

November 1989

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COORDINATED SCIENCE LABORATORY

**FINAL REPORT
OF
RESEARCH**

**FOR THE
JOINT SERVICES
ELECTRONICS PROGRAM**

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**FOR THE PERIOD
OCTOBER 1, 1986, THROUGH SEPTEMBER 30, 1989
FOR
CONTRACT N00014-84-C-0149**

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified			1b. RESTRICTIVE MARKINGS None		
2a. SECURITY CLASSIFICATION AUTHORITY			3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; distribution unlimited		
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE					
4. PERFORMING ORGANIZATION REPORT NUMBER(S)			5. MONITORING ORGANIZATION REPORT NUMBER(S)		
6a. NAME OF PERFORMING ORGANIZATION Coordinated Science Lab University of Illinois		6b. OFFICE SYMBOL (if applicable) N/A	7a. NAME OF MONITORING ORGANIZATION Office of Naval Research		
6c. ADDRESS (City, State, and ZIP Code) 1101 W. Springfield Ave. Urbana, IL 61801			7b. ADDRESS (City, State, and ZIP Code) Arlington, VA 22217		
8a. NAME OF FUNDING / SPONSORING ORGANIZATION Joint Services Electronics Program		8b. OFFICE SYMBOL (if applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER N00014-84-C-0149		
8c. ADDRESS (City, State, and ZIP Code) Arlington, VA 22217			10. SOURCE OF FUNDING NUMBERS		
			PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.
			WORK UNIT ACCESSION NO.		
11. TITLE (Include Security Classification) Final Progress Report					
12. PERSONAL AUTHOR(S) Jenkins, William Kenneth (Principal Investigator)					
13a. TYPE OF REPORT Progress		13b. TIME COVERED FROM 10/1/86 TO 9/30/89		14. DATE OF REPORT (Year, Month, Day) 1989 November	
15. PAGE COUNT					
16. SUPPLEMENTARY NOTATION					
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)		
FIELD	GROUP	SUB-GROUP			
19. ABSTRACT (Continue on reverse if necessary and identify by block number) This is the final progress report of the research conducted at the Coordinated Science Laboratory, University of Illinois at Urbana-Champaign, under the sponsorship of the Joint Services Electronics Program from 1 October 1986 through 30 September 1989. The report includes an overview of the three-year program accomplishments, a listing of the investigators, a listing of degrees awarded, and a listing of publications under JSEP sponsorship (listed by work units).					
20. DISTRIBUTION / AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS			21. ABSTRACT SECURITY CLASSIFICATION Unclassified		
22a. NAME OF RESPONSIBLE INDIVIDUAL			22b. TELEPHONE (Include Area Code)		22c. OFFICE SYMBOL

JSEP FINAL PROGRESS REPORT

For the Period

1 October 1986 through 30 September 1989

**Joint Services Electronics Program
Contract N00014-84-C-0149**

Monitored by the
Office of Naval Research

William Kenneth Jenkins
JSEP Principal Investigator
Coordinated Science Laboratory

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EXECUTIVE SUMMARY

Summary of the Program

This final report covers the Joint Services Electronics Program at the Coordinated Sciences Laboratory, University of Illinois at Urbana-Champaign, from October 1, 1986 through September 30, 1989. During this contract period, the program included twenty-three work units that covered five major technical areas: (1) Solid State Electronics, (2) Quantum Electronics, (3) Electromagnetics, (4) Information Systems, and (5) Electronics Research (Director's unit). There were seven units in Physical Electronics devoted mostly to the growth, characterization, and device fabrication of compound semiconductor materials. Quantum Electronics included three units: one unit studied charge density waves (DCWs) in superconducting materials, and two units dealt with plasmas and excited state chemistry of gases. Electromagnetics contained two units: one concentrated on monolithic millimeter-wave ICs with microstrip antennas and the second on the design and analysis of nonreflecting surface structures to control radar scattering characteristics. There were ten units in Information Systems covering important topics in computers, control, communications, and signal processing. Detailed discussions of individual accomplishments can be found in the "Annual Progress Report" covering each of years one, two, and three of the contract. During the three-year contract period, eight items were selected from among the many significant contributions and highlighted as "JSEP Most Significant Accomplishments." These accomplishments are summarized below.

JSEP MOST SIGNIFICANT ACCOMPLISHMENTS (October 1, 1986 - September 30, 1989)

The Heterostructure Hot Electron Diode (Unit 2 and Unit 5)

Professors J. J. Coleman and K. Hess, together with graduate students T. K. Higman and M. A. Emanuel, discovered a new switching mechanism in semiconductor heterostructures that resulted in the development of a new electronic device, the heterostructure hot electron diode (H^2ED). The operation of the H^2ED is based on a transition between two current conduction modes in a two-terminal structure, a low current tunneling mode, and a high current thermionic emission mode. Switching between these modes gives rise to an S-shaped negative differential resistance in the current versus voltage characteristic (as shown in Figure 1). These devices have application as a microwave oscillator. Microwave characterization is presently in progress, and preliminary results have demonstrated test-fixture-limited gain to 18 GHz. If no parasitic effects are encountered, and if the oscillation frequency is, in fact, electron transit time limited, oscillation in the 1000 GHz range may be possible.

This work represents a synergistic relationship between Professor Hess's theoretical work supported under Unit 2 and Professor Coleman's experimental work supported under Unit 5. Professor Hess developed the theoretical model of the new device and predicted its characteristics. Professor Coleman built the new device in his laboratory, measured the physical characteristics of his experimental sample, and is presently continuing its further characterization and development. It was announced in a press release by the University of Illinois at Urbana-Champaign to the UPI wire service that a patent disclosure has been filed on this new device, and a number of publications have appeared describing the technical details of the H^2ED .

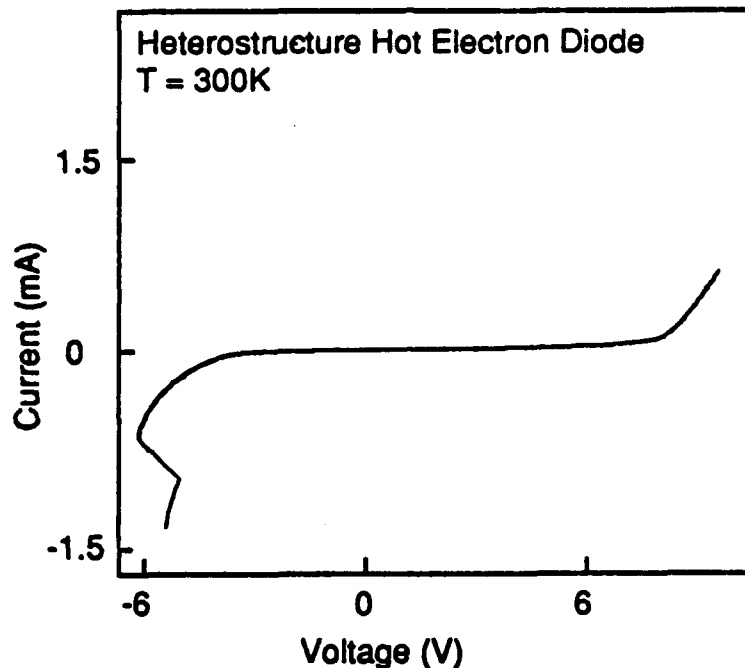


Fig. 1. Experimental room temperature dc I-V characteristics for the Heterostructure Hot Electron Diode (HHED) exhibiting the expected S-shaped NDR. The structure, grown on a (100) GaAs:Si n^+ substrate, consists of an undoped AlAs barrier (1500 Å), an undoped GaAs heating region (1300 Å), and a heavily doped $n + \text{Al}_{0.20}\text{Ga}_{0.80}\text{As}$ cap layer. The theoretical maximum frequency of oscillation is estimated to be 57 GHz.

Error-Control Coding and Spread-Spectrum Communication Techniques for the Army's SINCGARS Radio (Unit 21)

Several results of CSL research in error-control coding and spread-spectrum communications have been incorporated into the SINCGARS radio (Single Channel Ground/Airborne Radio Subsystem). This radio, the Army's newest tactical radio, was developed by ITT Aerospace/Optical Division for voice and data communications. It operates in both a single-channel mode and a frequency-hop spread-spectrum mode. In addition, an overlay is being developed by ITT and SRI International to enable SINCGARS radios to operate as packet radios in a mobile communication network.

Research results obtained by Professors M. B. Pursley and D. V. Sarwate and their graduate research assistants were employed by Professor Pursley to design the synchronization sequence that is utilized for timing acquisition in the SINCGARS receiver. In addition, for the packet radio version of SINCGARS (known as the SINCGARS Packet Overlay), Professor Pursley developed the error-control method that combines Reed-Solomon codes with side information derived from test patterns. The side information is used to erase unreliable data at the output of the demodulator so that the input to the decoder is a combination of data symbols and special erasure symbols. The code enables

the receiver to correct errors and erasures caused by noise and interference in the communication channel. The combination of coding and side information provides the capability for a large number of SINCGARS radios to operate simultaneously in the same frequency band. It also improves the radio's ability to communicate in the presence of various types of electromagnetic interference.

The decoding algorithm, developed and implemented in software by Professor Sarwate, is basically a mathematical description of the computations required to correct both errors and erasures. The actual computations prescribed by the algorithm are carried out in a microprocessor contained in the radio. The resulting decoder is capable of handling data rates in excess of 16,000 data symbols per second, the maximum signaling rate of the SINCGARS radio.

Professor Pursley also provided the analytical tools to evaluate the performance of the error-control scheme and assess its impact on the overall communication network performance. Analytical results from this effort, and other investigations conducted by Professor Pursley and Mr. J. R. McChesney of ITT, were used subsequently in the SINCGARS packet radio network simulation developed for the Army by SRI.

The research leading to the development of the approach used for error control in the SINCGARS radio was funded by JSEP during the early stages, funded by ARO during later stages, and developed into the actual SINCGARS application with funds provided by ITT and under individual consulting arrangements with SRI and ITT.

Design and Fabrication of a VLSI Digital Filter Integrated Circuit Module (Unit 17)

For a number of years, both NSF and JSEP have supported theoretical studies at the Coordinated Science Laboratory on the use of residue number arithmetic (RNS) for the design of high-speed VLSI circuits for the digital signal-processing functions that are required in modern communication and radar systems. Two years ago, Professors Jenkins and S. F. Lao carried out the successful design and fabrication of a semicustom VLSI digital filter module that demonstrates both the feasibility and desirability of using residue number theory design techniques in practice (Unit 17). A semicustom integrated circuit module was designed for an RNS digital filter using the IBM MVISA CAD system that is located on the campus of the University of Illinois at Urbana-Champaign. A programmable 4-bit module was designed as a basic building block for a finite impulse response digital filter that has order 8 and 14 bits of arithmetic precision. The module was designed using finite field logarithm additions to completely eliminate conventional multipliers on the chip and thereby improve speed and circuit density. The chip design was done with MVISA using a standard cell approach, and MVISA was then used to simulate the hardware operation and to estimate physical parameters. The chip was subsequently fabricated at the IBM Manassas facility, and 10 samples were eventually returned to the University of Illinois at Urbana-Champaign for testing and characterization. MVISA estimates that the 4.2 mm chip consumes 89 mW and operates at a system cycle frequency of 10 MHz, which corresponds to a data-cycle frequency of 1.2 MHz. The design used 529 out of a possible 560 available standard cells. A photo of the IC layout is shown in Figure 2.

Experience gained in the above experiment led to a new integrated circuit design based on a modular systolic architecture. This new IC contains a fundamental computational element that is monitored internally on-chip by an error detection scheme. Many similar computational modules can be interconnected to form a wide variety of pipelined systolic arrays for implementing important computational kernels required in signal processing applications. At the time of this writing, a set of test chips has been received from MOSIS and these chips are now being tested at the University of Illinois.

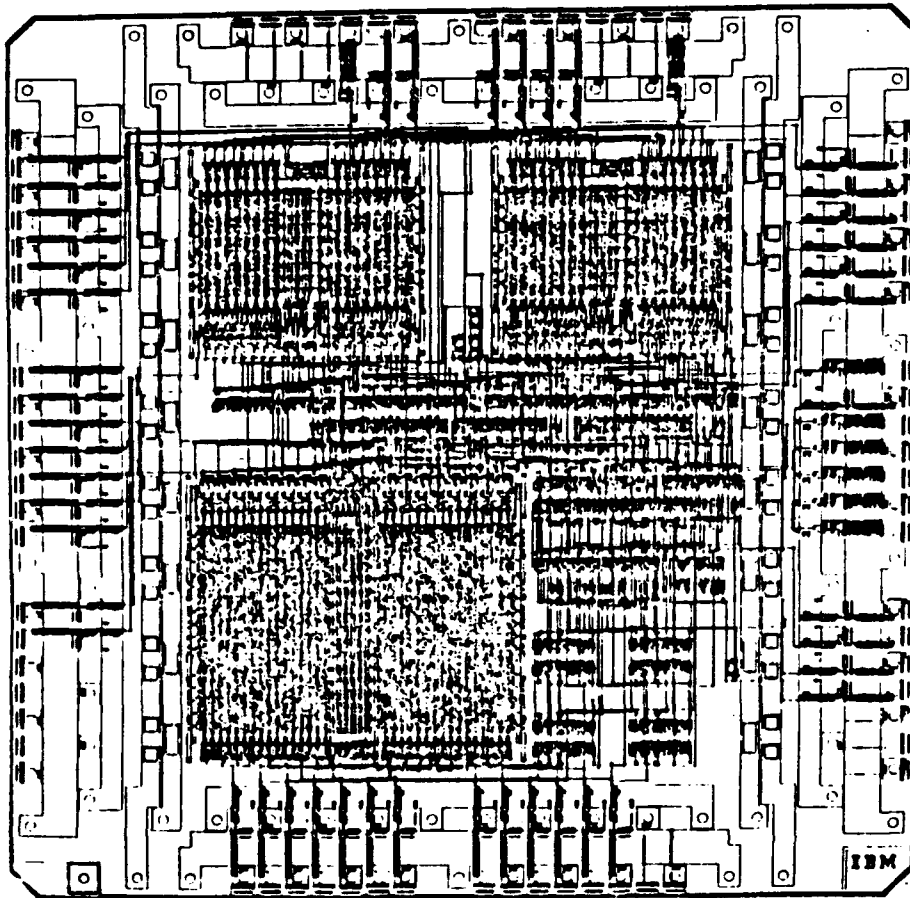


Fig. 2. A VLSI digital filter module designed with the MVISA CAD System.

Modeling and Simulation of New Microelectronic and Optoelectronic Devices and Circuits with the iSMILE Program (Unit 7)

During the last few years, Professors S. M. Kang and T. N. Trick, with graduate students K. Cioffi and A. T. Yang, collaborated on the development of circuit models for High Electron Mobility Transistors (HEMT) under the JSEP sponsorship. Traditionally, the task of developing new circuit models has been time consuming, mainly due to the intensive line-by-line modification of generic circuit simulators like SPICE or SLATE. As a result, the progress in computer-aided simulation of new microelectronic devices and circuits has been hampered by the slow model development process.

Under the JSEP sponsorship, Professor Kang and his Research Assistant A. T. Yang initiated the development of a new CAD tool, iSMILE (Illinois Simulator for Modeling of Integrated-circuit Level Elements). This program was first tried by Dr. Cioffi, now at Rockwell International, for his development of HEMT models. Circuit models are described to iSMILE by using a simple input file containing model topology descriptions and element characteristic equations. The iSMILE program then builds a circuit simulator based on circuit models, shielding the user from the laborious line-by-line program modifications. Owing to this unique feature, the model development time is reduced significantly from several months to a few weeks once the model developer has a clear understanding of underlying device physics.

Further development of the iSMILE program is continuing under the sponsorship of the National Science Foundation (NSF) Engineering Research Center for Compound Semiconductor Microelectronics. iSMILE has been used to develop lossy transmission models, multiple quantum well laser diode models, optical waveguide models, and photodetector circuit models in cooperation with Professors J. J. Coleman, T. A. DeTemple, and G. E. Stillman. Using these models and HEMT models, we have been able to simulate the speed performance of optical interconnect systems, which would not have been possible in such a short time without iSMILE.

The unique capability of the iSMILE program has been well recognized by industry collaborators. At their request, the iSMILE program has been ported to industrial researchers at Hewlett Packard, Boeing, GTE, AT&T, TI, and several universities. Results on circuit modeling and simulation were presented at the 1988 International Conference on Circuits and Systems and the 1988 International Conference on Computer Design. Further details of this work will be published in the 1989 Design Automation conference proceedings and journals. It was through the interdisciplinary team effort provided under the sponsorship of JSEP, NSF, and industry that enabled the development of new circuit models, as well as the novel CAD tool, iSMILE.

Scanning Tunneling Microscopy of the CDW Discommensuration Domain Structure in the Nearly Commensurate Phase of 1T-TaS₂ (Unit 8)

It has been known for some time from bulk NMR and XPS measurements that the nearly commensurate CDW phases exhibited by some of the layered transition metal dichalcogenides actually consist of relatively small commensurate regions separated by CDW phase kinks or discommensurations (DCs). Their existence and microscopic domain structure have previously been predicted by the Ginzburg Landau approaches of McMillan and Nakanishi; however, no direct observation of the DC domain structure has been made until now.

Recently, Professor Joe Lyding and one of his students, Mr. Stephen Skala, have been able to use their new variable temperature scanning tunneling microscope (STM) (thermal drift $< 1 \text{ \AA}/\text{hour}$) to study the nearly commensurate phase of 1T-TaS₂. Shown in Figure 3a is a representative STM image in which the larger period CDW is superimposed against the sulfur rows of the atomic lattice. From images like this, the commensurability of the CDW relative to the lattice can be studied. Shown in Figure 3b is a proposed model for the DC structure for Figure 3a and for 1T-TaS₂ in general. The small dots denote the sulfur atoms, the large dots are the CDW maxima, and the lines are the DCs between commensurate regions. Here it is seen that the domains are rhombohedral, with a characteristic length of $60 \text{ \AA}$ along each edge. The bold line to the right of Figure 3b represents a DC with a larger phase kink than the other DCs. The observed domain structure is not the hexagonal domain structure predicted by Nakanishi but one in which there are two equivalent CDW wavevectors (parallel to the DC boundaries), while the third wavevector passes through more DCs per unit length. This model also yields the correct average orientation of the incommensurate CDW wavevector relative to the lattice, as determined by bulk measurements.

Controlled Doping in MBE Si: Chemistry at the Atomic Level (Unit 1)

Fabrication of modern microelectronic devices requires precise control of dopant concentrations and depth distributions. Molecular beam epitaxy (MBE) is presently employed in many critical applications, such as the growth of superlattices and modulation-doped structures. However, most of the common dopants used in bulk Si wafers present serious problems during film growth by MBE due to low incorporation probabilities and/or pronounced surface segregation giving rise to uncontrolled profile broadening.

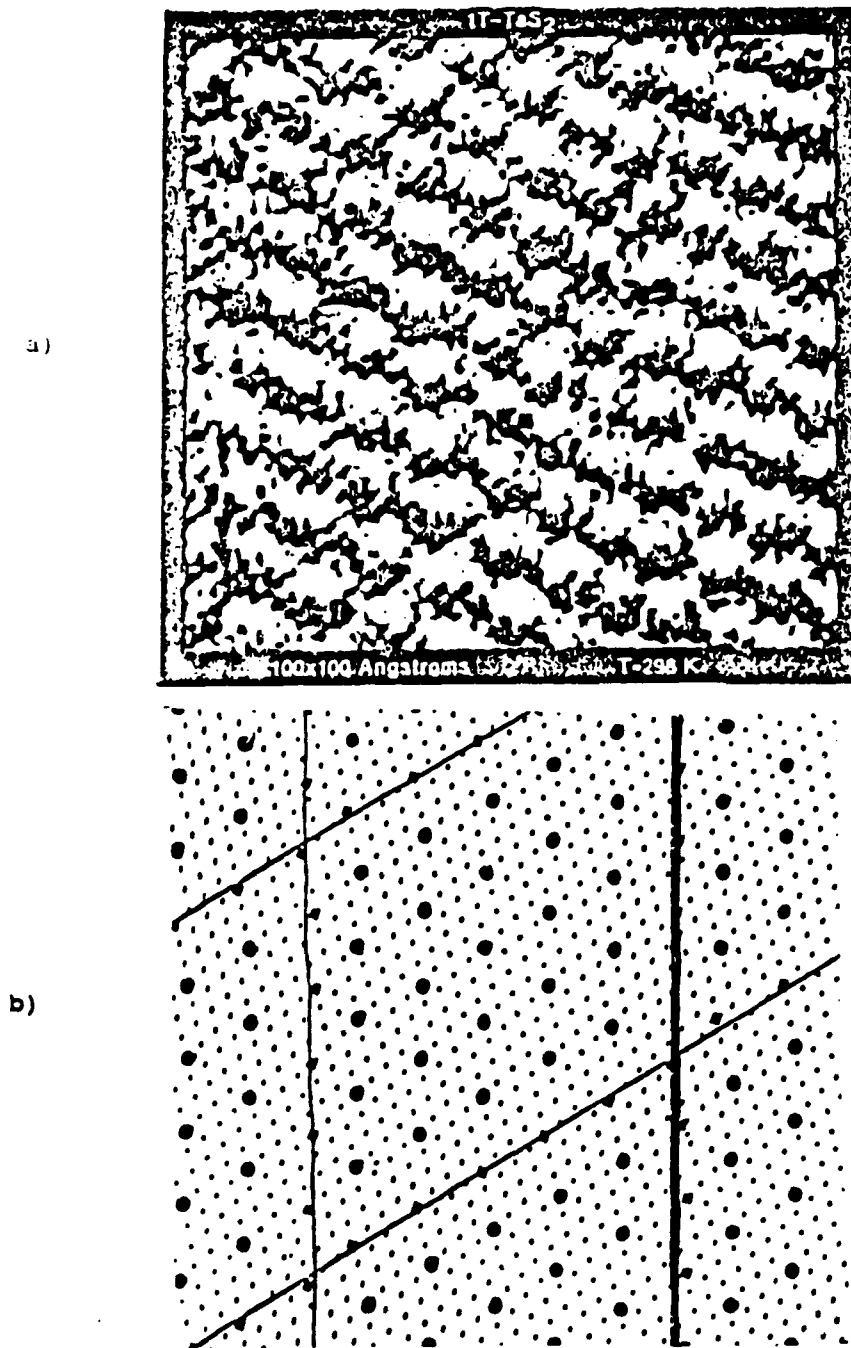


Fig. 3. a) STM image of the nearly commensurate phase of 1T-TaS₂ showing the orientation of the CDW (large period) relative to the atomic sulfur rows of the lattice. b) Discommensuration model constructed from a) where the small dots are atoms, large dots are CDW maxima, and the lines are discommensurations. The bold line is a discommensuration having a larger phase kink.

Under JSEP Unit 1, Professor Joe Greene has been investigating the use of low-energy (50-500 eV) accelerated-ion doping during MBE Si growth. The experiments are carried out using new ultra-high vacuum-compatible low-energy ion sources, which were developed as part of the research program. Sb, an important shallow donor in Si, and In, a deep acceptor, were chosen as model dopant materials.

Thermal Sb₄ and In, obtained from standard effusion cells, have low incorporation probabilities σ in MBE Si. σ_{Sb} ranges from 10^{-3} to 10^{-5} at growth temperatures T_s between 700 and 850 °C, while σ_{In} is $< 10^{-5}$ at $T_s > 550$ °C. These dopants also exhibit severe surface segregation with, in the case of Sb, steady-state surface accumulations during growth of up to a full monolayer. This not only gives rise to broad doping profiles but also limits the maximum usable doping concentrations. For example, obtaining Sb concentrations higher than $\approx 5 \times 10^{17} - 10^{18} \text{ cm}^{-3}$ with thermal-doping requires the use of extremely large Sb₄ fluxes, which results in the production of a high concentration of structural defects and a corresponding decrease in electron mobilities.

The University of Illinois at Urbana-Champaign Thin Film Physics Group is employing a combination of Auger electron spectroscopy (AES), low-energy and reflected high-energy electron diffraction (LEED and RHEED), plan-view and cross-sectional transmission electron microscopy (TEM and XTEM), secondary-ion mass spectrometry (SIMS), and temperature-dependent Hall measurements to investigate the growth, structure, dopant distribution, and electrical properties of Si films grown at $T_s = 800^\circ\text{C}$ with 150 eV Sb⁺ and 200 eV In⁺ dopant beams. Sb and In were found to incorporate, with unity probability, into substitutional, electrically active sites at concentrations up to at least $3 \times 10^{19} \text{ cm}^{-3}$ and $1 \times 10^{18} \text{ cm}^{-3}$, respectively. The films were essentially dislocation free with no indication of residual ion-induced damage. Data presented in Figure 4 show that carrier mobilities of Sb and In ion-doped films are equal to the best reported values for bulk Si even at doping concentrations extending well above those attainable by thermal-beam MBE. In fact, the hole mobilities are the highest ever reported for In-doped Si (note that the solid curve in Figure 4 corresponds to Si:B), whether bulk or thin film. Doping profiles in accelerated-beam modulation-doped structures were extremely abrupt. There was no indication from *in situ* AES and RHEED analyses of significant dopant surface accumulation during growth.

Conception and Demonstration of a New Mechanism of Tunnel Injection (Unit 24)

Professors Adesida, Kolodzey, and Leburton recently reported the conception and experimental verification of a new mechanism of tunnel injection into the active region of MODFET structures. Injection occurs through a tunnel junction parallel to the MODFET channel and is the basic mechanism for sophisticated high-speed multi-terminal devices. Two novel transistor structures were proposed—the BiTFET and the TIFET—that exploit the new injection principle in a configuration leading to Negative Differential Resistance (NDR) characteristics. Theoretical estimates of the relevant time constants indicate possible operation in the 100 GHz range.

With barrier height equal to the band gap, the use of tunnel junctions has the advantage of reducing thermionic emission competing with the tunneling current and results in high peak-to-valley NDR ratios that are suitable for high-power microwave devices.

TIFET structures have been fabricated and tested in our laboratory. Experimental I-V characteristics show evidence of tunneling in the 2-D channel of the MODFET across the tunnel junction (see Figure 5). A patent application for the new devices has been filed by University Patents, Inc.

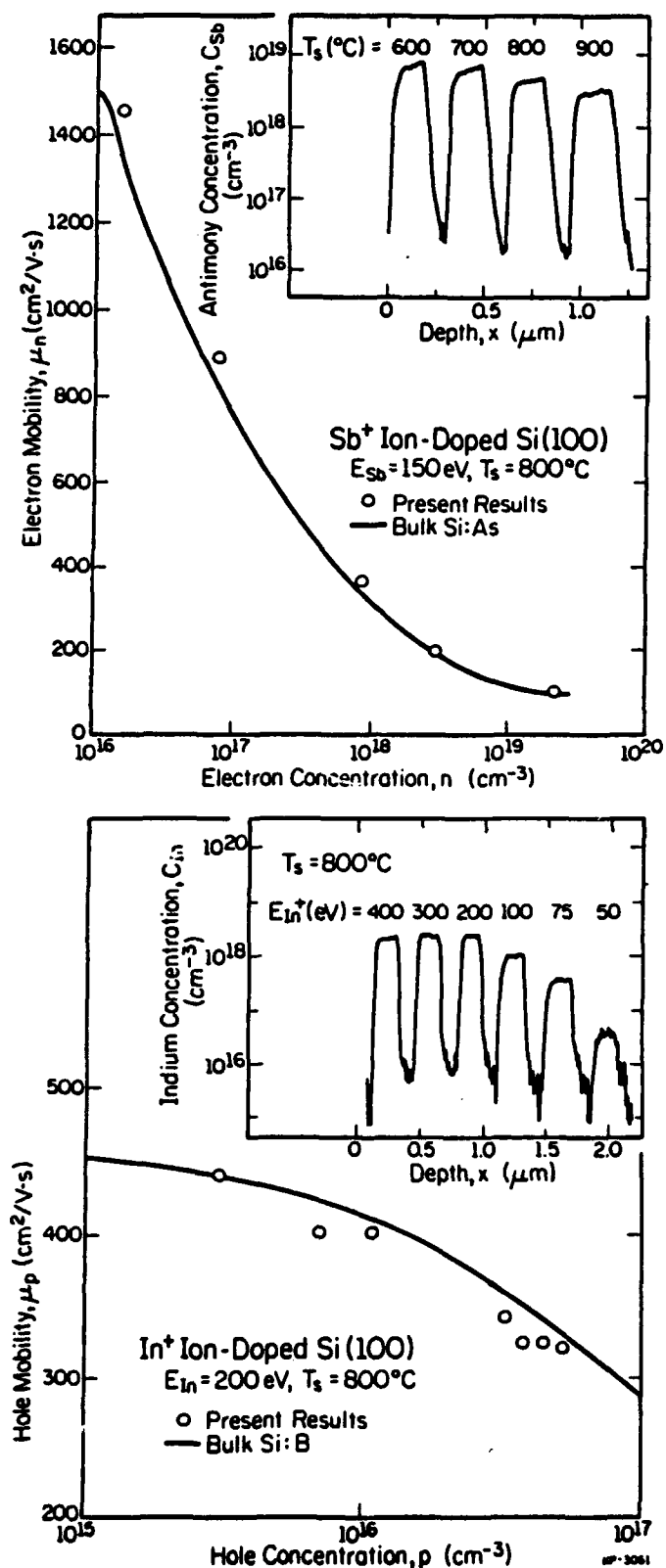


Fig. 4. Experimental carrier mobilities of Sb and In ion-doped films.

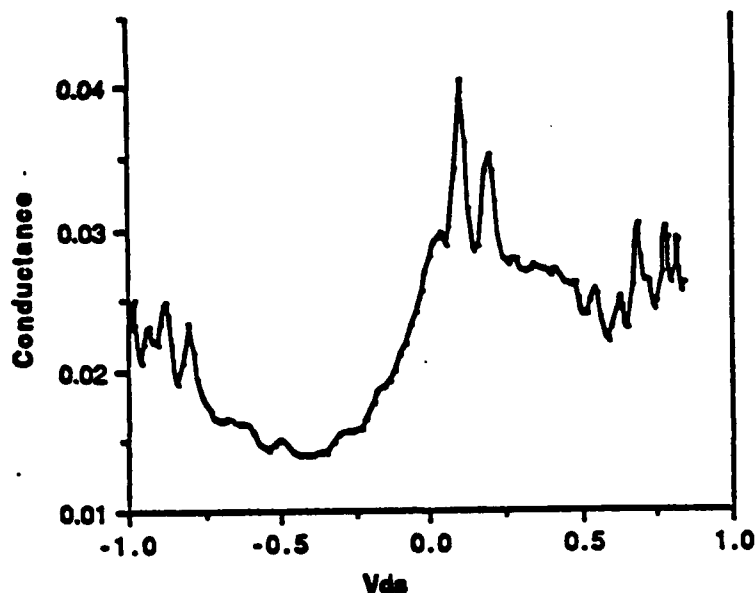


Fig. 5. Conductance vs. V_{ds} for GaAs/AlGaAs TIFET Device, $I_{sb} = +5\text{mA}$, $V_{gs} = 1\text{V}$

Completion of the University of Illinois EpiCenter (Unit 23)

In late 1989 construction of the University of Illinois EpiCenter was completed and researchers are now successfully growing materials. The EpiCenter is a world-class facility that consists of seven MBE chambers interconnected by high-vacuum transfer tubes. Having the chambers, each of which is dedicated to a different type of material growth and characterization, interconnected by vacuum lines allows samples to be moved from one growth environment to another without external contamination. Since the planning for this new facility was begun about five years ago and the construction has taken two years, the completion of this project is a major accomplishment. All of the JSEP discretionary funds provided under Unit 23 of the 86-89 contract were applied toward the purchase of several MBE chambers that will support future MBE research in the JSEP program. Since the EpiCenter is described in detail in the Annual Progress Report for year three of the contract, further details will not be presented in this report.

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John R. Tucker
Joseph T. Verdeyen
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JSEP-SUPPORTED DEGREES AWARDED
October 1, 1986, through September 30, 1989

April 1, 1986 - March 31, 1987

- [1] A. Ali, Graduate Student, "Time-domain reflectometry using scattering parameters and a de-embedding application," M.S. thesis, 1986.
- [2] D. W. Bailey, Research Assistant, "Estimators in Monte Carlo semiconductor electron transport simulations," M.S. thesis, 1986.
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- [5] T. Cwik, Graduate Student, "Scattering from general periodic screens," Ph.D. dissertation, 1986.
- [6] R. DeJule, Research Assistant, "Study of deep levels in (100) and (311) B molecular beam epitaxial gallium arsenide by constant capacitance deep-level transient spectroscopy," Ph.D. dissertation, Sept. 1986.
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- [8] K. B. Kahen, Ph.D., "Theoretical study of the transverse dielectric constant of superlattices and their alloys," Ph.D. dissertation, 1986.
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- [17] T. Wang, Research Assistant, "Theoretical studies of electronic transport in gallium arsenide material and devices using an ensemble Monte Carlo method," Ph.D. dissertation, 1986.
- [18] A. T. Yang, Research Assistant, "Delay modeling of bipolar ECL/EFL circuits," M.S. thesis, 1986.

April 1, 1987 - March 31, 1988

- [1] K. Beuscher, Research Assistant, "Representation, analysis, and design of multirate discrete-time control systems," M.S. thesis, Feb. 1988.
- [2] R. L. Cruz, "A calculus for network delay and a note on topologies of interconnection networks," Ph.D. thesis, July 1987.
- [3] M. A. Emanuel, Research Assistant, "Metalorganic chemical vapor deposition and its application to the growth of the heterostructure hot electron diode," Ph.D. thesis, May 1988.
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- [7] G. A. Hebner, "Measurement of the radiation temperature and electron density in parallel plate radio frequency discharges," Ph.D. thesis, Oct. 1987.
- [8] M. C. Hsueh, Research Assistant and Visiting Professor, "Measurement-based reliability / performability models," Ph.D. thesis, Sept. 1987.
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- [12] S. Manion, Research Assistant, "Two-dimensional electron gases in high magnetic fields," Ph.D. thesis, Jan. 1988.
- [13] J. J. Murphy, "A comparison of transform domain adaptive filters, with emphasis on the Hartley transform," M.S. thesis, Aug. 1987.

- [14] N. Pan, Research Assistant, "Hydrogenation of high purity gallium arsenide and liquid phase epitaxy growth of high purity indium gallium arsenide," Ph.D. thesis, Dec. 1987.
- [15] R. Ramaker, Research Assistant, "Design of low order controllers for robust disturbance rejection in large space structures," M.S. thesis, Sept. 1987.
- [16] V. M. Robbins, Research Assistant, "An experimental study of impact ionization in compound semiconductors," Ph.D. thesis, Jan. 1988.
- [17] G. Sasaki, "Optimization by simulated annealing: a time complexity analysis," Ph.D. thesis, Oct. 1987.
- [18] T. Ting, Research Assistant, "Robustness in feedback systems," Ph.D. thesis, June 1987.

April 1, 1988 - March 31, 1989

- [1] M. A. Aboelaze, Research Assistant, "Systematic design of computational arrays," Ph.D. thesis, Apr. 1988.
- [2] K. M. Baumgartner, Graduate Research Assistant, "Resource allocation on distributed computer systems," Ph.D. thesis, May 1988.
- [3] S. S. Bose, Research Assistant, "Low temperature magneto-photoluminescence characterization of high purity gallium arsenide and indium phosphide," Ph.D. thesis, 1988.
- [4] A. Chang, Graduate Student, "Numerical methods to solve the problem of scattering from electrically large bodies," Ph.D. thesis, 1988.
- [5] D. P. Connors, Research Assistant, "Balance of recurrence order in time-inhomogeneous Markov chains with application to simulated annealing," Ph.D. thesis, Apr. 1988.
- [6] M. A. Haase, Research Assistant, "Internal photoemission and energy band discontinuities at semiconductor heterojunctions," Ph.D. thesis, May 1988.
- [7] J. Higman, Research Assistant, "Theoretical studies of high field electron transport in silicon devices," Ph.D. thesis, 1988.
- [8] T. K. Higman, Research Assistant, "Experimental investigation of hot electron and related effects in gallium (aluminum) arsenide devices," Ph.D. thesis, 1988.
- [9] A. Kanevsky, Research Assistant, "Vertex connectivity of graphs: algorithms and bounds," Ph.D. thesis, 1988.
- [10] K. W. Kim, Research Assistant, "Monte Carlo studies of nonlinear electron transport in III-V semiconductors," Ph.D. thesis, 1988.
- [11] M. H. Kim, Research Assistant, "Photo-Hall studies of compound semiconductors," Ph.D. thesis, 1988.

- [12] I. C. Kizilyalli, Research Assistant, "Physics and simulation of high-speed heterostructure devices," Ph.D. thesis, 1988.
- [13] B. Lee, Research Assistant, "Characterization of shallow impurities in high-purity gallium arsenide and indium phosphide using photothermal spectroscopy: nonequilibrium incorporation of amphoteric impurities," Ph.D. thesis, Apr. 1989.
- [14] S.-F. Lin, Research Assistant, "Performance and robustness of adaptive controllers for linear stochastic systems," Ph.D. thesis, 1988.
- [15] W. G. Lyons, Research Assistant, "Transport studies and phenomenological model for sliding charge density waves in quasi one-dimensional conductors," Ph.D. thesis, Jan. 1989.
- [16] S. J. Manion, Research Assistant, "Acoustic phonon scattering in modulation doped aluminum_x gallium_{1-x} arsenide/gallium arsenide heterojunctions," Ph.D. thesis, 1988.
- [17] N. Pan, Research Assistant, "Hydrogenation of high purity gallium arsenide and liquid phase epitaxy growth of high purity indium gallium arsenide," Ph.D. thesis, 1988.
- [18] A. Reed, Research Assistant, "Residual impurity incorporation in the growth of high purity gallium arsenide by metalorganic chemical vapor deposition," Ph.D. thesis, 1988.
- [19] D. W. Smart, Research Assistant, "Parallel processing techniques for the simulation of MOS VLSI circuits using waveform relaxation," Ph.D. thesis, 1988.
- [20] R. Tamassia, Research Assistant, "Dynamic data structures for two-dimensional searching," Ph.D. thesis, 1988.
- [21] J. L. Trahan, Research Assistant, "Instruction sets for parallel random access machines," Ph.D. thesis, 1988.
- [22] H.-C. C. Tseng, "Internal manifold in system design with application to flexible link robot control," Ph.D. thesis, June 1988.
- [23] D. R. Wagner, Research Assistant, "A survey of high-speed digital filter structures and their finite precision behavior," M.S. thesis, May 1988.

PUBLICATIONS BY WORK UNITS

WORK UNIT NUMBER 1

TITLE: Crystal Growth from the Vapor Phase and Controlled Doping of Equilibrium and Metastable Semiconductor Alloys: Ion-Surface Interactions

SENIOR PRINCIPAL INVESTIGATOR:

J. E. Greene, Research Professor

JSEP-SPONSORED PUBLICATIONS

- [1] S. A. Barnett, H. F. Winters, and J. E. Greene, "The interaction of Sb_4 molecular beams with Si(100) surfaces: Modulated-beam mass spectrometry and thermally stimulated desorption studies," *Surf. Sci.*, vol. 165, pp. 303-326, 1986. (JSEP/SRC)
- [2] J. Knall, J.-E. Sundgren, G. V. Hansson, and J. E. Greene, "In overlayers on clean Si(100)2x1: Surface structure, nucleation, and growth," *Surf. Sci.*, vol. 166, pp. 512-538, 1986. (JSEP/SRC)
- [3] A. Rockett, J. Knall, M. A. Hassan, J.-E. Sundgren, S. A. Barnett, and J. E. Greene, "Thermal and accelerated (≤ 200 eV) In doping of Si(100) layers during molecular beam epitaxy," *J. Vac. Sci. Technol. A*, vol. 4, pp. 900-901, 1986. (JSEP/SRC)
- [4] A. Rockett, J. Klem, S. A. Barnett, J. E. Greene, and H. Morkoc, "Si incorporation and segregation on $\text{Ga}_{1-x}\text{Al}_x\text{As}$ (100) films grown by molecular beam epitaxy," *J. Vac. Sci. Technol. B*, vol. 4, pp. 519-520, 1986. (JSEP)
- [5] A. Rockett, J. Klem, S. A. Barnett, J. E. Greene, and H. Morkoc, "Si incorporation probabilities and depth distributions in $\text{Ga}_{1-x}\text{Al}_x\text{As}$ films grown by molecular beam epitaxy," *J. Appl. Phys.*, vol. 59, pp. 2777-2783, 1986. (JSEP)
- [6] T. C. McGlinn, T. N. Krabach, M. V. Klein, G. Bajor, J. E. Greene, B. Kramer, S. A. Barnett, A. Lastras, and S. Gorbatskin, "Raman scattering and optical absorption studies of the metastable alloy system $\text{GaAs}_{1-x}\text{Sb}_x$," *Phys. Rev. B*, vol. 33, pp. 8396-8401, 1986. (JSEP)
- [7] J. E. Greene, T. Motooka, J.-E. Sundgren, A. Rockett, S. Gorbatskin, D. Lubben, and S. A. Barnett, "A review of the present understanding of the role of ion/surface interactions and photo-induced reactions during vapor phase crystal growth," *J. Cryst. Growth*, vol. 79, pp. 19-32, 1986. (JSEP/DOE/SRC)
- [8] M. A. Hasan, J. Knall, S. A. Barnett, J.-E. Sundgren, A. Rockett, and J. E. Greene, "Accelerated-ion beam doping during Si growth by molecular beam epitaxy and ion-enhanced In film deposition using low energy (40 to 300 eV) In^+ ion source," *Vacuum* 36, pp. 1017-1018, 1986. (JSEP/SRC)

- [9] S. A. Barnett, H. F. Winters, and J. E. Greene, "Influence of Ion bombardment on the interaction of Sb with the Si(100) surface," *Surf. Sci.*, vol. 181, pp. 596-603, 1987. (JSEP/SRC)
- [10] S. I. Shah, J. E. Greene, L. L. Abels, Q. Yao, and P. M. Raccach, "Growth of single-crystal metastable $\text{Ge}_{1-x}\text{Sn}_x$ alloys on Ge(100) and GaAs(100) substrates," *J. Crystal Growth*, vol. 83, pp. 3-10, 1987. (JSEP/DOE)
- [11] J. E. Greene, "Crystal growth, atomic ordering, and physical properties of epitaxial metastable semiconductors," *J. Vac. Sci. Technol.*, vol. 5, pp. 1947-1948, 1987. (JSEP)
- [12] J. E. Greene, T. Motooka, J.-E. Sundgren, D. Lubben, S. Gorbatkin, and S. A. Barnett, "The role of Ion/surface interactions and photo-induced reactions during film growth from the vapor phase," *J. Nucl. Instr. Methods B*, vol. 27, pp. 226-242, 1987. (JSEP/DOE/ONR/SRC)
- [13] J. E. Greene, "Low-energy ion bombardment during film deposition from the vapor phase: effects on microchemistry and microstructure," *Sol. St. Technol.*, vol. 30, pp. 115-122, 1987. (JSEP/DOE/SRC)
- [14] M.-A. Hasan, S. A. Barnett, J.-E. Sundgren, and J. E. Greene, "Nucleation and initial growth of In deposited on Si_3N_4 using low-energy (≤ 300 eV) accelerated beams in ultra-high Vacuum," *J. Vac. Sci. Technol. A*, vol. 5, pp. 1883-1887, 1987. (JSEP/SRC)
- [15] M.-A. Hasan, J. Knall, S. A. Barnett, A. Rockett, J.-E. Sundgren, and J. E. Greene, "A low-energy metal-ion source for primary-ion deposition and accelerated-ion doping during molecular beam epitaxy," *J. Vac. Sci. Technol. B*, vol. 5, pp. 1332-1339, 1987. (JSEP/SRC)
- [16] N. Hirashita, J.-P. Noël, A. Rockett, L. Markert, J. E. Greene, M.-A. Hasan, J. Knall, W.-X. Ni, and J.-E. Sundgren, "Indium ion doping during Si molecular beam epitaxy," in *Materials Modification and Growth Using Ion Beams*, U. Gibson, P. P. Pronko, and A. E. White, Eds. Pittsburgh: Materials Research Society, in press. (JSEP/SRC)
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- [19] P. Fons, N. Hirashita, L. C. Markert, Y.-W. Kim, J. E. Greene, W.-X. Ni, J. Knall, G. V. Hansson, and J.-E. Sundgren, "Electrical properties of Si(100) films doped with low-energy (≤ 150 eV) Sb Ions during growth by molecular beam epitaxy," *Appl. Phys. Lett.*, vol. 53, p. 1732, 1988. (JSEP/SRC)
- [20] J.-P. Noël, N. Hirashita, L. C. Markert, Y.-W. Kim, J. E. Greene, J. Knall, W.-X. Ni, M. A. Hasan, and J.-E. Sundgren, "Electrical properties of Si films doped with 200 eV In^+ Ions during growth by molecular beam epitaxy," *J. Appl. Phys.*, vol. 65, p. 1189, 1989. (JSEP/SRC)

- [21] M. A. Hasan, J. Knall, S. A. Barnett, J.-E. Sundgren, L. C. Markert, A. Rockett, and J. E. Greene, "Incorporation of accelerated low-energy (50-500 eV) In^+ ions in Si(100) films grown by molecular beam epitaxy," *J. Appl. Phys.*, vol. 65, p. 172, 1989. (JSEP/SRC)
- [22] J. E. Greene, S. A. Barnett, J.-E. Sundgren, and A. Rockett, "Low-energy ion/surface interactions during film growth from the vapor phase," in *Ion Beam Assisted Film Growth*, T. Itoh, Ed. Amsterdam: Elsevier, 1989, Chapter 5, p. 101. (JSEP/SRC/DOE)
- [23] M. A. Ray, S. A. Barnett, and J. E. Greene, "A multi-aperture ion source with adjustable optics to provide well-collimated, high current density, low-to-medium energy ion beams," *J. Vac. Sci. Technol. A*, vol. 7, no. 2, p. 125, 1989. (JSEP/SRC/NASA)
- [24] J. Knall, S. A. Barnett, J.-E. Sundgren, and J. E. Greene, "Adsorption and desorption kinetics of In on Si(100)," *Surf. Sci.*, vol. 209, p. 314, 1989. (JSEP/SRC)
- [25] J. Knall, J.-E. Sundgren, L. C. Markert, and J. E. Greene, "Incorporation of In by recoil implantation during MBE growth of Si(100)," *Surf. Sci.*, vol. 214, p. 149, 1989. (JSEP/SRC)
- [26] J. Knall, J.-E. Sundgren, L. C. Markert, A. Rockett, and J. E. Greene, "Influence of the Si evaporation source on the incorporation of In during Si MBE growth: a comparative study of magnetically and electrostatically focused electron gun evaporators," *J. Vac. Sci. Technol.*, vol. B7, p. 204, 1989. (JSEP/SRC)
- [27] J. E. Greene, S. A. Barnett, J.-E. Sundgren, and A. Rockett, "Low-energy ion/surface interactions during film growth from the vapor phase: effects on nucleation and growth kinetics, defect structure, and elemental incorporation probabilities," in *Plasma-Surface Interactions and Processing of Materials*, O. Auciello, A. Grass-Marti, and D. L. Flamm, Eds. NATO Advanced Study Institute, in press. (JSEP/SRC/DOE)
- [28] L. C. Markert, J. Knall, J.-P. Noël, M.-A. Hasan, J. E. Greene, and J.-E. Sundgren, "Low-energy accelerated-ion doping of Si during molecular-beam epitaxy: incorporation probabilities, depth distributions, and electrical properties," in *Plasma-Surface Interactions and Processing of Materials*, O. Auciello, A. Grass-Marti, and D. L. Flamm, Eds. NATO Advanced Study Institute, in press. (JSEP/SRC/DOE)

WORK UNIT NUMBER 2

TITLE: Studies of Transport Phenomena in Semiconductors

SENIOR PRINCIPAL INVESTIGATORS:

K. Hess, Research Professor

J. P. Leburton, Research Associate Professor (participated during year one)

JSEP-SPONSORED PUBLICATIONS

- [1] K. Hess, T. K. Higman, M. A. Emanuel, and J. J. Coleman, "New ultrafast switching mechanism in semiconductor heterostructures," *J. Appl. Phys.*, vol. 60, no. 10, pp. 3775-3777, 1986. (JSEP/ONR/ARO)
- [2] J. Higman and K. Hess, "Comment on the use of the electron temperature concept for nonlinear transport problems in semiconductor p-n junctions," *Solid-State Electronics*, vol. 29, no. 9, pp. 915-918, 1986. (JSEP)
- [3] I. C. Kizilyalli, K. Hess, G. J. Iafrate, and D. Smith, "Dynamics of electron transfer between two adjacent channels as calculated by an ensemble Monte Carlo method," *Proc. NUMOS Workshop*, Los Angeles, CA, Dec. 1986. (ARO/JSEP)
- [4] J. P. Leburton, "Anomalous current oscillations in semiconductor-insulator-semiconductor structures and related devices," *NATO Summer School*, Antwerp, Belgium, 1986. (JSEP)
- [5] J. P. Leburton, "Microscopic interpretation of the current oscillations in $\text{GaAs}^+ - \text{AlGaAs-GaAs}^-$ tunnel junctions," *Proc. 18th I.C.P.S.*, Stockholm, Sweden, 1986, pp. 1623-1626. (JSEP)
- [6] S. L. Chuang and K. Hess, "Tunneling-assisted impact ionization for a superlattice," *J. Appl. Phys.* vol. 61, no. 4, pp. 1510-1515, Feb. 1987. (NASA/JSEP)
- [7] J. P. Leburton, "Space charge generation by LO phonon ionization of neutral donors in GaAs-AlGaAs-GaAs tunnel junctions," *Bull. Am. Phys. Soc.*, vol. 32, pp. 886, 1987. (JSEP)
- [8] T. K. Higman, J. M. Higman, M. A. Emanuel, K. Hess, and J. J. Coleman, "Theoretical and experimental analysis of the switching mechanism in heterostructure hot electron diodes," *J. Appl. Phys.*, vol. 62, no. 4, pp. 1495-1499, Aug. 15, 1987. (ONR/JSEP)
- [9] I. C. Kizilyalli and K. Hess, "Electron transfer between adjacent channels simulated by ensemble Monte Carlo methods," *J. Appl. Phys.*, vol. 61, no. 6, pp. 2395-2398, 1987. (ARO/JSEP)
- [10] S. J. Manion, M. Artaki, M. A. Emanuel, J. J. Coleman, and K. Hess, "Electron energy loss rates in AlGaAs/GaAs heterostructures at low temperatures," *Phys. Rev. B*, vol. 35, p. 9203, 1987. (ONR/JSEP)

- [11] K. Brennan, K. Hess, and F. Capasso, "Physics of the enhancement of impact ionization in multiquantum well structures," *Appl. Phys. Lett.*, vol. 50, no. 26, pp. 1897-1899, 1987. (JSEP/ONR/NSF)
- [12] I. C. Kizilyalli, and K. Hess, "Ensemble Monte Carlo simulation of a velocity-modulation field effect transistor (VMT)", *Japanese J. of Appl. Phys.*, vol. 26, no. 9, pp. 1519-1524, 1987. (ARO/JSEP)
- [13] T. K. Higman, S. J. Manion, I. C. Kizilyalli, M. A. Emanuel, K. Hess, and J. J. Coleman, "Observation of the transition associated with real-space transfer of two-dimensional electron gas to a three-dimensional electron distribution in semiconductor heterolayers," *Phys. Rev. B*, vol. 36, no. 17, pp. 9381-9383, Dec. 15, 1987. (JSEP/ONR/NSF)
- [14] S. J. Manion and K. Hess, "Phonon energy dependence of scattering in quasi-two-dimensional electron gases at low temperature," *J. Appl. Phys.*, vol. 62, no. 12, pp. 4942-4944, 1987. (JSEP)
- [15] I. C. Kizilyalli, K. Hess, T. Higman, M. Emanuel, and J. J. Coleman, "Ensemble Monte Carlo Simulation of Real Space Transfer (NERFET/CHINT) Devices," *Solid-State Electron.*, vol. 31, no. 3/4, pp. 355-357, 1988. (ARO/JSEP)
- [16] M. A. Emanuel, T. K. Higman, J. M. Higman, J. M. Kolodzey, J. J. Coleman, and K. Hess, "Theoretical and experimental investigations of the heterostructure hot electron diode," *Solid-State Electron.*, vol. 31, no. 3/4, pp. 589-592, 1988; also, *Proc. Fifth Int. Conf. on Hot Carriers in Semiconductors*, Boston, 1987. (ONR/JSEP)
- [17] I. C. Kizilyalli and K. Hess, "Ensemble Monte Carlo simulation of velocity modulation transistors (VMT) and real space transfer (NERFET, CHINT) devices," *Superlatt. and Microstruct.*, vol. 4, no. 3, pp. 287-288, 1988. (ARO/JSEP)
- [18] J. Kolodzey, J. Laskar, T. K. Higman, M. A. Emanuel, J. J. Coleman, and K. Hess, "Microwave frequency operation of heterostructure hot electron diodes," *IEEE Electron Dev. Lett.*, vol. 9, no. 6, pp. 272-274, 1988. (NSF/JSEP)
- [19] K. F. Brennan, D. H. Park, K. Hess, and M. A. Littlejohn, "Theory of the velocity-field relation in AlGaAs," *J. Appl. Phys.*, vol. 63, no. 10, pp. 5004-5008, 1988. (JSEP)
- [20] J. M. Higman, I. C. Kizilyalli, and K. Hess, "Nonlocality of the electron ionization coefficient in n-MOSFET's: An analytic approach," *IEEE Electron Dev. Lett.*, vol. 9, no. 8, pp. 399-401, 1988. (JSEP)
- [21] J. M. Higman, K. Kim, K. Hess, T. van Zutphen, and H. M. J. Boots, "Monte Carlo simulation of Si and GaAs avalanche emitting diodes," *J. Appl. Phys.*, vol. 65, no. 3, pp. 1384-1386, 1989. (JSEP/NSF/Cray/IBM)
- [22] J. M. Higman, K. Hess, C. G. Hwang, and R. W. Dutton, "Coupled Monte Carlo-drift diffusion analysis of hot-electron effects in MOSFET's," *IEEE Trans. Electron Dev.*, vol. 36, no. 5, pp. 930-937, 1989. (JSEP)

WORK UNIT NUMBER 4

TITLE: Basic Studies of the Optical and Electronic Properties of Defects and Impurities in Compound Semiconductor Epitaxial Layers and Related Superlattices

SENIOR PRINCIPAL INVESTIGATOR:

G. E. Stillman, Research Professor

JSEP-SPONSORED PUBLICATIONS

- [1] N. Pan, B. Lee, S. S. Bose, M. H. Kim, J. S. Hughes, G. E. Stillman, and K. Arai, "Si donor neutralization in high purity GaAs," *Appl. Phys. Lett.*, vol. 50, pp. 1832-1834, June 22, 1987. (NSF/JSEP)
- [2] S. S. Bose, B. Lee, M. H. Kim, G. E. Stillman, and W. I. Wang, "Influence of the substrate orientation on Si incorporation in MBE GaAs," *J. Appl. Phys.*, vol. 63, pp. 743-748, Feb. 1988. (NSF-CDR/JSEP/AFOSR/DARPA/IBM/ARO)
- [3] S. S. Bose, M. H. Kim, and G. E. Stillman, "Identification of residual donors in high purity undoped p-type epitaxial GaAs by magneto-photoluminescence," *Appl. Phys. Lett.*, vol. 53, pp. 980-982, Sept. 1988. (DARPA/AFOSR/JSEP/NSF-CDR)
- [4] B. Lee, M. H. Kim, S. S. Bose, G. E. Stillman, E. C. Larkins, E. S. Hellman, D. G. Schlom, and J. S. Harris, Jr., "Sulfur incorporation in undoped high purity n-type GaAs grown by molecular beam epitaxy," in *Proc. Int. Symp. on Gallium Arsenide and Related Compounds, Inst. Phys. Conf. Ser. No. 96*, Atlanta, GA, Sept. 1988, Chapter 2, pp. 23-28. (NSF-CDR/JSEP/Kodak/DARPA/ONR)
- [5] A. D. Reed, B. Lee, S. S. Bose, and G. E. Stillman, "Residual germanium incorporation in MOCVD grown GaAs," in *Proc. Int. Symp. on Gallium Arsenide and Related Compounds, Inst. Phys. Conf. Ser. No. 96*, Atlanta, GA, Sept. 1988, Chapter 3, pp. 135-140. (JSEP/NSF)
- [6] A. D. Reed, S. S. Bose, and G. E. Stillman, "Residual carbon incorporation mechanisms in MOCVD grown GaAs," in *Proc. Int. Symp. on Gallium Arsenide and Related Compounds, Inst. Phys. Conf. Ser. No. 96*, Atlanta, GA, Sept. 1988, Chapter 3, pp. 165-168. (JSEP/NSF)
- [7] M. J. McCollum, M. H. Kim, S. S. Bose, B. Lee and G. E. Stillman, "High purity epitaxial indium phosphide grown by the hydride technique," *Appl. Phys. Lett.*, vol. 53, pp. 1868-1870, Nov. 1988. (NSF-ECS/NSF-DMR/JSEP/NSF-CDR)
- [8] B. Lee, S. S. Bose, M. H. Kim, G. E. Stillman, and A. R. Calawa, "Spectroscopic studies of the influence of intentionally increased CO partial pressure on the incorporation of residual C impurities in MBE GaAs," *Appl. Phys. Lett.*, vol. 53, pp. 2438-2440, Dec. 1988. (JSEP/NSF)

- [9] A. D. Reed, S. S. Bose, and G. E. Stillman, "Residual carbon acceptor incorporation in gallium arsenide grown by metalorganic chemical vapor deposition," *Appl. Phys. Lett.*, vol. 54, pp. 1262-1264, Mar. 1989. (JSEP/DARPA)
- [10] B. Lee, K. Arai, B. J. Skromme, S. S. Bose, T. J. Roth, J. A. Aguilar, T. Lepkowski, N. C. Tien, and G. E. Stillman, "Spectroscopic studies of the influence of oxygen partial pressure on the incorporation of residual silicon impurities in vapor phase epitaxial gallium arsenide," *J. Appl. Phys.*, vol. 66, pp. 3772-3786, 1989. (AFOSR/JSEP/DARPA/NSF-CDR)
- [11] B. Lee, S. S. Bose, M. H. Kim, A. D. Reed, and G. E. Stillman, "Orientation dependent amphoteric behavior of group IV impurities in the molecular beam epitaxial and vapor phase epitaxial growth of GaAs," *J. Cryst. Growth*, vol. 96, pp. 27-29, 1989. (NSF-DMR/NSF-CDR/JSEP)
- [12] B. Lee, M. H. Kim, S. S. Bose, and G. E. Stillman, "Kinetic aspects of Si incorporation in the MBE growth of GaAs," *Frontiers of Surface Analysis Issue of Surface and Interface Analysis*, vol. 14, no. 10, p. 619, Oct. 1989. (JSEP/NSF-DMR/NSF-CDR)

WORK UNIT NUMBER 5

TITLE: Heterostructure Electronic Devices by Metalorganic Chemical Vapor Deposition (MOCVD)

SENIOR PRINCIPAL INVESTIGATOR:

J. J. Coleman, Research Professor

JSEP-SPONSORED PUBLICATIONS

- [1] T. K. Higman, M. A. Emanuel, J. J. Coleman, S. J. Jeng, and C. M. Wayman, "Structural analysis of Au-Ni-Ge and Au-Ag-Ge alloyed ohmic contacts on modulation doped AlGaAs-GaAs heterostructures," *J. Appl. Phys.*, vol. 60, p. 677, 1986. (JSEP/NSF)
- [2] P. A. Martin, K. Hess, M. A. Emanuel, and J. J. Coleman, "Deep level transient spectroscopy studies of defects in GaAs AlGaAs superlattices," *J. Appl. Phys.*, vol. 60, p. 2882, 1986. (JSEP/ONR)
- [3] K. Hess, T. K. Higman, M. A. Emanuel, and J. J. Coleman, "New ultrafast switching mechanism in semiconductor heterostructures," *J. Appl. Phys.*, vol. 60, p. 3755, 1986. (JSEP/ONR/ARO)
- [4] S. J. Manion, M. Artaki, M. A. Emanuel, J. J. Coleman, and K. Hess, "Electron energy loss rates in AlGaAs/GaAs heterostructures at low temperatures," *Phys. Rev. B*, vol. 35, p. 9203, 1987. (JSEP)
- [5] T. K. Higman, J. M. Higman, M. A. Emanuel, K. Hess, and J. J. Coleman, "Theoretical and experimental analysis of the switching mechanism in heterostructure hot electron diodes," *J. Appl. Phys.*, vol. 62, p. 1495, 1987. (JSEP)
- [6] M. A. Emanuel, T. K. Higman, J. M. Higman, J. M. Kolodzey, J. J. Coleman, and K. Hess, "Theoretical and experimental investigations of the heterostructure hot electron diode, *Solid State Electron.*, vol. 31, no. 3/4, pp. 589-592, 1988; also, *Proc. Fifth Int. Conf. on Hot Carriers in Semiconductors*, Boston, 1987. (JSEP)
- [7] T. K. Higman, S. J. Manion, I. C. Kizilyalli, M. A. Emanuel, K. Hess, and J. J. Coleman, "Observation of the transition associated with real-space transfer of a two-dimensional electron gas to a three-dimensional electron distribution in semiconductor heterolayers," *Phys. Rev. B*, vol. 36, p. 9381, 1987. (JSEP)
- [8] J. Kolodzey, J. Laskar, T. K. Higman, M. A. Emanuel, J. J. Coleman, and K. Hess, "Microwave frequency operation of the heterostructure hot-electrode diode," *Electron Dev. Lett.* vol. 9, p. 272, 1988. (JSEP/NSF)

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- [10] L. M. Miller and J. J. Coleman, "Metalorganic chemical vapor deposition," *CRC Critical Reviews in Solid State and Mater. Sci.*, vol. 15, no. 1, 1988. (JSEP/NSF/Army)
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- [13] T. K. Higman, M. E. Favaro, L. M. Miller, and J. J. Coleman, "Room temperature in high barrier heterostructure hot electron diodes and related resonant tunneling effects," in *Proc. 15th Int. Symp. GaAs and Related Compounds*, Atlanta, GA, 1988 *Inst. of Phys. Conf. Series* (1989). (JSEP/NSF)

WORK UNIT NUMBER 6

TITLE: Optical Properties of MBE-Grown Structures

SENIOR PRINCIPAL INVESTIGATORS:

M. V. Klein, Research Professor
H. Morkoç Research Associate Professor

JSEP-SPONSORED PUBLICATIONS

- [1] T. C. McGlinn, T. N. Krabach, M. V. Klein, G. Bajor, J. E. Greene, B. Kramer, S. A. Barnett, A. Lastras, and S. Gorbatkin, "Raman scattering and optical-absorption studies of the metastable alloy system $\text{GaAs}_x\text{Sb}_{1-x}$," *Phys. Rev. B*, vol. B33, pp. 8396-8401, 1986. (JSEP/NSF)
- [2] D. Y. Oberli, D. R. Wake, M. V. Klein, J. Klem, and H. Morkoç, "Transient Raman scattering in multiple quantum well structures," in *Ultrafast Phenomena V*, G. R. Fleming and A. E. Siegman, Eds. Berlin: Springer, 1986, pp. 207-209. (JSEP/AFOSR/NSF)
- [3] D. Levi, S.-L. Zhang, M. V. Klein, J. Klem, and H. Morkoç, "Raman study of the effects of annealing on folded LA and confined LO phonons in GaAs-AlAs superlattices," *Phys. Rev. B*, vol. 36, pp. 8032-8037, 1987. (NSF/JSEP/AFOSR/DOE)
- [4] C. Choi, N. Otsuka, G. Munns, R. Houdré, H. Morkoç, S. L. Zhang, D. Levi, and M. V. Klein, "Effect of In-Situ and Ex-Situ annealing on dislocations in GaAs on Si substrates," *Appl. Phys. Lett.*, vol. 50, no. 15, pp. 992-994, Apr. 13, 1987. (AFOSR/JSEP/NSF)
- [5] U. K. Reddy, G. Ji, R. Houdré, H. Unlu, D. Huang, and H. Morkoç, "Study of GaAs/AlGaAs and InGaAs/GaAs multiple quantum wells grown on non-polar substrates by photoreflectance," *SPIE*, vol. 794, pp. 116-120, 1987. (NASA/JSEP/AFOSR)
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- [8] V. K. Arora, D. S. L. Mui, and H. Morkoç, "Mobility degradation in a quantum well heterostructure of GaAs/AlGaAs prototype," *Appl. Phys. Lett.*, vol. 50, no. 16, pp. 1080-1082, Apr. 20, 1987. (JSEP/AFOSR)
- [9] D. Y. Oberli, D. R. Wake, M. V. Klein, J. Klem, T. Henderson, and H. Morkoç, "Time-resolved Raman scattering in GaAs quantum wells," *Phys. Rev. Lett.*, vol. 59, pp. 696-699, 1987; also, *Proc. SPIE*, vol. 793, 1987, pp. 58-61. (NSF/AFOSR/JSEP)

- [10] U. K. Reddy, G. Ji, T. Henderson, H. Morkoç, and J. N. Schulman "Investigation of GaAs/(Al,Ga)As multiple quantum wells by photoreflectance" *J. Appl. Phys.*, vol. 62, no. 1, pp. 145-151, July 1, 1987. (JSEP/AFOSR)
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- [15] M. V. Klein, T. A. Gant, D. Levi, and S.-L. Zhang, "Raman studies of phonons in GaAs/AlGaAs superlattices," in *Laser Optics of Condensed Matter, Proc. Third Binational USA-USSR Symp. Laser Optics of Condensed Matter*, Leningrad, USSR, June 1-6, 1987, J. L. Birman, H. Z. Cummins, and A. A. Kaplyanski, Eds. New York and London: Plenum Press, 1988, pp. 119-126. (NSF/JSEP/AFOSR)
- [16] D. Y. Oberli, D. R. Wake, and M. V. Klein, "Picosecond Raman and luminescence studies of carrier relaxation in quantum wells," *Laser Optics of Condensed Matter, Proc. Third Binational USA-USSR Symp. Laser Optics of Condensed Matter*, Leningrad, USSR, June 1-6, 1987, J. L. Birman, H. Z. Cummins, and A. A. Kaplyanski, Eds. New York and London: Plenum Press, 1988, pp. 95-101. (NSF/JSEP/AFOSR)

WORK UNIT NUMBER 7

TITLE: Computer-Aided Design of High-Performance Integrated Circuits with Ultra-Small Features

SENIOR PRINCIPAL INVESTIGATORS:

I. N. Hajj, Research Professor
 S. M. Kang, Research Professor
 V. B. Rao, Research Assistant Professor

JSEP-SPONSORED PUBLICATIONS

- [1] R. D. Freedman, S. M. Kang, C. G. Lin-Hendel, M. L. Newby, "Extraction of SPICE circuit models from symbolic gate matrix layout with pruning," in *ACM/IEEE Design Automation Conf. Proc.*, Las Vegas, NV, June 1986, pp. 418-424. (JSEP/AT&T)
- [2] S. M. Kang and H. Y. Chen, "Modeling of propagation delay for a class of domino CMOS circuits," in *Proc. 29th Midwest Symp. on Circuits and Syst.*, Lincoln, NB, Aug. 1986, pp. 907-910. (JSEP/SRC)
- [3] S. M. Kang, "Simulation of power dissipation in VLSI circuits," *IEEE J. on Solid-State Circuits*, vol. SC-21, no.5, pp. 889-891, Oct. 1986. (JSEP/SRC)
- [4] K. K. Cioffi, A. Yang, T. N. Trick, and S. M. Kang, "A charge-controlled circuit simulation model for MODFETs," *Workshop on Numerical Modeling of Processes and Devices of Integrated Circuits*, Palo Alto, CA, Nov. 1986. (JSEP)
- [5] S-L. Su, V. B. Rao, and T. N. Trick, "A simple and accurate node reduction technique for interconnect modeling in circuit extraction," *IEEE Int. Conf. Comput.-Aided Design*, Santa Clara, CA, Nov. 1986. (JSEP)
- [6] T. K. Yu, S. M. Kang, I. N. Hajj, and T. N. Trick, "Statistical modeling of VLSI circuit performances," *Digest of Technical Papers, IEEE Int. Conf. on Computer-Aided Design*, Santa Clara, CA, pp. 224-227, Nov. 1986. (JSEP/SRC)
- [7] V. B. Rao and T. N. Trick, "Network partitioning and ordering for MOS VLSI circuits," *IEEE Trans. Comput.-Aided Design of Integrated Circuits and Syst.*, vol. CAD-6, No. 1, Jan. 1987. (JSEP/IBM)
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- [10] J. L. Krysl and S. M. Kang, "The metastability properties and optimization of CMOS memory devices," *Proc. European Conf. on Circuit Theory and Design*, Sept. 1987, pp. 759-763. (JSEP/SRC)
- [11] S. M. Kang, "Metal-metal matrix (M^3) for high-speed MOS VLSI layout," *IEEE Trans. Comput.-Aided Des.*, vol. CAD-6, no. 5, pp. 886-891, Sept. 1987. (SRC/JSEP)
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- [14] F. P. Lai, S. M. Kang, and T. N. Trick, "A timing error corrector for VLSI synchronous path circuits," *Proc. Int. Conf. on Computer-Aided Design*, Nov. 1987, pp. 48-51. (JSEP/SRC)
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- [16] M. Y. Wu and I. N. Hajj, "Modified sequential CMOS circuit design," *Proc. Int. Conf. on Computer-Aided Design*, Santa Clara, CA, Nov. 1987, pp. 460-463. (JSEP)
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- [18] I. N. Hajj, G. DeMicheli, and H. Hsieh, "Decomposition techniques for large-scale circuit simulation," in *Circuit Analysis, Simulation and Design*, North-Holland Publishing Co., A Ruehi, Ed., 1987. (JSEP)
- [19] M. E. Mokari-Bolhassan and S. M. Kang, "Analysis and correction of VLSI delay measurement errors due to transmission line effects," *IEEE Trans. Circuits and Syst.*, vol. CAS-35, no. 1, pp. 19-25, Jan. 1988. (JSEP/SRC)
- [20] D. W. Smart and T. N. Trick, "Waveform relaxation on parallel processors," *Int. J. Circuit Theory Appl.*, vol. 16, no. 4, pp. 447-456, Oct. 1988. (JSEP/SRC)
- [21] T. K. Yu and S. M. Kang, "Statistical MOS VLSI circuit optimization with non-nested experimental design," in *Proc. Int. Symp. Circuits and Syst.*, June 1988, pp. 1799-1802. (JSEP/SRC)
- [22] K. R. Cioffi, S. M. Kang, and T. N. Trick, "Circuit simulation models for the high electron mobility transistor," in *Proc. Int. Symp. Circuits and Syst.*, June 1988, pp. 405-408. (JSEP)
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- [26] H. Y. Chen and S. M. Kang, "iCOACH: A circuit optimization aid for CMOS high-performance circuits," in *Proc. 1988 Int. Conf. on Comput. Des.*, Nov. 1988, pp. 372-375. (JSEP/SRC)
- [27] T. K. Yu, S. M. Kang, I. N. Hajj, and T. N. Trick, "iEDISON: An interactive statistical design tool for MOS VLSI circuits," in *Proc. 1988 Int. Conf. on Comput. Des.*, Nov. 1988, pp. 20-23. (JSEP/SRC)
- [28] I. Hajj and O. Tejayadi, "Parallel solution of piecewise-linear transistor circuits," in *Proc. Int. Symp. Circuits and Syst.*, Portland, OR, May 1989, pp. 681-684. (JSEP/SRC)
- [29] S. M. Kang and H. Y. Chen, "A global delay model for domino CMOS circuits," to appear in *Int. J. Circuit Theory Appl.* (JSEP/SRC)
- [30] W. J. Welch, T. K. Yu, S. M. Kang, and J. Sacks, "Computer experiments for quality control by parameter design," to appear in *J. Quality Technol.* (JSEP/SRC)
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- [33] P. Gee, M.-Y. Wu, I. N. Hajj, S. M. Kang, and W. Shu, "Automatic circuit synthesis using switching network logic and metal-metal-matrix (M^3) layout," in *Advances in Computer-Aided Engineering Design*, I. N. Hajj, Ed., JAI Press, 1989. (JSEP/SRC)
- [34] I. N. Hajj and S. Skelboe, "Multilevel parallel solver for banded linear systems," in *Aspects of Computation on Asynchronous Parallel Processors*, M. H. Wright, Ed. North Holland: Elsevier Science Publishers B. V., 1989, pp. 69-78. (JSEP/INTEL)
- [35] P. Gee, I. N. Hajj, and S. M. Kang, "An improved min-cut approach for gate matrix and metal-metal matrix circuit layout," *32nd Midwest Symp. on Circuits and Syst.*, Champaign, IL, Aug. 1989. (JSEP)
- [36] Y. H. Shih and S. M. Kang, "Fast MOS circuit simulation with a direct equation solver," *Int. Conf. on Comput. Des.*, Oct. 1989, pp. 276-279. (JSEP/AT&T)

WORK UNIT NUMBER 24
(Unit began 2nd reporting period)

TITLE: Electronic and Transport Properties of Ultra-Low-Dimensional Structures

SENIOR INVESTIGATORS:

J. P. Leburton, Research Associate Professor
I. Adesida, Research Assistant Professor
J. Kolodzey, Research Assistant Professor

JSEP-SPONSORED PUBLICATIONS

- [1] J. P. Leburton, "Anomalous current oscillations in semiconductor-insulator-semiconductor structures and related devices," in *The Physics of the Two-Dimensional Electron Gas*, J. T. Devreese and F. M. Peeters, Eds. Plenum Pub., 1987, pp. 227-257. (JSEP)
- [2] J. P. Leburton, "Microscopic interpretation of the current oscillations in $\text{GaAs}^+ - \text{AlGaAsGaAs}^-$ tunnel junctions," *Proc. 18th Int. Conf. on the Physics of Semiconductors*, Stockholm, Sweden, 1986, Engstrom, Ed.: World Scientific Press, 1987, pp. 1623-1626. (JSEP)
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- [4] J. P. Leburton "Phonon ionization of neutral donors in lightly doped GaAs: A model for the conductance oscillations in semiconductor-insulator-semiconductor tunnel structures," *Phys. Rev. B*, vol. 38, pp. 4085, 1988. (JSEP)
- [5] J. P. Leburton, J. Kolodzey, and S. Briggs, "Bipolar tunneling field effect transistor: a three-terminal negative differential resistance device for high-speed applications," *Appl. Phys. Lett.* vol. 52, pp. 1608-1610, 1988. (JSEP/NSF)
- [6] J. Kolodzey, J. Laskar, T. K. Higman, M. A. Emanuel, J. J. Coleman, and K. Hess, "Microwave frequency operation of the heterostructure hot electron diode," *IEEE Electron Device Lett.*, vol. 9, pp. 272-274, 1988. (NSF/JSEP)
- [7] J. P. Leburton and J. Kolodzey, "Tunneling injection into modulation doping structures: a mechanism for negative differential resistance three-terminal high-speed devices," *IEEE Trans. Electron Dev.*, vol. 35, no. 9, pp. 1530-1532, Sept. 1988. (JSEP/NRL/NSF)
- [8] S. Briggs and J. P. Leburton, "Size effects in multisubband quantum wire structures," *Phys. Rev. B*, vol. 38, pp. 8163-8169, 1988. (NSF/JSEP)

- [9] S. Briggs and J. P. Leburton, "Resonant Inter-subband optic phonon scattering in quasi-one dimensional structures," *Proc. 4th Int. Conf. on Superlattices, Microstructures and Microdevices*, Trieste, Italy 1988; also, *Superlatt. Microstruct.*, vol. 5, no. 2, pp. 145-148, 1989. (NSF/JSEP)
- [10] I. Adesida, E. Andideh, A. Ketterson, T. Brock, and O. Aina, "Reactive ion etching of submicrometer structures in InP, InGaAs and InAlAs," in *GaAs and Related Compounds 1988*, *Institute of Phys. Conf. Series #96*, p. 425 (1989). (JSEP/NSF)
- [11] I. Adesida, A. Ketterson, T. Brock, J. Laskar, J. Kolodzey, O. Aina, and H. Hier, "Fabrication and characterization of short gate length InAlAs/InGaAs/InP MODFETs," *Microelectronic Engineering J.*, vol. 9, p. 345, 1989; also presented at the 14th Int. Conf. on Microlithography, Vienna, Austria, Sept. 1988. (JSEP/NSF)
- [12] A. Ketterson, E. Andideh, I. Adesida, T. Brock, J. Baillargeon, J. Laskar, K. Y. Cheng, and J. Kolodzey, "Selective reactive ion etching for short gate-length GaAs/AlGaAs pseudomorphic MODFETs," *J. Vac. Sci. Technol.*, Nov./Dec. 1989 (to appear); also presented at the 33rd Int. Symp. on Electron, Ion, and Photon Beams, Monterey, CA, May 1989. (JSEP/NSF)
- [13] E. Andideh, I. Adesida, T. Brock, C. Caneau, and V. Keramidas, "Short period gratings for long wavelength optical devices," *J. Vac. Sci. Technol.*, Nov./Dec. 1989 (to appear); also presented at the 33rd Int. Symp. on Electron, Ion, and Photon Beams, Monterey, CA, May 1989. (JSEP/NSF)
- [14] I. Adesida, A. Ketterson, J. Laskar, S. Agarwala, T. Brock, J. Kolodzey, and H. Morkoç, "0.2 μ m T-gate InAlAs/InGaAs MODFET with $f_T = 170$ GHz," presented at Microcircuit Engineering, Sept. 1989, Cambridge University, England; also to appear in *Microelectronic Engineering J.* (JSEP/NSF/AFOSR)

WORK UNIT NUMBER 8

TITLE: Collective Electronic Transport in Quasi One-Dimensional Systems

SENIOR PRINCIPAL INVESTIGATORS:

J. R. Tucker, Research Professor
J. W. Lyding, Research Associate Professor

JSEP-SPONSORED PUBLICATIONS

- [1] R. E. Thorne, J. R. Tucker, J. Bardeen, S. E. Brown, and G. Grüner, "Phase-locking in charge density wave transport," *Phys. Rev. B*, vol. B33, pp. 7342-7345, 1986. (JSEP)
- [2] R. E. Thorne, W. G. Lyons, J. H. Miller, Jr., J. W. Lyding, and J. R. Tucker, "Current oscillations in charge density wave transport," *Phys. Rev. B*, vol. B34, pp. 5988-5991, 1986. (JSEP/NSF)
- [3] J. R. Tucker, "Dynamics of sliding charge density waves," *Physica*, vol. 143B, pp. 19-23, 1986. (JSEP/NSF)
- [4] J. R. Tucker, W. G. Lyons, J. H. Miller, Jr., R. E. Thorne, and J. W. Lyding, "Origin of the dielectric relaxation frequency in sliding charge density wave systems," *Phys. Rev.*, vol. B34, pp. 9038-9041, 1986. (JSEP/NSF)
- [5] R. E. Thorne, J. R. Tucker, and J. Bardeen, "Experiment versus the classical deformable model of charge density waves," *Phys. Rev. Lett.*, vol. 58, pp. 828-831, 1987. (JSEP/NSF)
- [6] R. E. Thorne, W. G. Lyons, J. W. Lyding, J. R. Tucker, and J. Bardeen, "Charge density wave transport in quasi one-dimensional conductors: I. Current oscillations," *Phys. Rev. B*, vol. 35, no. 12, pp. 6348-6359, Apr. 15, 1987. (JSEP/NSF)
- [7] R. E. Thorne, W. G. Lyons, J. W. Lyding, J. R. Tucker, and J. Bardeen, "Charge density wave transport in quasi one-dimensional conductors: II. Ac-dc interference phenomena," *Phys. Rev. B*, vol. 35, no. 12, pp. 6360-6372, Apr. 15, 1987. (JSEP/NSF)
- [8] J. R. Tucker, "Proposed NMR test of strong pinning and phase-slip in sliding charge density wave systems," *Phys. Rev. Lett.*, vol. 60, pp. 1574-1577, 1988. (JSEP/NSF)
- [9] R. E. Thorne, J. S. Hubacek, W. G. Lyons, J. W. Lyding, and J. R. Tucker, "Ac-dc interference, complete mode-locking, and origin of coherent oscillations in sliding charge density wave systems," *Phys. Rev. B*, vol. 37, pp. 10055-10067, 1988. (JSEP/NSF)
- [10] J. R. Tucker, W. G. Lyons, and G. Gammie, "Theory of charge density wave dynamics," *Phys. Rev. B*, vol. 38, pp. 1148-1171, 1988. (JSEP/NSF)
- [11] W. G. Lyons and J. R. Tucker, "Interpretation of the complete excitation spectrum for pinned charge density waves," *Phys. Rev. B*, vol. 38, pp. 4303-4306, 1988. (JSEP/NSF)

- [12] J. R. Tucker and W. G. Lyons, "Low-temperature depinning of sliding charge density waves," *Phys. Rev. B.*, vol. 38, pp. 7854-7857, 1988. (JSEP/NSF)

WORK UNIT NUMBER 9

TITLE: An Investigation of Plasma and Chemistry Processes in Cylindrical Magnetron Plasma Discharges

SENIOR PRINCIPAL INVESTIGATORS:

J. A. Thornton, Research Professor (deceased)

M. J. Kushner, Research Associate Professor (2nd and 3rd reporting periods only)

JSEP-SPONSORED PUBLICATIONS

- [1] J. A. Thornton, "RF driven cylindrical magnetron discharge sources," Keynote Address to be presented at 1987 Annual Symposium of the upstate New York Chapter of the American Vacuum Society, Rochester, New York, June 17-19, 1987 (invited). (JSEP)
- [2] G. Y. Yeom, J. A. Thornton, and A. S. Penfold, "Magnetic field designs for cylindrical-post magnetron discharge sources," *J. Vac. Sci. Technol. A*, vol. 6, no. 6, pp. 3156-3158, 1988. (JSEP)
- [3] G. Y. Yeom, J. A. Thornton, and M. J. Kushner, "Cylindrical magnetron discharges: I. Current-voltage characteristics for dc and rf-driven discharge sources," *J. Appl. Phys.*, vol. 65, no. 10, pp. 3816-3824, 1989. (JSEP)
- [4] G. Y. Yeom, J. A. Thornton, and M. J. Kushner, "Cylindrical magnetron discharges: II. The formation of dc bias in rf-driven discharge sources," *J. Appl. Phys.*, vol. 65, no. 10, pp. 3825-3832, 1989. (JSEP)
- [5] G. Y. Yeom and M. J. Kushner, "Magnetic field effects on cylindrical magnetron reactive ion etching of Si/SiO₂ in CF₄ and CF₄/H₂ plasmas," Amer. Vac. Soc. Fall Mtg., Atlanta, GA, 1988; also, *J. Vac. Sci. Technol. A*, vol. 7, no. 3, pp. 987-992, 1989. (JSEP)
- [6] G. Y. Yeom and M. J. Kushner, "Electrical characteristics of cylindrical magnetron RF discharges for etching and deposition," 41st Gaseous Electron. Conf., Minneapolis, MN, 1988; also, *Bull. Am. Phys. Soc.*, vol. 34, p. 324, 1989. (JSEP)
- [7] L. E. Kline and M. J. Kushner, "Computer simulations of material processing plasma discharges," to be published in *CRC Critical Reviews in Solid State and Mater. Sci.* (JSEP)
- [8] G. Y. Yeom and M. J. Kushner, "Si/SiO₂ etch properties using CF₄ and CHF₃ in cylindrical magnetron discharges," to be published in *Appl. Phys. Lett.* (JSEP)

WORK UNIT NUMBER 10

TITLE: Excited State Chemistry in Gases

SENIOR PRINCIPAL INVESTIGATORS:

J. G. Eden, Research Professor
J. T. Verdeyen, Research Professor

JSEP-SPONSORED PUBLICATIONS

- [1] J. G. Eden, "Photochemical processing of semiconductors: New applications for visible and ultraviolet lasers," *IEEE Circuits and Devices*, vol. 2, pp. 18-24, Jan. 1986. (JSEP)
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WORK UNIT NUMBER 11

TITLE: Monolithic Millimeter-Wave Integrated Circuits with Microstrip Antennas

SENIOR PRINCIPAL INVESTIGATORS:

S. L. Chuang, Research Associate Professor
Y. T. Lo, Research Professor

JSEP-SPONSORED PUBLICATIONS

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WORK UNIT NUMBER 12

TITLE: Investigation of Radar Scattering Characteristics of Controllable Surface Shapes with Application to Low Observable Targets

SENIOR PRINCIPAL INVESTIGATOR:

R. Mittra, Research Professor

JSEP-SPONSORED PUBLICATIONS

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WORK UNIT NUMBER 13

TITLE: High-Performance Testable Electronic Systems

SENIOR PRINCIPAL INVESTIGATORS:

J. A. Abraham, Research Professor
J. H. Patel, Research Professor

JSEP-SPONSORED PUBLICATIONS

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WORK UNIT NUMBER 14

TITLE: New Directions in Fault-Tolerant Computing

SENIOR PRINCIPAL INVESTIGATORS:

P. Banerjee, Research Associate Professor
K. Fuchs, Research Associate Professor
R. K. Iyer, Research Professor

JSEP-SPONSORED PUBLICATIONS

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WORK UNIT NUMBER 15

TITLE: Efficient Computation Techniques

SENIOR PRINCIPAL INVESTIGATORS:

D. J. Brown, Research Associate Professor
 M. C. Loui, Research Associate Professor
 F. P. Preparata, Research Professor
 V. L. Ramachandran, Research Assistant Professor

JSEP-SPONSORED PUBLICATIONS

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- [9] V. Ramachandran, "On driving many long wires in a VLSI layout," *J. Assoc. Comput. Mach.*, vol. 33, no. 4, pp. 687-701, Oct. 1986. (JSEP)

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WORK UNIT NUMBER 16

TITLE: High-Resolution Sensor Array Processing

SENIOR PRINCIPAL INVESTIGATORS:

T. S. Huang, Research Professor
W. K. Jenkins, Research Professor
D. C. Munson, Research Professor

JSEP-SPONSORED PUBLICATIONS

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WORK UNIT NUMBER 17

TITLE: Parallel VLSI Structures for Sensor Array Processing

SENIOR PRINCIPAL INVESTIGATORS:

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 B. W. Wah, Research Professor

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WORK UNIT NUMBER 18

TITLE: Adaptive Algorithms for Identification, Filtering, Control, and Signal Processing

SENIOR PRINCIPAL INVESTIGATORS:

P. V. Kokotovic, Research Professor
 P. R. Kumar, Research Professor
 J. V. Medanic, Research Professor
 W. R. Perkins, Research Professor

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WORK UNIT NUMBER 19

TITLE: Distributed and Decentralized Systems

SENIOR PRINCIPAL INVESTIGATORS:

T. Başar, Research Professor
J. B. Cruz, Jr., Research Professor (1st reporting period only)
P. R. Kumar, Research Professor

JSEP-SPONSORED PUBLICATIONS

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WORK UNIT NUMBER 20

TITLE: Robust Feedback Control of Nonlinear Systems

SENIOR PRINCIPAL INVESTIGATORS:

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JSEP-SPONSORED PUBLICATIONS

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WORK UNIT NUMBER 21

TITLE: Multiple-Terminal Digital Communication Systems

SENIOR PRINCIPAL INVESTIGATORS:

E. Arikan, Research Assistant Professor (1st reporting period only)
 B. Hajek, Research Professor
 M. B. Pursley, Research Professor
 D. V. Sarwate, Research Professor

JSEP-SPONSORED PUBLICATIONS

- [1] J. C. Kieffer, "Sturmian minimal systems associated with the iterates of certain functions on an interval," to appear in *Springer-Verlag Lecture Notes in Mathematics: Proceedings of the Special Year on Dynamical Systems, University of Maryland, 1986*, (Springer Verlag: New York), 1987. (JSEP/NSF)
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- [13] D. V. Sarwate, "Computation of cyclic redundancy checks via table look-up," *Commun. of the ACM*, vol. 31, pp. 1008-1013, Aug. 1988. (JSEP)
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WORK UNIT NUMBER 22

TITLE: Statistical Signal Processing in Communication Systems

SENIOR PRINCIPAL INVESTIGATORS:

A. R. Barron, Research Assistant Professor
H. V. Poor, Research Professor

JSEP-SPONSORED PUBLICATIONS

- [1] S. Zabin and H. V. Poor, "Parameter estimation in the Middleton class A interference model," *Abstracts of Papers: 1986 IEEE Int. Symp. Inform. Theory*, Ann Arbor, MI, Oct. 1986, p. 28. (JSEP)
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WORK UNIT NUMBER 23

TITLE: Basic Research in Electronics

SENIOR PRINCIPAL INVESTIGATOR:

W. Kenneth Jenkins, Research Professor

The objective of this unit is to provide discretionary funds to the Director for support of new initiatives on basic problems of electronic materials, devices, and systems in a timely manner and to provide early start-up funding of projects that present immediate opportunities of high scientific promise. These discretionary funds are an important feature of the JSEP program in that they support exploratory work on new topics, provide matching equipment funds in the laboratory, and support promising work of new faculty where appropriate.

In late 1989 construction of the University of Illinois EpiCenter was completed and researchers are now successfully growing materials. The EpiCenter is a world-class facility that consists of seven MBE chambers interconnected by high-vacuum transfer tubes. Having the chambers, each of which is dedicated to a different type of material growth and characterization, interconnected by vacuum lines allows samples to be moved from one growth environment to another without external contamination. Since the planning for this new facility was begun about five years ago and the construction has taken two years, the completion of this project is a major accomplishment. All of the JSEP discretionary funds provided under Unit 23 of the 86-89 contract were applied toward the purchase of several MBE chambers that will support future MBE research in the JSEP program. Since the EpiCenter is described in detail in the Annual Progress Report for year three of the contract, further details will not be presented in this report.