



COMPOUND

SEMICONDUCTOR

January/February 1997

Volume 3 Number 1

9 Things to Watch in 1997



Cell Phones



Fiber



Television



DVD



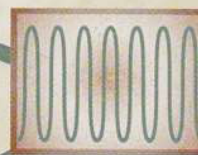
Satellites



LED's



Automotives



Microwaves

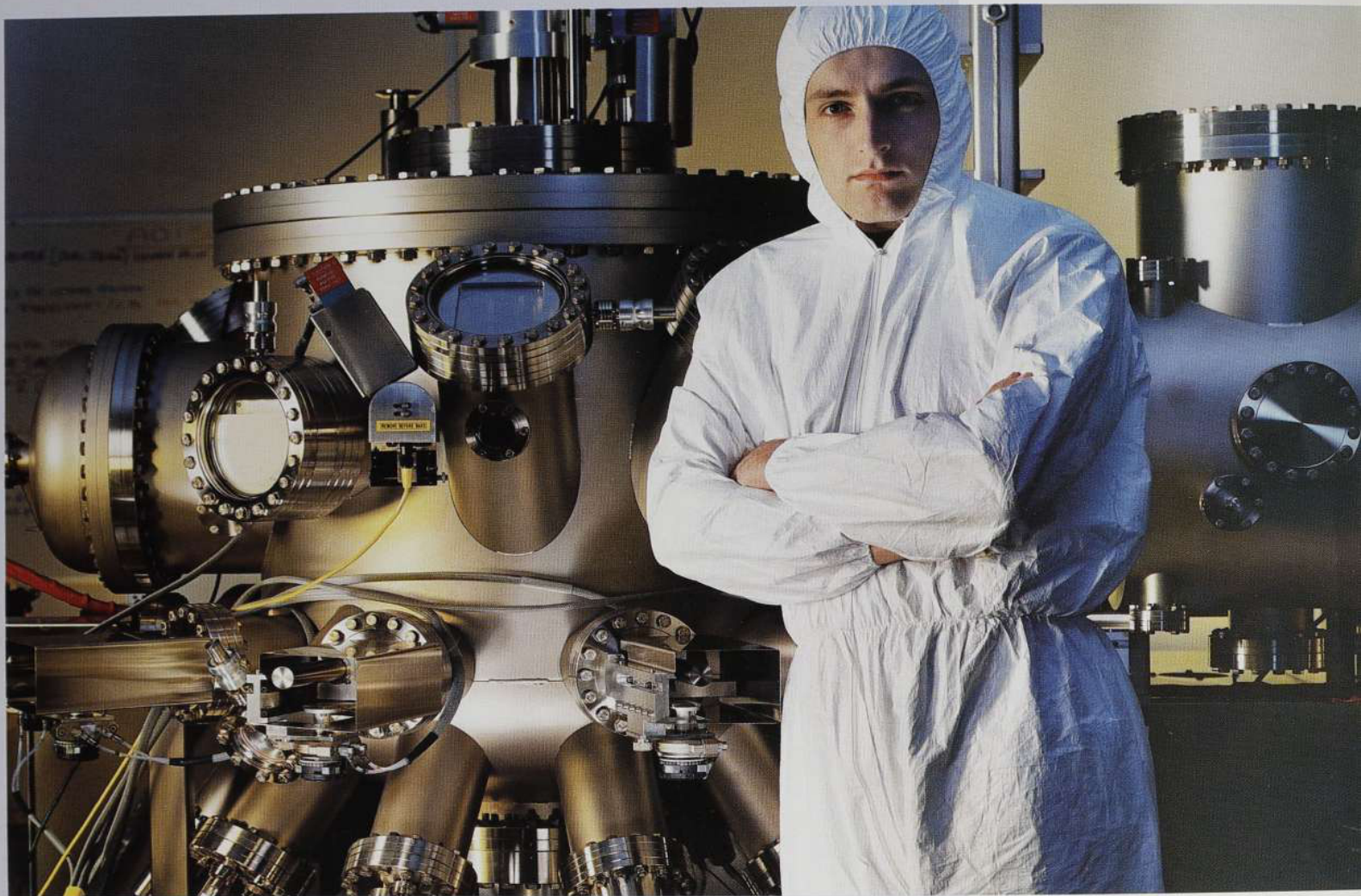


Military



He knows he's got the world's best MBE system. Wouldn't you like that peace of mind?

VG SEMICON



If you buy MBE epi GaAs, chances are it was grown on a V100. So if you're thinking of purchasing a production MBE system, the choice is easy.

All the world's leading epi companies choose the V100. Not simply because it is the best product. But also because we deliver on time, get you up and running quickly and give you great training and documentation. Our experienced worldwide team then provides direct help with technical and applications information and fast response for consumables and service.

The V100 has the highest throughput capacity for 3", 4" and 6" GaAs wafers for the lowest cost per wafer and the highest return on investment. Designed for high uptime in the production environment, our simple, uncomplicated designs are rugged, reliable and easy to maintain. Our proven automation technology minimizes wafer handling for low contamination and exceptional reproducibility.

Quite simply, the V100 delivers the best epi material, time and time again. For more information on the only MBE systems that come with peace of mind, why not call us. Or check us out on the Internet at <http://www.surface.fisons.co.uk/>

VG SEMICON - United Kingdom

The Birches Industrial Estate, Imberhorne Lane
East Grinstead, West Sussex, RH19 1XZ, UK.
Tel. +44 1342 325011, Fax. +44 1342 315800.
e-mail: sales@surface.fisons.co.uk

CHINA. VG China, Apt. 1008, Beijing Yanshan Hotel,
138A Haidian Road, Beijing 100086.
Tel. (86) 10 2564811.

FRANCE. Fisons Instruments, 85 Avenue Aristide
Briand, 94117 Arcueil, Paris. Tel. (1) 4740 4819.

GERMANY. Fisons Instruments, Postfach 73,
Peter-Sander-Strasse 43, 55252 Mainz-Kastel.
Tel. (6134) 2890.

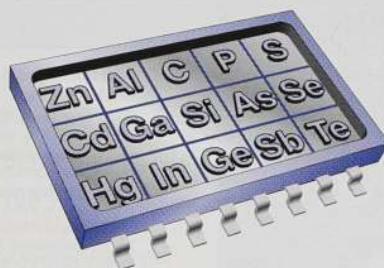
JAPAN. Marubun Corporation, 8-1 Nihombashi
Odenmacho, Chuo-ku, Tokyo 103.
Tel. (81) 33 639 9652.

KOREA. VG Instruments Korea,
Ssang Bang Building 4F, 210 Nonhyun-Dong,
Kangnam-gu, Seoul. Tel. (2) 548 2983.

SWEDEN, NORWAY, FINLAND.
Fisons Instruments Nordic AB,
Gardsfogdevagen 16, S-16170 Bromma.
Tel. (8) 629 2400.

TAIWAN. Scientek Corporation, 4F, No. 2, Lane 47,
Nankang Road, Sec. 3, Taipei. Tel. (8862) 788 7841.

USA. Fisons Instruments, 55 Cherry Hill Drive,
Beverly, MA. 01915. Tel. (508) 524 1000.



COMPOUND

SEMICONDUCTOR

COVER STORY

21 9 Things to Watch in 1997

Some of the top reasons why this looks like a good year for the compound semiconductor industry

OTHER FEATURES

6 Nitride News

Nichia demonstrates CW operation of a GaN laser

10 Device Feature

Motorola introduces a PHEMT for Cellular Applications

17 Conferences

Reports from the 1996 IEDM and LEOS Annual Meeting

32 Forum

Prof. Russell Dupuis of the University of Texas describes the current status efforts to realize a useful native oxide for III-V materials.

DEPARTMENTS

2 Calendar

4 Company Index

35 Research Review

38 Patents

43 Portfolio

44 Employment

NEWS

8 New Devices

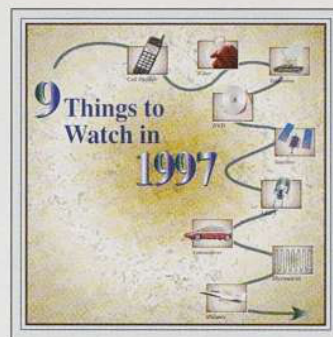
HP prototypes VCSELs & F-P lasers for LANs...first products from Philips/TriQuint collaboration...NEC Heterojunction FET.

11 News Briefs

The wake shield facility flies again...IEEE and LEOS awards.

13 News From Japan

New microelectronic and optoelectronic products...R&D news...rising gallium prices...falling wafer sales.



On the cover: 9 hot applications. Coverage begins on page 21.

Compound Semiconductor

is published six times yearly by Franklin Publishing
250 Selby Avenue
Suite 48

Saint Paul, MN 55102 USA
Tel [1] 612 227 5397
FAX [1] 612 227 5499

Individual annual subscription price: \$75 U.S., \$90 foreign.
Library rate: \$250 U.S. and foreign.

©Copyright 1997
by Franklin
Publishing - all rights reserved.

POSTMASTER

Second class postage paid at Waconia, MN and at additional mailing offices.

Send address changes to:
CS Subscriptions
250 Selby Avenue
Suite 48
Saint Paul, MN 55102 USA

Editor

Marie Meyer
Franklin Publishing
250 Selby Avenue
Saint Paul, MN 55102 USA
Tel [1] 612 227 5397
FAX [1] 612 227 5499
mmeyer@compsem.com

Microelectronics

Robert A. Metzger
Compound Semiconductor
6605 Williamson Dr. NE
Atlanta, GA 30328 USA
Tel [1] 404 705 8475
FAX [1] 404 255 9867
rametzger@aol.com

Contributing Editors

Optoelectronics

Gary Wicks
University of Rochester
Institute of Optics
Rochester, NY 15627 USA
TEL [1] 716 275 4867
FAX [1] 716 244 4936
wicks@optics.rochester.edu

Materials

Colombo Bolognesi
Simon Fraser University
Physics Department
Burnaby, BC V5A 1S6, Canada
TEL [1] 604 291 5964
FAX [1] 604 291 4951
colombo@cs.sfu.ca

UPCOMING EVENTS

1997 IEEE Int'l Solid-State Circuits Conf.

February 6-8, 1997 in San Francisco, CA, USA.
TEL [1] 202 639 4255 FAX [1] 202 347 6109
Net or Web: isscc@mcimail.com

Photonics West 1997

February 8-14, 1997 in San Jose, CA, USA.
TEL [1] 360 676 3290 FAX [1] 360 647 1445
Net or Web: PW97@spie.org

OFC '97

February 16-22 in Dallas, TX
Contact: OSA
TEL [1] 202 223 0920 FAX [1] 202 416 6100
Net or Web: osamem@osa.org or
http://www.osa.org

1997 Spring Meeting of the MRS

March 31-April 4, 1997 in San Francisco, CA.
TEL [1] 412 367 3004 FAX [1] 367 4373
Net or Web: http://www.mrs.org
See ad, page 4

Euro-MBE IX

April 6-10, 1997 in Oxford, England
Contact: Di Pullar-Macmillan
Imperial College
TEL [44] 44 171 581 3817 FAX [44] 171 581 3817

OMVPE- VIII

April 13-17, 1997 in Dana Point, CA, USA
TEL [1] 412 776 9000 FAX [1] 412 776 3770
Net or Web: csc@tms.org

IPRM '97

May 11-15 on Cape Cod, MA.
Contact: Stephen Forrest
Princeton University
TEL [1] 609 258 3000 FAX [1] 609 258 1954
Net or Web: forrest @ ee.princeton.edu

CLEO/QELS '97

May 18-23, 1997 in Baltimore, MD
Contact: OSA
TEL [1] 202 223 0920 FAX [1] 202 416 6100
Net or Web: osamem@osa.org or
http://www.osa.org

GaAs MANTECH '97

June 2-5, 1997 in San Francisco, CA
Contact: Terri Lockhart
Connections Plus
TEL [1] 908 747 3075 FAX [1] 908 741 1009
Net or Web: gaas@ee.wustl.edu or
http://www.ee.wustl.edu/GaAs/

IEEE RFIC Symposium

June 9-10, 1997 in Denver, CO
Contact: Louis C.T. Liu
TRW
TEL [1] 310 812 8372 FAX [1] 310 814 4656 or
Net or Web: louis.liu @ gmail2.sp.trw.com
http://www.ieee.org/mtt.html

If you would like your conference to be included in future issues, send the appropriate information by E mail to calendar@compsem.com, or by FAX to [1] 612 227 5499, attention "Calendar"

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

4th Wide Bandgap and Nitride Workshop

The 1997 edition of this workshop will be held March 11-14, 1997 in St. Louis, MO. The organizers plan to provide a forum for the exchange of ideas and invite all attendees to participate in the discussion of topics in areas covered by their own research.
Abstract Submission Deadline: February 3, 1997
Contact: Prof. R. D. Dupuis
Microelectronics Research Center
The University of Texas at Austin
PRC-MER 1.606D-R9900
Austin, TX 78712-1100 USA
TEL [1] 512 471 0537 FAX [1] 512 471 8575
NET dupuis@mail.utexas.edu

7th European Workshop on Metal-Organic Vapor Phase Epitaxy

EW MOVPE will be held June 8-11, 1997 in Berlin, Germany. This conference aims to bring together scientists and engineers actively engaged in MOVPE, VPE and CBE/MOMBE growth of compound semiconductor materials.
Abstract Submission Deadline: February 28, 1997
Contact: Dr. Wolfgang Richter
Technische Universität Berlin
Hardenbergstr. 36
D-10623 Berlin Germany
TEL [49] 30 3142 2078 FAX [49] 30 3142 1769
Net or Web: richter@gift.physik.tu-berlin.de or
http://www.hhi.de

2nd European GaN Workshop

EGW-2 will be held June 11 - 13, 1997 near Cannes, France. The scope will encompass all areas of research relating to the physical properties, crystal growth, epitaxial growth, doping, processing and device applications of the Group III-Nitride semiconductors.
Abstract Submission Deadline: March 1, 1997
Contact: Jean-Pierre Faure
CRHEA-CNRS Sophia Antipolis
Rue Bernard Gregory
F 06560 Valbonne France
TEL [33] 4 9395 4220 FAX [33] 4 9395 4142
Net: jpf@arheal.unice.fr
Web: http://www.crhea.unice.fr/EGW-2/index.htm

1997 Electronic Materials Conference

The 39th EMC will be held at Fort Collins, CO, USA on June 25-27, 1997. This conference provides a forum for topics of current interest and significance in the areas of preparation and characterization of electronics materials. Individuals actively engaged or interested in electronic materials research and development are encouraged to attend this meeting, and papers in this general subject area are solicited.
Abstract Submission Deadline: February 17, 1997
Contact: TMS, Customer Service Department
420 Commonwealth Drive
Warrendale, PA 15086 USA
TEL [1] 412 776 9000 x241 FAX [1] 412 776 3770
NET csc@tms.org

7th Int'l Symp. On Silicon Molecular Beam Epitaxy

7th Si-MBE will be held July 13-17, 1997 in Banff, Canada. This conference provides specialists in the field with a unique forum to assess progress in all aspects of Si-based MBE. This year, in addition to the regular technical sessions, special rump sessions are planned to discuss the future of Si-MBE in microelectronics research and of SiGe materials as an alternative to GaAs.
Abstract Submission Deadline: TBA
Contact: P. Lamoureux
National Research Council
Ottawa, ON K1A 0R6 Canada
TEL [1] 613 993 9431 FAX [1] 613 993 7250
NET mbe97@nrc.ca
Web: http://www.nrc.ca/confserv/

19th Int'l Conf. On Defects in Semiconductors

ICDS '97 will be held July 21-25 in Aveiro, Portugal. It covers a broad range of topics concerned with the fundamental properties of defects and impurities in semiconductors, such as Si, diamond, III-V's including nitrides, II-VI's, low-dimensional structures, including delta-doping, experimental and theoretical advances, and others.
Abstract Submission Deadline: February 22, 1997
Contact: Dr. Maria Helena Nazare
Departamento de Física
Universidade de Aveiro
3810 Aveiro Portugal
FAX [351] 34 24965
Web: http://www.ua.pt/event/icds97/

CALL FOR PAPERS

6th Int'l Symp. On Recent Advances in Microwave Technology

ISRAMT '97 will be held August 4 - 7 in Beijing, China. It will feature papers on all areas of microwave technology and its applications.
Abstract Submission Deadline: February 15, 1997
Contact: Prof. Bannali Rawat
Univ. of Nevada, Reno
EE Department
Reno, NV 89557-0153 USA
TEL [1] 702 784 1457 FAX [1] 702 784 6627
NET rawat@ee.unr.edu

IEEE Summer Topical Meetings

The IEEE will hold five topical meetings August 11 - 15, 1997 in Montreal, Canada. They are: GaN Materials, Processing, and Devices; Vertical-Cavity Lasers; Technologies for a Global Information Infrastructure; WDM Components Technology; and Advanced Semiconductor Lasers and Applications.
Abstract Submission Deadline: March 24, 1997
Contact: IEEE/LEOS '97
Summer Topicals 1997
445 Hoes Lane
Piscataway, NJ 08855-1331 USA
TEL [1] 908 562 3897 FAX [1] 908 562 8434

Eight International Conference on II-VI Compounds and Devices

II-VI '97 will be held August 25 - 29, 1997 in Grenoble, France. The conference will focus on fundamental aspects and on recent perspectives for applications of narrow and wide bandgap II-VI semiconductors. Areas of interest include: materials science, where many long-standing problems (particularly compensation) are still to be solved, low dimensional physics including semimagnetic heterostructures, and optoelectronic applications.
Abstract Submission Deadline: March 15, 1997
Contact: Le Si Dang
II-VI Conference Secretariat
Laboratoire de Spectrométrie Physique
Université J. Fourier - Grenoble 1, BP 87
F-38402, Saint Martin d'Hères Cedex France
FAX: [33] 76 51 45 44
Net or Web: lesidang@spectro.grenet.fr

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

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

III-V Nitride Materials and Processes Symposium

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

5th European GaAs Applications Symposium

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

24th International Symposium on Compound Semiconductors

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

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

ICCBCE 6 will be held September 8-10, 1997 in Montreux, Switzerland. The scope of this meeting is the entire spectrum of CBE, MOMBE, GSBCE, as well as related growth technologies. Mechanisms and processes of growth and film properties directly related to the growth process are the main focal points, but relevant characterization techniques, physical properties and the relation between materials and device properties are equally addressed.
Abstract Submission Deadline: April 1, 1997
Contact: Dr. Alok Rudra
Swiss Federal Institute of Technology
Institute for Micro and Optoelectronics
CH-1015 Lausanne Switzerland
FAX [41] 21 693 54 90
Net or Web: rudra@eldp.epfl.ch

16th North American Conference on Molecular Beam Epitaxy

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

1997 IEEE GaAs IC Symposium

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

2nd Int'l Conf. On Nitride Semiconductors

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

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

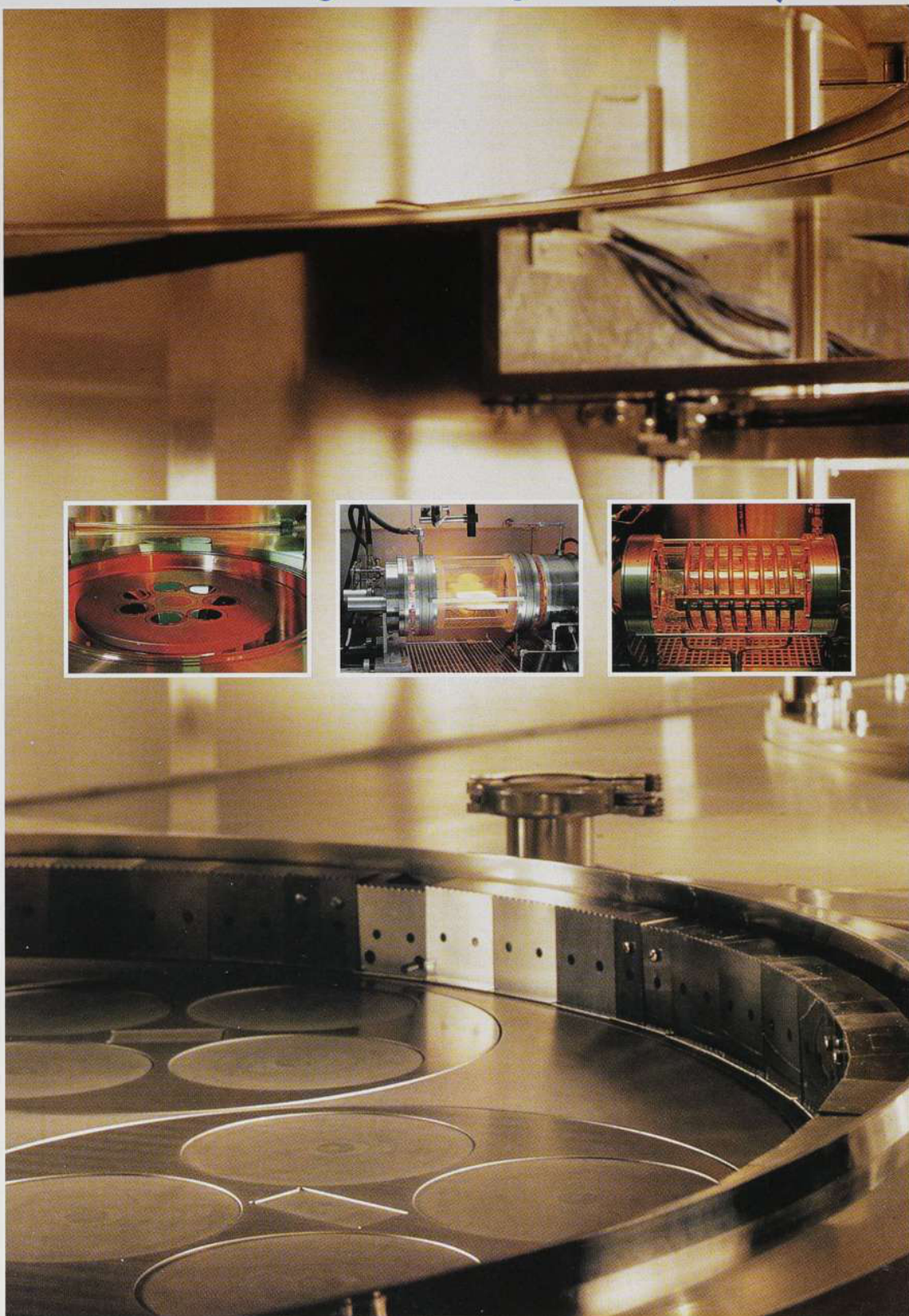
AIXTRON®

European Headquarters
Aachen, Germany
AIXTRON GMBH
Kackertstraße 15-17, 52072 Aachen
Germany
Phone: +49 (241) 89 09 - 0
Fax: +49 (241) 89 09 - 40
Customer Service Line
Phone: +49 (241) 89 09 - 91

US Headquarters
Chicago, IL
AIXTRON Inc.
1569 Barclay Blvd.
Buffalo Grove
IL 60089, USA
Phone: +1 (847) 215 - 73 35
Fax: +1 (847) 215 - 73 41

Sales and Service
Tokyo, Japan
Moritani & Co., Ltd /AIXTRON
2nd Section, 3rd Machinery Dept.
4th Sales Division
1-4-22 Yaesu, Chuo-Ku
Tokyo 103, Japan
Phone: +81 (3) 32 78 - 61 31
Fax: +81 (3) 32 78 - 61 21

<http://www.aixtron.com>



SPRING '97

1997 SPRING MEETING

MARCH 31- APRIL 4, 1997
SAN FRANCISCO, CALIFORNIA

EXHIBIT: APRIL 1-3

- **NEW MATERIALS DEVELOPMENT**
- **NEW CHARACTERIZATION METHODS**
- **NEW PROCESS TECHNOLOGY**

1997 SPRING MEETING SYMPOSIA

- A: Amorphous and Microcrystalline Silicon Technology - 1997
- B: Epitaxial Growth - Principles and Applications
- C: Processing of Compound Semiconductors for High-Speed Devices
- D: Gallium Nitride and Related Materials
- E: Defects and Diffusion in Silicon Processing
- F: Rapid Thermal and Integrated Processing VI
- G: Flat Panel Display Materials and Large-Area Processes
- H: Organic Electronic Materials and Devices
- I: Polycrystalline Thin Films III - Structure, Texture, Properties, and Applications
- J: Materials Reliability in Microelectronics VII
- K: Multilevel Process Integration
- L: Epitaxial Oxide Thin Films
- M: Magnetic Ultrathin Films, Multilayers, and Surfaces
- N: Low-Dielectric Constant Materials and Applications in Microelectronics
- O: Materials/Failure Analysis for Silicon ULSI Processing
- P: Science and Technology of Semiconductor Surface Preparation
- Q: Thermoelectric Materials - New Directions and Approaches
- R: Materials Issues Related to Development of Textured High-Temperature Superconducting Conductors
- S: Materials for Optical Limiting II
- T: Computational Materials Science at the Mesoscale
- U: Rapid Prototyping and Solid Freeform Manufacture
- V: Interfacial Effects and Organization of Inorganic-Organic Composite Solids
- W: Metastability and Critical Phenomenon in Polymer Phase Behavior
- X: Frontiers of Materials Research
- Y: Materials in Sports and Recreation
- Z: Workshop on Specimen Preparation for Transmission Electron Microscopy of Materials IV

For additional meeting information or to request a Call for Papers booklet, a detailed 1997 Spring Meeting Program Book, or information on symposium tutorials, publications, exhibit, career services center, or symposium aides, contact:

MRS Member Services

9800 McKnight Road
Pittsburgh, PA 15237-6006
Telephone (412) 367-3003
Fax (412) 367-4373
E-mail: info@mrs.org
MRS Website (<http://www.mrs.org>)

The MRS 1997 Spring Meeting will serve as a key forum for discussion of interdisciplinary leading-edge materials research from around the world. Various meeting formats — oral, poster, round-table, forum and workshop sessions — are offered to maximize participation.

Organization Index

Companies, Universities
and Laboratories appearing in this issue.

Company/Organization Page

A, B, C

Alcatel	22
Alpha	43
Anadigics	21, 22, 24, 26
APA Optics	17, 35
ATMI	43
Bell Labs	17, 42, 37
Cairo Univ.	35
Cambridge Univ.	42
Canon	41
Citizen	14
Cornell Univ.	35
Cree	43

D, E, F, G

Daimler-Benz	35, 38
Dowa Mining	15,
Ericsson	22
ETRI (Korea)	38, 40
Ferdinand Braun Inst.	17, 35
France Telecom	39
Fuji	37, 39
Fujitsu	13, 18
Furukawa	39, 41

H, I, J, K

Hewlett-Packard	8, 19, 28, 30, 31
Hitachi	40
Hitachi Cable	15
Honeywell	40
Hughes Research	35, 38, 40, 41
IBM	35, 38
Inst. Fur Halbleitertechnik	36
ITRI (Taiwan)	38
Intevac	41
JPL	18
Kulite	41

L, M, N, O

Loral	40
Lucent	22, 23, 40
Matsushita	14, 15, 22, 26, 38, 39
Meijo University	12, 17
MIT Lincoln Labs	37
Mitsubishi	13, 22, 26, 38, 39, 40
Mitsui Petrochemical	14
Motorola	10, 19, 22, 38, 40
Murata	38
NEC	8, 13, 14, 22, 26, 38, 40, 41
New Japan Radio	13
Nichia Chemical	6, 12, 15, 19, 30, 38
Nippondenso	41
Nokia	22
Nortel	22, 24
Northrup Grumman	17
NTT	15, 35, 40

P, Q, R

Philips	8, 19, 22, 39
Pioneer	42
Qualcomm	22
Rasa Industries	15
Raytheon	27, 30, 31, 38
Rockwell	35
Rohm	26, 39, 41

S, T

Sandia	37
Sanyo	22, 26, 40
SBRC	40
SDL	19, 43
Seiko	40
Sharp	22, 26, 38, 40, 41
Shin-Etsu	41
Simon Fraser Univ.	35
Sony	15, 19, 22, 26, 38
Stanford University	18
Sumitomo Chemical	38, 15
Sumitomo Electric	39, 41
Sumitomo Metal	15
SVEC	11
Swiss Fed. Inst. of Tech.	36
Tampere Univ.	37
Texas Instruments	17, 40, 41
3M	19, 39
Toshiba	18, 22, 26, 39
Toyoda Gosei	38
TriQuint	8, 21, 43
TRW	30, 38
Tutcore	37

U, V, W, X, Y

U.S. Army	36, 40
UMS	30
Univ. of Ca. Berkeley	36
Univ. of Ca Santa Barbara	12, 18, 42
University of Florida	12
Univ. of Houston	11, 39
Univ. of Illinois	32, 35, 40, 41
Univ. of Texas	32
Univ. of Tokyo	12, 18
Univ. of Virginia	35
Univ. of Wisc.	19
Vitesse	21, 23, 43
Vixel Corporation	40
Waseda University	15
Westinghouse	26
Xerox	41

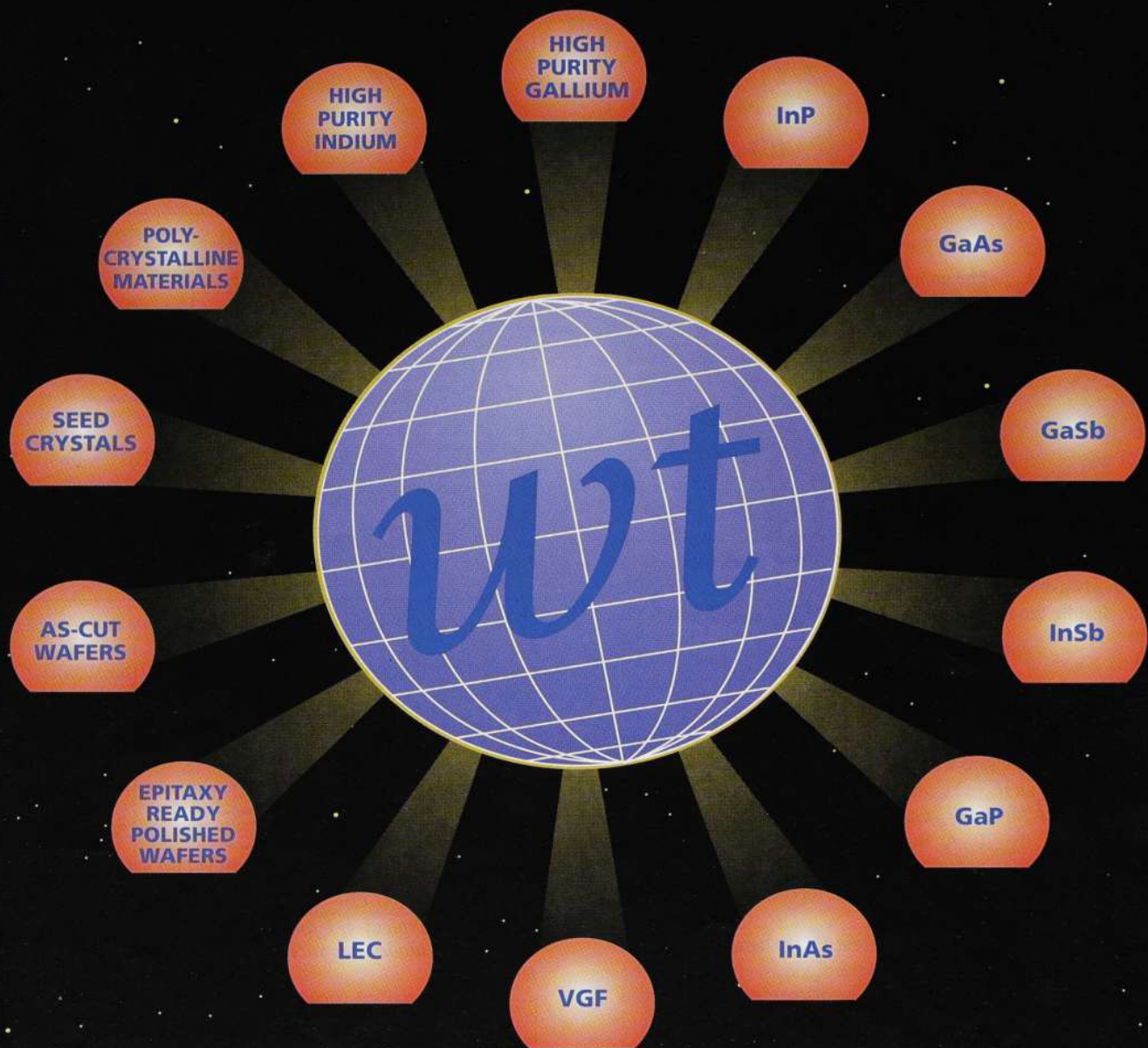
Advertiser Index

Company	Page
Advanced Ceramics	16
AIXTRON	3
American Xtal Technology	29
Bio-Rad Micromesurements	IBC
CTA	19
CVD Products	13
Dynatex International	9
Emcore	OBC
EPI MBE Products	25
EpiGress	37, 39, 41
GaAsNet	11
Litton Airtron	20
Morton International	14
MRS	4
Solkatronic Chemicals	7
Struers/Logitech	18
VG Semicon	IFC
Wafer Technology	5

Also New in this Issue

In addition to the Organization Index, this issue contains another new regular feature: coverage of recently issued compound semiconductor-related U.S. patents. See page 38.

The Universal Choice



With an unrivaled range of crystal growth techniques and leading-edge finishing procedures Wafer Technology provides you with III-V materials tailored to your requirements.

Whatever your substrate demands we're equipped to respond.
Wafer Technology – for all your III-V needs



WAFER TECHNOLOGY LTD
34 MARYLAND ROAD • TONGWELL • MILTON KEYNES MK15 8HJ • UK
TEL: +44(0)1908 210444 • FAX: +44(0)1908 210443

Quality system
approved to
BS EN ISO
9002:1994

Nichia Demonstrates CW Nitride Laser Operation

New announcement caps an incredible year for GaN laser research, closes the gap on the best II-VI lifetime results

Just eleven months after he announced the first ever observation of lasing action in a GaN-based structure, Shuji Nakamura of Nichia Chemical Industries announced the first successful room temperature continuous wave operation of a nitride laser. His report, which was given first at the LEOS meeting in Boston in mid-November, came just a few weeks after his first report of low temperature CW operation (CS 2(6), p. 13), and it capped off a truly amazing year in the field of nitride research.

How amazing? Consider Figure 1, which was part of Nakamura's announcement. Given that he has been able to go from zero to 35+ hours of room temperature CW operation in less than a year, he believes that he will soon eclipse the best mark reported to date for a shortwavelength II-VI laser diode (100 hours - see CS 2(2), p. 7). This despite the fact that the II-VI's have had a four-year head start.

Device Structure

The device used was a separate confinement heterostructure (SCH) InGaN multi-quantum well (MQW) diode, shown in Figure 2. The active layer was an $\text{In}_{0.15}\text{Ga}_{0.85}\text{N}/\text{In}_{0.02}\text{Ga}_{0.98}\text{N}$ MQW structure consisting of four 35 Å thick $\text{In}_{0.02}\text{Ga}_{0.98}\text{N}$ well layers forming a gain medium separated by 70 Å thick $\text{In}_{0.15}\text{Ga}_{0.85}\text{N}$ barrier layers. Nakamura says that the structure of the ridge-geometry diode was "almost the same" as that described in earlier reports of pulsed operation - for example, APL 69, 1477.

Figure 3 shows typical voltage-current (V-I) characteristics and the light output power per coated facet of the diode as a function of the forward DC current (L-I) at RT. No stimulated emission was observed up to a threshold current of 80 mA, which corresponded to a threshold current density of 3.6 kA/cm². The operating voltage at the threshold current was 5.5V.

Figure 4 shows the results of a lifetime test of the diodes under CW operation at room temperature. The operating current is shown as a function of time under a constant output power of 1.5 mW per facet controlled using an autpower controller. The operating current gradually increases due to the increase in the threshold current from the initial stage. The limit for this diode was around 27 hours; since this first report lifetimes of >35 hours have been achieved.

The laser emission was fundamental single mode emission with a peak wavelength of 405.83 nm. Nakamura predicts that further improvements in lifetime will be obtained by reducing the threshold current and voltage.

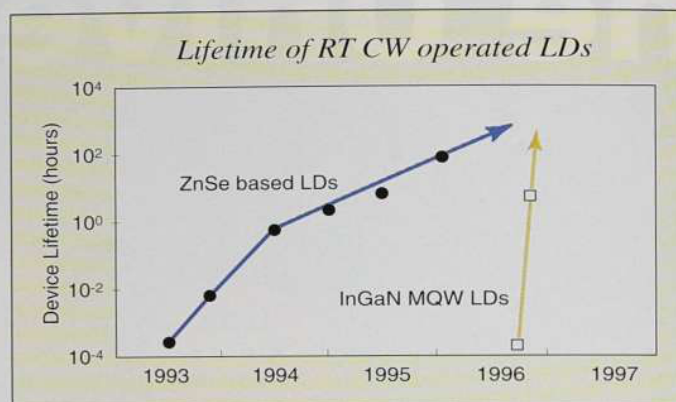


Figure 1. Nakamura's perspective on the blue laser race.

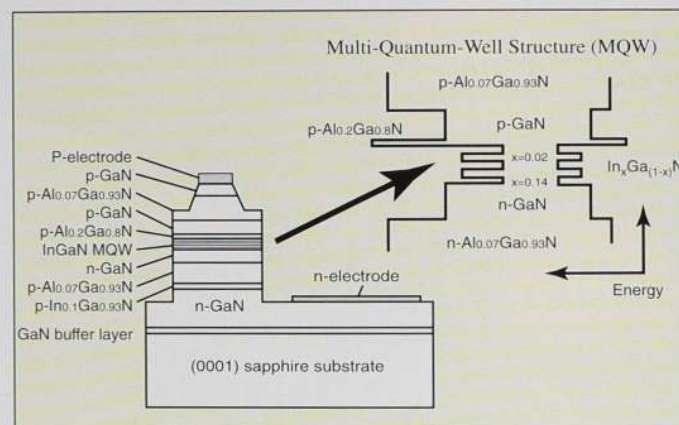


Figure 2. Structure of the successful diode.

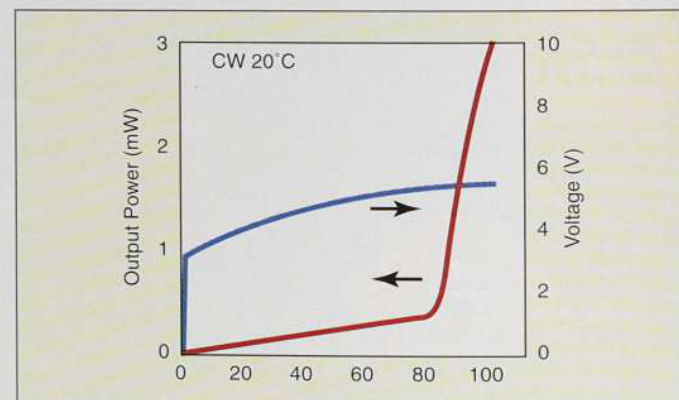


Figure 3. Typical L-I and V-I characteristics of InGaN MQW laser diodes measured under CW operation at room temperature.

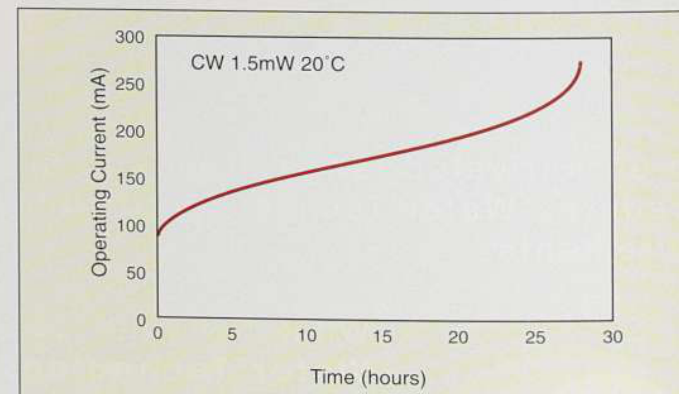
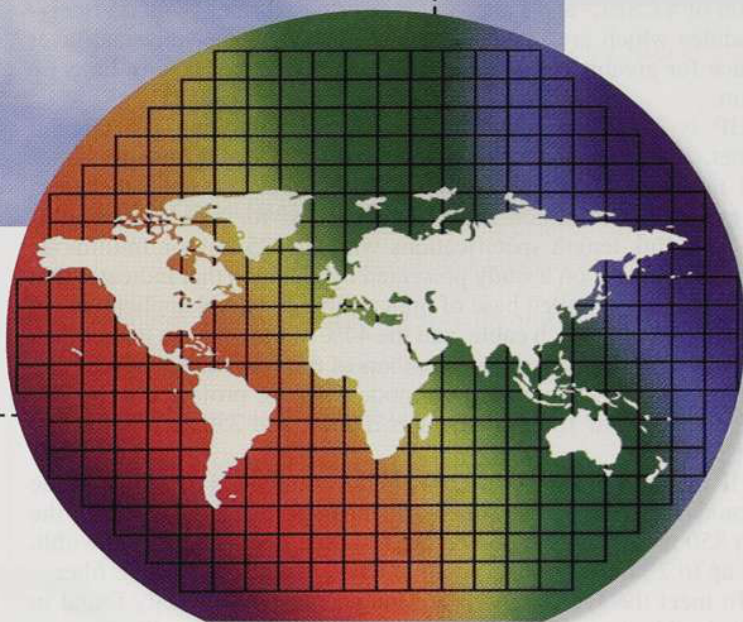


Figure 4. Operating current as a function of time under a constant output power of 1.5 mW per facet.

MEGA PERFORMANCE

MEGA PURITY

MEGABIT® II



Take your semiconductor process to a higher grade of purity and performance! Megabit® II, the next generation of high purity specialty gases from Solkatronic Chemicals, can take you there.

Megabit® II gases ensure performance consistency that maximizes yield. From Arsine to Phosphine, the Megabit® II gases are measured for ppb impurity levels. Solkatronic performs trace metals analyses on both gaseous and liquid phases. Megabit® II gases are delivered pure, and stay pure, in microPure® cylinders.

For more information on how to get mega purity and mega performance in your process with Megabit® II, call Solkatronic today.

MEGABIT® II GASES

Gas	Purity
Arsine	99.99994%
Ammonia	99.9997%
Chlorine	99.999%
Hydrogen Chloride	99.9995%
Nitrous Oxide	99.9998%
Phosphine	99.9999%

TRACE METALS ANALYZED

Sn	Mn
Zn	Cr
Sb	Fe
Mo	Mg
Si	Cu
Co	Ca
Ge	Li
Pb	K
Cd	Na
Ni	Ga

solkatronic®



Solkatronic Chemicals, Inc.
30 Two Bridges Rd Fairfield, NJ 07004-1530
Tel: 201-882-7900 Fax: 201-882-7967 Toll Free: 800-521-3981

HP Prototyping VCSELs, Fabry-Perot Lasers for Gigabit LANs

The Hewlett-Packard Components Group is prototyping a combination of VCSEL- and Fabry-Perot laser-based fiber-optic transceiver modules which are intended to provide a complete physical-layer interface for gigabit per second (Gbit/s) Ethernet LANs with links up to 2 km.

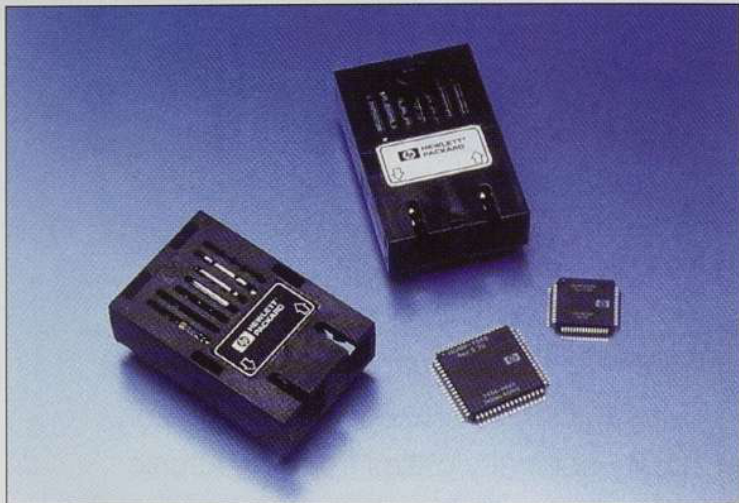
HP is active in the IEEE standards committee for Gigabit Ethernet, and the new products are said to be a response to issues raised in the standards-generating process. For example, there has been extensive discussion regarding the need for 550 meter multimode-fiber link-length specifications with 62/125 micron multimode fiber. This is based on a study presented by Compaq that indicates that almost all of the installed base of optical fiber for LAN applications in the U.S. is based on such cable, and the 44% of the runs are longer than 500m. Subsequent research by members of the committee showed that the limits for 62/125 micron multimode fiber are projected to be 200 meters for standard 780 nm CD laser diodes, and 250 meters for 850 nm VCSELs.

HP has shown that using 1300 nm lasers intended for single-mode fiber on 62/125 micron multimode fiber can permit link lengths in the 550 to 850 meter range based on the installed fiber-modal bandwidth. Links up to 2 kilometers are possible when using single-mode fiber.

To meet the specifications for longer runs - commonly found in campus backbones or between buildings in dense metropolitan areas - HP is prototyping a 1.25Gbit/s 1300 nm Fabry-Perot laser-based transceiver in the industry standard low-cost 1 x 9 package. For shorter runs - common in workgroup LAN environments - HP is prototyping similar transceivers based on 850 nm VCSELs. This unit is intended

to operate at distances of up to 500 meters in 50/125 micron multimode fiber, and up to 250 meters in 62.5/125 micron multimode fiber.

HP is also offering a discrete, fully integrated IC transceiver that incorporates the serialize/deserialize functions. HP believes that it will be the first component supplier to offer complete physical-layer-technology solutions for meeting the emerging industry standards for Gigabit Ethernet.



Examples of Hewlett-Packard's prototypes of VCSEL & Fabry-Perot laser-based transceivers for Gigabit LANs.

New Products for Digital Phones from Philips & TriQuint

A new range of GaAs MMIC power amplifiers for digital cellular and cordless phones have been announced by Philips Semiconductors. The family of six new products, called the CGY20xx-Series, is being manufactured using MESFET technology at the Philips Microwave Limeil wafer fab in France and at TriQuint's fab in the USA. This follows a wafer sourcing and technology sharing agreement signed between Philips and TriQuint in March, 1996. (CS 2(3), p. 18.)

The new devices are designed for use in digital handsets operating at 3.6 or 4.8 V, but can also be used for 6 V battery phones. The CGY20xx-Series includes devices with output powers and frequency ranges suitable for GSM, DCS, PCS, DECT and PHS handsets. They all feature zero dBm RF drive, high operating efficiency and low-cost plastic packaging.

Two of the new chips, which have identical performance but are produced at the two different sites, generate the 4W output power required for 900 MHz GSM applications. A third device provides 2 W output and is intended for use in 1.7 GHz GSM phones. They are all optimized for use with a 4.8 V battery supply, but two similar parts are available which are optimized for use on the 3.6 V supply being target for some of the latest handsets.

Typical output efficiencies in excess of 40% keep power dissipation low enough for these devices to be packaged in 48-lead plastic quad-flat packs. Another important feature is the provision of a separate on-chip buffer amplifier to drive a power sensing circuit, eliminating the need for an additional directional coupler on the antenna output.

For 1.9 GHz DECT handsets, Philips has introduced a 500 mW power amplifier optimized for use at 3.6 V. In applications like DECT, where now output power control is required, it can be operated in an "auto polarization" mode in which the chip is self-biased to a negative voltage in response to RF input. This eliminates the need for an external bias voltage generator. A similar device is available for PHS applications.

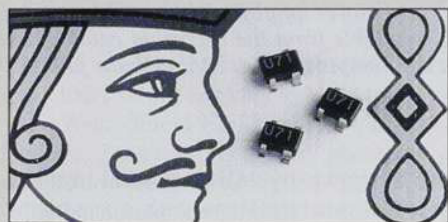
All of the MMICs in the CGY20xx-Series can deliver full rated output power with 0dBm RF input drive. This helps to keep parasitic signals at very low levels and simplifies the RF shielding required around the power amplifier.

The members of the CGY20xx-Series which are designated for GSM/DCS/PCS applications are priced at around \$10 in 100K volumes. The DECT and PHS models cost around \$5 in similar quantities. Volume production of all of these devices is currently underway.

NEC Heterojunction FET

California Eastern Labs has announced the availability of a new high performance heterojunction GaAs FET from NEC. According to CEL, a low noise figure, high output IP3, and low cost - just 99c in 100K quantities - make the new part a good choice for first stage LNAs for 1 to 3 GHz commercial receiver applications. The FET is housed in an ultraminiature plastic surface mount SOT-343 package to enhance applicability to PCS, GPS and other portable applications where size and weight are critical.

The new FET, model number NE34018, is in stock and available in bulk or on tape and reel.



The NE34018 Heterojunction GaAs FET. Performance figures at 2 GHz include +30 dBm output IP3, -18 dB input return loss, 0.8 dB noise figure, and 16.0 dB gain.

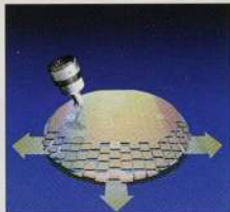
Looking Ahead

Here are just a few of the subject we'll be addressing in future issues:

- March/April: Epitaxy
- May/June: HBTs
- July/August: Diode Lasers
- Sept/Oct: Microwave Technology
- Nov/Dec: New Applications

If your company or research group has news relevant to these or other interesting compound semiconductor-related topics, we'd like to hear from you. Please contact the editor at the following address.

Marie Meyer
Editor, Compound Semiconductor
Franklin Publishing
250 Selby Avenue
Saint Paul, MN 55102 USA
TEL [1] 612 227 5397
FAX [1] 612 227 5499
E mail mmeyer@compsem.com



Scribe & Break TECHNOLOGY

chip free kerfs

non-contact breaking

*0.1 degree diamond
adjustment*

small die processing

*5 times faster than
sawing*

yield increases

*higher die
density on
the wafer*

*less residual
stress on the die*

wafer edge detection

multiple die sizes

pick & place compatible

*ideal for processing
lasers*



**DYNATEX
INTERNATIONAL™**

5577 Skylane Boulevard
Santa Rosa, CA 95403

Phone: 707-542-4227

Fax: 707-579-8599

Still Sawing Your Wafers?

{ Your Competition Isn't }

INCREASE YOUR MARGIN:

SPEED	120,000 die per hour 250μ x 300μ
MEMORY	Fully programmable
VERSATILITY	Multiple die size capability
ENVIRONMENTAL	No D.I. or toxic waste water
YIELD	Superior yield & improved efficiency

Dynatex is your source for this revolutionary generation of patented scribe and break technology for processing a wide variety of crystalline materials from GaAs and Silicon to Quartz, Lithium Niobate, Ceramic and Glass.

The DX-III has the versatility for placement in any production market where yields and an investment return are critical.

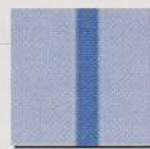
The DX-III is the SAW alternative.



DX-III Screen
(800X)



Saw (800X)



DX-III (800X)



DX-III

DYNATEX INTERNATIONAL

Motorola Introduces a PHEMT for Cellular Applications

Motorola has introduced a rather unique new power amplifier (PA) for wireless handsets: an InGaAs/AlGaAs pseudomorphic high electron mobility transistor (PHEMT).

Most GaAs PAs are fabricated from MESFET structures, and Dan Artusi, General Manager of Motorola's RF Semiconductor Division, admits that PHEMTs will likely always be more expensive. Nevertheless, Motorola believes that it can find a niche for its new device because of the benefits it provides at the system level. In their view, the power transmitter is a critical component for the next generation of cellular phones, because the requirement of reducing the size and weight of the batteries is creating a need for higher efficiency power devices operating at lower voltages. Using PHEMTs has allowed the company to achieve what it describes as "unprecedented efficiency".

Device Performance

A 0.8 micron gate length PHEMT with a total device width of 12 mm which demonstrated performance of 31.5 dBm output power, and greater than 75% power added efficiency (PAE) at 3.5 V for 850 MHz operation was reported by Motorola at the 1996 MTT-S meeting. [1] The new product, part number MRF9822, when operating at 3.5 V, can achieve efficiencies greater than 80% when tuned for maximum PAE. When tuned for maximum power, figures of 1.5 W are typical. When tuned for a trade-off favoring efficiency, the PHEMT device achieves an output power of 31.7 dBm, PAE of greater than 75%, gain of more than 11.5 dB, and negligible leakage current at an input power of 100 mW and a frequency of 850 MHz. Motorola believes that this is the best reported performance for any technology under these low voltage conditions. Figure 1 shows a plot of these RF parameters under the trade-off conditions.

According to Artusi, "The main issue in all portable equipment is efficiency - and what you have here is a device that can work with one battery cell, so you can make the battery pack smaller." Artusi's division is a merchant supplier, offering their products to all handset manufacturers. But the first high profile insertion for the product comes from their own parent: Motorola is implementing the new PHEMT device into their top-of-the-line StarTac cellular phones.

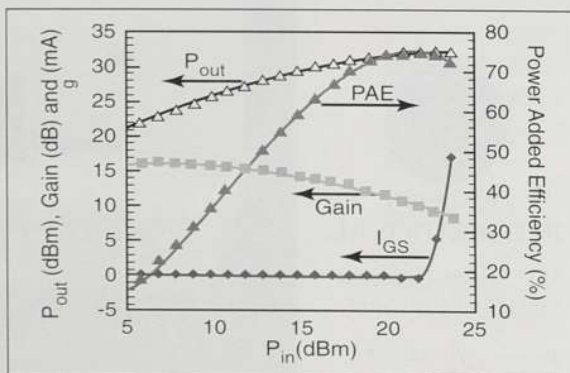


Figure 1. RF characteristics of the MRF9822 with a drain bias of 3.5V.



The MRF9822, Motorola's new 3.5 V high-efficiency PHEMT designed for use in low voltage power amplifiers in portable wireless electronics. The device is available from the Motorola catalog, and is currently being used in the company's StarTac cellular phones.

Fabrication

The PHEMT structure is grown by MBE on semi-insulating GaAs substrates. The epitaxial structure starts with a superlattice buffer layer which acts as a physical barrier to inhibit interface defects from propagating into the channel. The channel is formed from InGaAs with AlGaAs carrier confining layers. Above the channel is a thin GaAs layer, an AlAs etch-stop layer, and a heavily doped N+ ($5 \times 10^{18} \text{ cm}^{-3}$) GaAs cap layer.

Device fabrication begins with the patterning and selective wet etching of the N+ GaAs layer using a citric acid-based solution on a custom, automated etching tool. The N+ layer is removed everywhere but in a region that will enclose the ohmic contacts. The wet N+ etch is designed to be selective to the AlAs etch stop layer. A refractory gate electrode is patterned and etched using reactive ion etching over a region where the N+ GaAs layer was previously removed. Device isolation is accomplished via ion implantation of oxygen, as shown in Figure 2. Electrical contact to the heterojunction is made using Ni-Ge-W contacts to the top N+ layer.

Motorola reports that this fabrication process is amenable to high-volume/high-yield production. They are using a mixture of epi wafers grown in-house and purchased from outside sources.

The MRF9822 is priced at \$2.50 in quantities of 100,000. Samples and small quantities are available from stock. Production quantities are available on an eight-week lead time.

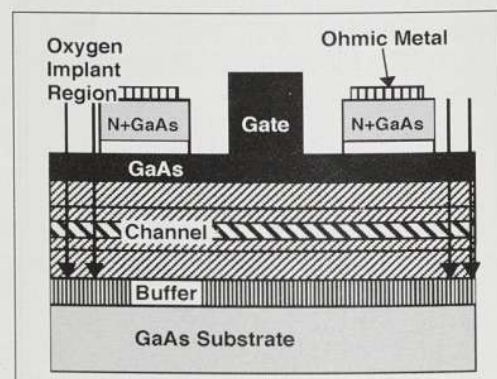


Figure 2. Schematic of the MRF9822, not showing interconnect metal.

¹ M. J. Martinez et al, 1996 IEEE MTT-S Symposium Digest, Vol 2, p. 551 (1996).

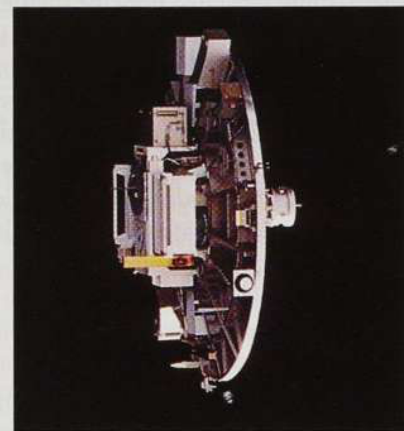
The Wake Shield Facility Flies Again

The latest mission for the orbiting MBE system yields 7 samples; more flights planned.

The world's most unusual MBE system had its third workout in November. The Wake Shield Facility (WSF), a 12 foot diameter, 2 ton orbiting epitaxy platform, was put into low earth orbit by the space shuttle Columbia during mission #80, which began on November 19, 1996. The WSF is designed to use the vacuum of space to assist in the MBE-growth of III-V epitaxial wafers. Seven samples, described as various GaAs, AlGaAs and InGaAs "transistor and junction devices" were grown on this mission.

The crew of Columbia, using the shuttle's robotic arm, released the WSF into space on

their fourth day in orbit. Once clear of the shuttle, the propulsion systems on board the WSF were used to move away from the shuttle and assume the position which creates the optimum vacuum in the craft's wake. The WSF flew on its own for 73 hours, during which time it grew the seven samples which had been planned for the mission. The crew then retrieved the satellite and returned it to the shuttle's payload bay. On the following day the WSF was again lifted using the robotic arm, and it grew an eighth sample, described as an oxide thin film, while attached to the arm.



The Wake Shield Facility in orbit, as seen from the space shuttle.

According to Plan

The WSF is the product of the Space Vacuum Epitaxy Center (SVEC) at the University of Houston [Houston, Texas]. SVEC director Alex Ignatiev says that everything on the WSF-3 mission went "exactly as planned". In contrast, the previous shakedown cruises were filled with unexpected events. During the first flight in February, 1994 the WSF could not be released from the robotic arm for free flight. As a result, the samples grown were contaminated by outgassing from the shuttle. However, that flight did demon-



The

GaAs Electronics

<http://www.gaasnet.com>

Industry Resource

strate the basic space wake concept. During the second flight, in September 1995, the WSF successfully separated from the shuttle, but the growth campaign was beset by the kinds of technical bugs familiar to operators of terrestrial MBE systems: power outages, sticky shutters, and arsenic flux instabilities. Nevertheless, four epi samples were produced, two of which reportedly showed very low oxygen and carbon contamination levels (at or below SIMS detection limits).

Back to Earth

What lies ahead for the WSF project? In the short term, watch for publication of the complete characterization data from the second flight in September, 1995. Although SVEC claims that those samples were "of record purity", the limited amount of data which is currently available to the public does not clearly demonstrate that similar results could not have been achieved on earth with a more conventional MBE system. The first results from devices fabricated from space-grown samples are also hoped for soon.

Ignatiev is also optimistic about a fourth flight for the WSF, which he hopes to get on the flight manifest for late 1998 or early 1999. That mission would involve cassette-to-cassette single-wafer growth of 50 - 100 samples. SVEC hopes to interest GaAs device manufacturers in ordering batches of 5-10 wafers to be grown to their specifications, with the ultimate goal of having them processed in commercial production lines, alongside wafers from more conventional sources.

Justifying the Cost

For many, the WSF project has a great deal of appeal, primarily because it is the first project of its kind to explore the use of the vacuum of space. (Other crystal growth experiments have all been focused on the effects of microgravity.) Sir Edmund Hilary is famously explained that he climbed mountains "because they are there"; similarly, perhaps the best justification for tinkering around in space is that it is there.

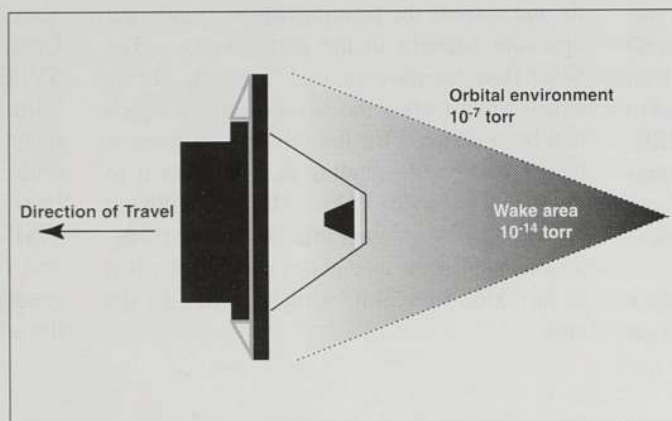
On the other hand, such tinkering around carries a hefty price tag. *Space Business News* reports that the investment in WSF to date is around \$30 million, and another \$7 million to \$12 million will be needed if the fourth mission is to proceed. Moreover, since its inception, promoters of the WSF project have argued that it will become a legitimate commercial enterprise. But the nature of the GaAs device business has been revolutionized by

shifting from the military market to high volume manufacturing since the WSF project was first launched in 1989. The relentless price pressures experienced by the terrestrial materials suppliers make it difficult to see how one could make a sensible economic argument for an approach as exotic as the WSF.

All of which raises the question: can the WSF project be justified on commercial grounds? Ignatiev believes so. He explains: "There are a number of things that are very unique to our environment that you can't reproduce on earth. But we are not talking about GaAs transistors for inexpensive cell phones. Instead, we are looking at the high-end of the GaAs devices market, which still exists [despite the sift away from the military market]. And in that market we believe that there are a number of applications that we can address, and in the course of doing so there are a number of approaches that we can take that are very difficult or not possible terrestrially.

One example is regrowth of epitaxial layers, which we can do very simply and effectively. Another example is growth interruptions, which we can integrate effectively into production designs. Perhaps most important is the fact that we can do growths over extremely large areas - we can do square meters of material at a time."

In short, he says "I believe that there are still significant benefits to be achieved by applying this technology, even though the GaAs industry has moved significantly forward." His next challenge will be to convince corporate interests to sign on for the proposed fourth mission - a task which may determine the fate of this very unusual project.



The concept of space wake formation. Traveling through low earth orbit at about 18,000 miles per hour, the 12 foot diameter, 4,350 pound stainless steel disk that makes up the WSF platform leaves an "ultra-vacuum" of around 10^{-14} Torr in its wake.

Awards

The recipient of the 1996 IEEE David Sarnoff Award is Hiroyuki Sakaki of the University of Tokyo. This is one of 21 Technical Field Awards made annually by the IEE Board of Directors for outstanding contributions to electrical and electronics engineering.

The award was made "for pioneering studies of quantum effects in semiconductor microstructures". Prof. Sakaki was involved in the first transport study of the two-dimensional electrons along interfaces of GaAs/AlGaAs quantum heterostructures. One of the earliest researchers to propose using quantum wire and quantum box structures for advanced electronic and photonic devices, he contributed to tunneling and other forms of crossbarrier transport in quantum heterostructures.

Other awards for compound semiconductor related work were presented the 1996 LEOS Annual Meeting in Boston in November. The IEEE/LEOS William Streifer Scientific Achievement Award was presented to John E. Bowers and Kam Y. Lau "for significant contributions to the understanding and design of high speed semiconductor lasers". The LEOS Engineering Achievement Award was presented to Isamu Akasaki and Hiroshi Amano of Meijo University and Shuji Nakamura of Nichia Chemical "for the technology breakthrough of making p-type gallium nitride, demonstrating very bright blue light emitting diodes, and developing a commercial LED product which is expected to have major impact in the display and other optoelectronic industries". The recipients of the LEOS Distinguished Lecturers award included Peter Zory of the University of Florida.

News from Japan

Microelectronics

Fujitsu Planning for GaAs Growth

Fujitsu has announced plans to reduce compound semiconductor device development cycle time in response to the burgeoning demand for mobile phone components. The company will invest ¥300 million (\$2.6 mil) to construct a development facility at Fujitsu Quantum Devices and will consolidate development and production forces there in order to respond to the changing market needs more quickly. The company expects the world market for communications compound semiconductor devices to grow from ¥166.5 billion (\$1.5 bil) in 1995 to ¥273.6 billion (\$2.4 bil) in 1999.

In a separate report, Fujitsu also announced that it plans to bolster its analog GaAs business. In response to the growing demand for mobile communications equipment, the company will double microwave device production to 3 million kits per month by next fall. One kit consists of 2-3 devices. The company reports that prices of microwave devices have declined 90% over the last four years, and yet the market has grown only 10-20% in value terms. While the HEMT market is not likely to expand significantly, the company will aim to maintain its leading position targeting global positioning system and digital satellite broadcasting applications.

Mitsubishi SatComm GaAs

A new millimeter wave amplifier has been introduced by Mitsubishi Electric. It consists of two MMICs: one IC amplifies millimeter wave signals at low noise, and the other controls the amplification level in the 40-50GHz range. The amplification IC uses a HEMT with a gate length of 0.15 micron. The company plans to put the amplifier into practical use for millimeter wave-based satellite communications applications in 1998.

New HEMT & MMICs from NEC

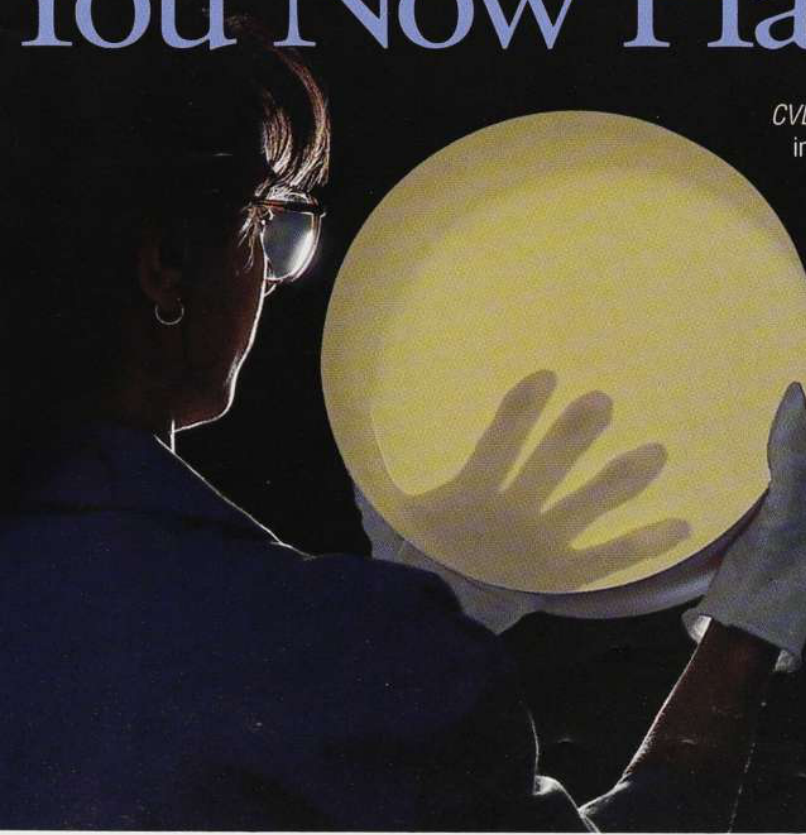
NEC has developed a double-doped HEMT for halving PDC (personal digital cellular) phone chip size. The new device is for use as a transmission power amplifier, a chip which usually takes up more footprint than any other PDC devices. It achieves a drain current of 640mA, a mutual conductance of 330 ms/mm and an on-resistance of 2.3 ohm-mm. Gate width has been reduced from typical 17.5mm to 7mm, and yet the HEMT achieves a power conversion efficiency of 56%, up from 50% with conventional FETs, when running on 3.4V.

NEC also reports that it has prototyped small milliwatt transmission and receiver modules for use in indoor wireless LAN and image transmission systems. Both modules measure 8.5x20.5x5mm, about 1/5 the size of cellular phone transmission modules, and have three built-in chips. Oscillator and amplifier ICs are MMICs which place FETs and capacitors on a substrate. The oscillator can directly oscillate at 60GHz. The company plans to launch volume production in 2000.

New Products from New Japan Radio

Chip maker New Japan Radio Corp. is also planning to increase its GaAs MMIC business. The company has developed the NJG1506R/1507R SPDT (single-pole, dual-throw) switches for 800MHz dual-band PDC and PHS applications, respectively. Both devices operate on 2.7V, feature low insertion losses, and are supplied in VSP8 packages which are 50% smaller than the SSOP package. The company will produce 300,000 units a month from December, 1996. Plans also call for expanding its GaAs MMIC portfolio by introducing various amplifiers and mixers for cellular and PHS phones.

You Now Have a Choice



CVD PRODUCTS is fast becoming *THE CHOICE SUPPLIER OF PBN* to leading edge technology companies all over the world. We have the experience, personnel and resources to produce *PBN (Pyrolytic Boron Nitride)* components which are the best in the industry. In fact, our *Pyrosyl™ PBN* has become the crucible and plate choice for many of the world's *MBE USERS AND CRYSTAL PULLERS*.

We carry common size crucibles, plates and components in stock for immediate delivery, or we can fabricate to print. All sales, design and engineering functions are performed in-house assuring fast responses to inquiries and shorter lead times for custom parts. Custom packaging is available to meet your specific needs.

For more information call *TOLL-FREE 1-800-700-1CVD* and request a copy of our free, full-color brochure.

MAKE CVD PRODUCTS YOUR CHOICE FOR PBN.



CVD Products, Inc.
4 Park Avenue Hudson, NH
03051-3927 USA
PHONE (603) 598-9122
TOLL-FREE 800-700-1CVD
FAX (603) 598-9126

Optoelectronics

Citizen Electronics will bolster its **infrared chip LED business**. The company will raise infrared chip LED production quickly from the current 2-5 million to 10 million units per month. Demand for infrared chip LEDs is growing for use in sensors of audio equipment and remote controllers for home electric appliances. The company's total production of chip LEDs, including the infrared and visible-light types, stands at 130 million units per month. The company, which claims to be the world's chip LED leader hopes to develop the infrared type into a new core business.

Matsushita Electric has developed a **DVD-RAM laser** which can operate at 100°C. The 650nm, 30mW laser achieves an optical damage level of 100mW, up from 60mW for its predecessor, by optimizing the design of the laser's active layer and lowering the optical absorption of the coating film on the edge of the chip. A DVD-RAM laser is required to have an optical damage level which is about 3 times its output level in order to be embedded in the system. The new laser can operate at temperatures of up to 100°C and features a noise level of 130dB. Matsushita Electronics, a Matsushita Group firm, will produce the laser towards the commercialization of DVD-RAM equipment.

Mitsui Petrochemical Industries has announced the development of a **high-power red AlGaAs laser**. The 860nm laser provides an output of 300mW, about 6 times the output of a CD pick-up semiconductor laser. It is expected to expand the storage capacity of optical devices such as CD-R drives and also pave the way for the development of new applications such as special printing equipment. The company is also working on a high-output 980nm laser.

NEC has developed an **optical fiber amp**. Measuring 75x110x23mm, about 1/3 the size of conventional units or the size of a cassette tape, the unit without a radiator is the world's smallest amp with a built-in control circuit. It integrates an optical isolator, an optical branching coupler and a photo detector into a single unit. The total number of components has been reduced from 10 to four, and the number of connection points has been cut from nine to three. The price will initially be set at about ¥2 million (\$17,544), but the company thinks once volume production expands it will be able to offer it at less than ¥1 million (\$8,772). NEC is aiming to ship 300 units per month over the next year or two.

NEC has also developed an **optical transceiver module** for use in 156 Mb/s transmission over a plastic optical fiber (POF). The module uses a 0.4mW LED emitting at 650nm. By offering a dynamic range of over 25dB, the module can support three times the data transmission speed of conventional modules and allows transmission via POF over a distance of 50m, which is 5 times more than conventional systems. The company claims that the module can send data over a distance of up to 100 m via a hard polyplastic optical fiber. The sample price will be set at ¥5,000. Volume production will start at 10,000 units monthly in fiscal 1997.

And NEC also reports that it has developed an **optical communications laser production technique** with improved accuracy in wavelength control. The new technique uses the WAVE (weighted variable-pitch electron beam drawing) method to overlay electron beams to create diffraction gratings with a pitch of 0.03nm, down from conventional 0.3nm. NEC has prototyped a 1.55-micron eight-wavelength laser and confirmed that the eight laser chips emit light with different wavelengths in 1.6nm increments with an error of less than 0.1nm. NEC plans to put the technique into practical use in 1997 for WDM networks.

A Commitment You Have Always Counted On

For over 30 years, Morton Metalorganics has consistently offered ultra-pure, high performance metalorganic precursors for MOCVD and MBE. We've grown with the market by providing not only innovative metalorganic solutions, but also a proven level of service that can only be supported by an international company with a 150-year history of exceptional customer relations.

With leadership positions in speciality chemicals, salt and automotive airbags you can continue to feel confident that Morton will expand on its commitment to offering products you can rely on, service you can depend on, and quality you can count on.



Morton

Morton Metalorganics
148 Andover Street
Danvers, MA 01923
tel: 508-750-9490
fax: 508-750-4298

Research & Development

The **Sony Research Center** has made a theoretical demonstration of a new type of **blue-green laser diode**. The new device reportedly uses CdPbSe and ZnSSe for its light emitting element. In an experiment, the company ran current at 500 A/cm² through a prototype laser and confirmed that there was no increase in the number of defects, suggesting that it could withstand continuous emission for a prolonged period of time. Sony plans to develop techniques to improve the reliability of the materials in order to extend continuous emission time to over 1,000 hours.

Sony also reports that it has developed a **blue-light organic electroluminescence (EL) material** with high heat resistance. The new material is a zinc complex, which emits 460nm or 550nm blue light stably even at around 350°C. It features a brightness of 20cd per sq. meter, a level comparable to that of known blue-light EL materials, none of which withstands a temperature of over 300°C. The company has prototyped a full-color display panel using the new device. While its light emitting efficiency is still low, the company considers it promising for stable, lasting emission of blue light.

Matsushita Giken has developed a **silicon-based light emitting device**. The company has used a technique to grow silicon atoms into micro particles about 10nm in diameter by colliding helium atoms against silicon atoms which are removed from a base material when it is exposed to a pulse laser, and to deposit the silicon atoms 150nm thick in a 2mm-diameter area, where part of silicon oxide film on a positive silicon substrate is removed. The company has confirmed that the device starts emitting red light with a wavelength of 750nm on 7V from the area at room temperature and that the intensity of the ray increases in proportion to the third power of the level of current.

NTT has developed a technique to produce devices which **integrate silicon circuits and III-V optoelectronic components**. The technique thermally glues silicon circuits on compound semiconductor film with polyimide, an organic polymer, and creates lasers on the film. Similar, photo detectors are created on the film. In an experiment, the company formed an array of 4x4 surface-emission lasers and confirmed that they operated properly. Plans call for prototyping a silicon chip with built-in lasers and photo detectors.

The **National Institute for Research in Inorganic Materials** of the Science and Technology Agency, in cooperation with an Aoyama Gakuin University group, reports that they have synthesized n-type phosphorus-doped epitaxial diamond thin film which achieves a carrier mobility of about 20 sq. centimeters/Vsec. The microwave plasma method, a vapor phase synthesizing technique the Institute developed in 1982, was used. The technique supplies methane gas and phosphine at 950°C and at 1/10 atmospheric pressure.

A **Waseda University** team led by Professor Kawarada has succeeded in forming a **diamond transistor on silicon substrate**. The team formed silicon carbide thin film over a silicon substrate and then deposited 10-100 micron-thick high-quality diamond film through chemical vapor deposition. The transistor created on the diamond film provided performance on a par with its counterpart on a diamond substrate, according to the professor. As the new technique allows the use of inexpensive silicon substrates, it is expected that silicon transistors will find a wider range of applications.

Industry

Hitachi Cable will expand its GaAs wafer production in response to a growing demand for epitaxial wafers for use in MMICs and other electronic devices for the communications market. The company will install an epitaxial process line including a new 4" single crystal puller and an MOCVD system and start operating the new line next spring. Investment will total about ¥2 billion (\$17.9 mil). The company aims to expand its compound semiconductor division sales by over ¥2 billion (\$17.9 mil), up from an estimated ¥4.5 billion (\$40.2 mil) in fiscal 1996.

Hitachi Cable has also announced a program to focus on development of **larger GaAs single crystals** in an attempt to reduce the cost. The company, which has produced GaAs compound semiconductors using both the boat and pulling techniques, will aim to expand the wafer diameter from today's 3 inches to 4-6 inches and the length from 60cm to 80cm gradually. Hitachi Cable says that the GaAs market is estimated at about ¥20 billion \$177.0 mil, of which they have a 30% share. The company also reports that while the demand for GaAs crystals is on the rise, there is a growing price competition among suppliers.

Gallium Prices Rising

Japanese suppliers reportedly raised the price of gallium metal about 20% last year due to the tightened supply and demand. As a result, some crystal makers raised the price of wafers by several percent this summer. Gallium users are now said to be increasing pressure to lower the price of the metal again, arguing that the entry of Taiwanese companies has lowered LED prices.

As is the case in the U.S., Rhone-Poulenc is said to be the leading supplier in Japan. Major Japanese suppliers include Sumitomo Chemical, Dow Mining, Sumitomo Metal Mining, Nichia Chemical and Rasa Industries. Dow Mining is the only Japanese maker that produces gallium from black ore mined in Japan. Other makers import low-purity gallium or collect scrap to refine it to increase purity.

Demand for gallium in 1996 was around 125 tons, roughly five times the demand in the U.S., which is the next largest market. See table.

The reasons for the increased prices are that demand for gallium is on the rise, and imports of crude gallium from Russia, which used to help stabilize the price, decreased in 1994, causing Japanese gallium suppliers to raise the price by about 20%. Demand continues to rise, and it does not appear that supply conditions will improve. Japanese suppliers are striving to sustain the price by focusing on collecting gallium from scrap.

Worldwide Supply and Demand for Gallium - 1996

Region	Supply	Demand
Japan	60 - 70	120 - 180
U.S.	11 - 13	25 - 27
Europe	43 - 44	6 - 7
CIS	36 - 37	-
Others	8 - 12	6
Total	158 - 176	157 - 170
<i>Units: Metric Tons</i>		
<i>Source: "Industrial Rare Metals (Japan) No. 112, 1996"</i>		

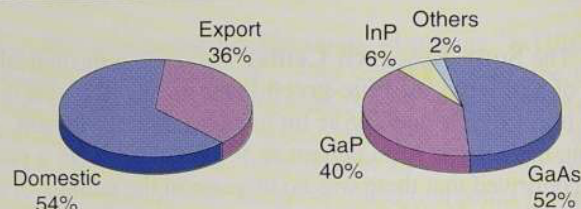
Decline Reported by Japanese Wafer Vendors

Shipments of compound semiconductor materials by the leading Japanese manufacturers slipped by 9% in the first half of fiscal year 1996 according to the Japan Manufacturers' Society of Compound Semiconductor Materials (JAMS-CS). Figures released in November show that shipments totaled ¥18,874 million (\$165.6 million) for the period from April to September 1996, compared to ¥19,486 million (\$171.2 million) for the previous six months, and ¥20,755 million (\$182.3 million) for the comparable period in fiscal 1995.

The decline was observed in both domestic and export shipments. Domestic sales accounted for 64% of total sales, and GaAs lead in the materials category, with 51% of the total. See Figures One and Two. These numbers are substantially unchanged from the previous six months.

News of the slump was not unexpected. As we reported previously (CS 2(5), p. 14), a noticeable slowdown had begun in the second half of FY 1995, as revealed in Figure 3.

JAMS-CS Chairman Kiyohiko Kimie, General Manager, Semiconductor Division, Sumitomo Electric Co. Ltd., offered the following observations. "The major reasons behind the decline include the following factors: 1) Although GaAs shipments were affected by inventory reductions in the visible LED and infrared LED markets, demand for IC and discrete electronic devices remained firm due to the growing use of mobile communications equipment such as cellular phones. As a result, GaAs shipments declined just 4% compared to the same period of the previous year; 2) GaP shipments were down 16% over the same period of the previous year, due to significant inventory reductions in the visible LED markets both at home and abroad. 3) InP shipments were down 8% due to the temporary production reduction in optical communications devices such as laser diodes." As for the future, he said, "While it is expected that the compound semiconductor industry will continue to experience the adjustment phase in the second half of fiscal 1996, we would like to see the global demand will pick up in the near future."



Figures One and Two: The value of shipments made by the nine members of the JAMS-CS during the first half of FY 1996. Segmented according to destination (left) and material type (right).

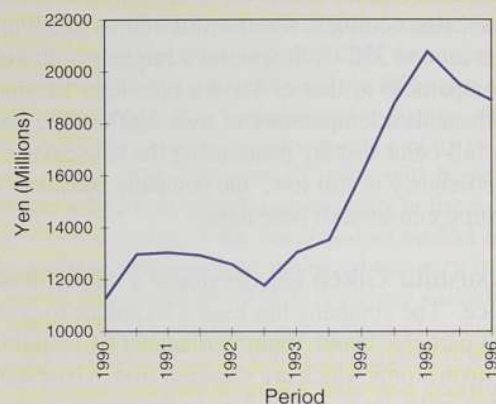


Figure Three: Value of compound semiconductor wafer shipments reported by the JAMS-CS members from FY 1990 through the first half of FY 1996.

Your Best Source for PBN—Worldwide



Advanced Ceramics developed Boralloy® and is the original patent holder and innovator of PBN products for MBE. No other company can match our experience, production capacity and customer service.

Our technical expertise and commitment to product development have resulted in several industry innovations which have increased crucible life and MBE yields:

- double-walled crucibles that improve aluminum deposition
- "hot lipped" crucibles that reduce defects during gallium deposition
- Boralectric® heaters that improve thermal uniformity and provide increased durability
- custom surface textures

**ISO9002
CERTIFIED**

Most of the world's leading companies involved in MBE and crystal growth rely on Advanced Ceramics Corp. Find out how Boralloy PBN products can improve your operation.

Advanced Ceramics
CORPORATION
11907 Madison Ave.
Cleveland, OH 44107 USA
Tel: 800-822-4322 or
216-529-3900
Fax: 216-529-3975

See ACC on the Internet: <http://www.advceramics.com>

1996 International Electron Device Meeting

*San Francisco, CA
December 8-11, 1996*

C. R. BOLOGNESI

More than 200 invited and contributed papers were presented at the IEEE IEDM conference which was held in San Francisco just before Christmas. The range of topics covered at IEDM is quite broad, and several interesting papers were given in fields ranging from III-V nitrides to advanced silicon-based devices.

Wide Bandgap Electronics

In a very interesting invited talk (paper 2.1), Asif Khan of APA Optics reviewed recent advances in III-V Nitride heterostructure field-effect transistors (HFETs). After describing the growth and fabrication technologies, Khan explained how doped-channel heterostructures are used to maximize the channel electron

sheet charge concentration while minimizing the carrier population in the AlGaIn barrier layers, thereby greatly improving the charge control characteristics of GaN/AlGaIn HFETs. He reported a cut-off frequency of 46.9 GHz and a maximum oscillation frequency of 103 GHz for a 0.12 μm gate device. The devices could be operated up to 200°C, with only a weak temperature dependence.

Another stimulating invited talk (paper 9.1), this time on widegap SiC electronics, was presented by A. K. Agarwal from Northrop Grumman, who highlighted progress in the area after providing a review of the physical properties of SiC materials. Whereas until very recently only small substrates were available, 1.5 inch diameter SiC wafers are now common, and 2 inch substrates are becoming available in the n+ and p+ varieties. 4H-SiC static induction transistors (SITs) have been fabricated with a 300 V breakdown voltage and a power output of over 450 W at 600 MHz with a 34.5 cm source periphery. Both 6H- and 4H-SiC MESFETs have been fabricated that can deliver power densities nearly 3 times higher than those normally obtained in GaAs MESFETs. High breakdown fields and saturation velocities make SiC promising for both power amplifiers and broadcasting applications in the 3-10 GHz frequency range. A number of SiC power devices such as Schottky and pn diodes, MOSFETs, and Gate Turn-Off Thyristors (GTOs) were also discussed in the presentation.

Isamu Akasaki from Meijo University reviewed (paper 9.2) progress in the crystal growth, conductivity control, and light emitters of group III nitride semiconductor materials. One of the interesting features of GaN

LEDs is that they show little degradation even after ten thousand hours of continuous operation, although they can contain dislocation densities of the order of $10^9 - 10^{11} \text{ cm}^{-2}$. This may be due to the fact that nitrides are much harder than other III-V compounds such as GaAs or InP.

A Bit of GaAs

A highlight of the conference was the late news paper (paper 10.7) presented by Fan Ren of Bell Laboratories - Lucent Technologies in which the fabrication of enhancement-mode p-channel GaAs MOSFETs was reported. The GaAs MOS structures were realized in UHV by electron beam evaporation deposition of a high dielectric constant $\text{Ga}_2\text{O}_3(\text{Gd}_2\text{O}_3)$ oxide. See CS 2(5), p. 36. The development of normally-OFF GaAs MOSFETs could improve the battery lifetime of various personal communication systems by reducing their power consumption.

An impressive display of GaAs device engineering was presented by J. Würfl from the Ferdinand-Braun-Institut für Höchstfrequenztechnik in a talk (paper 8.6) describing the realization of a 0.5 μm GaAs MESFET IC technology with devices operating from liquid nitrogen up to 500°C. At room temperature the devices exhibit a transconductance of 280 mS/mm which decreases to 100 mS/mm at 500°C. The devices showed no degradation after 700 hours of thermal/electrical testing at 350°C. The key to the implementation of these MESFETs was the use of WSiN diffusion barriers in the Schottky and Ohmic contact systems, and the use of a lanthanum hexaboride (LaB_6) internal Schottky barrier. An X-band MMIC mixer for reliable operation at ambient temperatures as high as 300°C was also demonstrated.

In the quantum electronics area, the report of a low 50 nW standby power III-V Tunneling static RAM (TSRAM) cell was presented by Paul van der Wagt from Texas Instruments (paper 16.6). The TSRAM cell relies on the integration of ultra-low current density resonant tunneling diodes (RTDs) achieved by inserting an InAlAs pre-barrier to reduce the RTD peak current density (which depends exponentially on the pre-barrier thickness), and heterostructure field-effect transistors (HFETs) grown by MOMBE on an InP substrate. By increasing the number of vertically integrated RTDs, a 100 nW multi-valued memory cell with three stable states was also obtained.

Gate length 1 μm , gate width 150 μm

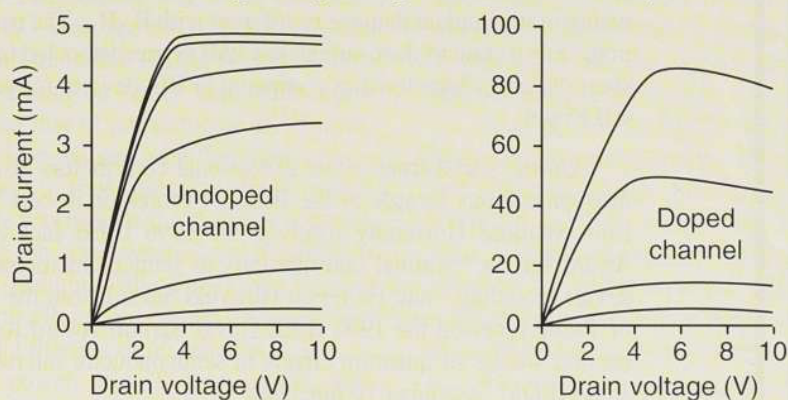


Figure 1. I-V characteristics of AlGaIn/GaN HFETs with undoped and doped channels. Asif Kahn, APA Optics.

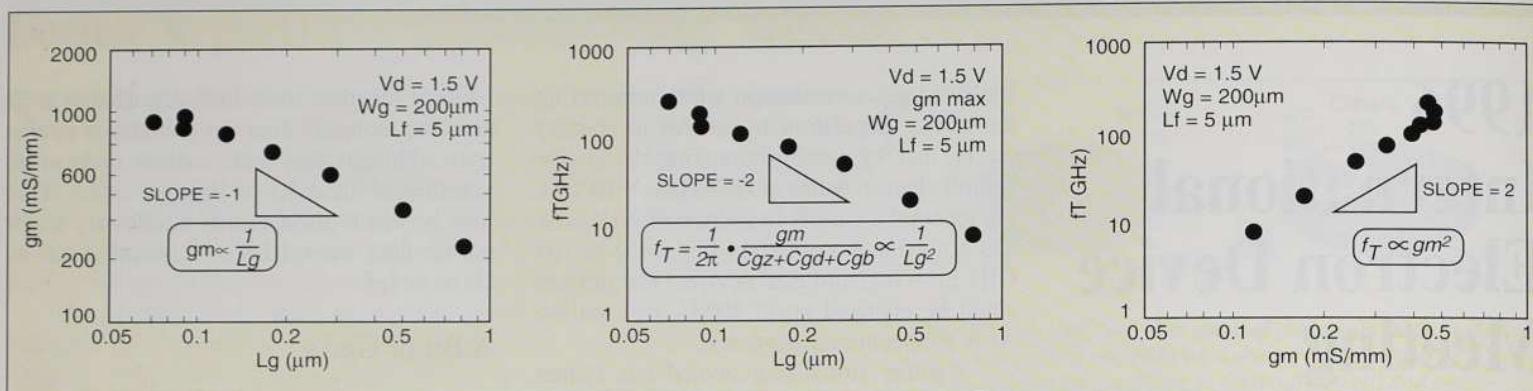


Figure 2: Various aspects of Silicon MOSFETs. Left: Dependence of transconductance on gate length. Middle: Dependence of cutoff frequency on gate length. Right: Dependence of cutoff frequency on transconductance. H. Momose, Toshiba.

Sub-Millimeter Wave Devices

Exciting work was also reported in the area of sub-millimeter wave devices by a group of researchers from UCSB and JPL. A. C. Molnar from UCSB showed (paper 8.7) that although resonant tunneling devices can be extremely fast they suffer from low output power densities when individual devices are considered. Fortunately, monolithic slot antenna coupled Schottky-collector resonant tunneling diodes (SRTDs) two-dimensional oscillator arrays can be integrated into a quasi-optical power combining arrangement. Oscillations at frequencies of up to 650 GHz were reported for 0.1 μm SRTD 64-element arrays fabricated with an 8 mask process. Output power measurement at 310 GHz on a 16-element SRTD array revealed a record power density of 440 W/cm² (lower bound value). Power measurements at higher frequencies were difficult as they approached the threshold of the Germanium bolometer.

Other Materials - Like Silicon

On the silicon-based electronics front, impressive RF characteristics for polysilicon gate MOSFETs with a 15 Å gate oxide produced by rapid thermal oxidation were reported by Toshiba (paper 5.1). H. S. Momose presented 0.07 μm gate length MOSFETs with excellent drain characteristics exhibiting a maximum transconductance of 1020 mS/mm at $V_{DS} = 1.5\text{ V}$. The cut-off frequency of the MOSFETs scaled with the square of the inverse gate length down to 0.1 μm : cut-off frequencies of more than 150 GHz were obtained for sub- 0.1 μm gates. Minimum noise figure values of 0.51 dB were measured at a frequency of 2 GHz for a 0.12 μm gate length (and less than 1.5 dB at 8 GHz), indicating that silicon MOSFETs may come into wide use in RF telecommunications large scale integrated circuits in the near future.

In another paper of great potential significance to the silicon IC industry, the use of decaborane ($\text{B}_{10}\text{H}_{14}$) in the formation of ultra-shallow p-type ion implanted regions was reported by K. Goto from Fujitsu (paper 17.1). Shallow boron implants are required to minimize short-channel effects in pMOSFETs (or to form shallow implanted base regions in NPN bipolar transistors) but are difficult to achieve with B^+ sources because of low beam currents at low implant energies. BF_2^+ ions are commonly used for shallow p-type implants but may lead to some problems due to the presence of fluorine in the implanted layers (for example, B diffusion through the gate oxide in devices utilizing a p+ polysilicon gate). On the other hand, $\text{B}_{10}\text{H}_{14}$ can be implanted with roughly one tenth the effective acceleration energy and a ten times higher effective beam current.

Interestingly, decaborane implanted wafers did not show a transient deep diffusion tail in RTA'd samples, in sharp contrast with what is observed in BF_2 implanted samples: this would suggest that the nature of the implant damage is different with $\text{B}_{10}\text{H}_{14}$. The use of $\text{B}_{10}\text{H}_{14}$ in the fabrication of deep submicron PMOS transistors led to improved short-channel characteristics compared to BF_2 devices for gate lengths < 0.15 μm .

On the social front, some exceptional contributors also accepted their prestigious awards at the IEDM: Professor Robert W. Dutton from Stanford University received the 1996 IEEE Jack A. Morton Award for his "seminal contributions to semiconductor process and device modeling," and Professor Hiroyuki Sakaki from the University of Tokyo received the 1996 IEEE David Sarnoff Award for his "pioneering studies of quantum effects in semiconductor microstructures" at the IEDM December 10 luncheon.

Dr. Bolognesi is a professor at Simon Fraser University, and is the Materials Editor for Compound Semiconductor.

For Precise Wafer Processing PM5 auto-lap

Confidently achieve a high quality surface finish and flatness on your II-VI & III-V materials

Automation means higher sample repeatability and less operator involvement

Touch button control of delicate wafer processing



Quality Materials Processing Technology



Logitech Product Group,
Radiometer America, Inc.
810 Sharon Drive, Westlake, Ohio 44145
Tel. (216) 871 0071
Fax. (216) 871 8188
<http://www.logitech-us.com>

Semiconductor Laser Results from LEOS '96

Boston, MA
November 18 - 22, 1996

GARY W. WICKS

Over 400 papers were presented at LEOS '96, the ninth annual meeting of the IEEE Lasers and Electro-Optics Society, which was held in Boston during the third week of November. As usual, semiconductor lasers dominated the agenda. Results presented included the latest nitride laser milestone, a new material system for II-VI lasers, high power near IR diode laser records, and development of VCSEL's for high speed data links.

One of the definite highlights of the meeting was the report by Shuji Nakamura of Nichia Chemical Industries of the first continuous wave room temperature operation of a GaN laser diode. The device lased for more than 30 hours in the violet at 406 nm with a threshold voltage of 5.5 volts and a threshold current density of 3.6 kA/cm². Nakamura pointed out that given the rapid rate of progress - moving from the first observation of lasing to more than 30 hours of CW operation in less than a year - he appears to be closing in fast on the best previous result for a shortwavelength laser, a 100 hour lifetime green II-VI laser announced by Sony in February, 1996. (See page 6 for more on Nakamura's result.)

There was also an interesting report on green diode lasers from the 3M/Philips collaboration. They are developing devices based on new II-VI materials which are unique in two aspects - they are beryllium-based, and they contain no sulfur. MBE growth of such materials should be easier and more reproducible than that of conventional II-VI materials for green lasers, since beryllium has a much lower vapor pressure than sulfur. BeMgZnSe was used as the cladding material, BeZnSe as the core material and CdZnSe as the active quantum well. The device lased at 511 nm with a threshold current density of 530 A/cm² and a lifetime of 65 minutes.

High power, near IR laser diodes were the topic of several papers. University of

Wisconsin researchers presented work on high power, aluminum-free lasers. At 980 nm wavelengths, the results are very impressive: 66% wall plug efficiency, the highest ever for any type of laser diode. Aluminum-free lasers typically employ GaInP and GaInAsP for the laser clads and cores, rather than the conventional high-aluminum composition AlGaAs clads and low-aluminum composition AlGaAs cores. Both aluminum-free and aluminum-containing near IR lasers use either InGaAs or GaAs quantum wells, depending on the lasing wavelength. The absence of aluminum and its associated oxidation problems is an advantage for laser structures that require regrowth. Additionally, it is suspected that reliability might be better in aluminum-free lasers. One area where there is essentially no difference between the two laser material systems is the catastrophic optical damage threshold (COD), which often limits the maximum output power of the laser. The U. Wisconsin group showed that the COD threshold is determined only by the material in the quantum well, not by the clad or core material.

On the other hand, high power AlGaAs-based diode lasers with record powers were reported by SDL. Outputs of 11.3 W at 870 nm and 9.3 W at 970 nm were reported in 100 μ m wide laser diodes. These record setting results were achieved by minimizing the aluminum content to reduce the series resistance and structuring the doping profile to minimize its overlap with the optical mode without degrading series resistance.

Also of note at LEOS '96 were reports from two industrial groups, Hewlett-Packard and Motorola, on the development of VCSEL's for high speed data link applications. Data transmission rates up to 1500 Mbit/sec are being targeted. The Motorola work showed projected room temperature lifetimes of greater than one million hours. This translates into well over a century of continuous operation.

Dr. Wicks is a professor at the University of Rochester, and is the Optoelectronic Editor for Compound Semiconductor

III-V Epi-Products
from the Specialists
in LPE



Epi-Equipment
Epi-Technologies
Epi-Materials

cta

Centrotherm Halbleitertechnologie GmbH
Joseph-von-Fraunhofer-Str. 7
52477 Alsdorf/Germany
Tel + 49-24 04-90680
Fax + 49-24 04-906868

Quality
Made in Germany

Growing For You:

IN QUALITY; CAPACITY; AND SERVICE

At Airtron, we don't make slogans. We make promises. So when we say Litton Airtron gallium arsenide is *Growing for You*, we mean it...

... In Quality

Our quality system in Morris Plains is now certified ISO 9002. And we've just added a new Class 10 clean room to insure our wafers' integrity.

... In Capacity

We've substantially increased the number of pullers, doubled the number of polishers, and expanded our packaging operation.

... In Service

With our increased production capabilities and the addition of state-of-the-art inspection and characteriza-

tion equipment, our response time has been sharply reduced. We can easily handle all of your special requests.

We're the largest supplier of SI GaAs in the world for the second year in a row. And we're the only GaAs manufacturer that can supply production quantities of large 6" (150 mm) wafers.

So whatever your gallium arsenide needs may be, count on Litton Airtron to deliver. Because no matter how big we get, we'll always be Growing for You.



Litton

Airtron

Litton Airtron
Electronics Materials Group
200 East Hanover Avenue
Morris Plains, New Jersey 07950
201-539-5500
Fax: 201-539-2210
E-Mail: Webmaster@airtron.com

(Germany Office)
Oberfoehrer Strasse 8
D-81679 Munchen 80, Germany
49-89-92204-0
EMAIL CODE: EURPPMG
Telex: 524596 Liton d
Fax: 49-89-98-51-84

(England Office)
6 First Avenue, Globe Park
Marlow, Buckinghamshire,
SL7 1YA England
44 62848-6060
Fax: 44-6284-72438

(Japan Office)
Litton-Westrex Company, Japan
Chiyoda Building
2-1-2, Marunouchi, Chiyoda-ku
Tokyo, 100 Japan
81-3-32116798
Fax: 81-3-32116797

9 Things to Watch in 1997

The global semiconductor industry may or may not be entering a recovery phase, depending upon who you talk to. Nevertheless, the applications for compound semiconductors look very good. Since the beginning of a new year is always a good time for cheery forecasts, we offer here our predictions as to what will be interesting in 1997.

MARIE MEYER

With the possible exceptions of Newt Gingrich and a few members of the British royal family who have had embarrassing conversations intercepted, it seems that *everybody* loves their cell phone. Therefore wireless handsets were easy to single out as the top hot topic in 1997. But that is not the only area worth watching. The outlook for our industry in 1997 looks remarkably good, because the applications for compound semiconductors include some of the most interesting areas of the global electronics market.

Sometimes it is nice to be in a niche market. The global semiconductor industry is a massive, \$150 billion/year enterprise. In comparison, sales of all compound semiconductor devices, including optoelectronics, add up to less than 5% of that total. The past year was terrible for many semiconductor companies. Worldwide revenue from chip sales actually declined by 8 - 10% in 1996, which is shocking for an industry which has become accustomed to double-digit growth rates. One can pin most of the blame on the freefall in prices for DRAMs, which account for 20% of the global semiconductor market.

On the other hand, 1996 was a great year for several companies in the compound semiconductor industry. This is especially true for the manufacturers of GaAs ICs. For example: over the past 18 months, the revenues at America's three independent GaAs fabs (Anadigics, TriQuint & Vitesse) rose by more than 50%.

With more high capacity silicon fabs scheduled to come on line in 1997, the problems in the memory sector are not likely to go away soon, which may mean that we will continue to see gloomy headlines about turmoil in the semiconductor industry in the mainstream press. But in reality, demand in several sectors of the electronics industry looks very good, especially in the communications field. As a result, the forecast for the compound semiconductor industry has never been better. Since the beginning of a new year is always a good time for optimism and enthusiasm, we present here our collection of some of the best examples why our niche looks good for 1997.



Cell Phones page 22



Fiber page 23



Television page 24



DVD page 26



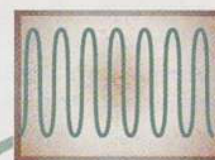
Satellites page 27



LED's page 28



Automotives page 30



Microwaves page 31



Military page 31

9 Things to Watch in 1997

#1 Cell Phones



This should be the year in which GaAs chip sales reach \$1 billion. If so, much of it will be due to cellular phones and other types of handsets for wireless communications. Any way you look at it, this is an incredible market. Several observers believe that over the next five to ten years the wireless industry as a whole will experience astronomical growth rates - perhaps as high as 35 to 40% per year.

Phones are the primary engine of growth in this area. The number of cellular subscribers reached 100 million in 1996, and their ranks continue to swell, perhaps reaching 200 million as soon as 1999. What does that mean for chip sales? According to Allied Business Intelligence [ABI, Oyster Bay, NY], revenue from the sale of semiconductors for cellular-type applications will grow at around 17.5%, or roughly one-half of the overall growth rate. The difference is due to increasing levels of integration and relentless price pressures.

ABI values the current market for all RF & microwave semiconductors at \$2.5 billion, and estimates that it will exceed \$4.5 billion by the year 2000. GaAs's share of that market is around 30%, and ABI predicts that it will increase throughout this period. Others agree. Magus Research [London, England] recently reported that that consumption of GaAs analog ICs for mobile communications will increase from 22.6 million units in 1995 to 175.8 million units by 2000, an average annual growth rate of 51%.

Telephone Technology

The current cell phone market is dominated by three manufacturers: **Motorola, Ericsson and Nokia**. In 1996 they shared around 75% of the estimated \$26 billion in handset sales. But there are a host of other electronics companies ready to challenge their position. The list includes Japanese giants like Matsushita, Mitsubishi, NEC, Samsung, Sanyo, Sony, Sharp and Toshiba; Europeans Philips and Alcatel; and North American companies such as Lucent, Northern Telecom, and Qualcomm.

The key to the future appears to lie in the introduction of new types of services, including the much-discussed personal communications services (PCS). This is good news for

GaAs. Most existing services are analog systems operating in the 800 MHz band. GSM, the most successful digital standard to date, works at around 950 MHz. But the popularity of cell phones is quickly filling up the available bandwidth. As a result, PCS has pushed up to 1.9 GHz. Conventional wisdom says this is the area of the spectrum where silicon becomes non-competitive, due to its lower F_t .

Hot Cell Phone Trends - all good for GaAs:

- Introduction of PCS at 1.9 GHz
- Proliferation of CDMA
- Demand for lower voltage & higher efficiency
- Dual banding - 800 MHz and 1.9 GHz in a small package

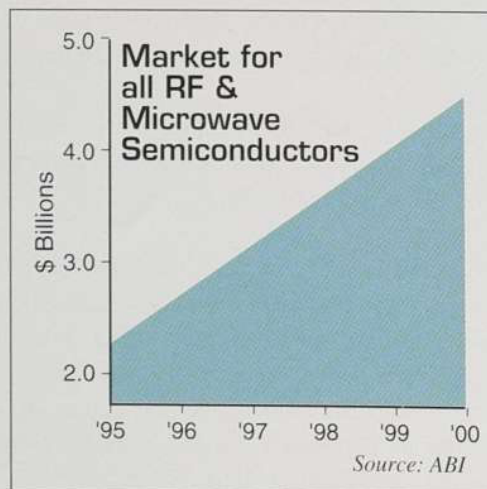
PCS is expected to have a major impact on the cell phone market in 1997 - especially in North America - and many observers believe that all PCS handsets will use GaAs power amplifiers (PAs).

1997 will also see at least three other big trends which also appear to favor GaAs. The first is the proliferation of cellular services based on code division multiple access (CDMA), which will allow the use of more carriers per cell. CDMA has been kicking around for some time now, but 1997 is sup-

posed to be its breakthrough year, with perhaps as many as 7 - 10 million CDMA handsets put into use. According to Charles Huang of Anadigics, CDMA requires greater spectrum purity than other access methods, such as those used in GSM, where most of the information is contained in the frequency domain. In CDMA, some of the information is carried by the amplitude, so the linearity of the power amplifier becomes much more important. And since GaAs MESFETs offer almost universally better linearity figures, Huang confidently predicts that CDMA's success will be a boost for GaAs IC manufacturers.

The next big trend is the relentless drive toward smaller and lighter phones which offer longer talktimes. Everyone agrees: expect more demand for low voltage, highly efficient handset designs. Dan Artusi, General Manager of the RF Semiconductor Division at Motorola, says that most of the impetus is coming from the digital arena, because of the complexity of the baseband processing in such phones. He says "in a digital phone, you want to push down to low voltages so you can have higher integration in the baseband portion. So obviously driving down the voltage of PA is desirable as well. This is an area where GaAs is very attractive." Motorola has even gone so far as to introduce PHEMT-based PAs in the 3 V range to meet the requirements of voltage vs. efficiency. (See page 10.)

The final trend worth watching is the proliferation of dual-band phones. Such phones are needed to ease the introduction of the new services at the higher frequencies. But the design of such phones is quite a challenge, as they must accommodate both the old 800 MHz cellular services and the new 1.9 GHz PCS. Huang notes that this is another area where GaAs has an important intrinsic advantage. He says "the semi-insulating GaAs substrate enables us to very freely integrate additional components, functions, interconnections and electrodes onto the same chip without the need to isolate each item. We believe that the more analog functions that the customer wants integrated onto the same chip, the more advantages that GaAs has. Therefore, we think that higher levels of integration for dual-band phones will be a very exciting field for GaAs technology."



#2 Fiber Optics



Fun fact of the day: According to KMI [Newport, RI], a leading fiber optic market research company, worldwide deployment of fiber reached 22.8 million kilometers in 1995, and by the year 2001 fiber deployments are expected to exceed 63 million kilometers - which is equal to 4,937 trips around the equator, or 82 round trips to the moon. How is that possible? Remember that each cable can carry multiple fibers - anywhere from ten to a thousand.

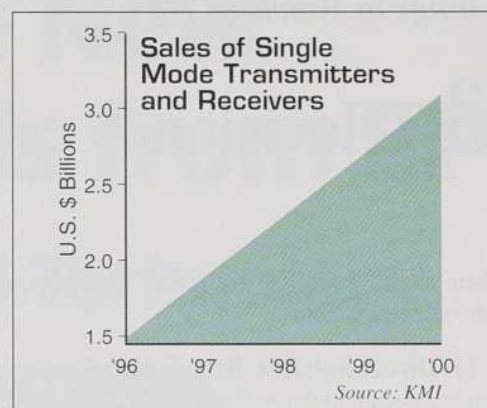
More interestingly, for readers of this magazine at least, is the enormous number of optoelectronic components that are needed to support all that fiber. Single mode fiber - the type which is used in long distance networks - accounts for around 90% of the total fiber infrastructure, and, as a rule of thumb, requires one transmit/receive pair for every 14 kilometers of deployment. A 1995 study released by KMI reports that current consumption of fiber optic laser diodes is around 1 million units a year, and that this figure will exceed 2.5 million per year by 2000. The company believes that sales of all types of transmitters and receivers for single-mode fiber - including lasers, LEDs, detectors, receiver and transmitter modules, and duplex transceivers - will double to \$3.1 billion in 2000 from \$1.5 billion in 1996.

Over the Long Haul

The major trends in long haul fiber optic networks seem to all be related to the need to keep up with the ever-increasing demand for transmission capacity. Of great strategic importance in 1997 will be the build-up of wavelength division multiplexing (WDM) systems. WDM allows multiple lasers to be coupled to a single fiber. Thus the 10 Gb/s transmission rate which is required in today's networks can be achieved by using four channels operating at 2.5 bit/s each. In the near future, when 20 and even 40 Gb/s will be required, WDM systems will allow the existing fiber installation to be upgraded by simply adding more cards to allow use of 8 or 16 channels.

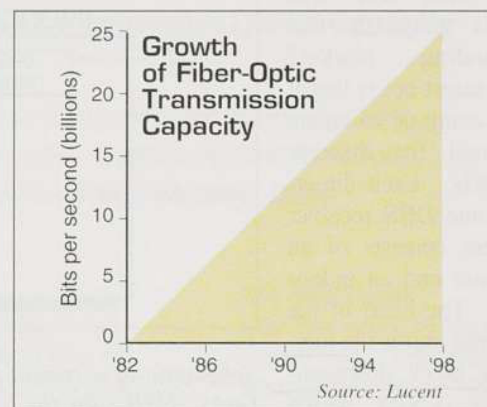
WDM saw its first deployments in 1996, and Greg Dougherty, Product Management and Market Operations Director for Optoelectronics at Lucent Technologies, says that he believes the WDM market will "explode" in 1997. The technique is very demanding in terms of the lasers used, because they must be capable of high-speed modulation and must also be reliably and reproducibly separated by as little as 1.5 to 0.75 nm.

Lucent recently an OEIC (optoelectronic integrated circuit) for this applica-



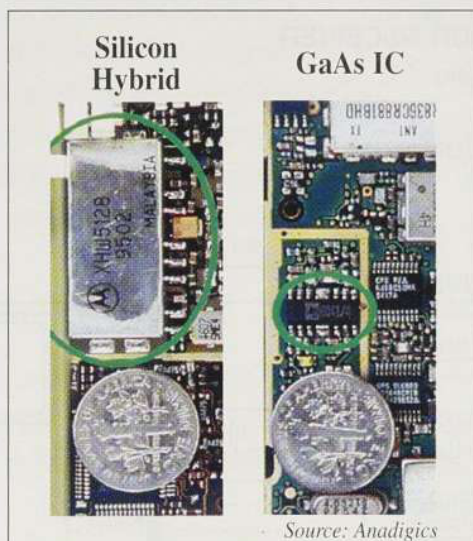
tion. Called an "electroabsorptive modulated laser" the new device includes a DFB laser and a voltage controlled optical modulator integrated onto the same InP chip. The modulator, which is interposed between the laser and the fiber, acts as an on-off shutter. This arrangement allows the laser to be operated continuously, eliminating chirp. And because the components are integrated onto a single chip, implementation is easier and more cost effective. Dougherty reports that Lucent, which is the world's largest supplier of single mode fiber optic components, believes that lasers of this type will greatly simplify the installation and administration of WDM networks.

The move up to 10 Gb/s creates demand not only for more sophisticated lasers, but also for high speed ICs to act as the multiplex/demultiplex transceivers. According to KMI's Richard Mack, there is general agreement in the telecom industry that GaAs has the edge in this area. Which is good news for GaAs IC makers, especially Vitesse, which reports that the majority of their internal investment is directed at developing high speed standard products for the communications business. Their recently introduced products include a 16:1 Mux/Demux chip set which is used to perform serialization and deserialization between 622 Mb/s and 10 Gb/s bit streams. Vitesse had an outstanding year in 1996 (see page 43), and they anticipate continued expansion into telecommunications - an area which is currently growing for them at around 70% a year.



Fab Capacity

If all of these technical trends - the introduction of PCS at 1.9 GHz, the proliferation of CDMA-based services, the need for low voltage and integrated dual-band RF front ends - are working in GaAs's favor, a new question arises: can the industry fulfill the increased demand? The signs are encouraging. GaAs IC processing capability is expanding. For example, three leading RF GaAs suppliers in the U.S. - Anadigics, TriQuint, and M/A-COM - have or will have increased their capacity by a factor of 2 - 4 by the end of 1997. More capacity should help increase customer confidence, and may help lower prices, which would add another competitive advantage for GaAs in this important market.



Less is More: example of the space reduction possible by switching from a hybrid silicon-based power amplifier to a GaAs IC. Shown is an Anadigics AWT0901 1 W power amplifier for a D-AMPS phone.

9 Things to Watch in 1997

#3 Television

There are at least three hot niches for compound semiconductors in the television field.

1) Direct Satellite Broadcast. Satellite television has been popular in Europe and Japan for several years, but was not really cost effective in the United States until 1995. Much of the problem was due to the limited amount of programming available via satellite, and the fact that it was broadcast in C-band (3.7 - 4.2 GHz), and required a 3 meter wide dish.

Today the situation is radically different. In 1995 Hughes, RCA and others began aggressively promoting satellite TV services offering hundreds of channels delivered via Ku-band (10.95 - 12.75 GHz) transmission, allowing the use of much smaller dishes. The response has been tremendous. A recent article in *Wireless Systems Design* claims that no other piece of wireless technology - not cell phones, not pagers, not even garage door openers - has gotten off to a faster start in the U.S. market than the digital home-satellite television receiver, with 1.2 million units installed in 1995. Worldwide, an estimated 40 million households are equipped for direct satellite TV reception.

All studies forecast strong growth in this market over the next few years, leading to a total of about 90 million households receiving satellite service by 2000. Picogiga, which has been fabricating HEMT wafers for the satellite dish market since 1988, predicts that the production of dishes will grow from 12.5 million units in 1996 to around 24 million units in 1998.

What role will GaAs play in this expanding market? The safest bet is that it will continue to create demand for discrete HEMTs. Each direct-to-home DBS receiver system consists of an outdoor and an indoor unit. The heart of the outdoor unit is the low-noise block down-converter (LNB), which receives, amplifies, and

converts the Ku-band signals to approximately 1.0 GHz for transmission to the indoor receiver unit. There have been many attempts to develop a single MMIC low noise amplifier (LNA) for the LNB. However,

to date, the only proven way to meet the stringent noise figure requirement (1.3 dB or better) has been to use a discrete HEMT in conjunction with the MMIC. Charles Huang of Anadigics predicts that this will remain the case because of the difficulty in monolithically integrating HEMT technology in a cost-effective manner. He also predicts that as the industry develops greater high volume manufacturing capabilities, opportunities for moving GaAs into the home will

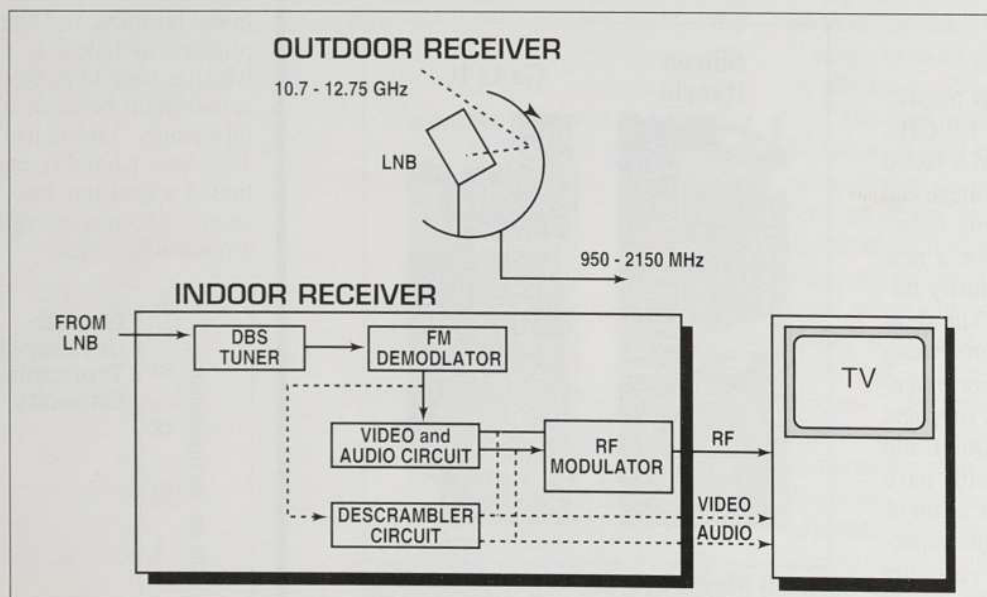
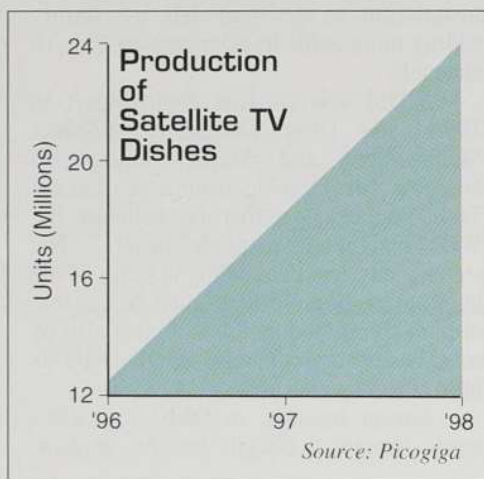
open up as well. Huang reports that his company, as well as NEC, Hitachi, Mitsubishi and others are now offering GaAs MMICs for use in the tuner of the indoor receiver, which provides power gain, automatic gain control, and image rejection.

2) Cable Television. DBS's biggest competitor - especially in North America - is cable television, called "CATV" in engineering circles. Although the technology has been around for years, there is a surprising level of innovation going on, inspired at least in part by the need to fend off the DBS challenge by offering better service to the consumer.

Steve Turley, Optoelectronic Product Manager at Nortel, cites several interesting developments in area of CATV lasers. Most notable are a move from the predominantly 1300 nm systems in use today to 1550 nm systems, and greater use of 980nm-pumped Er-doped fiber amplifiers. With regard to the later, he explains: "In the current systems the 1300nm broadcasting laser is used in an essentially point-to-point manner, or is perhaps split a very small number of times. Which means you need a lot of them. But the use of the optical amplifier allows the signal to be split many, many more times,

Television - What to Watch

- HEMTs & MMICs in DBS dishes, maybe MMICs in the house;
- Laser upgrades in CATV, GaAs ICs in set-top boxes;
- HDTV - the first commercial niche for SiC transistors?



Source: Anadigics

Schematic of a typical DBS receiver system. The LNB requires HEMTs and (sometimes) GaAs MMICs for the low noise amplifier; companies are also trying to push GaAs MMICs inside the house for the tuner.

Attention MBE System Operators

Introducing the New SUMO™ Effusion Cells from EPI

EPI Redefines Effusion Cell Technology



The EPI SUMO™ Effusion Cells – an important advance in MBE equipment technology, available for any production or research MBE system

The new EPI SUMO™ effusion cell is nothing short of revolutionary. It provides state-of-the-art uniformities and optimizes material quality, while maintaining very low levels of morphological defect densities and background doping levels. The beam equivalent pressure remains consistent throughout the life of the material charge, greatly enhancing reproducibility and operator convenience. Shutter activation-related flux transients are virtually undetectable. All models have large useful capacities, and configurations are available for both research and multi-wafer systems.

- **Excellent Material Quality**
- **Extremely Low Defect Densities**
- **Increased Flux to Power Ratios**
- **Long-Term Stability - more consistent beam equivalent pressures over the lifetime of the charge**
- **Virtually Undetectable Shutter Activation Related Flux Transients**
- **State-of-the-Art Deposition Uniformity**
- **Significantly Increased Useful Capacity**

*If you are looking for a way to maximize your MBE system up-time, increase throughput, improve material quality and reproducibility, and make your life a little easier, contact your local EPI sales office for more information about the EPI SUMO™ Effusion Cell. Be sure to ask for **The EPI SUMO™ Application Note, February, 1996.***



EPI
1290 Hammond Road
Saint Paul, MN 55110 U.S.A.
Phone: (1) 612-653-0488
Fax: (1) 612-653-0725
e-mail: info@epimbe.com

EPI Europe
147 Chorley New Road
Horwich, Bolton BL6 5Q
Greater Manchester, U.K.
Phone: (44) 1-204-668366
Fax: (44) 1-204-668466
e-mail: europe@epimbe.com

EPI Asia/Pacific
Our new office in Taipei,
Taiwan, will open in the
Second Quarter of 1997
Phone: (1) 612-653-0488
Fax: (1) 612-653-0725
e-mail: asia@epimbe.com

9 Things to Watch in 1997

Television con't

reducing the number of lasers needed and allowing for a most cost effective system."

The CATV laser market is roughly 1/10th the size of the telecom laser market. The CATV field is also becoming an interesting area for GaAs IC manufacturers. Anadigics reports that cable TV is its second fastest growing market, after wireless. They and others are delivering GaAs ICs for use in both the subscriber side (the set-top boxes) and the network side, in the form of line-extending amplifiers.

The market looks especially good for set-top box tuning circuits, which respond to input from the remote control and select and tune the desired channel. Because CATV operates over a huge bandwidth - from 50 to 750 MHz - and because it requires a low noise figure and very high dynamic range and high linearity, it is ideal for GaAs. And the next

generation will go up to 100 MHz, and will add on 50 more channels, which should further enhance GaAs's competitiveness.

3) High Definition Television. As we reported in our July/August 1996 issue, Westinghouse Electric has developed a SiC static induction transistor for use in solid-state high power UHF transmitters intended for the U.S. digital TV market. (CS 2(4), p. 4.) This is believed to be the first attempt to commercialize a SiC transistor. In late December, a critical roadblock to the implementation of HDTV was removed, as the FCC formally adopted the technical standards that would govern these transmissions. Jeff Jury of Westinghouse's Communication and Information Systems Division says "this is what we needed to move forward with production of our product - it will free up the equipment manufacturers to start work on digital conversion". Of course, it remains to be seen whether Westinghouse's approach is a favored one. So, as they say on TV - stay tuned.

#4 DVD



The big issues for DVD:

- Will it establish a beachhead in the consumer market in 1997?
- Will the roster of major laser suppliers change?
- Is it possible to make a cheap, reliable high power version of laser?

We must admit that 1997 will probably not be a great year for sales of optical memory devices using the new DVD standard. Manufacturers are expected to ship only a few million DVD players. The short-term forecast is a bit disappointing, but that is perhaps not surprising, given that the life-cycle of products of this type is 10-15 years - it takes time to establish a toe-hold in a market of this sort.

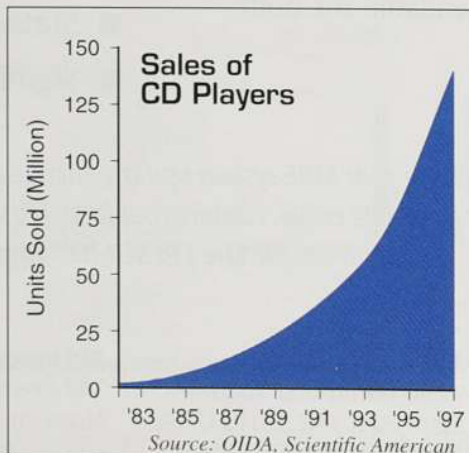
Nevertheless, DVD's first strides toward consumer acceptance should be one of the big stories in 1997. The potential market is huge: current sales of audio and computer products using the older CD format are around 150 million units/year. In addition, the stakes are high: several major Japanese electronics firms are treating DVD as the most important consumer electronics happening since the introduction of the VCR.

CD and DVD players are among the most familiar examples of electronic systems that are enabled by a compound semiconductor device - in this case, III-V semiconductor lasers. The CD format required 780 nm AlGaAs lasers, which are supplied primarily by four companies: Sony, Rohm, Sharp and Matsushita. But the DVD format calls for 635 - 650 nm AlGaInP laser diodes. Compared to AlGaAs, this material system exhibits lower p-type doping levels, lower hole mobilities, higher thermal resistivity, and a relatively low conduction band offset. These challenges, plus relatively low production volumes, make the new diodes expensive. According to Bob Steele of Strategies Unlimited, a discrete DVD laser currently costs up to \$15 - \$20, compared to around \$1 for discrete CD lasers (which are, of course, produced in much higher volumes). This set of dynamics may provide opportunities for

some additional companies to become significant players in this segment of the laser diode market. In addition to the four companies listed above, Toshiba, Mitsubishi, Sanyo and NEC are all believed to be developing high volume DVD laser manufacturing capabilities.

The DVD effort should also produce some interesting R&D news in 1997. Many analysts are predicting that the long-term success of DVD will be dependent upon its ability to provide "write-once" as well as fully erasable, rewriteable models. (All of the currently available products are read-only.) This extra capability might become available in 1998, but it will first require the development of an even more challenging laser diode, because the power output will need to be increased from 5 mW to around 35 mW. There is some question about whether the technology exists to produce such lasers in high quantities and reasonable costs. Nevertheless, several companies, including Mitsubishi, Sanyo, Matsushita and Sharp, have all recently reported that are all producing sample quantities of 635/650nm lasers with >30mW output.

And, in the meantime, there is still the existing market for CD lasers. Strategies Unlimited [Mountain View, CA] estimates that the current annual market is around 165 million units. This means that, in terms of units, CD lasers are the largest single application for semiconductor laser diodes, exceeding unit demand for telecom lasers by two orders of magnitude. (In terms of revenue, however, the CD laser market is less than half that of telecom!) Demand for CD lasers should persist until after the year 2000. But at that point, the older format is expected to give way to a full-fledged onslaught from DVD.



#5 Satellites



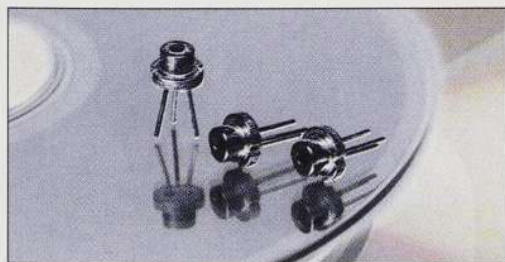
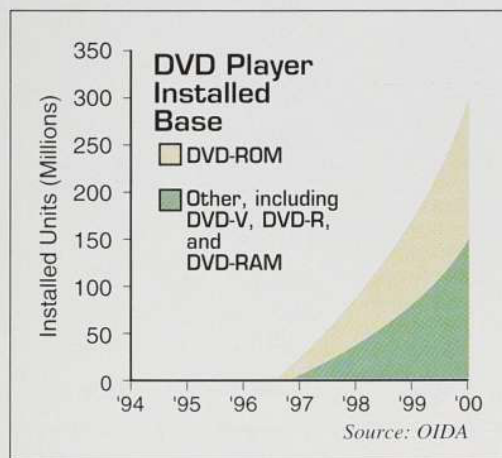
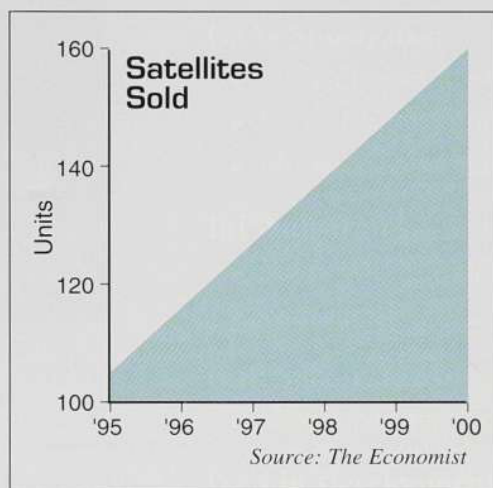
There will be a lot of GaAs orbiting the earth in the years to come. Demand for satellites has never been higher. As many satellites will be sold between 1995 and 1997 as were sold in the entire decade of the 1980's. Forecasts call for around 50 telecommunications satellites and 50 - 60 other types of "birds" to be launched per year. And satellite communications require microwave systems which are usually loaded with GaAs components.

The biggest trend in the commercial space industry is multiple-satellite networks. At least half a dozen such projects are underway. The most well-known example is Iridium, which is scheduled to launch the first of its 66 satellites this winter. Iridium is partly owned by Motorola, but the big GaAs winner for the project is Raytheon, which is the sole contractor for the communications modules. According to James DiLorenzo, General Manager of Raytheon Microelectronics [Andover, MA], each Iridium satellite will be equipped with three main mission antennas, each of which con-

tains 123 transmit/receive modules. All total, each satellite will require around 3,000 Raytheon GaAs MMIC chips.

The good news for Raytheon continues. They will also be the sole supplier of GaAs chips and transmit and receive modules for Iridium's biggest potential competitor - Globalstar, a 48 satellite network which is being launched by Loral later this year. And if that were not enough, DiLorenzo reports that Raytheon will also be supplying all of the RF GaAs components for the Iridium and Globalstar handsets, which should begin appearing in 1998.

Microwave GaAs isn't the only orbiting compound semiconductor. As we reported in our last issue, as many as one-half of the satellites currently under construction will be equipped with III-V solar cells as their primary power source (CS 2(6) 22). The need for more and better satellites may also open up some new R&D areas. Possibilities include better solar cells, rad-hard digital GaAs for on-board circuits, and emitters and detectors for laser-based satcom systems.



630 nm-band DVD lasers from NEC, offering optical output of 5 mW and operating temperature up to 60°C, with MTBF of 10,000 hours. Samples are priced at ¥15,000.

What Does it Stand For?

Everyone knows that "CD" is short for compact disc. But what does "DVD" stand for? We consulted the Interactive Multimedia Association DVD Special Interest Group. Given that they refer to themselves as "IMA-DVD-SIG", we thought they would know a thing or two about acronyms.

Their response? "Officially, DVD does not stand for anything." It seems that some members of the group called the standard Digital Video Disc, while others preferred Digital Versatile Disc. To resolve the dispute, the parties agreed that the acronym would be meaningless. Or, to be more precise, they agreed that "DVD" would be a catch-all category that would encompass five closely related optical disk formats:

- DVD-ROM: high capacity read-only data storage;
- DVD-V: a variant of DVD-ROM designed to deliver linear motion picture content;
- DVD-Audio: an audio-only format, similar to music CDs;
- DVD-R: a variation allowing one-time recording; and
- DVD-RAM: a fully erasable, rewriteable format.

The first three formats are ready to be shipped, although there is some question as to when Hollywood will begin to make interesting video content available. As noted above, the last two formats are somewhere near the end of their development cycle, and should appear in two - three years.

9 Things to Watch in 1997

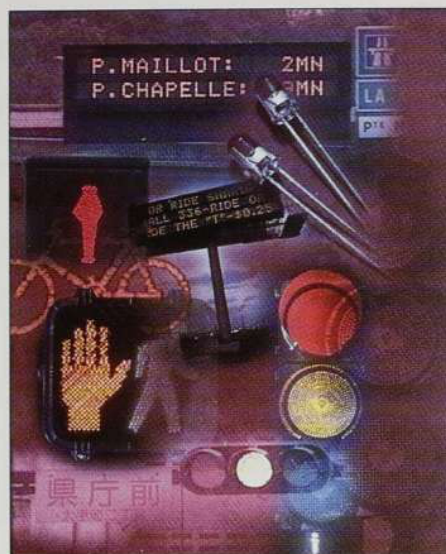
#6 LEDs for Everything

LEDs are becoming ubiquitous, appearing on everything from toothbrushes to electric guitars. Approximately 14 billion LEDs will be shipped worldwide in 1997, with a value of around \$2 billion dollars - making LEDs by far and away the biggest optoelectronic component sector. Strategies Unlimited has just released a report indicating that the LED market should exceed \$3 billion by 2001.¹ And according to the Optoelectronics Industry Development Association [OIDA, Washington, DC], visible LEDs currently are and will continue to be the largest optoelectronic component category in the worldwide market - see chart.

One of the best selling features of LEDs is their inherent dependability. According to David Evans, a Traffic Infrastructure Specialist at Hewlett-Packard, the mean time between failure for LEDs is typically 1.5 million hours or more, depending upon operating conditions. In comparison, today's incandescent bulbs burnout after around 8,000 hours. Another great feature is their high luminous efficiency. Evans says that the typical figure for the current generation of high luminance AlInGaP LEDs is around 15 - 20 lumens per watt, which is 2 X higher than color filtered incandescent lamps. And at a power dissipation of 40 mW, high luminance LEDs produce between 600 and 800 millilumens of total flux, which is enough to be seen even in bright sunlight.

You can expect to see more and more LEDs in everyday situations in 1997. Hewlett-Packard, which is the world's largest supplier of visible LEDs, describes their ability to penetrate new markets as "exhilarating". Some of the major recent developments include automotive exterior lighting, traffic signals, variable message signs for traffic management, and full color displays for commercial advertising.

And the future for visible LEDs? Well, you could say it looks bright - and colorful. As Mark Chandler, Marketing Manager for HP's Optoelectronics Components Group puts it, "every new innovation in materials and packaging will open up new applications, many of which we haven't even imagined yet".



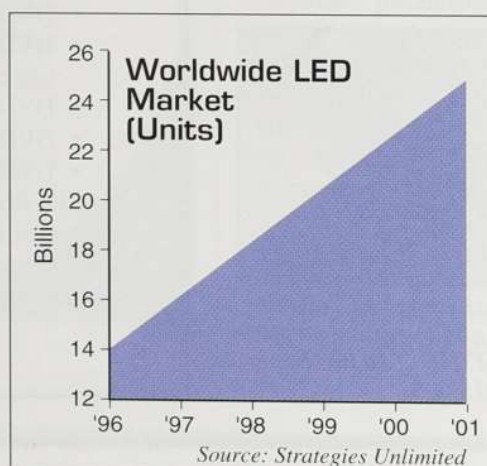
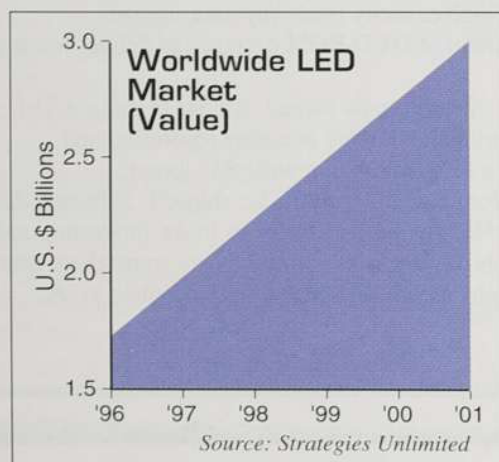
Hewlett Packard

A few of Hewlett-Packard's ideas about where to use LEDs in traffic management applications.

Optoelectronics Components Market US \$ Millions

Category	1995	2005	CAGR
Visible LEDs	1,500	3,500	8%
Laser Diodes	750	3,000	13%
Telecom Links	300	2,500	21%
Datacom Links	250	1,500	18%
IR-Com Links	50	700	27%
Other IR	700	1,600	8%
Optocouplers	600	1,600	9%
Photointerruptors	600	1,500	9%
Imaging Arrays	750	3000	13%
Other	300	500	5%
Total	5,800	19,400	12%

Source: OIDA



¹ "Visible LED Market Review and Forecast", Strategies Unlimited, Mountain View, CA. TEL [1] 415 941-3438, FAX [1] 415 941-5120, e-mail strultld@ix.netcom.com

VGF EXCELLENCE

USA HEAD OFFICE

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

FRANCE & GERMANY

SO.FRA.S.I.L
109 Rue De Javel
75015 Paris, France
Tel: (33) 1-4554-4000
Fax: (33) 1-4554-4004
Email:
100302.3612@compuserve.com

UNITED KINGDOM

West Associates
46 Leigh Road
Cobham, Surrey
United Kingdom, KT11 2LD
Tel: (44) 1932-868-006
Fax: (44) 1932-860-932
Email:
106020.3541@compuserve.com

JAPAN

AXT-Japan
565-15 Kitano-Machi
Hachioji, Tokyo 192, Japan
Tel: (81) 426-56-2032
Fax: (81) 426-56-6885
Email:
axtjapan@cg.netlaputa.or.jp

TAIWAN

Conary Enterprises Co., Ltd.
14F-3, No. 5, Lane 9, Sec. 3
Min-Sheng E. Road
Taipei, Taiwan, ROC
Tel: (886) 2-509-3174/5
Fax: (886) 2-501-6279
Email:
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
Email:
dkekorea@nownuri.nowcom.co.kr

GaAs Substrates:

- ▶ epi-ready SI and SC
- ▶ 2", 3", 100 mM and 150 mM
- ▶ all variety of orientations

InP Substrates:

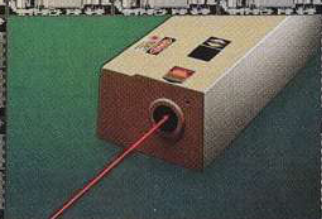
- ▶ 2" Fe- and S-doped
- ▶ 3" in development

GaP Substrates:

- ▶ 2" undoped and S-doped

GaN in Development

American
Xtal
Technology



9 Things to Watch in 1997

#7 Automotive Electronics



There will be around 55 million automobiles produced worldwide in 1997. A typical mid-range North American vehicle has an electronics content of around \$1,000. Thus, in terms of size - 55 million cars x \$1000 each = \$55 billion/year - the automotive electronics field is in the same league as the personal computer business.

Many consulting groups are forecasting rapid growth in this area. A recent report from Dataquest [San Jose, CA] predicts what they describe as "explosive" growth in the worldwide automotive electronics as "smart cars" become more of a reality. "So long as auto makers attempt to attract consumers with the latest James Bond-like electronic features, semiconductor and electronic component manufacturers stand to reap big benefits," says Greg Sheppard, a semiconductor application analyst at Dataquest. "It is conceivable that automobile electronics will be one of the top five growth markets for semiconductors over the next several years."

The automotive application that is most eagerly anticipated in the compound semiconductor industry is microwave frequency (76 GHz) on-board radar. This application could create demand for millions of GaAs MMICs per year. Although it will definitely take several years for this market to hit its stride, it appears that 1997 will be the first year that automotive radar appears in new car showrooms.

Cruising?

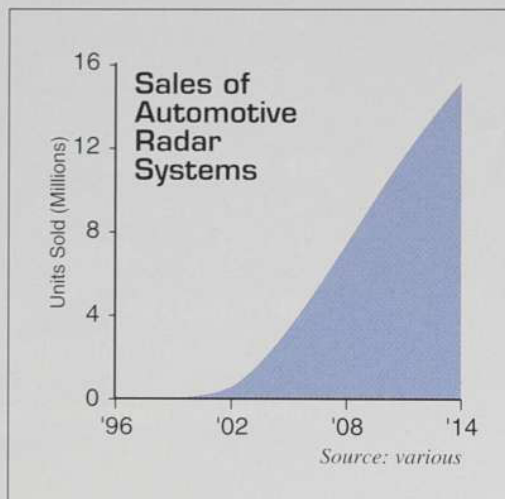
Rahul Dixit of TRW's Automotive Electronics Group describes the task at hand for the system and semiconductor manufacturers as "daunting", as they will be required to produce a robust, high-performance unit which can operate in a complex environment for \$100 - \$300 per unit. Clearly, the existing millimeter wave radar capability, developed for military and satellite applications, will need substantial fine-tuning before such targets can be met.

Heinrich Dambkes, President of United Monolithic Semiconductors, says "the first generation systems will be advanced cruise control systems, most probably based on hybrid circuits using GUNN, Schottky or perhaps PIN diodes. The second generation will be partially or completely based on GaAs MMICs for the RF-front end." His company is already offering a 3 chip demonstrator system.

Mercedes is expected to introduce the first automotive radars as an option on their 1998 model year "S-Class" cars, with a likely introduction in late 1997. It may be another 3 - 4 years before the

American and Japanese giants take the plunge. Consumer reaction will be monitored very closely. John Langley, the Automotive Radar Product Line Manager at Raytheon Microelectronics, explains: "One of the problems with the take-up of automotive radar is that the liability implications are enormous. So the initial applications are aimed at intelligent cruise control, rather than collision avoidance. It will therefore be offered as a comfort/convenience feature, which might be something of a problem, because the public may not be willing to pay \$800 - \$1,500 for it. But once we've built a few hundred thousand units and gotten a feel for it, then we can start to expand into safety areas." If and when that happens, higher prices might be possible.

But Langley remains optimistic about the early going, hopeful that the consumers will go for the new gadgets. He says "I have driven a lot of miles with intelligent cruise control, and I can tell you, it is a magic thing." Let's hope a little of that magic rubs off on the microwave GaAs makers.

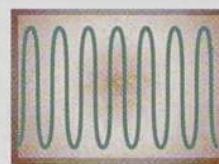


The Other Automotive Application

Even if the radar market never takes off, another automotive application is shaping up nicely: LEDs for indicators and lighting. In 1996 Hewlett-Packard announced a new family of LED assemblies, aimed at replacing incandescent bulbs in tail lamps, stop lamps and turn signals. Called "SnapLEDs", the new products use HP's transparent substrate AlInGaP technology to produce amber and red light. The company reports that the first vehicles to use the SnapLED assembly are expected to hit the road in mid-1997. And, as we reported in our last issue (CS 2(6), 14), Nichia Chemical has recently introduced a "white light" LED lamps (made by combining a blue LED with a YAG fluorescent layer) which is being targeted toward automotive interior lighting.

Thus it seems that both the microelectronics and the optoelectronics sectors of the compound semiconductor industry are poised to benefit from the predicted increase in spending on automotive electronics.

#8 Commercial Microwave Communications



The good news about microwave frequencies is that they are a natural niche for GaAs and InP analog devices. The bad news is that they are used primarily for military systems, which usually means expensive and even exotic solutions that lack high volume potential. But important decisions taken by the Federal Communications Commission (FCC) with regard to spectrum management in the United States have the potential to open up new applications for microwaves which are aimed at high volume, consumer-oriented markets.

On December 15, 1995, the FCC adopted a new set of rules which set aside 46.7 - 46.9 GHz and 76 - 77 GHz for unlicensed vehicular radars, and which allocated 59 - 64 GHz for unlicensed use for any application except for vehicular radars, with a limit on power density of 9uW/cm² at 3 m. For the first time in the U.S. it is now legal to transmit millimeter waves above 40 GHz for non-government uses.

Most of the interest in this decision revolves around the automotive radar application, which was discussed above. So what can the unlicensed bandwidth at 59 - 64 GHz be used for? Rory Van Tuyl of the Solid State Technology Laboratory at Hewlett-Packard begins his answer to that question by explaining what it is not good for: long-range communication. Oxygen absorption in this band confines propagation distance to around a kilometer. But this can also be a positive

feature, because it allows frequencies to be reused over short ranges.

One attractive potential use is wide bandwidth computer-to-computer wireless connections at data speeds up to 5 Gb/s. This would extend the data rates currently available to a fixed user through fiber optic cable. Van Tuyl explains: "A perennial problem for radio has been the huge differential between gigabit-per-second optical fiber rates and the kilobits- to megabits-per second rates possible with wireless. This 'data rate gap' might be breachable in this 59 - 64 GHz spectrum, which will clearly have the ability to handle a large number of broadband data streams simultaneously." Companies including Hewlett-Packard, Apple, Sun, Motorola, Hughes, and AT&T have defined a spectrum etiquette for sharing this band. They submitted their proposal to the FCC in December, 1996, an event which is seen as a key final step to allowing commercialization to proceed.

Encouragingly, Van Tuyl's analysis of the current status of semiconductor technology has lead him to the conclusion that "today's GaAs MMIC technology seems well suited to the challenge of producing low-cost RF modules for this band". He offers the hope that perhaps, after years of exile in the world of gold-plated hardware, millimeter wave GaAs is at last poised to flourish in commercial communications applications.

#9 Military Electronics



If this article were being written five years ago - perhaps even three years ago - it probably would have started with this category. But there has been a massive shift away from military applications in recent years. Consider a survey by the editors of *Microwave Journal* which found that GaAs wafer processing capacity in the U.S. rose 300% between 1993 and 1996, while at the same time the allocation of that capacity between military and commercial applications did a flip-flop, moving from 74% military/26% commercial in 1993 to 37% military/63% commercial in 1996.

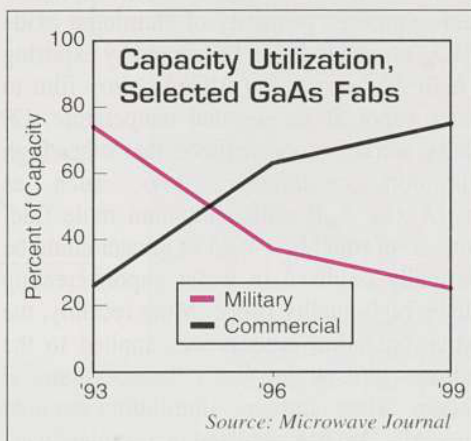
Despite the fact that military matters are clearly out of fashion, it should be noted that military spending in our industry will likely remain healthy in the near future, at least in the U.S. The Electronic Industries Association (EIA) predicts in their annual 10-year defense forecast that spending for military electronics will rise steadily to \$55.5 billion by 2006. Although military budgets have been much reduced, it appears that greater emphasis

on smart weapons will mean greater demand for high-tech solutions.

Raytheon, like many other companies, has leveraged the expertise that it developed via military contracting into a thriving commercial business. In 1993, 90% of their GaAs business was military; this year, it will be closer to 10%. Nevertheless, Raytheon's Jim DiLorenzo notes that R&D investment in solid

state technology for military applications remains robust - or, as he puts it, "nothing like it was in the heyday of the MMIC program, but significant nonetheless". There are some questions as to how many of the proposed programs will move into production, and what their time-frame might be, but even so, even this now-forgotten niche of the compound semiconductor industry might be interesting for at least some companies in 1997.

But everyone agrees that military spending is no longer determinative of the future of the industry - which is probably the best news of all.



III-V Compound Semiconductor Native Oxides - The Newest of the Semiconductor Device Materials

RUSSELL D. DUPUIS
MICROELECTRONICS RESEARCH CENTER
THE UNIVERSITY OF TEXAS AT AUSTIN
PRC/MER 1.606D-R9900
AUSTIN TX 78712-1100

Silicon dioxide (SiO_2), the "intrinsic" or "native oxide" [1] of silicon, was first introduced as an "electronic material" by Carl Frosch at Bell Telephone Laboratories in 1955. In this seminal work, Frosch pioneered the controlled oxidation of Si at high temperatures in a steam ambient. The resulting oxide is an extremely versatile and stable material which Frosch employed to demonstrate the "oxide masking" process for Si. This discovery also led to the development of Si-based metal-oxide-semiconductor (MOS) devices, prevalent in the vast majority of today's integrated circuit technology.

Until recently, it was believed that similar high-quality insulating oxide films could not be formed directly from the III-V compound semiconductors. There are many potentially important device applications for such an "intrinsic" (or "native") insulating oxide material. For example, if an oxide equivalent to SiO_2 could be formed from III-V's, passivation layers and high-performance metal-oxide-semiconductor field-effect transistors (MOSFET's) could be made using these materials. Many different approaches to address the passivation and insulation issue in compound semiconductor devices have been examined, including chemical vapor deposition (CVD) or sputtering of dielectrics such as SiO_2 , silicon nitride (Si_3N_4), and aluminum oxide (Al_2O_3), the direct oxidation of gallium arsenide (GaAs), dry oxidation of AlAs, and

the plasma oxidation of indium gallium arsenide (InGaAs) to name a few. All of these insulating films have relatively poor insulator-semiconductor interfaces, making them unsuitable for high-quality MOS and optoelectronic devices, as well as for the passivation of devices.

Formation and Properties of III-V Native Oxides

In 1990, Holonyak and co-workers at the University of Illinois at Urbana-Champaign (UIUC), discovered that the "native oxides" of the binary AlAs and the ternary $\text{Al}_x\text{Ga}_{1-x}\text{As}$ are similar in nature to SiO_2 and can be formed in much the same way. Holonyak and co-workers established that a high-quality, dense insulator composed primarily of aluminum oxide (AlO_x) compounds can be formed by exposing a high-Al-composition AlGaAs alloy film to water vapor at an elevated temperature. [2] These workers soon realized that other high aluminum containing alloys, such as $\text{In}_{0.5}(\text{Al}_x\text{Ga}_{1-x})_{0.5}\text{P}$, with aluminum mole fractions, x , of roughly $x \sim 0.45$ or greater could be thermally oxidized in water vapor, creating stable, high-quality films. More recently, the native oxidation process was applied to the indium phosphide (InP) based material system when indium aluminum arsenide ($\text{In}_{0.52}\text{Al}_{0.48}\text{As}$) was oxidized in a similar "wet" thermal environment.

It has long been known that single-crystal films of pure AlAs oxidize very rapidly in air. [3] This process does not result in a stable oxide film but instead, the oxidation leads to the corrosion of the layer and, ultimately, to its complete destruction—it turns to powder containing various phases of compounds from the Al-As-O-H phase diagram. However, when this oxidation process is carried out in a high-temperature environment ($\sim 450^\circ\text{C}$) containing water vapor, the result is a different phase of AlAs oxide—a highly stable oxide phase forms containing primarily AlO_x and a little AsO_x [2,4] As shown in Figure 1, the oxidation rate for AlGaAs alloys is strongly dependent upon the alloy composition and the temperature with activation energies ranging from 1.2 to 1.4 eV. [4]

The fundamental technology for the formation of III-V native oxides from Al-containing epitaxial layers is essentially the "Frosch steam oxidation process" which has been in use since it was invented in 1955 for producing SiO_2 layers on Si wafers. In this process, a bare Si wafer is exposed to water vapor in a N_2 or O_2 gas at high temperatures ($T_{\text{ox}} \sim 1050^\circ\text{C}$). However, in the case of III-V native oxides, an Al-containing epitaxial layer is required since stable Al-containing III-V "bulk" crystals do not exist. For native oxide formation, an epitaxial layer structure is first produced by metalorganic chemical vapor deposition (MOCVD) or molecular-beam epitaxy (MBE). Next, the Al-bearing regions are exposed where the native-oxide layer is desired. Then the wafer is heated to $\sim 450^\circ\text{C}$ in a water-vapor ambient. This is typically done by placing the wafer in a furnace tube containing a carrier gas flow (e.g., forming gas or N_2) that is bubbled through a heated water bubbler or "steam generator". The H_2O vapor concentration can be varied by changing the water temperature in the bubbler or the carrier gas flow rate. After the desired thickness of oxide film is produced, the steam is shut off and the oxidized wafer is cooled and removed from the furnace.

As noted above, the oxidation process has been demonstrated for the formation of native-oxide layers from many of the Al-containing alloys in the III-V systems, with most of the research being done with the AlAs binary and the AlGaAs, InAlAs, and InAlP ternaries. There are both similarities and differences among the native oxides formed from these materials. For example, as shown in Figure 1, the oxidation rates for $\text{In}_{0.5}\text{Al}_{0.5}\text{P}$ and $\text{Al}_{0.5}\text{Ga}_{0.5}\text{As}$ are quite different. At a given

temperature, the oxidation rate of AlGaAs is much faster than for a ternary film of InAlAs or InAlP having the same composition of Al (e.g., $x=0.5$). These data clearly indicate that the oxidation process itself consists of a complex series of reactions which involve both the Column III and the Column V subspecies.

Application to Devices

For the most part, these transparent and insulating native oxide layers have been applied to the demonstration of novel or improved optoelectronic light-emitting devices such as light-emitting diodes (LED's) and injection lasers. In these applications, their insulating properties and relatively low index of refraction ($n \sim 1.6$) make them useful for electrical and optical confinement. These aluminum-based oxides have been applied to such devices and structures as gain-guided stripe-geometry edge-emitting lasers [5], index-guided laser arrays [6], buried-mesa index-guided edge-emitting lasers, ring-cavity lasers, ultra-low threshold vertical cavity lasers [6], and photopumped [7] and electrically pumped [8] vertical-cavity surface-emitting lasers (VCSEL's) with native-oxide distributed Bragg reflector (DBR) mirrors.

In addition to the obvious differences in the chemical composition of these various III-V native oxides, the electronic properties of the native oxide-semiconductor interface are dramatically different as well. It has been shown that the oxidation of the upper AlAs cladding layer in an AlAs/GaAs DH structure results in a significant decrease in the PL efficiency of the GaAs layer. Other native oxides have much different effects. For example, we

have examined the luminescence behavior of InAlP/InGaP/InAlP double-heterostructure (DH) and quantum-well (QW) structures both in the "as-grown" condition and with the top InAlP cladding layer partially oxidized. Both the photoluminescence and time-resolved photoluminescence (TRPL) performance of these samples improved significantly with increasing thickness of the top InAlP cladding converted into oxide. These results are consistent with the passivation effect which has been observed for partially oxidized InAlGaP LED's.

In addition to the expected conventional "planar" oxidation of Al-containing layers (i.e., from the top down), the "lateral" oxidation (e.g., inward from the exposed edge of a buried layer) can also be employed in the design and fabrication of native oxide layers. Thus, there are two different oxidation modes which can be exploited in device design. In the "vertical" oxidation process, normally carried out on (100)-oriented surfaces, the diffusion of the oxidizing species through the oxide layer will primarily determine the growth rate of the oxide film for a given composition of Al alloy. It is generally observed that the oxidation rate is nearly a linear function of time, indicative of a relatively "porous" oxide. As noted above, the vertical oxidation rate is strongly dependent upon the material, e.g., it is much higher for AlAs than for InAlP.

However, the lateral oxidation process appears to be controlled by other factors, in addition to the Al composition of the film. In general, below a certain thickness limit, the lateral oxidation rate is dependent also upon the layer thickness: thicker layers oxidize faster than thinner layers. In fact, thin "high

Al composition" AlGaAs QW barrier layers appear to oxidize laterally at an exceedingly low rate, a feature which has been used by the UIUC group to make real-index-confined semiconductor "photonic lattice" light-emitting arrays, as shown in Figure 2. [9] It can be expected that the oxidation rate is dependent upon the orientation of the crystalline plane being oxidized and this may account for the primary differences in oxidation kinetics for vertical and lateral oxidation. A full understanding of the chemistry of the native oxidation process has yet to be developed.

The lateral oxidation process can be employed to greatly enhance current and optical confinement in semiconductor devices. For example, as shown in Figure 3, Holonyak and co-workers established that such a lateral oxidation process, which permits the formation of *buried oxide layers* [10] can be employed for current confinement and for the control of the optical mode in injection lasers. Recently, this lateral oxidation process has been used to improve the current confinement of narrow-aperture VCSEL's. [11,12] This process has also been used in the formation of alternating quarter-wavelength-thick layers of semiconductor-native oxide materials to form a distributed Bragg reflector (DBR) mirror, as shown in Figure 4. [7]

The native-oxidation process can also be applied to the fabrication of electronic devices, in particular, insulated-gate field-effect transistors. These devices rely upon the insulating properties of the oxides but also require a high-quality oxide-semiconductor interface, particularly for "enhancement-mode" devices. Holonyak and his group were the first to demonstrate a III-V MOSFET

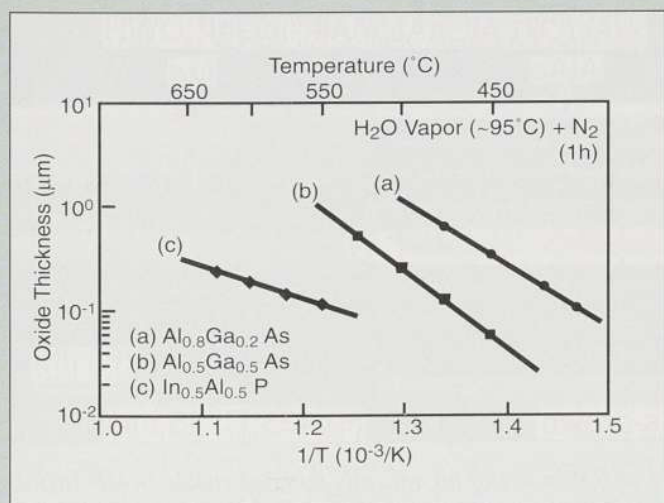


Figure 1: Arrhenius plot of the relative oxidation rates for various Al-containing III-V alloys. [4]

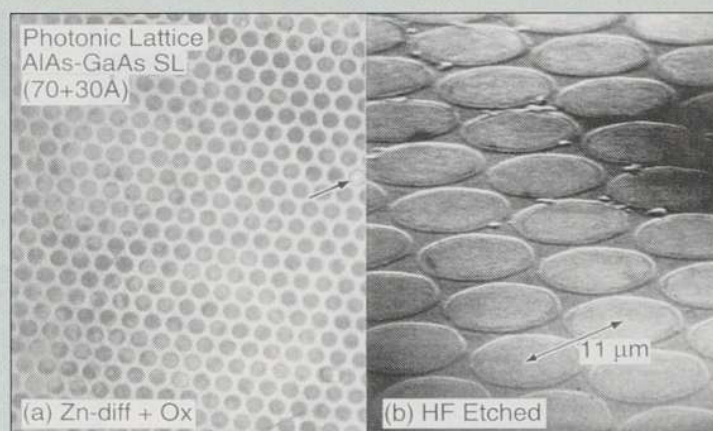


Figure 2: Images of a "photonic lattice" structure defined by selective oxidation and impurity-induced disordering. [9] (a) view of structure after processing; (b) higher magnification view after a portion of the native-oxide layer has been selectively removed using HF.

using this approach. They fabricated an AlGaAs/GaAs depletion-mode FET structure with a native-oxide insulated gate. [13] Recently, we have demonstrated a similar MOSFET in the InAlAs/InGaAs system through the oxidation of InAlAs to form an insulated gate. [14] Enhancement mode FET's will require additional work but we believe that such devices will soon be demonstrated.

Potential Commercial Applications

It has already been mentioned that III-V native oxide layers have been used for the demonstration of a variety of improved semiconductor devices as well as for the realization of novel device structures. The primary application investigated to date has been for optoelectronic devices, principally injection lasers. In the near term, the use of native-oxide laterally oxidized "current-confinement" regions in small-aperture VCSEL's will probably be the most actively explored commercial application for this technology. Another related and important commercial application is the passivation of the Al-rich regions of Fabry-Perot lasers, VCSEL's, and LED's to improve the long-term reliability of the devices. However, the native-oxide "insulated-gate" FET's and native-oxide-based semi-insulating isolation layers could also be used in the near future to improve the performance of III-V electronic devices. Possible obstacles to commercialization could be exposed during extended device reliability studies. For example, the oxidation process can possibly have a strong effect upon the concentration and nature of point defects and also result in the introduction of other impurities.

Summary and Conclusions

The high-temperature steam oxidation of Al-rich III-V compound semiconductor layers has been shown to lead to stable, dense "native-oxide" solid films with electrically insulating properties. The films exhibit relatively low indices of refraction as well, making these materials nearly ideal for applications to current and optical confinement in semiconductor device structures, e.g., injection lasers and LED's. The interface quality for certain oxide-semiconductor interfaces is of sufficient quality for enhanced luminescence to be observed for such oxidized structures. We believe that a fundamental understanding of these materials will lead to a diverse applications for their unique properties. The native oxides of Al-containing III-V's have already demonstrated their worth for a variety of discrete and integrated devices; it is likely they will be applied as well to III-V device integration. Many research groups at industrial, government, and academic laboratories worldwide are now exploring the application of these materials to devices. These oxide materials are poised to make a major impact in III-V electronics and optoelectronics, perhaps similar to the impact of the "native oxide" of Si-SiO₂-upon Si technology.

Acknowledgments

I wish to thank Prof. N. Holonyak, Jr., for interesting conversations on this topic. Since its inception, the native-oxide research at UIUC has been largely supported by the Army Research Office. The work at UT-Austin has been supported by DARPA and by the National Science Foundation.

REFERENCES

1. A thin film of the "intrinsic oxide" of Si, SiO₂, is normally called a "native oxide" if the film results from "unintentional" or uncontrolled oxidation. In the case of compound semiconductors, the term "native oxide" is used to describe an intrinsic oxide film formed by any oxidation process (as distinct from a deposited oxide layer). The term is intended to describe an oxide material formed directly from the semiconductor itself as opposed to a "foreign" oxide composed of a deposited film.
2. J. M. Dallesasse, N. Holonyak, Jr., A. R. Sugg, T. A. Richard, and N. El-Zein, *Appl. Phys. Lett.* 57, 2844 (1990).
3. J. M. Dallesasse, N. El-Zein, N. Holonyak, Jr., K. C. Hsieh, R. D. Burnham, and R. D. Dupuis, *J. Appl. Phys.* 58, 2235 (1990).
4. F. A. Kish, S. J. Caracci, N. Holonyak, Jr., K. C. Hsieh, J. E. Baker, S. A. Maranowski, A. R. Sugg, J. M. Dallesasse, R. M. Fletcher, C. P. Kuo, T. D. Osentowski, and M. G. Craford, *J. Electron. Mat.* 21, 1133 (1992).
5. J. M. Dallesasse and N. Holonyak, Jr., *Appl. Phys. Lett.* 58, 394 (1991).
6. J. M. Dallesasse, N. Holonyak, Jr., D. C. Hall, N. El-Zein, A. R. Sugg, S. C. Smith, and R. D. Burnham, *Appl. Phys. Lett.* 58, 834 (1991).
7. T. A. Richard, S. A. Maranowski, N. Holonyak, Jr., E. I. Chen, M. J. Ries, J. G. Neff, P. A. Grudowski, and R. D. Dupuis, *Appl. Phys. Lett.* 66, 589 (1995).
8. M. H. MacDougall, G. M. Yang, A. E. Bond, C. K. Lin, D. Tishinin, and P. D. Dapkus, *IEEE Photon. Tech. Lett.* 8, 310 (1996).
9. M. J. Ries, E. I. Chen, and N. Holonyak, Jr., *Appl. Phys. Lett.* 68, 2035 (1996).
10. S. A. Maranowski, A. R. Sugg, E. I. Chen, and N. Holonyak, Jr., *Appl. Phys. Lett.* 63, 1660 (1993).
11. D. L. Huffaker, D. G. Deppe, K. Kumar, and T. J. Rogers, *Appl. Phys. Lett.* 65, 97 (1994).
12. K. D. Choquette, R. P. Schneider, Jr., K. L. Lear, and K. M. Geib, *Electron. Lett.* 30, 2043 (1994).
13. E. I. Chin, N. Holonyak, Jr., and S. A. Maranowski, *Appl. Phys. Lett.* 66, 2688 (1995).
14. P. A. Grudowski, R. V. Chelakara, and R. D. Dupuis, *Appl. Phys. Lett.* 69, 388 (1996).

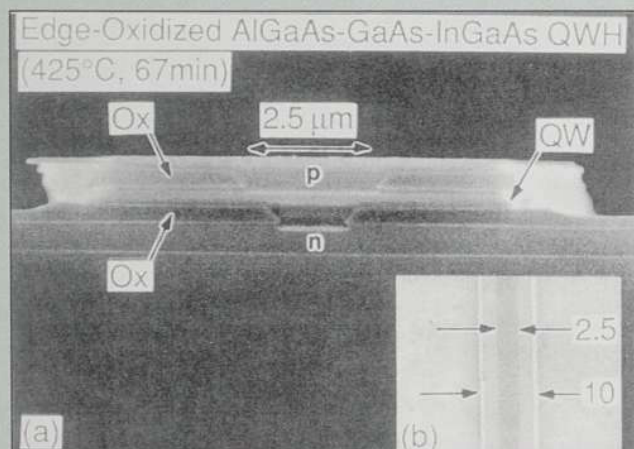


Figure 3: SEM photograph of a laterally oxidized current-confined QWH stripe-geometry injection laser structure formed by the selective lateral oxidation of buried AlAs layers. (a) cleaved cross section of laser after oxidation; (b) top view of the oxidized stripe. [10]

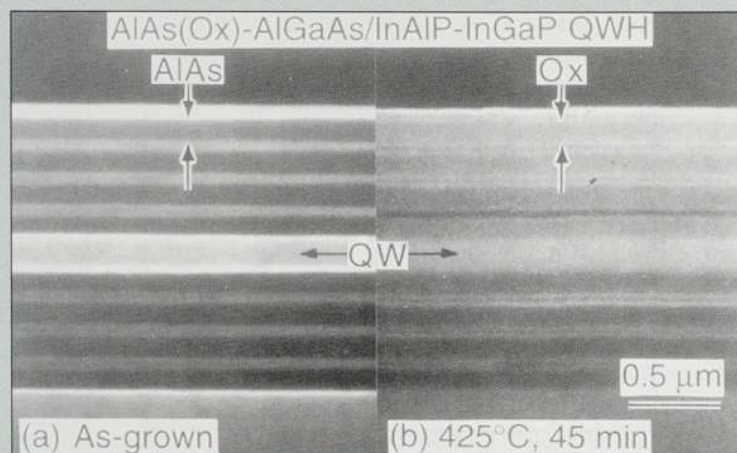


Figure 4: SEM image of an optically pumped visible InAlP-InGaP SQW VCSEL structure employing distributed Bragg reflectors composed of pairs of laterally oxidized InAlP-native oxide/InGaP materials. [7]

Research Review

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

Electronic Circuits and Devices

GaN/AlGaIn HFETs for 10-15 GHz Operation

M. Asif Khan et al, IEEE Electron Device Letters, 17(12), 584 [December 1996].

With a large bandgap (3.4 eV), high thermal conductivity (1.3 W/cmK), and saturated electron velocities in excess of 1×10^7 cm/s, GaN based FETs are excellent candidates for high power RF sources. Using a doped channel heterostructure FET (DCHFET) structure which utilizes a $\text{Al}_{0.15}\text{Ga}_{0.85}\text{N}$ layer to form the heterostructure, a 0.15 μm gate length device is reported on, which exhibits a f_{max} of 97 GHz and a maximum transconductance of 120 mS/mm. Connecting five 0.25 μm gate length devices in parallel, the combined devices exhibited CW microwave output power for operation up to 15 GHz, with a maximum output power of 270 mW/mm at 10 GHz. This is the first reported microwave performance for GaN HFETs at the frequency. Work performed at APA Optics [Blaine, MN], University of Virginia, Rockwell, and Cornell University.

70 GHz p-Type SiGe MODFET

M. Arafat et al, Electronics Letters, 17(12), 586 [December 1996].

SiGe p-type FETs are needed in order to develop Si/SiGe complementary structures. Self aligned SiGe p-type MODFETs grown by UHV-CVD are reported on which exhibit a two-dimensional hole gas mobility of 700 cm^2/Vsec , along with a hole sheet density of $3.5 \times 10^{12} \text{ cm}^{-2}$. Using liftoff to fabricate 0.1 μm T-shaped gates with Ti/Mo/Pt/Au, the resulting MODFETs exhibit a maximum extrinsic transconductance of 258 mS/mm and a current density of 60 mA/mm, along with a f_t of 70 GHz and a f_{max} of 55 GHz. This is the highest reported f_t for a p-type FET device. Work performed at the University of Illinois, Cairo University [Giza, Egypt], and IBM.

38 GHz SiGe MMIC Oscillator

C.N. Rheinfielder et al, IEEE Microwave and Guided Wave Letters, 6(11), 398 [November 1996].

In an effort to extend the frequency domain of Si-based circuits, SiGe HBTs, combined with a coplanar design, and high resistivity Si substrates (8000 ohm/cm), have been used in the fabrication of a 38 GHz LC oscillator. The SiGe HBT utilized a 250 Å $\text{Ge}_{0.3}\text{Si}_{0.7}$ thick base which was boron doped (p-type) at $1 \times 10^{20} \text{ cm}^{-3}$, and a 3000 Å collector which was antimony doped (n-type) at $5 \times 10^{16} \text{ cm}^{-3}$. This HBT exhibited an f_{max} of 80 GHz. At 38 GHz, the oscillator delivered an output power of 2 dBm with a PAE of 6%. This is the first SiGe oscillator demonstrated in this frequency range. Work performed at the Ferdinand-Braun-Institut [Berlin, Germany], and Daimler-Benz.

Selective MOCVD Growth of Extrinsic Base Regions in InP/InGaAs HBTs

M. Ida et al, IEEE Transactions on Electron Devices, 43(11), 1812 [November 1996].

In an effort to improve the f_{max} of an HBT through the reduction of base sheet resistance, the regrowth of the extrinsic region of the base with a thick heavily doped material has been employed. For InP/InGaAs HBTs, MOCVD selective regrowth of GaInAs on the extrinsic base regions was performed at high rotation speeds (1400 rpm), which improved selectivities, and allowed regrowth to be performed at a low temperature of 450°C. Prior to regrowth a preheating treatment 500°C was required (this is the same temperature as the HBT growth temperature). By utilizing a 1200 Å extrinsic base layer doped to a level of $4 \times 10^{19} \text{ cm}^{-3}$ (base doping of $2 \times 10^{19} \text{ cm}^{-3}$), the base resistance was reduced by half, and the f_{max} increased from 90 to 141 GHz. However, the selectively regrown device experienced Zn diffusion from the base into the emitter, resulting in degraded Gummel characteristics and base-emitter leakage. This behavior was attributed to the diffusion of group III interstitials from the InGaAs emitter cap layer into the emitter and base, where the introduction of these interstitials permitted rapid Zn diffusion. Future work will need to focus on further reduction of regrowth temperatures or on the introduction of interstitial barriers. Work performed at NTT.

InAs/AlSb Dual-Gate HFET's

The InAs/AlSb heterostructure system exhibits many outstanding characteristics, which should make it well suited for digital IC applications. However, InAs/AlSb-based HFETs exhibit pronounced impact-ionization related short channel effects which result in very high output conductances and a pronounced kink in its output characteristics.

Researchers at Simon Fraser University [Burnby, BC, Canada] and the Hughes Research Laboratories [Malibu, CA] have applied a dual-gate (DG) structure to InAs/AlSb HFETs in order to reduce these short channel effects. Grown by MBE on GaAs substrates, a 3 μm thick AlSb buffer is used as a strain relaxation layer to accommodate the 7% lattice mismatch between the AlSb/GaSb/InAs heterostructure system and the GaAs substrate. The HFET utilizes an active layer which consists of a 8 nm AlSb bottom barrier, a 10 nm undoped InAs quantum well, and a 5 nm AlSb top barrier. Hall measurements of the HFET structure indicate a room temperature mobility of 18,400 cm^2/Vsec with an electron sheet density of $1.86 \times 10^{12}/\text{cm}^2$. The DG-HFETs were fabricated with optical lithography, in which two 1.0 μm gates with a 1.0 μm intergate separation were used. A peak transconductance of 312 mS/mm was obtained, and the devices displayed a much lower output conductance than does the single gate HFET, as well as showing no kink effect for drain biases of up to 2.5 V (single gate HFETs exhibit a kink in output characteristics at 0.8 V). It is estimated that this device exhibits f_t values of 30 GHz-mm - comparable to that obtained with high speed InP/GaInAs/AlInAs based HEMTs.

The second gate enables the implementation of nonlinear functions such as multiplication, mixing and switching. To take advantage of it, a NAND logic function block prototype consisting of a single DG-FET and a 120 ohm load resistor was fabricated. The NAND gate was operated up to a frequency of 10 MHz (limited by circuit ringing due to the large stray parasitics associated with the needle probe used to test the circuit). Despite this slow speed, this first example of a simple circuit, combined with improved output characteristics, demonstrates the potential of the InAs/AlSb material system for high speed digital applications.

See "InAs/AlSb Dual-Gate HFET's," C.R. Bolognesi et al, IEEE Electron Device Letters, Vol 17(11), 334 [November 1996] and Demonstration of NAND Logic Switching in InAs/AlSb Dual-Gate HFET's, M.W. Dvorak et al, Electronics Letters, 32(24), 2273 [21 November 1996].

Bulk-like GaN on Sapphire and SiC

The great majority of GaN-based devices are fabricated by thin film deposition techniques such as MBE or MOCVD on sapphire or SiC substrates. GaN substrates would be preferable, but to date only very small bulk GaN substrates (a few millimeters wide) have been produced.

An alternate approach is the growth of very thick, high-quality GaN layers on sapphire or 6H-SiC. MBE or MOCVD are not suitable for such thick growths because of their relatively low growth rates. But a recent paper indicates that high-temperature vapor phase epitaxy (HTVPE) is capable of producing good quality bulk GaN films at high growth rates. Growth rates of 40-80 $\mu\text{m/hr}$ on both sapphire and SiC substrates were reported. Homogeneous films of 20 μm in thickness could be achieved with a total growth cycle of only 100 minutes. In contrast to thin film techniques, special buffer layers were not used. The epitaxial GaN films are almost transparent and exhibit optically smooth surfaces over 100 μm length scales.

The GaN films were characterized by X-ray diffraction and photoluminescence. X-ray FWHM of 420 - 1000 arc sec are achieved on (0001) 6H-SiC substrates, and of 1000-1250 arc sec on (0001) sapphire substrates. The higher FWHM correspond to the higher growth rates, and appear to indicate a lateral transport limitation of adatoms on the growth surface. Cross-sectional transmission electron microscopy measurements (XTEM) reveal a dislocation density of approximately 10^9 cm^{-2} , with the dislocations oriented perpendicular to the substrate. The GaN films grown on 6H-SiC are therefore of a higher structural quality, due to the reduced lattice mismatch and the better thermal stability of SiC. Low-temperature (6 K) photoluminescence measurements are dominated by the neutral-donor bound exciton (D^0X) with a typical line width of 3-5 meV at 3.472 eV. The emission energy is independent of the film thickness and of the substrate material used, indicating that the epitaxial films are free of substrate induced stress (compressive for SiC, and tensile on sapphire) at 6 K. The low-temperature PL spectrum of GaN films grown on sapphire exhibits a strong additional luminescence band at 3.42 eV which indicates unintentional oxygen doping from the sapphire substrate. The high-quality of the films suggests that thick HTVPE GaN films could serve as templates for homoepitaxial GaN device fabrication.

Work done at the University of California (Berkeley). See S. Fischer et al, "Properties of GaN Grown at High Rates on Sapphire and on 6H-SiC," Appl. Phys. Lett. 68(18), 2716 [28 October 1996].

Compound Semiconductor Materials

MOCVD Growth of (Al,Ga)Sb/GaSb Heterostructures

M. Behet et al, J. of Crystal Growth 167, 415 [1996].

Most of the growth and characterization work which has been done to date on the (Ga,Al)Sb/GaSb materials system has been carried out by MBE, in part because of difficulties associated with high-aluminum-content alloy growth by MOCVD. A recent work studied the MOCVD growth kinetics of bulk GaSb and AlSb layers in order to establish which precursor combination is best-suited for GaSb/AlSb growth in a low-pressure MOCVD system using the TMGa, TEGa, TMAI, TEAl group III sources, and TESb for the Sb precursor. It was found that the group III ethyl sources in combination with the TESb source showed the best-matched reactivity with a diffusion-limited growth regime above 870K for GaSb and AlSb. Good surface morphologies were obtained with V/III ratios of 7 for GaSb and 12.5 for AlSb at a growth temperature of 870K. Bulk GaSb layers exhibited native hole concentrations of $2 \times 10^{16} \text{ cm}^{-3}$ and mobilities of 650 cm^2/Vs at 300K, which compares to good MBE material. On the other hand, AlSb layers showed hole concentrations in the range of $10^{17} - 10^{18} \text{ cm}^{-3}$ which were attributed to C and O incorporation into the layers from the TEAl source. Ten-period GaSb/AlSb MQW samples were grown and characterized by low-temperature photoluminescence and Raman spectroscopy. The former revealed a good crystalline quality but indicate an 8% Ga content in the AlSb barrier and a 4% Al content in the GaSb quantum wells which are due to a reactor memory effect. Sharp X-ray diffraction patterns on the MQW samples confirm the high structural quality of the samples. Work done at the Institut für Halbleitertechnik [Aachen, Germany].

MOCVD or MBE for HEMTs and PHEMTs?

R. T. Lareau et al, J. of Crystal Growth 167, 406 [1996].

MOCVD or MBE for HEMT wafers? Everyone has opinions, but it is rare to see a published comparison of the two techniques. A recent paper provides a detailed analysis of delta-doped AlGaAs/GaInAs PHEMT structures commercially grown by MOCVD and MBE on 3 inch GaAs substrates. The epi wafers were assessed by contactless resistance, magneto-Hall effect, photoreflectance (PR), photoluminescence (PL), DXRD, RBS, SIMS and electro-chemical capacitance-voltage (EC-V) measurements, and then 0.1 μm gate FETs were fabricated and characterized.

Electron mobilities in the MOCVD 2DEG were found to be a little lower than in the MBE material, but were still excellent. The photoreflectance measurements indicated that the interface quality is slightly better in the MBE grown material, and that the indium content variation appears to be a bit larger for the MOCVD material although it remained smaller than 1 at%, as determined by RBS. The sheet resistance and the doping concentration variations as measured by SIMS and EC-V were also found to be slightly larger in the MOCVD wafers although they were still considered to be small. PHEMTs fabricated from the best MOCVD material showed average transconductances g_m of 753 mS/mm that approached those for the MBE wafer (796 mS/mm) as did their f_t 's (115 vs. 117 GHz). The MOCVD devices displayed a maximum stable gain of 15.45 dB compared to 16.20 dB for the MBE baseline devices. The variations in the device electrical parameters were also found to be a little larger in the MOCVD wafers. Work done at the Army Research Laboratory, Fort Monmouth, NJ.

Ultrafast Absorption Dynamics in LT-GaAs

U. Siegner et al, Appl. Phys. Lett 69(17), 2566 [1996].

Low-temperature grown GaAs is often used to generate picosecond and femtosecond pulses in photoconductive switches because of the short carrier trapping time in LT-grown semiconductors. While the response time to a single optical pulse is determined by the initial carrier trapping time, the maximum pulse repetition rate is limited by the carrier recombination rate. The growth temperature dependence of the trapping and recombination rates in LT-GaAs was studied by differential transmission spectroscopy. LT-GaAs samples 1 μm in thickness were grown by MBE on GaAs substrates at temperatures of 250, 300, and 350°C. Differential transmission data for a carrier density of $\sim 5 \times 10^{18} \text{ cm}^{-3}$ show a bleaching of the absorption ($\Delta T/T > 0$) in the 350 and 300°C samples with time constants of 13 and 4 ps, respectively. For the 250°C sample, on the other hand, the initial absorption bleaching changes to induced absorption ($\Delta T/T < 0$) within 0.6 ps. This peculiar behavior is explained by a build-up of trapped carriers in the defect states, with the induced absorption being caused by the re-excitation of the trapped carriers. The decay of the induced absorption signal, with a 265 ps time constant, corresponds to the recombination of the carriers trapped in point defects, and indicates that recombination takes place on a much slower time scale than carrier trapping. When the excitation carrier density is increased to $5 \times 10^{19} \text{ cm}^{-3}$, no induced absorption can be detected in the 250°C sample due to the dominance of bleaching and to the saturation of the point defects. It is noted that the saturation of the point defects occurs at a lower carrier density for the 300°C sample, as expected for a lower defect concentration in material grown at a higher temperature. Interestingly, the bleaching decay time constant was found to be shorter in samples grown at higher temperatures, a fact that can be explained if holes are also trapped by point defects (most likely on the Ga vacancy, V_{Ga}) while electrons are trapped on the EL2-like As_{Ga} antisite defect. The resulting recombination rate between carriers trapped on spatially different defect sites is expected to be slower than if one of the carriers is free because localization decreases the electron-hole wavefunction overlap. With fewer defects expected in material grown at higher temperatures, trapping decay times are increased but recombination decay times are shortened in LT-GaAs. Work done at the Swiss Federal Institute of Technology.

Optoelectronic Devices

980 nm Al-free Diode Lasers

P. Savolainen et al., IEEE Photonics Technology Letters 8(8), 986 [August 1996].

Erbium doped fiber amplifiers (EDFA's) operating at 1550 nm are likely to be important component in future lightwave communication systems. Successful implementation of EDFA systems require diode pump lasers that are efficient and reliable. Two pump wavelength bands are available for EDFA's, 1480 nm and 980 nm. The latter is preferred because of the larger wavelength difference between the pump and the 1550 nm signal. The standard material system for 980 nm diode lasers has been AlGaAs/GaAs/GaInAs. Recently, however, Al-free 980 nm lasers constructed of GaInP/GaInAsP/GaInAs have been giving the traditional material system some stiff competition. The group at Tampere University and Tutcore Ltd. in Finland has obtained impressive efficiencies and lifetimes in Al-free lasers grown by solid source MBE. This group has obtained the highest reported slope efficiencies for any type of 980 nm diode laser, 1.1 W/A. Devices of 4 μm widths exhibit maximum output powers of 550 mW. Preliminary lifetime tests up to 8000 hours indicate little or no degradation in output powers and no sudden failures.

For more news on Tutcore and Al-free lasers, see page x.

Strain-compensated Quantum Well Lasers

H.K. Choi et al., Electronics Letters 32(14), 1296 [4 July 1996].

N.K. Dutta et al., IEEE Photonics Technology Letters, 8(7), 852 [July, 1996].

T. Fukunaga et al., Appl. Phys. Lett. 69(2), 248 [8 July 1996].

The workhorse materials system, GaAs/AlGaAs, nicely lattice matches the GaAs substrate, and can produce strained quantum wells with the easy addition of indium to produce InGaAs. The only sign of strain available in this material system is compressive. More complicated material systems enable the construction of strain-compensated quantum wells which usually use compressive strain in the well and tensile strain in the barrier. Strain compensation provides additional flexibility in the design of quantum wells and is finding important applications for a variety of laser applications.

Initially strain compensation was used to avoid the limitation in the number of compressively strained quantum wells that could be put in a multi-quantum well active layer. The limitation arose from excessive strain that resulted from many strained layers, and was solved by compensating the strain in each well with a strain of opposite sign in the barrier. An example of this aspect of strain compensation is the recent use of ten InAsSb wells with InAlAsSb barriers in a 3.5 μm laser. At a temperature of 80K, the device produced 215 mW per facet output power, a record for any type of semiconductor laser with wavelengths longer than 2.2 μm . Work performed at MIT Lincoln Laboratories.

Another area of interest for strain-compensated multi-quantum well lasers is high speed modulation of lasers. A recent work shows that InGaAs wells with strain-compensating GaAsP barriers can be used to increase the amount of compressive strain that can be built into the wells, thereby improving modulation speeds. Other benefits of strain compensation are reported in these same structure, such as improved linewidth enhancement factor and wavelength chirp. Work performed at Bell Laboratories.

Strain compensation also has applications for single quantum well lasers. A recent report compared unstrained vs. strain-compensated barriers in compressive-strain single quantum well lasers that emit at 1.06 μm . The strain-compensated devices exhibited lower thresholds, higher slope efficiencies, less temperature sensitivity and better reliability. Work performed at Fuji.

Microlenses by Selection Oxidation of AlGaAs

O. Blum, et al., Electronic. Lett. 32(15) 1406 [18 July 1996].

The technique of selective oxidation of AlGaAs to form Al_2O_3 embedded in unoxidized material has found useful device applications, especially in VCSELs. The oxidation technique was recently used to construct microlenses. The starting material was a 2 micron thick AlGaAs layer with a linear composition grade from 98% aluminum at the top to 90% aluminum at the bottom. Stripe widths in the range of 25 to 50 microns were defined photolithographically. Lateral oxidation proceeded from the edge of the stripe toward the center. The technique is based on the fact that the lateral oxidation rate increases with aluminum composition. The oxidation reached in from both sides of the stripe, but the reach-in distance varied with the aluminum composition. The oxidation time and temperature were adjusted so that at the top of the layer the two oxidation regions from each side of the stripe just met in the stripe center. The resulting structure is a convex cylindrical lens. Cylindrical lenses with widths of 25 and 50 microns were constructed with focal lengths of 16.3 and 121 microns, respectively. With these techniques it seems feasible to incorporate intracavity lenses into VCSELs that could result in improved performance and novel effects. Work performed at Sandia National Laboratories.

SiC electronics:

– Smart power



The use of silicon carbide in semiconductor components is revolutionising the transmission of high-voltage power.

Reduced energy consumption, better use of the grid, increased controllability – silicon carbide is paving the way for smart power.

We develop equipment for bulk and epitaxial growth of silicon carbide to match your needs.

Contact us and we will tell you more. Start by reading our World Wide Web pages.

EPIGRESS

Ideon Science & Technology Park
SE-223 70 Lund, Sweden
Telephone +46 46 16 89 80
Fax +46 46 16 89 81
www <http://www.epigress.se>

PATENTS

Recently issued U.S. Patents. Headlines contain U.S. Patent # / Date Issued / Assignee.
The full text of any of these patents can be obtained by email from MicroPatent for \$1.50 each.
See <http://www.micropat.com/> and select the "PatentWEB™" option.

Microelectronics

05585289 / 1996 12 17 / Mitsubishi

FET: A field effect transistor and method of producing same in which a surface depletion layer that is produced in the vicinity of a gate electrode and affects device characteristics is controlled to suppress a gate pulse response delay, an increase in source resistance (Rs), and a channel concentration due to a large signal input.

05583353 / 1996 12 10 / NEC

FET, Heterojunction: A FET having a large gm value over the entire operating range from a low gate bias voltage to a high gate bias voltage. Disclosed is a heterojunction FET which includes an electron supply layer formed on a non-doped semiconductor layer serving as a channel forming layer and a current path forming layer formed on the electron supply layer. Since the current path forming layer has a larger carrier mobility than the electron supply layer, the mutual conductance value is kept high.

05583355 / 1996 12 10 / Motorola

FET, Ohmic Contacts: A III-V FET structure that has ohmic contacts produced by etching instead of lift-off, that provides a gate to ohmic contact spacing of less than one micron, that abuts the ohmic contacts to adjacent structures, and that is devoid of gold.

05578512 / 1996 11 26 / ITRI (Taiwan)

MESFET: GaAs MESFETs which have high breakdown voltage and high drain source current. Disclosed is a MESFET which includes a current enhancement region and a breakdown prevention region in the gate area, as well as a method for fabricating the same.

05585655 / 1996 12 17 / Matsushita

MESFET: An object of the present invention is to solve several problems observed in GaAs MESFETs in one stroke by using a withdrawn portion of the gate electrode which is formed by self alignment, so that an increase in chip size is not incurred even when a comb-type field-effect transistor is formed, and that the voltage resistance thereof is not lowered. Each of the source electrode and drain electrode is formed into a square configuration, while the gate electrode and its withdrawn portion extending therefrom in the direction of gate width are formed by self alignment using, as a mask, at least the source electrode of the source electrode and drain electrode.

05578844 / 1996 11 26 / Murata

MESFET: A GaAs MESFET whose withstand voltage is improved, which is less expensive and which has a reduced leakage current of the Schottky electrode. Disclosed is a Schottky junction with an active layer formed on a compound semiconductor substrate characterized in that a modified layer is formed in at least a portion of a region of the active layer on which region the Schottky electrode is formed and a vicinity of that region.

05580803 / 1996 12 03 / ETRI (Korea)

MESFET: A production method for ion-implanted self-aligned MESFET having self-aligned lightly doped drain structure and T-type gate.

05587328 / 1996 12 24 / Murata

MESFET: A semiconductor device manufacturing method with which a GaAs MESFET and an integrated

circuit using the same can be manufactured cheaply and with high yield by accurately forming a mushroom-shaped gate electrode with inexpensive equipment and a short process.

05572049 / 1996 11 05 / Hughes

HBT: Higher efficiency HBTs which include a multi-layer collector which provides higher reverse bias breakdown voltage, higher carrier mobility during relevant portions of the output signal swing, and a lower saturation voltage limit, or "knee" voltage.

05587327 / 1996 12 24 / Daimler Benz

HBT: A process for preparing a bipolar transistor for very high frequencies with low parasitic capacitances and low base lead resistance is described. The process includes forming a structured first layer with collector zone and insulation areas surrounding the collector zone on a monocrystalline lead layer. A series of monocrystalline transistor layers are grown on the first layer over the collector zone by differential epitaxy and a series of polycrystalline layers is grown at the same time over the insulation areas. A series of polycrystalline layers is designed as a base lead. For preparing a heterobipolar transistor on an Si substrate, the base layer preferably consists of strained SiGe. It is also possible to use III-V materials. A "collector-on-top" arrangement, in which the order of the transistor layers is reversed, is also possible.

05583059 / 1996 12 10 / IBM

HBT, SiGe on SOI: A SiGe-HBT structure for device integration on thin-SOI substrates. The emitter and base regions are vertical while the collector contact is lateral in the otherwise MOS-like device structure. This allows one to integrate a SiGe base, the device capacitances are reduced, and the transistor can be combined with fully-depleted CMOS in a SOI-BICMOS technology.

05585288 / 1996 12 17 / Raytheon

MMIC: A transmit/receive module including digitally controlled analog circuits is described. The digital circuits use a logic family adapted for use with analog monolithic integrated circuits. The disclosure also describes a preferred process to provide digital and analog microwave circuits on a common GaAs substrate.

05578961 / 1996 11 26 / Motorola

MMIC: MMIC bias apparatus, especially derived negative voltage for single supply MMIC RF power amplifiers. Disclosed is a MMIC in which no separate bias battery is required and efficiency is optimized.

05580419 / 1996 12 03 / TRW

MMIC Processing: A method for producing ultra dense and ultra fast integrated circuits utilizing a focused ion beam column and an ancillary chamber maintained under ultra high vacuum. Described in detail with reference to GaAs MMICs.

05584064 / 1996 12 10 / Sharp

HMT Circuit: A converter circuit to be used in outdoor Ku-band low noise block-down converters in satellite broadcasting receivers. The object is to allow cost reduction and downsizing by attaining a 27 dB or more isolation characteristic and by minimizing the number of components. The converter circuit is characterized by comprising two HMT units connected in series to each other.

Shortwavelength Light Emitters - Devices & Materials

05578839 / 1996 11 26 / Nichia Chemical

GaN Light Emitter: A light-emitting gallium nitride-based compound semiconductor device of a double-heterostructure. The double-heterostructure includes a light-emitting layer formed of a low-resistivity InxGa_{1-x}N compound semiconductor doped with p-type and/or n-type impurity.

05587593 / 1996 12 24 / Toyoda Gosei

GaN Light Emitter: A light-emitting semiconductor device includes a sapphire substrate whose main surface orientation is tilted by 1 to 4 degrees from its axis "a" <1120>, and layers epitaxially formed thereon. Tilting the surface orientation of the sapphire substrate enables uniform doping of a p-type impurity into the layers epitaxially grown thereon. As a result, the luminous intensity of the light-emitting semiconductor device is improved.

05583879 / 1996 12 10 / Toyoda Gosei

GaN Light Emitter: An object of the present invention is to reduce the threshold current for oscillation of a laser diode that emits in the blue to ultraviolet regions. The laser diode comprises a double hetero-junction structure. The active layer is magnesium (Mg)-doped-p-type conductive gallium nitride. The p-type doping is obtained by one or more of electron irradiation, laser irradiation, and heat treatment, including, in one aspect of the invention, heat treatment in the atmosphere of nitrogen gases under plasma state.

05585648 / 1996 12 17 / Tischler; Michael A.

GaN Light Emitter: A green-blue to ultraviolet light-emitting optical device, comprising gallium nitride material on a base structure including a silicon carbide substrate, which preferably consists of 2H-SiC, 4H-SiC, or a-axis oriented 6H-SiC. The carrier mobility and the transparency of the silicon carbide substrate are optimized by the selection of orientation and polytype, thus enhancing device performance.

05587014 / 1996 12 24 / Sumitomo Chemical

GaN Epitaxy: A method for heteroepitaxial growth of III-V GaN compound semiconductor crystals by using Group III metal-organic compounds and N as the raw materials to grow a semiconductor crystal in a reaction tube wherein at least one kind of Group V halogen gas and hydrogen halide is introduced before growth begins to carry out gas phase etching of the inner wall surface of the reaction tube.

05572539 / 1996 11 05 / Sony

II-VI Light Emitter: An optical device capable of effectively confining light to its light guide layers and preventing increase of the threshold value and decrease of the differential efficiency. The device comprises a II-VI compound semiconductor and at least a first light guide layer, an active layer or a light waveguide layer, and a second light guide layer are formed in this order. The first light guide layer differs from the second light guide layer in composition or thickness.

05587609 / 1996 12 24 / Sharp

II-VI Light Emitter: A II-VI semiconductor device having an electrode structure with small contact resistance, especially a device having a p-type ZnMgSSe layer, on which an electrode layer is formed with at least metallic nitride layer lying between the semiconductor layer and the electrode layer.

05585649 / 1996 12 17 / Toshiba

II-VI Light Emitter: A LED or semiconductor laser including an internal current blocking structure and improved ohmic contact. A structure is described including a very thin current blocking layer of n-type II-VI compound semiconductor on the p-clad layer and providing an opening, a p-contact layer of p-type II-VI compound semiconductor on the p-clad layer and the current blocking layer at the opening, and a p-side electrode on the p-contact layer.

05574296 / 1996 11 12 / 3M

II-VI Epitaxy: The present invention uses MBE in which a free-radical source is introduced. An object of the present invention is to provide a technique for producing conductive p-type II-B-VIA semiconductor films which can be used in devices such as light emitting diodes and light detectors.

Semiconductor Lasers - General

05586135 / 1996 12 17 / Sumitomo Electric

AlGaInP Cladding Layer: A semiconductor laser suitable for use as a pumping light source for an Er-doped optical fiber amplifier, which can easily provide a single transverse mode operation, and which can control optical confinement in both of the vertical and horizontal directions. The structure includes a cladding layer made of AlGaInP, lattice-matched with GaAs, to increase the conduction band discontinuity.

05588016 / 1996 12 24 / Fuji Xerox Co

AlGaInP, Doping: An object of the present invention is to improve an AlGaInP buried laser, manufactured by the mixed-crystal forming technique based on the Si impurity diffusion, so as to cause no leak current, to reduce the threshold current value, and to increase the efficiency.

05586136 / 1996 12 17 / Sanyo

AlGaInP, Misoriented Substrate: A visible AlGaInP laser grown on a GaAs substrate misoriented by not less than 9 degree nor more than 17 degree from a {100} plane of the substrate in a <011> direction. A tensile strain is introduced into the quantum well layer, allowing the well to be wider than in a conventional device. The cavity length is set to not less than 150 micron nor more than 300 micron. This makes it possible to increase the maximum operating temperature and decrease the oscillation threshold current.

05573976 / 1996 11 12 / Mitsubishi

AlGaInP Process: A method of fabricating a AlGaInP/GaInP semiconductor laser, including growing a window structure. The band gap energy of the window structure forming region is larger than that of the region outside it. Therefore, a semiconductor laser having a window structure can easily be fabricated with a high yield and with great repeatability.

05583881 / 1996 12 10 / Rohm

CD Laser: It is an object of the present invention to provide a semiconductor laser which can be used for both reading and writing of optical disks, providing output power as high as 20 mW or over for writing, and about 2 mW to 7 mW output power with low optical feedback noise for reading. It includes a means for having a minimum value of a coherence in a range between 2 mW and 7 mW of output of a light radiated from one of the facets which is a light output, and for preventing a phenomenon in which the output is reduced in a range at most 25 mW in accordance with an increase of the current, varied by a variation of a current applied to the active layer.

05587334 / 1996 12 24 / Matsushita

CD Laser: A 780 nm band semiconductor laser of low operating current and low noise to be used as the light

source for an optical disc. Confinement of carriers in an active layer is determined by a GaAlAs first light guide layer having a high AlAs mole-fraction and a regrowth process can take place readily since the regrowth extends to a second light guide layer having a low Al composition. Besides, it will become possible to realize multi-mode spectra by enhancing the AlAs mole-fraction of the first light guide layer with a resultant reduction in the effective refractive index step in the direction parallel to the junction plane.

05581572 / 1996 12 03 / France Telecom

DBR, Wavelength Tunable: The present invention relates to a distributed Bragg reflector laser, whose wavelength tuning range exceeds that of the DBR and which has a large number of accessible wavelength channels in said tuning range. In addition it is easy to control the spacing between the channels to which access can be obtained in the total wavelength tuning range. The control of the different electric currents necessary for the wavelength tuning of a laser according to the invention is also easy.

05585309 / 1996 12 17 / Mitsubishi

DH Laser: A high-performance double-channel buried-heterojunction semiconductor laser with reduced reactive current and a method for fabricating the semiconductor laser which includes doped regions to electrically separate an upper part of the mesa structure from a second conductivity type current blocking layer. Since the second conductivity type current blocking layer is not in contact with the mesa structure, no leakage current path is formed in the laser structure.

05588017 / 1996 12 24 / U.S. Philips

Fiber Optic Device: The invention relates to an optoelectronic semiconductor comprising a diode laser which at a first side thereof emits a first radiation beam with a first wavelength and which forms a radiation waveguide for a second radiation beam with a second wavelength greater than the first wavelength, which second beam can enter the laser at the first side, and a semiconductor which is present at a second side of the laser opposed to the first side, which is aligned relative to the laser, and which is sensitive to radiation of the second wavelength. Such a device is used as a transmitter/receiver unit in a fibre communication network.

05578863 / 1996 11 26 / U.S. Philips

Hermetically Sealed Diode: An optoelectronic semiconductor device with a radiation-emitting semiconductor diode suitable for use in optical read and write systems such as bar code readers, laser printers, and optical disc systems. The diode is hermetically sealed and a gaseous oxidizing compound is present inside the envelope to prevent deposits from forming on the coatings.

05574743 / 1996 11 12 / U.S. Philips

High Power: The object of the present invention is to realize a semiconductor diode laser which has a substantially linear (kink-free) P-I characteristic above the threshold current up to a very high optical power. One embodiment is characterized in that the length of the resonance cavity forms part of a set of lengths which lie at substantially equal distances from one another, while for each of the lengths forming part of the set the optical power at which the derivative of the optical power as a function of the current through the pn junction changes is a maximum.

05588015 / 1996 12 24 / Univ. of Houston

Interband Transitions: The invented semiconductor light emitting devices comprise two spatially coupled active QW regions residing in conduction and valence bands respectively, where the valence band-edge in one QW is higher in energy than the conduction band-edge of the other QW. This unique band-edge alignment between the two QWs provides a novel way to establishing efficient population inversion with a high carrier injection efficiency, and to easily manipulating transition rates and tuning emission wavelength in a broad range.

*The road
to better control:
— High-temperature
electronics*



*Better performance, more
efficient engines, advanced
information and communica-
tion solutions — the demands
for the development of new,
environmentally adapted
technical solutions are many
and diverse.*

*Silicon carbide, as the basis of
semiconductor components,
creates a whole new range of
opportunities for monitoring
and controlling processes in
an automobile engine; not
least because it can operate at
temperatures up to 600°C.*

*Let us tell you more about
what silicon carbide can do.
Why not start by reading our
World Wide Web pages?*

 **EPIGRESS**

Ideon Science & Technology Park
SE-223 70 Lund, Sweden
Telephone +46 46 16 89 80
Fax +46 46 16 89 81
www <http://www.epigress.se>

05583878 / 1996 12 10 / Furukawa

MQ Barrier. An object of the present invention is to provide semiconductor laser diodes operating in from 0.6 to 2.0 micron that can effectively suppress any overflow of carriers from the quantum well layer and operate with a low threshold current power, a high light emission efficiency and a high and stable optical output level as well as a high speed modulation capability and a high gain. These objects are achieved by providing a semiconductor optical device which includes a pair of optical confinement layers have multiquantum barrier (MQB) structures as part thereof.

05581570 / 1996 12 03 / Mitsubishi

Pulsed Oscillation: It is an object of the invention to provide a semiconductor laser that can produce a pulsation oscillation at a high power light output. Disclosed is a GaAs/AlGaAs semiconductor laser device in which the function of the saturable absorption region is enhanced and pulsation oscillation can be produced at a high power light output.

05579331 / 1996 11 26 / U.S. Army

QW, Delta Strained: It is an object of the present invention to provide a delta-strained quantum-well heterostructure in semiconductor lasers and optical amplifiers that effectively increases strain without forming dislocations, thereby gaining enhanced device performance. To attain this, the present invention contemplates a unique semiconductor device having a quantum well with a narrow, highly mismatched layer located near its center.

05574741 / 1996 11 12 / Mitsubishi

Superlattice Cladding: The present invention relates a high-power semiconductor laser device capable of suppressing facet deterioration in high-power operation. Disclosure includes superlattice semiconductor multi-layered structures between an active layer comprising a single layer and an upper and a lower cladding layer, respectively, and the superlattice semiconductor multi-layered structures in the vicinity of the laser facet are disordered by impurity diffusion or the like. As a result, the radius of the laser beam at the facets is enlarged, thereby to reduce the optical density at the laser facet, while the oscillation wavelength can be easily controlled because a single layer structure is employed for the active layer.

05577061 / 1996 11 19 / Hughes

Superlattice Cladding: A mid-IR laser is provided having novel AlAs/AlGaSb or InAs/AlGaSb superlattice cladding regions. The novel cladding regions can be deposited without the use of Group VI elements, which are not preferred source materials for MBE growth. Furthermore, the need for quaternary layers, such as AlGaAsSb, used in the prior art devices, is eliminated; consequently, the need for precise control of two Group V fluxes (As and Sb) is eliminated.

05577063 / 1996 11 19 / Mitsubishi

Window Structure: It is an object of the invention to provide a semiconductor laser having an improved window structure at facets of the laser that do not absorb laser light. It is another object of the invention to provide a semiconductor laser including an improved window structure produced, in part, by ion implantation by implanting ions at lower energies than previously employed.

Surface Emitters & VCSELs

05587335 / 1996 12 24 / Seiko Epson

Surface Emitter: A method of making a surface emission type semiconductor laser that comprises a substrate and an optical resonator on the substrate, the optical resonator including a pair of reflection mirrors respectively located on the substrate and light exit sides thereof and

a plurality of semiconductor layers formed between the reflection mirror pair, the light being emitted in a direction perpendicular to the substrate.

05574744 / 1996 11 12 / Motorola

VCSEL: This invention relates to optical couplers that are highly manufacturable and provide high performance. Disclosed is a substrate having a first surface having a VCSEL disposed therein and second surface having a photodetector integrated disposed therein, wherein the VCSEL directs a light signal toward the photodetector.

05574738 / 1996 11 12 / Honeywell

VCSEL: The present invention exploits a saturable absorber contained within the VCSELs distributed Bragg reflector which may itself be adjusted during fabrication or in operation. Under controllable operating conditions, the saturable absorber, strategically sized and placed, will force the VCSEL to self-pulsate in the GHz-regime.

05577064 / 1996 11 19 / Vixel Corporation

VCSEL: Photodiodes are integrally formed with VCSELs and superluminescent light emitting diodes (SLEDs) for monitoring optical radiation intensities. In different embodiments, the photodiode is epitaxially formed within a mirror of a VCSEL, non-epitaxially formed on top of a VCSEL, non-epitaxially formed on side of a VCSEL, or formed on the substrate on the side opposite the VCSEL.

Optoelectronics, Other

05583338 / 1996 12 10 / Texas Instruments

Detector: A HgCdTe S-I-S (semiconductor-insulator-semiconductor) two color infrared detector wherein the semiconductor regions are group II-VI, preferably HgCdTe, with different compositions for the desired spectral regions. The device is operated as a simple integrating MIS device with respect to one semiconductor. The structure can be grown by current MBE techniques and does not require any significant additional steps with regard to fabrication.

05580795 / 1996 12 03 / Loral Vought

Detector: A photoconductive isotype heterojunction impedance-matched infrared detector has blocking contacts which are positioned on the bottom side of the detector. The blocking contacts prevent transfer of minority carriers from the active region of the detector, thereby extending the lifetime of these carriers.

05581084 / 1996 12 03 / SBRC

Detector: It is an object of this invention to provide an improved two color IR detector of reduced complexity over conventional approaches. It is another object of this invention to provide a two color IR detector array having a common contact for each radiation detector or pixel of the array. Disclosed is an embodiment utilizing an array of dual-band HgCdTe radiation detectors.

05578162 / 1996 11 26 / Lucent

Integrated MQW Device: A hybrid semiconductor device is formed by bonding the conductors of one or more GaAs/AlGaAs multiple quantum well modulators to conductors on an IC chip, wicking an uncured epoxy between the modulators and the chip, allowing the epoxy to cure, and removing the substrate from the modulator.

05583351 / 1996 12 10 / Sharp

LED Display: Disclosed is a color display device comprising a silicon or GaP substrate with an array of pixels, each being formed by a group of three (red, green, blue) color sub-pixels provided on the substrate. The pixels are formed of InAlSb alloy, with a quantum well regions of InSb and barrier regions of AlSb, or are formed of AlGaAsSbN alloy, with quantum well regions of GaAsN and barrier regions of AlSb. Tuning of the

wavelength emission/absorption characteristics of the sub-pixels is by doping of the quantum well material with aluminum and/or by quantum confinement.

05583350 & 05583349 / 1996 12 10 / Motorola

LED Display: A full color light emitting diode display utilizes semiconductor light emitting diodes to produce red light and either organic or semiconductor light emitting diodes to produce blue and green light. An array of semiconductor light emitting diodes is formed on a semiconductor substrate and an array of organic or semiconductor light emitting diodes is formed on an optically transparent substrate. The substrates are attached together to form the multi-wavelength light emitting diode display.

05579155 / 1996 11 26 / NEC

Optical Amplifier. A semiconductor optical amplifier having a large gain and a high saturation optical output power. The band gap wavelength of the active layer in the vicinity of the light-emitting end is shorter than that in the vicinity of the light-receiving end. The active layer may have a MQW structure, or the active layer may have a tensile-strained (compressively strained) MQW structure in which the absolute strain quantity in the vicinity of the light-emitting end is larger than that in the vicinity of the light-receiving end.

05585957 / 1996 12 17 / NTT

Optical Integrated Device: An optical functional device, particularly a semiconductor light emitting device which is integrated on a semiconductor substrate having an unevenness pattern (ridges) by crystal growth and which has a wide-band oscillating characteristics. Another object of the present invention is to provide a monolithically integrated optical device having a plurality of such optical functional devices on a semiconductor substrate.

05574289 / 1996 11 12 / Hitachi

Optical Integrated Device: Disclosed is a semiconductor optical integrated device having a plurality of quantum well structures, formed on a single substrate, acting as optical waveguides, the plurality of quantum well structures respectively having different lattice mismatches with the substrate and/or different strains (e.g., respectively compressive strain and tensile strain).

05581108 / 1996 12 03 / ETRI (Korea)

Optical Switch: The present invention relates to an optical switch device to be used as a primary component in an optical transport system, and more particularly to an optical switch device possible to totally reflect an incident light on an optical waveguide therein in accordance with a change in refractive index occurring owing to current application and a manufacturing method of the same.

Materials & Misc.

05581571 / 1996 12 03 / Univ. Of Illinois

Al Oxides: The present invention relates to improved techniques and devices employing, inter alia, an aluminum-bearing III-V semiconductor material and a native oxide of aluminum that is formed in the semiconductor material. In the U.S. Pat. No. 5,262,360 assigned to the same assignee, there is disclosed a technique of forming a high quality, stable, and compact native oxide layer from an aluminum-bearing Group III-V semiconductor material. Applicant has discovered that by implementing oxidation to obtain a native oxide of aluminum after a device has been metallized, advantages can be obtained in device operation, reliability, and life. In accordance with an embodiment of the invention there is disclosed a method of making a semiconductor device which includes heating the metallized semiconductor structure in a water-containing environment to convert a portion of the aluminum-bearing III-V semiconductor material to a native oxide of aluminum.

05584929 / 1996 12 17 / Sumitomo Electric

Bulk Growth: A method of and a crucible for preparing a semiconductor crystal, which can prevent wetting of a raw material melt with respect to a crucible and which can suppress polycrystallization, for preparing a compound semiconductor single crystal in an excellent yield.

05576249 / 1996 11 19 / Hughes

Electrochemical Etch: It is an object of the invention to furnish a method of electrochemically etching a digitate edge pattern on a structure of alternating ultrathin semiconductor layers, for allowing selective electrical contacts to be added separately to the p-type and n-type layers of n-i-p-i photonic devices. It is another object of this invention to provide a novel and improved method for selectively etching p-type or n-type doped semiconductor material in the presence of the other type.

05578521 / 1996 11 26 / Nippondenso

GaAs on Si: This invention relates to method for causing vapor-phase epitaxial growth of GaAs or a like substance on the surface of a semiconductor substrate of silicon or the like, the epitaxial layers having a different lattice constant from that of the substrate.

05583880 / 1996 12 10 / Rohm

GaN Blocking Layer: An object of the present invention is to provide a semiconductor laser for the purpose of writing data into an optical disk, such a laser having large output and high light emitting efficiency and having a current blocking layers which restricts the absorption of light. The device includes an active layer an upper cladding layer and a lower cladding layer each made of aluminum gallium arsenide (AlGaAs) compound and a gallium nitride (GaN) current blocking layer having a stripe groove functioning as a current path provided in at least one of said cladding layers.

05576559 / 1996 11 19 / Intevac, Inc

InP Collector: This invention relates to (InGa)As/InP heterojunction devices utilizing a InP collector to extract electrons from a (InGa)As:p layer and more particularly to heterojunction devices having a smooth and monotonic potential energy gradient at the heterojunction for establishing drift of the conduction electrons from the (InGa)As:p layer to the InP layer. This structure has utility in a number of electronic devices requiring such electron transfer across an (InGa)As/InP heterojunction including p-i-n photodetectors and heterojunction bipolar transistors.

05580818 / 1996 12 03 / NEC

InP, Selective Growth: The present invention relates to a fabrication process for a semiconductor optical device integrating a plurality of optical semiconductor elements, such as laser diode (LD) and so forth, on a common substrate by using a SiO₂ mask formed on an n-type InP substrate. By this, regions having mutually different bandgap can be formed through one selective growth process. Also, it becomes possible to form the regions having large bandgap difference while avoiding lattice mismatching.

05585305 / 1996 12 17 / Shin-Etsu Handotai

LPE, Dopant Diffusion: A method for fabricating a semiconductor device in which the carrier concentration of a semiconductor layer, such as a clad layer, especially a double hetero junction type light emitting device, can be controlled to a targeted value within a relatively low concentration region by using diffusion from a highly doped LPE-grown layer.

05585306 / 1996 12 17 / Canon

LT Growth: A method for producing an epitaxial com-

pound semiconductor device under a crystal growth condition wherein a value equal to the number of arrival molecules of the higher vapor pressure material divided by the number of arrival molecules of the lower vapor pressure material is equal to or less than 2.5. More preferably, this value is equal to or less than 2.0. Under such condition, the crystal layer can be grown with a high quality at relatively low substrate temperatures lower than 500°C.

05581116 / 1996 12 03 / Sharp

Maskless Selective Epi: The present invention relates to a method for fabricating a semiconductor device by selectively controlling the growth of an epitaxial layer without a mask by irradiating a main surface of a substrate having a difference in level with light during the growth of a semiconductor layer by vapor phase epitaxy. The present invention also relates to a semiconductor device fabricated by the method.

05583074 / 1996 12 10 / Texas Instruments

Metallization: A semiconductor circuit, preferably formed from a III-V compound, wherein the dielectric is designed to provide improved adhesion to contacts, especially gold contacts, wherein the metallization is designed to provide improved adherability to the substrate as well as the dielectric without causing cracking as in the prior art. Employs an all sputter deposited, pattern etched TiW-Au interconnect and plasma deposited interlevel insulation.

05574745 / 1996 11 12 / Xerox

Novel Devices: This invention relates to novel semiconductor devices and structures which incorporate p-type and n-type wide bandgap material formed by impurity induced layer disordering of multiple semiconductor layers. In particular, this invention relates to five overlapping classes of novel devices: integrated transistor and edge emitting laser diodes; integrated transistors and surface emitting diodes; a laterally injected surface emitting laser diode; a carrier channeling or "nipi" device; and an interdigitated semiconductor device.

05572043 / 1996 11 05 / Furukawa

Schottky Junction: It is an object of the present invention to provide a Schottky junction device having a superlattice arranged on the Schottky interface in order to hold a high Schottky barrier and at the same time showing a high speed responsivity by resolving the phenomenon of hole-piling up due to the valence band edge discontinuity.

05574295 / 1996 11 12 / Kulite Semiconductor

3C SiC MOSFET: The use of 3C-SiC for semiconductor devices has been very limited. 6H-SiC, although more expensive than 3C-SiC, is more commonly used, due to problems associated with 3C-SiC. It is, therefore, a primary object of the present invention to provide a dielectrically isolated P-MOSFET device which substantially overcomes these problems.

05580382 / 1996 12 03 / Univ. of Illinois

III-V Doping: A process for efficient controlled N-type silicon doping of Group III-V materials. In a preferred embodiment doping with silicon tetrabromide attains incorporation efficiencies of approximately 0.37.

05581117 / 1996 12 03 / NEC

II-VI on Si: An object of the present invention to provide an Si base semiconductor monocrystal substrate having a suitable orientation for remarkably suppressing twin-formations and crystal defects and providing energy stability for a CdTe or Cd-rich CdZnTe semiconductor layer grown on the substrate. Such a substrate may be used for growth of HgCdTe

A new era: SiC high-frequency electronics



Regardless of whether we're talking about cellular phone or space communication, silicon carbide makes it possible to develop more robust components for higher power, higher frequencies, and for more powerful applications.

You can see the opportunities offered by silicon carbide. We listen to your needs and tailor make the equipment you need for tomorrow's silicon carbide electronics.

Contact us and we will tell you more. Start by reading our World Wide Web pages.

EPIGRESS

Ideon Science & Technology Park
SE-223 70 Lund, Sweden
Telephone +46 46 16 89 80
Fax +46 46 16 89 81
www <http://www.epigress.se>

The full text of any of these patents can be obtained by e-mail from MicroPatent for \$1.50 each. See <http://www.micropat.com/> and select the "PatentWEB™" option.

Fantastic Plastic, Part Two:

Organic Lasers?

We reported our last issue that organic materials are showing promise for future display applications. Given that these devices are somewhat similar to III-V LEDs, one begins to wonder whether there might also be an organic counterpart to the semiconductor laser. The answer it seems, is yes - and no. Optoelectronics Editor Gary Wicks explains.

Encouraging progress in organic LED's is receiving quite a bit of coverage in the press and technical journals. Claims of lasing in these materials have also been reported. Is the conventional (inorganic) semiconductor laser diode an endangered species? Probably not right away.

The efficiencies and lifetimes of organic LED's are becoming good enough to enable organic LED's to be considered as viable alternatives to inorganic LED's, especially for large area, patterned structures such as displays. Products along these lines are under development at Pioneer and other companies. Internal quantum efficiencies of some of the best organic LED's are on the order of 10%, numbers difficult to beat with inorganic semiconductor materials. Such high efficiencies naturally bring up questions about the possibility of constructing injection lasers in such materials. It has not happened yet, but there are some encouraging signs. Steps toward an organic laser diode include reported microcavity-induced enhancement in luminescence, and claims of optically pumped lasing.

Microcavity organic LED's, reported by Bell Laboratories, used device structures that resemble vertical cavity semiconductor lasers (VCSEL's). An organic LED structure was sandwiched between a high reflector dielectric stack and an partially reflecting aluminum surface layer. Light was taken out through the aluminum layer. The organics used in this work were the small-molecule materials, bis(triphenyl)amine and tris(8-hydroxyquinoline)aluminum. Observed microcavity effects include linewidth narrowing, and enhanced emission efficiencies and directionalities.

Laser Reports

There have been several reports of optically pumped lasing in organic thin film structures, but so far no reports of electrically pumped lasing. Some of the optically pumped organic lasers have used thin film structures that consist of polymer hosts doped with dyes similar or identical to those used in dye lasers. The Bell Labs group has reported optically pumped microdisk and microring lasers in such materials. This work may not be a direct step toward organic injection (electrically pumped) lasers, however, since these particular organic materials do not lend themselves well to electrical pumping.

Materials more conducive to electrical pumping include the small molecule organics used in the Bell Laboratory microcavity LED work, and conjugated polymers, such as poly(p-phenylenevinylene) (PPV). Optically pumped lasing in PPV thin film structures has recently been claimed by two separate groups, one from Cambridge University and one from University of California at Santa Barbara. Like the microcavity organic LED results from Bell Labs, the Cambridge work used a structure that resembles a conventional VCSEL (see Figure 1). The experimental evidence for lasing includes threshold-like behaviors for spectral line narrowing, directionality and fraction of emission in a narrow wavelength region. The lasing claims are not absolutely conclusive, however, since there is not yet clear evidence of lasing modes in far field patterns or spectra. Without such evidence the possibility of superluminescence, rather than lasing, cannot be dismissed. So, either the PPV structures are lasing, or they are very

close. This uncertainty is not especially crucial at present, since the structures are merely optically pumped. The real interest and payoff is in the construction of an organic injection laser. The existence of optically pumped lasing, or near-lasing, indicates that there is nothing in the physics of the light emission process that will prohibit successful electrically pumped lasing. Time will tell whether sufficient progress in contact resistance and material conductivity can be made to enable the construction of an organic injection laser. All that can be stated with certainty is that they're not there yet.

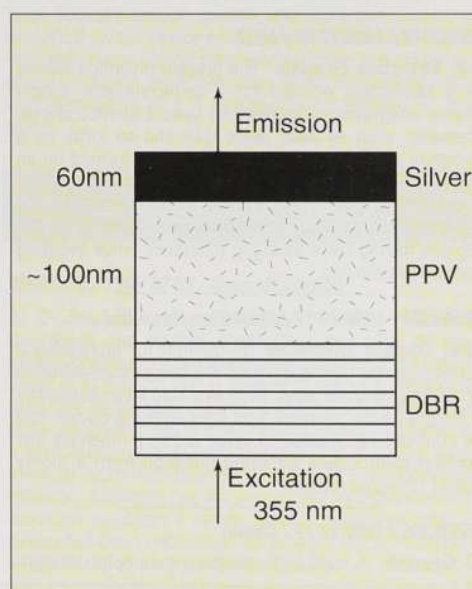


Figure 1: Schematic of a microcavity structure formed from poly(p-phenylenevinylene) (PPV). Optically pumped lasing in this structure was recently reported.

Ending on a High Note

MARIE MEYER

The seven stocks in the Compound Semiconductor Portfolio turned in a mixed but generally positive performance in 1996, resulting in a total gain on our hypothetical investment in 100 shares of each of 61%. The most impressive aspect of the Portfolio is that ended the year with substantially better performance than either the NASDAQ Composite (the NASDAQ being home to six of the seven listings) and the Semiconductor Sector Index - see Figure One.

And the Winner is...

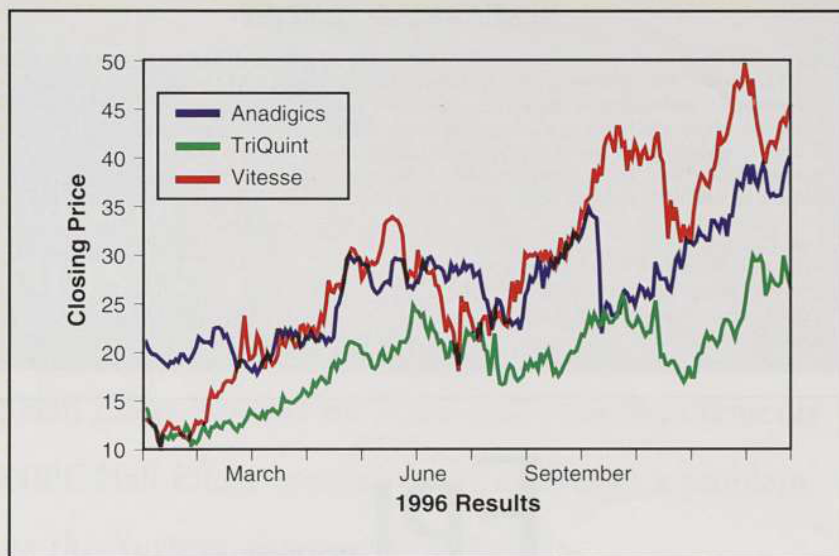
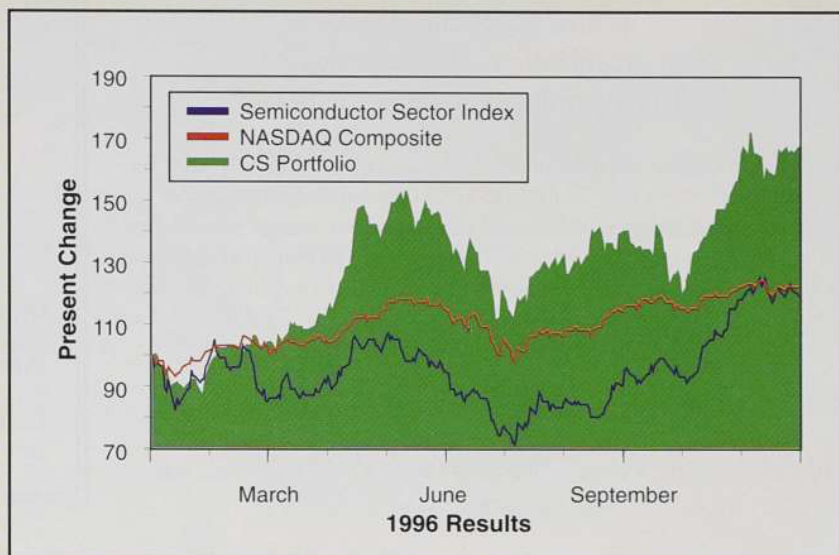
The big winners in 1996 were the investors in the GaAs IC companies generally, and Vitesse shareholders specifically. See Figure Two. Vitesse's share price rose an incredible 346% in 1996; Anadigics and TriQuint were both up 185%. Wow. All three companies are reporting consistent strong growth in revenues.

The disappointments in 1996 came primarily from Alpha and Cree. Strong growth in wireless has helped boost Anadigics and TriQuint's results, but it has not been as kind to Alpha, which has suffered from "softness" in orders for its wireless components, mostly diodes and switches. Undeterred, the company is going ahead with its bullish forecast for RF GaAs, and they are adding capacity. President and CEO Tom Leonard says "We made a decision when the market went soft that we would continue with our plans for expansion, even though we did not have enough demand to satisfy our capacity... now that looks like a good decision, because the demand is vibrant, and we expect the early part of 1997 to be great."

Cree certainly appears to be doing a lot of things right strategically. For example, they are steadily decreasing the percentage of revenues derived from contract work, in favor of more product revenues and licensing fees. For examples, contracting as a percent of total revenue has decreased from 53% in 1994 to 35% in 1996. But there are remaining issues which may be harder to tackle. The biggest one, of course, is the fundamental question: can a SiC-based LED product line compete with the GaN -on-sapphire approach typified by Nichia? The events of the coming year may provide the answer.

In Our Next Issue

This will be our last report on the 1996 edition of the Portfolio. Next time we will introduce the new, expanded 1997 version, which will include several new companies which went public in 1996, including Celeretek, Picogiga, and Semiconductor Laser International.



The Compound Semiconductor Portfolio

Company	Symbol**	Closing Price			52 Week		P/E Ratio*
		1/2/96	12/31/96	Change	Hi	Lo	
Alpha Industries	AHA	13 5/8	7 3/4	-58%	13 7/8	5 3/4	◆
Anadigics	ANAD	21 1/4	39 3/4	+185%	40 1/2	17 3/4	42
Advanced Technology Materials	ATMI	10 3/8	17 3/8	+166%	18 1/2	9 5/8	67
Cree Research	CREE	14 3/4	9 7/8	-66%	21 1/2	8 1/4	55
SDL***	SDLI	16 15/16	26 1/2	+155%	32 21/64	15	◆
TriQuint Semiconductor	TQNT	14 1/4	27 5/16	+185%	30 3/4	9	47
Vitesse Semiconductor	VTSS	13 1/8	44 3/4	+346%	51 1/4	9 3/4	71
		Portfolio Value****, 12/31/96			\$18,656.25		
		Change since 1/2/96			+61%		

Notes:

* P/E Ratio is determined by dividing the closing price by the company's per-share earnings for the most recent four quarters.

** AHA traded on AMEX; all others on NASDAQ

*** Split three-for-two on June 12. Historical prices adjusted retroactively.

**** Portfolio valuation began on 1/2/96 with 100 shares of each company, but now includes 50 additional shares of SDL, following their split.

◆ - Loss in the most recent four quarters

Compound Semiconductor
is now accepting ads
from organizations and individuals
regarding employment opportunities.

Rates & Specifications for Standard Ads. Standard ads with minimum formatting (as shown below) are available at \$25.00 per line or fraction thereof (88 characters per line), with a \$100.00 minimum. To submit your ad by mail send the ad copy as a text-only file (<filename>.txt) on a 3.5" DOS formatted diskette to: CS Employment, Franklin Publishing, 250 Selby Avenue, Suite 48, Saint Paul, MN 55102 USA. You may also submit your ad copy by E mail by sending it as an plain text file (no encoding) to: jobs@compsem.com.

Orders & Deadline. Check or purchase order must accompany order/ad copy. No agency discounts. *Compound Semiconductor* is published bi-monthly. Orders and copy are due on the 15th day of the month which precedes the cover date.

Display Ads

Black and white display ads are available for companies wishing to use their own formatting style. Sizes and rates are given below. Send camera-ready art to: CS Employment, Franklin Publishing, 250 Selby Avenue, Suite 48, Saint Paul, MN 55102 USA.

Size	Dimensions	Rate
1/4 page	5"H x 3 3/8"W	\$1,350
1/2 page	5"H x 8 3/8"W	\$2,600
1 page	10 7/8"H x 8 3/8"W	\$3,350

Orders & Deadline. Check or purchase order must accompany ad. No agency discounts. *Compound Semiconductor* is published bi-monthly. Orders and copy are due on the 15th day of the month which precedes the cover date. For example: ads for our March/April issue are due on February 15. The magazine is normally mailed in the third week of the first month of the cover date.

RESEARCH SCIENTIST

Universities Space Research Association (USRA) has the need of a Research Scientist to work in the Alliance for Microgravity Materials Science and Applications (AMMSA) at the NASA/Marshall Space Flight Center. This person will perform experiment research and analyses of melt and vapor growth of II-VI compound semiconductors and conduct various characterization on the grown crystals in support of Marshall Space Flight Center's ground-based and space flight experiments on the preparation and crystal growth of semiconducting compounds and alloys. The applicant should have a Ph.D. degree in physics, materials science or related field. USRA is an AAP/EEO employer. Send resume and 3 references' names/addresses no later than 1/31/97 to:

Paula Cushman, CPCM
Associate Director for Administration, AMMSA
Universities Space Research Association
4950 Corporate Drive, Suite 100
Huntsville, AL 35806



Positions Available

GaAs MBE Engineer: Manage state-of-the-art production multi-wafer MBE reactors. Supervise production MBE personnel. Set growth sequences and conditions. Assist in the characterization of MBE grown material and the interpretation of data. Provide technical assistance in the area of materials and electronic devices to Sales Department and customers. Assist in the implementation of ISO 9000 quality system. Salary is competitive and commensurate with experience. Requires MS with significant experience, or Ph.D. with growth experience. Area of expertise should be Materials Science, Physics, or Electrical Engineering. Send resume to: Human Resources, Quantum Epitaxial Designs, Incorporated, 119 Technology Dr., Bethlehem, PA, 18015. Fax: (610) 861-5273.

Materials Characterization Engineer: Characterize MBE grown GaAs, and InP multi-layer semiconductor materials, with the use of X-ray diffraction, Hall, Photoluminescence, Polaron C-V profiling, and other techniques. Interpret data and assist growth personnel. Assist in the implementation of ISO 9000 quality system. Salary is competitive and commensurate with experience. 40 hours per week. Requires BS degree in Materials Science, Physics, or Electrical Engineering. Send resume to: Human Resources, Quantum Epitaxial Designs, Incorporated, 119 Technology Dr., Bethlehem, PA, 18015. Fax: (610) 861-5273.

Applications Engineer: Assist in technical interaction with customers on issues concerning MBE grown GaAs microwave material. Lead trouble shooting efforts, interpret data, and coordinate problem solving process. Position requires familiarity with GaAs based microwave devices, MBE, and GaAs material, and excellent communications skills. Salary is competitive and commensurate with experience. Requires MS with significant experience, or Ph.D. Area of expertise should be Materials Science, Physics, or Electrical Engineering. Send resume to: Human Resources, Quantum Epitaxial Designs, Incorporated, 119 Technology Dr., Bethlehem, PA, 18015. Fax: (610) 861-5273.



Employment Opportunities

EPI MBE Products is the largest Molecular Beam Epitaxy (MBE) equipment manufacturer in North America and has been the international leader in quality and innovation in the MBE field since 1986. EPI MBE Products is looking for dynamic individuals to fill the following position:

Technical Sales Engineer

EPI MBE Products is looking for a Technical Sales Engineer to join our St. Paul, MN team in the sales, marketing and support of our complete line of components for MBE. Responsibilities include technical sales and follow-up support in the North American market. The successful candidate will have strong written and verbal communications skills with knowledge of vacuum technology and research environments. Fluency in German or Japanese a plus. Knowledge of Molecular Beam epitaxy is preferred, but not required. For more information about EPI MBE Products, please access our web site at www.epimbe.com. For confidential consideration, send your resume to:

Brian Dlugosch
EPI MBE Products
1290 Hammond Road
St. Paul, MN 55110

Every Hall System you'll ever want!



MODULAR Resistivity & Transport Properties of Semiconductors & Thin Films

With many years experience of building Hall Effect Systems we know that your requirements often change with time. With the HL5500PC Hall Effect System, this is no longer a problem.

As your needs change the System changes with you.

We offer a two temperature stage for rapid QA measurements, a choice of cryostats, a wafer mapping stage and a buffer amplifier module that extends the measurement range to 10^{12} ohms.



RC2400

Other products in the range include the RC2400 Alloying Furnace and the HL5900PC Hall Profiler.

Call for details



HL5900PC

BIO-RAD

Semiconductor
Systems Division

USA

Bio-Rad Micromasurements, 520 Clyde Avenue, Mountain View, CA 94043-2212
Phone 415-961-6900 Fax 415-961-6715

Europe

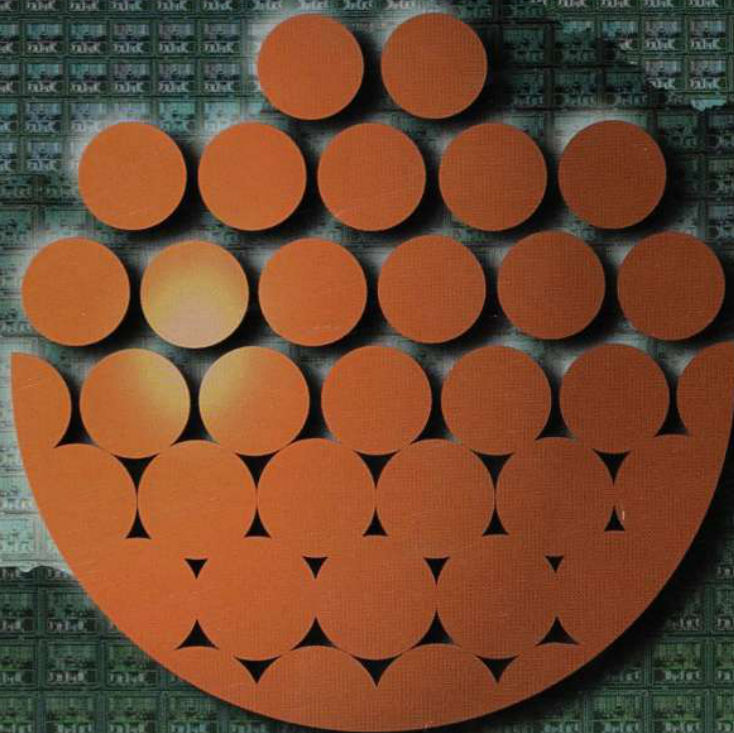
Bio-Rad Micromasurements Ltd, Bio-Rad House, Maylands Avenue, Hemel Hempstead, Herts, HP2 7TD, UK
Phone +44 (0) 1442 232552 Fax +44 (0) 1442 234434

Japan

Nippon Bio-Rad Laboratories KK, Cosmo Park Bldg, 5-7-18 Higashinippori, Arakawa-ku, Tokyo 116
Phone 03-5811-6288 Fax 03-5811-6273

Pacific Rim

Bio-Rad Pacific Ltd, Unit 1111, 11/Floor, New Kowloon Plaza, 38 Tai Kok Tsui Road, Kowloon, Hong Kong
Phone 852 2789 3300 Fax 852 2789 1257



BREAK THROUGH TO *TURBO*DISC CVD TECHNOLOGY

Break through the barriers in advanced materials device manufacturing.

EMCORE provides the complete line of TurboDisc MOCVD Deposition Systems for the production of compound semiconductors materials, metals, and oxides - from device research, to pilot production, to mass production throughput.

- ◆ Reliable - Over 100 multi-wafer systems in the field worldwide and still counting
- ◆ Highest throughput
- ◆ Lowest cost of ownership
- ◆ < 1% Uniformity
- ◆ Widest choice of materials grown
- ◆ Worldwide customer service

Putting Science To Work

emcore

EMCORE Corporation • 35 Elizabeth Avenue • Somerset, NJ 08873 • (908) 271-9090 • Fax: (908) 271-9686
Visit EMCORE on the World Wide Web at <http://www.Emcore.Com>

GaN
GaAs
InGaAlP
GaP
BaSrTiO
SrTiO
PZT
YBaCuO
AlGaAs
InGaAsP
InGaAs
InGaP
InAlAs
InSb
Si
SiGe
Cu
SiC
W
Si₃N₄
CdTe
HgCdTe
Diamond
Pd
TiN