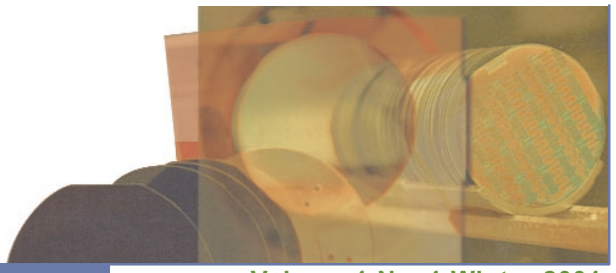
WIMS WORLD

University of Michigan College of Engineeering

A quarterly update from the Engineering Research Center for Wireless Integrated Microsystems

Volume 1 No. 1 Winter 2001



MESSAGE FROM THE DIRECTOR

Welcome to WIMS WORLD, our new quarterly newsletter, intended to keep you up-to-date on the exciting happenings here in the Center for Wireless Integrated MicroSystems (WIMS). Formed in September 2000 as an Engineering Research Center (ERC) with funding from the National Science Foundation and a consortium of companies, it will act as a worldwide focal point for work in microsystems. The Center merges efforts on micro-power circuits, wireless interfaces, sensors, and wafer-level packaging to create information-gathering modules roughly a cubic centimeter in size that can act as wireless front-ends for global and local information networks and as bridges to the cellular world. Essentially, these are smart wireless MicroElectroMechanical Systems (MEMS). WIMS will become pervasive over the next decade, and we hope to have a major role in their development and application. Significant funding from organizations such as the National Institutes of Health and the Defense Advanced Research Projects Agency is also helping us meet our goals.

In reflecting on our first six months as a Center, I feel a certain sense of pride that we have managed to get forty-two new doctoral projects launched, hire key new personnel, and attract over twenty companies as partners in this new adventure. The companies represent many of the international leaders in the microelectronics, automotive, chemical, and biomedical industries. We will profile some of these companies and their activities in future issues.

Much of my excitement about this Center is because of the wonderful advances in research that are already beginning to emerge from it. For example, we recently realized our first wireless pressure sensor, forerunner of devices that may someday be implanted in stents to allow the measurement of intra-arterial pressure and flow by simply waving an rf wand over the implant site. We have also recently developed a new approach to silicon-glass wafer-level vacuum seals with the ability to measure the residual pressure in such cavities anywhere anytime. These vacuum cavities are key in the realization of accurate barometric pressure sensors for our environmental monitoring testbed. We are also now in fabrication with micromachined chromatography columns for the μGC that is the centerpiece of that testbed. In the neural probe area, one of our external collaborators, Daryl Kipke (Arizona State University), is still obtaining consistent high-quality recordings with one of our silicon probes after more than one year in vivo (and still counting). The ability to record from tissue over long periods of time will be key in realizing the ERC's neural prosthesis testbed, which will begin a new era in our ability to treat disorders such as deafness, epilepsy, and (perhaps) blindness. So there is definitely a LOT going on in research, and it is truly exciting.

Some of my excitement is also due to efforts in education. WIMS is a great vehicle for illustrating basic scientific principles at the junior high and high school levels, and for attracting more of our youth into careers in engineering. Last summer, a month-long course on WIMS was held for underrepresented minority students at Michigan State. The vehicles for learning about WIMS in this course were wireless sensor-equipped robots that were a great deal more than mere toys. This course made a real difference in many of the students' lives, and it was a priviledge to participate in it. I recently had the opportunity to travel to East Lansing where we are setting up a pilot WIMS program at Okemos High School. The excitement of the teachers there is matched only by my own! So our Center is up and running and I hope you find the activities reported here in WIMS WORLD interesting.

Ken D. Wise
Director
Engineering Research Center for Wireless Integrated Microsystems

INDUSTRIAL LIAISON

This is to remind IAB (Industrial Advisory Board) members that the spring meeting will be held on May 1-2 at the Chrysler Center - Chesebrough Auditorium. The formal meeting will review the progress of the Center and poster sessions will allow for extended discussions with students.

To keep members informed of events between IAB meetings, we will use the newsletter and Web site - www.eecs.umich.edu/wims. If at any time you have a question or suggestion regarding the Center (project plans, status of a program, courses - planned or available, interns, etc.), please contact me.

Note that videotapes and Real Video® of the WIMS Seminars are available to members. If you wish to have a copy of a seminar (see the Events section of the Web site for a complete list), please contact me. Videotapes of the keynote addresses at the Microsystems Symposium 2001 are also available.

The main message of this column is that I will be glad to facilitate discussions with or assistance from any of the Center faculty, students or staff.

Joseph M. Giachino
Associate Director

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MICHIGAN STATE UNIVERSITY

MichiganEngineering

RECENT EVENTS

ERC LAUNCH

September 14-15, 2001 the National Science Foundation and the University of Michigan, Michigan State University and Michigan Technological University people met in Ann Arbor to launch the ERC for Wireless Integrated Microsystems. Dr. Lynn Preston, Deputy Division Director of the Engineering Education and Centers Division of NSF discussed the NSF's expectations of an ERC. The WIMS leaders reviewed their plans for the research programs, education and industrial collaboration. The two-day meeting featured open discussions on the various phases of developing and administering an ERC. ~ JG

Lynn Preston of NSF and Ken Wise at the ERC Launch

WIMS IAB KICKOFF

November 2, 2000 marked the inaugural Industrial Advisory Board meeting of the WIMS Engineering Research Center. IAB members were welcomed by Ken Wise, WIMS ERC Director. Stephen Director, Dean of the College of Engineering, expressed the University's commitment to making the Center an educational and research resource to the nation. Dr. Lawrence Goldberg reviewed the National Science Foundation's expectations for the ERC partnership among industry, academe and government. Dr. Goldberg also described to the industrial members how their input through **S**trengths, **W**eakness, **O**pportunities and **T**hreats (SWOT) analysis can help the ERC become stronger. The WIMS Director gave a brief overview of the ERC and a description of how each of the Testbed Applications (Neural Prosthesis and Environmental Microsystem) brings together the efforts of each Research Thrust Area. The IAB elected Nader Najafi of Integrated Sensing Systems and Jeff Dykstra of Motorola to serve as Chair and Vice Chair of the IAB Executive Committee. Both were in attendence at the Executive Committee meeting which followed the IAB meeting. ~ JG

IAB members take a break and pose for a group shot in front of University of Michigan's College of Engineering

TV COMES OF AGE

Jerry Hodak of WXYZ-TV, the Detroit ABC affiliate, visited WIMS in February. The result was a feature story during the evening news describing MEMS technology, work being done in MEMS at the University of Michigan and its applications to the general public. The feature story aired February 23, 2001. ~ JG

Khalil Najafi (left) and Jerry Hodak (right) of WXYZ-TV

WIMS RESEARCHERS AWARDED IEEE BEST PAPER

Researchers from WIMS were presented with the Best Paper Award from the Editorial Board of the IEEE Transactions on Semiconductor Manufacturing. Presented to the most outstanding paper published during the year, the paper entitled, *Automated Generation of Thin Film Process Flows - Part 1: Basic Algorithms*, by M. Zaman, E. Carlen, and C. Mastrangelo describes algorithms used in the development of Michigan synthesis tools for integrated circuits (MISTIC), a planar device process compiler that automatically generates process flows from schematics. The unique capabilities of the MISTIC TCAD package have been demonstrated using a BiCMOS technology example. The award was presented at the annual Advanced Semiconductor Manufacturing Conference. ~ JG

THURNAU PROFESSORSHIP AWARD

Professor Richard Brown was named a Thurnau Professor by the University of Michigan Regents in February. Established in 1998, the Thurnau Professorships recognize and reward faculty members who have made outstanding contributions to undergraduate education.
Professor Brown has been honored several times for his teaching, including receipt of a Distinguished Faculty Award from the Michigan Association of Governing Boards of Universities and Colleges, a State of Michigan Teaching Excellence award, and a College of Engineering Teaching Excellence Award.

EDUCATION HIGHLIGHTS

- A set of four core courses supporting MEMS technology are being developed that will be offered at all three universities, starting in Fall Term 2001.
- A two-day meeting was held in March at Michigan Technological University to coordinate plans to offer a Masters of Engineering degree program that will prepare graduate level engineering students to become WIMS/MEMS proficient.
- A short course incorporating WIMS robots and microcontroller programming will be presented to pre-college students this summer in programs at Michigan State University and the University of Michigan. A laboratory incorporating WIMS robots and microcontroller programming is being established in the Okemos school system. This laboratory will be available to all students, including those in the elementary school. This laboratory will familiarize students to engineering in general and WIMS/MEMS in particular.
- A high school teacher workshop is being organized for summer 2001 as part of the process to permeate WIMS/MEMS science and technology into the high school curriculum.
- Sponsors are being sought for an "engineering enterprise" - undergraduate students design, plan and manufacture a product at Michigan Technological University. If interested please contact the Center.
- As part of the outreach program ten women and minority students have been recruited and supported on WIMS research and testbed projects at the three universities.
- A newly-revised course at UM is giving students experience with microsystems development. The class members define, design, fabricate, and test a complete microsystem in one semester. Using a two-chip combo based on E/D NMOS and dissolved-wafer technologies, the class this term has developed sensors for pressure, flow, visible light, acceleration, and mechanical vibration/shock along with a micromirror output device.
~ KW

RESEARCH HIGHLIGHTS

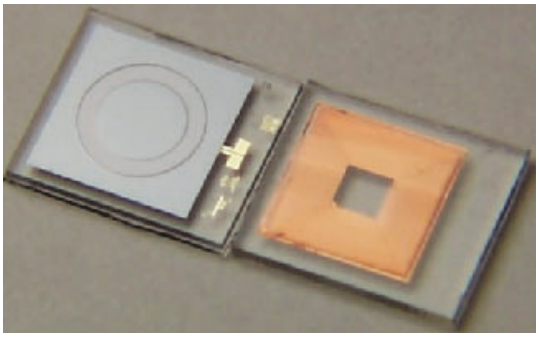
SENSORS

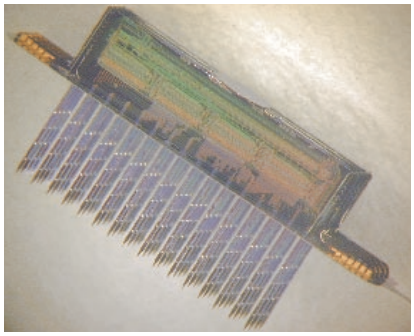
Wireless Pressure Sensors
Wireless sensors have many applications, including the measurement of pressure in tires and in the intracranial, intraocular, and intra-arterial areas. Wireless passive and active pressure sensors are being developed, and their size-accuracy-power tradeoffs are being studied. This work is funded by a gift from Ms. Pauline Anderson and by the NSF WIMS ERC.

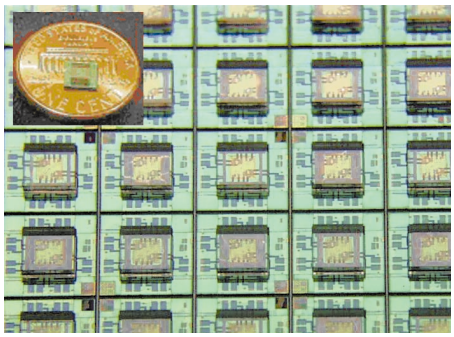
and temperature-programmed tuning of retention/separation, an array of chemical microsensors for recognition and quantification of eluting analytes, and pneumatic components to direct sample flow. This versatile microinstrument will occupy a few cc, provide analysis of complex gas/vapor mixtures in a few minutes at an average power of ~1 mW, and upload data via a wireless link to a remote monitoring station.

number of technologies needed for protecting, interconnecting, and assembling WIMS. Wafer-level hermetic and vacuum encapsulation techniques based on deposited thin films and capsules/shells will be developed. Poly-crystalline diamond, SiC, and metal films are candidate materials for packaging using thin-films. Different bonding techniques, including anodic, polymeric compression, localized heating, and solder bonding technologies will be used for her-

teries are typically the primary determinant of size and weight, a circuit that requires only one battery would significantly improve the performance and usefulness of the system. Therefore, we designed a general-purpose rail-to-rail IO opamp in a 0.18 µm digital process that operates over a supply voltage of 1.8 to 0.9 V. Select transistors operate in weak inversion, which reduces power and permits operation down to 900 mV, over temperature. At 900 mV, the opamp draws 130 µA and







Left: This passive wireless pressure sensor folds back-to-back, measuring 6mm x 6mm x 1mm overall. It contains an electroplated copper RF coil and resolves < 4mmHg. **Middle:** A four-probe 256-site 3D microelectrode array for recording and stimulation in the central nervous system. The probe shanks are on 400µm centers. **Right:** Photograph of an array of silicon-glass sensors containing vacuum reference cavities sealed at wafer level.

3D Microelectrode Arrays
The ability to completely instrument three-dimensional blocks of tissue is critical for the neural prosthesis testbed being developed under the NSF WIMS ERC. Technology has been developed to allow electrode arrays of arbitrary size to be microassembled with high yield. On-platform fuses allow the use of partially-configured arrays as needed. This work is supported by the NIH/NINDS Neural Prosthesis Program.

Micro-GC
One focus of the Sensors and Microinstruments Thrust is the development of a micro gas chromatograph (µGC) comprising an on-board calibration source, a multi-stage preconcentrator, a separation module with pressure

MICROPACKAGING

High-Quality Vacuum Packaging
Achieving high-quality vacuum packaging at wafer level is critically important for future microsystems, especially in glass-silicon anodically-bonded structures, where outgassing from the glass can compromise device performance. A process has been developed for creating vacuum reference cavities for barometric pressure sensors, resonators, and similar devices that allows the cavity to be sealed at low wafer temperatures. Any residual cavity pressure can be monitored while the device is in use.

The micropackaging thrust will focus on the development of a

metic and vacuum packaging (see photo). Miniature connectors incorporating electrical and fluidic interconnects will be developed to allow easy and modular assembly of microsystems that incorporate several different components. These interconnect and assembly technologies will be critical to the low-cost and volume and production of microsystems that are smaller than 1cc.

µPOWER CIRCUITS

Key metrics of portable devices are size, weight, and battery life. Alkaline batteries supply 1.5 to 0.9 V over their lifetime. Other battery technologies, including rechargeable batteries, demonstrate similar cycles. Since bat-

has an open loop gain of 80 dB (10 kΩ load), a bandwidth of 1.3 MHz, and a phase margin of 60° (150 pF load).

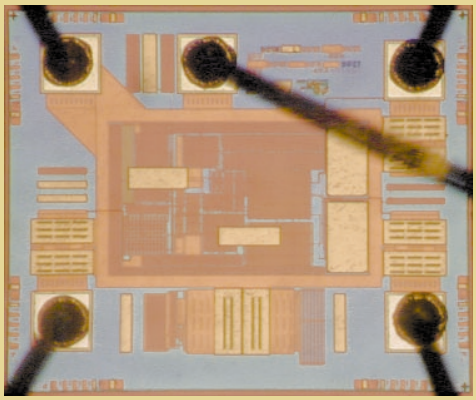
WIRELESS

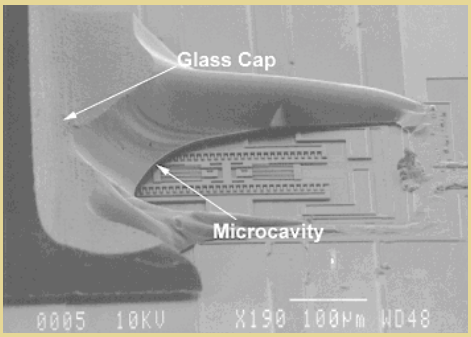
The Wireless Interfaces Task seeks to utilize MEMS technology to attain orders of magnitude power savings for the two-way wireless transceivers included in each environmental monitor. Target specifications for each transceiver include a maximum power consumption of 1 mW while transmitting over greater than 1 km. The basic strategy for power reduction involves trading power for the increased frequency selectivity (or *Q*) provided by vibratig micromechanical resonators and switches [BCTM'00]. Using MEMS tech-

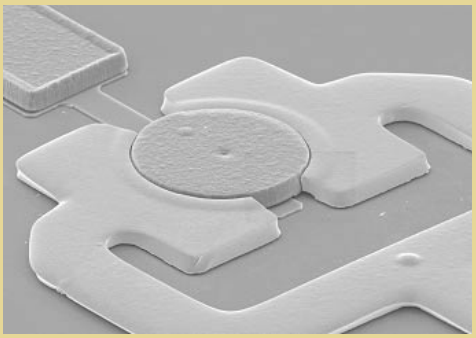
nology, resonators with Q's in excess of 5,000 can be integrated alongside transistor circuits onto a single chip, allowing a degree of front-end selectivity and tunability never before possible in communication transceivers. In particular, with Q's this high, front-end channel selection may be possible, and if so, the dynamic ranges of succeeding stages in the transceiver can be reduced greatly, allowing a substantial reduction in power. Additional power savings are also possible through the use of high Q micromechanical resonators in the local oscillator synthesizer.

The photo at bottom right shows an SEM of a 156 MHz micromechanical disk resonator [IEDM'00] capable of achieving Q's in excess of 9,000 when vibrating in a radial contour mode. Since the target RF frequency for these communicators is ~1 GHz, some amount of frequency extension is needed, and this comprises a first endeavor of the Wireless Interfaces Task. Upon achieving this frequency, micromechanical circuits (e.g., filters [Bannon], mixers [IEDM'98], and oscillators [Trans'01]) are planned for inclusion into a largely passive mechanical transceiver front-end that achieves power savings through a combination of superior frequency selection and passive device operation. Pursuant to attaining such a front-end circuit, mixed circuit/MEMS technologies are presently being explored that combine high frequency BiCMOS transistor circuits with micromechanical circuits to attain a complete system-on-a-chip implementation of this transceiver.

To round out the above research on transceiver internal components, miniature antenna ideas are also being explored under the Wireless Interfaces Task.







Top: A 900 mV 0.18 µm opamp with on-chip biasing and ESD protection. **Middle:** Photograph of vacuum-encapsulated micro-resonators packaged using glass capsule bonded to the silicon substrate using the localized heating technique (the glass cap is forcefully broken away to reveal the resonator underneath). **Bottom:** SEM of a 156 MHz micromechanical disk resonator. The Q for this device is 9,400.

[BCTM'00] C. T.-C. Nguyen, "Micromechanical circuits for communication transceivers (invited)," *Proceedings*, 2000 Bipolar/BiCMOS Circuits and Technology Meeting (BCTM), Minneapolis, Minnesota, September 25-26, 2000, pp. 142 -149.

[IEDM'00] J. R.Clark, W.-T. Hsu, and C. T.-C. Nguyen, "High-Q VHF micromechanical contour-mode disk resonators," *Technical Digest*, IEEE International Electron Devices Meeting, San Francisco, California, December 11-13, 2000, pp. 399-402.

[Bannon] F. D. Bannon III, J. R. Clark, and C. T-C. Nguyen, "High frequency micromechanical filters," *IEEE J. Solid-State Circuits*, Vol. 35, No. 4, pp. 512-526, April 2000.

[IEDM'98] A.-C. Wong, H. Ding, and C. T.-C. Nguyen, "Micromechanical mixer+filters," *Technical Digest*, IEEE International Electron Devices Meeting, San Francisco, California, December 6-9, 1998, pp.471-474.

[Trans'01] S. Lee, M. U. Demirci, and C. T.-C. Nguyen, "A 10-MHz Micromechanical Resonator Pierce Reference Oscillator for Communications," to be published in the *Technical Digest* of the 11th International Conference on Solid-State Sensors and Actuators (Transducers), Munich, Germany, June 7-10, 2001.

WIMS ERC STUDENT LEADERSHIP COUNCIL

OVERVIEW

The WIMS ERC Student Leadership Council had its first meeting in January 2001. It gained official registration with the UM Engineering Council in mid-February. Currently there are 132 students on the roster. The leadership committee for the WIMS-SLC is as follows:

President:
Stefan Nikles
Vice-President:
Andrew DeHennis
Educational Chair:
David Lemmerhirt
Social Chair:
Timothy Harpster
Industry Chair:
John Clark
UMEC Representatives:
Brian Stark
Faculty Advisor:
Professor Leo McAfee

EDUCATION

On January 31, a group of ERC students volunteered as special awards judges at the National Engineers' Week Future City Competition at the Spirit of Ford exhibit building in Dearborn, MI. Middle school students from Metro Detroit worked in teams of four to six people to design an ideal city for the future using SimCity 2000 software. Each design consisted of a layout complete with energy resources, transportation systems, and communications networks. Each group presented a poster, a 3-D model with moving parts, and a short paper describing their design. Groups of judges evaluated the teams and selected one team to represent Michigan at the national competition to be held in February. Several external sponsors presented special awards to recognize outstanding efforts in more specific areas of the project.

ERC students Andrew DeHennis, Brian Jamieson, David Lemmerhirt, Michael McCorquodale, and Brian Stark partnered with members of the Southeast Michigan chapter of IEEE to evaluate student projects and recommend a winner for the IEEE Electro-Technology Special Award, recognizing a team of middle school students who used electrical technology especially well in their design. Some teams had elaborate schemes for electrical power generation and distribution such as microwave power and nuclear fusion - simple enough systems to implement according to the unencumbered creativity of these teenage minds. One potential application for WIMS technology in the future was suggested by one the groups in the form of a wristwatch communicator that would use holographic imaging to communicate with a partner.

The judges were impressed with the levels of technological interest and understanding. They were pleased to see a new generation of students think creatively about how technology can be used constructively to sustain and improve the quality of life in the future. Volunteering at this event allowed the engineering students to challenge the teams to explain their ideas thoroughly and think critically about their designs.

On Wednesday, March 28th, the Education Committee sent judges to the Science and Engineering Fair of Metropolitan Detroit, to act as judges in this years' competition.

For more information contact:
David Lemmerhirt
dlemmerh@umich.edu

SOCIAL

ERC affiliated students have been involved in the Winter 2001 Intramural sporting events. The ERC is represented by men's and co-ed volleyball teams and a mini-soccer team. Each team has battled their way into the Winter 2001 IM playoffs and has high hopes of winning the coveted IM championship T-shirts. The ERC IM teams have vowed to obtain these trophies as a symbol of our appreciation for our newlyfounded Center for Wireless Integrated MicroSystems.

Top: ERC Student Andrew DeHennis discussing a team project at the National Engineers' Week, Future City Competition. **Below:** IEEE Southeast Michigan Chapter member with Brian Jamieson and Andrew DeHennis talking with a student team.

For more information contact:
T.J. Harpster
tharpste@eecs.umich.edu

INDUSTRIAL

The industrial committee was formed to foster closer ties between the Center and its industrial partners, and to provide ERC students with an avenue to interact with them. Our first task has been to establish contact with ERC companies and to compile a list of companies potentially interested in hiring interns from the ERC. For the future, ideas include short courses presented by industry, site visits, and establishment of an industry committee.

The Industrial Committee of the WIMS SLC has been busy in the past few months. We have focused on three major thrust areas to facilitate student-industry interactions. Our first goal is to develop an internship program. We propose to establish policies among faculty and students for both the timing and research impact of internships. We will then contact the IAB companies to see what opportunities exist and try to facilitate student contact with the IAB. Our next goal is to establish a core knowledge base. We intend to identify experts from core knowledge areas in the IAB to advise students with technical difficulties while not compromising proprietary information. Finally, we would like to initiate some site visits so that students may see how industry operates and assist the infusion of ideas from industry to the Center and vice-versa.

For more information contact:
John Clark
jrclark@eecs.umich.edu

SEMINAR SERIES

January 9, 2001
Dr. Gary Bjorklund
Nanovation Technologies
New Integrated Device Technologies for Dense Wave Division Multiplexing

January 16, 2001
Jospeh Giachino
Visteon
Sensor Packaging - The key to commercial success

January 23, 2001
Prof. Teresa Zwolan
UM Medical School
Cochlear Implants: An Update

January 30, 2001
Dr. Timothy Faley
UM CoE
Technology Transfer: How do we do that?

February 06, 2001
Prof. Gabriel Rebeiz
UM CoE
RF MEMS Switches and their applications in commercial and military systems

February 13, 2001
Prof. Ken Wise
UM CoE
Reflections on MEMS and Innovation

February 20, 2001
Dr. David Harame
IBM
Status and trends in SiGe BiCMOS Technology.

March 6, 2001
Reza Navid and Timothy Harpster
ERC Doctoral Students
(Reza Navid) *3rd order intermodulation distortion in capacitivley Drive:CC:Beam Micro-Mechanical resonators*
(Timothy Harpster)
Passive wireless humidity sensors for in-situ remote wireless testing of Micropackages

March 13, 2001
Prof. Yogesh Gianchandani
University of Wisconsin
Electrothermal Microactuators for Long Throw and High Force In-Plane Applications

March 20, 2001
Dr. Robert V. Shannon
House Ear Institute
Speech Recognition under conditions of frequency-place compression and expansion

March 27, 2001
Brian Jamieson and John Clark
UM Doctoral Students
(Brian Jamieson) *Active Neural Recording Probes for Neurophysiology Research*
(John Clark) *High-Q VHF Micromechanical Contour-Mode Disk Resonators*

For more information check the Events section of our Web site, www.eecs.umich.edu/wims. To find out how to gain access to archived material via MEonline contact:
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WIMS Administrative Manager
karenr@eecs.umich.edu
(734) 647-1779

PUBLICATIONS

WIMS papers presented at the 14th IEEE International Conference on MicroElectro-Mechanical Systems. The papers are published in the Technical Digest of the Conference (IEEE Catalog Number: 01CH37090).

D. Papageorgiou, S.C. Bledsoe, M.Gulari, J.F.Hetke, D.J. Anderson, K.D. Wise
A Shuttered Probe with In-Line Flow Meters for Chronic In-Vivo Drug Delivery

B.A. Parvis, T.-K. Allen Chou, C. Zhang, K. Najafi, M.O. Muller, P.D. Washbaugh, L.P. Bernal
Performance of Ultrasonic Electrostatic Resonators for use in Micro Propulsion

T. J. Harpster, B. Stark , K. Najafi
A Passive Wireless Integrated Humidity Sensor

P. Selvaganapathy, M.A. Burns, D.T. Burke, C.H. Mastrangelo
In-Line Electrochemical Detection for Capillary Electrophoresis

Hung Tsai and Liwei Lin
A Thermal Bubble Actuated Micro Nozzle-Diffuser Pump

M. Krishnan, S. Brahmasandra, D. Burke, C. Mastrangelo, M. Burns
Design of Multiple Reaction Systems for Genetic Analysis

W. Hsu, J. Clark, C. T.-C. Nguyen
A Sub-Micron Capacative Gap Process for Multiple-Metal-Electrode Lateral Micromechanical Resonators

R. Navid, J. Clark, M. Demirci, C. T.-C. Nguyen
Third Order Intermodulation Distortion in Capacitely-Driven CC-Beam Micromechanical Resonators

S. Nickles, K. Najafi
Reliability and Contact Resistance of Polysilicon Beam Leads for use in a High-Density Connector

Y.T. Cheng, W.T. Hsu , L. Lin, C. T.-C. Nguyen, K. Najafi
Vacuum Packaging Technology Using Localized Aluminum/ Silicon-To-Glass Bonding

WIMS papers presented at the International Electron Devices Meeting, San Francisco, CA, December 10-13, 2000. The papers are published in the Technical Digest of the Conference (IEEE Catalog Number: 0-7803-6441-4)

W.T. Hsu, J.R. Clark, C. T.-C. Nguyen
Mechanically Temperature-Compensated Flexural-Mode Micromechanical Resonators

J.R. Clark, W.T. Hsu, C. T.-C. Nguyen
High- VHF Micromechanical Contour-Mode Disk Resonators

J.-B. Yoon, C. T.-C. Nguyen
A High-Tunable Micromechanical Capacitor with Movable Dielectric for RF Applications

The following is a list of WIMS supported oral presentations at the ANACHEM 2000 Conference held on November 16th.

T. Krebsbach, E. T. Zellers
Silsesquioxane derivatives as thin film adsorbents

S. Buck, E. T. Zellers
Monolayer Encapsulated Metal Nanoclusters as Chemical Sensor Interface Materials

M.-D. Hsieh, E. T. Zellers
UV-Photopolymerization of Gas-Phase Monomers for Microanalytical System Applications

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