Spring 2010

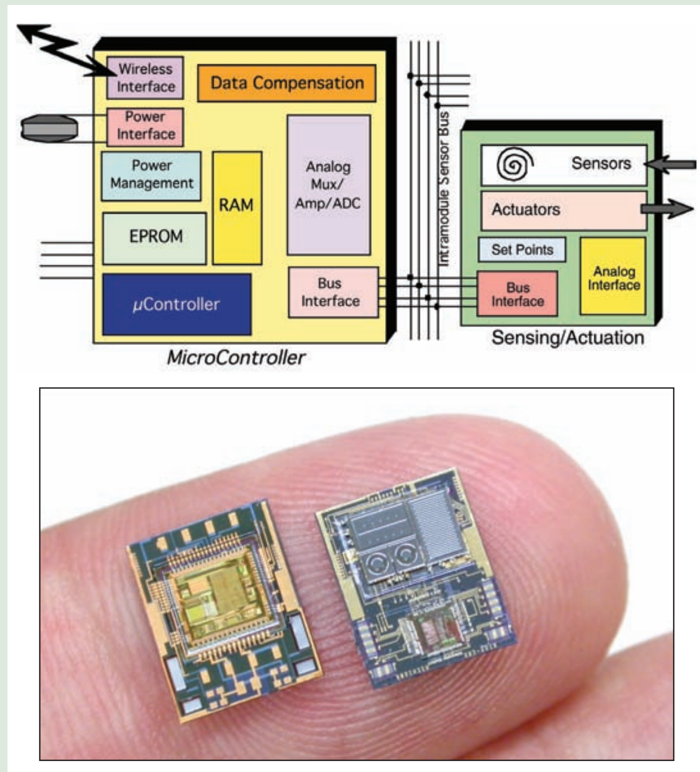
WIMS WORLD

Director's Message

This past quarter was very important in the history of the WIMS ERC. We turned in a draft of our Final Report to the National Science Foundation in April and had our last Site Visit in May, combined as usual with a meeting of our Industrial Advisory Board. And in June, there was the biennial Hilton Head sensor meeting, which featured papers by many of our students and former students. This was the last full quarter of direct NSF support for the Center, but after "graduation" from NSF funding in September, our work will continue under funding from other NSF programs, other federal agencies, industry, the University of Michigan, and U-M's College of Engineering.

As I look back over my career in microelectronics, I'm grateful for the exciting opportunities the area provided. The sensor efforts started out as an offshoot of the broader microelectronics community and were built on the conviction that integrated circuit technology could be used to form integrated sensors and microactuators and that these devices would be necessary in allowing microelectronics to become truly pervasive in changing the world. Integrated sensors were a great fit to the interdisciplinary nature of research universities, and the field was led by six schools in the U.S. and a few more around the globe during the 1970s, '80s, and early '90s. In the '80s, the conferences that defined the field were born, and by the mid-1990s, we witnessed a major proliferation of funding and players (academic and industrial) worldwide. It was, and still is, an area ripe with innovation. Several years ago, I commented in this newsletter that a mark of success for "MEMS" would be when it disappeared; instead of being a technology looking for applications it would simply be the way certain functions are done. Today, that has largely occurred. Even though the MEMS family tree has more branches than ever, a portion of the field has matured and is indeed changing the world. Just as paradigm shifts in electronics were introduced by the inventions of the transistor and the integrated circuit, I believe another paradigm shift has been introduced by the confluence of very low-power signal processing, sensing, and wireless connectivity. The resulting microsystems will create new electronics that will reach out into untold application domains to enhance our quality of life.

Success in this new electronics will demand some changes. Universities may do most of the research, but it will not be enough to stay with materials- and device-level projects alone. Fundamental work in these areas must continue but will need enough of an application overlay to steer the results into solving real problems. And university research will need to address the entire system — data acquisition, interpretation, communication, and integration — so programs will need to be bigger than one or two faculty, be interdisciplinary, and have enough staff to produce working prototypes that can demonstrate solutions to important problems. The NSF Engineering Research Centers are very well targeted but there are too few of them.



Model for microsystems. Such hybrid, densely integrated, digitally compensated wireless devices will change the world more than we can possibly imagine.

With most support for academic research currently coming from federal agencies, some states need to do a lot more, defining and supporting research centers in key areas of societal need. Too many states ignore this area, oblivious to the critical roles such centers can play in creating jobs and improving the quality of life. As a result, academic research has sometimes grown topsy-turvy with too many players and too little coordination. In Indiana, where I grew up, things were better partitioned. If you wanted to go into law, you went to IU; if you wanted engineering, you went to Purdue. Efficiency was improved and the state could take a stronger role in supporting critical areas. But with the present reliance on the federal government alone, demands far outstrip available

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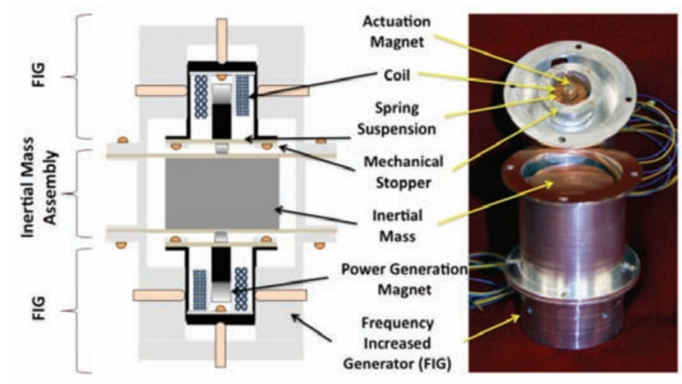
Research Highlights

A Vibration-Harvesting System for Bridge Health Monitoring

Tzeno Galchev, James McCullagh, Rebecca L. Peterson, and Khalil Najafi

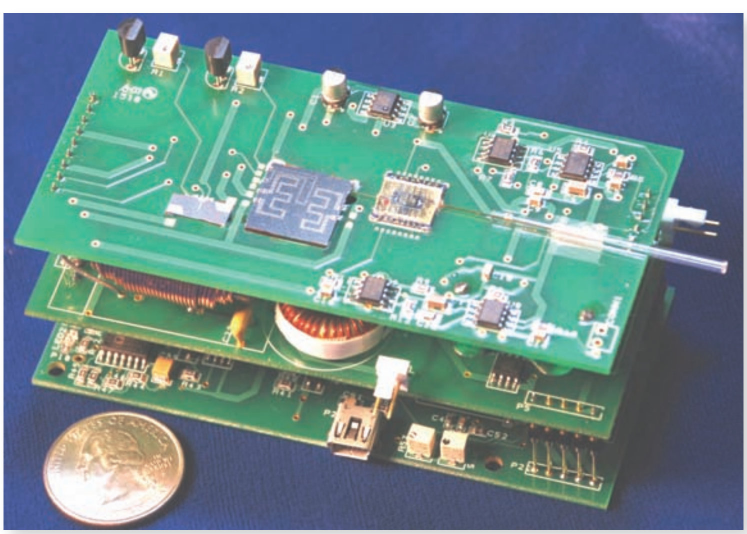
Wireless sensor nodes can be used to monitor the structural health of critical infrastructure such as bridges, but alternate power sources are needed to avoid costly battery replacement during long-term field deployment. To this end, an energy harvester capable of scavenging low-amplitude, low-frequency, non-periodic bridge vibrations was designed, fabricated, and tested. The harvester uses a Parametric Frequency Increased Generator (PFIG) non-resonant architecture, where a bi-stable, low-frequency mechanical structure is used to induce high-frequency mechanical oscillations in an electromechanical transducer. An inertial mass, responding to bridge vibrations, snaps back and forth between two Frequency Increased Generators (FIGs). The mass and FIGs latch and de-latch magnetically; when de-latched the FIG resonates to convert stored mechanical energy into electrical. Two sets of cascaded 6-stage Cockcroft multipliers rectify and boost the FIG voltage, to be stored and supplied to the sensor node. Energy harvesting has been successfully demonstrated with low-frequency (<10Hz) vibrations to power LEDs or ring oscillators. The fabricated device generated a peak power of 57μW and an average power of 2.3μW from an input acceleration of 0.55m/s^2 (55mg) at only 1Hz. The device bandwidth at 55mg is 10Hz, its internal volume is 43cm^3 (68 including casing), and it operates over unprecedentedly large acceleration (0.55–9.8m/s^2) and frequency ranges (up to 30Hz) without modifications or tuning. ■



The PFIG schematic shown alongside a photograph of the partially opened device.

A Palm-Size, Completely Integrated μGC

Robert Gordenker, Hassan Lahiji, Shaelah M. Reidy, Katharine Beach, and Kensall D. Wise

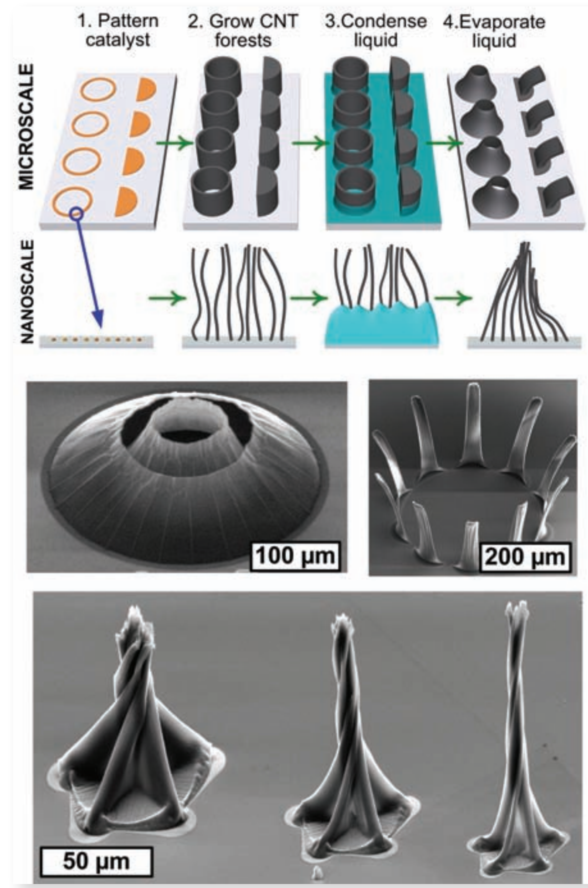


Although the WIMS ERC has demonstrated a variety of μGC systems during the past several years, they were typically driven by and interfaced to a laptop computer running LabView and other commercial software. Such systems were effective in terms of bench-top characterization of the fluidic components, but were inappropriate for field use. During the past quarter, the first palm-size completely integrated μGC system was completed, including all necessary temperature control electronics, an embedded Cypress processor, and a USB interface. The system is integrated on four 10cm × 4cm printed circuit boards. Power electronics is included to allow the programmable control of column temperature over a wide range while driving the preconcentrator to produce sub-second injection pulses using thermal desorption. The first application of this system will be in detecting explosives in urban warfare settings, mounting it on a remotely controlled Scarab robot developed by the University of Pennsylvania. This work is being funded by the U.S. Army Research Laboratory under Contract W911NF through the Microelectronics Center of Micro Autonomous Systems and Technology (MAST) Collaborative Technology Alliance (CTA). ■

3-D Carbon Nanotube Microstructures by Capillary Forming

Sameh Tawfick, Michael De Volder, Sei Jin Park, Davor Copic, and A. John Hart

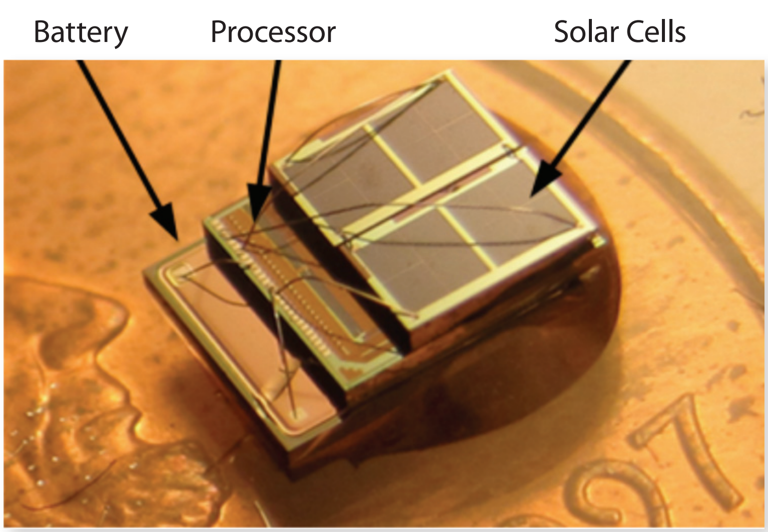
Existing methods of fabricating three-dimensional (3-D) microstructures suffer from tradeoffs among feature geometry, heterogeneity, resolution, and throughput. As a promising alternative, lithographically defined patterns of vertically aligned carbon nanotubes (CNTs) can be transformed into three-dimensional (3-D) geometries by self-directed capillary action initiated by liquid condensation. We call this process "Capillary Forming." During this process, the CNTs hierarchically aggregate due to equilibrium between capillary forces and elastic restoring forces. Variation of the initial forest geometry and the type of wetting interaction between the liquid and the CNTs enables spatial programming of the resulting 3-D microstructures. Using this approach we have fabricated batches of CNT microstructures having programmed bends, twists, and reentrant features. We have demonstrated that capillary formed CNT structures are over 100 times stiffer than as-grown CNTs, and we have enabled self-directed formation of 3-D CNT/polymer nanocomposites with stiffness exceeding that of conventional microfabrication polymers. This work may find future applications in cost-effective fabrication of biomimetic surfaces, metamaterials, multi-scale circuits, and novel sensors and actuators. This work will be published in *Advanced Materials* (2010) and was performed at the University of Michigan's Lurie Nanofabrication Facility. ■



Fabrication of 3-D CNT microstructures by capillary forming.

A Millimeter-Scale, Nearly Perpetual Sensing System With Stacked Battery and Solar Cells

Gregory Chen, Matthew Fojtik, Daeyeon Kim, David Fick, Junsun Park, Mingoo Seok, Mao-Ter Chen, Zhiyoong Foo, David Blaauw, and Dennis M. Sylvester



The Phoenix-II processor with solar cells and a microbattery on a U.S. penny.

An 8.75mm^3 sensor system has been implemented with a near-threshold ARM Cortex-M3 processor, custom 3.3fW-leakage-per-bit SRAM, two 1mm^2 solar cells, a thin-film Lithium battery, and an integrated power management unit. The millimeter-scale system enters a 550pW data-retentive standby mode between sensor measurements to achieve multi-year lifetime with only one battery charge. It recharges the battery with harvested solar energy to enable nearly perpetual operation. The device is being developed for an intraocular pressure sensor and other applications. ■

Recent Events

WIMS Celebrates Ten Years and Looks to the Future

Razi Haque explains his work on intraocular pressure sensors to Dr. Kurt Petersen, a pioneer in MEMS commercialization, at the Site Visit Poster Session.

In May, the WIMS ERC held its final NSF Site Visit in Ann Arbor. The Visit was attended by Ms. Lynn Preston, Deputy Division Director (Centers) at the National Science Foundation, by Andreas Weisshaar and Larry Goldberg, present and past Program Managers for the ERC at the NSF, and by a number of governmental, industrial, and academic leaders who formed the Site Visit Review Committee. The day started with a presentation, "The WIMS ERC: A Ten-Year Fantastic Voyage," in which ERC Director Ken Wise reviewed major accomplishments over the past decade in research, education, and technology transfer. Over the years, the ERC has had 49 core faculty participants spread across 10 universities representing 16 different disciplines. All combined, the faculty have published 346 journal articles and 811 archival conference presentations, including a dozen invited keynote papers. The invited papers of the Center have spanned virtually every major microelectronics and MEMS meeting. The Center, furthermore, has graduated over 150 Ph.D. students, and its 72 short courses have enrolled 3424 students, including 1055 women and 1319 students from underrepresented minorities. In addition, over 60 percent of pre-college students with some participation in a Center-directed course have entered college majoring in engineering.

On the applications side, the Center has had 38 industrial members, formed 11 startup companies, generated 103 patent disclosures, and been awarded 59 patents. The presentation reviewed major contributions in the ERC's five thrust areas and in its intraocular, cochlear, cortical, and environmental testbeds. In all of these areas, the ERC continues to lead the state of the art, generating results that promise to have significant impact on the quality of life for millions of people worldwide. Individual presentations in the various thrust areas then reviewed these developments in detail. In its report, the Review Committee concluded the following:

> "The WIMS ERC has had a major impact over its ten-year history. The history is one of significant developments in areas of micropower processors, innovative packaging, wireless communication, environmental power scavenging, and systems development in the testbed areas of environmental monitoring and biomedical applications. … WIMS' combination of exceptional core technology and compelling systems-level testbeds has enabled the Center to pursue the dual trajectories needed to realize effective application-driven microsystems. … The partnering that has occurred across the engineering disciplines has been hugely successful. … Within the U.S. this represents one of a few university centers that have the facilities to conduct microscale research at the systems level. It is difficult to overestimate the impact of this facility and support staff with its capability of fabricating complete systems on the future of microsystems development in a university setting."

Ribbon cutting to officially open the expanded Lurie Nanofabrication Facility for processing. L to R: Liz Brater, Dean David Munson, Andy LaBarre, Ken Wise, and Dennis Grimard.

The afternoon saw the Grand Opening of the Robert H. Lurie Nanofabrication Facility (LNF), which will play a major role in the future of the transformed ERC. The event was attended by Andy LaBarre (Assistant to Representative John Dingell), State Senator Liz Brater, State Representative Rebekah Warren, MEDC Representative Gary Krause, Ann Arbor Mayor Pro Tem Marcia Higgins, Dean David C. Munson, Jr., our WIMS ERC site visitors, and industrial personnel from across the country. Remarks were given by Ken Wise, Andy LaBarre, Dennis Grimard (LNF Managing Director), and David C. Munson, Jr., followed by the official ribbon-cutting ceremony. The LNF represents a major commitment to continued excellence in microsystems by the WIMS ERC, the College, and the University.

Khalil Najafi, Dean David Munson, and Lynn Preston present a "Grand Master of Microsystems Engineering" certificate to ERC Director Ken Wise.

In the evening, a Celebration Dinner was held in the Gerald R. Ford Presidential Library, attended by ERC faculty, staff, and students along with officials from government, industry, and academia. The program was conducted by Khalil Najafi, former ERC Deputy Director and now Chair of Electrical and Computer Engineering at U-M. Special recognition was given to Karen Richardson and Barbara Rice for their long and superb service to the Center as Administrative and Financial Directors, respectively, and to Ken Wise for having survived ten years as its Director. It was a grand evening and a fitting climax to what has been, indeed, a ten-year fantastic voyage. ■

Director's Message

Continued from page 1

resources, proposal funding rates are abysmally low, and the cost of funding university research is almost prohibitive for much of industry. Federal support for shared facilities (e.g., MOSIS, NNIN) and the use of pre-proposals to increase the efficiency of the research enterprise are bright spots in all of this along with the SBIR program.

Industry today probably faces the greatest challenges of all. It is far too driven by the short-term goals demanded by Wall Street rather than the need to create long-term value for its shareholders and employees. Computer-based trading has allowed speculation to replace investment, and globalization has allowed companies to forget the commitments they have to the people they employ. The growth of startups has helped at least partially to compensate for losing the large industrial research organizations of previous years, at the cost of job stability. It will take leadership at many levels to correct these problems, but we can do it if we put long-term success above short-term profit and develop greater synergy among academia, government, and industry. Ultimately, we are all in this boat together, and as noted by another engineer over two hundred years ago, "We must, indeed, all hang together, or most assuredly we shall all hang separately." (Benjamin Franklin, 1776)

After nearly four decades here at Michigan, I am turning over the reins of ERC leadership to Professor Yogesh Gianchandani. He has already brought new energy and valuable new ideas to the Center, and I know it will continue to serve as a national/international resource and a model for this revolutionary new electronics. I want to thank my many university colleagues, government sponsors, and industrial friends for helping make this Center such a success during its first decade and for making my career so fulfilling and so much fun. I wish you all continued success as we tackle new problems together. ■

Ken D. Wise

Director, Engineering Research Center
for Wireless Integrated MicroSystems

Personnel Focus

Spotlight on Our Staff

Over the years we have used this column to introduce various members of our technical staff, but this time it seems appropriate to highlight our dedicated administrative people, who have contributed in so many essential ways to the success of this Center. First, we should highlight Karen Richardson and Barbara Rice, our Administrative and Financial Directors, respectively. No one did more over the past decade for this Center than these two fine persons. They are great examples of selfless service and the very highest of standards. Days, evenings, and weekends, they worked unceasingly to make the Center succeed.

Karen S. Richardson
Administrative Director

Barbara L. Rice
Financial Director

Rose Anderson, Bonnie Grigg, and Jonathan Plummer have supported our outreach activities, such as our publications and Web site. These individuals have been superb, and our activities in this area today are unsurpassed in quality. David DeWeerd, Debra Lyons, and Mary McCune, working in the areas of finances and purchasing, have kept us in the black and running smoothly — no small task when draped across ten universities, nearly 50 faculty, and several hundred students. Finally, our thanks go to Trasa Burkhardt and Nicole Frizzell for helping out in essential ways with all of the myriad things that have to be addressed to make an ERC successful. All of these people are very good at what they do and willing to do whatever is needed whenever it is needed. Many thanks! ■

Rose Anderson
WIMS Graphic Designer

Bonnie Grigg
Assistant to Ken Wise

Jonathan Plummer
WIIMS Webmaster

David DeWeerd
Financial Analyst

Debra Lyons
Financial Assistant

Mary McCune
Financial Assistant

Trasa Burkhardt
Secretary Intermediate to Professors Khalil Najafi and Yogesh Gianchandani

Nicole Frizzell
Administrative Assistant to Professors Dennis Sylvester and Michael Flynn

Recent Events

Hilton Head Sensors Workshop Showcases WIMS

The 14th biennial *Solid-State Sensors, Actuators, and Microsystems Workshop* was held on Hilton Head Island, S.C., in early June, consisting of 36 oral presentations and 96 poster papers. The University of Michigan presented eight papers at the meeting, including four of the orals. These included important papers from the WIMS ERC on an ultra-low-power, intraocular pressure sensor (authored by Razi Haque); the first thermally modulated, two-dimensional micro gas chromatography system (Shaelah Reidy); and a 15Atm pressure sensor based on microdischarges (Heidi Zipperian). The Workshop was sponsored by the Transducer Research Foundation (TRF) and is well known for its relaxed setting and opportunities for informal interaction, attracting leaders in MEMS and microsystems from throughout North America and around the world. The evening rump session at this year's meeting commemorated the 25th anniversary of the conference, which began in 1984 with Ken Wise (WIMS ERC Director) as its founding General Chair and Kurt Petersen as Technical Program Chair. ■

A portion of the estimated 45 attendees at the 2010 Hilton Head Solid-State Sensors, Actuators, and Microsystems Workshop who are Michigan faculty, staff, students, or alumni.

Industrial Liaison's Report

We are approaching the end of the ten-year period where an ERC has NSF support and moving rapidly forward to being a graduated ERC. At the recent day-long May 18 Industrial Advisory Board meeting, we highlighted our accomplishments and presented our plans for the future. (For details, our Web site (www.wimserc.org) includes a retrospective, titled "A Ten-Year Fantastic Voyage," which describes the key accomplishments of the ERC). The end of the day festivities included a celebratory Grand Opening ceremony of the Lurie Nanofabrication Facility, a key resource for both the University of Michigan and our industrial partners. The culminating event of the day was our Celebration Dinner held in the Gerald R. Ford Presidential Library on U-M's North Campus where the leadership, NSF team, industrial affiliates, and staff were recognized and thanked for their efforts that made the Center a success story. All these events are a platform from which we are launching an even stronger WIMS ERC.

The post-graduate WIMS ERC will continue to emphasize systems research aimed at addressing societal needs in the areas of energy, health care, environment, and security. To make it easier for industry to engage and emphasize collaborative translational research, members will have the opportunity to sponsor research projects that utilize the Center's staff. The purpose of these projects will be to allow members understand, encourage, and capitalize on the commercialization potential of specific technologies. The transformed Center will help members accelerate the application of new technology into product by having the technical staff assist in reducing the risk members undertake in developing new product. Member companies will continue to get an inside look at our intellectual property and an opportunity to interact with faculty and students. We will continue to provide a forum for pre-competitive engagement between diverse companies and look for companies to provide us with targets for performance requirements for mass production, and insights on market forces. I invite you to join us as the Center moves forward in driving core research in microsystems and their use in addressing critical national needs.

If you are in the Ann Arbor area, please plan to spend some time with us to get updated on our latest technical results and tour the expanded Lurie Nanofabrication Facility. We also welcome seminars from companies to apprise us on new developments in industry. To schedule a seminar date, please contact me at (734) 615-3096 or at giachino@eecs.umich.edu. We will be scheduling visits to member companies in the next few weeks as well. ■

Joseph M. Giachino
Associate Director, Industry

Presentations and Publications

Conference Presentations/Papers

SRC/ATIC/NSF Forum on Minimum Energy Electronic Systems, Abu Dhabi, May 2010

K. D. Wise, "Integrated Biomedical Microsystems and Neural Interfaces," (Invited)

Solid-State Sensors, Actuators, and Microsystems Workshop, Transducers Research Foundation, Inc., Hilton Head, SC, June 2010

H. Chang, S. K. Kim, T. Sukaew, F. Bohrer, and E. T. Zellers, "A Microfabricated Gas Chromatograph for Sub-ppb Determinations of TCE in Vapor Intrusion Investigations," pp. 278–281.

C. K. Eun and Y. B. Gianchandani, "A Wireless-Enabled Radiation Detector Using Micromachined Steel and Glass Elements in a TO-5 Package," pp. 380–381.

R. M. Haque and K. D. Wise, "An Intraocular Pressure Sensor Based on a Glass Reflow Process," pp. 49–52.

F. Ozkeskin and Y. B. Gianchandani, "A Hybrid Technology for Pt-Rh and SS316L High Power Micro-Relays," pp. 182–185.

S. M. Reidy, S.-J. Kim, K. Beach, B. Block, E. T. Zellers, K. Kurabayashi, and K. D. Wise, "A Microfabricated Comprehensive Two-Dimensional Gas Chromatography System," pp. 78–81.

S. A. Wright, H. A. Zipperian, and Y. B. Gianchandani, "A 15-atm Pressure Sensor Utilizing Microdischarges in a 1.6 mm^3 Ceramic Package," pp. 53–56.

IEEE Device Research Conference, Notre Dame, IN, June 2010

K. D. Wise, "Microelectronics in the 'More Than Moore' Era," (Invited Plenary), pp. 3–4.

Journal Articles

A. T. Evans, S. Chiravuri, and Y. B. Gianchandani, "Transdermal Power Transfer for Recharging Implanted Drug Delivery Devices Via the Refill Port," *Biomedical Microdevices*, Springer, 12(2), pp. 179–185, April 2010, DOI 10.1007/s10544-010-9397-2 (erratum: DOI 10.1007/s10544-010-9397-2).

S. Green and Y. B. Gianchandani, "Tailored Magnetoelastic Sensor Geometry for Advanced Functionality in Wireless Biliary Stent Monitoring Systems," *IOP Journal of Micromechanics and Microengineering,* 20(7), pp. 1–13, July 2010, paper 075040, online June 28, 2010, DOI 10.1088/0960-1317/20/7/075040.

A. T. Evans and Y. B. Gianchandani, "Note: A Low Leakage Liquid Seal for Micromachined Gas Valves," *Review of Scientific Instruments*, vol. 81, pp. 1–3, paper 066105, published online June 24, 2010.

M. J. White, G. F. Nellis, S. A. Klein, W. Zhu, and Y. B. Gianchandani, "An Experimentally Validated Numerical Modeling Technique for Perforated Plate Heat Exchangers," *Journal of Heat Transfer*, 132(11), pp. 1–9, November 2010, article 111801, published on-line August 2010, DOI: 10.1115/1.4000673.

C. Eun, R. Gharpurey, and Y. B. Gianchandani, "Wireless Signaling of Beta Detection Using Micro-Discharges," *IEEE/ASME J. Microelectromechanical Systems*, 19(4), pp. 785–793, August 2010.

Doctoral Dissertations

Tzeno V. Galchev, *"Energy Scavenging From Low-Frequency Vibrations"*
University of Michigan, 2010
Postgraduate Position: Postdoctoral Researcher, University of Michigan
Advisor: Professor Khalil Najafi

Andrew J. Gross, *"Low-Power, Integrated, Thermoelectric Microcoolers for Microsystems Applications"*
University of Michigan, 2010
Postgraduate Position: Sandia National Laboratories, Albuquerque, NM

Education Highlights

Dean Aslam Gives Micro and Nano Workshops in Saudi Arabia

Eight 4-hour workshops, attended by over 250 students from 24 schools and colleges and 30 science teachers, were given by Dean Aslam at Taibah University, Medina, Saudi Arabia. Nanotechnology concepts and micro-robotic systems were explained using a number of hands-on demos including maple-seed robotic fliers, LEGOs, and static charges. Based on feedback from the attendees and organizers, these hands-on workshops were very successful. For example, one student described his participation in the workshop as "the most moving educational experience in my life." According to the chair of Electrical Engineering Department, "This was an outstanding success." A representative sample of 24 students from the audience gave the following ratings for overall satisfaction: 10/10 by 13, 9/10 by 8, and 8/10 by 3 students. In addition to the workshops, Dean Aslam visited research facilities at Taibah and King Abdullah University of Science and Technology and discussed research collaborations. ■

Left – In June 2010, Dean Aslam gives pre-college and undergraduate workshops in Saudi Arabia. Left and Below – Shows Taibah University President (Madinah, Saudi Arabia) addressing the participants.

Faculty and Student Awards

David Wentzloff Honored

On April 19, St. George's Feast Day was celebrated, a tradition when U-M EECS faculty serve lunch to the students as a way of saying thanks and good luck. Professor David Wentzloff was honored with the 2010 HKN Professor of the Year Award. This is an annual award voted on by members of Eta Kappa Nu, the honorary society for electrical and computer engineers. ■

Professor Khalil Najafi (ECE Chair), Professor David Wentzloff, Matt Lauer (HKN President), and Professor Farnam Jahanian (CSE Chair).

Student Innovators Win Clean Energy Contest

The first place team in the 2009–2010 Clean Energy Prize business plan competition, established by DTE Energy and the University of Michigan, featured technology developed U-M's Department of Electrical Engineering and Computer Science. The team Enertia, comprising **Tzeno Galchev** and **Ethem Aktakka**, Ph.D. fellows in electrical engineering, and Adam Carver, U-M MBA student, won the top prize of $50,000.

The team's plan is for a device that can harness vibrations to generate electricity to power small electronics, such as remote sensors and surgically implanted medical equipment. The small generators can extend the lifetime of wireless electronic devices tenfold, while at the same time replacing toxic electrochemical batteries.

Both Galchev and Aktakka conduct research in energy harvesting technology, under the direction of Professor Khalil Najafi. The technology upon which Enertia based its business plan was developed within the WIMS ERC. ■

Visit our Web site at http://wimserc.org to find out more information about these seminars and to view them on streaming video. You can also see a schedule of upcoming seminars, as well as a listing of publications.

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