Wireless Integrated MicroSensing & Systems
WIMS²
microsystems for
Health • Environment • Infrastructure

Michigan Engineering

Horizons

Microsystems for the Next Generation

January 2014

Guest Editorial

Kevin Ward, MD

Professor of Emergency Medicine
Director, Michigan Center for Integrative Research in Critical Care
Executive Director, Fast Forward Medical Innovation Initiative

The Engineering-Medicine Collaborative: High Octane Fuel for the Innovation Engine

Innovation is now all the rage across academia and industry and this term is now firmly embedded in our research, teaching, and even clinical care lexicon. If you ask students and faculty what they mean by innovation and what motivates them you are likely to get many answers.

At its foundation, innovation is about problem solving. However, when put in this context, many don't see why or how the new Innovation movement is any different than what they have always done and they are puzzled why Innovation centers and initiatives are popping up all around us. For me, these centers and initiatives are in response to acknowledging that innovation is as much about the process of getting the great idea to impact as it is about the great idea itself. When viewed in this manner it becomes easier to perhaps understand why commercialized product development output from universities is not proportional to the level of federal investment.

The traditional research enterprise (at least in medicine) has not been engineered to routinely bring its discovery science and great ideas to vertical product form factors such as therapeutics, devices, diagnostics, health information technology, etc. With a combination of new educational programs, funding vehicles, and cross unit collaborations, it should be possible to routinely transition from ideas to products by helping partners take the risk out of new technologies.

In November of 2013 the University of Michigan Medical School launched a new innovation initiative called Fast Forward Medical Innovation (FFMI), which integrates the Medical School Office of Research's existing commercialization teams – Business Development and the Michigan Translational Research and Commercialization (MTRAC) for Life Sciences – under a single umbrella. The FFMI program will bring a holistic approach to biomedical innovation at the University of Michigan, including:

- Establishing a front door for supporting biomedical innovation at the Medical School and the Health System.
- Accelerating innovation and commercialization of research from inception to impact for therapeutics, devices, diagnostics, and health information technology.

(Continued on page 2)

WIMS² California Outreach Event

January 30, 2014
Santa Clara, California

WIMS² is planning a series of extended technical sessions outside Ann Arbor. The purpose is to increase access and provide opportunities for detailed discussions with member companies.

The first event is on Thursday, January 30 and will cover micro gas chromatography, single cell assay chips for cancer detection, high frequency MEMS, and fused silica MEMS. This event will take place at Agilent's headquarter facility at 5301 Stevens Creek Blvd in Santa Clara and is intended for all employees of WIMS² member companies, not just Agilent employees. Currently scheduled speakers include Profs. Yogesh Gianchandani, Katsuo Kurabayashi, and Mina Rais-Zadeh. The event will start at 1 pm and will last until about 4:30 pm. At press time, around 20 WIMS² faculty and students were planning on attending as this event coincides with the last day of the *MEMS 2014 Conference* in San Francisco.

Sign up for this event is required and can be accessed from the links on the far right hand side of the WIMS² home page (http://wims2.org).

Registration and event details available at wims2.org.

Guest Editorial

(Continued from page 1)

- Collaborating with commercial partners via novel partnership models.
- Creating an entrepreneurial ecosystem by enhancing knowledge of technology transfer and entrepreneurship through education.
- Enhancing collaborations with key units across the U-M campus, such as the Office of Technology Transfer, College of Engineering Center for Entrepreneurship, Business Engagement Center, and other schools and colleges.

I consider the last bullet above to be key in our ability to maximally leverage the other four. As I look at the innovation landscape across the University of Michigan and compare it to other universities, I see a distinct edge. This edge is the tremendous collaborative potential between a topped ranked Medical School and College of Engineering.

Geographical proximity between the Medical School and College of Engineering is not enough to fully harness this power. We must make every effort to explore deliberate strategies, which blur the lines between medicine and engineering in a way that encourages or even mandates greater collaboration between faculty and students for product development, entrepreneurialism, and commercialization. The FFMI program will be working closely with the College of Engineering's Center for Entrepreneurship to create an innovation road map that aligns existing and new resources that bring greater value to both existing and new collaborations.

Such strategies will accelerate not only our ability to push homemade innovation out to industry, it will be far more attractive to industry partners as they will be able to envision more "one stop shopping" not only for their own product innovation but for co-product development and innovation with us, allowing more product pipelines as opposed to singular products.

FFMI and its programs like MTRAC (http://medicine.umich.edu/medschool/research/strategic-research-initiative/medical-innovation/u-m-mtrac) should be viewed as a new fuel source and force multiplier for creating greater team science. I am excited about its potential to assist many of the excellent centers in the College of Engineering like WIMS^2 and the Wu Manufacturing Center, and institutes such the Bio-Interfaces Institute to more readily intersect with translationally disease-focused centers in the Medical School such as the Cardiovascular Center, the Cancer Center, and the Michigan Center for Integrative Research in Critical Care, to accelerate life saving and altering ideas to commercial impact. It was gratifying to see that a significant number of the first round of MTRAC proposals consist of medicine and engineering collaborations.

So while we have always had innovation and collaboration, let's move forward together with new strategies and resources that bring greater value and efficiencies to our efforts to get those great ideas to impact. ■

Khalil Najafi Receives IEEE Sensors Council Award

Prof. Najafi receiving the Technical Achievement Award from Prof. Vladimir Lumelsky, Past-President of the IEEE Sensors Council along with Prof. Troy Nagle, President of the IEEE Sensors Council.

Prof. Khalil Najafi was the recipient of the IEEE 2013 Sensors Council Technical Achievement Award at the *2013 IEEE Sensors Conference* in Baltimore this past November. The award was given "for leadership in microsystem technologies and seminal contributions to inertial sensors and hermetic wafer-level packaging." This award honors a person with outstanding technical contributions within the scope of the IEEE Sensors Council, as documented by publications and patents. It is based on the general quality and originality of contributions. Previous award winners include Prof. Wen Ko, Case Western and Prof. Tom Kenny, Stanford. In addition to his research work, Prof. Najafi was the founding Deputy Director of the WIMS Center and is current Co-chair of the Department of Electrical Engineering and Computer Science at University of Michigan. Congratulations Prof. Najafi!!

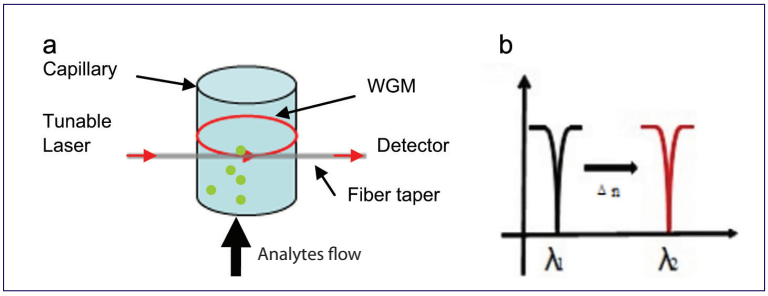
IEEE MEMS 2014 Conference

WIMS^2 has twelve papers at the *IEEE International MEMS 2014 Conference*, to be held in San Francisco from January 26–30. Some of the WIMS^2 papers and posters topics include a monolithic Knudsen pump, magnetoelastic tags, "birdbath" gyroscopes, microdischarge based pressure sensors, Lame'-mode resonators, micro gas chromatographs, trimming approaches for fused silica resonators, 2D microscanners, ultrasonic knives for micro surgery, x-ray based blood pressure sensors, microfluidic cell culture platforms, and carbon nanotube forests. Research groups represented at this conference include those led by Profs. Gianchandani, Najafi, Rais-Zadeh, Kurabayashi, and Yoon. WIMS^2 will have a booth at the conference and will also be hosting a reception the evening of Monday, January 27. For an invitation to the reception send an email to info@wims2.org, or sign up on the WIMS^2 website.

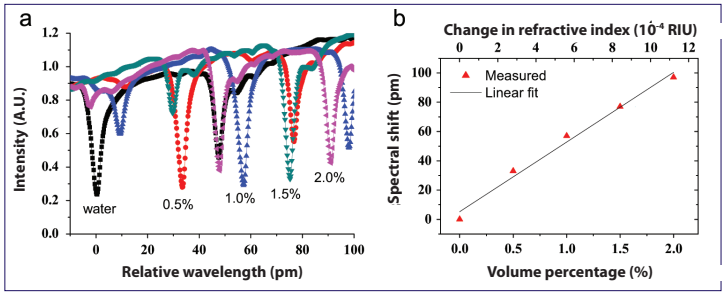
Optical Glucose Sensor

Prof. Xudong "Sherman" Fan, Prof. Yuan Luo, Jia Ge, and Prof. Zhen Chen

A potentially low-cost and painless method of measuring body glucose in interstitial fluid has been developed by Prof. Xudong "Sherman" Fan's research group and their collaborators. The novel device uses an opto-fluidic ring resonator where 980 nm light is coupled into and confined in a tapered fiber, which is placed in contact with a capillary or microfluidic device containing the fluid. The capillary forms a high-Q resonant structure that supports whispering gallery modes, which extend about 100 nm into the capillary. The amount of glucose inside the capillary changes the effective refractive index, and the resonant wavelength. The detection limit of glucose in interstitial fluid is 0.32 mM, 10x better than the clinically required level. The research team believes that the interstitial fluid could be extracted non-invasively and painlessly thus leading to more frequent monitoring and better patient health. Other members of the research team include Dr. Maung Kyaw Khaing Oo from Prof. Fan's group and Prof. Yuan Luo, Jia Ge, and Zhe Chen from Jinan University in China. Prof. Fan's work was supported by the National Science Foundation. This work was originally published in *Photonic Microdevices/Microstructures for Sensing IV*, which was edited by Xudong Fan, Hai Xiao, and Anbo Wang. It can be found in *Proceedings of SPIE*, vol. 8376 or on the WIMS^2 website. ■



(a) The optofluidic ring resonator (OFRR) is a piece of thin-walled capillary whose circular cross section supports a high-Q whispering gallery mode (WGM). This allows the evanescent field to interact with analytes flowing in the capillary. (b) A spectral shift of WGM will be induced by the variations in refractive index of ISF with varied glucose concentration.

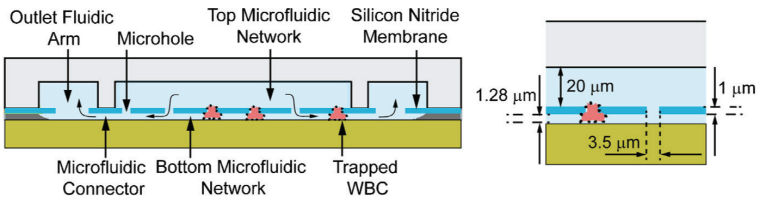


Calibration of OFRR sensor with aqueous ethanol solutions. Line with square symbol corresponds to (a) Spectral shift of the WGMs wavelength as a function of time when different concentrations of ethanol pass through the capillary. (b) A linear relationship between the refractive index of ethanol solutions and the spectral shift.

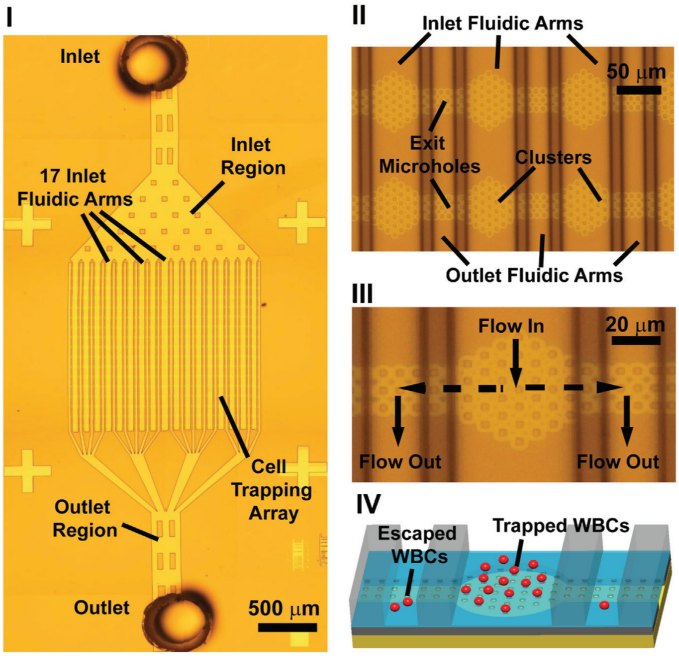
Microfluidic Blood Cell Trap

Prof. Nikos Chronis, Anurag Tripathi, and Prof. James Riddell

Prof. Nikos Chronis along with his graduate student Anurag Tripathi (now with Intel) and Prof. James Riddell from University of Michigan Health System, Department of Internal Medicine have developed a three-dimensional microfluidic biochip trap that can isolate individual white blood cells from whole blood. Unlike many microfluidic devices, this device traps cells as they travel perpendicularly into the plane of the substrate rather than through a maze of pillars across the plane of the substrate. This design increases the trapping efficiency of the blood cells up to 87%. The chip consists of an array of 10,700 holes. It is made with a one micron thick silicon nitride membrane, silicon, and PDMS. Once trapped, the cells can be imaged using standard fluorescent tagging and imaging techniques. This technology can also be used to trap and detect other types of cells merely by changing the diameter of the holes in the silicon nitride membrane. This work is available for download on the WIMS^2 website and was originally published in *Sensors and Actuators B: Chemical*, 186 (2013) pp. 224–251. ■



Cross section of white blood cell trap.

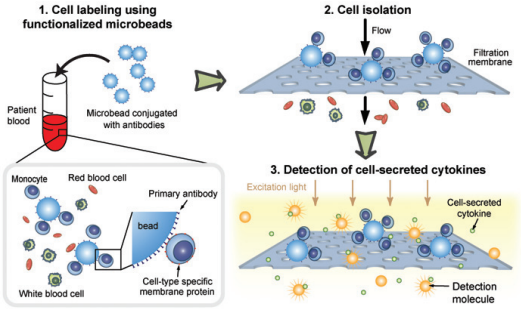


Picture of fabricated white blood cell trap (I-III) and 3D schematic (IV).

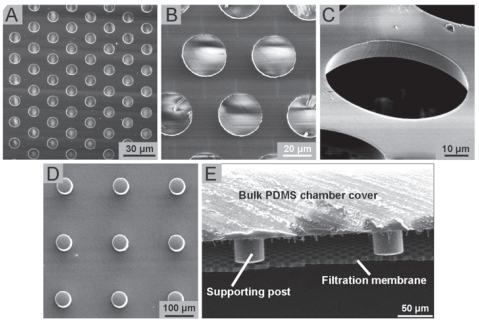
Surface Micromachined Micro Filtration Membranes

Profs. Katsuo Kurabayashi, Jianping Fu, Timothy Cornell , Thomas Shanley, Rong Fan, Raymond Lam, and students Weiqiang Chen, Boram Oh, Nien-Tsu Huang

Prof. Katsuo Kurabayashi and his collaborators (Prof. Jianping Fu from Mechanical Engineering, Profs. Cornell and Shanley from Pediatrics and Communicable Diseases, Prof. Rong Fan from Yale, Prof. Raymond Lam from the City University of Hong Kong plus graduate students Weiqiang Chen, Boram Oh, and Nien-Tsu Huang) have been working on novel micromachining techniques for PDMS (polydimethylsiloxane) to form micro filtration membranes and using that technology to build biomedical devices. In one project, Prof. Kurabayashi and his collaborators isolated and phenotyped subpopulations of immune cells from blood samples. The blood samples were combined with microbeads conjugated with antibodies. The immune cells of interest were immobilized on the beads by the antibodies while the rest of the constituents of the blood was unaffected. Because of the mechanical rigidity and well-defined size of the microbeads, the bead-bound cells were trapped on the PDMS membrane at a capture rate above 99%. Then the presence of the immune cells was detected optically. The advantage of this technique over standard ELISA assays is a seven to ten fold reduction in assay time. A similar technique works with tumor cells. This work was originally published in *Advanced Healthcare Materials* and is available on the WIMS^2 website. ■



Schematic of isolation and immunophenotyping of immune cells from blood.

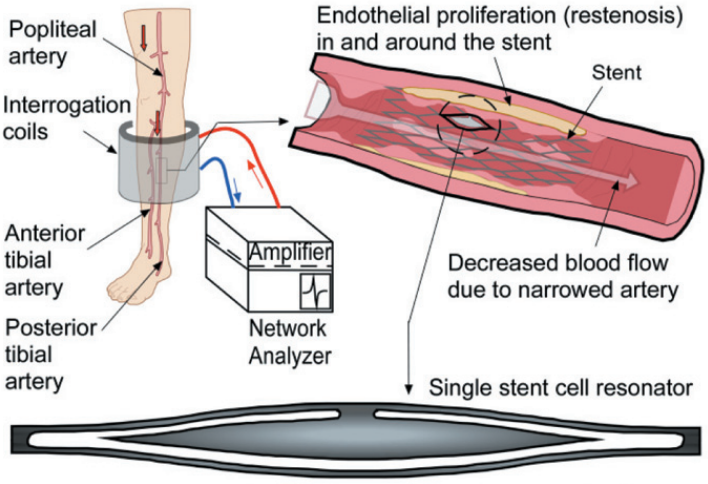


Images of micro filtration membrane constructed from PDMS.

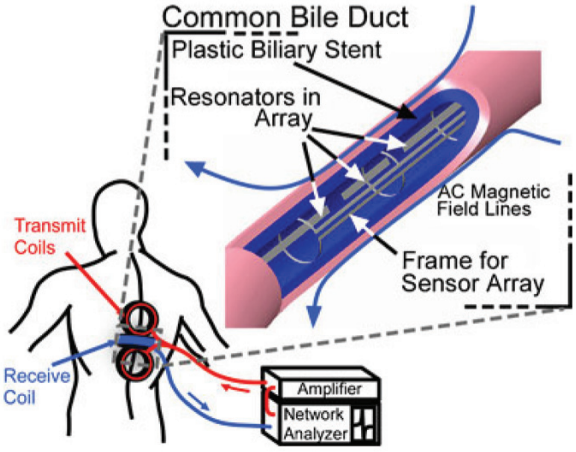
Wireless Magnetoelastic Sensors

Anupam Viswanath, Dr. Scott Green, Prof. Richard Kwon MD, Prof. Grace Elta MD, and Prof. Jurgen Kosel

Dr. Scott Green and Prof. Yogesh Gianchandani have made some exciting progress in their work on magnetoelastic sensors. Recent publications have highlighted the application of these devices in both the circulatory system and in bile ducts where they can detect tissue accumulation on arterial stents and biliary sludge on a stent in the bile duct. The biliary stent sensor was recently tested on a swine which showed no ill effects four weeks after the stent was implanted. The team found that the biliary stent could be interrogated wirelessly through more than 7 cm of tissue. The stent is interrogated by measuring its resonant frequency, which changes when the stent is loaded with additional mass. Members of the research team in addition to Dr. Green and Prof. Gianchandani include graduate student Anupam Viswanath, Profs. Richard Kwon and Grace Elta from the Division of Gastroenterology – University of Michigan Health System, and Prof. Jurgen Kosel, from King Abdullah University, Saudi Arabia. Parts of this work were reported at the MEMS 2013 conference and in the journal *Biomedical Microdevices* and in the journal *Micromechanics and MicroEngineering*. All three publications are available on the WIMS^2 website. ■



Stent placement in the posterior tibial artery along with a schematic of the single stent cell sensor.



Conceptual diagram of the magnetoelastic monitoring system.

Industrial Liaison Report

Dr. Andy Oliver

Industrial Liaison and Principal Staff Scientist

One of the missions of WIMS^2 is technology transfer and the education of our industrial members about the technology transfer process. The transfer process happens at a different pace for different types of technologies. The current interest in social media and software companies, for example Twitter and Facebook, is partially based on the relatively low development costs and quick time to market for software-based products. In contrast, my informal poll of the MEMS industry says that on average, between ten and twenty iterations are needed between a working prototype and production, and each iteration can last several months. To aid the technology transfer process WIMS^2 organized the *Workshop on Nano and Micro Manufacturing*[1] last May. It was held to discuss the difference between research and development and how the transfer between the two can be accelerated.

One of the benefits of the WIMS^2 Center is that it allows members the opportunity to see a technology mature. Members have the opportunity to become involved in the research process and to hire or fund center graduates to continue developing a technology. WIMS^2 has had a great deal of success commercializing different types of technologies through both start up companies such as Ambiq, NeuroNexus, and HandyLab, and existing companies such as Dexter Research and Stryker Corporation.

The October 19, 2013 issue of *The Economist*[2-3] featured two articles that addressed the problems that occur when the research and development efforts are not connected. They were titled, "How Science Goes Wrong," and "Trouble at the Lab; Unreliable Research," and described a long list of problems in the science community. An article in *Nature*[4] disclosed that researchers at Amgen were only able to reproduce the results from 11% of the 53 papers they studied, and this result was duplicated by researchers from Bayer in *Nature Reviews Drug Discovery*[5]. These problems can be mitigated if companies in development efforts work with the institutions that did the original research.

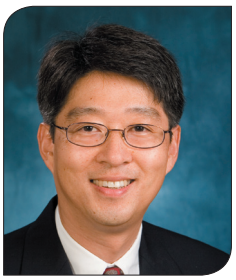
The problems reported in *The Economist* articles are not an excuse for bad science or results based on contaminated cell lines or dirty glassware. First, success or failure in engineering research is often less ambiguous than in basic science. While the performance of a system or device can be subject to interpretation or various errors, the basic functionality is usually obvious. The device either works or it doesn't. Second, WIMS^2 has a critical mass of students and faculty for an informal peer review system to provide a sounding board for questionable results. Third, the resources available at WIMS^2 including the high-quality students, top-notch faculty, laboratory facilities like the LNF[6], and the financial support of WIMS^2 members and other research sponsors make it easier to do high-quality and reproducible engineering research. Another resource is the University of Michigan's free consulting service for data collection and analysis, the Center for Statistical Consultation & Research[7]. The resources at WIMS^2 are significant advantages that should not be underestimated.

If you are interested in learning more about the WIMS^2 Center, in getting in touch with the researchers, or in hiring WIMS^2 graduates, I invite you to visit our website at wims2.org, or email info@wims2.org.

1. http://nano-microworkshop.com/
2. Anonymous, "How Science Goes Wrong," *The Economist*, October 19, 2013, p. 13.
3. Anonymous, "Trouble at the Lab; Unreliable Research," *The Economist*, October 19, 2013, pp. 26–30.
4. C.G. Begley and L. M. Ellis, "Raise Standards for Preclinical Cancer Research," *Nature*, vol. 483, March 29, 2012, pp. 531–533.
5. F. Prinz, T. Schlange, and K. Asadullah, "Believe It or Not: How Much Can We Rely on Published Data on Potential Drug Targets," *Nature Reviews Drug Discovery*, vol. 10, no. 9, September, 2011, p. 712.
6. lnf.umich.edu
7. http://cscar.research.umich.edu/ ■

New WIMS^2 Webmaster

Ms. Wendy Umbriac was hired in September as a Web Applications Programmer/Webmaster for WIMS^2. The retirement of Jon Plummer, our previous webmaster, was announced in our summer 2013 newsletter. Wendy quickly took up support of the Center's website, and looks forward to assisting with a strategic vision for the center's online presence. Before joining the Center, Wendy worked both in the University of Michigan College of Engineering's Computer Aided Engineering Network and at Enlighten (a digital marketing company) in Ann Arbor. She can be reached through the WIMS^2 website at info@wims2.org. Welcome aboard Wendy. ■



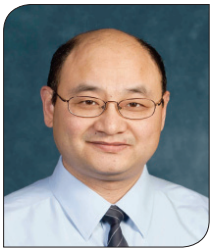
The subject of this issue's personnel focus is **Prof. Euisik Yoon** who heads the WIMS^2 Biomedical Thrust. He received the BS and MS degrees in electronics engineering from Seoul National University in 1982 and 1984, respectively, and the PhD degree in electrical engineering from the University of Michigan, Ann Arbor, in 1990.

From 1990 to 1994, he worked for the Fairchild Research Center of the National Semiconductor Corp. in Santa Clara, CA, where he engaged in researching deep submicron CMOS integration and advanced gate dielectrics. From 1994 to 1996, he was a Member of the Technical Staff at Silicon Graphics Inc. in Mountain View, CA, where he worked on the design of the MIPS microprocessor R4300i and the RCP 3-D graphic coprocessor. He accepted faculty positions in the Department of Electrical Engineering at Korea Advanced Institute of Science and Technology (KAIST) in Daejon, Korea (1996–2005) and in the Department of Electrical and Computer Engineering at the University of Minnesota, Minneapolis, MN (2005–2008). During the academic year of 2000–2001, he was a Visiting Faculty at Agilent Laboratory, Palo Alto, CA. In 2008, he joined the Department of Electrical Engineering and Computer Science at the University of Michigan, Ann Arbor, MI, where he is a Professor and the Director of the Solid-State Electronics Laboratory and the Lurie Nanofabrication Facility. His research interests are in MEMS, integrated microsystems, and VLSI circuit design. Some of his current research projects are in neural interfaces such as the biobolt project, a minimally invasive neural recording technology, and integrating optics in the probes in the emerging area of optogenetics. His recent work on ultra-compliant neural probes with biodegradable silk coatings received an award at the *IEEE Transducers Conference* in 2013. He is also developing microfluidics platforms for drug discovery and small form factor imagers.

Dr. Yoon was the co-recipient of the Student Paper Award at the *IEEE International Microwave Symposium* in 1999 and 2000. He has served on various Technical Program Committees including the *Microprocesses and Nanotechnology Conference* (1998), the *International Sensor Conference* (2001), the *IEEE Asia-Pacific Conference on Advanced System Integrated Circuits* (2001–2002), the *International Conference on Solid-State Sensors, Actuators and Microsystems (Transducers)* (2003, 2005), the *IEEE International Electron Device Meeting* (2006–2008), and the *IEEE International Conference on Micro Electro Mechanical Systems* (2006, 2009–2010). He also served on the *IEEE International Solid-State Circuit Conference* program committee (2003–2007) and was a general chair of *International Symposium on Bio Micro & Nanosystems* (2005). Prof. Yoon and his student Fan Wu won the outstanding oral paper award for a "Multi-Shank Silk-basked Parylene Neural Probe from Reliable Chronic Recording," at the *Transducers 2013 Conference*."

Prof. Yoon explains his work in this video. https://www.youtube.com/embed/EbSBMfbSwm0?ref=0 ■

Sherman Fan Elected Fellow of the Optical Society of America



Xudong "Sherman" Fan was recently selected as a Fellow of the Optical Society of America (OSA). This honor is only awarded to a very small percentage of OSA members. Sherman is an Associate Professor in the Biomedical Engineering Department at the University of Michigan and works in the Environmental Sensors and Subsystems Thrust in the WIMS^2 Center. He received his BS and MS from Peking University in 1991 and 1994, respectively, and PhD in physics and optics from Oregon Center for Optics at the University of Oregon in 2000.

Between late 2000 and 2004, he was a project leader at 3M Company on fiber optics and photonic sensing devices for biomedical applications. In August of 2004, he joined the Department of Biological Engineering at the University of Missouri as an assistant professor. In January of 2010, he joined the Biomedical Engineering Department at the University of Michigan as an associate professor.

Prof. Fan's research includes photonic bio/chemical sensors, micro/nano-fluidics, and nano-photonics for disease diagnostics and bio/chemical molecular analysis. He has over 100 peer-reviewed publications and over 10 issued/pending patents. He is a recipient of 3M Non-Tenured Faculty Award (2004, 2005, and 2006), American Chemical Society Petroleum Research Junior Faculty Award, the Wallace H. Coulter Early Career Award (Phase I and Phase II), and the National Science Foundation CAREER Award. ■

Seminar/Webinar Series

Past Seminars and Webinars

July 31, 2013
Xudong (Sherman) Fan, PhD/Webinar
Associate Professor
Biomedical Engineering Depart.
University of Michigan
"Smart Multi-Dimensional Gas Chromatography"

November 13, 2013
Prof. Zhiyu Hu/Seminar
Director, Institute of Nano Micro Energy, Shanghai University
Shanghai, China
Director, National Key Laboratory of Science and Technology on Micro/Nano Fabrication,
Shanghai Jiao Tong University, Shanghai, China
"Creating 2D Nanocatalytic Combustion Pattern Using Micro Nano-fabrication Technology and Its Infrared Thermography Analysis"

Webinars can be viewed at http://wims2.org/media/webinars.html
Seminars can be viewed at http://wims2.org/media/seminars.html

Fall 2013 Industrial Advisory Board Meeting

In October, the WIMS^2 IAB meeting was held in Sunnyvale, CA for the convenience of the WIMS^2 members based near there. Twenty-one industrial members of WIMS^2 from four companies plus three guests joined nine faculty and three staff from WIMS^2 at the semiannual event. The format of this event allowed the faculty to go into greater technical detail than normal and also allowed the inclusion of some special presentations by Profs. Sherman Fan, Katsuo Kurabayashi, and Ted Zellers on gas chromatography and environmental sensing. Other faculty attending this event included Profs. Yogesh Gianchandani, David Blaauw, David Wentzloff, Mina Rais-Zadeh, Euisik Yoon, and Jerry Lynch. While it was not feasible for students to present posters at the event, about 25 technical posters were displayed around the room, and served to start several in-depth discussions. The Industrial Advisory Board also met. In general, they were very supportive of having periodic meetings outside of Ann Arbor because it allows more participation from member companies.

2013 IEEE Sensors Conference

WIMS^2 researchers played a prominent role in the *2013 IEEE Sensors Conference* held in Baltimore, Maryland from November 3–6. Prof. Yogesh Gianchandani was the Technical Program Chair and there were two invited talks from WIMS^2, two presentations, and one poster presentation. The invited talks were from Prof. Sherman Fan who talked about "Smart Multi-Dimensional Gas Chromatography" and Prof. Mingyang Liu who spoke on "In-Situ Soil Moisture Monitoring: From Physical Models to Optimal Control to System Development." Topics of the oral and poster presentations included: microdischarge-based radiation detectors, wireless enabled sensor systems for radiation detection on cell phones, and magneteo elastic strain sensors.

The WIMS^2 Center instigated and helped organize an industrial panel at the conference. The topic was "Wearable Sensors: the Good, the Bad, and the Alluring" and was moderated by WIMS^2 alumni Andrew DeHennis and Brian Jamieson. Panelists include Ross Alcazar from XM Squared, Tori Hanna from Under Armour, Amar Kendal from MC10, Maurizio Mcagono from Heapsylon, Abhi Chavan from Corventis, and Babak Parviz from Google. The last two are also alumni of the MEMS and microsystem programs at Michigan. The panel addressed common tradeoffs such as battery life, integration level, and feature set as well as the human factors that will allow these devices to become an accepted (or even sought-after) feature of our daily attire. Applications of wearable sensors and electronics include healthcare, fitness, wellness, access to the internet, social media, and communications. ■

WIMS^2 alumni and friends at IEEE Sensors 2013.

Industrial Panel on Wearable Sensors at IEEE Sensors 2013.

Biomedical Electronics and Devices Meeting

An international meeting on biomedical microsystems was held on August 26, 2013 in Ann Arbor. Participants included eight faculty from National Chiao Tung University's Biomedical Electronics Translational Research Center and the National Program on Nano-technology, (in Taiwan) as well as faculty and staff from WIMS^2 and some outside industrial visitors. In total, more than 50 people attended the event. The Taiwanese visitors included Profs. Peter Wu and Morris Ker, Directors of the BETRC, as well as Prof. Yu-Ting Cheng who graduated from Prof. Najafi's group in 2000. The purpose of the meeting was to highlight promising research on neural prosthetics, epilepsy control, bio-optoelectonics, organs on a chip, and other exciting topics. One potential outcome of the meeting is the establishment of more collaborative efforts between Michigan and the Taiwanese university. This event is part of Michigan's 40-year effort in biomedical devices, which was originally started by Prof. Ken Wise in 1974. ■

Attendees at the Biomedical Microsystems Workshop.

Learning, Mentorship, and Academic Genealogy

Many years ago at the conclusion of a doctoral thesis defense in chemical engineering, the graduating student was presented with his academic genealogy. It was a record of mentorship stretching back several hundred years. I'd never heard of such a thing, but I was impressed. I wondered at the time what kind of academic genealogy I might have but didn't pursue it. In all the years I worked with my advisor at Stanford, I can't recall him ever mentioning who his advisor was.

Genealogy has exploded into something of a passion for a lot of people these days as they try to recover their family histories. I started working on mine as a teenager and the results now fill four volumes, trekking back through the Civil War and the Revolution to Indian wars on the Pennsylvania and New York frontiers, the first German migration to America, and the first settlers in New Netherland. But academic genealogy…?

Henry J. Zimmerman (1916-2007)

Engineering is such a relatively recent field that going back more than a few academic generations one is apt to find ancestors that didn't have PhDs at all. (Research in electrical engineering began at Michigan in 1875 but it didn't become a department until 1895.) A few years ago I discovered that my advisor's advisor was in that camp. Henry Zimmermann (1916–2007) was a Professor at MIT and directed their Research Laboratory of Electronics back in the 60s and 70s. He made important contributions to radar, microwave systems, antennas, and signal processing, but there is no indication he that had a PhD. So there my curiosity rested until a few weeks ago when an academic great-grandchild of mine at Purdue kindled it anew by identifying Zimmermann's principal mentor and tracing a portion of his lineage. With that as a starting point, I sat down and dug further. The results reflect the tremendous amount of information available on the web today and the fact that we are a lot more closely related to the people we read about in history than we might think.

Arnold Sommerfeld (1868-1951)

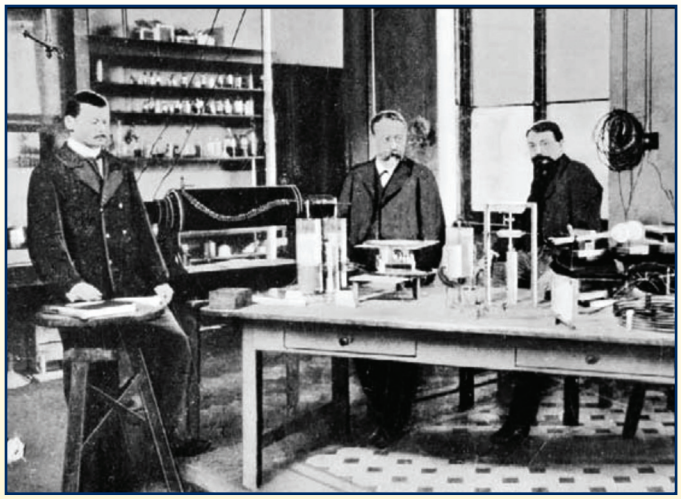
My academic lineage begins then in the MIT Radar Laboratory during World War II with Zimmerman and his mentor, Wilmer Barrow, but Barrow was from Germany, where he got his PhD in physics (1931) working with Arnold Sommerfeld and Jonathan Zenneck. I still have one of Sommerfeld's books but never dreamed he was my academic great grandfather! He has the distinction of having trained more Nobel laureates than anyone else in history (Heisenberg, Pauli, Debye, and Bethe; Brillouin was his student; Linus Pauling was his post-doc). His lineage can be traced back through five generations of mathematicians to Carl Friedrich Gauss (1777–1855), who made seminal contributions to astronomy, electromagnetics, optics, and just about everything else. His students included Kirchhoff, Mobius, and Dirichlet.

Another six generations removed and we wind up with Friedrich Leibniz (1597–1652), whose son Gottfried developed infinitesimal calculus and refined the binary number system.

Carl Friedrich Gauss (1777-1855)

Jonathan Zenneck received his PhD the same year as Sommerfeld (1891), and after a tour in the military and a year working in zoology, he entered the emerging field of radio science in 1895 as an assistant to Ferdinand Braun. Zenneck made fundamental contributions to radio science, directional antennas, and the cathode ray tube, receiving the IEEE Medal of Honor in 1928. Braun's degree was in physics (1872), but his contributions would warm the heart of any electronics engineer. It was Braun who discovered that a point-contact semiconductor rectifies alternating current and who built the first cathode-ray tube and cathode-ray oscilloscope. He also began wireless telegraphy, introducing tuned closed-circuit transmitters, inductively-coupled antennas, and crystal diode rectifiers. He invented phased-array antennas and received the Nobel Prize in Physics with Marconi in 1909. Albert Schweitzer is said to have been one of his students.

Jonathan Zenneck (1871-1959)



(L to R) Jonathan Zenneck, Ferdinand Braun, and Mathias Cantor at the University of Strassburg, 1899.

(Continued on page 9)

We can travel back in Braun's line through physicists whose students included the likes of Röntgen, Clausius, and Helmholtz to chemists who discovered cadmium, chromium, beryllium, and iridium and who established the basis for modern chemistry.

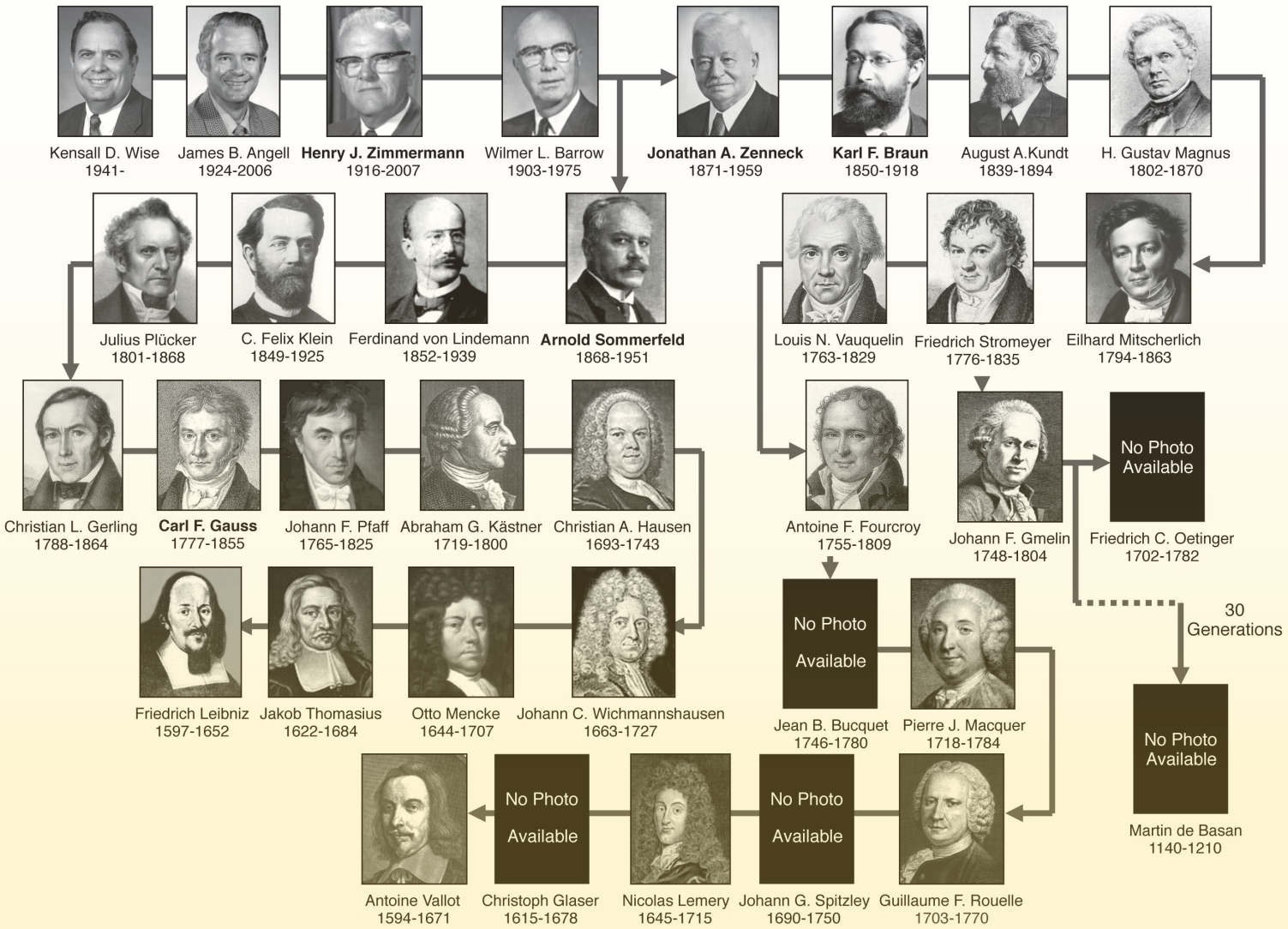
Ferdinand Braun (1850-1918)

About 1800, one line leaves Germany for France and leaves chemistry for medicine and pharmacy. Antoine Vallot (1597–1671) was personal physician to King Louis XIV. A second line remains in Germany until it moves to Italy about 1580 and to Paris about 1380, remaining there and in Spain as far back as Martin de Bazan (1140–1210). I have always understood that monasteries were the repositories of knowledge in the middle ages, and we see that here, encountering Saint Albert (Magnus) and Saint Dominic along the way. Tracing these lines was a fascinating look at the gathering and passing of knowledge over many centuries, and I am impressed that in science, as in DNA, we are a lot more connected than we might ever have guessed. It has also left me with the vague suspicion that with this kind of background, maybe I should have accomplished a little more! ■

Ken D. Wise
Professor Emeritus
Electrical Engineering
Founding Director, WIMS

Saint Dominic (1170-1221)

The Genealogy of Michigan MicroSystems



Nine WIMS² Talks at ISSCC 2014

WIMS² has nine talks at the *2014 International Solid State Circuits Conference (ISSCC)* in San Francisco in February. ISSCC is the flagship conference of the Solid-State Circuits Society, and is the premier forum for the presentation of advances in solid-state circuits and electronic systems-on-a-chip. This years theme is "Silicon Systems Bridging the Cloud." Profs. Blaauw and Sylvester have six papers at the conference and Profs. Yoon, Wentzloff, and Flynn have one each. Titles of the papers include:

"A 160nW 63.9fJ/conversion-step Capacitance-to-Digital Converter for Ultra-Low-Power Wireless Sensor Nodes"

"A Reconfigurable Sense Amplifier With Auto-Zero Calibration and Pre-Amplification in 28nm CMOS"

"A 32kb SRAM for Error-Free and Error-Tolerant Applications With Dynamic Energy-Quality Management in 28nm CMOS"

"A 23Mb/s 23pJ/b Fully Synthesized True-Random-Number Generator in 28nm and 65nm CMOS"

"A 3nW Fully Integrated Energy Harvester Based on Self-Oscillating Switched-Capacitor DC-DC Converter"

"An Implantable 64nW ECG-Monitoring Mixed-Signal SoC for Arrhythmia Diagnosis"

"A Static Contention-Free Single-Phase-Clocked 24T Flip-Flop in 45nm for Low-Power Applications"

"243.3pJ/pixel Bio-Inspired Time-Stamp-Based 2D Optic Flow Sensor for Artificial Compound Eyes"

"A 100MS/s 10.5b 2.46mW Comparator-less Pipeline ADC Using Self-Biased Ring Amplifiers"

David Blaauw

Dennis Sylvester

David Wentzloff

Euisik Yoon

In addition to the regular talks, Prof. David Wentzloff is speaking at the Low Power Radio Forum on "WIreless Communication for Cubic mm Sensor Nodes."

Many of these papers are collaborative, such as the paper entitled "An Implantable 64nW ECG-Monitoring Mixed-Signal SoC for Arrhythmia Diagnosis". It was authored by Profs. Blaauw and Sylvester along with collaborators Prof. Zhengya Zhang from the ECCS Department; Profs. Hakan Oral and Omer Berenfeld from the U. Michigan Medical Center; Research Scientist Grant Kruger; Postdoctoral Scholar Yoonmyung Lee; and students Dongsuk Jeon, Yen-Po Chen, Yejoong Kim, and Zhiyoong Foo. The paper by Prof. Yoon, the Thrust Leader for Biomedical Sensors and Subsystems, also crosses thrust boundaries. The paper "243.3pJ/pixel Bio-Inspired Time-Stamp-Based 2D Optic Flow Sensor for Artificial Compound Eyes" covers both circuit and algorithm development as well as incorporating a biologically inspired design scheme.

In addition to the technical papers, Prof. Mike Flynn is organizing the 6th University of Michigan ISSCC networking reception and reunion.

The *ISSCC* meeting will be held from February 9–13 at the San Francisco Marriott Marquis in downtown San Francisco, CA. ■

WIMS² ADVANTAGE

- **Intellectual Property:** WIMS² members are not only given preferential treatment on intellectual property rights but also the knowledge on how to use the intellectual property.
- **Technology Transfer:** Membership in the research center eases the transfer of technology from the university to industry.
- **Prototyping:** WIMS² will build prototypes for companies, thus transferring technology from university to industry.
- **Targeted Research:** Collaborators can sponsor targeted research projects specifically for company needs. These projects can take advantage of existing research and provide a significant value to WIMS² members.
- **Recruiting:** WIMS² members receive preferential access to graduate students.
- **Top Notch Students:** Produces graduates who are educated in a multi-disciplinary environment with 10+ courses in microsystems.
- **World Renowned Researchers:** The WIMS² research center eases access to faculty, many of whom are internationally known, for consulting or partnering on proposals.
- **Micro and Nanofabrication Facilities:** 20,000+ square foot clean room space with more than 120 tools.

Member Partners

Agilent Technologies, Inc.
Honeywell International
Ricoh Innovations, Inc.
Texas Instruments, Inc.

Associate Members

Dexter Research Center, Inc.
ElectroDynamic Applications, Inc.
ePack, Inc.
Fleetilla, LLC
InvenSense, Inc.
PicoCal, Inc.
Sandia National Laboratories
Twisthink, Inc.

Strategic Partners

MEMS Industry Group
Roger Grace Associates

Journal Articles

(From December 2012 – February 2014)

J. H. Seo, J. Liu, X. Fan, and K. Kurabayashi, "Fabry-Pérot Cavity Sensor-based Optofluidic Gas Chromatography Using a Microfabricated Passive Preconcentrator/injector," *Lab on a Chip*, vol. 13, pp. 851–859, December 2012.

S. J. Kim, S. Paczensny, S. Takayama, and K. Kurabayashi, "Preprogrammed Capillarity to Passively Control System-level," *Lab on a Chip*, vol. 13, pp. 2091–2098, February 2013.

W. Chen, N. T. Huang, X. Li, Z. T. F. Yu, K. Kurabayashi, and J. Fu, "Emerging Microfluidic Tools for Functional Cellular Immunophenotyping: A New Potential Paradigm for Immune Status Characterization," *Frontiers in Oncology*, vol. 3, p. 98, April 2013.

S. J. Kim and K. Kurabayashi, "Uniform-temperature, Microscale Thermal Modulator With Area-adjusted Air-Gap Isolation for Comprehensive Two-Dimensional Gas Chromatography," *Sensors and Actuators B: Chemical*, vol. 181, pp. 518–522, May 2013.

G. Bahl, K. H. Kim, W. Lee, J. Liu, X. Fan, and T. Carmon, "Brillouin Cavity Optomechanics With Microfluidic Devices," *Nature Communications*, (Online), June 2013.

D. Chen, J. H. Seo, J. Liu, K. Kurabayashi, and X. Fan, "Smart Three-dimensional Gas Chromatography," *Analytical Chemistry*, vol. 85, pp. 6871–6875, June 2013.

D. W. Dumbauld, T. T. Lee, A. Singh, J. Scrimgeour, C. A. Gersbach, E. A. Zamir, J. Fu, C. S. Chen, J. E. Curtis, S. W. Craig, and A. J. García, "How Vinculin Regulates Traction Forces and Adhesion Strength," *Proceedings of the National Academy of Sciences of the United States of America*, pp. 9788–9793, June 2013.

A. Kaplan, M. Tomes, T. Carmon, M. Kozlov, O. Cohen, G. Bartal, and H. G. L. Schwefel, "Finite Element Simulation of a Perturbed Axial-Symmetric Whispering-Gallery Mode and Its Use for Intensity Enhancement," *Optics Express*, vol. 21, no. 12, June 2013.

S. J. Kim, S. Paczensny, S. Takayama, and K. Kurabayashi, "Preprogrammed, Parallel On-Chip Immunoassay Using System-Level Capillarity Control," *Analytical Chemistry*, vol. 85, pp. 6902–6907, June 2013.

V. Thakar, Z. Wu, A. Peczalski, and M. Rais-Zadeh, "Piezoelectrically Transduced Temperature-Compensated Flexural-Mode Silicon Resonators," *IEEE/ASME Journal of Microelectromechanical Systems (JMEMS)*, pp. 815–823, June 2013.

W. Chen, N. T. Huang, B. Oh, R. H. W. Lam, R. Fan, T. T. Cornell, T. P. Shanley, K. Kurabayashi, and J. Fu, "Surface Micromachined Microfiltration Membranes for Efficient Isolation and Functional Immunophenotyping of Subpopulations of Immune Cells," *Advanced Healthcare Materials*, vol. 2, pp. 965–975, July 2013.

Z. Fan, Y. Sun, Di Chen, W. Chen, C. Deng, and J. Fu, "Acoustic Tweezing Cytometry for Live-cell Subcellular Control of Intracellular Cytoskeleton Contractility," *Scientific Reports*, (Online), July 2013.

V. J. Gokhale, O. Shenderova, G. McGuire, and M. Rais-Zadeh, "Infrared Absorption Properties of Carbon Nanotube/Nanodiamond Based Thin Film Coatings," *IEEE/ASME Journal of Microelectromechanical Systems (JMEMS)*, (Online), July 2013.

K. Scholten, K. Reddy, X. Fan and E. T. Zellers, "Vapor Discrimination by Dual-Laser Optical Reflectance of a Single Thiolate-Monolayer-Protected Gold Nanoparticle Film," *Analytical Methods*, (Online), July 2013.

T. Sukaew and E. T. Zellers, "Evaluating the Dynamic Retention Capacities of Microfabricated Vapor Preconcentrators as a Function of Flow Rate," *Sensors and Actuators B: Chemical*, pp. 163–171, July 2013.

T. Li, Q. Bai, and Y. B. Gianchandani, "High Precision Batch Mode Micro Electro Discharge Machining of Metal Alloys Using DRIE Silicon as a Cutting Tool," *Journal of Micromechanics and Microengineering*, 095026, pp. 1–11, August 2013.

X. Luo and Y. B. Gianchandani, "A Pulsed High Voltage Generator Utilizing a Monolithic PZT Element and Evaluation of Nonlinear Piezoelectric Behavior in Transient Mode," *IEEE/ASME Journal of Microelectromechanical Systems (JMEMS)*, vol. 22, no. 4, pp. 930–937, August 2013.

M. Sadeghi, R. L. Peterson, and K. Najafi, "Air Flow Sensing Using Micro-Wire-Bonded Hair-Like Hot-Wire Anemometry," *Journal of Micromechanics and Microengineering*, vol. 23, no. 8, August 2013.

E. E. Aktakka, R. L. Peterson, and K. Najafi, "High-Stroke and High-Deflection Bulk-PZT Diaphragm and Cantilever Micro Actuators and Effect of Pre-Stress on Device Performance," *IEEE/ASME Journal of Microelectromechanical Systems (JMEMS)*, (Online), September 2013.

S. An and Y. B. Gianchandani, "A Dynamic Calibration Method for Pirani Gauges Embedded in Fluidic Networks," *Journal of Microelectromechanical Systems (JMEMS)*, (Online), September 2013.

S. An, N. Gupta, and Y. B. Gianchandani, "A Si-Micromachined 162-Stage Two-part Kundsen Pump for On-chip Vacuum," *IEEE/ASME Journal of Microelectromechanical Systems (JMEMS)*, (Online), September 2013.

E. Hendarto and Y. B. Gianchandani, "Thermocapillary Actuation of Millimeter-Scale Rotary Structures," *Journal of Microelectromechanical Systems (JMEMS)*, (Online), September 2013.

E. E. Aktakka, N. Ghafouri, C. E. Smith, R. L. Peterson, M. M. Hussain, and K. Najafi, "Post CMOS FinFET Integration of Bismuth Telluride and Antimony Telluride Thin Film Based Thermoelectric Devices on SOI Substrate," *IEEE Electron Device Letters*, vol. 34, pp. 1334–1336, October 2013.

M. T. Breckenridge, R. A. Desai, M. T. Yang, J. Fu, and C. S. Chen, "Substrates With Engineered Step Changes in Rigidity Suggest a Role for Subcellular Biases in Traction Force in Driving Durotaxis," *Cellular and Molecular Bioengineering*, (Online), October 2013.

Y. Shim, J. P. Raskin, C. R. Neve, and M. Rais-Zadeh, "RF MEMS Passives on High-resistivity Silicon Substrates," *IEEE Microwave and Wireless Components Letters*, vol. 22, pp. 632–634, October 2013.

K. H. Kim, G. Bahl, W. Lee, J. Liu, M. Tomes, X. Fan, and T. Carmon, "Cavity Optomechanics on a Microfluidic Resonator With Water and Viscous Liquids," *Light: Science & Applications*, 5, (Online), November 2013.

Y. Shao, X. Tan, R. Novitski, M. Muqaddam, P. T. List, L. Williamson, A. P. Liu, and J. Fu, "Uniaxial Cell Stretching Device for Live-Cell Imaging of Mechanosensitive Cellular Functions," *Review of Scientific Instruments*, vol. 84, (Online), November 2013.

V. J. Gokhale and M. Rais-Zadeh, "Uncooled Infrared Detectors Using Gallium Nitride on Silicon Micromechanical Resonators," *IEEE/ASME Journal of Microelectromechanical Systems (JMEMS)*, (Online), December 2013.

K. K. Huang, J. K. Brown, I. Ansari, R. R. Rogel, Y. Lee, H. Kim and D. D. Wentzloff, "An Ultra-Low-Power 9.8 GHz Crystal-less UWB Transceiver With Digital Baseband Integrated in 0.18μm BiCMOS," *IEEE Journal of Solid-State Circuits*, pp. 3178–3189, December 2013.

(Continued on page 12)

Journal Articles (Continued)

Y. Shao and J. Fu, "Integrating Micro/Nanoengineered Functional Biomaterials for Cell Mechanics and Mechanobiology: A Materials Perspective," *Journal of Advanced Materials* (JAM), (Online), December 2013.

T. Li, K. Visvanathan, and Y. B. Gianchandani, "A Batch Mode Micromachining Process for Spherical Structures," *Journal of Micromechanics and Microengineering*, (Online), February 2014.

Conference Publications

(From July 2013 – January 2014)

(IFCS) IEEE International Frequency Control Symposium, Prague, Czech Republic, July 2013

V. A. Thakar and M. Rais-Zadeh, "Optimization of Tether Geometry to Achieve Low Anchor Loss in Lamé Mode Resonators"

(CICC) Custom Integrated Circuits Conference, San Jose, CA, September 2013

O. Seunghyun, N. E. Roberts, and D. D. Wentzloff, "A 116nW Multi-Band Wake-up Receiver With 31-bit Correlator and Interference Rejection"

Annual Meeting of Japan Society of Fluid Mechanics, Tokyo, Japan, September 2013

S. Nayake, H. Sugimoto, N. K. Gupta, and Y. B. Gianchandani, "Thermally Enhanced Membrane Gas Separation"

(μTAS) International Conference on Miniaturized Systems for Chemistry and Life Sciences, Freiburg, Germany, October 2013

B. Oh, N.-T. Huang, W. Chen, J. Seo, K. Kurabayashi, and J. Fu, "Localized Surface Plasmon Resonance (LSPR) Optofluidic Biosensor for Label-Free Cellular Immunophenotyping," pp. 92–94.

W. Chen, N.-T. Huang, B. Oh, T. T. Cornell, T. P. Shanley, K. Kurabayashi, and J. Fu, "Microfluidic Immunophenotyping Assay Platform for Efficient Isolation and Immunomonitoring of Subpopulations of Immune Cells"

IEEE International Conference on Sensors, Baltimore, MD, November 2013

X. Fan, "Smart Multi-Dimensional Gas Chromatography," (invited)

M. Liu, "In-Situ Soil Moisture Sensing: From Physical Models To Optimal Control To System Deployment," (invited)

R. Malhotra and Y. Gianchandani, "A Microdischarge-based Neutron Radiation Detector Utilizing Sputtered Gadolinium Films for Neutron Conversion"

V. Pepakayala, Y. B. Gianchandani, "A Passive, Wireless Strain Sensor Using A Microfabricated Magnetoelastic Beam Element"

Y. Sui and T. Li, "A Wireless-Enabled Sensor System for Distributed Radiation Detection on Android Cellphones"

ASME IMECE - International Mechanical Engineering Congress & Exposition, San Diego, CA, November 2013

K. Kumar, A. Besharatian, R. L. Peterson, L. P. Bernal, and K. Najafi, "Theoretical and Experimental Analysis of Active Valve Pumping for High Flow Rate Applications"

(IEDM) IEEE International Electron Devices Meeting, Washington, DC, December 2013

A. Ansari and M. Rais-Zadeh, "HEMT-based Readout of a Thickness-mode AlGaN/GaN Resonator"

(MEMS) IEEE International Conference on Micro Electro Mechanical Systems, San Francisco, CA, January 2014

Y. Qin, Y. B. Gianchandani, "A Micro Gas Chromatograph With Integrated Bidirectional Pump for Quantitative Analyses"

S. An, Y. Qin, and Y. B. Gianchandani, "A Monolithic Knudsen Pump With 20 sccm Flow Rate Using Through-Wafer ONO Channels"

M. N. Gulari, M. Ghannad-Rezaie, P. Novelli, N. Chronis, and T. C. Marentis, "An X-ray Detectable Pressure Microsensor for Monitoring Coronary In-Stent Restenosis"

X. Luo, C. Eun, and Y. Gianchandani, "Fabrication of a Monolithic Microdischarge-based Pressure Sensor for Harsh Environments"

A. Viswanath, T. Li, and Y. B. Gianchandani, "High Resolution Micro Ultrasonic Machining (HR-μUSM) for Post-Fabrication Trimming of Fused Silica 3-D Microstructures"

J. Tang, S. R. Green, and Y. B. Gianchandani, "Miniaturized Magnetoelastic Tags Using Frame-Suspended Hexagonal Resonators"

V. A. Thakar and M. Rais-Zadeh, "Passive Temperature Compensation of Piezoelectrically Actuated Lamé Mode Resonators"

H. Jeong, T. Li, J. Park, and Y. B. Gianchandani, "Ultrasound-assisted Micro-knife for Cellular Scale Surgery"

IEEE Meeting on Silicon Monolithic Integrated Circuits in RF Systems (SiRF), Newport Beach, California, January 2014

K. Ben Ali, C. Roda Neve, Y. Shim, M. Rais-Zadeh, and J. P. Raskin, "Non-linear Characteristics of Passive Elements on Trap-rich High-resistivity Si Substrates"

J.-K. Woo, J. Cho, C. Boyd, and K. Najafi, "Whole-Angle-Mode Micromachined Fused-Silica Birdbath Resonator Gyroscope (WA-BRG)" ■

Doctoral Dissertations

Karthik Balareddy, September 4, 2013
"Development of Highly Sensitive and Selective Optical and Electrical Sensors for Micro-Gas Chromatography"
Chair: Prof. Xudong Fan

Mohammed Hassan Ghaed, October 8, 2013
"Wireless Transceivers for Biomedical Microsystems"
Chair: Prof. Dennis Sylvester

Seungdo An, October 24, 2013
"Si-Micromachined Knudsen Pumps for High Compression Ratio and High Flow Rate"
Chair: Prof. Yogesh Gianchandani

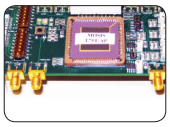
James McCullagh, January 13, 2014
"Power Conversion Circuits for Low Power, Low Voltage and Non-Periodic Vibration Harvester Outputs"
Chair: Prof. Khalil Najafi ■

Patents Issued

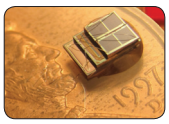
Mingoo Seok, Dennis Sylvester, David Blaauw, Scott Hanson, and Gregory Chen, "Reference Voltage Generator Having a Two Transistor Design," U.S. Patent No. 8,564,275, issued October 22, 2013. ■

WIMS^2 Research Thrusts Summary

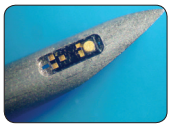
WIMS^2 is focused on fundamental and translational research on MEMS, microsystems, and microsensors through research, education, and industry partnerships. The applications for this research are centered on sensors and systems in three areas: 1) biomedical instrumentation, 2) MEMS-enabled gas chromatographs, and 3) sensors for infrastructure. The core technologies that support these applications include: micro and nanoscale fabrication, micromachined RF filters and resonators, packaging, power harvesting, low-power circuitry, and wireless interfaces. The combination of core technologies and applications focus distinguishes WIMS^2 from other university research efforts.



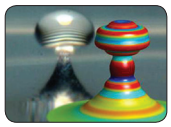
The **Wireless Interfaces Thrust** *(David D. Wentzloff, Thrust Leader)* undertakes basic and applied research in wireless interfaces for microsensor applications. Topics include CMOS RF circuits, low-power transceivers, miniature antennas, novel architectures, digital dominant wireless and sensor networking. The applications for this work are short-range biomedical devices and medium-range moderate data rate environmental sensing applications.



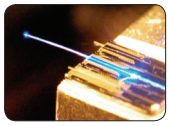
The **Micropower Integrated Circuits Thrust** *(Dennis M. Sylvester, Thrust Leader)* is directed at greatly reducing the power requirements of integrated circuits used in microsystems. Topics of interest include low-power digital and analog circuits, new circuit and system architectures, system software, power management, and energy harvesting.



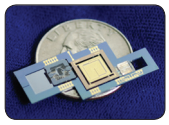
The **Advanced Materials, Processes and Packaging Thrust** *(Yogesh B. Gianchandani, Thrust Leader)* involves developing processing techniques for traditional and non-traditional MEMS materials, such as stainless steel, vacuum and wafer-level packaging, wafer bonding, assembly and interconnect technologies, mechanical protection of microsystems, and thermal management issues. It also includes the investigation of new types of transduction methods for devices ranging from micro-gyroscopes to monolithic gas pumps.



The **High Frequency MEMS Thrust** *(Mina Rais-Zadeh, Thrust Leader)* undertakes research in RF MEMS, Optical MEMS, and THz MEMS from a basic science and applied research perspective. The Thrust is exploring advanced RF devices and microsystems, high-*Q* optical and acoustic resonators, terahertz modulators, terahertz imagers, terahertz sources, miniaturized antennas, metamaterials, plasmonics, and near field optics.



The **Biomedical Devices Thrust** *(Euisik Yoon, Thrust Leader)* includes neural interface technology which was pioneered by the University of Michigan. It also includes work on microfluidic systems for medical applications such as cell sorting and "lab-on-a-chip" applications and other areas such as typing device tissue interactions and flexible systems. This research area leverages basic research in microfabrication, low-power circuits, and wireless and RF devices.



The **Environmental Sensors Thrust** *(Edward T. Zellers, Thrust Leader)* is centered around an integrated gas chromatograph (GC) targeted at rapid gas analysis with sub-part-per-billion sensitivity. Applications include sensing of complex mixtures, explosives, and pollutants. This research leverages technologies developed in the microfabrication area. The small scale of these devices enable greater portability, lower power consumption, and faster response time than larger systems. The Thrust also includes development of novel radiation detectors.

The **Built Environment Sensing Thrust** *(Jerome P. Lynch, Thrust Leader)* is developing microsystems to monitor the health of buildings, bridges, and the status of aircraft fuselages and naval vessel hulls. These devices are often connected together in wireless sensor networks that can communicate, measure, and analyze. Technology from the other research areas such as microfabrication, power harvesting, low-power circuits, and wireless devices are important enabling technologies for this effort. ■

Horizons

Microsystems for the Next Generation

***Horizons* is published by the Center for Wireless MicroSensing & Systems (WIMS^2)**

2114 Electrical Engineering and Computer Science Bldg. (EECS)
1301 Beal Ave.
Ann Arbor, MI 48109-2122
Telephone: 734-647-1779
Fax: 734-647-2342

info@wims2.org

http://wims2.org