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Final Report

Engineering Foundation Conference
ADVANCED HETEROSTRUCTURE TRANSISTORS V

November 29 - December 4, 1992

Keauhou Beach Hotel, Kona, Hawaii

Contents: Technical Highlights
Program
Participants List

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Advanced Heterostructure Transistors V
Technical Highlights
T.C.L. Gerhard Sollner, Chairman

The meeting was opened by an address by A. Shibatomi from Fujitsu Limited, who discussed the Fujitsu view of the III-V market. Noteworthy are that the microwave III-V market is only \$100M, while that for optoelectronics is \$1B, this latter divided roughly 1/3 space applications, 1/3 military, and 1/3 communications. The 1992 component market was divided as follows: 83% MESFET, 14% HEMT, 3% HBT. Expectations are that the market share of HEMT and HBT devices will take over a combined total of 45% by 1996. The GaAs IC business is now \$200M, roughly split between digital and analog. Computers take up 1/3 of the digital business, of which 48% are supercomputers, 24% are workstations. Fujitsu is investing in 4-in-wafer processing, and is combining 0.8- μ m-GaAs MESFETs, with BiCMOS for cache RAM, for a 355 GFlop machine. The large chips will dissipate 20-30 W, requiring liquid cooling. Fujitsu clearly sees a bright future for III-V-based systems.

The session on Heterostructure FETs concentrated on power devices. L. Eastman of Cornell University reported 5 W at 4 GHz with 70% efficiency and 15 dB of gain from a GE device, and 1 W at 4 GHz with 80% efficiency from Raytheon. J. Wolter described avalanche breakdown via DX centers in AlGaAs, and theoretical optimization of deep submicron HFETs for power handling was reported by M. Das.

Silicon-germanium HBTs have made several improvements. K. Ismail of Cairo University and IBM showed how the Si/SiGe band lineup can be changed by strain relief, producing barriers to electrons as well as holes. Very high mobilities were reported, and the claim was made that SiGe devices at 77 K may be operationally equivalent to III-V devices at room temperature. This would clearly be important given the fabrication advantages of silicon-based technologies. Silicon-germanium HBT technology seemed to be too complex to insert into digital processes, but SiGe FETs may not be. The best SiGe HBT reported was $f_T = 50$ GHz, $R_B = 50 \Omega$, for a $2.0 \times 0.2 \mu\text{m}$ device by M. Nakamae from NEC Corporation.

Resonant-tunneling diodes (RTDs) have been combined into potentially multigigahertz shift-register circuits by G. Sollner at MIT Lincoln Laboratory. A transistor that controls current by pinching off a resonant-tunneling diode has been combined by K. Meazawa at NTT into logic circuits very similar to the diode circuits of the Lincoln Laboratory group. A similar transistor using a Schottky contact to control the RTD current was analyzed by Eaves, who also discussed the problem of additional structure in the I-V curve from impurity states in the quantum well. M. Rodwell of UC Santa Barbara suggested a Schottky contact for an RTD that should reduce the contact resistance and increase the maximum oscillation frequency significantly.

R. Behringer of AT&T reported experiments in optically controlled patterned growth of Na gratings using a technique that may be applicable to imaging In or Ga atoms during MBE growth.

The consequences of optical phonon propagation in AlGaAs structures were discussed experimentally by G. Maracas of Motorola and L. Eastman of Cornell, and theoretically by K.-W. Kim of the University of North Carolina. Interesting effects occur because optical phonons in GaAs cannot propagate in AlAs and conversely. However, calculations showed that the electron-phonon scattering rate does not decrease, as might be expected in confined structures, in fact, it increases above bulk values for 2-D quantum wells.

HBT papers from III-V materials dwelt mostly on materials issues and centered on carbon doping and its associated strain and activation. A paper by K. Goosen of AT&T combined electrooptical devices with HBTs for optical interconnects, which are denser, faster, and cooler than their electrical competition.

Several novel devices were reported. S. Luryi of AT&T described a 3-input gate that can be switched between AND and NOR functions, and the output can be either electronic or 10 μ W of bandgap light. J. Sone of NEC introduced a new concept for a unipolar Ge transistor for operation at 4 K and interfacing to superconducting circuits. He calculates a current gain of 16 at 10 K with a 50-nm base. He also discussed a lateral resonant-tunneling transistor for the same application. H.-C. Liu also proposed a unipolar transistor in SiGe technology.

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PROGRAM

ADVANCED HETEROSTRUCTURE TRANSISTORS V

November 29 - December 4, 1992

Chair:

T. C. L. G. Sollner, MIT Lincoln Labs

Co-chairs:

K. Ploog, Max Planck Institute

H. Hasegawa, Hokkaido University

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Engineering Foundation Conferences

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Sunday, November 29, 1992

3:00 p.m. - 9:00 p.m.

REGISTRATION AND CHECK-IN

6:00 p.m.

DINNER

7:30 p.m. - 9:30 p.m.

SOCIAL HOUR

Monday, November 30, 1992

7:00 a.m.

BREAKFAST

8:00 a.m.

OPENING AND WELCOMING

G. Sollner, MIT Lincoln Lab

INTRODUCTION

G. P. Fisher, Engineering Foundation

8:30 a.m.-12:10 p.m.

HETEROSTRUCTURE FETs

Co-chairs: H. Goronkin and A. Shibatomi

8:30 a.m.

"Markets of Compound Semiconductor Devices"

A. Shibatomi, Fujitsu Limited

9:00 a.m.

"InP-Based High Breakdown Voltage HFETs"

J. A. del Alamo, S. R. Bahl, and
D.R. Greenberg, Massachusetts Institute of
Technology

9:30 a.m.

"Extending the Power Limits for MODFETs
with InGaAs Channels"

L. F. Eastman, Cornell University

9:50 a.m.

"Instabilities and Current Filamentation in
HEMT-Structures"

J. Wolter, Eindhoven University of
Technology

10:10 a.m.

"Optimization of Gate-to-Drain Separation
in Ultrasubmicrometer Heterostructure
Field-Effect Transistors for Maximum Power
Gain Performance"

J-W. Chen, M. Thurairaj, and M. B. Das,
Pennsylvania State University

10:30 a.m.

COFFEE BREAK

10:50 a.m.

"Complementary Heterojunction Field-Effect
Transistors"

K. Yoh and M. Inoue, Osaka Institute of
Technology

11:10 a.m.

"InAs/AlSb Heterostructure Field Effect
Transistors"

H. Kroemer, University of California

11:30 a.m.

"Heterojunction JFETs (HJFETs) Grown by
MOCVD"

M. M. Hashemi, J. B. Shealy, S. P.
DenBaars, and U. K. Mishra, University of
California

11:50 a.m.

"Transport Regimes of Pseudomorphic
AlGaAs/n⁺-InGaAs HFETs"

D. R. Greenberg and J. A. del Alamo, MIT

Monday, November 30, 1992 (continued)

12:15 p.m.	LUNCH
2:00 p.m.-5:00 p.m.	AD HOC SESSIONS
6:00 p.m.-7:30 p.m.	DINNER
7:30 p.m.- 9:00 p.m.	<u>Si/Ge HBTs</u> Co-chairs: H. Kroemer and T. Masselink
7:30 p.m.	"Will SiGe/Si Compete with III-V Compounds in High Speed Applications?" K. Ismail, Cairo University and IBM
8:00 p.m.	"Comparison of Si Homojunction and Si/SiGe Heterojunction Bipolar Transistors and ICs" H-U. Schreiber and J. N. Albers, Ruhr- Universitat Bochum
8:20 p.m.	"LSI-Oriented SiGe HBT Technology" M. Nakamae, NEC Corporation
8:40 p.m.	"Design of Si/Si _{1-x} Ge _x HBTs for Analog and Other Applications" J. C. Sturm, Princeton University
9:00 p.m.-10:00 p.m.	SOCIAL HOUR

Tuesday, December 1, 1992

7:00 a.m.

BREAKFAST

8:30 a.m. - 12:10 p.m.

QUANTUM EFFECT DEVICES I: RESONANT TUNNELING

Co-chairs: S. Hiyamizu and S. Luryi

8:30 a.m.

"A New Resonant Tunneling Multi-Terminal Device for Logic Circuits Employing Monostable-Bistable Transition"
K. Maezawa and T. Mizutani,
NTT LSI Labs

9:00 a.m.

"New Problems in Resonant Tunneling Devices"
L. Eaves, University of Nottingham

9:30 a.m.

"An Artificial Retina Based on Resonant Interband Tunneling Devices"
H. N. Levy, D. A. Collins, and T. C. McGill, California Institute of Technology

9:50 a.m.

"Analog-to-Digital Conversion Using Resonant Tunneling Diodes"
R. C. Potter, Allied-Signal Aerospace Technology Center

10:10 a.m.

COFFEE BREAK

10:30 a.m.

"Resonant Tunneling Diode Circuits"
T. C. L. G. Sollner, MIT Lincoln Laboratory

11:00 a.m.

"A New III/V-Gigabit-SRAM Cell Using a Double-Emitter Resonant-Tunneling Hot Electron Transistor Structure"
N. Yokoyama, Fujitsu Laboratories

11:30 a.m.

"Electron Coherence in Finite Superlattices"
M. A. Reed, J. W. Sleight, Yale University,
R. J. Aggarwal, MIT, Y-C. Kao, Texas Instruments Inc.

11:50 a.m.

"Resonant Interband Tunneling Structures for Quantum Functional Devices"
S. Tehrani, Motorola

12:10 p.m.

LUNCH

2:00 p.m. - 5:00 p.m.

AD HOC SESSIONS

6:00 p.m. - 7:30 p.m.

DINNER

Tuesday, December 1, 1992 (continued)

7:30 p.m. - 9:00 p.m.

HETEROSTRUCTURE EPITAXY AND TRANSPORT I

Co-chairs: T. Ishibashi and P. Enquist

7:30 p.m.

"Using Light as a Lens for Submicron, Neutral Atom Lithography"
R. E. Behringer, G. Timp, D. M. Tennant, and J. E. Cunningham, AT&T Bell Labs, M. Prentiss and K. K. Berggen, Harvard University.

8:00 p.m.

"Control of Compound Semiconductor Interfaces by Si Interface Control Layer and Its Applications"
H. Hasegawa, M. Akazawa, S. Kodama, K. Koyanagi, S. Suzuki, Y. G. Xie, and T. Sawada, Hokkaido University

8:20 p.m.

"Interfaces in MBE-Growth InGaAs/AlGaAs - Their 'Optimization' and Characterization"
H. Riechert, Siemens AG Research Labs

8:40 p.m.

"AlGaIn/GaAs Heterostructures, a New Basis for HBT and MODFET Devices"
K. H. Bachem, Fraunhofer-Institut of Applied Solid State Physics

9:00 p.m. - 10:00 p.m.

SOCIAL HOUR

Wednesday, December 2, 1992

7:00 a.m.	BREAKFAST
8:30 a.m. - 11:50 a.m.	<u>QUANTUM-EFFECT DEVICES II: REDUCED DIMENSIONS AND SCATTERING</u> Co-chairs: N. Yokoyama and L. Eaves
8:30 a.m.	"Transport Devices Based on Quantum Wires and Coupled Quantum Boxes: Their Advantages and Limitations" H. Noge, Quantum Wave Project, JRDC
9:00 a.m.	"Photon-Assisted Quantum Transport in Quantum Point Contacts" Q. Hu, MIT
9:20 a.m.	"Manipulation of Ballistic Electrons by Ion-Implanted in-Plane-Gated Structures" Y. Hirayama, A. D. Wieck, S. Tarucha, and Y. Horikoshi, NTT Basic Research Labs
9:40 a.m.	"Magnetic Focusing in Gated Nanostructures" P. Kelly, D. Freidman, R. Taylor, A. Sachrajda, P. Coleridge, P. Zawadzki, and J. Adams, National Research Council of Canada
10:00 a.m.	COFFEE BREAK
10:30 a.m.	"Quantized Conductance of Ballistic Constrictions in InAs/AlSb Quantum Wells" S. J. Koester, C. R. Bolognesi, M. J. Rooks, E. L. Hu, and H. Kroemer, University of California
10:50 a.m.	"Effects of Random Potentials in Quasi-One Dimensional Ballistic Channels" Y. Takagaki, Q. Li, and D. K. Ferry, Arizona State University
11:10 a.m.	"Theory of Optical-Phonon Modes in Ultrasmall Electronic Devices" K. W. Kim, North Carolina State University
11:30 a.m.	"Hot Electron and Hot Hole Regimes of Complementary Heterostructure Field Effect Transistors" F. Schuermeyer, Wright Patterson AFB, M. Shur, University of Virginia, E. Martinez and D. Grider, Honeywell Sensors and Signal Processing Laboratory.
11:50 a.m.	LUNCH
2:00 p.m. - 5:00 p.m.	AD HOC SESSIONS
6:00 p.m. - 7:30 p.m.	DINNER

Wednesday, December 2, 1992 (continued)

7:30 p.m.-9:00 p.m.

HETEROSTRUCTURE EPITAXY AND TRANSPORT II

Co-chairs: H. Hasegawa and K. Ploog

7:30 p.m.

"Advanced Si Heterostructure Devices Formed
by Molecular Beam Epitaxy"

M. Miyao and K. Nakagawa, Hitachi Ltd.

8:00 p.m.

"Facetted MBE Growth of (GaAl)As on RIE
Patterned Surfaces"

G. Weimann, Walter-Schottky-Institut,
Technische Universität München

8:20 p.m.

"Epitaxy for Phonon Suppression Structures"

G. Maracas, Arizona State University

8:40 p.m.

"Transport and Optical Properties of InAs
GaAs Short-Period Strain Layer
Superlattice"

M. Spencer, Howard University

9:00 p.m.-10:00 p.m.

SOCIAL HOUR

Thursday, December 3, 1992

7:00 a.m.

BREAKFAST

8:30 a.m. - 11:50 a.m.

III-V HBTs

Co-chairs: G. Weimann and L. Eastman

8:30 a.m.

"Optically-Interconnected HBT Chips"
K. W. Goossen, J. E. Cunningham, J. A. Walker, and W. Y. Jan, AT&T Bell Labs

9:00 a.m.

"Carbon-Doping for Advanced GaAs Devices"
C. R. Abernathy, AT&T Bell Labs

9:20 a.m.

"Carbon Doping Beyond 10^{19}cm^{-3} in GaAs and $\text{Al}_x\text{Ga}_{1-x}\text{As}$ by Solid-Source MBE"
K. H. Ploog, Paul-Drude-Institut für Festkörperelektronik
A. Fischer, Max-Planck-Institut für Festkörperforschung

9:50 a.m.

COFFEE BREAK

10:20 a.m.

"Application of Low Pressure OMVPE Carbon Doping to AlGaAs/GaAs HBT Structures"
P. M. Enquist and D. B. Slater, Jr., Research Triangle Institute

10:50 a.m.

"A New Collector-Up HBT Structure Prepared by FIB Technology Combined with MBE Overgrowth"
T. Ishibashi, A. Fischer, A. D. Wieck, and K. Ploog, Max-Planck-Institut für Festkörperforschung

11:10 a.m.

"InGaAs Double Heterojunction Bipolar Transistors Grown on GaAs Substrates"
H. Ito, NTT LSI Labs, J. S. Harris, Jr., Stanford University

11:30 a.m.

"Bipolar Transistors Compatible with InP/InGaAs PIN Processing"
W. R. McKinnon, National Research Council of Canada

11:50 a.m.

LUNCH

2:00 p.m. - 5:00 p.m.

AD HOC SESSIONS

5:00 p.m. - 6:00 p.m.

SOCIAL HOUR

6:00 p.m.

BANQUET AND ENTERTAINMENT

Friday, December 4, 1992

7:00 a.m.

BREAKFAST

8:30 a.m. - 12:20 p.m.

HETEROSTRUCTURE DEVICES AND PHENOMENA

Co-chairs: T. C. L. G. Sollner and H. Ito

8:30 a.m.

"Light-Emitting Charge Injection
Transistors in InP-Based Heterostructures"
S. Luryi, AT&T Bell Labs

9:00 a.m.

"Hybridized Circuits of Superconducting
Devices and Semiconductor Transistors with
Extremely Low Voltage Swing"
J. Sone, NEC Corporation

9:20 a.m.

"Heterostructure Photonic Devices for the
Long Wavelength Infrared Region"
H. C. Liu, National Research Council of
Canada

9:40 a.m.

"The Effect of the Electron-Plasmon
Interaction on the Calculated Ratio of the
Collector to Emitter Currents in Hot
Electron transistors"
K. F. Brennan and N. S. Mansour, Georgia
Institute of Technology

10:00 a.m.

COFFEE BREAK

10:30 a.m.

"Numerical Analyses of Device Instabilities
Due to Deep Levels"
Y. Ohno, NEC Corporation

11:00 a.m.

"New Transistor Concepts of Mixed Bipolar
and Monopolar Heterojunction Structures"
W. Anderson and H. L. Hartnagel
Institut für Hochfrequenztechnik Technische
Hochschule Darmstadt

11:20 a.m.

"Study on High Output Conductance and
Impact Ionization in the InGaAs Channel for
InAlAs/InGaAs/InP MODFET"
G-G. Zhou, Hewlett Packard and Stanford
University
A. Fischer-Colbrier, Hewlett Packard
J. S. Harris, Stanford University

11:40 a.m.

"Metal Base Resonant Tunneling Hot Electron
Transistor"
M. V. Weckwerth and J. S. Harris, Stanford
University

12:00 Noon

"A Novel Electron Emitter with AlGaAs
Planar Doped Barrier"
W.N. Jiang and U.K. Mishra, University of
California

12:20 p.m.

LUNCH AND ADJOURNMENT

Engineering Foundation Conferences

ADVANCED HETEROSTRUCTURE TRANSISTORS V

Keauhou Beach Hotel
Kailua-Kona,
November 29 to December 04, 1992

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