Summer 2007

WIMS WORLD

Director's Message

A few weeks ago, I toured the new addition to our Michigan Nanofabrication Facility (MNF). Now nearing completion of the construction phase, it will bring our total cleanroom area to a little over 10,000nsf, backed up by many times that in supporting infrastructure—clean air, clean water, temperature/humidity control, power, effluent management, and so on. It is an outstanding facility and a tribute to many groups, especially our own cleanroom personnel. An investment in microsystems and nanotechnology, the facility represents both a tremendous commitment and an act of faith.

I sometimes wonder what life would have been like if I had been a history professor! It would probably have been a lot simpler. I would probably have been free to spend more of my time pursuing scholarly matters instead of funding for equipment, supplies, and staff. And just maybe, I would have had as much fun. But, I probably wouldn't have made as much difference. Microelectronics has been a continuing fascination for me, and I think most of us who started out in the early days of integrated circuits realized that we had an opportunity to change the world. But it is an expensive game to play, especially at a university.

I have seen four academic cleanrooms take shape during my career. The first was at Stanford during the formative years 1965–1972. That facility started with a homemade mask maker, a homemade mask aligner, and some castoff Fairchild furnaces, but it fueled a lot of seminal work and educated an outstanding group of students, many of whom went on to lead the development of microelectronics worldwide. In those days, if you had clean water, an aligner, and a few furnaces, you could make important contributions, and the financial commitment was relatively modest.

The first cleanroom here at Michigan (1972–1980) used a mix of purchased and donated equipment, but we had to clean pigeon feathers out of the furnace loading areas on occasion and our APCVD oxide/nitride/poly system could run only if the furnaces were idling and the cooling water, recirculating through a chiller intended for a drinking fountain, didn't heat up too much. That laboratory enabled us to train leaders for the microelectronics industry and help create the field of MEMS, but the required investment was still quite modest.

The present Michigan cleanroom (1982–1988) was designed as part of the EECS building and required a much more major investment. For twenty years, this class-10/class-100 facility has served us well with a full set of tools for silicon and compound device/circuit fabrication. It allowed us to remain a world leader in MEMS and microsystems. The new cleanroom is a commitment to excellence for the next twenty years, but one that now requires a staggering investment. When equipped, the overall facility will represent an investment of over $100M, but that's only part of it. To really deliver also requires an investment in people. In each of these cleanrooms, the facilities got us in the game, but it was the people who produced the victories. With much of the current investment coming from private donors, their acts of faith give us a responsibility to deliver results that will really make a difference. We can only do that by developing the necessary core technologies in the MNF, applying them in important areas, and then successfully transferring them to industry for products that will help people. That means bridging what has been called the "valley of death" and will require underpinning support for facilities and staff, carefully balancing research with application and involving industry early. We have a responsibility to make this work, and the stakes have never been higher. ■

The new addition to the Michigan Nanofabrication Facility, now nearing completion—a commitment to continued excellence in microsystems and nanotechnology.

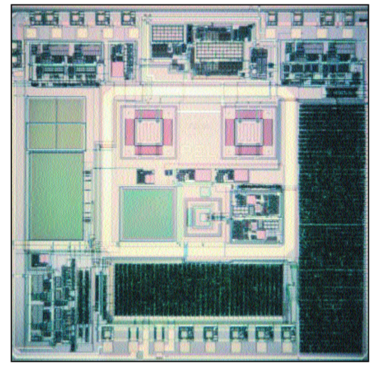
Ken D. Wise

Director, Engineering Research Center for
Wireless Integrated MicroSystems

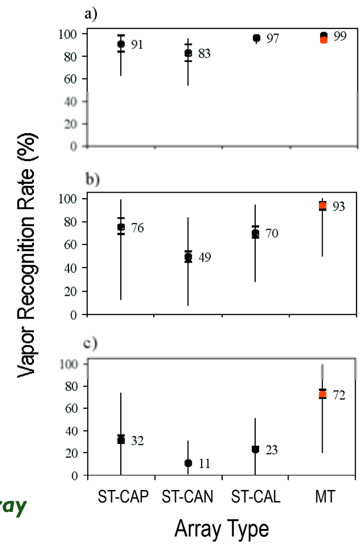
Research Highlights

Multi-Transducer Arrays for Determination of Organic Vapor Mixtures

Chunguang Jin and Edward T. Zellers



In most applications of microfabricated sensor arrays to multi-vapor analysis, the devices employed operate on the same transduction principle. It stands to reason that arrays incorporating sensors that operate on different transduction principles should enhance response diversity by probing different aspects of the vapor-interface interaction, thereby improving vapor discrimination. This study explored and compared capabilities for vapor recognition and quantification with polymer-coated single-transducer (ST) and multi-transducer (MT) arrays. The picture at the right shows an MT array chip (7mm x 7mm) consisting of three different transducers, all with on-chip signal processing circuitry, produced by collaborators P. Kurzawski and A. Hierlemann at ETH, Zurich. Each chip has one cantilever (CAN), one capacitor (CAP), and one calorimeter (CAL), coated with the same polymer. Data from five chips, each with a different polymer layer, were pooled for this study. The primary data set consisted of experimentally derived sensitivities for 11 organic vapors obtained from these 15 microsensors. These were used in Monte Carlo simulations coupled with principal component regression models to assess expected performance. Recognition rates for individual vapors and for vapor mixtures of up to four components were estimated for single-transducer (ST) arrays of up to 5 sensors and MT arrays of up to 15 sensors. Our findings are fourfold. First, recognition rates are not significantly improved by including more than 5 sensors in an MT array for any specific analysis, regardless of difficulty. Second, optimal MT arrays consistently outperform optimal ST arrays of similar size, and with judiciously selected 5-sensor MT arrays one-third of all possible ternary vapor mixtures are reliably discriminated from their individual components and binary component mixtures, whereas none are reliably determined with any of the ST arrays. Third, a "universal" MT array consisting of eight sensors was defined, which provides the best possible performance for all analytical scenarios. Accurate quantification is predicted for correctly identified vapors. Lastly, quaternary mixtures could not be analyzed effectively with any of the arrays. ■

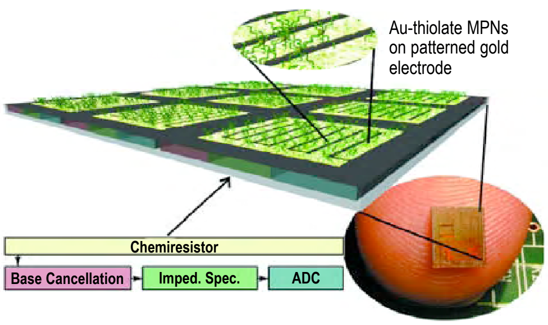


Comparison of 5-sensor ST CAP, CAN, and CAL arrays to 5-sensor MT arrays for recognition of a) 11 individual vapors, b) 55 binary mixtures, and c) 165 ternary mixtures. In a), the 5-sensor MT array is the best selected from 3003 different 5-sensor combinations. In b) and c), a different (optimal) 5-sensor MT array is chosen for each mixture. The confidence interval around the mean recognition rate is shown for each array type, along with the range (minimum to maximum) of recognition rates.

On-Chip Auto Calibrating Impedance Analysis for Gas Sensors

Daniel Rairigh and Andrew J. Mason

Chemiresistors (CR) coated with thiolate-monolayer-protected gold nanoparticles (MPN) exhibit a highly sensitive resistance change in response to absorbed vapors and provide extremely low-detection limits. In practical applications, resolution is limited by the precision of measurement circuits and noise sources in the transducer and electronics. Theoretically, the capacitive response of a CR can be used to improve sensitivity, but this parameter has not been adequately explored due in large part to the absence of appropriate instrumentation circuits. The aim of this project is to develop a microelectronic instrumentation circuit that will elucidate, with high resolution, both the resistive and capacitive response of a CR within a platform suitable for monolithic integration of a gas sensor array microsystem.



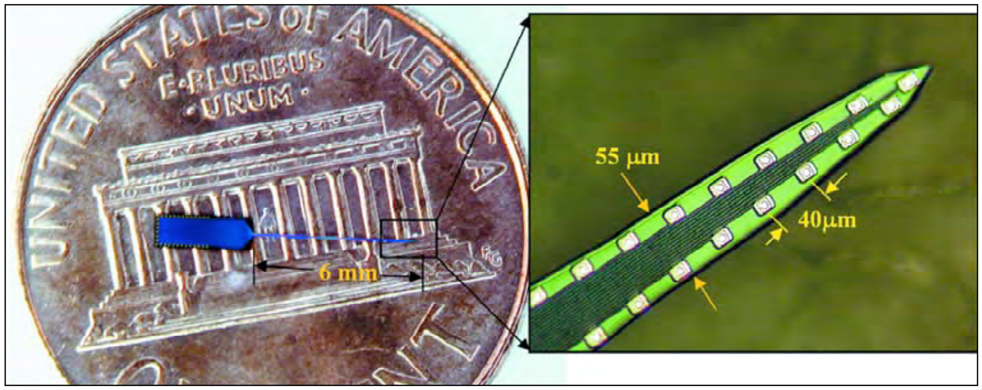
Chemiresistors (CR) coated with thiolate-monolayer-protected gold nanoparticles (MPN) form highly sensi - tive gas sensor arrays when combined with on-chip, low-noise instrumentation capable of canceling baseline drift values and extracting full-impedance spectra response.

The primary challenges for high-resolution CR instrumentation circuitry include 1) presence of significant variance (between elements) and drift (over time) in baseline resistance, 2) smallness of sensor response (~1ppm) relative to baseline value, and 3) measurement of both resistive and capacitive responses to maximize sensitivity. To address these challenges, a new readout circuit for CR sensor arrays has been developed based on impedance spectroscopy (IS). The CMOS analog readout circuit provides rapid, self-calibrated baseline cancellation. After baseline cancellation, IS measurement is applied to extract real and imaginary impedance components as a function of excitation frequency to reveal both resistive and capacitive responses simultaneously. The compact, low-noise instrumentation circuit is suitable for on-chip sensor array integration, which eliminates wiring noise, focuses dynamic range, and maximizes measurement resolution in a single-chip gas analysis system. ■

New High-Density Neural Probes for Studying Effects of Alzheimer's Disease on the Brain's Recording Machinery

Ning Gulari and Kensall D. Wise

The hippocampus is a structure in the brain that is known to play an important role in the recording of information into long-term memory. The hippocampus is also one of the earliest and hardest hit areas of the brain in Alzheimer's disease. Professor György Buzsáki of Rutgers University, a long-time collaborator and ERC outreach faculty member, has been studying how the neuronal circuits of the brain, especially in the hippocampus region, support its cognitive capabilities. Because neural signals are meaningful only when considered in the context of signaling by a whole population of cells, this is a challenging problem requiring simultaneous recording from a large number of neurons in close proximity to each other. Thus, a high-density recording electrode array that is very small in size is crucial. Neural probes created by the University of Michigan and formed using lithographically defined thin films are reliable and can both record and stimulate multiple sites simultaneously. A single-shank, 32-site probe has, for the first time, been fabricated successfully using projection lithography to achieve submicron feature sizes. As a result, this new probe has twice the site density as its predecessors. The new high-density array will offer high-resolution simultaneous monitoring of different hippocampal sub-regions for the first time while minimizing tissue damage, paving the way for better understanding of this critical brain region. ■



New single-shank, 32-site recording probe on the back of a U.S. penny.

Digital Microfluidics With Marangoni Flows—A Contact-Free Technique for Manipulating Microdroplets for Microscale Bioanalytical Systems

Amar S. Basu and Yogesh B. Gianchandani

Microdroplets are an emerging trend in microscale biological and chemical analysis systems. Rather than the traditional approach of guiding reagents in microfluidic channels, samples and reagents are instead dispersed as droplets in a continuous oil phase. With volumes in the range of pico- and femtoliters, microdroplets can provide low reagent consumption, fast reaction times, and high throughput for biochemical analyses. The concept of digital microfluidics uses a PFP (Programmable Fluidic Processors) to manipulate droplets real-time; however, the difficulty with many PFPs is that they rely upon droplet interactions with surface electrodes, which results in contamination, sample loss, and limited reusability.

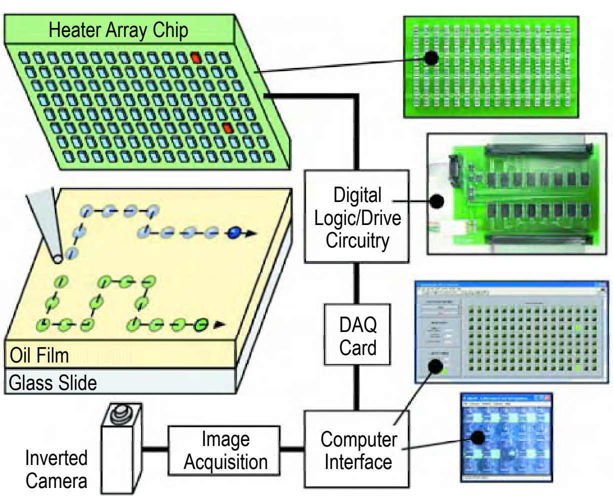


Figure 1 – The complete system for programmable, contact-free droplet actuation based on Marangoni flows, including a 128-pixel array of resistive heaters suspended above the oil layer, control circuitry, and a graphical user interface.

Ongoing work at the Center has resulted in a PFP that allows for contact-free manipulation of droplets. Marangoni flows, driven by gradients in surface tension, are used to transport droplets without physical contact to the oil or the samples. The flows are localized and programmatically controlled by an array of heaters suspended above the oil layer. This project has developed and tested a 128-pixel system, which can manipulate and merge microdroplets with volumes <800nL at speeds up to 200µm/s. Supporting simulation models show that the Marangoni effect scales favorably to smaller dimensions, providing >1mm/s flow velocities with <5 degree change in surface temperature. ■

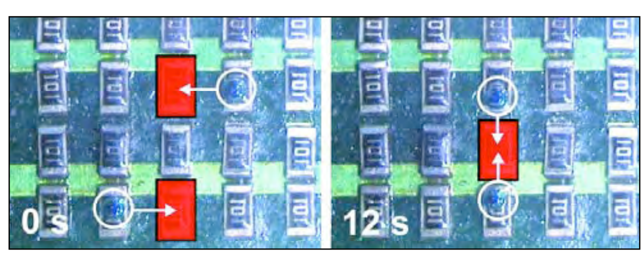


Figure 2 – Droplet merging.

Generic Telemetry Chip for Power and Bidirectional Data Telemetry in Implantable Microsystems

Amir M. Sodagar, Kensall D. Wise, and Khalil Najafi

Thanks to advances in microtechnology, stand-alone subcutaneous operation of biomedical microsystems is now not only possible, but is facilitating important new applications, such as auditory and visual prostheses and bio-signal recording.

To be *implantable*, a microsystem, in general, needs to receive its operating energy from the outside and be able to communicate with the external world bidirectionally. Implantable microsystems, independent of their application, require wireless interface modules with the general block diagram of Figure 1. Data, clock, and power are transferred to the microsystem via the *forward telemetry link*, and a *reverse telemetry link* transmits data from the system to the outside world.

To help minimize the time and effort in designing wireless interface modules with the same general functionality, a generic telemetry chip (GenTel) has been designed for power and bidirectional data telemetry in implantable biomedical microsystems. Figure 2 shows a photograph of the fabricated chip, which measures 2.2mm x 2.2mm. The programmability available in the regulated supply voltage (~2V–5V) and its current delivery (up to 15mA), a similar programmability available for carrier frequencies and bit rates of the forward and reverse telemetry links, and the option of performing data encoding for reverse data telemetry are among the features that make this chip a generic solution for a variety of implantable biomedical microsystems. ■

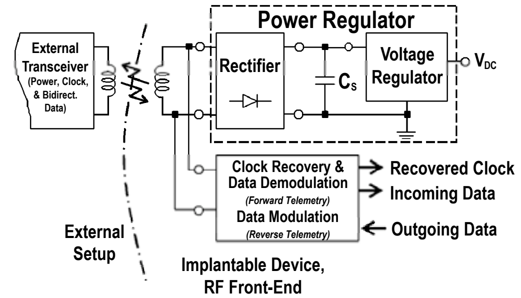


Figure 1 – General block diagram for the bidirectional wireless interface module.

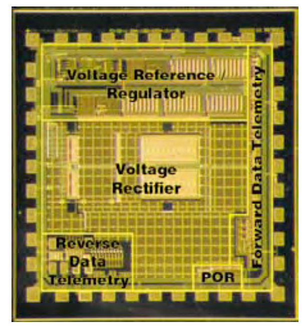
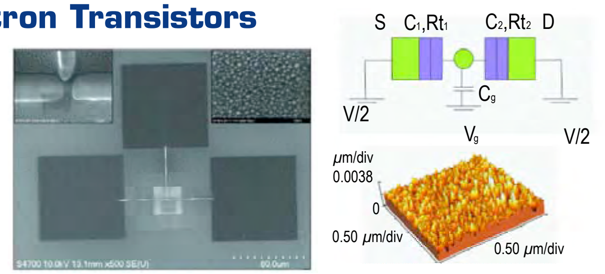


Figure 2 – GenTel chip die.

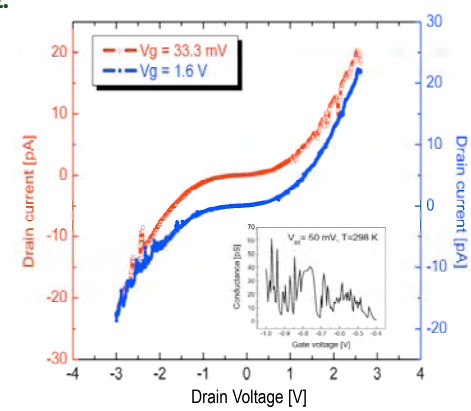
First Room-Temperature, Operational, Single-Electron Transistors From Focused Ion-Beam Deposition

P. Santosh Kumar Karre and Paul L. Bergstrom

Single-electron transistors (SET), operating on the principle of Coulomb blockade (CB) in nanostructures, are promising candidates for future ultra-low-power and high-density integrated devices. SETs are similar to field-effect transistors, but the channel is replaced by a conducting island sandwiched between two tunnel junctions. Because the channel is reduced to a conducting island with dimensions of only a few nanometers, the energy levels in the island are discrete. To observe the CB effect at room temperature, the tunnel resistance of the tunnel junctions must be much greater than the quantum resistance (~26.0kΩ), requiring ultra-low junction capacitances in the range of a few attoFarads, and limiting the average diameter of the quantum-confining islands to below 10nm. Progress towards the realization of room-temperature-operating SETs has been slow because of the technological limitations in the fabrication of nanostructures with sub-10nm dimensions. Room-temperature operation is a critical requirement for practical applications of these devices in logic circuits, as memory elements, sensitive electrometers, and nanosensors. Fabrication of uniform-sized, sub-10nm, quantum-confining islands in a device configuration has been a major challenge in the progress of SET technology. Our novel approach to fabricating SETs uses tungsten nanoislands that exhibit excellent room-temperature operation. Our approach was made possible by recent developments in focused ion beam (FIB) deposition. Several measures suggest success with this method. One, the nanoislands fabricated by FIB deposition have an average diameter of 8nm. Two, the resistance per tunnel junction of the device is calculated to be 25.13GΩ, which is over five orders of magnitude higher than the threshold quantum resistance 26.0kΩ, thus enabling the confinement of electrons to the tungsten quantum dots. Three, the effective capacitance of the device is estimated to be 0.499aF, which yields capacitance of individual tunnel junctions at 0.947aF and charging energy of the device at 160.6meV. Thus, the estimated charging energy is much higher than the thermal fluctuations at room temperature, resulting in the observation of Coulomb blockade and Coulomb oscillations even at room temperature. ■



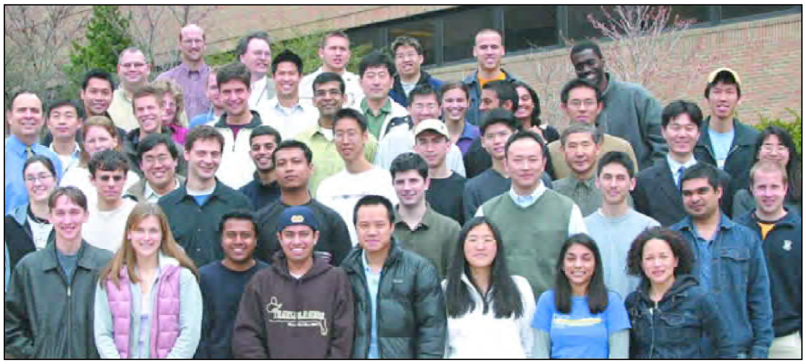
Micrograph of fabricated room-temperature SET (inset on left shows active device area, and inset on right shows conducting nanoislands). Pictorial view of the device structure is shown at top right, and a micrograph of the fabricated nanoislands in Tungsten is shown at bottom right.



Room-temperature device characteristics showing clear Coulomb blockade and oscillations.

Education Highlights

WIMS Education Impacts Culture of Engineering Education: A Look at Undergraduate Education



EECS 425 Undergraduate Students.

This article is the first of a three-part series about the impact of WIMS Education programs on engineering education. This article describes two undergraduate project-oriented courses. The WIMS Center encourages undergraduate students to include capstone major design experience (MDE) project courses and research experiences in their programs. A second article will describe undergraduate research projects, including impact on graduate education. The third article will focus on the impact of WIMS pre-college programs on engineering education.

At Michigan Technological University (MTU), an Integrated Microsystems Enterprise (IME) has the mission to develop and embed world-class wireless sensing systems for applications in science education, environmental monitoring, industrial processes and products, and commercial venues. The IME organizes undergraduate student teams that apply microsystem technologies to real-world system application projects; and it serves as a multi-year capstone major design experience recognized by the Accreditation Board for Engineering and Technology (ABET). In the IME course sequence, students can enroll as early as the second semester of their first year and continue through graduation. The Enterprise operates with both team projects and individual projects supported by fee-for-services and product earnings principles. Enterprises have high appeal to students in engineering (electrical, chemical, and mechanical); computer science; and business. Every year, graduation partially depletes the IME, but new students introduce suggestions based on a "new-set-of-eyes," thoughtful analysis, and mentoring. The IME has pursued several projects during its first five years and can boast some impressive achievements. For example, the Enterprise won first-place in the MTU Undergraduate Expo in Spring 2004. Notably, during the prior academic year (2006–2007), the IME initiated a goal to complement WIMS Education pre-college curriculum initiatives by developing a data acquisition cube (DAC) with plug-and-play, front-end sensor cards that would facilitate exploration of science principles in a high school science class, including acceleration, force, dimensions/altitude, vibration, temperature, light, weather monitoring, and electrical variables.

In EECS 425—Integrated Microsystems Laboratory—at the University of Michigan (U of M), students work in teams to develop a microsystem of

(Continued on page 8)

Personnel Focus

Craig R. Friedrich earned both his B.S. (1978) and M.S. degree (1981) in Mechanical Engineering from Louisiana Tech University (LTU), and a Ph.D. (1987) in Mechanical Engineering from Oklahoma State University. His industrial experience includes serving as senior product engineer at the Pangborn Corp., working in the Nuclear Engineering Division of the Norfolk Naval Shipyard, and providing private consulting in accident reconstruction and products liability. Professor Friedrich joined the faculty of LTU in 1987, where he later became the Associate Director of the Institute for Micromanufacturing (IfM) and the Group Leader in Micromechanical Processes. While at IfM, he pioneered the new field of mechanical micromilling and applied the process to rapid development of x-ray lithography masks, microfluidic components, precision-machined photonic prototypes, and other similar devices and structures.

In 1997, Professor Friedrich joined Michigan Technological University (MTU) where he has helped build research programs in microtechnologies and most recently in nanotechnologies, particularly in nanobiotechnology. He has been involved in the WIMS ERC since the original proposal was developed in 1998, and he has supported both testbeds. Mechanical micromachining has been used to provide microfluidic function in glass substrates and valves, as well as reusable microfluidic connectors for the Center's μGC. Prototype packages of ceramics and plastics have also been investigated as alternatives to silicon. He has also led the development of several types of microactuators for the cochlear implant component of the neural prosthesis testbed. These actuators are capable of providing shape control to attached electrode arrays, and a lithographic process has been developed to mass-produce the devices. It is expected that these devices will form the basis of a complete insertion tool that deposits the electrode array into the ear, and is then removed.

Professor Friedrich has presented many invited talks and edited many volumes in the area of mechanical micromachining. He has received research and teaching excellence awards at both LTU and MTU. Notably, while pursuing his Ph.D., he designed and built a research payload that later flew aboard the Shuttle Columbia in 1991. In addition to continuing with his research interests, Professor Friedrich now serves as Associate Chair and Director of Graduate Studies of the Mechanical Engineering – Engineering Mechanics Department at MTU. ■

Personnel Focus

Pamela Holland Obiomon earned a B.S. degree (1990) in Electrical Engineering from the University of Texas at Arlington, a M.S. degree (1992) from Prairie View A&M University, and a Ph.D. (2003) in Electrical Engineering from Texas A&M University. From 1998 to 1999, she was an adjunct professor at the Rochester Institute of Technology (RIT) where she taught courses in device fabrication and conducted research in the area of latchup minimization techniques. From 2000–2002, she worked for United Space Alliance, a major contractor with NASA, in the Shuttle Avionics Integration Laboratory at the Johnson Space Center, Houston, Texas, where she was responsible for the integration and testing of shuttle hardware and software. She joined the faculty at Prairie View A&M University as an assistant professor in 2003, where she participated in the development of the Computer Engineering program. She became a member of the ERC faculty via collaboration in 2005.

Professor Obiomon's primary role in the Center is to support the Environmental Monitoring and Implantable Neural Testbeds by developing a very-low-power microsystem, able to run on energy scavenging alone, which gathers and stores data from the environment. The research provides important information for optimizing the two testbeds, while also generally addressing the low-power, small-size end of the WIMS spectrum.

Professor Obiomon is spearheading efforts to establish a new area of concentration in the Electrical and Computer Engineering curriculum at Prairie View A&M University to include undergraduate and graduate courses in microsystems and biosensors. For example, she and her students are currently working on capacitive sensor applications in tracking eye pressure for the study of glaucoma and in studying pressure and flow in the cardiovascular system. ■

Industrial Liaison's Report

Our members have already received our Student Resumé Book via the Members Only section at our Web site and via CD at our October Industrial Advisory Board Meeting. The resumé book includes graduate students interested in full-time positions and internship positions, as well as undergraduate students interested in full-time positions.

The Center strives to ensure that all interested students complete an internship at a member company. The internship is an excellent opportunity for real-world experience while still pursuing a degree, and our students are particularly well suited for such placements. They already have the unique experience of working in teams for a sustained period of time, not just for a single course. In many cases, these teams span across different universities and long distances.

Overall, we are preparing our students for success in engineering during the decades ahead. As we move more and more into a global economy, the ability to adapt to new conditions and challenges is critical for professional growth. The ERC utilizes many tools to help the students meet the global challenge. Our testbed meetings use video conferencing so that remote sites can engage better in the meeting discussions. During our Industrial Advisory Board meetings, the ERC sponsors mixers organized by the Student Leadership Council, where students from all of our participating partner universities mingle and network. In addition, students are supported in presenting papers at international conferences where they meet foreign researchers with the same interests, as well as experience local culture. Finally, the Student Leadership Council officers attend the NSF annual meeting where they have the opportunity to engage with other ERC students and exchange experiences.

An internship at a company allows our students to use their ERC-acquired experiences (technical and non-technical) in a new environment where some of the driving forces (cost, facility utilization, etc.) may be different from those they have encountered in school. In turn, the company benefits from having new engineers bring new experiences to the company team. Internships are an excellent opportunity for companies to not only recruit talented young engineers, but to have those interns share their experiences with the whole team.

Internships allow the interns and the company engineers to pool their knowledge and experiences in a way that is not possible at conferences and workshops. If you have not already considered sponsoring a WIMS internship or if you have any questions about the program, please contact me. Internships are truly a win-win situation.

If you, or one of your colleagues, is interested in sharing your activities with our students, please contact me at either (734) 615-3096 or giachino@eecs.umich.edu to schedule a seminar. As always, please visit when in the Ann Arbor area so we can share our latest technical developments and progress with the laboratory expansion. ■

Joseph M. Giachino
Associate Director, Industry

Presentations and Publications

Conference Presentations

IEEE/EMBS International Conference Neural Engineering, Hawaii, USA, May 2007

A. Kamboh, A. Mason, and K. Oweiss "A High-Yield Area-Power Efficient DWT Hardware for Implantable Neural Interface Applications," pp. 212–216

American Society for Engineering Education (ASEE) 2007 Conference and Exposition, Hawaii, USA, June 2007

L. C. McAfee, "Factors for an Effective LSAMP REU," *ASEE Conference Proceedings CD (Paper #AC 2007–2381)*

L. C. McAfee and A. Kim, "Successful Pre-College Summer Programs," *ASEE Conference Proceedings CD (Paper #AC 2007–2415)*

The 50th IEEE International Midwest Symposium on Circuits and Systems (MWSCAS '07), Montreal, Canada, August 2007

D. A. Ortiz and N. G. Santiago, "High-Level Optimization for Low-Power Consumption on Microprocessor-Based Systems," pp. 1265–1268

12th International COMS Conference, Melbourne, Australia, September 2007

E. Romero, R. O. Warrington, and M. R. Neuman, "Energy Scavenging at the Microscale"

Publications

A. Mason, Y. Huang, C. Yang, and J. Zhang, "Amperometric Readout and Electrode Array Chip for Bioelectrochemical Sensors," *IEEE International Symposium on Circuits and Systems (ISCAS)*, pp. 3562–3565, May 2007.

K. Oweiss, "Area-Power Efficient Lifting-Based DWT Hardware for Implantable Neuroprosthetics," *IEEE International Symposium on Circuits and Systems (ISCAS)*, pp. 2371–2374, May 2007.

C. Yang and A. Mason, "Precise RSSI With High Process Variation Tolerance," *IEEE International Symposium on Circuits and Systems*, pp. 2870–2873, May 2007.

A. Kamboh, M. Raetz, A. Mason, and K. Oweiss, A. Mason, Y. Suhail, A. Kamboh, and K. Thomson, "A Scalable Wavelet Transform VLSI Architecture for Real-Time Signal Processing in High-Density Intra-Cortical Implants," *IEEE Transactions on Circuits and Systems I*, vol. 54, no. 6, pp. 1266–1278, June 2007.

P. S. Karre, P. L. Bergstrom, G. Mallick, and S. P. Karna, "Room Temperature Operational Single Electron Transistor Fabricated by Focused Ion Beam Deposition," *Journal of Applied Physics*, 102, pp. 024316, August 2007.

N. Basak, G. L. Harris, J. Griffin, and K. D. Wise, "Thick Photoresist BPR-100 Characterization and Application to Silicon and Silicon Carbide MEMS," *Micro and Nano Letters*, September 2007.

O. Biscette, O. Ejofodomi, G. L. Harris, J. Griffin, and K. D. Wise, "GaAs/GaAlAs Prosthetic Retina," *Electronics Letters*, September 2007.

A. Mason, A. V. Chavan, and K. D. Wise, "A Mixed-Voltage Sensor Readout Circuit With On-Chip Calibration and Built-In Self-Test," *IEEE Sensors J*, vol. 7, no. 9, pp. 1225–1232, September 2007.

J. P. Seymour and D. R. Kipke, "Neural Probe Design for Reduced Tissue Encapsulation in CNS," *Biomaterials*, vol. 28, no. 25, pp. 3594–3607, September 2007.

S. Wright and Y. B. Gianchandani, "Controlling Pressure in Microsystem Packages by On-Chip Microdischarges Between Thin-Film Titanium Electrodes," *Journal of Vacuum Science and Technology B: Microelectronics and Nanostructures*, 25(5), pp. 1711–1720, September 2007.

Seminar Series

*** September 18, 2007**
Professor Christofer Hierold
ETH Zurich
"Carbon Nanotube Sensors"

**Available for viewing on website*

Recent Events — Moving Day at EPB

The WIMS ERC moved this summer to its new location in the Electrical Engineering and Computer Science building.

Education Highlights *(Continued from page 5)*

their choice, typically consisting of a two-chip combination: a transducer chip and a circuit chip. In course projects, students advance from defining a concept, through design, fabrication, and testing in a 14-week, one-semester course. Students keenly develop understanding of interactions among design, fabrication, and testing; six weeks are spent in microsystem design, five weeks in fabrication, and three weeks in testing. For many students, the course project is the only chance they will ever have to take a chip all the way from inception to final validation. Mask fabrication and ion implantation are done in foundries; processes involving chemical vapor deposition are done by process engineers at the Michigan Nanofabrication Facility, with students performing all other processing steps. Designs created by students at MSU and MTU are fabricated at U of M and are then returned to them for testing; during those fabrication weeks, MSU and MTU students fabricate other devices in their own laboratories. Visible imagers, pressure sensors, accelerometers, g-switches, tactile imagers, microflowmeters, micromirror arrays, mass sensors, Pirani gauges, and resonators have been realized. Often, course projects are placed in student resumés and receive broader exposure. Three years ago, an EECS 425 project won second place in the Design Automation Conference student design contest and was featured there and at the International Solid-State Circuits Conference. Students come from various engineering majors (electrical, mechanical, biomedical, and chemical) and from physics.

In sum, course-based projects are opportunities for enrichment experiences for undergraduate students to develop in-depth technical capabilities, confidence, and professional maturity. And, course projects are receiving recognition and awards. Indeed, undergraduate course projects are having positive impacts and changing the culture of undergraduate engineering education. ■

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