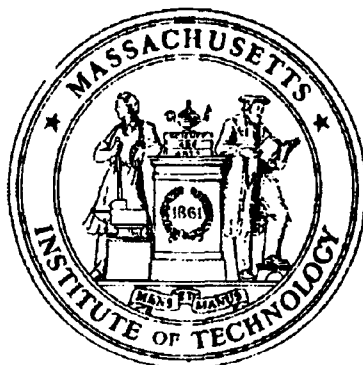


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**Final Report
to the
U. S. Army Research Office
for
Contract DAAL03-89-C-0001
“Basic and Applied Research in the Field of
Electronics and Communications”
November 1, 1988 - October 31, 1991**

**Research Laboratory of Electronics
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Cambridge, Massachusetts 02139**

**Submitted by
Professor Jonathan Allen, Principal Investigator
July, 1992**

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**Overview of the MIT Research Laboratory of Electronics
Joint Services Electronics Program
for the period
November 1, 1988 - October 31, 1991**

The MIT Research Laboratory of Electronics Joint Services Program is comprised of nineteen work units spanning a broad array of topics in high-speed optics, surfaces and phase transitions, submicron structures, electronic conduction, properties of electronic interconnects, and atomic and molecular physics.

A major emphasis of the work in high-speed optics has been the development of femtosecond optical pulses by means of nonlinear, self-limiting optical processes. These ultrashort pulses have been used as probes of electronic processes, and also in a variety of novel techniques for optical signal processing. Optical transmission in fiberoptic systems has also been studied, including techniques for the introduction of solitons with a resulting high signal-to-noise ratio.

In the area of surfaces and phase transitions, a balanced program includes both theorists and experimentalists. Theoretical studies have allowed the accurate prediction at atomic-level dimensions of realistic semiconductor surfaces at room temperature, subject to deposition of electronic materials such as aluminum. These theories also account for surface reconstruction among the top monolayers of a substrate lattice. Accurate studies have also characterized phase transitions in chemisorbed systems, and high-resolution x-ray diffuse scattering has been used to experimentally confirm theoretical predictions of surface restructuring, as well as to reveal new phenomena in model systems. Unique phases in colloidal crystals have also been revealed experimentally, and a new apparatus has been built to study chemical reaction dynamics on semiconductor surfaces, thus providing for the first time an accurate characterization of chemical reactions at semiconductor surfaces as a result of common processing procedures such as reactive ion etching.

The JSEP program at MIT has built up a strong submicron structures laboratory which utilizes x-ray lithography to build a large array of structures and electronic devices. One example of the exploitation of this capability is the construction of very narrow field-effect transistors, which show quantum confinement effects, and which have led to a new understanding of electronic conduction in submicron silicon field-effect transistors. Many other extremely small structures and devices which exhibit novel quantum effects at low temperatures are also being fabricated. By means of the control of kinetic growth processes, the microstructural evolution of thin-film electronic materials (including both semiconductors and metals) has been extensively studied and characterized with a view toward providing high-quality semiconductor materials, as well as metals with large grain size which are resistant to electromigration. Following the theme of studying the properties of interconnect structures, basic electromagnetic studies of multilayer media have been made in the time domain so that transmission characteristics in complex computer interconnect structures can be precisely understood.

A major thrust of the MIT Research Laboratory of Electronics JSEP program has been fundamental studies of high-precision metrology using the techniques of atomic and molecular physics. Recently, with the advent of laser techniques to provide for atom isolation at millikelvin temperatures, new experiments are leading to techniques for the precision measurement of mass and time using trapped atomic particles. In fact, the entire MIT RLE JSEP program is increasingly characterized by techniques for the manipulation and representation of individual atoms and charge carriers. This new understanding is expected to lead to an entirely new class

of electronic devices based on new effects brought about by a variety of quantum confinement phenomena that are exhibited at very small sizes and very low temperatures.

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the Joint Services Electronics Program
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**Degrees Awarded Under Joint Services Support
November 1, 1988 - October 31, 1991
Contract DAAL03-89-C-0001**

Quantum Well Heterostructures for Guided Wave Optics

No degrees reported.

High-Frequency InAlAs/InGaAs Metal-Insulator-Doped Semiconductor Field-Effect Transistors (MIDFETs) for Telecommunications

No degrees reported.

Substitutional Doping of ZnSe Grown by Chemical Beam Epitaxy

No degrees reported.

Stability and Reliability of Thin Films and Thin Film Lines

No degrees reported.

Electromagnetic Waves in Multilayer Media

Chang, Jr., I.Y., S.B./S.M., 1989

Lam, C-W., S.M., 1989

Lee, C.F., Ph.D., 1990

Nghiem, S.V., S.M., 1988

Tsuk, M.J., Ph.D., 1990

Yang, Y-C.E., Ph.D., 1989

Sub-100nm Structures: Technology and Electronics

Early, K.R., Ph.D., 1991

Ismail, K., Ph.D., 1989

Meyer, P.G., S.M., 1989

Shahidi, G.G., Ph.D., 1989

Ultralow-Temperature Measurements of Nanometer-Scale Semiconductor Devices

No degrees reported.

Quantum Transport in Low-Dimensional Disordered Systems

No degrees reported.

The Consequences of Low-Dimensionality in Oxide Superconductors

No degrees reported.

Ultrafast Optical Devices

Amparan, A.B., S.B., 1990

Kesler, M.P., Ph.D., 1988

Khatri, F.I., S.B., 1990

Femtosecond Optical and Electronic Processes

LaGasse, M.J., Ph.D., 1989
Schoenlein, R.W., Ph.D., 1989

Microwave Quantum Optics and Precision Measurements

Gentile, T.R., Ph.D., 1989

Precise Physical Measurements

Kuchnir, D.L., S.B., 1989
Magill, P.D., Ph.D., 1988
Martin, P.J., Ph.D., 1988

Measurement of Electron-Phonon Interactions Through Large-Amplitude Phonon Excitation

No degrees reported.

Resonance Raman Studies and Applications

No degrees reported.

Excitations, Groundstate Properties, and Phase Transitions of Surfaces

No degrees reported.

High-Resolution of X-Ray Diffuse Scattering

Evans-Lutterodt, K.W., Ph.D., 1989

Statistical Mechanics of Surface Systems and Quantum-Correlated Systems

Hilliard, Jr., J.E., S.B., 1989
Hoston, Jr., W.C., S.M., 1991
Hui, K.C-L., Ph.D., 1989
Marko, J.F.D., Ph.D., 1989
Netz, R.R., S.M., 1991
Pickett, G.T., S.B., 1989

Step Structures on Semiconductor Surfaces: Thermodynamics, Kinetics, and Influence on Heteroepitaxy

No degrees reported.

Electronic Processes in the Etching of Deposition on Semiconductor Surfaces

McGonigal, M., Ph.D., 1989

Publications Acknowledging Joint Services Support

November 1, 1988 - October 31, 1991

Contract DAAL03-89-C-0001

1.1.1 Published Journal Articles

- Alerhand, O.L., A.N. Berker, J.D. Joannopoulos, D. Vanderbilt, R.J. Hamers, and J.E. Demuth. "Finite-Temperature Phase Diagram of Vicinal Si(100) Surfaces." *Phys. Rev. Lett.* 64(20):2406-2409 (1990).
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- Bahl, S.R., W.J. Azzam, and J.A. delAlamo. "Strained-Insulator $\text{In}_x\text{Al}_{1-x}\text{As}/\text{n}^+ - \text{In}_{0.53}\text{Ga}_{0.47}\text{As}$ Heterostructure Field-Effect Transistors." *IEEE Trans. Electron Devices.*
- Chu, W., S.A. Rishton, M.L. Schattenburg, D.P. Kern, and H.I. Smith. "Fabrication of 50 nm Line-and-Space X-ray Masks in Thick Au Using a 50 keV Electron Beam System." *J. Vacuum Sci. Tech. B.*
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1.1.3 Journal Articles Submitted for Publication

- Hui, K. "Domain Wall Study of the Stacked Frustrated Triangular Lattice." *Phys. Rev. Lett.*

1.1.4 Books/Chapters in Books

- Ceyer, S.T., D.J. Gladstone, M. McGonigal, and M.T. Schulberg. "Molecular Beams as Probes of Dynamics of Reactions on Surfaces." In *Physical Methods of Chemistry*. Eds. B.W. Rossiter, J.F. Hamilton, and R. C. Baetzold. New York: Wiley, 1989.
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1.1.5 Theses

Amparan, A.B. *Measurements of Antireflection Coatings on AlGaAs Diode Lasers*. S.B. thesis, Dept. of Electr. Eng. and Comput. Sci., MIT, 1990.

Chang, Jr., I.Y. *Plane Electromagnetic Wave Scattering*. S.B. and S.M. thesis, Dept. of Electr. Eng. and Comput. Sci., MIT, 1989.

Early, K.R. *Experimental Characterization and Physical Modeling of Resolution Limits in Proximity Printing X-Ray Lithography*. Ph.D. diss., Dept. of Electr. Eng. and Comput. Sci., MIT, 1991.

Evans-Lutterodt, K.W. *Synchrotron X-ray Diffraction Studies of Surface Phase Transitions*. Ph.D. diss., Dept. of Physics, MIT, 1989.

Gentile, T.R. *Microwave Spectroscopy and Atom-Photon Interactions in Rydberg States of Calcium*. Ph.D. diss., Dept. of Physics, MIT, 1989.

Gladstone, D.J. *Reaction Dynamics of Fluorine with Silicon (100): Design of a Molecular Beam Surface Reactive Scattering Chamber*. Ph.D. diss., Dept. of Chem., MIT, 1989.

Hilliard, Jr., J.E. *Monte Carlo Simulation of a One-Dimensional Ising System with Competing Interactions Using Domain Walls*. S.B. thesis, Dept. of Physics, MIT, 1989.

Hoston Jr., W.C. *Multicritical Phase Diagrams of the Blume-Emery-Griffiths Model with Repulsive Biquadratic Coupling: Mean-Field and Renormalization-Group Studies*. S.M. thesis, Dept. of Physics, MIT, 1991.

Hui, K.C.-L. *Quenched Disorder and Competing Interactions in Spin Systems*. Ph.D. diss., Dept. of Physics, MIT, 1989.

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Kesler, M.P. *Ultrafast Dynamics in GaAlAs Laser Diodes*. Ph.D. diss., Dept. of Electr. Eng. and Comput. Sci., MIT, 1988.

Khatri, F.I. *Simulations of Additive Pulse Modelocked Laser Start-Up*. S.B. thesis, Dept. of Electr. Eng. and Comput. Sci., MIT, 1990.

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LaGasse, M.J. *Femtosecond Optical Nonlinearities in AlGaAs*. Ph.D. diss., Dept. of Electr. Eng. and Comput. Sci., MIT, 1989.

Lam, C-W. *Frequency-Domain and Time-Domain Methods for Analyses of Microstrip Structures in Anisotropic Media*. S.M. thesis, Dept. of Electr. Eng. and Comput. Sci., MIT, 1989.

Lee, C.F. *Finite Difference Method for Electromagnetic Scattering Problems*. Ph.D. diss., Dept. of Electr. Eng. and Comput. Sci., MIT, 1990.

- Magill, P.D. *Classical Resonance in Vibrationally Inelastic Collisions of Diatomic Molecules: Experiments and Modeling*. Ph.D. diss., Dept. of Physics, MIT, 1988.
- Marko, J.F.D. *On Structure and Scaling at First and Second Order Phase Transitions*. Ph.D. diss., Dept. of Physics, MIT, 1989.
- Martin, P.J. *Momentum Transfer to Atoms Moving Through a Standing Wave of Light*. Ph.D. diss., Dept. of Physics, MIT, 1988.
- McGonigal, M. *Reactive Chemisorption of Molecular Fluorine on Si(100)*. Ph.D. diss., Dept. of Chem., MIT, 1989.
- Meyer, P.G. *Fabrication of Deep Submicron MOSFETs Using a Self-Aligned Cobalt Disilicide Process*. S.M. thesis, Dept. of Electr. Eng. and Comput. Sci., MIT, 1989.
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- Tsuk, M.J. *Propagation and Interference in Lossy Microelectronic Integrated Circuits*. Ph.D. diss., Dept. of Electr. Eng. and Comput. Sci., MIT, 1990.
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1.1.6 Meeting Papers Presented

American Physical Society Meeting, St. Louis, Missouri, March 20-24, 1989.

Antoniadis, D.A. "Surface Superlattice and Quasi-One-Dimensional Devices in GaAs."

Field, S.B., J.H.F. Scott-Thomas, M.A. Kastner, H.I. Smith, and D.A. Antoniadis. "Conductance Oscillations Periodic in the Density of a One-Dimensional Electron Gas."

Liu, C.T., K. Nakamura, D.C. Tsui, K. Ismail, D.A. Antoniadis, and H.I. Smith. "Far-Infrared and Magneto-Capacitance Measurements on GaAs/AlGaAs Lateral Surface Superlattice."

Scott-Thomas, J.F., S.B. Field, M.A. Kastner, D.A. Antoniadis, and H.I. Smith. "Periodic Oscillations in the Conductance of Si MOSFETs."

Smith, H.I. "X-Ray Lithography and Nanostructure Fabrication."

American Physical Society Meeting, Anaheim, California, March 12-16, 1990.

Marko, J.F. "Density Functional Theory of Phase Transitions in Fluids of Anisotropic Particles."

American Physical Society, General Meeting, Cincinnati, Ohio, March 18-22, 1991.

Berker, A.N. "Quenched Fluctuation Induced Second-Order Phase Transitions."

Hoston, W., and A.N. Berker. "New Multicritical Phase Diagrams from the Blume-Emery-Griffiths Model with Repulsive Biquadratic Interactions."

Rappe, A.M., and J.D. Joannopoulos. "Convergent and Transferable Pseudopotential for Ab-Initio LDA Calculations."

Rittenhouse, G., K. Early, and J.M. Graybeal. "A Novel Structure for a Three-Terminal Superconducting Resonant Tunneling Device."

American Physical Society, Interdisciplinary Laser Science/LSTG Meeting, Monterey, California, September 23-27, 1991.

Ketterle, W., A. Martin, M.A. Joffe, and D.E. Pritchard. "Slowing Atoms with Diffuse Laser Light."

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Li, K., M.A. Tassoudji, R.T. Shin, and J.A. Kong. "Simulation of Electromagnetic Phenomena Using a Finite Difference-Time Domain Technique."

American Vacuum Society, Boston, Massachusetts, October, 1989.

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Fujimoto, J.G. "Femtosecond Lasers and Ultrafast Measurement Techniques."

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Goodberlet, J.G., J. Wang, J.G. Fujimoto, P.A. Schulz, and S.R. Henion. "Modelocked $Ti:Al_2O_3$ Laser with a Nonlinear Coupled External Cavity."

Hall, K.L., E. Ippen, J. Mark, and G. Eisenstein. "Sub-Picosecond Gain Dynamics in InGaAsP Diode Laser Amplifiers."

Ippen, E., and K.L. Hall. "Ultrafast Optical Nonlinearities in Semiconductor Optical Amplifiers."

Keith, D.W., M.L. Schattenburg, H.I. Smith, and D.E. Pritchard. "Diffraction Gratings for Atoms."

Liu, L.Y., J. Mark, H.A. Haus, and E.P. Ippen. "Additive Pulse Mode Locking: A Mechanism for Femtosecond Pulse Generation with Coupled Nonlinear Resonators."

Pritchard, D.E., K. Helmerson, M. Xiao, and K.-X. Sun. "Radio Frequency Spectroscopy of Trapped Neutral Atoms."

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Berker, A.N. "Absence of Temperature-Driven First-Order Phase Transitions in Systems with Random Bonds."

Hoston, W., and A.N. Berker. "Dimensionality Effects on the Multicritical Phase Diagrams of the Blume-Emery-Griffiths Model with Repulsive Biquadratic Coupling: Mean-Field and Renormalization-Group Studies."

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Fujimoto, J.G., and H.A. Haus. "Femtosecond Time Domain Diagnostics of Nonlinear and Linear Waveguide Properties."

Interdisciplinary Laser Conference, Fifth, Stanford, California, August 27-31, 1989.

Haus, H.A. "Femtosecond Lasers with Fiber Optics."

International Conference on II-VI Semiconductors, Berlin, West Germany, August 21-25, 1989.

Gunshor, R.L., M. Kobayashi, L.A. Kolodziejski, and A.V. Nurmikko. "Wide Gap II-VI Heterostructures."

International Conference of Atomic Physics, Ann Arbor, Michigan, July 1990.

Pritchard, D.E. "Atom Optics."

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Gunshor, R.L., M. Kobayashi, L.A. Kolodziejski, A.V. Nurmikko, and N. Otsuka. "MBE of Wide Bandgap II-VI Compounds."

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Pritchard, D.E. "Experimental Studies of Atom Diffraction and the Mechanical Forces of Light on Atoms."

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Goodberlet, J., M.J. LaGasse, R.W. Schoenlein, M. Ulman, P. Schulz, J.G. Fujimoto. "Femtosecond Pulse Generation and Amplification in Ti:Al₂O₃."

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International Symposium on Nanostructure Physics and Fabrication, Texas A&M University, College Station, Texas, March 8-10, 1989.

Smith, H.I., K. Ismail, W. Chu, A. Yen, Y.C. Ku, M.L. Schattenburg, and D.A. Antoniadis. "Fabrication of Quantum-Effect Electronic Devices Using X-Ray Nanolithography."

Materials Research Society, Spring Meeting, San Diego, California, April 24-29, 1989.

Gunshor, R.L., L.A. Kolodziejski, M. Kobayashi, A.V. Nurmikko, and N. Otsuka. "Wide Gap II-VI DMS Superlattices: MBE Growth and Characterization."

Materials Research Society, Fall Meeting, Boston, Massachusetts, November 27-December 2, 1989.

Bennett, B.R., and J.A. del Alamo. "Index of Refraction Anisotropy in Mismatched InGaAs/InP Heterostructures Measured by Ellipsometry."

McGonigal, M., M.T. Schulberg, D.J. Gladstone, K.B. Laughlin, and S.T. Ceyer. "Reactions of F₂ with Si(100)."

Rochester Conference on Coherence and Quantum Optics, Sixth, University of Rochester, Rochester, New York, June 26-28, 1989.

Gentile, T.R., B.J. Hughey, T.W. Ducas, and D. Kleppner. "Experimental Study of Two-Photon Rabi Oscillations."

Pritchard, D.E., and B.G. Oldaker. "Light Forces and Atom Diffraction - An Illustrated Summary."

Statistical Mechanics Meeting, New Brunswick, New Jersey, May 15-17, 1991.

Hoston, W., and A.N. Berker. "Bicritical and Tetracritical Phase Diagrams of the BEG Model: Dimensionality Effects."

Netz, R.R., and A.N. Berker. "Microscopic Theory of Smectic A and C Phases of Frustrated Liquid Crystals."

Topical Meeting on Ultrafast Phenomena, Monterey, California, May 14-17, 1990.

Goodberlet, J., J. Jacobson, J. Wang, and J.G. Fujimoto. "Ultrashort Pulse Generation with Additive Pulse Modelocking in Solid State Lasers: Ti:Al₂O₃, Diode Pumped Nd:YAG and Nd:YLF."

Workshop on Compound Semiconductor Materials and Devices, Hilton Head, South Carolina, February 20-22, 1989.

del Alamo, J.A., and W.J. Azzam. "A Floating-Gate Transmission-Line Model (FGTLM) Technique for Accurate Measurement of Source Resistance in HFETs."

1.1.7 Published Meeting Papers

Anderson, K.K., M.J. LaGasse, H.A. Haus, and J.G. Fujimoto. "Femtosecond Studies of Nonlinear Optical Switching in GaAs Waveguides Using Time Domain Interferometry." *Proceedings of the International Society for Optical Engineering (SPIE)*, 1216:2-12, Los Angeles, California, January 16-19, 1990.

Antoniadis, D.A., K. Ismail, and H.I. Smith. "Lateral Surface Superlattices and Quasi-One-Dimensional Structures in GaAs." *Proceedings of the Science and Engineering of 1- and 0-Dimensional Semiconductors NATO Advanced Research Workshop*, Cadiz, Spain, March 29-April 1, 1989.

Blum, K.I., D.Y. Noh, A. Mak, K.W. Evans-Lutterodt, J.D. Brock, G.A. Held, and R.J. Birgeneau. "Structure and Phase Transitions of Ge(111) and Si(111) Surfaces at High Temperatures." *Proceedings of the International Conference on Surface Scattering*, Germany, June 1991.

Early, K., M.L. Schattenburg, and H.I. Smith. "Absence of Resolution Degradation in X-ray Lithography for λ from 4.5nm to 0.83nm." *Proceedings of the International Conference on Microlithography, Microcircuit Engineering*, Cambridge, England, September 26-28, 1989.

Gunshor, R.L., L.A. Kolodziejski, M. Kobayashi, A.V. Nurmikko, and N. Otsuka. "Metastable Zincblende MnTe and MnSe: MBE Growth and Characterization." *Proceedings of the Materials Research Society Symposium* 151:141-149 (1989).

Keith, D.W., D.E. Pritchard. "Atom Optics." *Proceedings, NATO Advanced Study Institute on New Frontiers in Quantum Electrodynamics and Quantum Optics* Istanbul, Turkey, August 14-26, 1989.

Ku, Y.C., H.I. Smith, and I. Plotnik. "Low Stress Tungsten Absorber for X-ray Masks." *Proceedings of the International Conference Microlithography, Microcircuit Engineering*, Cambridge, England, September 26-28, 1989.

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Yen, A., R.A. Ghanbari, E.H. Anderson, and H.I. Smith. "Fabrication of 100 nm-Period Gratings Using Achromatic Holographic Lithography." *Proceedings of the International Conference Microlithography, Microcircuit Engineering*, Cambridge, England, September 26-28, 1989.

1.1.8 Meeting Papers Accepted For Publication

Nelson, K.A. "Impulsive Stimulated Raman Scattering with Single-Pulse and Multiple-Pulse Excitation." *Proceedings of the 12th International Conference on Raman Spectroscopy*, Columbia, South Carolina, August 13-17, 1990.

Weiner, A.M., D.E. Leaird, G.P. Wiederrecht, M.J. Banet, and K.A. Nelson. "Spectroscopy with Shaped Femtosecond Pulses: Styles for the 1990s." *Proceedings of the SPIE Conference on Optoelectronics and Lasers*, Los Angeles, California, June 14-19, 1990.