increase in die size. Self-biasing MMICs also affect the number of interconnects required—a major source of failure. UMS has reduced the interconnections in its LNA from 7 to just 3. Another cost factor is the reduction of chip size. MMIC sizes currently are 6-7 mm², and are fast shrinking to dimensions of 3 mm² and below, largely as a result of design experience but also due to the availability of highly sophisticated simulation tools.

In future, Daembkes believes low cost surface mount packages will enable considerable price reductions for mm-wave devices, although leadless packages are not as yet commonly available as catalog products. Flip-chip mounting is another methodology with considerable potential for low cost modules, but its use in real production environments was still some way off, he said.

Keiichi Ohata from Japan's **NEC Corporation** gave an overview of mm-wave MMIC packaging technology. Highly manufacturable, cheap and compact packages are needed to enable the commercialization of mm-wave modules, for example for operation at 60 GHz in automotive radar and home network links.

In Japan, technological developments were primarily centered on highly producible flip-chip bonding for coplanar waveguide (CPW) MMICs and low cost multi-layer ceramic packages, said Ohata. Low temperature co-fired ceramic (LTCC) technologies, previously in use up to frequencies of around 30 GHz, can now be reliably implemented in packages operating up to W band (>100 GHz). In such multi-chip module packages, MMICs are flip-chip bonded into cavities formed in the multi-layer LTCC substrate, and an embedded or E-CPW with a thin dielectric film is adopted for interconnection among the



The world's leading merchant supplier of 2", 3", 4" and 6" epiwafers for optoelectronic and electronic applications.

PHEMT

LMHEMT

HBT

GaNP
AlGaAs
InP

MESFET

PIN

GaNAs
GaAs

VCSEL

Infrared
Visible

Laser

Infrared
Visible

LED

Infrared
Visible

Solar Cell

Multi-Junction

US (610) 861-6930

UK (44) 2920-839-400

www.iqep.com

6 (6), p. 35]. Operating from a 3.5 V supply, the company's chipset demonstrated 55% PAE in the GSM band and 50% in the PCS band.

United Monolithic Semiconductor (UMS) also has a new industrial InGaP/GaAs HBT MMIC process for use up to the X-band (10 GHz). Hervé Blanck described the company's HB20P process, which is based on commercially available InGaP emitter structures and which also can be used in lower frequency applications such as VCOs and PAs for mobile phones. At 10 GHz, an HBT power amplifier demonstrated 1 W of output and 60% PAE (Figure 2), the first such high power HBT device qualified at this frequency, said Blanck.

Packaging Considerations

Heinrich Daembkes, also of **UMS**, gave an interesting view of the influence of GaAs MMIC designs on the structure and cost of high frequency transceiver modules and radar systems for volume markets. In terms of the distribution of costs, the trend showed MMICs staying about the same, while both testing/tuning and assembly costs would be lower in futures modules, he said.

MMICs (Figure 3). This forms a total RF front end module exhibiting low frequency dispersion up to 100 GHz of operation.

In addition, the antenna can also be printed on the LTCC substrate such as in the case of the low cost 60 GHz transceiver module shown in Figure 3. At this frequency, the multichip module delivers 10 dB of output power, and 10 dB of conversion gain for the receive function. The transmission loss was just 0.22 dB/mm at 60 GHz. Ohata noted that the functionality of future integrated RF front ends would be advanced using electromagnetic simulation to reduce losses and new fabrication technologies, such as silicon micro-machined substrates and filters.

Ministry Posts & Telecom

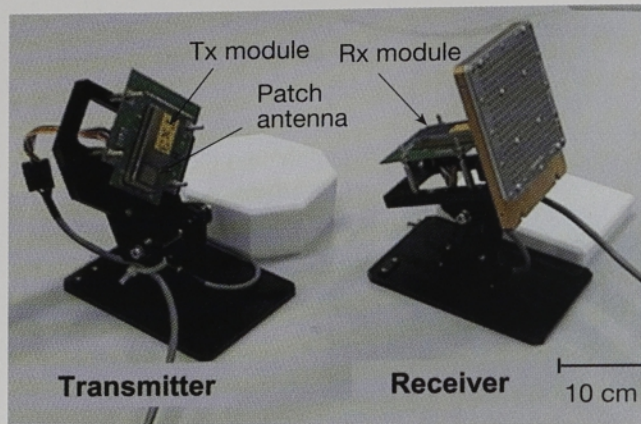


Figure 4. Prototype wall-mounted 60 GHz MMIC-based transmitter and receiver module system. The transmit module, which contains an integrated patch antenna, upconverts incoming 1.1 GHz satellite signals to 59 GHz and re-transmits them to the receiver the signal for down conversion to 1.1 GHz.

60 GHz Home Link Systems in Japan

The 60 GHz band was recently deregulated in Japan, and this frequency is now being considered for mm-wave links to connect electronic devices in the home. One of the advantages of this frequency is its wide allocated bandwidth (>5 GHz), which will allow video at high data rates. According to Kiyoshi Hamaguchi of Japan's **Ministry of Posts and Telecommunications**, around 10% of the Japanese population would be interested in buying such systems if the price was right, which might explain the large number of presentations from major Japanese corporations. Hamaguchi presented a prototype wall-mounted 60 GHz MMIC transmitter and receiver system (see Figure 4), which is designed to distribute incoming satellite signals.

Masao Nakagawa of **Keio University/Kawasaki Research Center** discussed the results of the Wireless Home Link (WHL) group, a subcommittee of the Multimedia Mobile Access Communications Promotion Committee. WHL is currently proposing a wireless version of the IEEE 1394 interconnect/protocol standard. 1394 regulates wired connections over distances of 4.5 m between portable devices using conventional copper or plastic optical fiber (POF) at data rates up to 400 Mb/s and above [see CS 6

(7), p. 71]. A combination of wireless and wired connections could be used to link future homes with CATV, terrestrial TV and broadcast satellite, internet access and digital video camera transmission, said Nakagawa, and to enable networking between PCs and printers and scanners (see Figure 5). Wired sections would employ fiber-to-the-home or LMDS to replace the telephone lines in future systems. In the envisaged network, the car also receives high bandwidth information using a 60 GHz link, such as maps and

music written to a storage device.

Technical presentations regarding the feasibility of high-volume manufacture of millimeter-wave modules were also given. Several wireless home links were demonstrated, including studies of non-linear distortion effects and new antenna structure described by authors from **Oki Electric**, in addition to a 500 Mb/s transceiver compatible with the Wireless 1394 standard from **NEC**. Yoshihisa Amano from **Sharp** noted that manufacture is consider-

ably simplified by employing an integrated MMIC up/down converter module and V-shaped connection interface for the antenna. **Fujitsu's** Yasutake Hirachi described low cost 60 GHz transmitter and receiver modules, both of which integrate antenna functions. Error free high-speed data transmission up to 100 Mbps was demonstrated for distances up to 9 m.

The 2001 European Microwave Week will be held in London from September 24th to 28th.

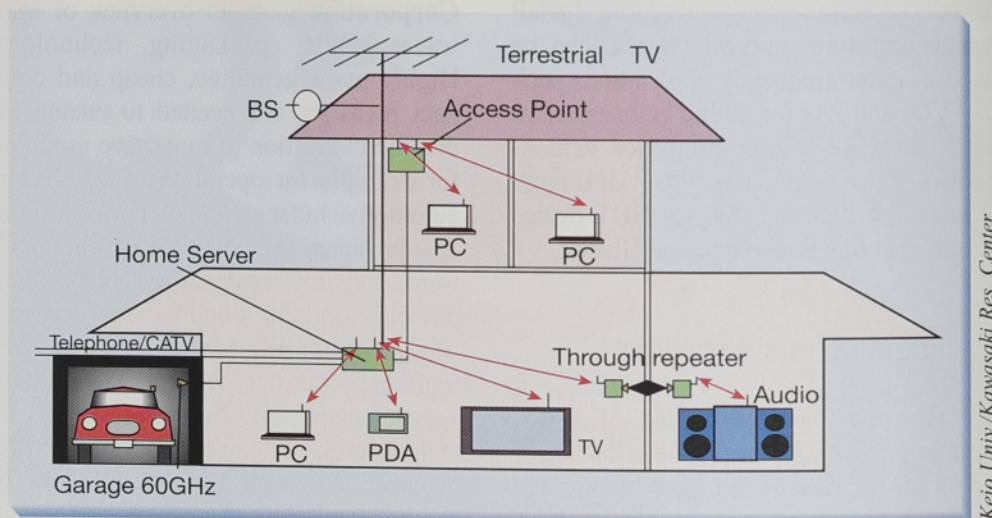


Figure 5. Devices in the home linked using a combination of wired (i.e. FTTH for telephone, CATV) and mm-wave wireless signals (shown in red). Using this system, terrestrial TV and broadcast satellite (BS) antennas, audio and TV sets, a car with a mm-wave antenna in the garage, gateway (A-D conversion/modulation), PCs and personal digital assistants (PDAs) can all be connected.

Keio Univ./Kawasaki Res. Center

Fabless GaAs Companies Feature Prominently in the Latest Rounds of Financing Activity

Multilink to join Stanford Microdevices and Endwave in the equity markets

MARIE MEYER

Fabless semiconductor companies are becoming quite common in the silicon industry, but are still somewhat of a rarity in the compound semiconductor field. But this situation is likely to change as Stanford Microdevices, Endwave Corporation and Multilink Corporation all assume higher profiles in the U.S. equity markets. Stanford Microdevices went public in May, Endwave launched its IPO on October 17, and Multilink is expected to go public later this year, market conditions permitting. All three have a product portfolio dependant upon GaAs, but none of them have a GaAs fab. In fact, for all three their success to-date has been predicated on a foundry arrangement with TRW's GaAs operation.

Stanford Microdevices, headquartered in Sunnyvale, CA, is believed to be the largest fabless vendor of RF components for communications. They offer discrete devices, ICs, and multi-component modules, which are sold through three large distributors—Richardson, Avnet, and Mini-circuits Laboratories. The latter re-labels Stanford's products with their own brand name. These three companies account for as much as 95% of Stanford's sales.

Figure 1 illustrates the company's manufacturing scheme. In addition to TRW, Stanford outsources the fabrication of its wafers to four other companies: Nortel and Global Communications Semiconductor (GCS) for InGaP HBTs, Temic Semiconductors for SiGe HBTs, and Ultra RF for LDMOS. Of the five

foundries, TRW is currently supplying the majority of Stanford Microdevices' wafers. In the last quarter, approximately 70% of total net sales were AlGaAs HBT products. The remainder were divided between InGaP HBTs (8%) and SiGe (22%); the LDMOS products are just now being introduced.

After inspection at Stanford Microdevice's main facility in Sunnyvale, the wafers are shipped to five packaging companies. The products are then returned to Sunnyvale for final testing, quality assurance, and tape and reel assembly for final shipment.

Stanford Microdevices is pursuing the wireless communications market, with emphasis on infrastructure, as opposed to

making chips for handsets like RF Micro Devices or Anadigics. Allied Business Intelligence has forecast this market to grow from \$1.6 billion per year at present to \$3.2 billion by 2003—a CAGR of 25%. [See Figure 2]. Stanford Microdevices offers, or has under development,

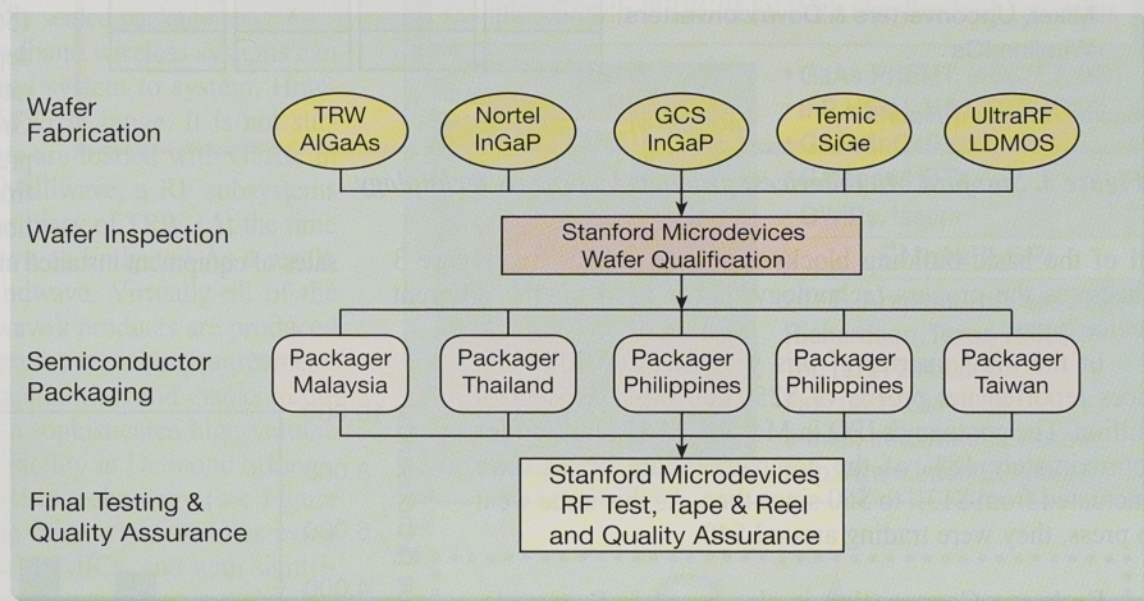


Figure 1. Manufacturing flow at Stanford Microdevices.

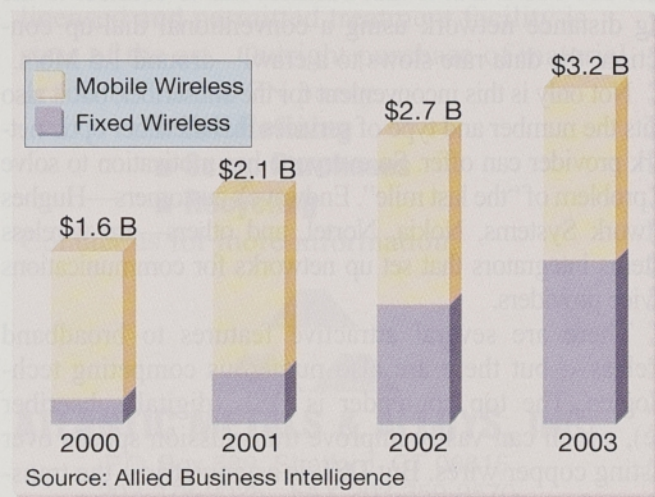


Figure 2. RF component wireless infrastructure market.

Current Products

Low-Noise Amplifiers
Pre-Drivers
Drivers
Power Amplifiers
Switches
Discrete Devices

GaAs	InGaP	SiGe	LDMOS
x		x	
x	x	x	
x	x		
			x
x			
x		x	

Products Under Development

Modulators & Demodulators
Mixer, Upconverters & Downconverters
Wireline ICs

		x	
		x	
	x		

Source: Company reports

Figure 3. Stanford Microdevices: products by process technology.

all of the basic building blocks of an RF subsystem. Figure 3 illustrates the process technology that is used for the different device types.

In the third quarter of this year Stanford Microdevices reported net profits of \$250,000 on sales of \$8.9 million. The company's IPO in May raised \$55 million for approximately 18% of the company. Share prices have fluctuated from \$13¾ to \$60 since then. As this issue went to press, they were trading around \$40.

Endwave Corporation is also based in Sunnyvale, and they are also pursuing the wireless communications market. But they are focusing on higher frequency components and RF subsystems for broadband (e.g. high data-rate) wireless systems.

Endwave is working on the problem of the "access bottleneck", which is illustrated in Figure 5. Today's long distance fiber optic networks have data transmission rates of 10,000 megabits (Mb/s) per second. Many businesses have networks on their premises that can transmit data at up to 100 Mb/s. But if that business has to connect to the long distance network using a conventional dial-up connection, the data rate slows to a crawl—around 1.5 Mb/s.

Not only is this inconvenient for the subscriber, but it also limits the number and type of services that the fiber optic network provider can offer. So everyone has motivation to solve the problem of "the last mile". Endwave's customers—Hughes Network Systems, Nokia, Nortel, and others—are wireless systems integrators that set up networks for communications service providers.

There are several attractive features to broadband wireless—but there are also numerous competing technologies. The top contender is DSL (digital subscriber line), which can vastly improve transmission speeds over existing copper wires. But DSL is asymmetric—the transfer rate from the subscriber to the network is significantly slower than when the content is moving in the other direc-

tion. Thus DSL, like CATV access, seems best suited to consumer-oriented use. Broadband wireless, on the other hand, can be fully symmetric or asymmetric, whichever the service provider chooses. And, unlike "fiber to the home" or "fiber to the desktop", broadband wireless does not require new cable installation or the acquisition of rights-of-way.

Most importantly, it is fast. Today's broadband wireless access networks can support data transmission rates of up to 155 Mb/s, although the most common deployments support data transmission rates of 15 to 50 Mb/s. The Strategis Group estimates that the customer premises equipment market will grow from \$443 million this year to \$5.4 billion in 2004. This market encompasses

sales of equipment installed at subscribers' premises to complete the

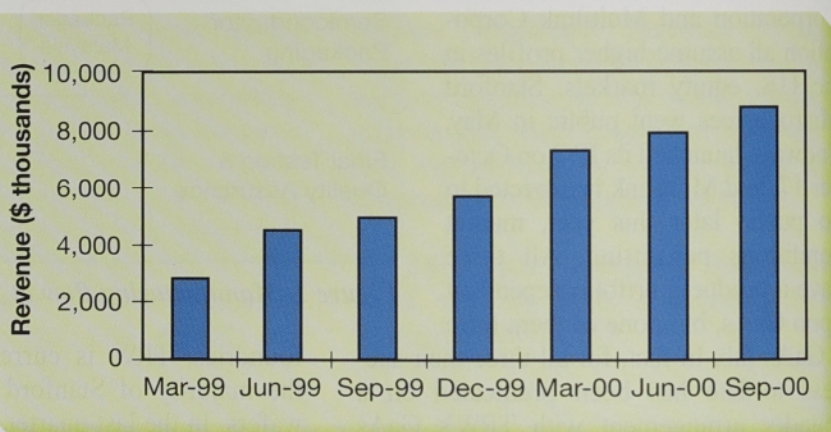


Figure 4. Stanford Microdevices revenues.

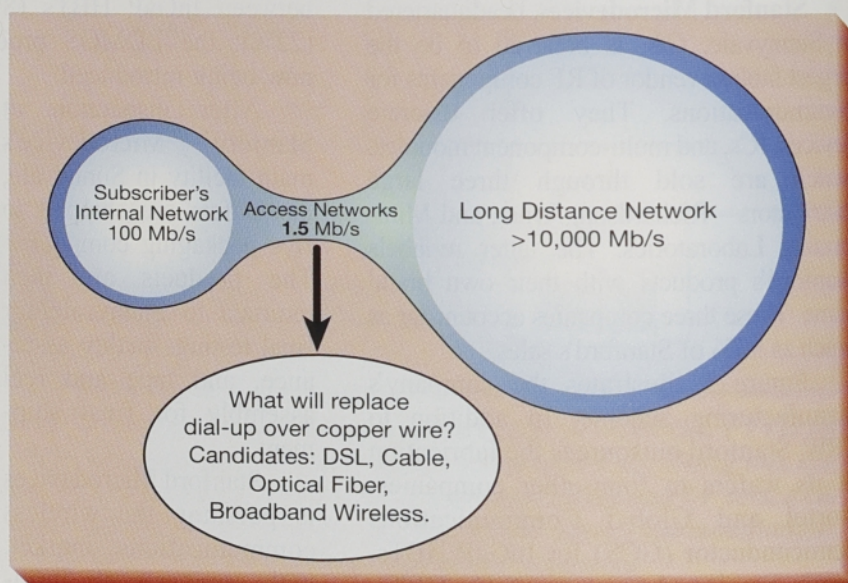


Figure 5. The access bottleneck.

link of a broadband wireless access system to the subscribers' internal networks.

Endwave offers a range of products with varying levels of integration—see Figure 6. Their most basic offerings are RF modules, consisting of LNAs, PAs, frequency converters and frequency multipliers. The modules are used to provide basic RF functions, and are often used by Endwave's customers to simplify product prototyping by avoiding the need to acquire and assemble individual devices. Endwave also offers integrated transceivers that combine transmit and receive functions into one package, as well as broadband antennas. And the company also offers highly integrated "outdoor units", which consist of a transceiver module, and electronics and control section, and an antenna. These subsystems provide complete radio functionality in a single, environmentally sealed package.

The operating frequency for broadband wireless systems can vary widely from region to region and system to system. However, almost all fall within the 18–65 GHz range. It is not surprising, then, that Endwave's products are loaded with GaAs. In March 2000 Endwave merged with Milliwave, a RF subsystems supplier that was a wholly-owned subsidiary of TRW. (At the time of the merger, the company was known as Endgate.) As a result, TRW owns 43% of the shares in Endwave. Virtually all of the GaAs devices incorporated into Endwave's products are produced by TRW, via a multi-year, but non-exclusive, supply agreement. Endwave has its own circuit design capabilities, and thanks to the Milliwave acquisition, they also have a sophisticated high-volume microwave module assembly and test facility in Diamond Springs, CA. Endwave believes that their flip-chip technology (see Figure 7) allows them to assemble multi-chip microwave modules using less GaAs real estate than conventional MMICs, and with significantly fewer wire bonds than hybrid microwave ICs (and simultaneously doing away with the need for individual tuning).

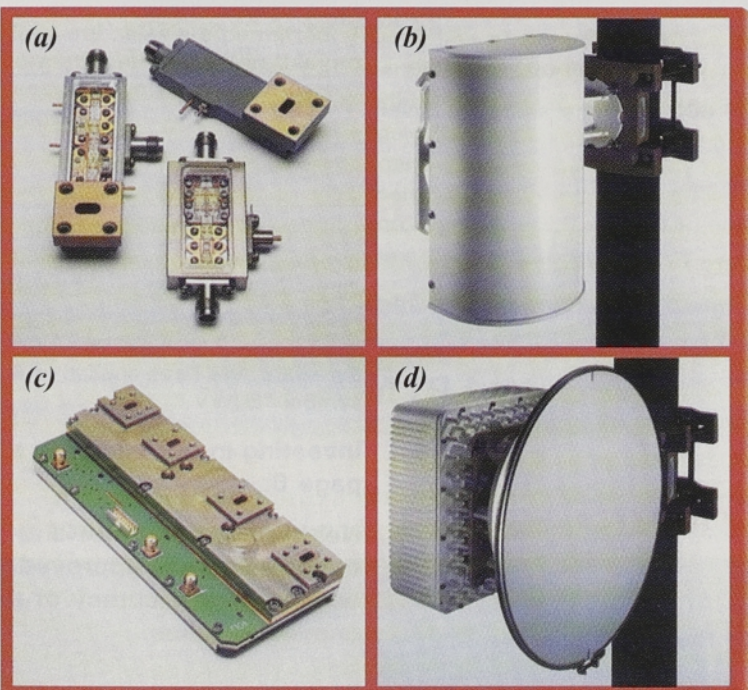


Figure 6. Endwave Products: (a) RF modules; (b) antenna unit; (c) integrated transceiver; (d) fully integrated outdoor unit.



Intelligent Epitaxy Technology, Inc.

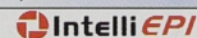
IntelliEPI provides best-valued 2" to 6" epitaxial wafers using 4x4" and 4x6" multi-wafer MBE reactors

- State-of-the-art multi-wafer MBE for high volume production runs
- Proprietary real-time sensor monitoring/control facilitates low cost epi-growth with high yield
- Value-added in-depth growth data for Fab line processing correlations (Growth Pedigree)

Complete Growth PEDIGREES With Our Breeds of Epi-wafers



- GaAs PHEMT, MESFET, HBT
- InP HEMT, HBT, RTT, RTD
- GaAs/InGaP etch-stop
- C-doped HBTs
- QWIPs, lasers



201 E. Arapaho Rd., Ste 200
Richardson, Texas 75081
Tel: (972) 234-0068
Fax: (972) 234-0069
e-mail: info@intelliEPI.com
<http://www.intelliEPI.com>

GAAS WANTED! GaSb & GaP

for recycling. **GaAs...GaSb...GaP...
Epi Scrap...Wafer Scrap.... Grinding &
Polishing Sludge.** Top prices paid. Our fully
licensed and permitted treatment facility is
state of the art. Outright purchase of material
or toll refined to 7N purity.

- Toll Refining
- Scrap Purchases
- Recycling

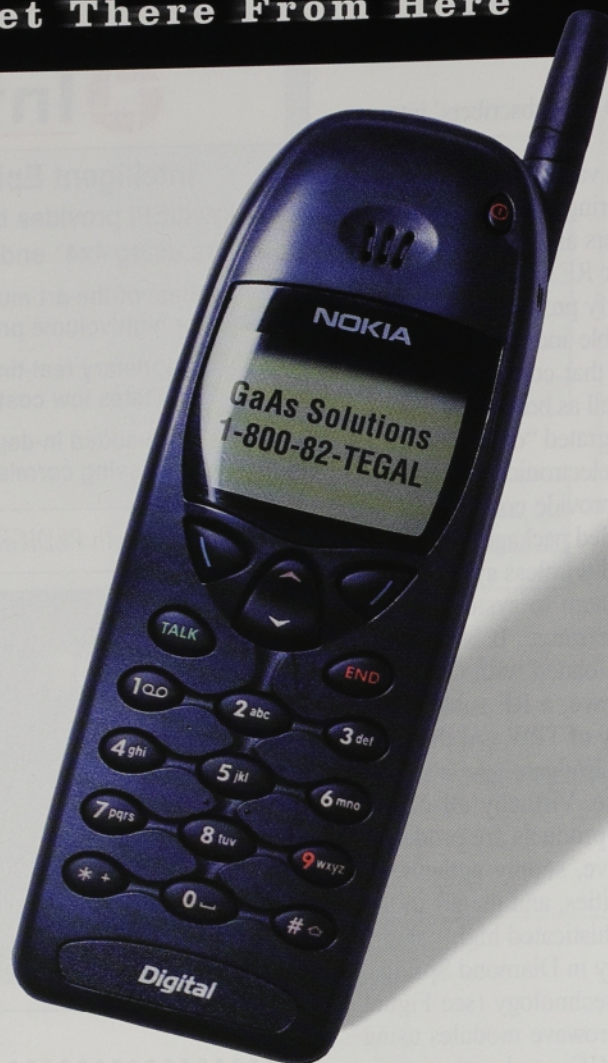
Contact us for more information:



ATLANTIC METALS & ALLOYS, INC.

P.O. Box 589, Stratford, CT 06615
203-378-9025 FAX 203-359-9570
e-mail: atlanticm@snet.net

You **Can** Get There From Here



GaAs solutions are just a phone call away.

It's a fact. Wireless and high-speed communications have replaced the PC as the technology driver for semiconductors. A result of this trend is increased challenges to plasma etch of the enabling materials used in the fabrication of these devices. At Tegal, we've drawn on over fifteen years of experience with these unique challenges to produce **two specialized solutions**. The **900G Series** has been configured with special sensors and electrode designs to address the unique demands of compound semiconductors - such as gallium arsenide (GaAs), indium phosphide (InP) and silicon germanium (SiGe) - which are commonly used in the production of telecommunications devices. Scalable

from 3- to 6-inch wafers at an affordable price, the 900G Series is the most flexible automated cassette-to-cassette transport available for III-V substrates. The **6500 Series** provides you with advanced gold interconnect etch capabilities-the new alternative to traditional lift-off techniques with better CD control for finer line pitch. The 6500 Series is great for etching active features in HBT, HEMT, MMIC devices and trench features in optoelectronics. Tegal's patented Rinse-Strip-Rinse option offers an integrated solution for resist removal and surface passivation. Both systems are production-proven with guaranteed uptime greater than 90%. So give us a call!

Call 1-800-828-3425 or visit www.tegal.com

Si₃N₄

InP

SiO₂

tegal

Polyimide

Au

GaAs

TEGAL CORPORATION

2201 S. McDowell Boulevard

Petaluma, California 94955-6020

tel 707.763.5600

fax 707.773.3015

www.tegal.com

AUSTRIA CHINA ENGLAND FRANCE GERMANY ISRAEL ITALY JAPAN KOREA NETHERLANDS SINGAPORE TAIWAN

Endwave has yet to attain profitability, although sales are growing. [See Figure 8]. In the first half of 2000, three companies—Hughes, Nokia and Nortel—represented 76% of the company's business in the first half of this year. Endwave faces competition not only from other microwave components suppliers (for example, Celeritek, Filtronic, Raytheon and Thomson-CSF) but also from vertically integrated wireless systems companies. For example, Ericsson is active in the broadband wireless systems market, but it manufactures its own RF subsystems in-house.

Real success for Endwave won't occur until a bigger market for broadband wireless opens up, allowing them to reap the benefit of economies of scale. Most of the company's shipments to date have been for site demonstrations and initial commercial

deployments. Endwave shipped its first outdoor units for a system trial in August, 1998 and received the first commercial order in December 1999.

Endwave went public on October 17, raising \$84 million for around 20% of its outstanding shares.

The third company leveraging TRW's GaAs operation is **Multilink Technology Corporation** of Somerset, NJ. Unlike the other two, Multilink is focused on digital and mixed signal semiconductors for optical networks. The company's products are designed for 10 gigabits per second (Gb/s) (OC-192) DWDM and SONET/SDH equipment. Products for 40 Gb/s (OC-768) are said to be in the early stages of development. Multilink's top three customers for the first half of 2000 were Lucent, Cisco and Alcatel.

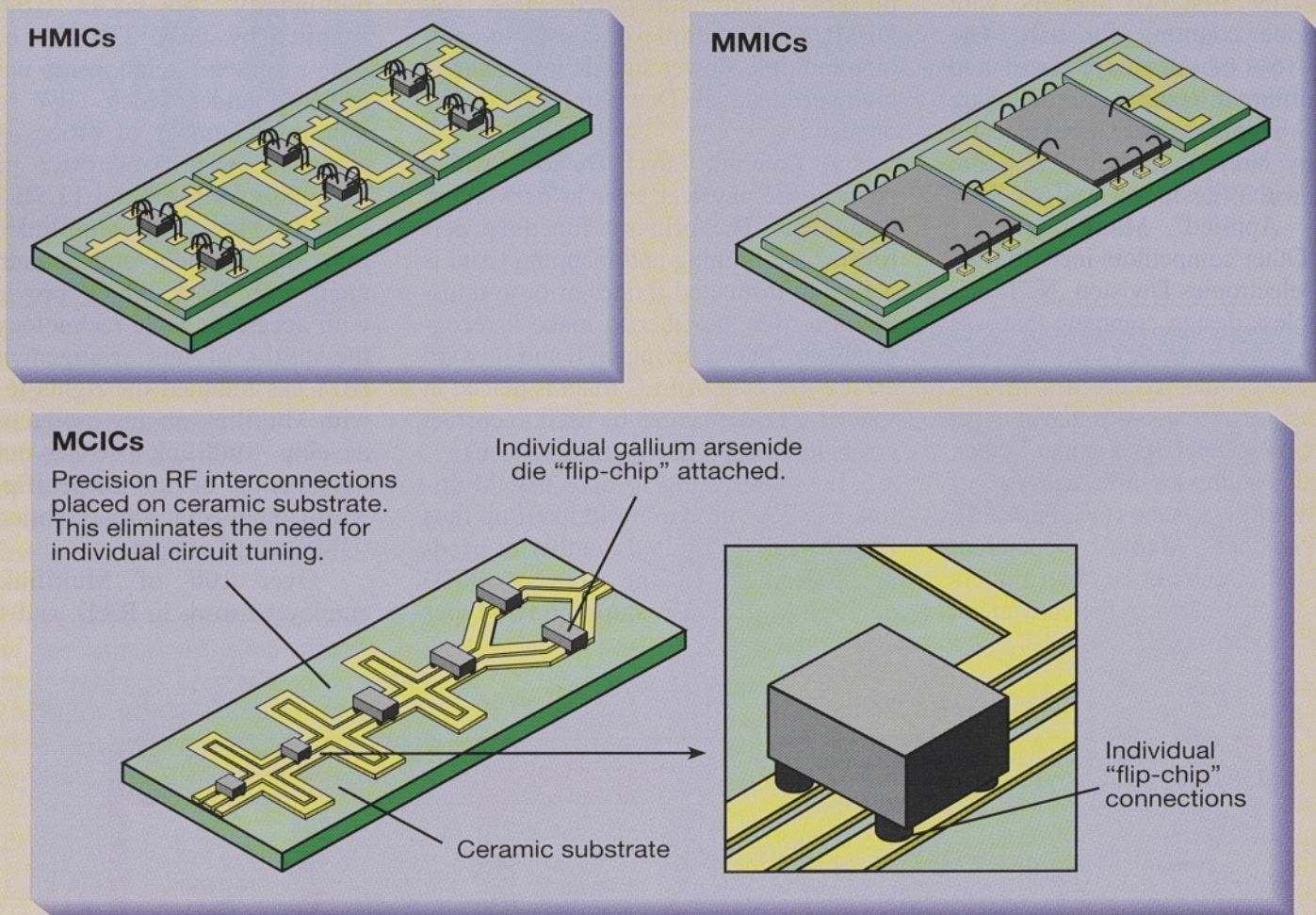


Figure 7. Hybrid Microwave ICs (HMICs) consist of multiple GaAs devices bonded to ceramic substrates and interconnected with bond wires, many of which must be individually tuned. Monolithic Microwave ICs (MMICs) are larger GaAs devices containing both active circuits and interconnects that are then bonded to ceramic substrates. They require a small fraction of the number of bond wires used in HMICs, making them suitable for automated assembly. However, they also require more GaAs "real estate" and require more design expertise. Multi-Chip ICs—based on flip-chip technology—allows the use of fewer wire bonds than HMICs and less GaAs than MMICs. According to Endwave, these MCICs "lend themselves to automated manufacturing processes which enable high product quality and reliability and lower unit cost at high volume".

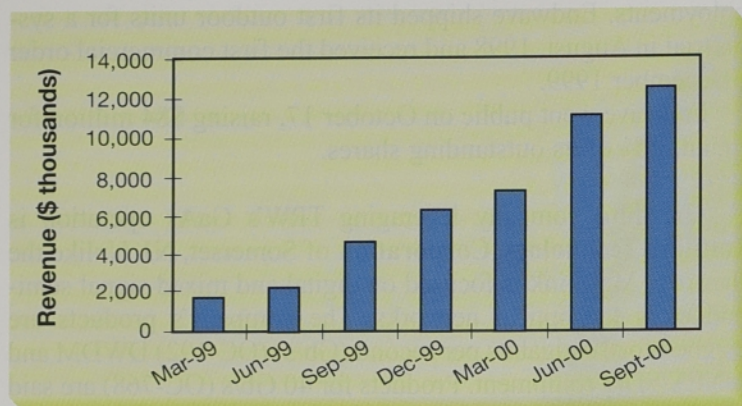


Figure 8. Endwave revenues.

Together, these three represent a whopping 84% of the company's \$28.6 million in sales in the first two quarters, with Lucent alone counting for half. The remaining 16% of sales were distributed over 20 different companies, including Ciena, JDS Uniphase, and Qtera (recently acquired by Nortel). Multilink is going toe-to-toe with Vitesse, as well as SiGe specialist Applied Micro Circuits (AMCC). Other competitors include Nortel's Microelectronics Division, NTT, and Giga, a fabless design company that was recently acquired by Intel.

Like those other companies, Multilink designs ICs and modules that connect data processing devices to optical fiber. Their strategy addresses three segments of optical networking systems (see Figure 9):

1) Physical Media Dependent (PMD) Layer Devices, i.e. transmitters and receivers that perform the conversion

between electrical and optical signals. Transmitters consist of a laser diode and an external modulator and a driver, which amplifies and conditions signals. Receivers consist of a detector and a transimpedance amplifier (TIA) which amplifies the electrical pulses.

2) Physical

Layer Devices, which are collectively known as either multiplexers or demultiplexers (often abbreviated MUX and DEMUX). A multiplexer is used to combine multiple slower signals into a single high-speed signal. Demultiplexers do the opposite.

3) Datalink Layer Devices, which connect the physical layer to networking equipment. The primary functions performed are framing and mapping (data is placed in formatted frames prior to transmission over the fiber to make it recognizable on the receiving end) and forward error correction or FEC (data is placed in special frames that can be used to correct errors that occur during transmission).

It is interesting to note that Multilink has been able to build itself up thus far with only a limited number of product offerings. In the area of PMD devices, Multilink is shipping two types

of crystal-based modulator drivers. No integrated (e.g. semiconductor) drivers are offered at this time. In the datalink area, Multilink plans to begin shipments of its first FEC devices for 10 Gb/s systems during 2001. The company says it has several datalink products in development, but none in production. But Multilink's product portfolio for physical layer devices is more fully developed. Six different products for the 10 Gbit/s market are currently shipping, and three more are in advanced development.

Clearly these mixed signal devices are what is currently driving the company. Multilink says they are based "predominantly" on GaAs HBT wafers supplied by TRW. The two companies have a strategic relationship dating back to 1997, under which TRW supplied a minimum number of processed wafers annually for a fixed price per wafer. TRW also owns around 12.5% of Multilink. In May 2000 Multilink signed a joint development and foundry agreement with IBM, which provides them with access to SiGe technology. One of the quirks of this arrangement is that IBM has retained the rights to compete with Multilink on any products they co-develop. Multilink also has outsourcing agreements of an unspecified nature with United Monolithic Semiconductors (UMS) and TriQuint.

Over 100 of Multilink's 230+ employees work in R&D, and they have

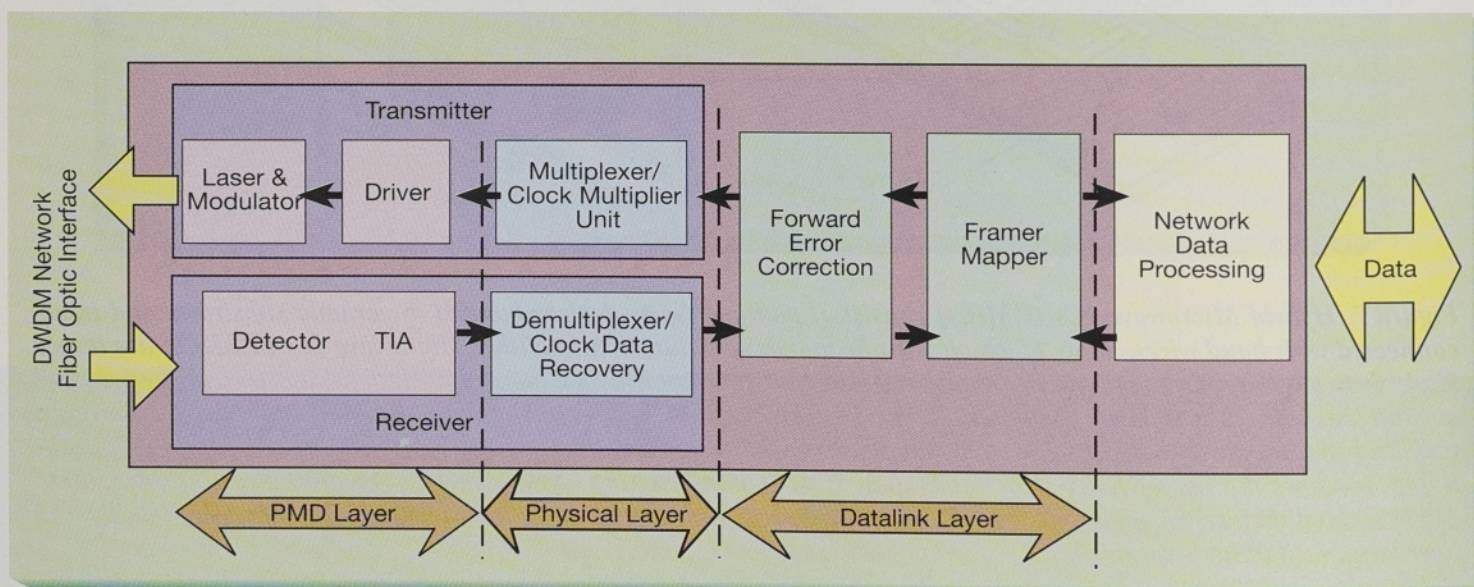
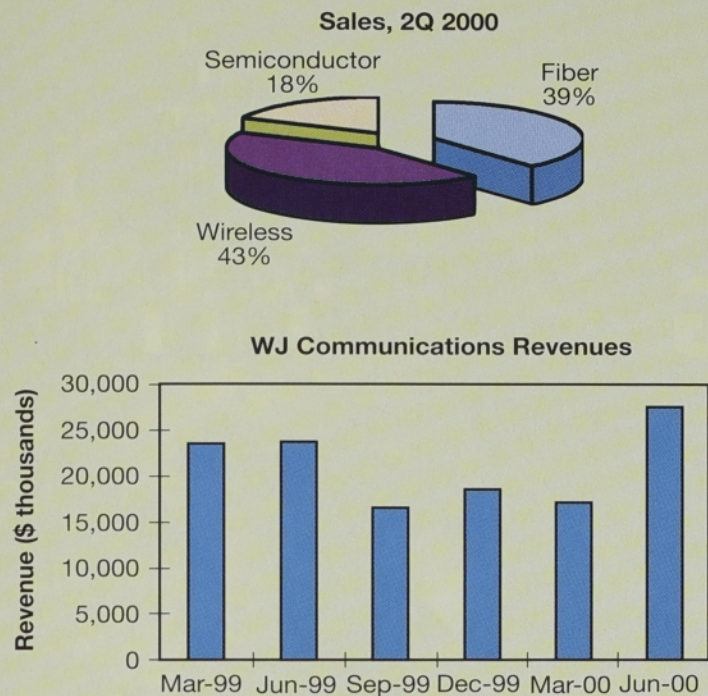


Figure 9. Functions required in fiber optic systems.

WJ Communications

One of the other "new" companies on the scene is, in fact, more than 4 decades old. WJ Communications is a direct descendant of Watkins-Johnson, divested of the former defense contracting and semiconductor equipment businesses. The new WJ sells RF components and subassemblies for use in broadband communications. It includes a smallish GaAs operation in Milpitas, CA, at a fab that was purchased from Samsung in 1998. Applications from 2–30 GHz are addressed. The company has one 3" and one 4" line, and plans to convert to all 4" in the near future. WJ sells around 90% of its output on a merchant basis to companies such as Nortel, Lucent, Ericsson and Nokia.

WJ Communications was listed on the NASDAQ on August 18, having raised \$86 million in their IPO. After opening at \$16, share prices have since varied from \$25 ½ to \$59 ½. WJ reported a net profit of \$560,000 on sales of \$27.6 million in the second quarter of this year.



40 more engineers working in marketing, business development and application engineering.

Multilink filed for an IPO on October 5. The company hopes to raise up to \$150 million, for an as-yet undetermined percentage of the company. Multilink posted a net loss of \$4.7 million for the first half of 2000 on sales of \$18.6 million.

There are those that would say that the TRW HBT process is archaic (or worse) on three counts: it uses AlGaAs, not InGaP; the p-dopant is beryllium, not carbon, and the growth is done by MBE, not MOVPE. But yet, it seems to work quite well, as first demonstrated by RF Microdevices, and now these three companies.

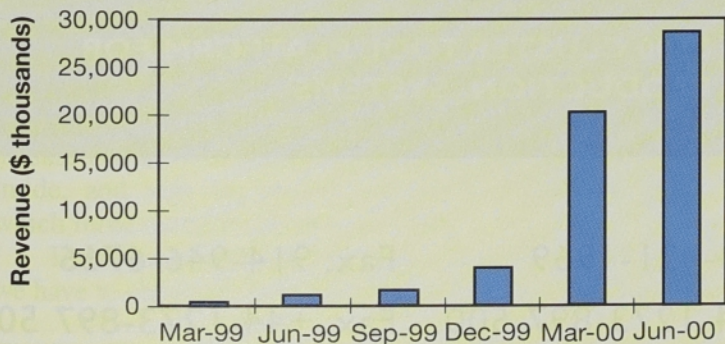
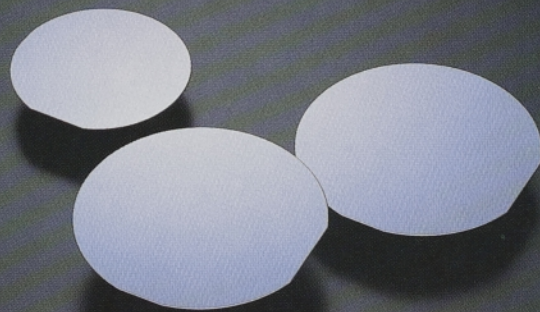


Figure 10. Multilink revenues.

High Performance Starts Here



GaAs substrates and epitaxial wafers

- Semi-insulating 2" - 6" LEC substrates
- n- and p-type 2" and 3" HGF and VGF substrates
- Epitaxial wafers (3" - 6") for FETs, HEMTs and HBTs (MOVPE process)
- AlGaAs epitaxial wafers for LDs and red LEDs

U.S.A. Hitachi Cable America Inc.

New York Office Ph: (914) 993-0991, Fax: (914) 993-0997,
E-mail: thatano@hitachi-cable.com

Los Angeles Office Ph: (310) 373-0719, Fax: (310) 375-0781,
E-mail: syoshida@hitachi-cable.com

Europe Hitachi Cable International, Ltd.

London Branch Ph: 44-171-439-7223, Fax: 44-171-494-1956
E-mail: kazuhiko_okiyama@cc.hitachi-cable.co.jp

Japan Hitachi Cable, Ltd.

Head Office Ph: 81-3-5252-3686, Fax: 81-3-3213-0402
E-mail: hitoshi_kambayashi@cc.hitachi-cable.co.jp

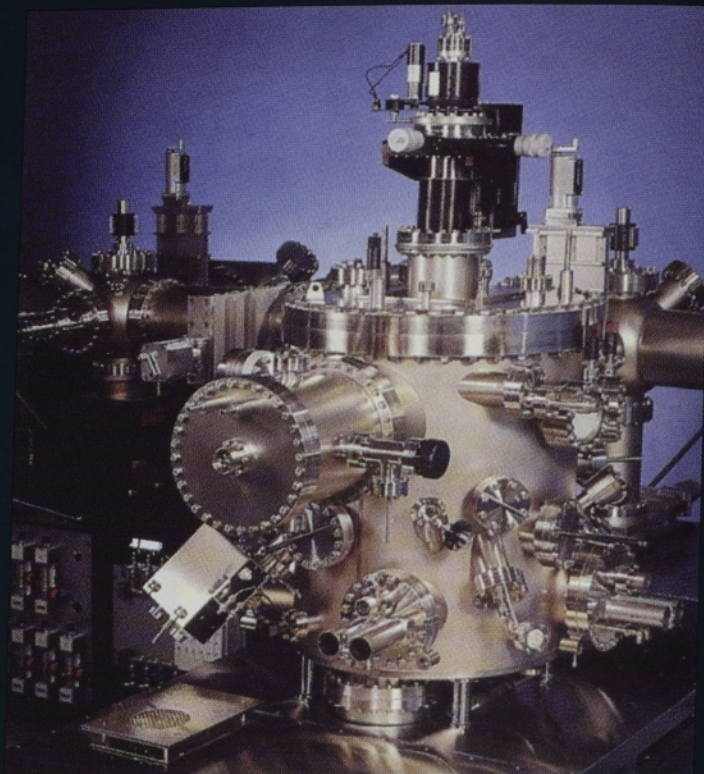


Hitachi Cable, Ltd.

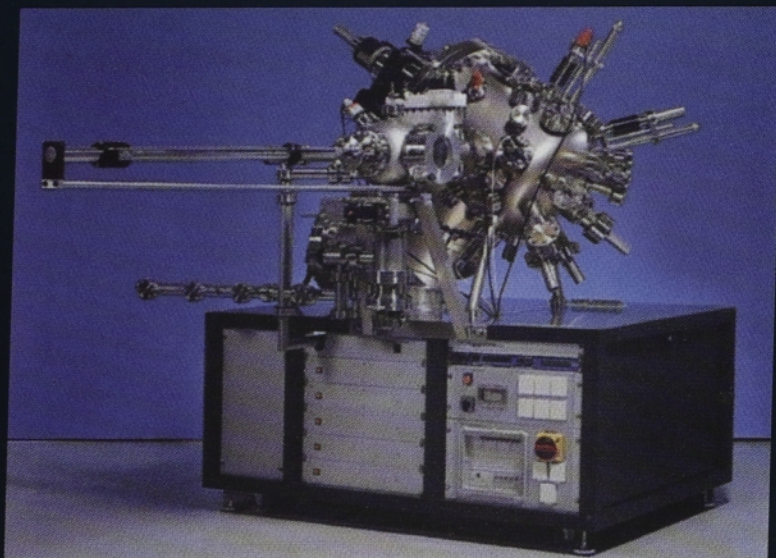
<http://www.hitachi-cable.co.jp/gaas/>

MBE TECHNOLOGY

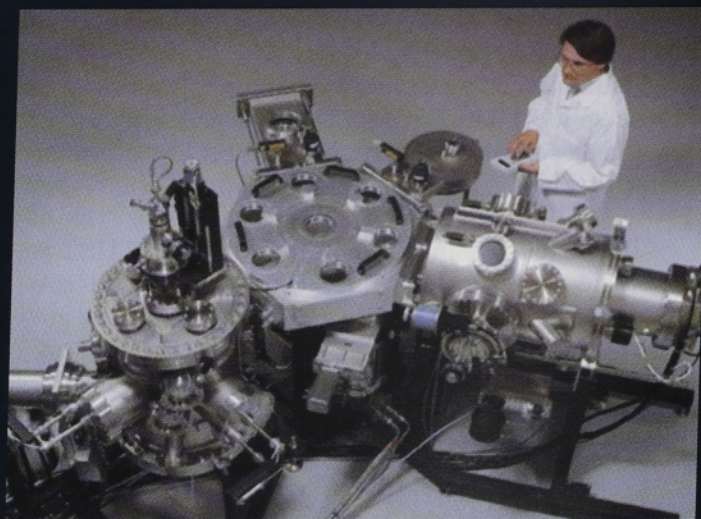
PROVEN MBE TECHNOLOGY FOR DEMANDING MATERIALS FROM R&D TO PRODUCTION



SGC-600 MBE SYSTEM FOR SiGe EPITAXY



**DCA 450 MBE SYSTEM FOR III-V, II-VI
AND III-NITRIDE EPITAXY**



**E600 CLUSTER TOOL PLATFORM FOR
PRODUCTION SYSTEMS**

DCA
INSTRUMENTS

E-mail: info@dca.fi
www.dca.co.uk

**USA
UK**

**FINLAND
GERMANY**

Tel: 914-421-1969

Tel: +44-1273-897 500

Tel: +358-2-2382 500

Tel: 49-3303 401 200

Fax: 914-946-6766

Fax: +44-1273-897 507

Fax: +358-2-2388 993

Fax: 49-3303 505 113

Improved InGaAs/InP DHBT Technology for 40 Gbit/s Optical Communication Circuits

J. GODIN*, M. RIET, S. BLAYAC, PH. BERDAGUER, J.-L. BENCHIMOL, A. KONCZYKOWSKA, A. KASBARI, PH. ANDRÉ and N. KAUFFMANN

OPTO+,
Groupement d'Intérêt Économique,
Marcoussis, France

The rapid development of the information age services calls for ever-increasing bandwidth, which will be provided by Terabit/s optical networks based on DWDM and higher bit-rates per wavelength. 40 Gbit/s ETDM transmission has been demonstrated by several research teams (e.g. [1]), and higher bit-rates with more stringent specifications are currently studied for more operational systems, for example those using forward error coding (FEC) or advanced coding (such as duo-binary schemes [2]).

InP HBT technology is a promising technology to address these needs, due to its excellent frequency characteristics and its built-in threshold voltage uniformity [3]. We present improvements and optimization of our already proven technology. Our design methodology has also been enhanced with predictive modelling and interconnection model extraction tools. Based on this new technology, improved versions of the main circuits for 40+ Gbit/s have been designed.

Improved InGaAs/InP DHBT Technology

Enhanced performance has been obtained using full self-alignment, base-collector minimization and a graded base. The HBT is based on a CBE-grown epitaxial structure [4]. This consists of a highly doped InGaAs/InP emitter contact, a low-doped InP emitter, a highly C-doped ($4 \times 10^{19}/\text{cm}^3$) and graded base ($\text{Ga}_{1-x}\text{In}_x\text{As}$ where $0.43 < x < 0.53$) and a composite InGaAs/InGaAsP/InP collector to minimize the collector current blocking effect. The structure is completed with an n+ InP layer and a highly doped InGaAs/InP subcollector. Self-alignment is obtained using emitter and base metal contacts as etch masks. The devices are then planarized and passivated by polyimide, and vias are etched for device interconnections, for which three metal levels are available.

To improve the frequency characteristics of this technology, we have to minimize both the base spreading resistance (R_B) and

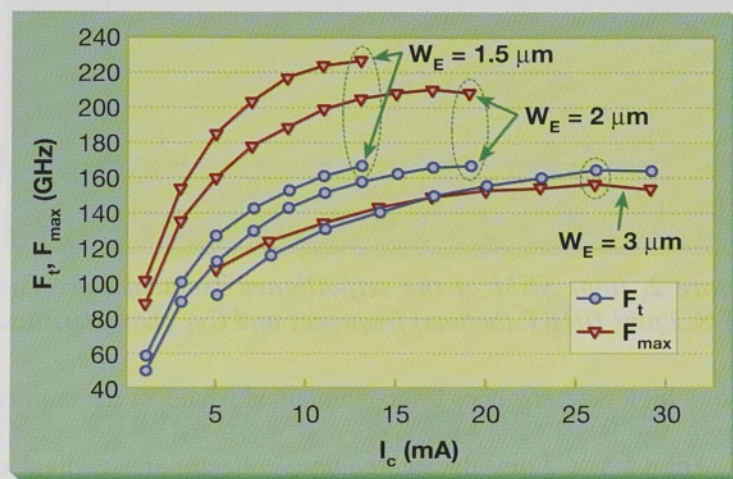


Figure 1. DHBT frequency characteristics for different values of the emitter width (W_E).

the intrinsic base-collector junction capacitance (C_{BC}). As these are both proportional to the emitter width (W_E), reducing this width results in a largely enhanced $F_{\max}$ [5]. As shown in Figure 1 [6], reducing the metal width from $3 \mu\text{m}$ to $1.5 \mu\text{m}$ is effective in increasing $F_{\max}$ from 160 GHz to 210 GHz.

Increasing the perimeter to area ratio generally results in serious current gain decrease. This effect, particularly critical for GaAs HBTs, is not observed on our devices. This important feature is explained by the association of the low InGaAs base material surface recombination velocity and of the compositionally graded-base [7] which prevents carriers from recombination at the E/B junction surface. The use of a graded base thus eases the HBT scaling and allows emitter width reduction without current-gain degradation.

As dimensions are decreased, parasitic effects tend to dominate. A degradation of F_t is observed for smaller length emitters; this can be attributed to the non-scaling extrinsic base-collector capacitance, while the other RC delays are independent of the emitter length [6].

In order to minimize this parasitic capacitance, a self-aligned base-pad isolation process has been introduced, which

* France Telecom R&D. Tel: +33 1 6963 4693; Fax: +33 1 6963 1422;
Email: jean.godin@optoplus.fr

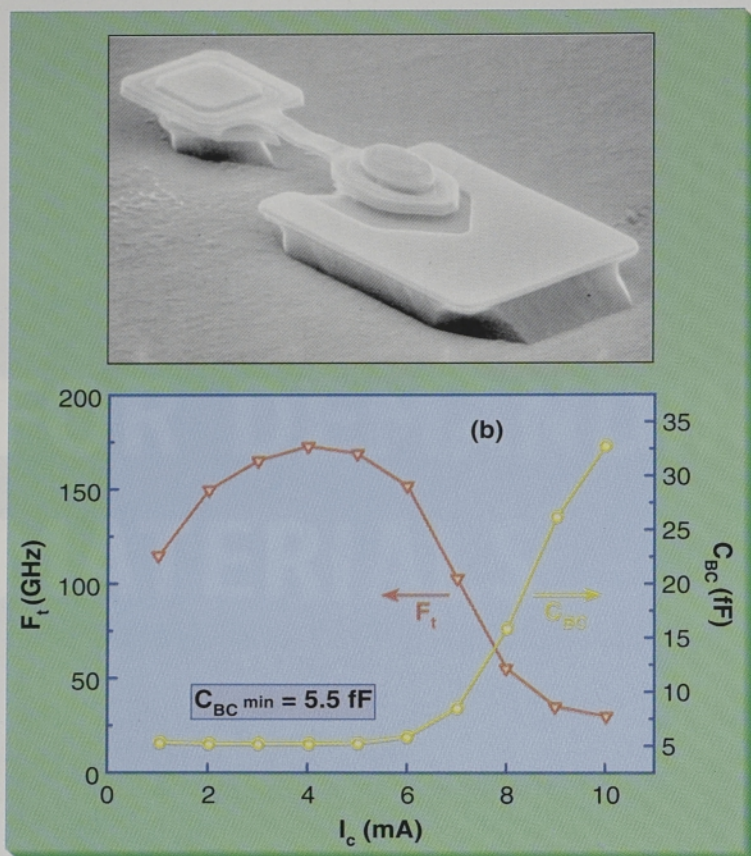


Figure 2. (top) SEM of the self-Aligned Isolated Base-Pad $1.5 \times 2 \mu\text{m}^2$ DHBT. (bottom) frequency and C_{BC} characteristics.

allows high performances to be maintained whatever the emitter length.

For a $1.5 \times 2 \mu\text{m}^2$ device, the base-collector area is divided by a factor of 2. Values of F_t exceeding 150 GHz and C_{BC} as low as 5.5 fF are achieved for currents in the 2–6 mA range (see Figure 2), which is suitable for very low power consumption circuits.

Improvements in Design Methodology

To benefit from these increased performances, the design methodology [8] was enhanced with some new features. Our predictive modelling tool takes into account all technological innovations. It computes simple but accurate CAD models using analytic formulas. It is used not only for device optimization but also for circuit optimization in the function of technological and geometrical parameters.

As the operating frequency increases, the layout parasitic effects must be taken into account to an increasing extent. The SYLAM layout tool helps to achieve symmetrical layout of complementary paths (especially with multiple symmetry axes). An automated extraction of layout parasitics has been realized [9], which allows identification of critical connections.

To improve matching of critical paths where low impedance is required (such as EF-driven lines), pseudo-microstrip lines are realized with two metallic levels. The line impedance values obtained by electromagnetic simulation show that the line

impedance can be reduced by a factor of at least 3 when a conventional microstrip line is replaced with a pseudo-microstrip line realized with two metallic layers, where the upper layer is used as ground.

Circuit Design

The technological and methodological improvements described above were demonstrated by designing two of the more demanding circuits for high bit-rate communications, the driver and the decision circuit. The architecture and layout of each circuit was critically reviewed, and special care was taken to maximize the switching speed and to minimize the time jitter.

Driver Circuit Optimization

The driver has to provide a large and clear signal to the modulator, so the important functional characteristics are the output swing and the time jitter. Optimization of circuit performances was carried out according to technological and geometrical parameters, using the predictive modeling tool mentioned above. In particular, the impact of collector thickness (W_C) was closely analyzed. W_C is an important parameter because it controls the trade-off between the base-collector capacitance (C_{BC}) and the

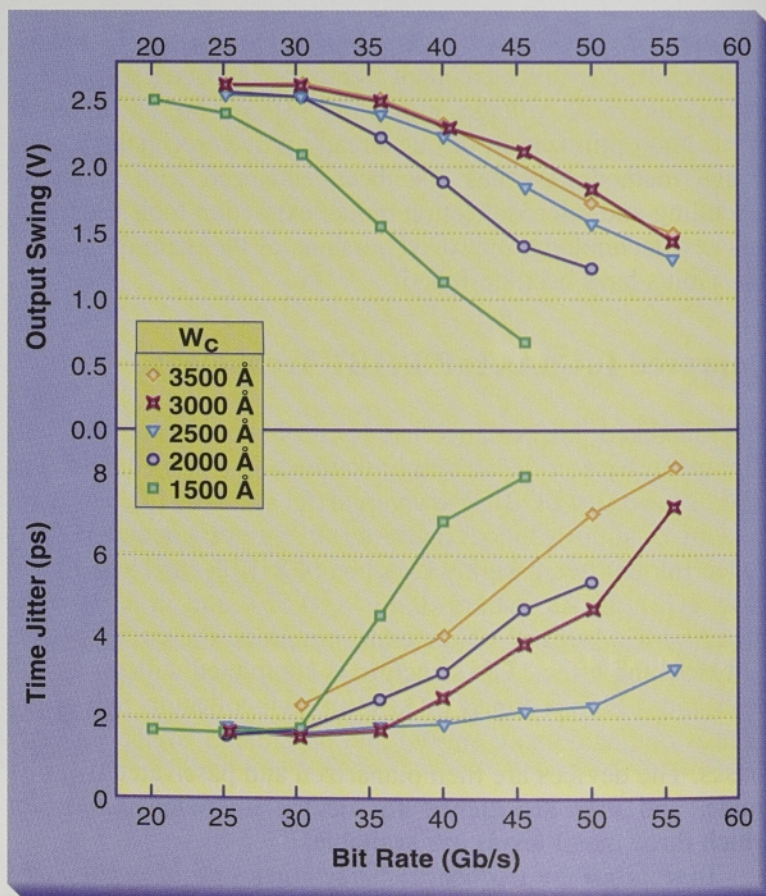
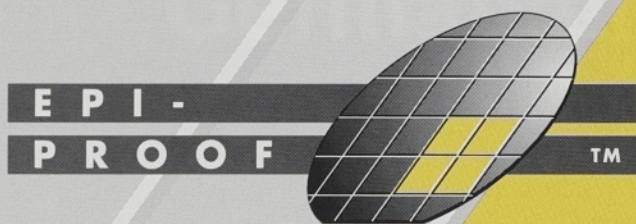


Figure 3. Functional characteristics vs. bit rate as a function of collector thickness (W_C).

COMPETENCE IN METALORGANICS

**TBA, TBP & UDMHy -
every batch is epitaxial tested**

Unique certified quality standard



EPI-PROOF™
is a registered trademark of MOCHEM GmbH

**N°1 supplier of TBA & TBP
worldwide**

A s k f o r c o m p e t e n t i n f o r m a t i o n s :

Our products are distributed worldwide by:

	telephone	e-mail
USA/Can/UK ..EMF Ltd. - Cambridge/UK.....	+44-1223-364-080....	jd@emf.co.uk
Europe.....MOCHEM GmbH - Marburg/Germany.....	+49-6421-305-250....	s&d@mochem.de
Singapore.....StandWell Electronics Pte. Ltd./Singapore.....	+65-283-6192.....	standwel@cyberway.com.de
Japan.....TOMOE SHOKAI Co. Ltd.	+81-3-3734-1124.....	uematsu@tomoeshokai.co.jp
Taiwan.....please contact MOCHEM GmbH/Germany...	+49-6421-305-250....	s&d@mochem.de

Headquarter:

MOCHEM GMBH
Hannah-Arendt-Str. 3-7

Postfach 1746 · 35007 Marburg / Germany
telephone: +49-6421-305-250 · fax: +49-6421-305-251
e-mail: info@mochem.de · www.mochem.de

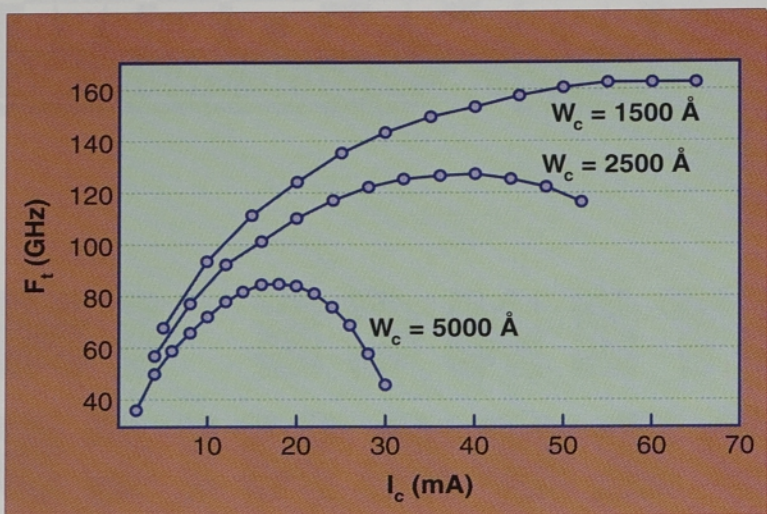


Figure 4. F_t vs. I_c for different W_c ($W_E=3\mu\text{m}$).

forward transit time (t_F). It also sets the breakdown voltage (BV_{CE}) and the range of operating current of the transistor. Figure 3 presents the output swing level and the time jitter against bit-rate, for different W_c values. This study shows that the optimal driver performance, combining both large swing ($>2\text{ V}$) and low time jitter, can be obtained for W_c between 2500 Å and 3000 Å.

However, Figure 4 shows that the transistor frequency performance as measured by F_t is optimum for $W_c=1500\text{ Å}$. This shows clearly that a quite different result is obtained depending on whether the transistor or circuit performance is optimized. We can state that F_t (and F_{max}) alone are not sufficient criteria for transistor optimization, if we take into account the specific circuit application. This confirms similar results for static divider circuits [10]. It also shows that it could be very useful to have some flexibility in the epitaxial layer definition to suit specific logic or circuit needs (for a similar approach, see [11]).

Following above simulations, MUX-driver circuits have been designed and fabricated with different collector thickness (1500 Å, 2500 Å and 3500 Å). Measurement results were in agreement with those predicted by simulation, and the best results were obtained for $W_c = 2500\text{ Å}$. In Figure 5, the measurement of the driver module (2.2 V_{pp} for 40 Gbit/s) is presented.

Decision Circuit Design

Simulation results have also been obtained for a decision circuit, a key electronic component in optical transmissions systems. Since it operates at the highest frequency for a given bit-rate, a decision circuit constitutes a meaningful benchmark to evaluate and qualify a technology for 40 Gbit/s applications. To permit comparison, a conventional emitter-coupled logic (ECL) architecture has been chosen. The designed decision circuit consists of an input buffer, a master-slave D-type flip-flop (MS-DFF) and an output buffer.

Simulation results for bit-rates of 40 and 50 Gbit/s indicate that fast rise and fall times (about 11 ps between 10 and 90%) as well as good eye opening are expected. From these simulations

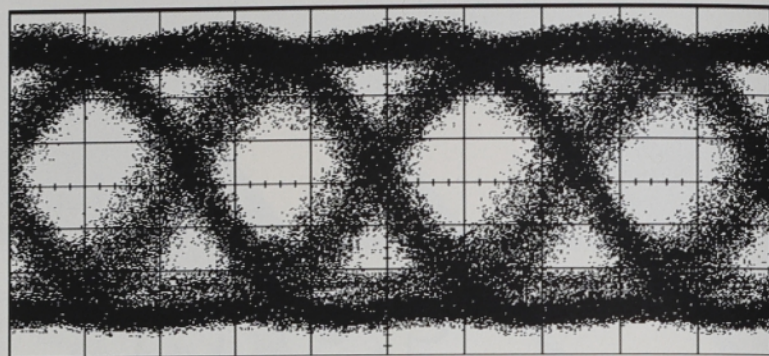


Figure 5. MUX-Driver module measurement (2.2 V_{pp} @40 Gbit/s).

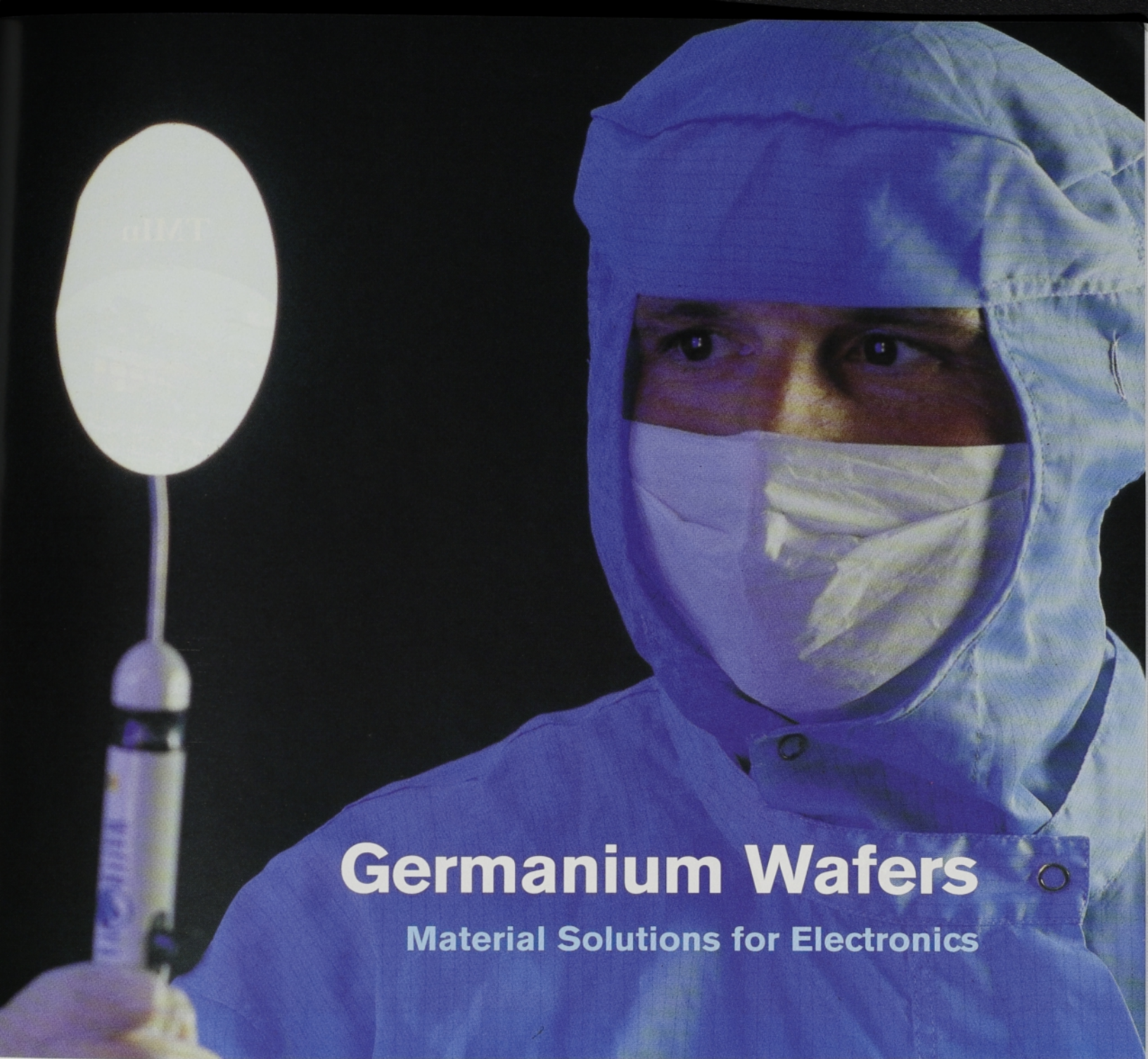
we can expect to achieve higher operating frequencies using the same technology and improved architectures (e.g. [12,13]), which will allow higher bit-rate specifications to be addressed.

Conclusion

We have described several improvements in our InP DHBT technology and in our design methodology. We have shown that by isolating the base-pad, we can avoid the degradation of frequency characteristics associated with emitter length scaling, and achieve significant frequency performances at low current. We have also demonstrated the value of having some flexibility in epitaxial layer definition in order to optimize functional characteristics. Clearly, these results demonstrate the suitability of InP DHBT technology to address the needs of very high bit-rate optical communication circuits.

References

- [1] T. Otsuji et al., *Proc. ECOC 1999*, p. 154
- [2] M. Yoneyama et al., *IEEE Trans. Microwave Theory and Techniques*, 1999, 47(12), p. 2263
- [3] M. Mokhtari et al., *IEEE J. Solid-State Circuits*, 1997, 32(9), p. 1371
- [4] J. Godin et al., *Proc. GaAs IC Symp. 1999*, p. 185
- [5] M. Rodwell et al., *Proc. IPRM 1999*, p. 169
- [6] S. Blayac et al., *Proc. IPRM 2000*, p. 481
- [7] J. Mba et al., *Proc. ESSDERC 1998*, p. 404
- [8] P. André et al., *IEEE J. Solid-State Circuits*, 1998, 33(9), p. 1328
- [9] N. Kauffmann and A. Konczykowska, *Proc. ISCAS 2000, Geneva, May 2000*
- [10] M. Sokolich et al., *Proc. IPRM 1999*, p. 195
- [11] R. Pulella et al., *Proc. IPRM 1998*, p. 68
- [12] M. Suzuki et al., *Review of the Electrical Communications Laboratories*, 1987, 35(4), p. 373
- [13] K. Ishii et al., *IEEE J. Solid-State Circuits*, 1995, 30(1), p. 19



Germanium Wafers

Material Solutions for Electronics

UM Electro - Optic Materials is a leading supplier of germanium, indium, selenium, tellurium, silicon and zinc selenide. Since the early nineties, we have been providing the telecommunications industry with polished germanium wafers for the production of gallium arsenide-on-germanium solar cells for satellites.

Large size epi-ready germanium substrates with unique crystallographic perfection are a state-of-the-art solution for epitaxial growth of III-V compounds. This opens opportunities for the most demanding applications both on and off the planet. By combining technical expertise, human commitment and partnership with our customers we

keep on exploring opportunities in electronics - now and in the future.

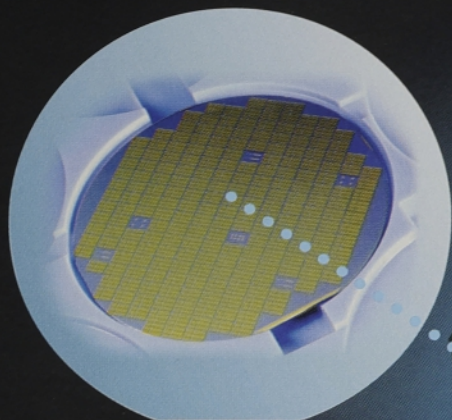


Top quality germanium wafers for electronics

UM Electro-Optic Materials, Watertorenstraat 33, B - 2250 Olen, Belgium, tel + 32 14 24 55 97, fax + 32 14 24 55 34, e-mail: eom@um.be

The Best Devices Start With The Best Sources

TMGa



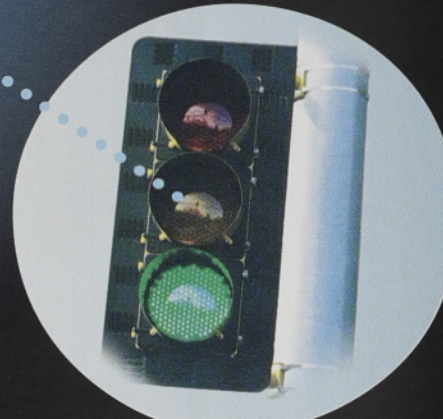
TMI_n



TMAI



CP₂Mg



Rohm and Haas is committed to helping our customers grow the finest quality epitaxial films.

- Worldclass OptoGrade™ Performance
- 30 years as a world leader (previously Morton)
- Expert technical consulting and service
- Highest purity, consistency and selection
- Stable flow TMI_n bubblers

Rohm and Haas Worldwide

USA:

North Andover, MA

978-557-1700

Fax: 978-557-1701

Asia-Pacific:

Tokyo, Japan

81-3-5488-3230

Fax: 81-3-5488-3231

Europe:

Paris, France

33-2-3861-8118

Fax: 33-2-3883-8896

* PSINet Stadium Video Display by SACO Smartvision, Inc.

* VCSEL wafer by Bandwidth Semiconductor

Website: www.metalorganics.com



OptoGrade™

Quietly Improving the Quality of Life™

3rd Quarter Earnings Round-Up

MARIE MEYER

In this issue we welcome four new companies to the Portfolio. All four were introduced elsewhere in this issue. For Alcatel Optronics see page 31, for Endwave and Stanford Microdevices see pages 49-55, and for Riber see page 37. We should note that France is home to three of the companies in the table—Alcatel Optronics, Picogiga and Riber—and has, therefore, moved past Wales (home of IQE and Trikon) as the second most well-represented country.

Massachusetts facility. “Simply put, our outlook has never been brighter,” Aldrich said.

Anadigics reported that sales were up 44% to \$51.1 million. Net income was \$7.1 million, a record for the company. The revenue increase was due to demand for cable and fiber optic communications ICs. Broadband revenues reached \$30.4 million, sales for cable products were \$23.6 million, and sales of fiber ICs were

\$6.8 million. However, wireless products revenues were \$20.7 million, a decline of 18% from the previous quarter. This was consistent with Anadigics’ earlier warning [CS 6(7), p. 86] regarding inventory corrections and component shortage issues at the company’s largest customer.

Celeritek reported record revenues of over \$23 million for the quarter, up 115% from same period the year before. Net income this quarter was \$2,620,000, com-

GaAs Companies

Alpha Industries reported record sales and profits for the quarter ended September 30. Net sales grew 75% to \$73.2 million. Income was \$10.6 million. Broadband wireless applications represented 20% of total sales in the quarter. Alpha’s products in this area include chips for cable modems and two-way digital set-top boxes. In addition Alpha has a preferred supplier relationship with Nortel for fiber-optic and next-generation wireless networking offerings. Alpha’s CEO David Aldrich said that Alpha has also diversified its customer base in the wireless handset market, having “substantially increased” production volume with Mitsubishi, Samsung and Siemens. Alpha also has PAs and switches designed into three new phones from Motorola. On the wireless infrastructure side, Aldrich reported “strong gains with Alcatel, Ericsson and Nokia, increasing our positions in 2.5 and 3G platforms”. The company also announced production volume shipments of InGaP emitter HBT power amplifiers in the quarter, and launched a plan to convert to 6-inch GaAs production at the company’s Woburn,

Company	Symbol	Closing Price Nov 3	52 Week Low - High	Market Cap*	P/E Ratio**
GaAs IC Companies					
Alpha	AHAA	40 1/8	22 3/8 - 78 1/4	1.719B	52
Anadigics	ANAD	25 1/2	15 3/4 - 112 1/8	761.6M	31
Celeritek	CLTK	39 5/8	6 1/2 - 85 1/4	463.2M	N/A
Conexant	CNXT	30 1/16	20 7/16 - 132 1/2	6.849B	N/A
Endwave	ENWV	16 7/16	13 1/2 - 20 5/8	534.9M	N/A
RF Microdevices	RFMD	24 5/16	12 1/16 - 92 1/4	3.918B	69
Stanford Microdevices	SMDI	23 5/8	13 3/4 - 60 1/4	622.5M	N/A
TriQuint	TQNT	40 1/16	18 5/8 - 67 3/4	3.130B	57
Vitesse	VTSS	75 7/16	35 5/8 - 115 11/16	13.550B	108
Opto Companies					
Agilent	A	46 13/16	38 3/16 - 162	21.207B	42
Alcatel Optronics	ALAO	65 5/8	48 9/16 - 71 3/4	1.083B	55
Coherent	COHR	43 3/8	19 7/8 - 107 3/8	1.172B	18
Cree	CREE	119 3/4	43 7/16 - 202	4.233B	103
JDS Uniphase	JDSU	81 1/4	41 5/16 - 153 3/8	77.823B	N/A
SDL	SDLI	262 1/2	56 13/16 - 460 1/2	22.718B	238
Uniroyal Tech.	UTCI	9 13/16	4 3/8 - 36 7/16	255.6M	31
Semiconductor Materials & Equipment Companies					
ATMI	ATMI	19 1/2	15 3/4 - 60 3/4	578.9M	17
Emcore	EMKR	42 15/16	6 1/16 - 86 1/2	1.454B	N/A
Kopin	KOPN	16 7/8	10 3/8 - 49 7/8	1.067B	98
Tegal	TGAL	2 15/16	2 1/16 - 13 1/2	36.7M	N/A
Trikon	TRKN	14 1/2	3 1/4 - 28 9/16	169.2M	13.5
European Shares (Currency Data in Euros)					
Aixtron	AIX	150	53 - 179	4.68B	263
Filtronic	FTC	13.72	12.4 - 39.14	1.1B	N/A
IQE	IQE	7	6.63 - 13.22	1.0B	422
Picogiga	PICO NM	32.85	7.25 - 36.50	212M	77
Riber	RIBER	25.50	9 - 38.50	493.5M	74

*Market Capitalization = # shares × current share price

** Price/Earnings Ratio = (income for last 4 quarters ÷ # shares) ÷ current share price

pared with a net loss of \$958,000 for the year-ago period. In the quarter Celeritek received its first orders for InGaP HBT-based products, specifically CDMA power amplifier modules [see page 19].

RF Micro Devices reported revenues of \$102.2 million, an increase of 48.3% over the corresponding quarter in 1999, but up just 4.1% over the previous quarter. Net income was \$17.7 million.

Commenting on the recent slowdown, David Norbury, President and CEO, stated, "Obviously, we are disappointed by order activity in the September quarter and our preliminary outlook for the December quarter. We believe, however, that this is a short-term market correction issue for the company because of the significant production programs we expect to begin ramping in the March and June quarters. Based on our analysis of industry data, we currently expect the handset market will grow between 35 and 40 percent in calendar 2001, and with proper execution our growth should exceed overall growth in the handset market."

TriQuint Semiconductor reported that revenues for the third quarter were a record \$80.6 million, a 90% increase over the \$42.5 million in the third quarter of 1999. Net income was also a record at \$21.0 million, a 191% improvement over the year ago period. Sequentially, revenues increased 14% over the June quarter.

Commenting on the results, Steven J. Sharp, TriQuint's Chairman, President, and CEO stated, "We are extremely pleased with the rapid growth in our two key markets, wireless and optical networks." He went to say, "Our bookings remain very strong, particularly for products used in optical networks applications."

Vitesse reported revenues \$138.0 million, an increase of 71% over the \$80.7 million in third quarter of 1999 and an increase of 21% over the previous quarter. Net income was \$40.3 million. Vitesse President and CEO, Lou Tomasetta, said, "I am pleased to report another exceptionally strong quarter. We saw continued strength across all areas of our communications

product lines". The company indicated that CMOS now accounts for 16% of total sales, and that shipments of Vitesse's first SiGe product have commenced. The SiGe product is a high-speed, highly integrated transceiver array.

Materials and Equipment Companies

On October 30 **Emcore** warned investors in advance of its November 15 earnings release that results for the quarter would be negatively effected by \$7 million of non-recurring R&D costs. The company said it is accelerating its investment in R&D relating to array transceivers, and plans to ship the first prototypes before the end of the year. On the basis of the current backlog and project revenue from new products, Emcore also raised its revenue estimates for 2001. For the third quarter the company said that it would announce that revenues for the quarter and twelve months ended September 30 increased approximately 135% and 79%, respectively, to approximately \$34 million and \$104 million.

Kopin reported that revenue for the third quarter increased 145% to \$23.8 million, with net income of \$4.2 million, compared to a loss of \$353,000 in the year-ago period. GaAs HBT wafers accounted for 75% of the company's sales, and revenues in this area increased 133% to \$17.9 million. Kopin's CyberDisplay product line produced revenues of \$5.3 million.

In its GaAs business, Kopin reported that it continued to see strong demand in the third quarter from Nortel Networks and other customers for epiwafers for their high-speed OC-192 SONET chipsets. "We remain bullish about the long-term outlook for both the wireless and optical markets, and are confident that we are well-positioned to capitalize on their future growth," said John Fan, Kopin's President and CEO.

Kopin recently formed an Optical Communication Products Group, which will focus on broadband telecom applications. The company also announced that Hong Choi, a well-known researcher from

MIT Lincoln Labs, would be joining the company as chief technology officer, with responsibility for expansion into optoelectronics manufacturing. Kopin's recently announced acquisition of Super Epitaxial Products [see page 39] is part of that effort.

Looking ahead, Fan predicted that sales in the GaAs area would be flat in the December quarter, adding that "industry projections and our own discussions with customers suggest that we will see growth resume again in the first quarter of 2001."

Tegal announced a return to profitability in the third quarter. Revenues increased 182% to \$13.3 million. Net income was \$162,000, compared with a net loss of \$4 million in the same period last year and a net loss of \$2.3 million in the previous quarter. The company indicated that demand from manufacturers of telecom semiconductors was the driving force behind their positive results. During the quarter Tegal received follow-on orders for multiple 900 series etch systems from three leading wireless telecommunications device manufacturers, as well as reorders for its etch systems from eight existing customers.

Trikon's revenues for the quarter were \$31.5 million, and the company reported that its backlog has increased to new record levels, with a book-to-bill ratio for the quarter of more than 1.4. Net income of \$7.1 million was up 94% compared to the year-ago period. Commenting on the results, Nigel Wheeler, President and CEO, said, "our continued strong performance is largely a result of Trikon's excellent performance across three areas. Our low-k technologies are leading edge; our products and processes for compound semiconductor manufacture are the best there are, and our customer support is second to none." Wheeler also noted that one third of Trikon's sales come from the compound semiconductor market. "We feel we have competitive strengths in this market, as we bring to it our silicon wafer experience based in high volume, high reliability equipment that can compete and win against the industry giants in all three technologies: plasma etch, CVD and PVD," he said.

Opto Companies

Alcatel Optronics reported record sales of Euro 124.9 million (~\$112 million), up 173% over Euro 45.7 million (~\$41 million) in the same period last year. Income from operations more than tripled to Euro 26.6 million, compared with Euro 7.5 million in 1999, and included R&D expenses of Euro 9.3 million, representing 7.4% of sales. "We have registered an outstanding performance," says Jean-Christophe Giroux, CEO of Alcatel Optronics. "Revenue growth has been very strong and we are seeing solid demand in all product lines, especially with our innovative subsystem solutions now representing 50% of our product mix. In addition, new orders from existing external customers during the third quarter demonstrated their growing demand for the full line of the Alcatel Optronics product family."

Coherent announced sales of \$155.0 million for the quarter, an increase of 18% compared to the same period last year. Net income for the quarter was \$43.7 million. For the fiscal year just ended, Coherent reported bookings and sales of \$640.5 million and \$568.3 million, respectively, representing a 33% and 21% increase from last year.

During the quarter, the Company received \$10.0 million of new orders for its telecom products, an increase of more than 900% over the corresponding prior year period. Sales of these products were \$5.3 million. Bernard Couillaud, Coherent's president and CEO, stated, "We recently announced the establishment of the Coherent Telecom-Actives Group as a separate operating group to better focus our efforts on the fast growing semiconductor laser-based components segment of the telecommunications market. We are also expanding our production capacity for passive and active components at our facilities in Auburn, California and Tampere, Finland in order to meet the growing demand for the DWDM market."

Cree reported record revenues for the quarter of \$37.64 million, a 13%

increase sequentially and an 80% increase over the same period last year. Product revenue grew 88% on a year-over-year basis, and 14% sequentially. Net income increased 178% to \$12.65 million compared to the same period last year. Neal Hunter, chairman and CEO, said: "We believe the introduction of our new ultra bright LEDs, with two times the brightness of our high brightness products, will provide an opportunity for additional market penetration. Additionally, we have demonstrated world records for near UV LED efficiency at Cree Lighting and continue to make considerable progress in our RF and blue laser development."

JDS Uniphase reported sales of \$786 million, up 29% over the previous quarter and up 171% over the same period last year. Net income was \$177 million, compared to \$65 million in the same period last year, an increase of 172%.

SDL announced record revenues of \$146.5 million, a 33% increase over the previous quarter and a 208% rise compared to the same period last year. A net income of \$40.4 million was also recorded. Revenue from communications products for both terrestrial and undersea fiber optic systems increased 38% over the second quarter and by 332% over the prior year quarter, and represented a record 90% of total revenue.

SDL's Chairman and CEO, Donald Scifres said, "Demand remained exceptionally strong in both terrestrial and undersea segments, both in traditional areas of SDL leadership, such as pump lasers, as well as in emerging product areas such as Raman amplification and optical transmitter and receiver modules. In order to serve this growing backlog of orders, we have started or have plans to expand all of our manufacturing facilities around the world. With the many long-term contracts and design wins accomplished this year, we are able to project that SDL will be a \$1 billion company in 2001."

SiC



High-Power Electronics

Epigress is dedicated to serving all your needs for SiC "hot-wall" CVD epitaxial equipment and SiC sublimation growth; from the VP508 single wafer CVD system to the new VP2000HW multiwafer production system as well as the SB50/100 seeded sublimation tool. In research as well as in production, Epigress will smooth your path to taking full advantage of the SiC technology for power-, high frequency- and high-temperature electronics.

For more information, visit:
www.epigress.com



EPIGRESS
A Member of the AIXTRON Group

Ideon Science & Technology Park
SE-223 70 Lund, Sweden

Reflections on a Semiconductor Crystal Surface

D.A. ALLWOOD, I.R. GRANT*, N.J. MASON, R.A. PALMER and P.J. WALKER

University of Oxford, UK

*Wafer Technology Ltd, Milton Keynes, UK

GaAs-based III-V devices rely upon a high degree of perfection in both the bulk and surface crystal quality of the GaAs substrates on which they are grown. The treatment of these substrates before growth is a matter of debate [1] and confusion within the growth community. Historically, after crystal growth, sawing, and polishing, the wafer was packaged in wax or in direct contact with plastic. The grower then needed to degrease the wafer using trichlorethylene, methanol and then isopropanol before etching away any saw—and polishing—damage using a sulphuric acid/hydrogen peroxide etch [2].

For reasons of continuity, some device manufacturers still treat their substrates in this way. Ironically, there is a good chance that with the improvements in wafer manufacturing that have occurred over the last several years, such treatment could be doing more harm than good. With increasing volumes of substrates in use in any one run, many growers have been able to use the substrates straight from the manufacturers' boxes. The first company to offer this facility was Wacker-Chemitronic GmbH, who registered the term "Epi-Ready" as a trademark [3]. Their approach was to provide a wafer with low metal contamination from the polishing and a final surface whose carbon and oxide layers were removable by in situ cleaning in an MOVPE reactor.

All current manufacturers claim that the wafer polish quality is sufficiently high to avoid the need for any wet-chemical treat-

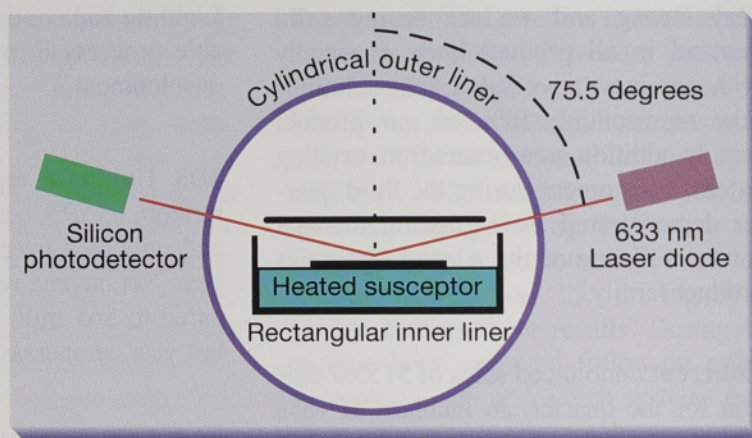


Figure 1. Schematic cross-section of crystal growth reactor showing the laser reflecting off the GaAs wafer that is heated on the susceptor.

ment (either for degreasing or damage removal). They may not use the term "Epi-Ready" but would claim their substrates are ready for growth. We will thus use the term *epiready* as a generic term meaning no further treatment necessary after purchase. It is difficult to avoid a thin layer of oxide growing on the wafer after the surface has been polished and washed, but provided this is desorbed or reduced in the reactor without damaging the surface then the substrate can be deemed to be *epiready*. We have undertaken an extensive study of the nature of an *epiready* GaAs surface with particular reference to the oxide left after manufacture.

Measurement of GaAs Oxide Thickness

We have previously used the optical set-up shown schematically in Figure 1 to measure the growth of epitaxial layers only a few atoms thick [4]. The technique uses p-polarized light from a 633 nm diode laser reflected at a high angle of incidence. This optical arrangement, close to Brewster's angle, leads to a reflectivity that is very surface sensitive. We observed that during pre-growth heating to deoxidise the surface the optical response changed in a reproducible way [5]. Figure 2 shows the optical response of the GaAs wafer during a heating and cooling cycle, under a continuous flow of tBAs (a source of both arsenic and atomic hydrogen). The reflected signal rises as the wafer is heated

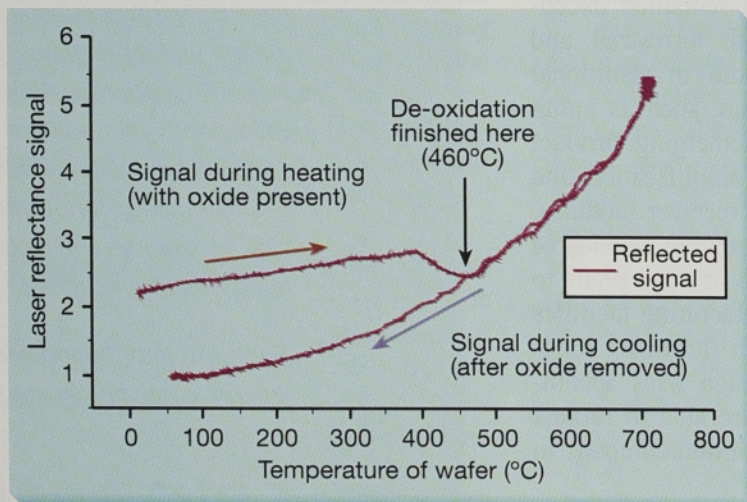


Figure 2. The intensity of the laser beam reflected off a GaAs wafer as it is heated to 700°C and then cooled.

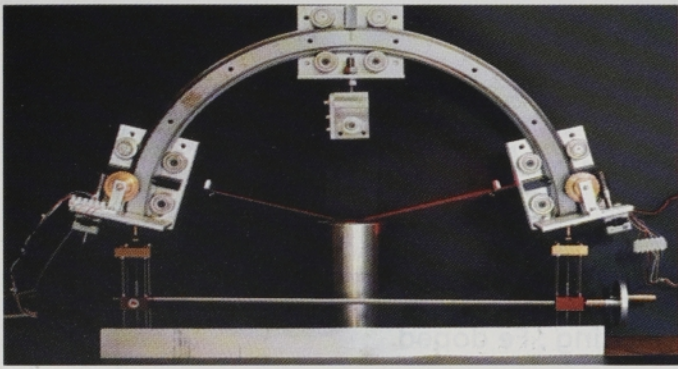


Figure 3. Arc rail, developed at Oxford University, showing the variable angle of reflectance (near to Brewster's angle).

because of changes in the optical properties of the GaAs with temperature [6]. However, at about 400°C the signal drops and then begins to rise again until 700°C is reached. The wafer is then cooled at the same rate (40°C/minute) as the heating and the signal re-traces the original path until it reaches the 400°C region where it now follows a different route.

The data can be explained as follows. The wafer is initially covered in a thin layer of oxide; at the temperature where this is reduced by the atomic hydrogen the reflected light intensity drops, and then continues to rise due to the heating. On cooling the oxide is no longer present below 400°C because the atmosphere of hydrogen does not contain any trace of water or oxygen. If the heating cycle is then repeated, it follows the path of the lower trace, showing that the surface has not been damaged under the conditions used. If the wafer is heated to 800°C the paths of subsequent traces do not coincide due to damage on the surface of the wafer scattering the laser beam. This damage is probably incongruent evaporation of arsenic.

The extreme surface sensitivity we observe in Figure 2 is a result of the use of the optimum angle of incidence, and to this end, we arranged the equipment so that we could vary it from 70–80° as seen in Figure 3. We then modelled the GaAs oxide optical response to determine the optimum angle and the expected sensitivity.

Figure 4 shows that for GaAs the optimum angle is close to 75.5° and at that angle, the technique can distinguish between a clean surface and a surface with only 10 Å of oxide on. Notice the logarithmic scale of reflectivity indicating the very high sensitivity of this particular optical arrangement. Also, notice that the reflected signal inten-

sity is expected to be reduced as the oxide is removed and this is indeed what is observed in Figure 2.

Up to now, in MOVPE, there has been no direct way of monitoring the surface during heating to determine if the oxide has been removed or the surface damaged. We have confirmed the technique is monitoring oxide, and not some artifact of the surface,

by measuring the rate of re-growth of a deoxidized GaAs surface.

Figure 5 shows the expected asymptotic increase in oxide thickness. The initial rapid increase in thickness is eventually limited by the speed of diffusion of oxygen through the oxide layer. Such a trace is typical for oxide growth on many surfaces. Indeed, the initial re-oxidation is so rapid

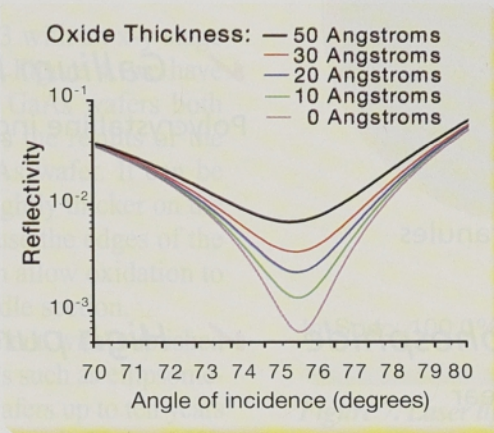


Figure 4. Modelled reflectivity from a GaAs wafer covered in various oxide thicknesses.

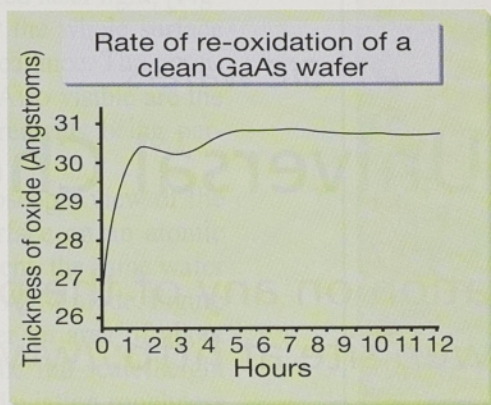
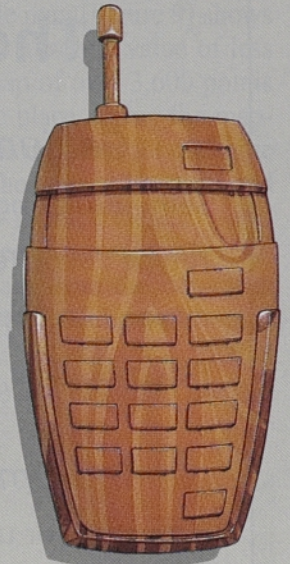


Figure 5. Reoxidation of a previously de-oxidized GaAs wafer by exposure to ambient air for 12 hours.

SiGe



High-Frequency Electronics

If you want to be among the leaders in the field of RF and wireless applications it's time to explore the advantages with silicon germanium.

Epigress UHV-CVD equipment will take you into a new era of high-frequency silicon germanium electronics.

From R&D units to production systems through technology transfer arrangements and process guarantees, Epigress delivers the total solution to your needs.

For more information, visit:

www.epigress.com



EPIGRESS
A Member of the AIXTRON Group

Ideon Science & Technology Park
SE-223 70 Lund, Sweden



The Wafer Technology Product Range

✓ Gallium Arsenide

Semi-insulating : Undoped

n-type : Si or Te doped

p-type : Zn doped

Polycrystalline ingots, slices or granules

✓ Indium Phosphide

Semi-insulating : Fe doped

n-type : S, Sn or undoped

p-type: Zn doped

Polycrystalline ingots, slices or granules

✓ Indium Antimonide

n-type : Te or undoped

p-type : Ge doped

Polycrystalline ingots, slices or granules

✓ Gallium Antimonide

n-type : Te doped

p-type : Zn or undoped

Polycrystalline ingots, slices or granules

✓ Indium Arsenide

n-type : S or undoped

p-type : Zn doped

Polycrystalline ingots, slices or granules

✓ Gallium Phosphide

Polycrystalline ingots, slices or granules

✓ Zinc Germanium Diphosphide

Polycrystalline ingots for non-linear optical applications

✓ High purity MBE source material

✓ High purity indium metal

✓ High purity gallium metal

✓ SiC wafers

"The Universal Choice"

For more information on any of the products visit the
Wafer Technology web site at <http://www.wafertech.co.uk>.

Wafer Technology's quality system is approved to BS EN ISO9002:1994

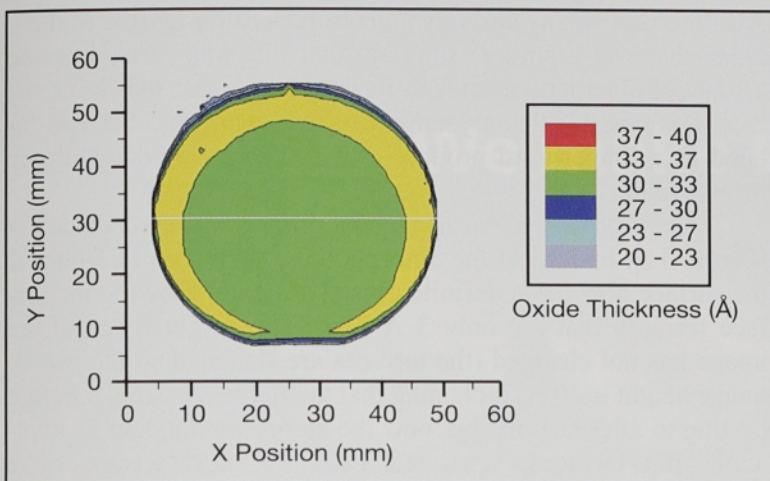


Figure 6. Oxide thickness map of an epi-ready GaAs wafer prior to deoxidation.

as to be impossible to capture with our current set-up. The time taken to move the wafer from the de-oxidation equipment to the reflectivity equipment is only a few seconds and in that time something like 20 Å of oxide has grown on the wafer.

GaAs Epi-ready Wafers

By utilizing the arc rail shown in Figure 3 with an x-y stage underneath, and by using the modelling from Figure 4, we have been able to map the thickness of oxide on GaAs wafers both before and after de-oxidation. Figure 6 shows the results of the mapping of a 50 mm diameter epi-ready GaAs wafer. It can be seen that the oxide is of uniform thickness, slightly thicker on the outside than the inside. This is probably because the edges of the wafer have steps in the crystal surface that can allow oxidation to take place more easily than on the flatter middle section.

The absolute thickness is in good agreement with published values obtained using more elaborate techniques such as ellipsometry and x-ray diffraction [7]. We have studied wafers up to ten years old that show very similar oxide maps to that shown in Figure 6 [8].

A new technique for assessing whole wafers is laser light scattering. We used a commercial instrument (Bio-Rad RPM 2000) to assess the surface roughness over the whole wafer. When an epi-ready substrate is looked at using scattered laser light, [Figure 7] there is an anisotropic scattering over the whole surface giving a figure-of-eight or Maltese cross appearance. The possible origin of this artifact is discussed below. Also visible are the high intensity (red) spots due to the measurements being performed in a non-clean room environment.

While oxide mapping has given a macroscopic view of the wafer surface, we can observe the same surface on an atomic scale by using AFM. As a baseline measurement, the same wafer that was mapped in Figure 6 was examined in AFM mode. Figure 8 shows the results of this measurement over an area of about $20 \times 20 \mu\text{m}^2$. The intensity scale indicates the full-scale height variation of 15 Å (and a measured standard deviation roughness of 3 Å). This high degree of flatness is obtained by chemo-mechanical polishing. Some residual micro-scratches left after polishing can just be seen.

Deoxidised GaAs Wafer

The surface of the wafer after it has been deoxidized using a procedure similar to that shown in Figure 2 is quite different from an epi-ready GaAs surface. Firstly the oxide map [Figure 9] shows a uniform thickness of oxide with a lower absolute value of less than 30 Å. The time taken to make the map of over 3,600 points was sufficient for the re-oxidation to take place during the mapping [see Figure 5]. This is why the value is different for one edge of the wafer as this is where the raster of the laser beam starts and so the oxide has not had a chance to grow as thick there.

The laser light scattering from the deoxidized substrate [Figure 10] shows a high particle count (again from the non-clean room conditions of measurement). The overall background signal is less than for the as-received wafer suggesting a smoother macroscopic surface than for the epi-ready substrate in Figure 7.

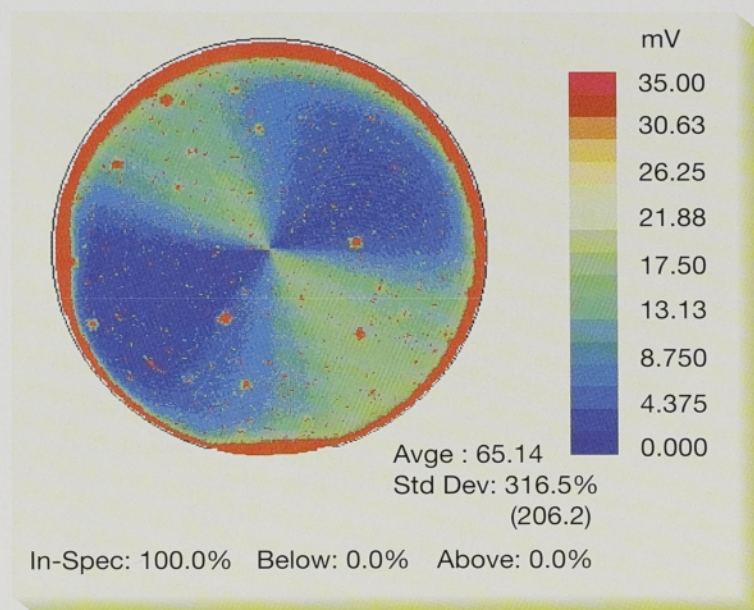


Figure 7. Laser light scattering of an epi-ready GaAs wafer prior to deoxidation. A high mV signal is equivalent to high scatter.

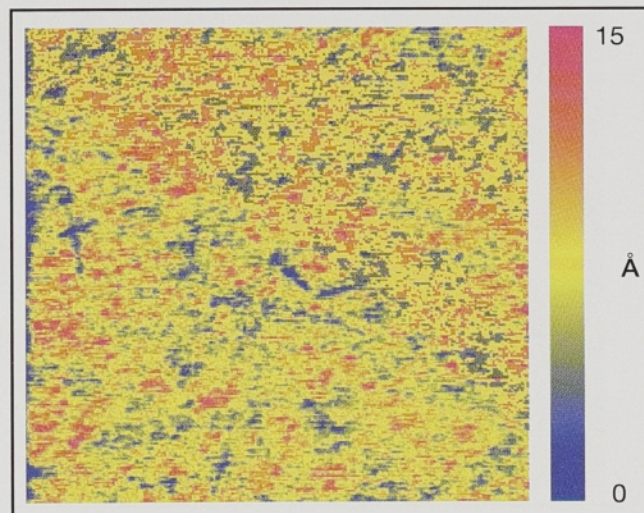


Figure 8. $20 \times 20 \mu\text{m}^2$ AFM image of an epi-ready GaAs wafer prior to deoxidation.

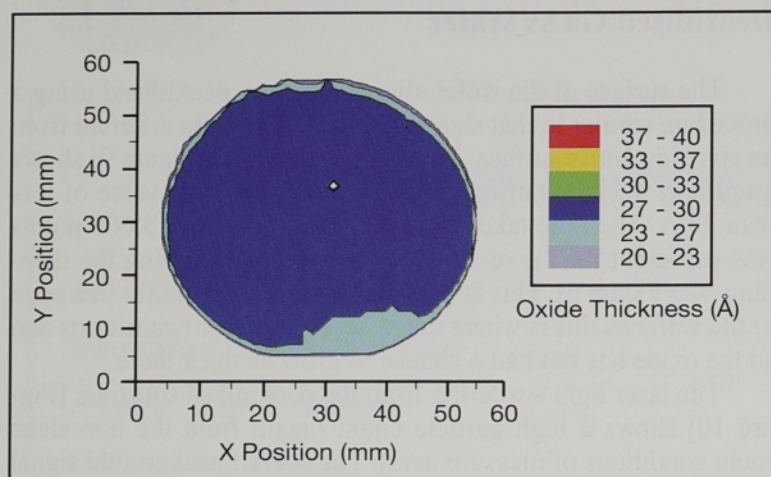


Figure 9. Oxide thickness map of an epi-ready wafer after deoxidation (the oxide is already regrowing during the measurement).

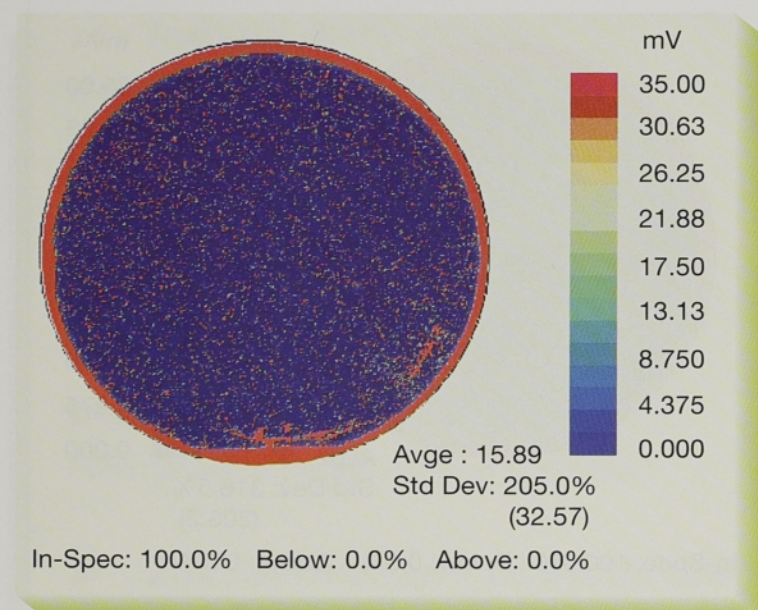


Figure 10. Laser light scattering of a deoxidized epi-ready GaAs wafer. A high mV signal is equivalent to high scatter.

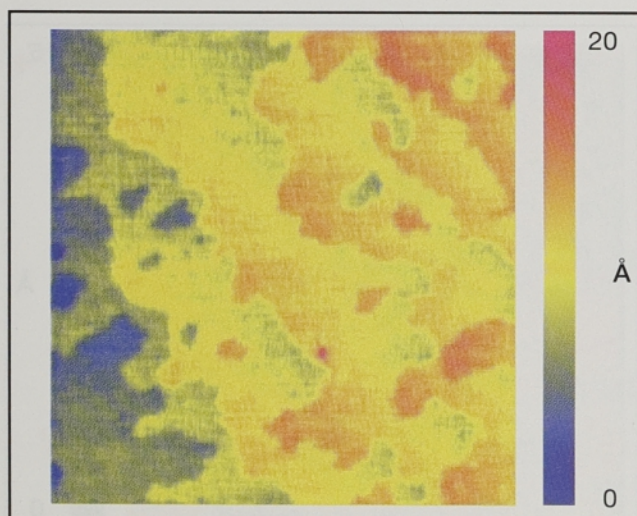


Figure 11. 20 × 20 μm² AFM image of a GaAs wafer surface after heating and cooling to 700°C (as shown in Figure 2).

Also the lack of any strongly anisotropic scattering (the Maltese cross shape in Figure 7) suggests that this was certainly some artifact of older native oxide or its interaction with the GaAs surface. It is possible that crystalline arsenic, which has been postulated as a longer-term product of older native oxide, could be responsible.

The AFM image is also quite different after deoxidation [Figure 11]. Instead of the amorphous surface seen in Figure 8, the surface now has a definite crystal structure showing the surface terraces that are only 3 Å high. The height range of the image has not changed (the terraces are flattened so the overall image height is 20 Å) indicating that the flatness is similar before heating to after heating, but now the atoms are lined up in atomically flat terraces, separated from the next terrace by a monatomic step edge. The fact that the terraces are atomically flat is also confirmation that the surface of the wafer has not been damaged by the heating and cooling cycle in agreement with the interpretation given to the data in Figure 2. The micro scratches observed in the Figure 8 have also been removed by the de-oxidation/annealing process.

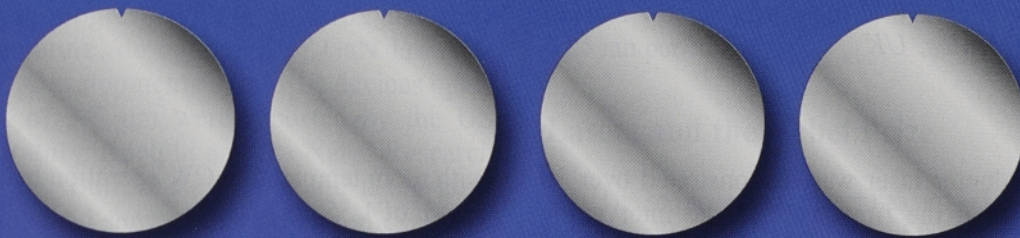
We have also investigated older substrates with regard to oxide mapping and AFM and found results very similar to an epi-ready wafer with a slightly increased oxide thickness over a period of years. Despite some manufacturers putting a time limit on the epi-ready nature of their wafers we could find no difference after long-term storage provided the wafers were deoxidized in the presence of atomic hydrogen (from tBAs or arsine). We have found no difference between different manufacturers, different off-cuts, or dopants using the techniques discussed here. It is not yet clear what role annealing and sublimation of As or Ga or GaAs are having in achieving the surface seen in Figure 11 and this is currently under investigation. Is the surface seen in Figure 11 buried under the amorphous oxide layer seen in Figure 8 and revealed as soon as that oxide is removed, or are the atomic terraces only achieved after annealing/sublimation has taken place once the oxide is gone? Merely heating GaAs in a flow of molecular hydrogen does not produce such a surface [9].

In conclusion we have shown something of the nature of an epi-ready GaAs surface and what happens when it is deoxidized in an MOVPE reactor. Further details of this work can be found in the references below [1, 5-9].

References

- [1] D. Allwood et al, in *Handbook of Thin Film Process Technology, Part G—“Substrate Preparation for Thin Film Deposition”*, edited by L. Vescan (Institute of Physics, Bristol, UK, 2000).
- [2] H. Fronius et al, *Jpn. J. Appl. Phys. Part 2*, 1986, 25, p.L137
- [3] J. Schwar, *Mats Sci. Eng.*, 1991, 9, p.23
- [4] P. Klipstein et al, *J. Crystal Growth*, 1998, 195, p.168
- [5] D. Allwood et al, *J. Crystal Growth*, 1998, 195, p.163
- [6] D. Allwood et al, *J. Electronic Materials*, 2000, 29, p.99
- [7] D. Allwood et al, *Thin Solid Films*, 2000, 364, p.33
- [8] D. Allwood et al, *Proc. ICMOVPE-X, Japan, June 2000; to be published in J. Crystal Growth*
- [9] D. Allwood et al, *Mats Sci. Eng. B—Solid State Materials For Advanced Technology*, 1999, 66, p. 83

We make lots of these



so you can do lots of this



for very little of this.



And, may we add, we do that quite well.

For more information on EMCORE's pHEMT and HBT epiwafers,
call sales at EMCORE — 732-271-9090.

*pHEMT and HBT Epiwafers by EMCORE —
Capacity, Cost, Performance.*



17th IEEE Semiconductor Laser Conference

HUW WILLIAMS

University of Cardiff, Wales, UK

The first semiconductor laser was demonstrated over 30 years ago soon after the first laser. In the intervening period, this type of device has rapidly developed to become the most widely used form of laser. The maturity of this field was reflected in the recent Semiconductor Laser Conference, which had over 300 delegates from 14 different countries, drawn from both the commercial and academic communities. A measure of the importance of semiconductor devices within the laser community was provided by the attendance at the conference of Charles Townes, who was awarded the Nobel prize in 1964 for the co-invention of the laser with Arthur Schalow.

The major application of laser diodes is within optical fiber communications systems and with the Internet revolution providing a drive towards ever increasing data transfer speeds it was this area that dominated the conference. The tone was very much set by the three invited review talks which all addressed issues in optical communications. Larry Coldren from University of California, Santa Barbara reviewed the progress towards vertical cavity laser diodes emitting in the 1.3–1.55 μm wavelength range, which have applications in short haul Ethernet systems. The development of lasers for ultra-high capacity, Terabit networks was described by Ikuo Mito from NEC, Japan and in the final talk Fabrice Devaux from Alcatel, France described progress towards all-optical handling of information within fiber systems.

Optical Communications

The focus on optical communications was continued in the mainstream sessions—over two thirds of the talks were on lasers for this area of application. The current research on VCSELs is predominantly aimed at producing 1.3 μm wavelength devices for data communications networks. The variety of approaches towards realizing these particular lasers encapsulate the inventiveness and flexibility of the work in semiconductor lasers and reflect the main research routes followed in their development. As ever the epitaxial growth of new materials provides a major impetus for progress. The use of InGaAsN gives 1.3- μm -emitting material on GaAs substrates and successful laser devices were reported by the US national laboratories at Sandia and Lawrence Livermore. An alternative approach is to use the traditional InP-based material system for these wavelengths and grow AlGaAsSb material for the high refractive index contrast mirrors required for vertical cavity laser diodes. Progress in this area was reported by the University of California, Santa Barbara

with room temperature CW operation being achieved at a wavelength of 1.55 μm .

The use of quantum confinement has provided much improved laser characteristics and the quantum well lies at the heart of all modern laser diodes. The development of quantum dot structures now provides complete three-dimensional confinement of electrons and holes and again allows the growth of 1.3 μm material on GaAs substrates. These structures also have the lowest threshold current densities of any semiconductor laser.

The ingenuity of laser diode research is displayed in the wafer bonding approaches to producing a 1.3 μm VCSEL. Here mismatched lattice materials are bonded together to form a composite structure thus combining the benefits of InP-based gain regions with GaAs-based reflectors. This approach also allows the use of an 850 nm VCSEL as an optical pump for an InP quantum well system. Such hybrid devices have been developed by Gore Photonics and are close to being implemented within data links.

DWDM Sources

The work on devices for high capacity networks is concentrated on producing single mode lasers with controllable wavelength. These tunable lasers form the basis of dense wavelength division multiplexing (D-WDM) systems in which additional information transfer is achieved by parallel transmission at different wavelengths. A common approach is to use a multi-section semiconductor laser which contains integrated optical modulation and wavelength tuning elements so that the wavelength tuning and data encoding can all be achieved on a single chip. Devices such as this developed by Lucent Technologies are capable of transmitting data at 2.5 Gb/s into 20 different wavelength channels over a distance of 680 km. Such technology will allow future telecommunications networks to operate at rates of over 1 Terabit per second.

High Power Devices and Pumps

The micron scale of semiconductor lasers has not inhibited the development of high power devices and progress in this area was highlighted in the talk from the Ferdinand-Braun Institute, Germany showing a laser bar producing 146 W of power at a wavelength of 810 nm. Research on devices at 980 nm for optical pumping of erbium-doped fiber amplifiers is also a key area and SDL Inc. presented results on single mode devices capable of coupling over 0.5 W of power into an optical fiber.

Long and Short Wavelength Devices

The extension of laser diode operation to new wavelengths also continues. Until recently the development of blue-emitting semiconductor lasers was predominantly due to a single company, Nichia Chemical of Japan. Now other groups are also making progress, with both Xerox and Sony reporting room temperature, dc operation of GaN lasers at powers above 10 mW. Developments in mid-IR devices operating at wavelengths of 3-5 μm were reported by the US Army Research Laboratory, Adelphi and the Naval Research Laboratory, Washington. Both these groups are using antimonide-based materials and showed that powers in excess of 10 mW can be achieved at 180 K while at lower temperature greater than 100 mW can be realized.

Quantum Dot R&D

Semiconductor laser research has provided a fertile area for cross-collaboration between advanced engineering concepts and fundamental physics. This continues and in addition to the work on telecommunications lasers there was a session addressing issues within quantum dot laser systems. This is a topic that is coming of age and is ready to make the transition from research laboratory to commercial product. Professor Bimberg from the Technical University, Berlin reported on InGaAs dot devices operating at 1.1 μm with

5W of output power and very low threshold current densities of less than 50 A/cm. Further evidence of the potential of quantum engineering was provided by the group at Center for High Technology Materials at the University of New Mexico, who demonstrated continuous tuning of a quantum dot laser over 183 nm. Also, researchers at Cardiff University, Wales showed quantum dot devices whose wavelength is thermally stable, shifting by only 0.05 nm per $^{\circ}\text{C}$.

Lasers and the Nobel Prize

The semiconductor laser has proved to be a remarkable device, using the fundamental physics of the quantum world and playing a role in an enormous range of technologies that impinge on every aspect of modern life. This highly successful interaction between physics, technology and commerce has recently been highlighted by the award of this year's Nobel Prize for Physics to Zhores Alferov and Herbert Kroemer, who independently developed the double heterostructure laser diode [see page 7]. It was this development which provided lasers capable of operating with low currents in the mA range and so made them commercially viable. The 2000 Semiconductor Laser Conference demonstrated that the vitality and diversity of semiconductor laser research continues, undertaking fundamental investigations of the optical properties of advanced materials and structures and also providing commercial opportunities within the booming e-economy.

LET'S GROW!

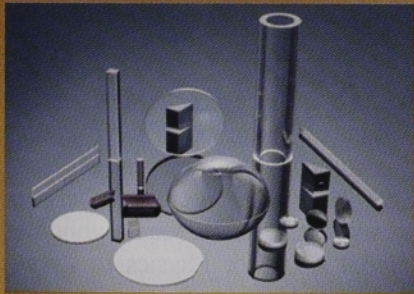
Rather than spending your time and energy looking for extra funding, now you can tap into the power of MBE with the Compact 21™, our new 2" research system. This versatile reactor provides you with all the MBE tools you need starting at... 350 K\$! To find out more, call your RIBER representative.

R I B E R

Products and Services for the Compound Semiconductor Industry

Tel: +33 1 47 08 92 50 / Fax: +33 1 47 08 32 39 / E-mail: info@riber.com / Website: www.riber.com

Sapphire substrates for Nitride deposition



Vertically integrated Cz sapphire growth and fabrication assure the ability to consistently manufacture substrates to meet the most stringent industry standards

- **Precise wafer orientations**
- **Class 100 packaging**
- **Laser marking available**
- **Full technical support**

sapphireproducts.com



The Third European Conference on Silicon Carbide and Related Materials

MIETEK BAKOWSKI, PER ERICSSON, CHRIS HARRIS, STEFAN KARLSSON, SUSAN SAVAGE and ADOLF SCHÖNER

ACREO AB

Electrum 236, SE-164 40 Kista
Sweden

The third European conference on Silicon Carbide and Related Materials (ECSCRM2000) was held this year at Kloster Banz, Germany. The conference consisted of seven plenary talks, five invited talks, and 199 contributed papers for oral or poster presentation. Around 330 people from 23 different countries attended the meeting, which was organised by the **Friedrich-Alexander University Erlangen-Nürnberg** and **SiCED GmbH**.

The conference contained sessions on bulk growth, epitaxy, surface/interfaces, structural characterization, defects, processing, devices, measurement techniques, electrical and optical characterization, and industrial contributions. This review contains a cross-section of the contributions within these sessions, and a few highlights are presented in more detail.

Bulk Material and Epitaxy

One of the problems that high frequency and high power transistor developers have been struggling with is the poor quality and expense of the semi-insulating substrates that are available today. During ECSCRM2000, **Thomson-CSF** (France) showed some promising results from MESFETs that were processed on semi-insulating substrates from **Okmetic** (Finland). Okmetic uses a novel high temperature CVD (HTCVD) technique to produce their substrates; this technique has been presented at earlier conferences. These substrates are said to have excellent quality and to be much purer than commercially available material.

The **Ioffe Institute** (St. Petersburg, Russia) together with the Emerging Materials Research Laboratory at **Mississippi State University**, USA presented interesting results from their efforts to grow epitaxial layers on porous material. The porous material consisted of a substrate with a few microns of a highly porous layer on the surface [see Figure 1]. This was achieved by an electrochemical treatment of the substrate surface. The two groups reported a significant reduction of structural defects such as micropipes, dislocations and point defects in epitaxial layers grown on the porous layers. Properties such as electrical and thermal conductivity of the porous layers have not yet been fully

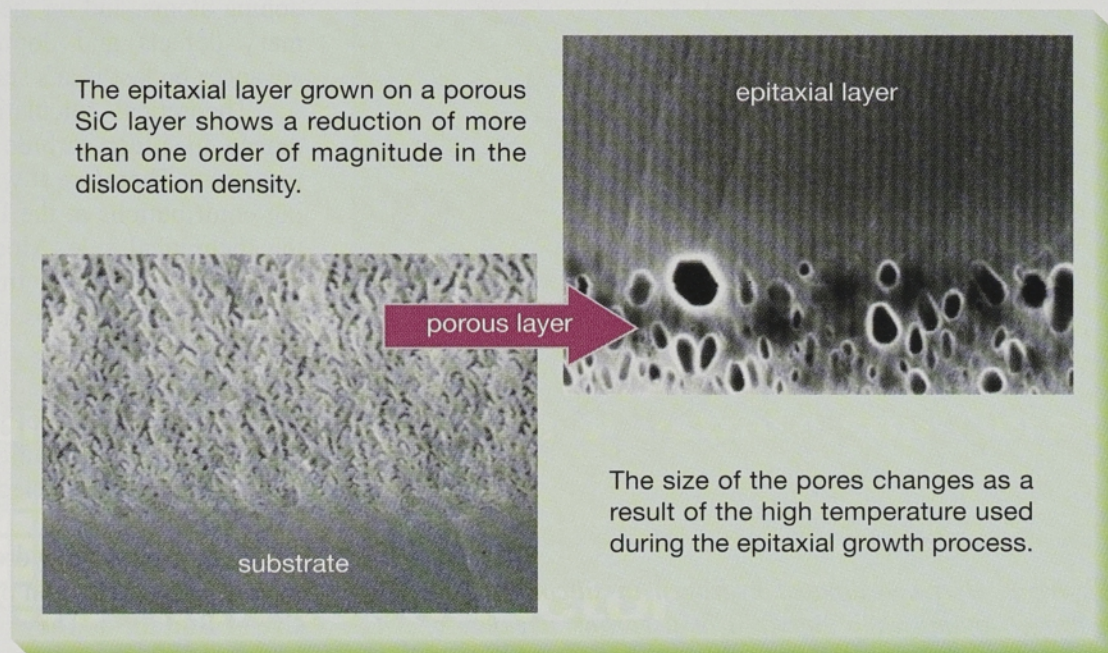


Figure 1. Results of epitaxial growth on a porous SiC layer, as observed by the Ioffe Institute, Russia and Mississippi State University, USA. The figure shows cross-sectional SEM micrographs after the formation of the porous SiC layer (left) and after growing an epitaxial layer (right).

Courtesy of S. Sadow, Emerging Materials Research Laboratory, Mississippi State University, USA.

evaluated and therefore a question mark still remains regarding the usefulness of these layers as a starting point for practical applications.

The first CVD system resulting from the merger between **Aixtron AG** and **Epigress AB** was presented by members of both companies. The machine—a child of Aixtron's multi-wafer technology using gas foil rotation and the Epigress hot-wall technique—is called the Hot-Wall Multiwafer Planetary Reactor VP2000 and is capable of growth on seven 2-inch or five 3-inch wafers. The main new feature is the independent actively heated reactor ceiling with a temperature profile that can be precisely adjusted. Although growth has not yet been carried out in the new system, a lot of effort has been put into the simulation of temperature uniformity, flow dynamics and gas phase reactions. This system is a serious candidate for large area growth of high quality silicon carbide.

Implantation and Defects

Following in the footsteps of its predecessors, the ECSCRM2000 conference was largely devoted to fundamental problems in silicon carbide as a material. More sophisticated techniques to visualize and detect growth defects continue to be developed, which contribute to the analysis and understanding of

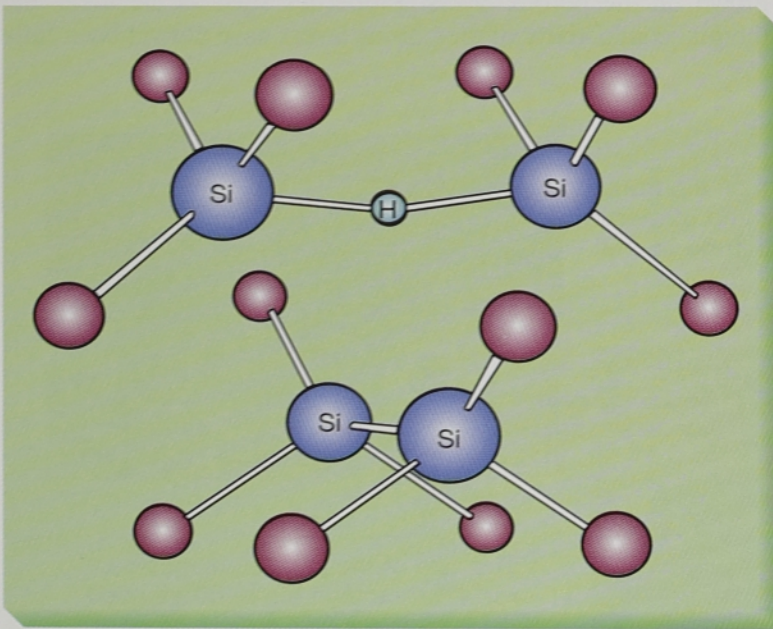


Figure 2. Over-coordinated hydrogen in silicon carbide. The hydrogen atom, when captured in a carbon vacancy of SiC, enters a three-center-bond with two of its Si neighbors. (Unmarked spheres are carbon atoms.) The resulting defect is a hole trap. A second hydrogen atom may take the other bridge position, giving rise to a double hole trap. Unlike other semiconductors, the carbon vacancy of SiC cannot be passivated by hydrogen. [See also: *Phys. Rev. Lett.* 2000, 84, p. 4926.] Courtesy of P. Deák, Department of Atomic Physics, Technical University of Budapest.

their origin, and also increase the pressure on commercial substrate suppliers to continue and increase their efforts in material R&D.

A number of contributions reported the results of electron paramagnetic resonance (EPR) measurements, which identify the fingerprints of defect structures plus their hyperfine interaction with neighboring silicon and carbon atoms. An extensive study of the generation and annealing behavior of intrinsic-related defect centers in 4H and 6H silicon carbide was presented by the Institute of Applied Physics, **University of Erlangen**, in collaboration with the **Japan Atomic Energy Research Institute**. Epitaxial layers were irradiated with high energy electrons, protons, helium, and heavier ions, and isochronal annealing was then carried out at different temperatures ranging from 700°C to 2000°C. Three prevailing defects were subsequently observed using deep level transient spectroscopy (DLTS). These defects could be identified from literature as the E1/E2-, Z1/Z2-, and R-centers. In contrast to earlier reports, it was found in this study that the Z1/Z2-center could be annealed out at temperatures above 1400°C. The most stable defect was the E1/E2-center, which was still present in the DLTS spectra after a 1700°C anneal. The R-center disappeared at temperatures as low as 800–1000°C.

In the fabrication of SiC-based devices, ion implantation is a key technology due to its ability to selectively dope the material through masking techniques. The technology status of ion implantation was presented at the conference through numerous contributions on radiation-induced primary defects such as vacancies and anti-sites, on the introduction and activation of doping atoms, and on the formation of complexes between primary defects and doping atoms. However, no significant advances on last year's status were reported.

Theoretical calculations of the electronic properties of defects in silicon carbide have become a major topic in the last few years. Therefore it was not surprising that several interesting contributions at the ECSCRM2000 conference came from the theoretical side. Modern molecular simulations are nowadays capable of predicting the stability as well as the energetic and spectroscopic observable properties of complex defect structures. The results obtained from these theories are now comparable with those from experiment. Quantitatively the calculated energies are not yet within the accuracy of experimental methods, but qualitative estimates on the formation probability and the electronic properties of defects can be made.

The theory of hydrogen in silicon carbide was another interesting contribution presented by a group from the **University of Budapest**. They predict a high concentration of mobile positively charged hydrogen ions in p-type silicon carbide, whereas the most stable hydrogen form in n-type silicon carbide is the hydrogen molecule H₂ [see Figure 2]. Interstitial hydrogen is more likely to form complexes with silicon vacancies and shallow acceptors than with carbon vacancies and shallow donors. This would explain the hydrogen passivation effects of dopants that are experimentally observed in electrical measurements.

silicon carbide

4H and 6H Wafers
51mm and 35mm

***We Now Have
Silicon Carbide
Epitaxy!***

rising

Finally, a real choice in silicon carbide substrate suppliers.

Europe:

Wafer Technology, Ltd.
Telephone: +44 (0) 1908 210 444
Fax: +44 (0) 1908 210 443
E-mail: klamb@wafertech.co.uk
Website: <http://www.wafertech.co.uk>

Japan:

New Metals and Chemicals Corporation
Telephone: 03-3201-6585
Fax: 03-3271-5860
E-mail: mail@newmetals.co.jp
Website: <http://www.newmetals.co.jp>



**sterling
semiconductor**

sterlingsemiconductor.com

North America:

Sterling Semiconductor, Inc.
22660 Executive Drive, Suite 101
Sterling, VA 20166-9535 USA
Telephone: 703-834-7535, ext. 205
Fax: 703-834-7537
E-mail: sales@sterlingsemiconductor.com

Korea

Seokyo Commerce Company
Telephone: 82-2-597-3961
Fax: 82-597-3964
seokyo@netsgo.com

Taiwan

Marketch International Corp.
Telephone: 03-594-7478
Fax: 03-594-7479
chuton7@iris.seed.net.tw

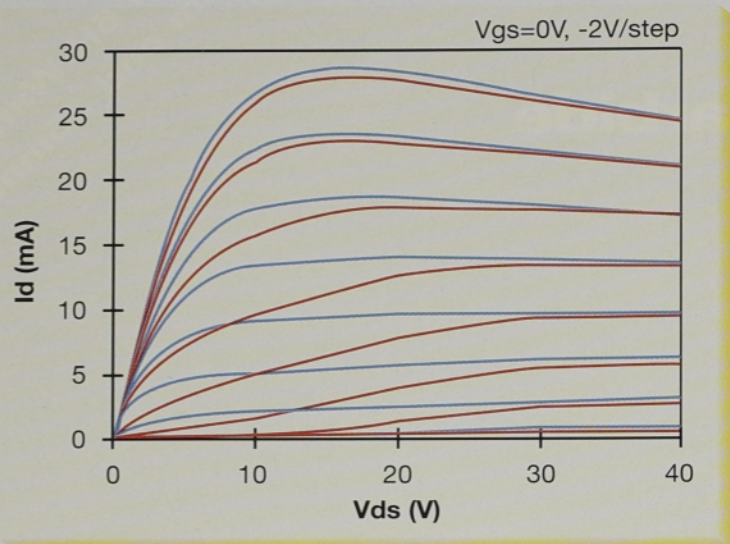


Figure 3. The effect of so-called “current slump” of a SiC MESFET device. The increase that is seen in drain resistance is demonstrated here using the contrast between non-illuminated (red lines) and illuminated conditions (blue lines).

Courtesy of C. Brylinski, Thomson-CSF, Orsay Cedex, France.

The two most prominent defects, the B-related D-center observed by DLTS and the D1-center observed by photoluminescence after irradiation processes, were the subjects of a defect forum, which was held on the evening of the first conference day. This defect forum was an attempt to bring together experimental and theoretical physicists. It included an overview of the techniques that can be used for defect characterization as well as the theories behind calculations of the formation and stability of defect structures. On the experimental side, correlation of the results from different measurement techniques is the biggest challenge now. An outcome from the discussions was the fact that international collaboration is required in order to finally solve the problem of identifying defect structures.

Microwave Devices

The representation of the microwave community at the ECSCRM meeting was limited to a handful of presentations perhaps reflecting the relative maturity of this technology in SiC. The French group from **Thomson-CSF** presented their latest achievements (40W at 1.5 GHz), while noting that the Europeans are significantly behind the corresponding results from the USA. Reliability or rather instability in the DC performance of MESFET devices is still seen as the major bottleneck, preventing widespread product launch in this area. The effect known as “Current Slump” is seen as an increase in drain resistance following electrical stressing of the devices [see Figure 3]. The mechanism behind the associated “slump” in current is due to charge trapping either at impurities in the substrate material on which the MESFET is made or at defects at the surface of the device. The Thomson group also presented results showing that by growth of an optimized buffer layer or use of very pure semi-

insulating substrates the effect of current slump can be minimized or avoided completely.

The correlation of degradation with substrate/buffer quality provides a convincing argument that with adequate surface passivation the instability problem can be solved with improved material quality. The group from **Chalmers University of Technology** (Gothenburg, Sweden) reported their work on simulation of MESFET device performance. In particular they concluded that an accurate fix of their DC measured data could only be obtained by assuming a degraded value of bulk mobility for the MESFET structure. The mechanism responsible for the lower effective mobility may again relate to the presence of charged impurities in the buffer or substrate material.

The controversial question of the relative merits of SiC as compared to its competing wide bandgap semiconductor GaN was taken up in a detailed presentation from Michael Shur from **Rennsler Polytechnic, USA**. In a talk in which he likened the cost of SiC substrates to New York real estate prices, Shur presented a detailed study of the merits of the nitride materials for electronic applications. He argued strongly in favor of GaN as a material for which the ability to make controlled bandgap engineering ultimately will provide a significant performance advantage over SiC. The combination of GaN on a SiC substrate was suggested to be even more advantageous to a future GaN substrate. The dual material system looks set to be a topic for increasing development in the near future.

Power Devices

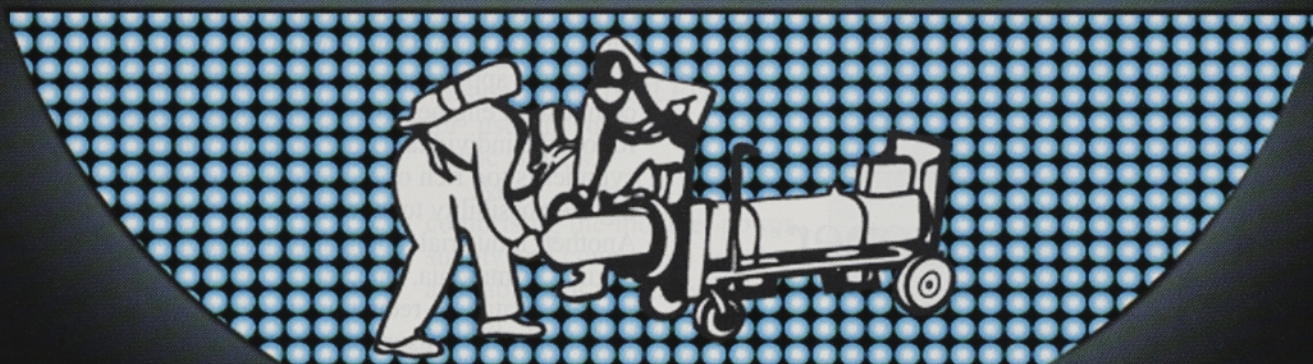
Infineon Technologies AG (Munich, Germany) presented their strategy for market introduction and industrial exploitation of SiC power devices. It was promised that a 6 A, 600 V Schottky rectifier (SBD, or Schottky barrier diode) developed by **SiCED GmbH** would be commercially available by next year at \$3 apiece. (SiCED GmbH is a spin-off company from **Siemens**, based in Erlangen, Germany). Infineon plans to introduce these in 100 W to 2 kW switched-mode power supplies.

ABB (Kista, Sweden), who are engaged in developing high-voltage rectifiers for power transmission and distribution, disclosed in two separate presentations that they have encountered serious stability problems in their pin diodes. The instability manifests itself as a drift in the I-V characteristic when passing forward current for a prolonged time. The instability is believed to be related to the generation- and recombination-enhanced movements of dislocations in the silicon carbide material. The source of the dislocations is believed to be stacking faults related to the strain at the upper (anode) end region of the diode or at the interface between the highly doped substrate and the low doped epilayer. ABB's disclosure was a conscious message to the international silicon carbide community that this issue should be addressed, as it will be of major significance for all bipolar SiC power devices.

The major highlight in the area of MOSFET development was a series of results obtained by researchers at **Kyoto University** on silicon carbide cut on the (11 $\bar{2}$ 0) face. High inversion



solkatronic



The Best and the Brightest!

It's Solkatronic Megabit® II High-Purity Gases

**For the highest visibility Photonics and other III-V compounds,
use Solkatronic Megabit II.**

- Arsine 99.99994% pure
- Phosphine 99.9999% pure
- Blue Ammonia® 99.99994% pure
- 2 manufacturing locations for unending supply and speedy delivery
- Continuous product consistency and reliability



Solkatronic Chemicals

351 Philadelphia Avenue • Morrisville, PA 19067
Tel 215-736-0700 Fax 215-736-3666 Toll Free 800-521-3981
www.solkatronic.com

For the brightest Photonics... Solkatronic

A Business Unit of Air Products and Chemicals, Inc.

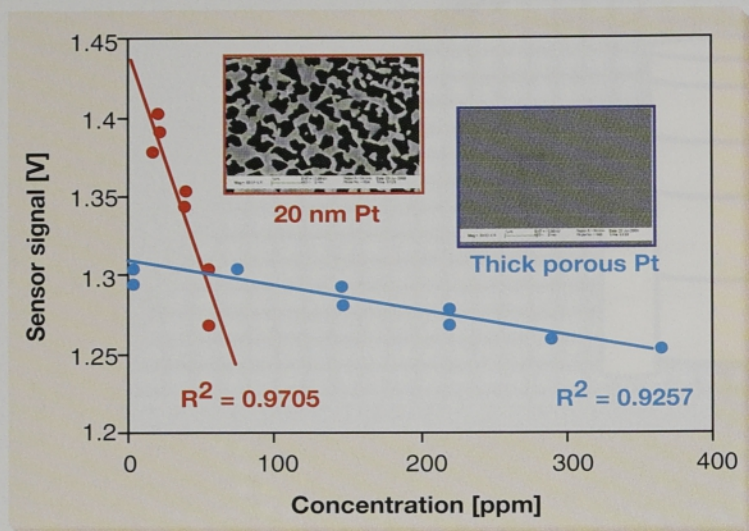


Figure 4. Sensor response as a function of ammonia concentration in diesel exhaust for two sensors with different active layers. The inset pictures show the difference in the structure of the active layers. This figure demonstrates that the sensitivity and range of the sensor can be tailor-made by choosing an appropriate active layer. [See also: *Conf. Proc. EuroSensors XIV, August 27–30, 2000, Copenhagen, Denmark.*]

Courtesy of A. Lloyd Spetz and H. Svenningstorp, S-SENCE, Linköping University, Sweden.

channel mobilities were observed in both 6H-SiC and 4H-SiC MOSFETs (116 and 96 cm²/Vs, respectively), and much lower interface state densities near the conduction band edge were reported, as compared to those obtained on the commonly-used (0001) Si-face. Also lower values of the threshold voltage were obtained for 4H-SiC(11 $\bar{2}$ 0) MOSFETs as compared to the 4H-SiC(0001) MOSFETs (4 V and 7.8 V, respectively).

Other contributions on power devices included two presentations on JBS (junction barrier diode) development, one by the **Alabama Microelectronics Center** and **Mississippi State University**, and the other by **ABB, Cree** (Durham, NC, USA) reported on a high voltage 1 mm $\times$ 1.4 mm BJT in 4H-SiC able to block 1800 V, and two papers on GTO (gate turn-off) thyristors were presented.

Sensors

There were only two contributions on silicon carbide sensors. One was an invited contribution from **S-SENCE**, which is based at **Linköping University** in Sweden. An overview of the work on gas sensors which is being carried out by S-SENCE and its industrial partners was presented. It was shown that these gas sensors can be used at temperatures up to and above 600°C, and that their function has been demonstrated in several industrial applications. One such application is the cylinder-specific monitoring of a combustion engine, where it has been shown that the sensors can follow the individual firing of each cylinder. If the mixture in one cylinder is too rich or too lean, the sensor can detect this, providing the possibility to automatically adjust the cylinder concerned. Another industrial application is ammonia detection in diesel engines. Ammonia, injected in the form of urea, is used for the selective catalytic reduction of nitric oxides in diesel exhaust. It was shown that sensors have been developed that show high selectivity to ammonia molecules, and their application in the exhaust pipe of a diesel engine has been demonstrated [see Figure 4]. An overview of this work has recently been published in the April 2000 issue of this magazine [see CS 6(3), p. 76].

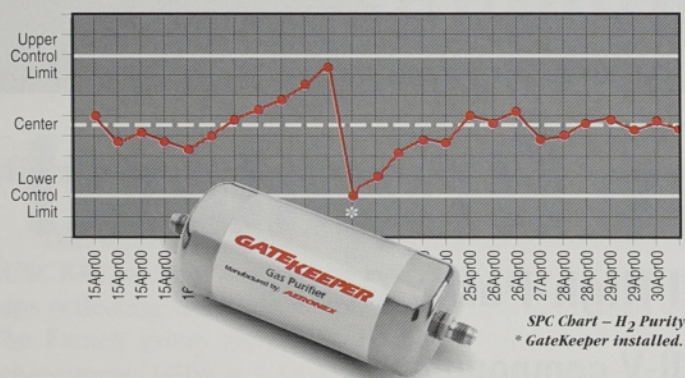
The other sensor presentation featured a high temperature pressure sensor based on 3C-SiC/SOI for turbine control applications. This was presented by the **Technical University of Berlin**, Germany, together with both academic and industrial partners. The device was produced by bonding a SOI wafer to a silicon wafer, and subsequently depositing a SiC layer on top. Piezoresistors were then formed by reactive ion etching. The device was shown to have a sensitivity of 0.5 mV/bar up to a pressure of 10 bar, and a reduced sensitivity of 0.03 mV/bar at higher pressures. It has a maximum operating temperature of 400°C.

Future Silicon Carbide Conferences

The next European Conference on Silicon Carbide and Related Materials (ECSCRM) will be held in September 2002 in Linköping, Sweden.

In the meantime, the next International Conference on Silicon Carbide and Related Materials (ICSCRM2001) will be held in Tsukuba, Japan on Oct 28–Nov 2, 2001.

Aeronex GateKeeper® Gas Purifier



No gas excursions, no scrapped wafers, no contaminants, no gas problems, period.

The GateKeeper is the most cost effective, easy to facilitate gas purification technology on the market. GateKeeper purifiers remove molecular contaminants to sub ppb levels from both inert and specialty gases in point-of-use, area and bulk applications. Our unique technology requires no heat or power and is hydrocarbon free. And all GateKeeper purifiers are easily regenerated to eliminate your disposal problems.

For more information on The GateKeeper contact Aeronex or visit our Website for help in selecting the right purifier for your needs.

6975 Flanders Drive, San Diego, California 92121 / Telephone: 858-452-0124 or 800-511-9761 / Website: www.aeronex.com

AERONEX
THE SOURCE FOR GAS PURIFICATION

Developments in InGaN-on-SiC LEDs and Lasers at Osram

V. HÄRLE,* B. HAHN, H.-J. LUGAUER, G. BRÜDERL,
D. EISERT, U. STRAUSS, A. LELL and N. HILLER

Osram Opto Semiconductors
Regensburg, Germany

The formation of major new manufacturers of lighting products in the optoelectronics field reflects the growing trend towards designing high brightness LEDs into an increasing range of niche and general lighting applications. Osram Opto Semiconductors, the joint venture formed between Infineon and Osram at the beginning of 1999, has a leading position in the optoelectronic market with a number one ranking in Europe and, depending on the product groups considered, is in the top three LED suppliers worldwide by revenue.

Osram Opto Semiconductors' blue LEDs have been in mass production since 1998, with the automotive market providing some of the first applications. In some Audi models, for example, up to several hundred LEDs can now be found both inside for dashboard and switch lighting (Figure 1) and outside on the exterior for center-mounted stop lamps. Osram Opto Semiconductors' LEDs are available in standard radial and surface mount (SMT) designs such as the TOPLED, which is a low profile package widely used by motor manufacturers. The SMT design uses a chip mounted in a resin, which helps to couple out the light. For displays, Osram Opto Semi-

conductors manufactures a red-green-blue LED chip package called the Multi-LED, in addition to discrete white LED devices for use as back-lighting in consumer products and cell phones. The company now also supplies high power versions of its TOPLED device for use in road and railway traffic signals.

More complex systems comprising the module, power supply and connectors are also available. For specialty illumination applications, Osram Opto Semiconductors manufactures and markets LED lamp modules for high contrast backlighting of billboards, sign-age and general lighting applications. Linear modules also allow light from LEDs to be coupled into plastics for edge lighting and marker trails, and modules supply effect lighting and architectural lighting. Osram Opto Semiconductors markets a package that contains 32 high power TOPLEDs in a high luminous flux device with a wide viewing angle. LEDs are attached to either a fixed or flexible printed circuit board, and the module size can be reduced by breaking and splitting it to allow lighting to be placed in a confined space.



Figure 1. Some of the applications for Osram Opto Semiconductors' LEDs include backlighting for Audi's dashboards and major brand name washing machines.

Markets for Short Wavelength Devices

One of Osram Opto Semiconductors' main aims is the development of high brightness InGaN-on-SiC LEDs across the entire visible spectrum, including

* Contact: Dr. Volker Härle at
Osram Opto Semiconductors
GmbH & Co. OHG, Wernerwerkstr. 2,
D-93049 Regensburg. Tel: + 49-941-202-1423;
email: volker.haerle@osram-os.com

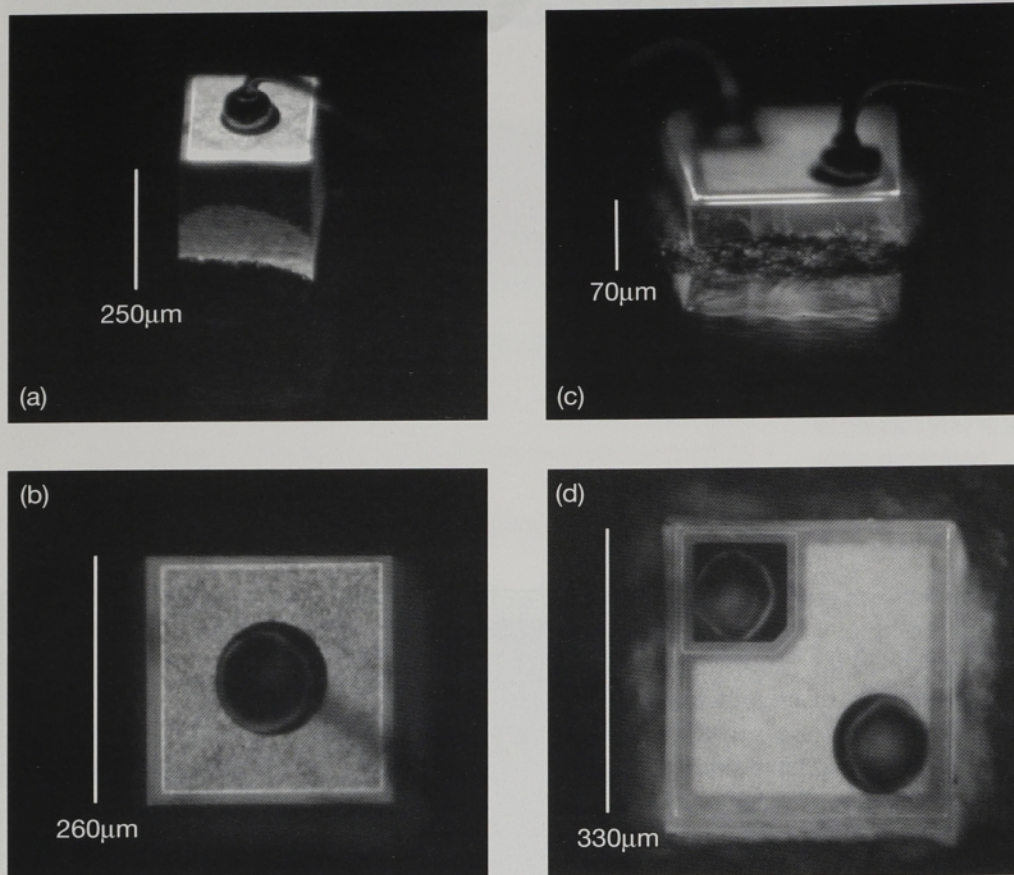


Figure 2. Comparison of InGaN chips based on SiC (parts a and b) and sapphire substrates (parts c and d). SiC substrates allow LED and laser diode designs with vertical current flow using conducting buffer technology. SiC can also be cleaved to produce high quality facets, reducing the amount of device processing.

green in the near future and later, yellow. Among the spectrum of colors available, blue and green LEDs based on InGaN have a significant influence on worldwide LED revenues, and each technological step in performance, especially in brightness, is enabling new applications.

This is particularly true for white LEDs, which are produced using blue or UV LEDs in combination with down converting phosphors. There is great potential for this type of solid-state lighting: the world's total energy consumption for lighting is approximately 2.3×10^3 TWh, 20% of which is consumed in the US and 8% in Germany. Energy savings, as well as reduced maintenance costs, are key motivators for the development of white LEDs. However, to access the potentially huge market for conventional light sources, brightness levels still have to surpass those of incandescent bulbs, which currently supply luminous efficiencies of about 20 lm/W, not to mention 30 lm/W for halogen lamps and almost 70 lm/W for fluorescent

lamps. One of Osram Opto Semiconductors' major targets is to enhance the rate of technological development of this type of product.

The second key driver in the optoelectronic market is the short wavelength laser. At the beginning of 1999, the first commercially-available InGaN-based lasers operating in the blue part of the spectrum were introduced. These short wavelength devices offer potential markets for DVD lasers, laser printers and projection systems, instrumentation and a whole variety of other applications. Osram Opto Semiconductors recently introduced Europe's first short wavelength violet laser, and expects these devices to become commercially available in a few years time.

Substrate Issues

Both sapphire and SiC substrates are widely used to grow high-quality InGaN-based LEDs. Sapphire is an inexpensive and transparent substrate of high crystal quality.

SiC, on the other hand, has less lattice mismatch to GaN compared to sapphire, and allows the fabrication of high quality InGaN-based devices with electrostatic discharge resistance corresponding to the human body model (up to 2000 V).

SiC also has the advantage of being highly electrically- and thermally-conductive. This allows a standard LED and laser diode design with top and bottom contacts as a result of a vertical current flow design. Using SiC substrates, the vertical current flow is achieved using an AlGaN conducting buffer layer before growth of the device layers, and both the chip size and processing costs are reduced as an additional top contact is avoided and only one wire bond is required. In contrast, insulating sapphire substrates require both *n* and *p*-contacts to be placed on top of the device. The *n*-contact is achieved in sapphire by placing it on a mesa etched down to the *n*-layer, at the expense of additional processing.

SiC also has the advantage that it can be cleaved readily. This is important when processing high quality facets for laser diodes. Finally, the excellent thermal conductivity of SiC can remove heat efficiently, enabling high power operation of laser diodes, LEDs and transistors. Thus, Osram Opto Semiconductors has decided to employ SiC substrates for its devices.

Figure 2 (parts a and b) shows Osram Opto Semiconductors' LED grown on SiC, which has only one top contact with an Au bond pad in the center. The second contact is located on the backside of the SiC substrate, indicating the vertical current structure of the device. In contrast, the device in Figure 2 (c and d) employs a sapphire substrate and clearly shows the necessity for two top contacts. Having two top contacts leads to more complicated and expensive dry etching processes, photolithography and the requirement of two metals for *n*- and *p*-contacts. Using a single contact means that device sizes can be reduced to around 200 µm by 200 µm on SiC substrates, and the yield of InGaN-on-SiC LEDs is around 2× that of sapphire-based devices per sq. meter.

Figures 2a and c show the difference in thickness for sapphire and SiC-based devices. The InGaN-on-sapphire LED has been lapped down to 70 µm, which is necessary for cleaving, whereas the InGaN-

Right substrate

may completely change
your business vision

GaN-on-SiC

AlN-on-SiC

GaN-on-sapphire

AlN-on-sapphire

GaN bulk

AlN bulk

SiC epi
micropipe density
< 5 per cm^2



Technologies and Devices International, Inc.

8660 Dakota Dr., Gaithersburg, MD 20877, USA

Tel. 301 208 8342 Fax 301 330 5400 welcome@tdii.com

<http://www.tdii.com>

on-SiC device was sawn at its original thickness of 250 μm —a process that is not as yield-sensitive as cleaving. Additionally, when considering packaging, sapphire-based devices require two die bonds, yielding more expensive devices compared to SiC devices, which only need one bond.

LED Device Structure

The standard blue LED structure with a wavelength between 450 and 470 nm is grown by low pressure MOVPE in a production scale reactor on conducting SiC substrates (Figure 3). The device consists of several hundred nanometers of low Al-content AlGaIn:Si conducting buffer layer, followed by several microns of GaN:Si. The MQW active region comprises undoped InGaIn quantum wells, and is followed by a thin electron barrier layer with high Al content and a 200 nm GaN:Mg contact layer. The quality of the AlGaIn/GaN buffer layers is very important for both the I - V characteristics and quantum efficiency of the LED.

The InGaIn quantum wells are grown under different conditions than the surrounding barriers. This leads to a higher crystal quality and proves to be necessary for high recombination efficiency. Special care has been taken to optimize the doping profile in the AlGaIn:Mg electron barrier and the subsequent GaN:Mg contact layer. A homogenous Mg concentration at the quantum well interface is necessary for efficient radiative recombination. Excessively high concentrations of Mg tend to disturb the interface, producing increased non-radiative recombination rates, whereas too low a concentration results in poor carrier injection behavior together with an increased forward voltage. The GaN:Mg layer has a very high Mg concentration of around $1 \times 10^{20} \text{ cm}^{-3}$ at the top surface to improve the ohmic properties of the p -contact.

Chip and Package Considerations

Although electrically-conducting SiC substrates offer many benefits compared to sapphire, both exhibit different optical properties that must be taken into account when designing LEDs. The refractive index of SiC is higher than that of sapphire, and

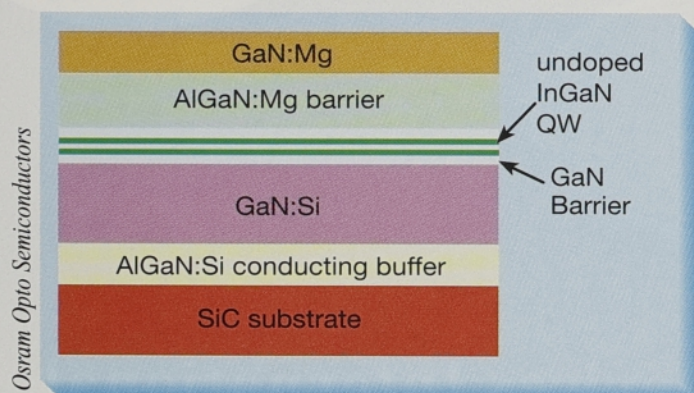


Figure 3. Osram Opto Semiconductors' blue LED device structure grown by MOCVD.

the doping necessary to achieve good conductivity leads to a slight absorption at wavelengths in the blue spectral range.

At Osram Opto Semiconductors we have analyzed the different modes of light extraction in SiC and sapphire-based LEDs to optimize the device performance of our SiC-based LEDs. The results of a far field pattern analysis for an GaN-on-SiC LED are shown in Figure 4a. The emission characteristics of SiC were compared with the characteristics of an ideal Lambertian emitter. The SiC-based LED follows the ideal Lambertian characteristics except for almost horizontal emission (Figure 4a), where it exhibits sideward intensity deviations. For a sapphire-based LED, however, these deviations are not found near the horizontal, but are more pronounced at latitudes towards the normal.

These differing characteristics can be explained by considering the light emerging from the active layer (Figure 4b). In the vertical direction, light is coupled out directly through the top of the mesa. Assuming an index of refraction of $n = 2.5$ for GaN, the angle of total reflection to the ambient air ($n = 1$) is 23° . This part of the emission gives rise to the Lambertian part of a far field pattern. However, at the side of the LED, only light from a narrow cone can be coupled out in a direct way because the epitaxial layer of GaN-based diodes is relatively thin (3 μm) compared to the lateral extent of the diode. Therefore, most of the light coupled out from the side-walls has suffered multiple reflections at the interfaces between GaN and air on top or between GaN and the substrate at the bottom. At the top of the device, total internal reflection will occur (partially attenuated by contact layers).

However, at the epitaxy/substrate interface, the reflectivity will depend on the substrate material. In the case of sapphire, the lower refractive index ($n = 1.7$) compared to GaN leads to the epitaxial layer behaving like a waveguide with a large numerical aperture, and a high fraction of sideward emission over a relatively large angular range is observed. However, the refractive index of SiC ($n = 2.7$) is higher than that of GaN ($n = 2.5$). Therefore, no total internal reflection occurs at the interface between SiC and GaN, and only light rays at grazing incidence angles will be reflected with relatively high efficiency. Thus, for the SiC-LED, we observe emission to the side in a small angular range of about 15° (see Figure 4a).

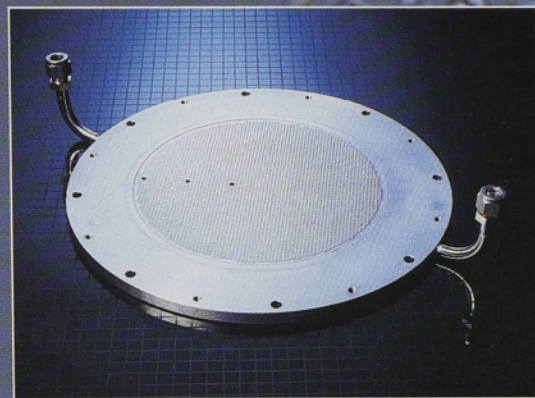
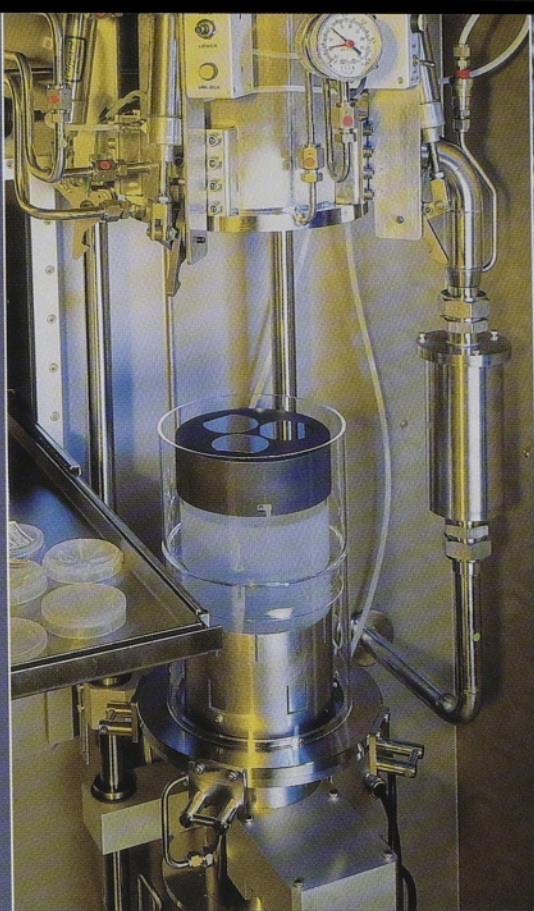
In general, we found that for sapphire the GaN epitaxial layer serves as a waveguide and emission to the side is important, but for SiC this channel is not as efficient and more light escapes through the substrate. For our SiC-based LEDs, a special chip design and optimized package design has since been developed. The combination of the new chip design together with the package and resin allows additional light out coupling through the substrate. The brightness improvement was as much as 80% compared to the standard device. The most promising results for improved light extraction efficiencies are shown in the Table.

Laser Diodes

The improvements in epitaxy and chip technology achieved for blue LED's have also had a positive effect on the development of short wavelength lasers. The typical device structure consists of

Thomas Swan Multi-Wafer MOCVD Systems

- Unique Close Coupled Showerhead (CCS) Technology
- True scaleable concept
- Proven technology for InP, GaAs and GaN production
- Production and R&D Equipment available in 1x2", 3x2", 6x2" and 18x2" configurations



Thomas Swan Scientific
Equipment Ltd

Buckingway Business Park
Cambridge CB4 5UG. UK

Tel: +44 (0) 1223 519444

Fax: +44 (0) 1223 519888

email: sales@thomasswan.co.uk

Web: www.thomasswan.co.uk



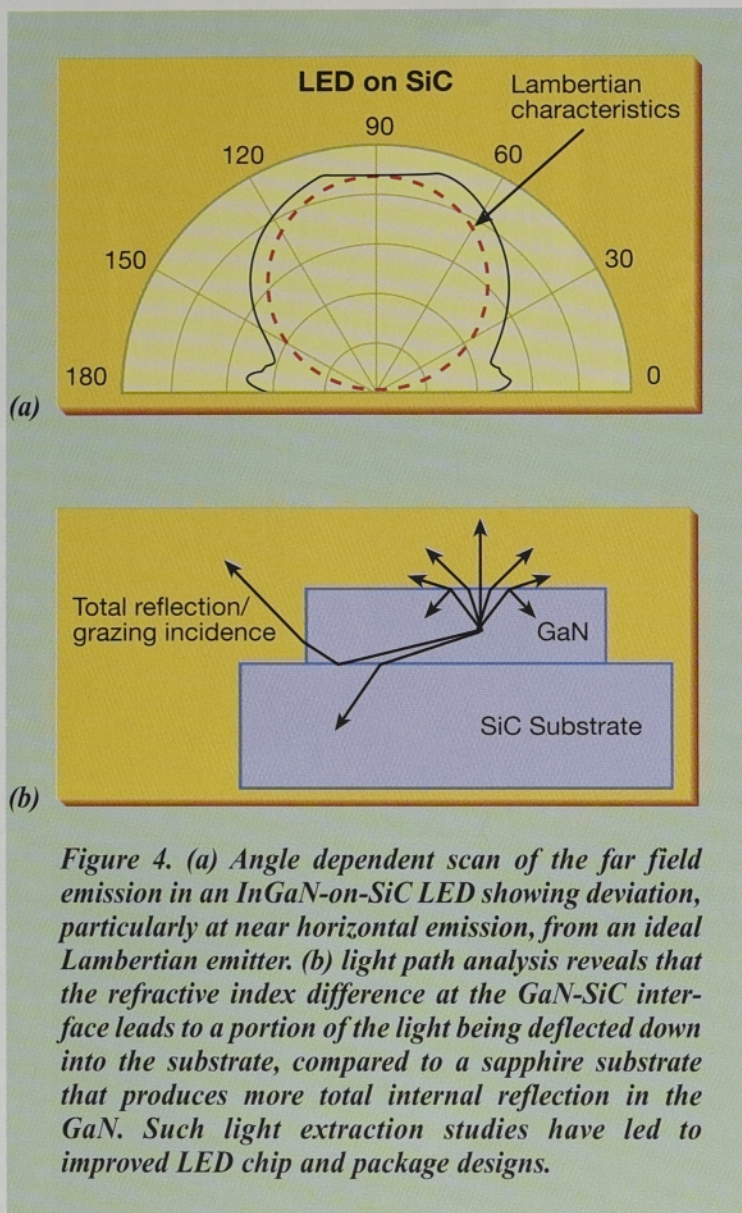


Figure 4. (a) Angle dependent scan of the far field emission in an InGaN-on-SiC LED showing deviation, particularly at near horizontal emission, from an ideal Lambertian emitter. (b) light path analysis reveals that the refractive index difference at the GaN-SiC interface leads to a portion of the light being deflected down into the substrate, compared to a sapphire substrate that produces more total internal reflection in the GaN. Such light extraction studies have led to improved LED chip and package designs.

a thick AlGa_N:Si cladding layer, a GaN:Si *n*-waveguide layer, a multiple quantum well active zone with 2 nm thick In_{0.15}Ga_{0.85}N quantum wells separated by GaN barrier layers, a thin AlGa_N:Mg electron blocking layer, a GaN:Mg *p*-waveguide layer, a AlGa_N:Mg cladding layer and a GaN:Mg contact layer. Using SiC as the substrate, it is possible to begin epitaxial growth directly with the *n*-AlGa_N cladding layer without the requirement of a low temperature nucleation layer. As the strain perpendicular to the growth direction is released after a few hundred nanometers, the *n*-cladding layer is not limited in thickness, and only limited in aluminum composition by a reduction in the ability to *n*-type dope at high aluminum fractions. Thus, the optical wave does not leak into the SiC substrate, where absorption becomes critical at wavelengths below 420 nm.

This structure allows fast, easy processing of gain guided lasers without the need to dry etch. In addition,

index-guided devices can be fabricated with modest technological effort. Both the possibility of using cleaved facets instead of dry etched facets (as usually performed on lasers with sapphire substrates) and the high thermal conductivity for effective heat dissipation makes SiC an attractive substrate choice, until bulk GaN with sufficient quality eventually becomes available.

Device Technology

The chip process used for gain guided lasers involved thinning the SiC substrate, followed by a Ni-Au based metallization. An isolating SiO₂ layer was deposited over the surface of the epi-wafer, and openings in this dielectric current blocking layer were subsequently created by photolithography and wet etching. The choice of stripe widths has been varied from 2 to 20 μm. For *p*-type ohmic contacts, various metallization schemes based on high work function metals such as Pt, Pd, and Ni with an Au overlay have been applied. After lithography and etching, the contacts were sintered at temperatures between 350 and 600°C for 1–5 minutes. Standard wafer cleaving methods were used to produce laser facets.

The cavity length in the laser was varied between 300 and 1200 μm. The cleaved facets of (Al,In)Ga_N lasers grown on SiC substrates are of high quality, exhibiting facet roughness of less than 1 nm (measured by AFM). To reduce the threshold current, dielectric coatings consisting of a stack of quarter wavelength layers of dielectrics were used at the front and backside facet. The backside mirror reflectivity of the laser cavity was measured to be 98%, while the reflectivity of the front face varied between 50% and 75% respectively, depending on the number of layers in the dielectric coating stack. Single lateral and transverse mode devices were produced using ridge waveguide structures, using reactive ion etching (RIE) in a BCl₃/Cl₂/Ar plasma to produce ridge patterning with smooth surfaces (Figure 5).

Laser Results

The laser characteristics were measured under pulsed current injection at room temperature. The pulse width was 150 ns with a duty ratio between 0.05% and 2%. At the threshold condi-

5 mm radial (450–470 nm) LED (radiant flux unless noted)	2nd generation LED	3rd generation LED (chip and package optimized by Osram Opto)
Blue LED@20 mA	4.2 mW	7 mW
Blue LED@40 mA	7 mW	11 mW
White LED@20 mA (luminous flux)	0.6 lm	1 lm

Table. Comparison of Osram Opto Semiconductors' blue and white LED technology (second generation LED) and recently optimized chip technology and package design (3rd generation LED) for (Al,In)Ga_N-on-SiC devices. Except for the white LED, units of radiant flux are used for unpackaged chips, as the luminous efficiency is a function of packaging and optics.

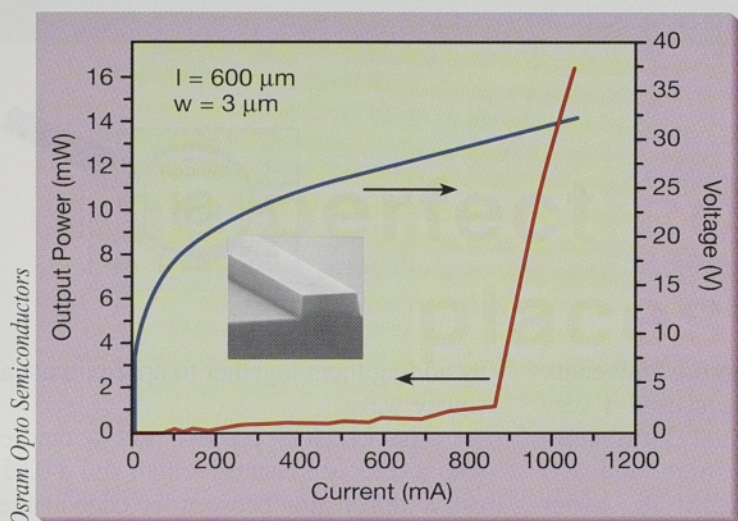


Figure 5. P-I and V-I diagram for a 416 nm laser with uncoated mirrors. Inset: RIE in a $\text{BCl}_3/\text{Cl}_2/\text{Ar}$ plasma was used to produce high quality surfaces on ridge patterned waveguide laser structures.

tion, the peak laser emission wavelength ranged from 393 to 428 nm. Laser emission was observed for stripe widths between 3 and 10 μm and cavity lengths of 300 to 1200 μm . For gain guided lasers, the best threshold currents (I_{th}) obtained were 330 mA for a 50% / 98% (front / back facet) coated 600 μm laser cavity with a stripe width of 3 μm . 600 μm stripe width devices with the highly reflecting mirror coating demonstrate threshold currents of 14.5 kA/cm² at a threshold voltage of 17 V. From measurements of the laser threshold of different cavity lengths and mirror coatings, the internal loss was estimated to be in the range 25 and 40 cm⁻¹. The good electrical confinement afforded by the epitaxial structure enables high temperature laser operation at 90°C under pulsed conditions. A characteristic temperature of between 200 and 290 K was evaluated in the 10°–90°C temperature range.

Osram Opto Semiconductors has made considerable technological advancements with InGaN-on-SiC lasers and LEDs. The company aims to continue improving the brightness of its LEDs in order to enable further solid-state lighting applications. Osram Opto also intends to improve short wavelength lasers in order to leverage potential new markets for these devices, including data storage and display applications.

Acknowledgement

The authors would like to acknowledge the partial support (laser research) of the German government (BMBF).

MAINTECH SAPPHIRES

Maintech, Inc. specializes in high-quality, semi-finished synthetic Sapphire for final processors, as well as epitaxial wafers for the end user.

- Sapphire Substrates for Blue LEDs: 2", 3" and 4"
- Superior Wafer Specifications for Orientation, Flatness and Surface Finish
- Prompt Delivery
- Exceptional Prices

THE DECISION IS CRYSTAL CLEAR!

Tel: 215-289-7861
Fax: 215-289-8657
e-mail: craigs@maintechinc.com
web site: www.maintechsapphires.com

1957-D Pioneer Road
Huntingdon Valley, PA 19006

MAINTECH
INCORPORATED

RF NITRO

GaN ON THICK SAPPHIRE
GaN ON THIN SAPPHIRE
GaN ON SiC

ACHIEVE OPTIMAL FABRICATION RESULTS WITH RF NITRO'S III-N SERIES OF GaN-EPITAXIAL MATERIAL

- RF Nitro's Patented FME Multi-Wafer Growth Technology
- 2" Doped and Undoped GaN-Based Transistor Structures
- Uniform Thickness and Al Composition
- Insulating GaN Buffer Layers
- High 2DEG Mobilities at High Sheet Densities
- Grown on Thick (0.013"), Thin (0.006") Sapphire, or SiC Substrates
- Optional GaN Buffer Thickness and AlGaN Barrier Dimensions Available
- High throughput 8x2 Reactor provides minimal wafer variance
- In-Stock for Expedited Delivery

For a Datasheet or Quotation, please contact RF Nitro Communications at:

RF NITRO
Communications Inc

10420 Harris Oaks Boulevard, Suite F • Charlotte, NC 28269
sales@rfnitro.com • tel 704.596.9060 • fax 704.596.0950

Cheap Integrated Power

ROBERT A. METZGER



Those in the CMOS community (without access to a BiCMOS process, where the bipolar component offers greater design latitude but at the expense of greater cost), will, when in the company of those in the wireless/RF arena, invariably point out that the least expensive way to implement a radio on a chip (full transceiver and baseband functions) is with a straight CMOS process.

Without getting into the controversy concerning the merits of single chip versus a module approach in the implementation of a radio, the wireless/RF engineer will rebut the CMOS engineer by explaining that while CMOS might be able to handle many RF functions such as the LNA, receive/transmit switch and up/down converters, the power amplifier remains a major challenge for CMOS technology.

Two research groups have recently reported progress in this area, by combining laterally diffused MOS (LDMOS) structures on a SOI substrate. In an LDMOS structure, as compared to a basic NMOS structure, rather than having a heavily doped n⁺ region butting against the edge of the gate, a lightly doped n⁻ region is used that results in significantly reduced gate-drain capacitance, and by tailoring of the width of the n⁻ region, the breakdown voltage can be significantly increased.

As a consequence of these characteristics, LDMOS devices in discrete form have made significant inroads into high power RF base station applications. However, in the case of an integrated front-end, the power amplifier requires inductors, which as a result of the lossy Si substrate are of poor quality and degrade the overall RF performance. Fortunately, using a SOI substrate greatly reduces substrate coupling, improving the inductor's Q-factor, and allowing the fabrication of adequate performance on-chip inductors.

The first group, from the University of Illinois at Chicago, have used a very basic CMOS logic process (1.2 μm) combined with a SOI substrate and LD regions to fabricate LDMOS power MOSFETs [1]. The SOI structure used consisted of a 400 nm buried oxide and a 200 nm epitaxial Si layer, with the LD regions formed by angled ion implantation to produce a lightly doped region that penetrated under the perimeter of the gate by a distance of approximately 0.6 μm .

The smallest device made had an effective channel length of 0.77 μm and exhib-

by adding them together to approximate a square wave.

The LDMOS process uses a device with a 0.35 μm channel length and a 3.85 μm n⁻ drift region between the edge of the gate and the drain contact. The resulting device exhibited an f_t of 4.5 GHz and breakdown voltage of 20 V.

On-chip inductors were fabricated atop a 3.0 μm oxide platform, delivering a Q-factor of 6.1 at 900 MHz and 7.2 at 1.8 GHz, with an inductance of 5.2 nH. In addition, the amplifier was fabricated with on-chip input and output matching networks, so that no external components were needed for amplifier operation.

At 900 MHz and with a 5 V supply, the amplifier delivered 23 dBm of output power with 16 dB gain and a 49%

PAE. While this power level shows improvement over those obtained by the University of Illinois effort (partially a consequence of the larger device dimensions), the power levels obtained with this LDMOS/SOI process were still only in the 200–300 mW level, which is significantly lower than that obtained using other device technologies.

However, it is expected that further improvement will be obtained through the reduction of dimensions of the device, in addition to improvements in Q-factors. What is important at this stage of research is not that these devices operate at the same performance level as the more expensive competition, but that they are operating at all—these being the first reports of RF SOI/LDMOS processes.

At 900 MHz, the Si LDMOS amplifier delivered 23 dBm of output power and a 49% PAE.

ited a breakdown voltage of 36 V, along with an I_{DS} of 165 mA (at a V_{DS} of 5 V). This device exhibited an f_t of 6.9 GHz and an f_{max} of 10.1 GHz, making it suitable for the commercially important 0.6 to 2.4 GHz region.

Using this LDMOS structure, a class A amplifier was fabricated, producing a PAE of 25% and a maximum output power of 115 mW at 1.0 GHz operation. While these performance values are well below that of III-V devices (or even Si BJTs), this nevertheless represents a first attempt for LDMOS on SOI.

A research group from Hong Kong University is also examining in more detail the compatibility of LDMOS/SOI for RF integrated power applications [2]. Tan and co-workers have reported on a fully integrated power amplifier, including the use of on-chip inductors. This power amplifier was configured for class E operation, in which the amplifier is turned on and off periodically. As a consequence, the power transistor requires a square wave input to toggle it on and off. This square wave is generated using various harmonics of the input frequency and

References:

- [1] K. Shenai et al, *IEEE Electron Device Letters*, October 2000, Vol. 21(10), p. 500.
- [2] Yue Tan et al, *IEEE Journal of Solid-State Circuits*, October 2000, Vol. 35(10), p. 1481.

**The perfect combination
places you in paradise.**



The best choice of a bright business

*Looking for cost down of your compound semiconductor epiwafer ,
a stable quality of volume demand,
or an alliance business in your design stage
— UEC's MOVPE technology is your best choice.*

Products & Service

**2", 3", 4" and 6" Mass production of III-Vs epitaxial
wafers & chips: AlInGaP, InGaN, AlGaAs, InGaAsP**

Device

AlInGaP UHBLED (560~650nm)

Visible LD, LED · Infrared LD, LED · VCSEL Laser · DBR Laser

HBT MMIC · P-HEMT MMIC

Applications

Full color display, Traffic signal, Automotive, Aerospace, Optical storage, Telecommunication, Wireless, Satellite.

INTRODUCING A NEW COMPOUND SEMICONDUCTOR EQUIPMENT COMPANY YOU'VE KNOWN FOR 15 YEARS.

EPI MBE Products Group is now Applied Epi. We're taking a new name because we've become more than the premier MBE components company. We now offer the industry's most productive compound semiconductor manufacturing tools — bar none.

We will continue to develop today's most advanced MBE components and research systems. But now, we're integrating our MBE expertise with proven standards and architecture from the silicon semiconductor equipment industry to create the world's most innovative, most cost-effective and highest capacity tools for MBE production.

With our new production systems, you can capture your share of the explosive compound semiconductor market and put your fab on the fast track. Without Applied Epi tools you simply won't run fast enough to keep up.

To learn more about Applied Epi — and our new, high-throughput MBE production systems — call us at (651) 482-0800.

You can also visit www.applied-epi.com/new
or send email inquiries to info@applied-epi.com.

Applied Epi