2006 SUMMARY OF ENGINEERING RESEARCH

A Report of Activities during 2005

This report is part of the larger 2006 Summary of Engineering Research, available on the Web at www engr uiuc edu research and on CD-ROM. The Summary of Engineering Research represents the extensive engineering research program conducted in 2005 at the University of Illinois at Urbana-Champaign. Detailed statistics about research in the College of Engineering are included in the Directory of Engineering and Engineering Technology Programs and Research, published by the American Society for Engineering Education, Washington, D.C.

How to use the Summary of Engineering Research: Research projects are listed by title, followed by the names of the investigators and the sponsoring agencies. Projects are sorted by major topic areas. Project descriptions are brief. Additional information on each project may be obtained from the investigator in charge (denoted by an asterisk). Mailing addresses are provided on the introductory page.

How to obtain publications: Please consult academic and public libraries for the journal articles, papers, and books listed in this report. Information about technical reports is available from the Engineering Documents Center, Grainger Engineering Library Information Center, 1301 West Springfield Avenue, Urbana, IL 61801, USA. To search the center's collection on the Internet, please visit the website at search grainger uiuc edu top. Copies of theses can be found at the University of Illinois Library, www library uiuc edu, or may be purchased from University Microfilms, 300 Zeeb Road, Ann Arbor, MI 48106, USA, www umi com.

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Abbreviation key for College of Engineering departments and major labs:

• Advanced Transportation Research and Engineering Laboratory (ATREL)
• Aerospace Engineering (Aerosp. Engr.)
• Agricultural and Biological Engineering (Ag. & Biol. Engr.)
• Bioengineering (Bioengr.)
• Chemical and Biomolecular Engineering (Chem. & Biomol. Engr.)
• Civil and Environmental Engineering (Civil & Environ. Engr.)
• Computer Science (Comput. Sci.)
• Coordinated Science Laboratory (CSL)
• Electrical and Computer Engineering (Elect. & Comput. Engr.)
• Frederick Seitz Materials Research Laboratory (FS-MRL)
• General Engineering (Gen. Engr.) or Industrial & Enterprise Systems Engineering (Indus. & Enter. Syst. Engr.)*
• Materials Science and Engineering (Mat. Sci. & Engr.)
• Mechanical and Industrial Engineering (Mech. & Indus. Engr.) or Mechanical Science and Engineering (Mech. Sci. & Engr.)*
• Micro and Nanotechnology Laboratory (MNTL)
• Nuclear, Plasma, and Radiological Engineering (Nucl., Plasma, & Radiol. Engr.)
• Physics
• Theoretical and Applied Mechanics (Theoret. & Appl. Mech.)*

*In August 2006, the Industrial Engineering program was merged with the General Engineering Department, which became the Industrial and Enterprise Systems Engineering Department. The Theoretical and Applied Mechanics Department merged with the Mechanical and Industrial Engineering Department, which became the Mechanical Science and Engineering Department. Please check department links at www engr uiuc edu for current faculty lists.
Micro and Nanotechnology Laboratory

Kent D. Choquette, Interim Director

Micro and Nanotechnology Laboratory
208 N. Wright Street
MC-249
Urbana, Illinois 61801-2355
217-333-3097
http://www.micro.uiuc.edu

The Micro and Nanotechnology Laboratory, a multidisciplinary research facility in the College of Engineering, houses advanced equipment to support research in photonics, microelectronics, nanotechnology, and biotechnology. This laboratory is one of the nation's largest and most sophisticated university-based clean room facilities. It contains more than 8,000 square feet of class 100 and class 1000 clean-room laboratory containing a wide array of semiconductor processing technologies as well as state-of-the-art, ultra-high speed optical and electrical device and circuit measurement capabilities. The laboratory is presently undergoing an $18M expansion, scheduled to be completed in Dec. 2006, which will add 45,000 square feet of laboratory and office space. The laboratory is a User Facility that is available for use by university and industrial personnel from across the nation. More details on the available processing tools and fabrication technologies can be found at http://www.micro.uiuc.edu/

The research activities that are facilitated by the laboratory can be divided into four areas:

• Optoelectronics and Photonic Systems
• Microelectronics for Wireless Communications
• Microelectromechanical Systems
• Nanobiosystems

Faculty from the Electrical and Computer Engineering Department and other Departments participate in ongoing research in the Micro and Nanotechnology Laboratory.

The research programs of the Optoelectronics and Photonic Systems area are centered on the conceptualization, design, fabrication, and testing of microelectronic and optoelectronic devices, circuits, components, and systems for lightwave communications and optical interconnects. A focus of this research area is the development of novel photonic devices leveraging nano-fabrication techniques.

The activities of the Microelectronics for Wireless Communications area include the design and fabrication of state-of-the-art, low-power RF and microwave monolithic integrated circuits (MMICs) and GHz analog-to-digital converters for advanced wireless communication systems and advanced digital radar systems. A focus of this research area is the development of ultra-high speed heterojunction bipolar transistors.

The above two research areas are supported in the laboratory with extensive development of growth, characterization, and processing technologies for a broad range of III-V semiconductor materials, quantum wells, superlattices, and nanostructures. The III-V materials include compounds and alloys with bandgaps appropriate for visible and infrared light emitting diodes, edge emitting lasers, vertical cavity surface emitting lasers (VCSELs), detectors, field effect transistors (FETs), and heterojunction bipolar transistors (HBTs).

The Microelectromechanical Systems (MEMS) research involves the development of micromachining methods using a variety of materials, such as silicon, gallium arsenide, and polymers, to enable applications in many interdisciplinary areas, including wireless communications, optoelectronics, and biomedical engineering. A particular emphasis of this area is the development of integrated micro-fluidic devices and systems.

The Nanobiosystems research area focuses on utilizing the various technologies developed in materials, nanofabrication, devices, and MEMS to study and solve biological issues. Examples of research activities being carried out include analysis of biomolecular flow patterns in nanoscale channels and pores, integration of nano-pore sensors into silicon-based transistors, integration of lasers onto biochips for real-time fluorescence study of bioreactions, and implantation of active devices in cells to study cellular biochemistry.

The Micro and Nanotechnology Laboratory has in the past housed various research centers, including the Engineering Research Center for Compound Semiconductor Microelectronics (funded by the National Science Foundation), the Center for Optoelectronic Science and Technology, and the Center for Bio-Optoelectronic Sensors and Systems (both funded by the Defense Advanced Research Projects Agency). It currently houses the DARPA-funded Center for Hyper-Uniform

A list of faculty members associated with the the Micro and Nanotechnology Laboratory during the reporting period is provided.

**Institute for Genomic Biology**

H. Lewin

**Department of Bioengineering**

B. Wheeler

**Department of Chemical and Biomolecular Engineering**

P. Kenis
D. Leckband
C. Zukoski

**Department of Chemistry**

P. Bohn
J. Moore

**Department of Electrical and Computer Engineering**

I. Adesida
J. Bernhard
S. Bishop
S. Boppart
K. Y. Cheng
K. Choquette
S. L. Chuang
J. Coleman
G. Eden
M. Feng
C. Gardner
K. Hess
N. Holonyak, Jr.
K. C. Hsieh
K. Kim
J. P. Leburton
C. Liu
J. Lyding
G. Papen
U. Ravaiolli
E. Rosenbaum
J. Schutt-Aine
G. Timp
J. Tucker
A. Webb

**Department of Materials Science and Engineering**

J. Abelson
L. Allen

P. Braun
J. Weaver
G. Wong

**Department of Mechanical Science and Engineering**

N. Aluru
T. Saif
M. Shannon
L. Phinney

**Department of Nuclear, Plasma, and Radiological Engineering**

G. Miley

**Department of Physics**

I. Bezryadin
D. Van Harlingen
A. Yazdani

**Faculty and Their Interests**

**Ilesanmi Adesida**

Electronic and transport properties of ultra-low dimensional semiconductor structures, advanced processing methods for electronic devices, high-speed optoelectronic devices and integrated circuits, radiation effects

**Keh-Yung Cheng**

Molecular beam epitaxy technology, optoelectronic integrated circuits, high speed devices, in situ fabrication of nanostructures, quantum wire lasers, vertical cavity surface emitting lasers, Sb-based IR detectors and electronic devices

**Kent Choquette**

Vertical cavity surface emitting lasers (VCSELs), micro- and nanocavity lasers, optoelectronic devices, selective oxidation of compound semiconductors, hybrid heterogenous integration, nanoprocessing fabrication, photonic crystal materials, Si-based optoelectronics

**James J. Coleman**

Semiconductor lasers, optoelectronics, epitaxial growth

**Brian Cunningham**

Nanotechnology, photonic crystals, biosensors, micro/ nanofabrication methods and materials detection instrumentation
Milton Feng
High-speed devices and ICs for wireless and light emitting transistors for optoelectronics (optoelectronic IC), monolithic microwave and millimeter-wave IC, digital IC, high field transport properties, RF-MEMS for wireless communications, advanced Si-CMOS device physics

Nick Holonyak, Jr.
Semiconductors, semiconductor device physics, semiconductor crystal growth and junction formation, diffused Si devices, SCR, TRIAC, double injection, luminescence, light emitting diodes (LEDs), heterojunctions, lasers, tunnel diodes, compound semiconductors, quantum well heterostructures, superlattices, quantum well lasers, impurity-induced layer disordering, Al-based III-V native oxides and their use in heterostructures devices

Kuang C. Hsieh
Semiconductor materials/devices processing and characterization

Chang Liu
MEMS, microsensors, microintegrated fluidic systems, MEMS for nanotechnology, wireless interface for sensors, sensitive skin

Gregory Timp
Fabrication, development, and characterization of the performance of silicon MOS nanotransistors to discover the fundamental limitations of the silicon MOSFET; atomic physics and light pressure forces on single atoms for lithography applications; mesoscopic and nanostructure physics, including measurement of the low temperature transport characteristics of high electron mobility transistors that resemble electron waveguides. Hopping (thermally-assisted tunneling) conductivity of localized electrons in a two dimensional impurity band formed in the inversion layer of a silicon metal-oxide-semiconductor field effect transistor (MOSFET); the effect of superlattices on lattice-dynamical properties of graphite intercalation compounds using Raman scattering, extremely high field magnetoresistors, Schubinkov-deHaas effect (using high resolution microscopy), high resolution x-ray scattering; nanometer-scale lithography to probe biological function

Advanced Processing and Circuits

AlGan/GaN HFET Fabrication and Characterization
I. Adesida,* V. Kumar, A. Kuliev
Triquint Corporation
Conducted in the Micro and Nanotechnology Laboratory
This project involves a collaboration with Triquint Corporation on the fabrication of AlGan/GaN HFETs. Technologies for the fabrication of the HFETs will be developed.

Gallium Nitride Optoelectronics
I. Adesida,* L. Zhou
Conducted in the Micro and Nanotechnology Laboratory
This project focuses on experimental issues for the fabrication of novel optoelectronic devices and circuits in gallium nitride and related materials. UV detectors, field effect transistors, and heterojunction bipolar transistors will be investigated. Methods for integrating these devices will also be explored.

Porous GaN: Production, Characterization, and Applications
I. Adesida,* P. Bohn,* X. Li,* S. Kim
U.S. Office of Naval Research, N00014-01-1
Conducted in the Micro and Nanotechnology Laboratory
This program involves the generation and characterization of porous GaN and SiC for applications in growth of high quality epitaxial layers. Matrices with dimensions down to 50 nm are to be achieved for the porous materials.

Processing of Gallium Nitride and Related Compounds
I. Adesida,* L. Zhou, F. Khan
ATMI/Air Force
Conducted in the Micro and Nanotechnology Laboratory
This program consists of the development of viable processing methods for gallium nitride and related compounds. A systematic study of etching techniques, ohmic contact formation, and other metallizations will be conducted and applied to devices.

* Denotes principal investigator.
Resonant Enhanced Modulators
I. Adesida,* S. Rommel
Air Force; Sarnoff Corporation

Conducted in the Micro and Nanotechnology Laboratory

This is a collaborative program with Sarnoff Corporation on resonant enhanced modulators in InP-based heterostructures. Waveguides with coupling rings are to be fabricated and characterized in InP-heterostructures. High precision patterning using inductively coupled plasma reactive ion etching and electron beam lithography will be used in fabricating the modulators.

Silicon-Germanium Modulation-doped Field Effect Transistors
I. Adesida,* K. Ismail*
National Science Foundation, ECS 97-10418

Conducted in the Micro and Nanotechnology Laboratory

This collaborative program with IBM Corp. is intended to significantly advance the growth and fabrication technologies for SiGe/Si modulation-doped field effect transistors (MODFETs) needed for low-power, high-speed microwave and digital applications. Specific goals are to study the physics of short gate-length p-type, n-type, and complementary MODFETs and to demonstrate simple circuits.

Ultra-High-Power GaN Power Amplifier at X-Band
I. Adesida,* W. Lu, D. Selvanathan
Air Force; TRW Corporation

Conducted in the Micro and Nanotechnology Laboratory

This collaborative project with TRW Corporation is to fabricate an ultra-high-power GaN-based HFET amplifier on SiC at X-Band. Various processing techniques for GaN will be developed as part of this project.

Digital Signal and Imaging Processing

Multisensor Information Fusion
Z. P. Liang, H. Pan, K.-Y. Cheng*
kycheng@uiuc.edu
Defense Advanced Research Projects Agency, MDA972-00-1-0020

Conducted in the Micro and Nanotechnology Laboratory

This project is a component of research conducted in the Center for Bio-Optoelectronic Sensor Systems (BOSS). The primary mission of this center is to develop sensor and processing technology for detection of biochemical agents in battlefield situations. Prof. Liang is responsible for developing statistical algorithms for multisensor information fusion.

Electromagnetic Communication and Electronics Packaging

Design and Fabrication of MEMS Probe Station
J. Schutt-Ainé,* C. Liu, D. Lambalot
University of Illinois Research Board

Recent advances in microelectronics have led to considerable reduction in size of components in integrated circuits (ICs). Typical VLSI circuits have dimensions in the submicron range and feature size that can be as low as 0.25 microns. This reduction is a result of several requirements for higher density and shorter interconnection delays. Future state-of-the-art microprocessors will accommodate more than a million transistors in an area of a few hundred squared millimeters. Along with these trends, several issues related to signal integrity and testing have moved to the forefront. With submicron dimensions, interconnect resistance has become a major bottleneck in circuit performance, leading to signal degradation and delays. In addition, measurement and testing in submicron geometries, which allows for determining the performance of the structure, is a challenging task. Nowadays, the methods employed consist of fabricating special-purpose test vehicles for evaluation, which often require expensive mask processes and complex de-embedding schemes. This investigation proposes to implement a nondestructive testing methodology for submicron integrated circuits using the recent advances in microelectromechanical systems (MEMS). More specifically, we intend to fabricate and test a microprobe structure that will permit the high-frequency characterization of submicron interconnects and devices in integrated circuits.

High Frequency Devices

38-GHz Ion Implantation GaAs MESFET Technology Transfer Program
M. Feng,* J. Middleton, S. K. Hsia
Northrop Grumman Corp.; M/A-Com/Amp

Conducted in the Micro and Nanotechnology Laboratory

This project is aimed at the technology transfer of the University of Illinois 0.25 μm gate GaAs MESFET for 24-GHz and 38-GHz MMICs for LNA and VCO to M/A-Com. for low-cost production.

* Denotes principal investigator.
50-GHz Ion Implanted GaAs MESFET
TriQuint Semiconductor
Conducted in the Micro and Nanotechnology Laboratory
This program is to study the 50 GHz to 100 GHz ion implanted GaAs MESFET for millimeter-wave integrated circuit application.

50-GHz Ion-implanted Enhanced/Depletion/Power GaAs MESFETs
M. Feng, H. Hsia, D. Becher, Z. Tang, J. J. Hwang, Shen
Network Device Inc.
Conducted in the Micro and Nanotechnology Laboratory
This project is to develop enhancement mode, depletion mode, and power mode (E/D/P) GaAs MESFETs operated at 50 GHz.

50-GHz Self-Aligned Gate MESFETs
M. Feng, D. Becher, D. Caruth
Vitesse Semiconductor Corp.
Conducted in the Micro and Nanotechnology Laboratory
We have investigate Vitesse self-aligned gate MESFET for the analog applications in term of noise gain and power. We have compare performance with the University of Illinois realigned gate FET with Vitesse and to understand device improvement issues.

ADC Circuit Design on a Sigma-Delta Modulator
M. Feng, M. Heins, D. Barlage
U.S. Army Research Office, DAAH04-96-0218 (Intel Fellowship)
Conducted in the Micro and Nanotechnology Laboratory
This project is aimed at design of 3 Gbit/s for an 8-bit ADC. Our first goal is to design the subcircuits library of comparator, sample, and hold circuit and OA design of an ADC.

AlGaAs/GaAs HBT Modeling
M. Feng, P. Mares, M. Hein
Rockwell Microelectronics, Inc.
Conducted in the Micro and Nanotechnology Laboratory
This project aims to establish a useful SPICE model for HBT integrated circuits application. Our approach is based on 45-MHz to 50-GHz bias-dependent microwave data collection on an HBT device using HP-ICCAP. Temperature-dependent microwave data collection will be included in the model.

CAD Design Tools for an Integrated Millimeter-Wave Wireless Communication Microsystem
M. Feng, S. C. Shen, J. J. Hwang, M. Heins
Defense Advanced Research Projects Agency, F30602-97-2-0328
In collaboration with C. Liu. Conducted in the Micro and Nanotechnology Laboratory.
We are developing CAD capabilities for a gigahertz wireless communication and distribution microsystems. We are also developing scalable MMIC modules with integrated MEMS components.

Center of Hyper Uniform Nanophotonic Technologies for Ultrafast Optoelectronic Systems
M. Feng, R. Chan, K. Cimino, W. Hafez, F. Dixon
Defense Advanced Research Project Agency HUNT Program
Conducted in the Micro and Nanotechnology Laboratory
The goal of this project is to develop new optical source laser and LED using light emitting transistors modified by quantum well base and DBR to achieve high speed modulation of optical interconnect.

Development Materials for GaN-based Minority-Carrier Power Electronic Devices for Advanced DoD Systems
M. Feng, J. Lai, K. Price
Defense Advanced Research Projects Agency, GaN Power Program (under UTA team-Prof. Russel Dupuis)
Conducted in the Micro and Nanotechnology Laboratory
This program is to study material interface of heterjunction, minority carrier transport property in GaN HBT system, since HBT provides high linearity and high efficiency power amplification.

Digital Radar Receiver
M. Feng, J. Fendrich
Mayo Foundation; Defense Advanced Research Projects Agency
Conducted in the Micro and Nanotechnology Laboratory
This project performs the design and fabrication of an RF front end (400-700 MHz) fully tunable receiver system. We are working closely with the Mayo Foundation MIT-Lincoln Lab and Defense Advanced Research Projects Agency to build two brassboard RF receiver front ends for digital radar applications.

* Denotes principal investigator.
Direct Ion Implantation GaAs MESFETs
M. Feng,* H. Hsia, Z. Tang, D. Becher, S. Shen
GaAstronics Co.

Conducted in the Micro and Nanotechnology Laboratory
This project is to develop low-cost ion-implanted GaAs MESFETs for 5.8-GHz MMICs.

GaAs- and InP-based HBT Reliability
M. Feng,* D. Barlage, M. Heins
U.S. Army Research Office, DAAH04-94-0369

Conducted in the Micro and Nanotechnology Laboratory
This project is to set up an HBT reliability test. HBT reliability has become a major issue because of heterostructure interface and fast diffuse p-type impurities in both InP- and GaAs-based HBTs. We will test HBT devices from Rockwell, Hughes, and TRW for the basic failure mechanism.

GaN HBT Technology
M. Feng,* J. J. Huang
U.S. Navy, UTA 99-0302

Conducted in the Micro and Nanotechnology Laboratory
GaN has great potential to be a power source in millimeter wave ICs and high-speed electronics due to its large breakdown voltage and higher saturation velocity. In collaborate with Prof. Dupuis at the University of Texas at Austin, we have fabricated GaN HBT with beta >100.
There are many problems to be solved in terms of current and power efficiency issues at millimeter wave frequency.

High-Frequency Measurement Project on High-Tc Superconductor
M. Feng,* J. Fendrich, H. S. K. Hsia
National Science Foundation, DMR 89-20539

In conjunction with the Science and Technology Center for Superconductivity. Conducted in the Micro and Nanotechnology Laboratory.
This project has contributed to the study of BKBO and YBCO film characterization at microwave and terahertz frequencies. A parallel-plate resonator (10 GHz) was built to characterize sheet resistance in the microwave frequency. A noncontact coherent time-domain spectroscopy (THz) was used to characterize real and imaginary parts of conductivity. An on-wafer cryogenic microwave probing technique (1-40 GHz, 15-300K) is employed to establish patterned film scattering parameter. This work also aims to develop engineering model parameters using a GHz on-wafer probe technique.

Hybrid and Monolithic OEIC Receivers
M. Feng*
Defense Advanced Research Projects Agency, Center for Optoelectronics Science and Technology

Conducted in the Micro and Nanotechnology Laboratory
This project is aimed at hybrid integration of a PIN/GaAs transimpedance amplifier at 20 GHz operation. The monolithic IC is involved in design and fabrication of 4-channel OEIC receivers using GaAs MESFET technology.

InGaAs/InP BiFET for ADC Applications
M. Feng,* D. W. Seo, H. Hsia, Z. Tang
Defense Advanced Research Projects Agency, N66001-97-C-8618

Conducted in the Micro and Nanotechnology Laboratory
We have developed a 200-GHz InGaAs/InP HFET and integrated it with a 200-GHz HBT. Using this technology, we will construct a fifth-order Sigma-Delta ADC for a 16-bit and 3 FDR > 100 dbc.

InGaP HBT for ADC Applications
M. Feng,* D. W. Seo, J. Mu, M. Heins
Defense Advanced Research Projects Agency, N66001-96-C-8615

Conducted in the Micro and Nanotechnology Laboratory
We are developing an InGaP HBT device model (thermal and electrical model) for implantation into MDS and HSPICs. The second-order Sigma-Delta ADCs with 5 Gbits and 8-bit resolution has been designed, simulated, and fabricated.

Intelligent Vehicle Highway System Chip Sets (II)
(IVHS)
M. Feng,* H. Hsia
Northrop Grumman Corp.

Conducted in the Micro and Nanotechnology Laboratory
This project is a follow-up of the TRP/DARPA contract based on the success of the University of Illinois 24-GHz and 38-GHz GaAs MESFET MMIC for LNA and VCO.
The new contract is aimed at low-cost implementation of a 0.1 μm gate GaAs MESFET and MMIC by direct ion implantation for 77-GHz LNA and VCO collision avoidance radar.

* Denotes principal investigator.
Intelligent Vehicle Highway System Chip Sets (IVHS)
M. Feng,* P. Apostolakis, J. Middleton
Northrop Grumman Corp.

Conducted in the Micro and Nanotechnology Laboratory
This project is a joint development effort between the University of Illinois and Northrop Grumman Corp. on millimeter-wave IC chip sets for IVHS. We will design transmitter, receiver, mixer, and oscillator millimeter-wave ICs using co-planar technology. The mask and fabrication will use University of Illinois ion implanted, super-low-noise GaAs MESFETs, and a monolithic IC process.

Millimeter Wave Technology HBT and HFET
M. Feng*
Sumitomo Chemical America, Inc.

Conducted in the Micro and Nanotechnology Laboratory
We will design and fabricate MOCVD-grown, doped channel HFETs and InGaP and AlGaAs HBTs. We will characterize these devices and optimize their performance for 24- to 77-GHz applications.

Millimeter-Wave ICs and Packages
M. Feng*
Georgia Institute of Technology, NSF Package Research Center

Conducted in the Micro and Nanotechnology Laboratory
This project is to develop 38-GHz and 77-GHz coplanar MMICs for flip chip packages.

MOCVD HEMT Technology
M. Feng,* Z. Tang
Sumitomo Chemical America, Inc.

Conducted in the Micro and Nanotechnology Laboratory
We will investigate the performance of MOCVD grown P-HEMT and HEMT technology and its performance comparison between MESFETs and MBE-grown HEMTs.

Modeling of Flip Chip Interconnects for RF/Wireless
M. Feng,* J. Schutt-Aine
Georgia Institute of Technology, NSF ERC Package Research Center, SBC GIT E21-N50-G5

Conducted in the Micro and Nanotechnology Laboratory
The next generation of wireless personal communication links and wireless LAN and WAN will be focused in the millimeter wave range due to wide bandwidths and less interference effects. This work is to develop a low-cost solution of millimeter-wave MMICs flip chip technology. This work will provide the design, simulation, and process of MMICs operating at 38 GHz for a real application in point-to-point communication links. The Georgia Tech PRC will provide the flip chip package technology.

Monolithic Millimeter-Wave Integrated Circuits Technology
M. Feng*
Northrop Grumman Corp.

Conducted in the Micro and Nanotechnology Laboratory
This project is a joint effort with Northrop Grumman Corp. for developing 0.25 μm gate and 0.1 μm gate GaAs FET-based technology for the application in monolithic millimeter wave ICs (MMWICs). Based on the high-frequency device characterization, an equivalent circuit model will be generated. This model will then be used for MMWIC design. The fabrication of the MMWICs will be demonstrated.

Noise Characterization of Self-Aligned Gate GaAs MESFETs
M. Feng*
ITT Corp.

Conducted in the Micro and Nanotechnology Laboratory
This project aims to reduce the minimum noise figure on the direct ion-implanted self-aligned GaAs MESFETs based on the design of experiments in terms of dose and gate overlay.

Novel Giga Sampling Analog-to-Digital Conversion for Direct Digital Receiver
M. Feng,* D. W. Seo
National Science Foundation, ECS-9979341

Conducted in the Micro and Nanotechnology Laboratory
We proposed novel GHz ADC architecture, the folding and interpolation-based 15-bit subrange A/D converter, will reduce the transistor count by one-third and the area by 60%. The subrange ADC requires a very precise and wide-band track and hold amplifier to maximize input bandwidth to greater than 2 GHz and converter resolution to greater than 15 bits.

Optical Correlation Spectroscopy Using Reconfigurable Diffraction Grating
M. Feng,* Q. He, K. F. Chen, J. J. Huang
Defense Advanced Research Projects Agency Center (DARPA) BOSS Program, MDA972-00-1-0020


* Denotes principal investigator.
with K. Y. Cheng. Conducted in the Micro and Nanotechnology Laboratory.

Sponsored by DARPA, the goal of this program is to develop a nano spectrometer for biological and chemical agents detection. Our group is to design and fabricate reconfigurable grating using novel MEMS switch. It is capable of detecting 3-10 μm wavelength.

**Technology for Efficient, Agile Mixed Signal Microsystems**

M. Feng,* R. Chan, K. F. Chen, W. G. Ho

*Defense Advanced Research Projects Agency, TEAM Program*

_Under BAE Systems and collaboration with Greg Timp. Conducted in the Micro and Nanotechnology Laboratory._

The goal is to develop silicon RF CMOS with Ft and Fmax > 400GHz with 20 nm gate. The RF mixed signal circuits will be developed based the fastest RF CMOS technology.

**Technology for Frequency Agile Digitally Synthesized Transmitter**

M. Feng,* J. Lai, M. Hafez, M. Hampson, D. Chan, B. Chu-Kung

*Defense Advanced Research Projects Agency TFAST Program*

_Under BAE Systems and Vitesse Semiconductor. Conducted in the Micro and Nanotechnology Laboratory._

The goal is to develop InP DHBT with Ft and Fmax > 500 GHz with sub-micron scaling of emitter size down to 0.1 micron. The technology is also required to demonstrate Flip-Flop speed over 200 GHz. A VLSI InP technology of over 10,000 transistor level of mixed signal Direct Digital Synthesizer (DDS) will be developed.

**VCSEL and Smart Pixels for VLSI Photonics**

M. Feng,* N. Holonyak, Jr., K.-Y. Cheng, K. C. Hsia

*Defense Advanced Research Projects Agency, DAAG55-98-1-0303*

_Conducted in the Micro and Nanotechnology Laboratory_

This project is to develop oxide confined VCSELs at 85 nm and 1330 nm, as well as smart pixels for VSLI photonics.

**Wavefunction Engineering of Individual Donors for Si-Based Quantum Computers**

M. Feng,* R. Chan, C. Chuang

*Defense Advanced Research Projects Agency, Quantum Computer Program, DAAD19-01-1-0324*

_In collaboration with John Tucker. Conducted in the Micro and Nanotechnology Laboratory._

The goal is to place individual phosphorus donors into silicon with atomic precision, demonstrate electronic control over wavefunction overlap, and characterize the spin singlet and triplet states of the two-electron system on couple donor pairs.

**YBCO Superconducting Transmission Line Characterization**

M. Feng,* J. Fendrich

*Superconductor Technology Inc.*

_Conducted in the Micro and Nanotechnology Laboratory_

This project studies the design rule of MCM using a superconductor as an interconnect line. Loss and phase delay are compared between gold and the superconductor line. Bit-error-rate and crosstalk will also be examined.

**Optical Imaging**

**Optical Biopsy of Cancer using Optical Coherence Tomography**

S. A. Boppart,* J. J. Coleman, K. D. Choquette, M. Shahidi, R. Folberg, T. DasGupta

boppart@uiuc.edu

*University of Illinois at Urbana-Champaign and University of Illinois at Chicago Intercampus Research Initiative on Biotechnology*

_Conducted in the Beckman Institute for Advanced Science and Technology_

The high-resolution, real-time imaging capabilities of optical coherence tomography (OCT) allow for the acquisition of "optical biopsies" of tissue. Images approaching the level of histology can be acquired without the physical resection and processing of tissue that is common practice today. A compact and portable OCT system is being constructed for clinical use in local hospitals and at the University of Illinois at Chicago. This system will be used to identify various stages of cancer growth as well as metastases and be compared directly to results obtained with histology, the gold-standard for diagnosis. In certain clinical scenarios, the use of real-time OCT may replace the need for tissue excision and analysis.

* Denotes principal investigator.
Optical Physics and Engineering

Nanofibrous Scaffolds for Cartilage Engineering
B. T. Cunningham, D. Griffon
bcunning@uiuc.edu, dgriffon@uiuc.edu
Beckman Institute for Advanced Science and Technology

Conducted in the Micro and Nanotechnology Laboratory, the Beckman Institute for Advanced Science and Technology, and the College of Veterinary Medicine

The project aims to optimize production of chitosan nanofibers with nanometer-scale diameter for chondrocyte attachment and proliferation. Utilizing nanometer-scale lithography, a silicon template wafer is used to produce large area rubber molds. By filling the molds with chitosan solution, curing the chitosan solution to a solid, and harvesting the cured fibers from the mold, large populations of fibers with any desired diameter can be produced in large quantities. The fibers produced by this method will be used to determine the extent to which the diameter of chitosan fibers affects in vitro chondrogenesis. Our working hypothesis is that decreasing the diameter of chitosan fibers will improve chondrocytes’ attachment, proliferation, and matrix production.

Optical Biosensors
B. T. Cunningham
bcunning@uiuc.edu
SRU Biosystems

Conducted in the Micro and Nanotechnology Laboratory

An optical biosensor is used to rapidly screen protein-small molecule interactions that are not easily screened by other methods. The assay is based upon a sensor technology called a "photonic crystal" structure that is inexpensively manufactured from sheets of plastic film and incorporated into disposable microplates. By eliminating the need for a label, the assay is less susceptible to errors and artifacts caused by conformational change or blocking of active binding epitopes. It is envisioned that the technology will be used in the context of a primary screen of a chemical library and as a secondary screen for measuring dose-response characteristics of a protein-small molecule combination.

Photonic Crystal Biosensor Nanostructures and Materials for Advanced Performance
B. T. Cunningham*
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National Science Foundation

Conducted in the Micro and Nanotechnology Laboratory

The specific aims of the research project investigate means for advancing the state-of-the-art for photonic crystal biosensor performance and applications. Sensor designs will be approached first by computer simulation using rigorous coupled wave analysis (RCWA) and finite difference time domain (FDTD) methods, followed by fabrication and testing of the structure. The design goals will be to produce more narrow resonant spectra, higher surface/volume ratio, and higher electromagnetic field interaction with adsorbed material than first-generation designs. The incorporation of different materials to increase surface electromagnetic field intensity, and structures to maximize the interaction of the field with adsorbed biomolecules, will be demonstrated.

Tunable Optical Filters Using Photonic Crystals and Nonlinear Dyes
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Batelle

Conducted in the Micro and Nanotechnology Laboratory

Photonic crystal narrowband reflectance filters can be designed with resonant wavelengths over the visible portion of the light spectrum and may have utility as countermeasures against laser-based systems designed to induce temporary or permanent blindness in pilots. A photonic crystal that would block laser illumination at specific wavelengths while allowing all other wavelengths to reach the pilot’s eyes could be incorporated into the visor of a fighter pilot. In addition, a photonic crystal-based visor might incorporate nonlinear dye material that would rapidly respond to hostile laser illumination and would allow controllable tuning of the filtered wavelength.

* Denotes principal investigator.
Integration of Photonic Crystal Sensors with Nanofluid Flow Channels
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NSF Center for Nanoscale Chemical-Electrical-Mechanical Manufacturing Systems (NanoCEMMS)
Conducted in the Micro and Nanotechnology Laboratory and in Roger Adams Laboratory

The project objective is to incorporate plastic-based photonic crystal optical sensors within nanofluidic flow channels for the detection of biochemical interactions between mixed reagents, temperature of reagents, pressure within sealed reaction vessels, and as a means for indicating the presence or absence of fluid at particular locations within a fluid network. Using integrated sensors and fluid control within a single small chip, we plan to demonstrate the ability to simultaneously monitor large numbers of photonic crystal sensors within the chip using a noncontact optical imaging scanner instrument.

Optoelectronics

Nanoscale Chemical-Electrical-Mechanical Manufacturing Systems
K. D. Choquette*
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National Science Foundation

The objective of the NSF Center for Nanoscale Chemical-Electrical-Mechanical Manufacturing Systems (NanoCEMMS) is the development of a manufacturing capability for manipulation and sensing of materials ultimately at the nanometer scale. To this end, the Photonic Device Research Group is developing optical sources for application in the eventual toolbit, which enables a new revolution of manufacturing. We are developing photonic crystal vertical cavity lasers that employ photonic crystal effects in the direction of light propagation. These devices are promising for the high-power, single-mode operation that will be required for optical sensing at the toolbit. The holes inherent to this device are also suitable for material introduction pores of the toolbit assembly. In addition, we are developing integrated vertical cavity surface emitting lasers (VCSELs) and photodetectors. Such a device will find application in fluorescence identification and position sensing. We are thus pursuing close packed 2-dimensional arrays of intermeshed VCSELs and photodetectors for use as optical sensors.

Next-Generation Optical Materials and Devices
K. D. Choquette,* J. J. Coleman
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National Science Foundation

The goal of nanotechnology is to create materials and devices that exhibit novel and significantly improved properties due to their nanoscale size. We are developing nanophotonic light sources with enhanced characteristics for future photonic ultra-high-capacity communication systems. We seek to combine aggressive advances in 3-dimensional electronic confinement obtained from quantum dots with the unprecedented optical confinement achieved from photonic crystals to develop the next generation of highly efficient microcavity optical sources.

Photonic Crystal Emitters for Next Generation Light Sources
K. D. Choquette*
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Army Research Laboratories

We are developing vertical cavity laser sources with enhanced characteristics for future photonic and remote sensing applications. Our devices consist of vertical cavity surface emitting lasers that are transversely defined by a photonic crystal. The pursuit of suitable nanotechnologies required for photonic crystal fabrication in a variety of materials is under way. Specifically, electron beam and focused ion beam lithography are being developed for photonic crystal fabrication. This work will also focus on transversely coupled photonic crystal defects, producing coherently coupled vertical cavity laser arrays.

Photonic Crystal Nanophotonic Devices
K. D. Choquette*
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U.S. Air Force Office of Scientific Research

The objective is to develop nanophotonic devices based upon photonic crystal nanocavities employing a variety of semiconductor material systems. Our goal is to develop the photonic crystal design and processing techniques to maximize cavity quality values, minimize cavity volume, and minimize waveguide loss. We will also explore novel vertical photonic crystal nanocavities incorporating quantum dots, and pursue coupling photonic crystal cavities and waveguides for integrated devices with post-processing cavity tuning techniques.

* Denotes principal investigator.
Spatial, Temporal, and Spectral Localization for Advanced Photonic Applications
K. D. Choquette,* J. J. Coleman
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Defense Advanced Research Project Agency

Future chip-based optoelectronic systems will require an unprecedented decrease of size and operating power, while simultaneously incorporating greater functionality and complexity. This research program builds on advanced materials and device concepts to create a multifunctional photonic crystal based photonic integrated circuit that incorporates quantum dot active regions. We will explore diode injection and extraction to and from engineered quantum dot structures, integrated with spatial selectivity within photonic crystal waveguides and optical nanocavities. This project will encompass three levels of technology research: system integration, novel device structures, and advanced epitaxial growth. In the Photonic Device Research Group, our objective is to demonstrate a photonic microsystem composed of an electrically injected optical source, compact waveguides, detectors, and optical memory elements.

VCSEL Reliability
K. D. Choquette*
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Sun Microsystems

We are investigating the reliability of vertical cavity surface emitting lasers (VCSELs) operating under high temperature and humidity. This research involves the fabrication of several different VCSEL structures, which will be life tested. After testing, the characteristics of the VCSELs will be examined, and in particular the influence of the laser structure on reliability will be ascertained.

Fundamental Research on Infrared Photodetectors
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U.S. Army Research Office, Multidisciplinary Research Program of the University Research Initiative Program, DAAD 19-01-1-0591

This is a Multidisciplinary Research Program of the University Research Initiative (MURI) project on the fundamental issues of infrared detection. We will focus on the following: investigation of HgCdTe defects using first-principles theory together with optical and electrical characterization, which includes nanotechnology characterization of both III-V and II-VI materials using the near-field scanning optical microscope (NSOM) and the transmission electron microscope (TEM); type II antimony-based quantum-cascade photodetectors; and quantum-dot infrared photodetectors (QDIPs) for high sensitivity normal incidence detection. We will also collaborate closely with industry and government laboratories.

High-Speed Wavelength-Agile Optical Network
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National Science Foundation

We propose to explore the architecture and device development issues necessary to develop optical local area networks (LANs) that are ready to interface with optical metropolitan area networks (MANs). Our goal is to develop a clear plan for integration of multiwavelength LANs and MANs in order to improve the degree to which the benefits of high bandwidth in the MANs are delivered to end users on the LANs. Our tasks include the following: quantitatively evaluate the impact of wavelength conversion on network reliability and study the design of all-optical access architectures that leverage high-speed wavelength conversion and add/drop channel capabilities; design and fabricate tunable laser sources and wavelength converters using composite resonator vertical cavity lasers; design and fabricate a novel semiconductor-based wavelength converter capable of format-transparent and ultrafast wavelength conversion; and design and fabricate add/drop filters and photodetectors.

Power and Energy Systems

Fully Integrated Switch-Mode Power Supplies
P. L. Chapman,* C. Liu
Grainger Center for Electric Machines and Electromechanics

A typical switch-mode dc power supply involves several integrated circuits and discrete passive components. By moving all the circuitry to a single integrated circuit, the circuit is reduced in size and potentially cost. Power management and distribution within a chip are better enabled. Several versions of a step-up dc-dc converter have been demonstrated. Newer versions will take advantage of MEMS technology to improve the quality of the passive components and reduce the space occupied by the chip.

* Denotes principal investigator.
Semiconductor Lasers

1065 and 1040 nm DBR Laser Diodes
J. J. Coleman*
HRL Laboratories

Conducted in the Micro and Nanotechnology Laboratory

Narrow linewidth, tunable semiconductor lasers are of interest to a variety of applications, including fiber optic communication systems, optical generation of microwave radiation, remote optical sensing, and molecular spectroscopy. Various configurations of tunable lasers have been analyzed, and a two- or three-section distributed feedback (DFB) or distributed Bragg reflector (DBR) laser is often the choice. The goal of these programs is to develop narrow linewidth, single longitudinal mode, strained layer InGaAs DBR laser diodes operating near 1065 and 1040 nm for remote sensing applications.

Development of Advanced Laser Diode Sources for Remote-Sensing Applications
J. J. Coleman,* G. C. Papen*
National Aeronautics and Space Administration, NAG 1-1861

Conducted in the Micro and Nanotechnology Laboratory

Several outstanding technical issues for narrowband systems, such as water vapor DIAL lidars, must be resolved before solid-state, laser-based remote-sensing systems have widespread use. One issue is the development of cw local oscillators (LOs) based on semiconductor laser diode technology for use as injection seeders, which has not been fully realized because of the severe linewidth, tunability, and stability requirements of narrowband systems. This project will develop novel semiconductor devices specifically for use as tunable LO sources for narrowband water vapor DIAL systems operating in the 940 nm region. Researchers will focus on a novel ridge-waveguide, distributed-Bragg-reflector laser, which has significant performance improvements for optical remote-sensing applications relative to conventional Fabry-Perot or distributed-feedback lasers.

EOSS+ Laser Diode Substrate
J. J. Coleman*
Northrop Grumman Corp.

Conducted in the Micro and Nanotechnology Laboratory

The electro-optic test station known as the EOSS+ is designed to support the testing of laser platforms at 1.064 nm through the use of a laser diode source. The characteristics of this diode, such as center wavelength and peak power, are determined by the capabilities of the test receiver and the design of the EOSS+ unit itself. The purpose of this program is to provide for the fabrication of a custom-built diode grown from a novel substrate designed to meet specification.

High Brightness Laser Diodes
J. J. Coleman*
Nuvonyx, Inc.

Conducted in the Micro and Nanotechnology Laboratory

The objective of this program is to address several issues related to the MOCVD growth and characterization of InGaAs-GaAs strained layer lasers in the range of 920 nm to 1080 nm for high brightness applications. This approach will be to develop a real index guided laser with integrated beam expanders and other active and passive optics formed by selective area epitaxy. Present narrow stripe semiconductor lasers are generally limited to less than 200 mW of fundamental mode output power, because of the narrow aperture. If the beam can be expanded while retaining fundamental mode operation, then the operating power can be correspondingly increased.

Narrow Linewidth, Multiple Wavelength, Simultaneous-Emission Laser Diodes for Remote Optical Sensing and Other Applications
J. J. Coleman*
National Science Foundation, ECS 9900258

Conducted in the Micro and Nanotechnology Laboratory

The proposal describes a program to develop multiwavelength, simultaneous-emission lasers based on a ridge-waveguide distributed Bragg reflector semiconductor laser. The specific example of an application that defines the need of such lasers is the differential absorption, remote optical sensing of water vapor. A multiwavelength source with closely spaced narrow laser lines would be useful to obtain the detailed absorption profile without having to turn the laser on and off the absorption peak as is practiced currently. This program is designed to study and develop a simple multiple wavelength source suitable for these kinds of applications.

Semiconductor Laser Transmitters for Integrated Optical Interconnects
J. J. Coleman*
National Science Foundation, ECD 89-43166

Conducted in the Micro and Nanotechnology Laboratory

This program involves development of semiconductor lasers suitable for use in integrated optoelectronics. There are a number of key technical issues to be addressed in this
program, including the development of etched facet structures, distributed feedback and distributed Bragg reflector grating structures, monolithic space division multiplexing arrays designed for fiber coupling, selective epitaxy for wavelength division multiplexing arrays and for multielement integration, master oscillator-power amplifier (MOPA) configurations, frequency stabilization, and distributed Bragg pulse shaper high-speed parallel-to-serial packet encoders.

Naturally Nanostructured Epitaxial Semiconductors

J. M. Gibson,* D. G. Cahill, J. E. Greene, A. M. Zangwill, J. J. Coleman

*Natinal Science Foundation, DMR 9705440

Conducted in the Coordinated Science Laboratory

This FRG/GOALI proposal addresses basic materials science and engineering issues in a collaborative program between the University of Illinois and Hewlett-Packard Laboratories to understand fundamental phenomena and interactions associated with naturally nanostructured epitaxial semiconductors. Goals of the project are to obtain semiconductor epitaxial nanostructures smaller than feasible via lithography and to examine their applications to novel devices. Strain-induced self-organization and kinetically driven pattern formation are two approaches being taken to achieve naturally nanostructured materials.

Semiconductors

Photoluminescence Studies of Semiconductor Nanostructures and Rare Earth-doped Semiconductor Materials

S. G. Bishop,* I. Adesida, J. J. Coleman, J. O. White

University of Illinois

Conducted in the Micro and Nanotechnology Laboratory

This research program applies photoluminescence (PL), photoluminescence excitation spectroscopy, time resolved PL, and PL imaging to the characterization of defects and impurities in bulk and epitaxial semiconductor materials, and the composition, doping, thickness, interfaces, uniformity, and quantum confinement effects in semiconductor nanostructures. Rare earth-doped semiconducting glasses and rare earth implanted GaN are being developed as sources of near- and mid-IR radiation. Excitation of the intra-4f shell emission from rare earth dopants (e.g. Er\(^{3+}\), Pr\(^{3+}\), Dy\(^{3+}\)) in chalcogenide glasses by broad band optical absorption in the Urbach edge of the host glass is under investigation as a novel optical pumping mechanism.

High Quantum Efficiency Infrared Photodetector Arrays Based on Nanowire Heterostructures

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National Reconnaissance Office, NRC000-05-C-0023

Conducted in the Micro and Nanotechnology Laboratory

The goal of this project is to develop high quantum-efficiency, high color-contrast multi-wavelength quantum wire infrared photodetector (QWRIP) arrays. The QWRIP uses a self-assembly approach to create high-density nanoscale quantum wire structures that provide the basis for high quantum efficiency infrared detection. The QWRIP combines the best features of the quantum well infrared photodetector (QWIP) and quantum dot infrared photodetector (QDIP) to offer normal incidence absorption, high quantum efficiency, and adjustable infrared absorption from 8 to 40 \(\mu m\). Unique polarization sensitive absorption properties of quantum wires enable two distinct quantum wire infrared detection layers (or a quantum wire layer and a quantum well layer) with different spectral responses to be monolithically integrated without interference, yielding excellent color contrast.

Center of Hyper-Uniform Nanophotonic Technologies for Ultra-Fast Optoelectronic Systems (HUNT Center)


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Defense Advanced Research Projects Agency, University Photonics Research Centers Program, HR0011-04-1-0034

Conducted in the Micro and Nanotechnology Laboratory

The mission of the HUNT Center (Center of Hyper-Uniform Nanophotonic Technologies for Ultra-Fast Optoelectronic Systems) is the development of critical technologies, including hyper-uniform nano-photonic fabrication, high performance quantum dot vertical-cavity surface-emitting lasers, and ultra-fast light-emitting transistor-based lasers for the realization of ultra-fast (\(\geq 100\)Gb/s) optoelectronic interconnect systems. Center programs encompass semiconductor nanoscale materials growth, nano-patterning, nanoscale material analysis, nanostructure laser device design and fabrication, optical receiver design and fabrication, as well as high-speed optoelectronics integrated heterogeneously on a common semiconductor platform to perform ultra-fast optical interface functions.

* Denotes principal investigator.
GaAs-based Metal-Oxide-Semiconductor Structures
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Agere Systems
Conducted in the Micro and Nanotechnology Laboratory
The goal of this research program is to develop oxide deposition techniques for the fabrication of GaAs-based metal-oxide-semiconductor field effect transistors (MOSFETs). Various oxides, including SiO$_2$, Al$_2$O$_3$, Ga$_2$O$_3$, and Gd$_3$Ga$_5$O$_{12}$ are deposited on GaAs in an ultrahigh vacuum system at Bell Laboratories to form MOS structures. Researchers will characterize their structural, optical, and chemical properties through transmission electron microscopy, photoluminescence spectroscopy, and Auger electron spectroscopy, respectively, to improve the oxide deposition process.

Ultra-High-Speed Heterojunction Bipolar Transistors
K.-Y. Cheng* kycheng@uiuc.edu
Semiconductor Research Corporation, SRC-2001-NJ-946
Conducted in the Micro and Nanotechnology Laboratory
The goal of this research is to develop viable techniques that allow demonstration of Inp-based HBTs with $f_T>400$GHz for insertion into the ultra-high-speed (>100 GHz) circuits.

VCSEL and Smart Pixel Research for VLSI Photonic Systems
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kycheng@uiuc.edu
Defense Advanced Research Projects Agency, DAAG55-98-1-0303
Conducted in the Micro and Nanotechnology Laboratory
The purpose of this research is to develop technology related to VLSI photonic systems. The scope of the program ranges from basic materials research, to the fabrication of large-scale integrated circuits, to advanced technologies for the integration of systems in heterogeneous materials. Goals of the project include the design, growth, fabrication, and testing of III-V semiconductor vertical cavity surface-emitting lasers; the development of smart pixels, circuits for the detection of optical signals, intelligent routing of the information, and re-emission of optical signals; and the development of techniques for the integration of heterogeneous materials.

Materials Research for High-Performance Optoelectronic Devices Employing III-V Compound Semiconductor Native Oxide Layers
N. Holonyak, Jr.*
National Science Foundation, DMR-9612283
Conducted in the Micro and Nanotechnology Laboratory
The primary thrust of this program is the growth and characterization of heteroepitaxial materials employing quantum wells, quantum dots, layer disordering, and native oxide device definition, e.g. buried apertures. This work is focused on the development of better lasers, LEDs, and transistor lasers.

Surface Engineering for Compliant Epitaxy
K. C. Hsieh,* K.-Y. Cheng,* I. Adesida
Defense Advanced Research Projects Agency, F49620-98-1-0496
Conducted in the Micro and Nanotechnology Laboratory
The goal of this research is to realize dislocation-free and stress-relaxed lattice mismatched epitaxy growth of different compound semiconductors on various substrates across the whole wafer or on selected areas for device integration applications. Our immediate goals include fundamental understanding of the growth conditions related to the formation of strained-modulated and defect-absorbing templates and the development of techniques to fully control the formation of strain-absorbing and deformable growth templates with an emphasis on processing simplicity and system integrability. InP-based optoelectronic and microwave devices will be integrated selectively on surface-engineered GaAs substrates.

Wafer Bonding for Advanced Optoelectronic Devices
K. C. Hsieh,* K.-Y. Cheng
Defense Advanced Research Projects Agency, MDA 972-00-1-0020
Conducted in the Micro and Nanotechnology Laboratory
The goal of this research is to develop wafer-bonding technologies for hybrid integrating mismatched device structures for advanced optoelectronic integrated circuits. The potential applications include fabricating high-performance visible LEDs, vertical-cavity-surface-emitting lasers, resonant-cavity photodetectors, 2-D and 3-D photonic crystals, and high-performance semi-insulating wafer substrates. Our current efforts are focused on developing high-efficient wafer-bonding strategy and fundamental understanding of the hybrid interface properties, including interface microstructures, electrical and optical characteristics, interface strain/stress and
adhesion properties, and so forth. The long-term goals will include developing chip-scale photonic/electronic integration methodologies for high-density 3-D architectures.

**Biologically Inspired Artificial Haircell Sensors**
C. Liu,* D. L. Jones, F. Delcomyn  
*U.S. Air Force Office of Scientific Research, F49620-01-1-0496*

*Conducted in the Micro and Nanotechnology Laboratory*

This work is aimed at developing artificial haircell sensors that are inspired by biological haircell sensors. This work is focused on studying the fundamental principles of neurological responses of haircells to develop micromachined devices that mimic the performance of biological entities.

**CAD Design Tools for Millimeter-Wave Wireless Communication Microsystems**
C. Liu,* M. Feng, S. M. Kang, E. Michielssen, J. Schutt-Ainé  
*Defense Advanced Research Projects Agency, Composite-CAD Program, F30602-97-0328*

*Conducted in the Micro and Nanotechnology Laboratory*

A mixed technology computer-aided design system is being developed for the cost effective design of wireless communication modules that will ultimately enable networked distributed MEMS. The module, operating at millimeter-wave frequencies, will allow direct interface between MEMS transducers and the free-space electromagnetic radiation. MEMS components offer unique advantages for RF circuits. As an example, micromechanical switches exhibit lower insertion loss and higher isolation compared with conventional electronics switching components. MEMS fabrication technology for silicon and composed semiconductor materials is being studied in order to realize mechanical RF switches as well as high-gain antennas to validate results of the E-M simulation.

**Efficient Computational Prototyping of Mixed Technology Microfluidic Components and Systems**
C. Liu*  
*Defense Advanced Research Projects Agency*

*Conducted in the Micro and Nanotechnology Laboratory*

The objective is to develop microfluid components (including pumps and valves), materials (including polymeric MEMS and biodegradable materials), and applications (including drug delivery systems). Microfluid circuits are on the scale of micrometer to millimeter; they are used to transport biological and chemical materials.

**Integrated Biomimetic Sensors Using Artificial Hair Cells**
C. Liu,* F. Delcomyn  
*National Aeronautics and Space Administration, NAG 5-8781*

*Conducted in the Micro and Nanotechnology Laboratory*

The main focus of this work is to develop prototype micromachined artificial haircell (AHC) sensors that can be used as modular building blocks for a variety of sensors for sensing acceleration, flow rate, and tactile information.

**Integrated Capillary Microelectrode Arrays for Studies of Olfactory Response Patterns in the Insect Brain**
C. Liu*  
*Defense Advanced Research Projects Agency, Controlled Biological Systems Program*

*Conducted in the Micro and Nanotechnology Laboratory*

This project aims to develop the first arrayed capillary microelectrodes using integrated microfabrication technology and to demonstrate the enhanced capabilities for monitoring neurological behavior of insect olfactory systems.

**Integrated Sensing: Biomimetic Sensors for Autonomous Underwater Vehicles**
C. Liu,* G. Karniadakis, C. Chryssostomidis  
*National Science Foundation, ECS 02-25519*

*Conducted in the Micro and Nanotechnology Laboratory*

A team of researchers from the University of Illinois and the MIT Ocean Engineering Department join efforts in developing artificial lateral line sensors for autonomous underwater vehicles (AUV) that are useful for underwater exploration, warfare, and security. The lateral line sensor is a basic flow sensor for nearly all species of fish and many amphibian animals. We will develop micromachined underwater flow sensors with artificial haircells, shear stress sensors based on thermal transfer, and pressure sensors. Such sensors will be developed on a flexible substrate suitable for underwater applications.

* Denotes principal investigator.
Integrated Sensitive Skin with Advanced Data Architecture
C. Liu,* N. Shanbhag, D. L. Jones
National Science Foundation, IIS 00-80639
Conducted in the Micro and Nanotechnology Laboratory

An interdisciplinary team of researchers will develop microfabricated, multiple modality sensor skin with advanced data structure and signal processing algorithms. A flexible sensor skin that imitates biological tactile sensors faces important challenges in terms of microfabrication, materials, density of sensors, and accompanying circuits. Prof. Liu and students will develop advanced multimodal sensors with self-configuration capabilities. Prof. Shanbhag is developing energy efficient signal processors, while Prof. Jones is interested in developing signal processing algorithms that are biologically inspired.

Mechanically Conformal and Electronically Reconfigurable Aperture (RECAP) Using Low-Voltage MEMS and Flexible Membrane for Space-based Radar Applications
C. Liu*
Defense Advanced Research Projects Agency
Conducted in the Micro and Nanotechnology Laboratory

The objective is to develop micromachined antennas with reconfigurable wavelength and directionality using micromachined switches. We are currently developing micromachining processes based on polymeric materials to realize three-dimensional RF MEMS.

CAREER: Biologically-Inspired Integrated Sensors for Robotics Applications
C. Liu*
National Science Foundation, IIS 99-84954 CAR
Conducted in the Micro and Nanotechnology Laboratory

This CAREER award is aimed at imitating biological haircell sensors that are widely used in the biological world. The research is focused on developing micromachined artificial haircell sensors for flow sensor applications.

Research Experience for Undergraduates (REU)
C. Liu*
National Science Foundation, IIS 99-84954 REU
Conducted in the Micro and Nanotechnology Laboratory

This grant provides undergraduate students with opportunities to conduct advanced research projects in C. Liu's research group.

Nanoscale Science and Engineering Center (NSEC): Center for Integrated Nanopatterning and Detection Technologies
C. Mirkin (Northwestern Univ.), C. Liu, S. Sligar, G. Shartz, M. Ratman, M. Hersam, and others
National Science Foundation, SBC NW 0830-520-N602
Conducted in the Micro and Nanotechnology Laboratory

This is an NSEC center project in which more than 20 faculty members located at Northwestern University, the University of Illinois, the University of Chicago, and others are participating. The central objective of this center is to develop integrated nanopatterning technologies. The major thrusts in this project are nanopatterning techniques, optical chemical sensors, and microfluid platforms for biological detection. The C. Liu group works in the first and third areas.

Parallel, Ultrafast Sub-100 Nanometer Dip-Pen Nanolithography
C. Mirkin, (Northwestern Univ.) C. Liu*
Defense Advanced Research Projects Agency, Army NW 0650-300F245
Conducted in the Micro and Nanotechnology Laboratory

The Dip Pen Nanolithography (DPN) method is uniquely capable of directly patterning chemicals onto substrates with sub-100 nm spatial resolution. It is a powerful technique for depositing materials for surface chemistry. However, the DPN method typically relies on single probes and is serial in nature. In this work, we develop highly parallel arrayed DPN probes using micromachining techniques. Both passive and active probes are being developed. The active probes can be lifted individually. The actuation is based on thermal bimetallic bending or piezoelectric bending.

Wavefunction Engineering of Individual Donors for Si-Based Quantum Computers
J. Tucker,* M. Feng, Y. C. Chang, T. C. Shen (Utah State Univ.), R. R. Du (Univ. of Utah)
U.S. Army Research Office, 42257-PH-QC

The goal of this multi-investigator program is to develop the basic fabrication and measurement technologies needed to implement a silicon-based quantum computer. To do this, researchers must place individual phosphorous donors into the silicon lattice with atomic precision, establish electrical control over wavefunction overlap between donor-pairs, and successfully detect spin states of the resulting two-electron system by measuring the presence or absence of electronically-induced polarization. The research team does not propose working quantum
logic gates within this three-year project. If successful, however, that goal will be undertaken in a follow-up program that incorporates SiGe overgrowth and patterning of individual top-gates for each P-atom donor.

**Solid State Devices**

**Luminescence and Laser Studies in III-V Semiconductors**
N. Holonyak, Jr.,* G. Walter  
*National Science Foundation, ECS 82-00517  
Conducted in the Micro and Nanotechnology Laboratory in conjunction with the Department of Physics

Heterojunctions in Al$_x$Ga$_{1-x}$As-GaAs and related materials are being examined. Quantum size effects have been observed and have led to single and multiple active layer quantum-well diode light emitters and lasers. Stimulated emission, absorption, disorder, alloy clustering, carrier scattering, phonon processes, tunneling effects, and impurity diffusion in these structures are being studied. Impurity-induced disordering and Al-bearing native oxides are being studied and used to form stripe-geometry lasers and more complicated array structures. Quantum well lasers have been operated in an external grating cavity in an extended wavelength range. Newer forms of quantum-well lasers have been realized, including native-oxide-defined lasers and waveguides. Quantum dot lasers coupled to quantum well lasers are being studied. Also, heterojunction bipolar light emitting transistors (HBLETs) have been identified and are being studied; these include HBLETs both with and without quantum well and quantum dot modifications.

**Quantum-Well Heterostructures**
N. Holonyak, Jr.,* G. Walter  
*National Science Foundation, DMR 89-20538  
Conducted in the Micro and Nanotechnology Laboratory in cooperation with the Department of Physics and the Frederick Seitz Materials Research Laboratory

The fundamental properties of III-V heterostructures grown by vapor phase epitaxy are being studied. On quantum-well MOCVD AlGaAs-GaAs heterostructures, laser operation 400 meV above $E_g$(GaAs) has been observed, the first cw 300 K laser operation has been achieved, laser operation on phonon-sidebands below the confined-particle states has been observed, and alloy disorder and clustering in quantum-well heterostructures have been identified. Impurity-induced disordering of quantum-well heterostructures and Al-bearing native oxides, that is, the native oxide of Al$_x$Ga$_{1-x}$As formed at 400° to 500°C with H$_2$O + N$_2$, are being examined via TEM and photoluminescence studies. This project is the first (1977) to realize p-n quantum-well lasers and to coin the name "QW lasers."

**Thin Films and Charged Particles**

**Epitaxial Growth and Characterization of GaN-based Nitride Semiconductors Using Plasma-assisted Molecular Beam Epitaxy for Development of High-Speed, High-Power Heterostructure Electronic Devices**
K. Kim,* I. Adesida,* S. J. Hong, T. Day, C. W. Park  
*ETRI Electronics, Inc.

The dual objectives of this work are to grow and characterize device-quality heterostructure GaN-based films and use them to develop high-speed, high-power electronic devices. The materials growth is achieved using a plasma-assisted molecular beam epitaxy system designed and fabricated at the University of Illinois. The plasma source is capable of producing contamination-free nitrogen plasmas. The films are characterized using a variety of microanalysis techniques including RHEED, XRD, SEM, TEM, AFM, PL, CL, SIMS, and Hall measurement.

**Tunneling Microscopy**

**Protein Logic**
J. W. Lyding,* S. A. Boppart,* M. Gruebele, G. Timp;  
N. Aluru* (Gen. Engr.), P. Braun* (Mat. Sci. & Engr.), J. Moore* (Chem.)  
*National Science Foundation, NIRT  
Conducted in the Beckman Institute for Advanced Science and Technology

This program seeks to integrate functional protein arrays with nanoscale CMOS on silicon. Natural and artificial ion channels are being utilized to interface between biology and silicon. Selective chemistry utilizing STM patterning is being used to fabricate the protein templates.

* Denotes principal investigator.
Journal Articles

Advanced Processing and Circuits


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Theses

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Optical Physics and Engineering


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Semiconductor Lasers


Semiconductors


### Awards and Honors

**Ilesanmi Adesida**  
Scientific Member, Bohmische Physical Society  
Fellow, Institute of Electrical and Electronics Engineers (IEEE)  
Engineering Council Advisors List for Outstanding Advising, University of Illinois, 1993, 1999  
Distinguished Lecturer, IEEE Electronic Device Society, 1977-1999  
University Scholar, University of Illinois, 1997, 1999  
Associate Member, Center for Advanced Study, 2000-2001

**Keh-Yung Cheng**  
Fellow, Institute of Electrical and Electronics Engineers (IEEE), 2001  
Fellow, American Association for the Advancement of Science (AAAS), 2004  
Ministry of Education Distinguished Visiting Chair Professor, National Tsing-Hua University, Hsinchu, Taiwan, 2003-2004

**Kent Choquette**  
Fellow, IEEE/Laser and Electro-Optical Society  
Fellow, Optical Society of America  
Distinguished Lecturer, IEEE/Laser and Electro-Optical Society, 2000-2001  
Distinguished Lecturer, IEEE/Laser and Electro-Optical Society, 2001-2002  
Engineering Council Award for Excellence in Advising, University of Illinois, 2004

**James J. Coleman**  
Fellow, American Association for the Advancement of Science  
Fellow, American Physical Society  
Fellow, Institute of Electrical and Electronics Engineers (IEEE)  
Fellow, Optical Society of America  
IEEE LEOS William Streifer Scientific Achievement Award  

**Franklin Woeltge Professorship**, University of Illinois Electrical and Computer Engineering Department, 2002

**Milton Feng**  
Fellow, Institute of Electrical and Electronics Engineers (IEEE)  
Fellow, Optical Society of America  
Associate Member, University of Illinois Center for Advanced Study, 1998  
Outstanding Research Award, Dr. Pan Wen Yuan Foundation, Taiwan, 2000  
Nick Holonyak, Jr. Professorship, University of Illinois, 2000-2005  
Best Student Paper Award, International GaAs Manufacturing Conference, 2003

**Nick Holonyak, Jr.**  
Member, National Academy of Engineering  
Member, National Academy of Sciences  
Fellow, American Academy of Arts and Sciences  
Life Fellow, Institute of Electrical and Electronics Engineers (IEEE)  
Fellow, Optical Society of America  
Fellow, American Physical Society  
Member, Center for Advanced Study, University of Illinois  
John Scott Medal, City of Philadelphia, 1975  
Edison Medal, IEEE, 1989  
National Medal of Science, 1990  
Honorary Doctor of Science, Northwestern University, 1992  
Honorary Member, Ioffe Physical-Technical Institute, St. Petersburg, Russia, 1992  
Centennial Medal, American Society for Engineering Education, 1993  
John Bardeen Chair Professor of Electrical and Computer Engineering and of Physics, University of Illinois, 1993-1994  
Honorary Doctor of Engineering, Notre Dame University, 1994  
Fellow, International Engineering Consortium  
Eminent Member of Eta Kappa Nu  
Distinguished Alumnus of Tau Beta Pi  
Foreign Member of the Russian Academy of Sciences  
IEEE Third Millennium Medal, 2000  
Frederic Ives Medal of the Optical Society of America, 2001  
National Medal of Technology, 2002  
Fellow, American Association Advancement Science  
IEEE Medal of Honor, 2003  
Global Energy International Prize, 2003  
Washington Award, Western Society of Engineers, 2004
Lemelson-MIT Prize, 2004  
Von Hippel Award, Materials Research Society, 2004

**Chang Liu**  
Academician, Academia Sinica, 1998  
Faculty Early Career Development Program (CAREER) Award, National Science Foundation, National Science Foundation, 2000