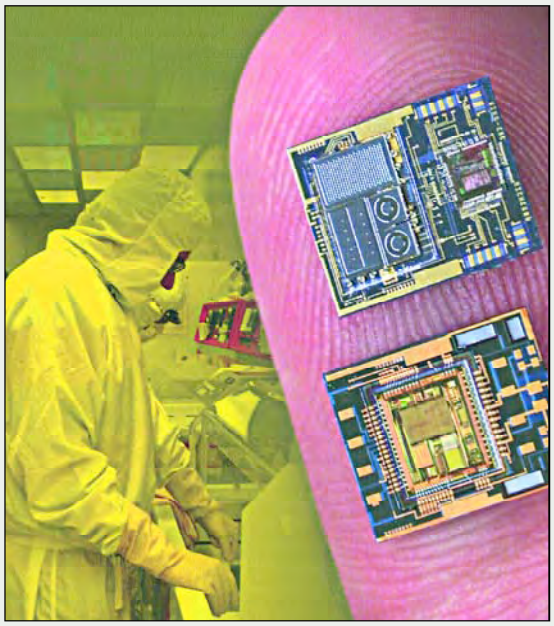
Fall 2007

WIMS WORLD

Director's Message

We started our eighth year as a Center this past term and are now hard at work on plans to expand the Center as we move into an era of decreased funding from the National Science Foundation. That sounds like a conflict in terms, expanding while we are decreasing, but I'm hoping that out of the seed efforts that the NSF has funded here will come a new Center marked by increased flexibility, an expanded and still more diverse faculty, and a continuation of efforts on things that will really make a difference in terms of solving problems of national importance in health care, the environment, security, and energy. If we are to succeed here, it will require two things, both of which are rare to find within academia. The first is a continuation of the *teaming* we have had in this Center over the past eight years—teaming among faculty, students, staff, and our university infrastructure, and teaming among universities on a national and global scale. Finding good ideas is a challenge, and translating those ideas into microsystems is a challenge, but I think in some ways teaming is the most difficult challenge of all. Universities are not set up to make teaming the natural way of things. Faculty are independent and are primarily judged on individual accomplishment. But teaming means that everyone has to set aside a little of what they want to do in order to do things needed by a greater goal. As I have said before in this column, that means that the projects in each of the application areas must be compelling, but it also means that a spirit of cooperation must pervade the entire Center. That is very hard to pull off but in the end is enormously important.



***Microsystems: Big Plans for Small Tools.* Cover illustration from *Search & Discovery, Research at Michigan*, Winter 2008.**

As I have reflected on the past eight years, I have been more and more grateful for the teaming that has characterized the WIMS ERC. We started with a core group of faculty that genuinely enjoyed working together. Many of that original team have now gone on to new opportunities. Others have replaced them, bringing new expertise and perspectives, and our Center has been enriched as a result. Somehow the teaming has continued, but it is harder now than when the Center was new, and it will have to be reborn again with a new and larger set of faculty. Again, working on problems that are compelling and that attack major societal issues is part of the incentive to team. Microsystems are truly an opportunity to change the world.

The second challenge will be to create a *core infrastructure* to support system integration. The realization of microsystems requires a level of staff that cannot be supported on "soft" money, and in spite of the fact that most funding agencies today want to see research prototypes, few faculty can support the infrastructure required to create them, even by teaming. As a result, academic research tends to focus on theory, modeling, materials, and devices. The dilemma is that getting to the microsystem level is what is really required to demonstrate solutions to real problems. Few universities have made the investment required to underpin the necessary core infrastructure with "hard" money and yet without it, research prototypes cannot be realized. Early partnering might allow such prototypes to be generated in industry, but such partnerships typically do not occur until much later in the game, taking the research prototypes into manufacturing prototypes.

These are the real challenges then for successfully taking WIMS to the next level—*teaming* and *infrastructure*, mixed with a more vigorous industrial program. They will require leadership and a willingness to make a high-stakes investment in the future. But if we meet these challenges, the payoff will be no less than to enhance the quality of life for our children and grandchildren. Previous generations did that, and we should do no less. ■

Ken D. Wise

Director, Engineering Research Center for
Wireless Integrated MicroSystems

Research Highlights

Cool MEMS: Micromachined Thermoelectric Cryogenic Cooler

Andrew Gross[1], Gi-Suk Hwang[2], Sang Woo Lee[1], Hanseup Kim[1], Citrad Uher[3], Massoud Kaviany[2], and Khalil Najafi[1]

[1]*Department of Electrical Engineering and Computer Science, University of Michigan*
[2]*Department of Mechanical Engineering, University of Michigan*
[3]*Department of Physics, University of Michigan*

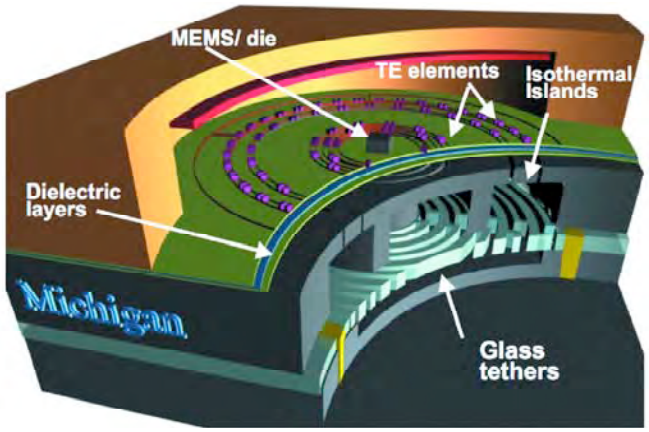


Figure 1 – Cooler showing multi-layer structure.

Electronic and micromechanical devices/circuits, such as resonant sensors, low-noise amplifiers, and micromechanical resonators, exhibit superior performance when operated at low temperatures. To take advantage of these potential performance gains, low-power microscale cooling systems must be developed that can be integrated easily with a wide variety of microfabricated devices. The goal of this project is to develop microthermoelectric coolers capable of cooling MEMS and electronic devices below 200K, while dissipating less than 100mW of power, all in a chip no larger than a few millimeters on a side.

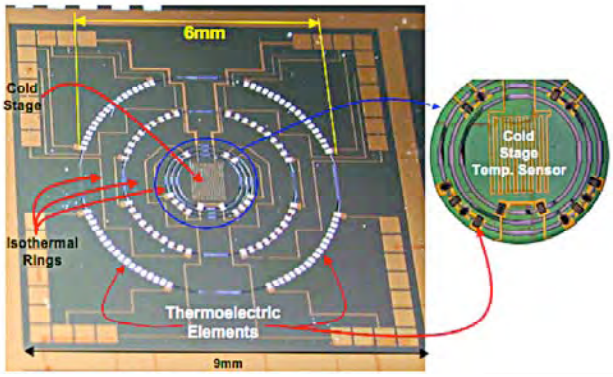


Figure 2 – Fabricated micromachined thermoelectric cooler.

Thermoelectric cooling is quite attractive for small-size devices because its solid-state operation makes it a robust option for microfabrication and long-term operation. Bismuth telluride and antimony telluride have been chosen as the thermoelectric materials for their good thermoelectric properties in the temperature range being pursued. New techniques for depositing and patterning these materials using wafer-level processing have been developed. In order to reduce power, increase cooling temperature, and improve efficiency, these materials were integrated onto a multi-layer, thermally isolating structure (Figure 1). This structure has provided a measured thermal resistance of >15000K/W. The resulting preliminary cooler (Figure 2) has produced a temperature difference of up to 8K, which is quite consistent with modeling results, and modeling suggests that with further optimization of the thermoelectric material properties, and optimization of structure design, temperature differentials as high as 100K easily could be achieved. ■

Student Leadership Council 2008 Officers

The WIMS SLC is part service organization, part social club, and part government that represents students involved in our Engineering Research Center, and is open to all undergraduate and graduate students affiliated with the WIMS ERC.



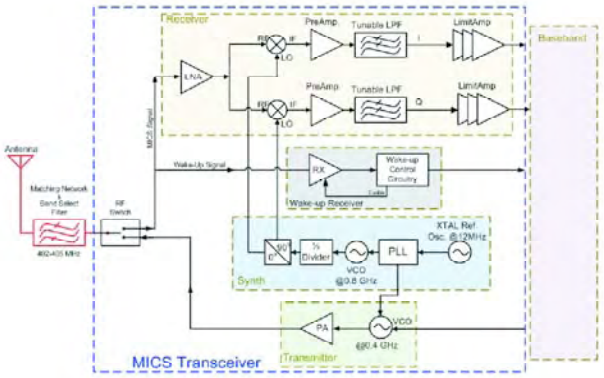
Left to Right – **Chao Yang** (MSU Chairperson), **Zongliang Cao** (MSU Associate Chairperson), and **P. Santosh K. Karre** (MTU Chairperson)

This year's newly elected Student Leadership Council officers are:
Left to Right – **Andy Gross**, Industrial Committee Chair; **Wonbin Hong**, Public Relations Chair; **Angelique Johnson**, Vice President; **Tzeno Galchev**, President; **Allan Evans**, Social Committee Chair; **Etham Aktakka**, Activities Chair; and **Niloufar Ghafouri**, Education Committee Chair (inset).

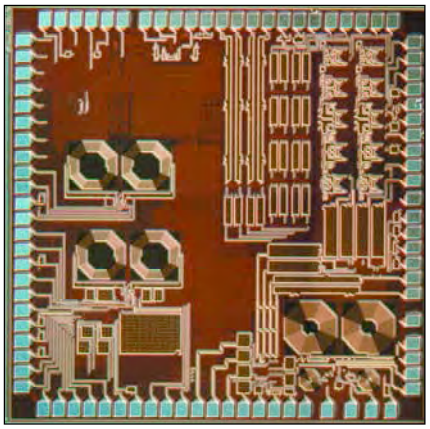
Low-Power Medical Implant Communications Service (MICS) Transceiver

Zheng Wang, Huseyin Savci, James Griggs, Pin Ying, and Numan Dogan

The medical implant communications service (MICS) is an unlicensed, mobile radio system for transmitting data between an outside control unit and implanted medical devices. The MICS transceiver will enable important new applications such as auditory and visual prosthetics and bio-signal recording. In 1999, the FCC allocated the frequency band of 402–405MHz on a shared secondary use basis for medical implant communication services. Biocompatibility, ultra-low-power consumption, and extremely small size are some of the challenges in developing an implant device.



The top figure shows the block diagram of the MICS transceiver. All circuit building blocks with the exception of the RF switch and wake-up receiver have been implemented with a 0.18μm IBM RF CMOS process. The bottom figure shows the micro-photograph of the MICS transceiver, which measures 3mm x 3mm. Reduced supply voltage (1V) has been used for all the circuit blocks for low-power consumption. After careful design of each block, such as LNA, Mixer, PA, and VCO, corners analyses and post-layout simulations are used to ensure first-pass success. Use of reduced supply voltage (1V) and low-power operation presents many challenges for RF and analog circuits. Reduced overdrive voltage and low-current biasing results in increased sensitivity to process and supply variations. In response, dynamic body biasing has been employed to improve the circuit performance for process and supply variations. In TX and RX modes, the MICS transceiver consumes 5mA and 4mA, respectively. Overall, NF of the receiver is 8dB. An 80-pin TQFP is used for testing and characterization of the transceiver building blocks. Lastly, surface-mount PCB is used for test and characterization. ■



Vacuum Packaging of High-*Q* Micromachined Gyroscopes

Sang-Hyun Lee, Jae Yoong Cho, Sang Woo Lee, and Khalil Najafi

Vacuum packaging of micromachined gyroscopes for use in inertial navigation has been a major challenge. A wafer-level, environment-resistant package that can provide a stable, high-level vacuum has been developed and demonstrated with tuning-fork micromachined gyroscopes created at Georgia Tech. The vacuum package (Figure 1) incorporates a suspended platform, made from a thin glass layer, that supports the gyroscope and isolates it from the external environment; a silicon cap that provides vacuum; and vertical feedthroughs that transfer signals to the outside world. A thin-film getter is used to improve the vacuum pressure inside the package. Micromachined resonant gyroscopes with a quality factor Q, as high as 80,000 at room temperature, have been packaged and tested. This is the highest Q reported for any wafer-level, vacuum-packaged microgyroscope. To produce this high Q, the pressure inside the package is less than 5mTorr. The packaging technology is generic and is compatible with both die- and wafer-level processing. Any MEMS die, fabricated using any MEMS technology, can be vacuum packaged using this technology. The packaging technology can also be used with a variety of MEMS devices, including micromachined resonators used in RF-MEMS and micromachined infrared (IR) detectors. If your group is interested in utilizing this technology for prototype packaging please contact Professor Najafi. ■

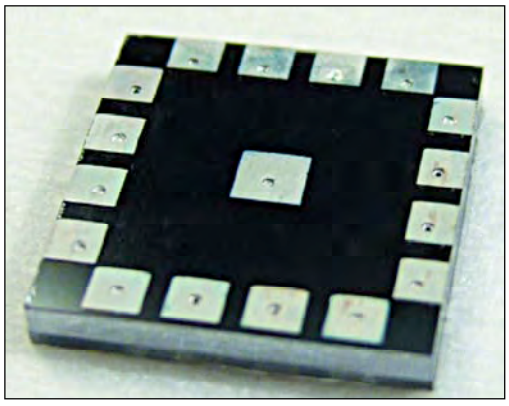


Figure 1 – Photograph of a completed vacuum package showing the vertical feedthroughs on the front side of the chip. The feedthroughs connect the gyroscope inside the package and is neither visible nor vulnerable to the outside world.

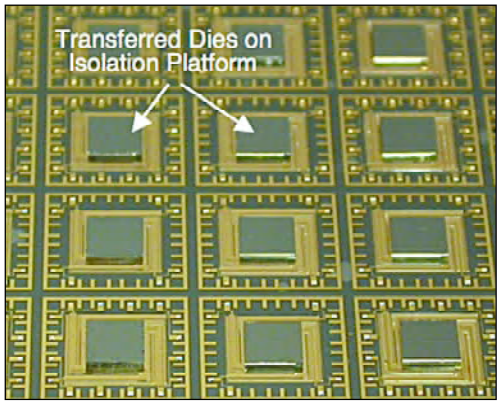


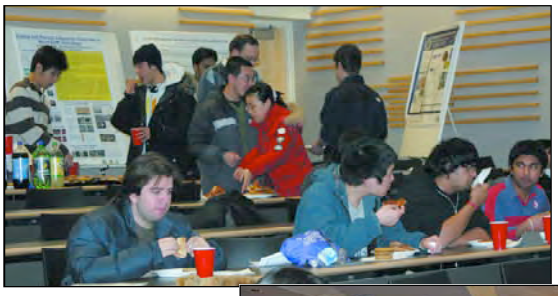
Figure 2 – Photograph showing a number of microgyroscope dies mounted on the suspended glass platform that provides environmental isolation. The cap wafer for vacuum packaging is not shown here.

Recent Events

Industrial Advisory Board Meeting Brings Industry, Faculty, and Students Together

On October 23-24, WIMS hosted its Industrial Advisory Board meeting at the Four Points Sheraton in Ann Arbor. Once again, members of industry had the opportunity to talk with WIMS students about their projects during the poster sessions. In addition to meeting the research faculty and students, the IAB had the opportunity to meet with U-M faculty serving administrative roles. During the Round Table discussions, Professor Stephen Forrest, U-M Vice President for Research, reviewed the new initiatives that the University has enacted to reduce the barriers and provide incentives for an increasingly productive interaction with industry. At the IAB dinner, U-M President Emeritus James Duderstadt addressed the challenges and opportunities that the global, knowledge-driven economy will present to the training of the engineers of the future. Another highlight of the evening was the presentation of the WIMS Student Leadership Council's (SLC) Outstanding Leadership Award, which was given to Ruba Borno, by current SLC President, Tzeno Galchev. ■

Introduction to WIMS: Undergraduate Research



In December, the WIMS ERC sponsored an evening program to introduce WIMS research to U-M undergraduate students. The goal was to excite interest in the cutting-edge work done by the Center's faculty, staff, and students in the areas of WIMS and MEMS, and their numerous applications. Following a casual "eat and greet" where guests and hosts could mingle and have some refreshments, the event officially commenced with a presentation by Center Director Ken Wise. Professor Wise gave an overview of WIMS, and leading WIMS faculty took over the podium with their own focused introductions of the Center's various research thrusts and system testbeds. With the WIMS ERC's growing impact on more and more of society's most pressing needs, each student guest, no doubt, found something at the event of special interest to him or her. The event concluded with informal discussions between students and faculty, who hoped to both enlighten and recruit. The timing of the event was opportune, as 10 to 15 new undergraduate research positions are available for Winter Term 2008 at the U-M. ■

Education Highlights

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

Robert Hennessy, José Diaz-Velazquez, Rachel Lance, Adam Borchert, D'Mark Hunter, Edna Kollarits, Ramon Mercado-Reyes, Fatima Otori

This article is the second of a three-part series covering the impact of WIMS Education programs on engineering education. The first article highlighted WIMS project-oriented courses: MTU's Integrated Microsystems Enterprise (IME) multi-term major design experience (MDE) and U-M's EECS 425 Integrated Microsystems Laboratory single-term MDE. This second article describes two initiatives that permit undergraduate students to participate in the WIMS research endeavor, including subsequent impact on graduate education. The third article will focus on the positive effects of WIMS pre-college programs.

Undergraduate students benefit highly from MDE courses and research experiences in their programs, and it has influenced their decisions to pursue graduate study. Accordingly, the ERC has developed two undergraduate research programs: (1) WIMS Undergraduate Research (WUGR) program for students attending U-M or a core partner university (MSU, MTU); and (2) Research Experiences for Undergraduates (REU) summer program primarily for students at universities external to the Center. In both programs, the research projects directly engage students in pioneering interdisciplinary experiences with mentoring by advanced graduate students, post-docs, and world-class faculty members. Students learn first hand the satisfaction of frontier research endeavors with achievements that benefit society. Undergraduates get a glimpse of graduate student life at a major research university. Also, they establish potentially lasting connections for future career networking opportunities while making valuable contributions to the WIMS research enterprise. Graduate students benefit by gaining research project management experience. WIMS has operated six summer REU programs since 2002, involving 52 students in research, communication skills, professional ethics, graduate study, and social events. Proudly, 83% of eligible REU students have entered graduate study. Since 2003, the WUGR program has provided year-round research opportunities to approximately 100 students with the sole component being research projects with mentoring. Each Fall Term, the Center conducts an "Introduction to WIMS Undergraduate Research" session to attract undergraduate students. At U-M, the standard schedule is for students to conduct independent-study research during the Winter Term, followed by full-time research during the Summer Term.

Notably, students from these programs have been recognized by high placement in contests, competitions, awards, recognitions, and publications. Overall, undergraduate research programs are having positive impacts and changing the culture of undergraduate and graduate engineering education. ■

Personnel Focus

Numan S. Dogan earned a B.S. degree in Electrical Engineering from Karadeniz Technical University, Trabzon, Turkey, in 1975; his M.S. in Electrical Engineering from Polytechnic University, New York, NY, in 1979; and a Ph.D. in Electrical Engineering from the University of Michigan in 1986. From 1986 to 1994, he was a faculty member at Washington State University, Pullman, WA. From 1995 to 1998, he served as Chair of the Department of Electrical Engineering, Tuskegee University, Tuskegee, AL. In 1998, he joined the North Carolina A&T State University, Greensboro, NC, where he is now Professor of Electrical and Computer Engineering. He joined WIMS ERC faculty (Wireless Interfaces Thrust) in August 2004. He is currently working on the design and implementation of a medical implant communication service (MICS) transceiver. The MICS transceiver is an ultra-low-power, unlicensed (402–405MHz), mobile radio system for transmitting data between an outside control unit and implanted medical devices. His research group successfully designed and implemented the first MICS transceiver prototype using an IBM 0.18μm CMOS process. The MICS transceiver measures 3mm x 3mm and operates with a 1V supply voltage. It is currently being tested for functionality and performance. Professor Dogan also developed a partnership with 3Phoenix, Inc. and received Phase I and Phase II ONR STTR projects to design and implement wireless sensor networks for U.S. Navy Applications. His SOI CMOS UHF receiver work was recognized by the NASA Glenn Research Center with a Group Achievement Award in 2007. In addition, Professor Dogan has received numerous invitations to deliver lectures and seminars on low-power RF CMOS circuits for wireless applications. He is a Senior Member of the IEEE and was the founding member of the IEEE joint chapter (SSC, ED, and MTT-S), serving as Chapter Secretary in its first two years. He also served as the Chair of the IEEE Central North Carolina Section and the Vice Chair of the IEEE North Carolina Council. His newest research is in the area of RF/millimeter-wave CMOS circuits for wireless applications. ■

Tech Day 2007

WIMS ERC students participate in Tech Day each year. Tech Day is the U-M College of Engineering's annual fall event that invites prospective high school students and their parents to explore Michigan Engineering. Tech Day brings over 500 prospective students to campus. High school students in the 11th and 12th grades and prospective college transfer students are welcome to participate in a full day of scheduled events. The Center's participation showcases our cutting-edge research and helps to entice the best students into science and engineering. Prototype MEMS and integrated circuit devices are displayed for students to view. Additionally, systems made in our undergraduate microsystems laboratory class, EECS 425, are highlighted. This year, the students and their parents were also given a tour of the Michigan Nanofabrication Facility. ■

Industrial Liaison's Report

***Industrial Advisory Board* Meeting**
May 20–21, 2008

During the late fall, I attended two meetings that addressed the same concern—how to change engineering education to ensure that we produce the most innovative engineers of the future. The Industrial Advisory Board (IAB) meeting in October and the NSF Engineering Research Center Annual Meeting in November both explored the issue of keeping our graduates in the forefront of engineering.

One theme common to both meetings was the need to expand the team concept and system development. One part of the expanded team concept involves offering business courses that show engineers the process of taking their innovations to market. Fortunately, WIMS is deeply involved in supplying an opportunity for our students to work in teams and gain business acumen. Our testbed concept requires that our students work in teams, and each testbed technical director works with the teams to ensure that their individual efforts support the testbed.

The U-M College of Engineering, in conjunction with the Business School, is not only offering student courses, it is encouraging students to partner with MBA students to produce business plans and seek funding for their ventures. Similarly, the Enterprise Program at Michigan Technological University has undergraduates forming business ventures to market their innovations. While this is an excellent start, the meetings made clear that we must continue to improve.

U-M President Emeritus James Duderstadt addressed our IAB concerning the state of engineering education. Dr. Duderstadt emphasized that engineering education must change much as medical education changed in the beginning of the 20th century. Minor changes in how things are done will not keep us in the forefront; rather, we must examine engineering programs in depth and make substantial changes to the engineering profession. Dr. Duderstadt has authored a report, *Engineering for a Changing World—A Roadmap to the Future of Engineering Practice, Research, and Education*, that addresses this challenge.

The IAB also heard from U-M Vice President for Research, Stephen R. Forrest, on the actions the University is undertaking to enable robust industry interactions. The University has reduced the overhead charges for industrially-sponsored research and will also now consider cost sharing for industrial research programs. The University has also established a Business Engagement Center to connect industry more effectively and efficiently with the many resources available around campus. One of the aims is to involve students in research that in the long term is targeted for commercial applications. The research will still need to be innovative, challenging, and publishable. To obtain more information about the Business Engagement Center contact Daryl Weinert (weinert@umich.edu), Interim Executive Director.

While the WIMS ERC is changing, we realize that the global marketplace is also rapidly changing. To stay in the forefront, we need to adapt quickly. If you have any suggestions on how we can assist in meeting the challenges of the coming years, please contact me.

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 Sensors Conference, Atlanta, GA, October 2007

Y. Li, K. Baek, M. N. Gulari, and K. D. Wise, "A Drug-Delivery Probe With an In-Line Flowmeter Based on Trench Refill and Chemical Mechanical Polishing Techniques," pp. 1144–1147

C. Jin, P. Kurzawski, A. Hierlemann, and E. T. Zellers, "A Comparison of Multi-Transducer Arrays and Single-Transducer Arrays for the Determination of Multi-Vapor Mixtures," pp. 1217–1220

K. Najafi, "Packaging of Implantable Microsystems," pp. 58–63

S. W. Yoon, S. Lee, N. C. Perkins, and K. Najafi, "Vibration Sensitivity of MEMS Tuning Fork Gyroscopes," pp. 115–118

Emerging Nanoscience Applications in Technology and Biomedicine (ENATBio), Wayne State University, Detroit, MI, October 2007

A. Shao, D. M. Aslam, and E. T. Zellers, "Carbon Nanotube Selective Growth for Micro Gas Chromatograph and Chemical Nano-Sensors"

Munushian Lecture, University of Southern California, Los Angeles, CA, November 2007

K. D. Wise, "Wireless Integrated MicroSystems: Coming Revolution in the Gathering of Information," (Invited)

SRC/NSF Forum on Nanomorphic Systems, Stanford University, Stanford, CA, November 2007

K. D. Wise, "Opportunities in Nanomorphic Systems: Microsystems Based on Nano-technology and Beyond"

Microelectromechanical Systems-Materials and Devices, Materials Research Society 2007 Fall Meeting, Boston, MA, November 2007

H. Xia, W. R. Knudsen, and P. L. Bergstrom, "Fabrication of C54-TiSi2 Thin Films by Using Cathodic Arc Deposition and Rapid Thermal Annealing," vol. 204 (5), pp. Paper #DD6.29

EEJ Int. Analog VLSI Workshop, Bunratty, Ireland, November 2007

D. Rairigh and A. Mason, "Compact Impedance Spectroscopy for High Density Sensor Arrays"

IEEE International Symposium on System-on-Chip, Tampere, Finland, November 2007

S. Hanson, B. Zhai, D. Blaauw, and D. Sylvester, "Energy-Optimal Circuit Design," pp. 1–4

IEEE International Conference on Biomedical Circuits and Systems (bioCAS), Montreal, Canada, November 2007

C. Yang, D. Rairigh, and A. Mason, "Fully Integrated Impedance Spectroscopy for Biochemical Sensor Arrays," pp. 21–24

IEEE International Symposium on Circuits and Systems (ISCAS), New Orleans, LA, November 2007

C. Yang and A. Mason, "Precise RSSI With High Process Variation Tolerance," pp. 2870–2873

International Conference on Engineering Education and Research (iCEER), Melbourne, Australia, December 2007

L. C. McAfee Jr., K. D. Wise, and P. L. Bergstrom, "Improved Engineering Education Through Undergraduate Projects and Research"

L. C. McAfee Jr., K. Najafi, Y. B. Gianchandani, M. P. Flynn, K. D. Wise, and M. M. Maharbiz, "A MEMS/Microsystems/Electronics Curriculum With International Dissemination"

40th International Symposium on Microarchitecture, Chicago, IL, December 2007

M. Chu, R. A. Ravindran, and S. A. Mahlke, "Data Access Partitioning for Fine-Grain Parallelism on Multicore Architectures," pp. 369–378

Publications

A. M. Kamboh, A. Mason, and K. Oweiss, "Analysis of Lifting and B-Spline DWT Implementations for Implantable Neuroprosthetics," *Journal of Signal Processing Systems*, December 2007.

H. Kim and K. Najafi, "Characterization of Aligned Wafer-Level Transfer of This and Flexible Parylene Membranes," *Journal of Microelectromechanical Systems*, vol. 16 (6), pp. 1386–1396, December 2007.

J. A. Potkay, G. R. Lambertus, R. D. Sacks, and K. D. Wise, "A Low-Power Pressure- and Temperature-Programmable micro GC Column," *Journal of Microelectromechanical Systems*, vol. 16, pp. 1071–1079, October 2007.

Doctoral Dissertations

Ivan T. Bogue, "Digitally Assisted ADCs"
University of Michigan, 2007
Postgraduate Position: Senior Mixed Signal Design Engineer with Xilinx, Cork, Ireland
Advisor: Professor Michael P. Flynn

Wen-Lung Huang, "Fully Monolithic CMOS Nickel Micromechanical Resonator Oscillator for Wireless Communications"
University of Michigan, 2007
Postgraduate Position: Postdoctoral Fellow, University of California at Berkeley
Advisor: Professors Clark T.-C. Nguyen and Michel M. Maharbiz

Jay Mitchell, "Low Temperature Wafer Level Vacuum Packaging Using Au-Si Eutectic Bonding and Localized Heating"
University of Michigan, 2007
Postgraduate Position: U-M Research Fellow and CEO of ePack, Inc.
Advisor: Professor Khalil Najafi

Bhaskar Mitra, "DC Pulse-Powered Microdischarges on Planar Electrodes and Their Use in Liquid Phase Chemical Sensing in Ambient Air"
University of Michigan, 2007
Advisor: Professsor Yogesh B. Gianchandani

Robert M. Senger, "Micropower Digital Design Techniques for the Nanometer Realm"
University of Utah, 2007
Postgraduate Position: IBM, Austin, Texas
Advisor: Professor Richard B. Brown

Warren C. Welch, III, "Vacuum and Hermetic Packaging of MEMS Using Solder"
University of Michigan, 2007
Postgraduate Position: RF Micro Devices, North Carolina
Advisor: Professor Khalil Najafi

Motorola Awards Grant to WIMS for Teens Program

MSU's WIMS for Teens program was recently awarded an Innovation Generation Grant from the Motorola Foundation. Eileen Sweeney, Director of the Motorola Foundation, praised the WIMS for Teens program and justified the $50,000 grant in this way: "All of us at Motorola are advocates for education and applaud the work that MSU is doing to ignite an interest in science, math, and engineering at an early age, particularly for girls and the underserved." The money will enable the summer residential program to double in capacity and expand from one week to two weeks. ■

Seminar Series

***October 9, 2007**
Surendra K. Ravula, Sandia National Laboratories
"Hybrid Neural Microsystems for Studying Signal Transduction in the Nervous System"

***October 17, 2007**
Professor Massood Atashbar, Western Michigan University
"Sensor Technology Research at Western Michigan University"

***October 25, 2007**
Joshua J. Whiting, Ph.D., Sandia National Laboratories
"Next Generation MicroChem Lab Development at Sandia National Laboratories"

***November 7, 2007**
Professor David Wentzloff, University of Michigan
"An Introduction to Ultra-Wideband Communication, Circuits, and Systems"

***December 5, 2007**
Dennis Buss, Ph.D., Texas Instruments, Inc.
"Si Technology Roadmap for Ubiquitous Computing"

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WIMS WORLD is published quarterly by the Engineering Research Center for Wireless Integrated MicroSystems.

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