Editorial

WELCOME to the IEEE SENSORS JOURNAL Special Issue on Microsensors and Microactuators: Technology and Applications. This special issue was inspired by the fact that over the last decade, micromachining has matured well beyond the threshold of academic curiosity and the use of silicon microsensors and microactuators has been increasing at a high rate. Microsensors appear in great numbers, notably in automobiles, process controls, biomedical applications, and scientific instrumentation. From the collection of published papers in this issue, readers will note the shift of emphasis in microelectromechanical systems (MEMS) research from core microfabrication technologies to application-specific microsensors and microactuators. More than ever, the work on microdevices is focused on the application-driven selection of fabrication technologies (or the integration of several technologies), suitable materials, system-level integration, and packaging.

While working on preparation of this issue, we observed a great interest in the microsensor community in research related to chemical and biological sensors, with seven papers addressing this area out of the final selection of 17 peer-reviewed papers published in this issue. Readers will find in this issue several interesting biosensors based on different sensing mechanisms. Gunter *et al.* presented their work on using a piezoresistively transduced microcantilever to detect single-stranded DNA. The approach is based on functionalizing the gold film surface of a cantilever with thiolated single-stranded DNA. In the presence of complementary single-stranded DNA in the sensing medium, hybridization occurs and the cantilever responds by dimensional changes, which are detected piezoresistively. Another approach to DNA sensing is presented by Towery *et al.*, in which a quartz crystal microbalance (QCM) is used. The QCM is functionalized and driven piezoelectrically into resonance. When hybridization occurs, the effective mass of the QCM increases, lowering the resonant frequency, which is then detected piezoelectrically. Radke *et al.* presented a biosensor based on impedance measurement with immobilized antibodies on interdigitated gold electrodes. Trace amount of bacteria in the sensing medium, once attached to the immobilized antibodies, causes detectable changes in the impedance. Finally, Yotter *et al.* presented a two-part overview on sensing biological metabolic activities at the single-cell level with lab-on-a-chip platforms. Part one describes the use of optical means to detect intra- and extra-cellular metabolites with fluorescent and phosphorescent probes, colorimetric sensors, evanescent wave sensors, surface plasmon resonance sensors, and infrared absorption spectroscopy. Part two reviews the uses of chemical, electrochemical, resonance, and impedance sensors to quantify oxygen, carbon dioxide, glucose, and pH levels. Applications are highlighted in disease diagnoses.

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New materials and mechanism designs are enablers of novel microsensors. In this issue, a number of papers present chemical or physical sensor devices with advanced materials. Zimmermann *et al.* developed chemical sensors for vapors of organophosphorous compounds, useful for environmental and automatic process analysis and control, by using polymer-coated acoustic wave devices. They experimentally investigated the performance of a set of polysiloxanes, determined the optimal polymer structure, synthesized the polymer, and discussed experimental characterization results. Mahajerzadeh *et al.* discussed a chemical sensor for detecting low concentrations of hydrogen sulfide by measuring the conductivity of tin oxide doped with copper oxide exposed to a gaseous environment. The material is optimized with respect to sensitivity and cross sensitivity to other gas compounds. Another sensor for the detection of the presence of hydrogen peroxide is developed using carbon electrodes modified with screen-printed colloidal gold, demonstrated by Xu *et al.* Although polysilicon is the most commonly used material for micromachined sensors, many high-temperature sensor applications demand wide-bandgap materials such as silicon carbide. A review of recent progress pertaining to the manufacturing and use of polycrystalline SiC is presented by Gao *et al.*

In this issue, you will find a variety of interesting papers ranging from purely theoretical to experimental, from application driven to technology motivated. Zhu *et al.* constructed a detail dynamic model of a tri-axial microaccelerometer with piezoelectric thin-film sensing using Lagrange's formalism, a useful approach for the design, analysis, optimization, and characterization of such sensors. A comprehensive overview of microsensors and microactuators for macrofluidic control is presented by Huang *et al.* Young *et al.* discuss a class of capacitive pressure sensors employing single-crystal 3C-SiC diaphragms, a critical material for sensors operating in high-temperature environments, such as those in advanced industrial, automotive, and aerospace–sensing applications. Many emerging applications require angular rate sensors that are small, cheap, and accurate. In this issue, John *et al.* propose and analyze a new differential phase angular rate sensor employing a vibrating beam mass structure that traces an elliptical path when subject to rotation due to the Coriolis force. Since the approach is utilizing the phase differential, it is independent of the driving amplitude, removing the need for complex amplitude control circuits. MEMS sensors and actuators enable many new applications. For example, Lan *et al.* present a novel application of microaccelerometers for target classification by detecting the seismic signal of moving vehicle targets with a microaccelerometer and recognizing targets using advanced signal processing method.

Microactuators are important for many industrial applications. Actuators are desired to have a large range of motion, low-biasing voltage or power, and large out of force. Lee *et al.* discussed an actuation mechanism that translates small, in-plane displacement (3.1 micrometers under 3-V dc

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bias) to large out-of-plane rotation (26.4°). They successfully demonstrated a variable optical attenuator based on this mechanism. Microsensors integrated with advanced circuitry provide added performance advantages (such as low-noise low-power operations) beyond device miniaturization. Circuit implementation, under the constrictions of functional integration, is a critical aspect of microsensor development. Wu *et al.* included a novel low-photocurrent retinal focal-plane optical sensor with advanced circuitry elements, based on innovative signal-conditioning algorithms, resulting in a power consumption of less than 8.8 μW/pixel at 3.3-V bias.

We are proud of the product you are holding in your hands. This special issue is a collection of high-quality papers that cover this process with the hope of it becoming of archival value to its practitioners and followers.

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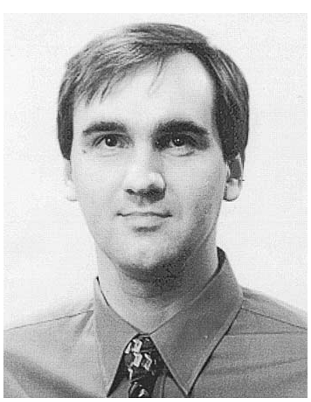
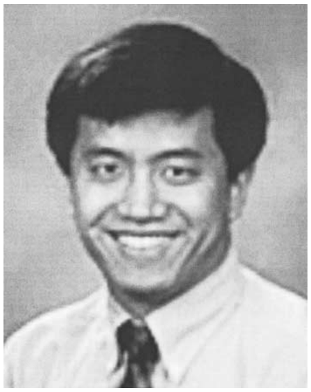


Andrei M. Shkel (S'95–A'98) received the Diploma (with excellence) in mechanics and mathematics from Lomonosov's Moscow State University, Moscow, Russia, in 1991 and the Ph.D. degree in mechanical engineering from the University of Wisconsin, Madison, in 1997.

After receiving the Ph.D. degree, he joined the Berkeley Sensor and Actuator Center, Berkeley, CA, as a Postdoctoral Researcher. He then held research and consulting positions in several hi-tech and venture companies, including MEMSolutions, Inc., Solus Microtechnologies, VIP Sensors, Endevco, Inc., Silicon Valley Venture, etc. He is on the faculty at the University of California, Irvine (UCI), where he is an Assistant Professor in the Departments of Mechanical and Aerospace Engineering, Electrical Engineering and Computer Sciences, and Biomedical Engineering. He is also the Director of the UCI Micro-Systems Laboratory. He holds three U.S. patents (nine are pending) on micromachined angle-measuring gyroscopes, design and fabrication of monolithic optical switches, and hybrid surface micromachining processes. He is a member of the Editorial Advisory Board for the ISA magazine *SensorTech*. His professional interests, reflected in over 50 publications, include solid-state sensors and actuators, MEMS-based neuroprosthetics, sensor-based intelligence, and control theory.

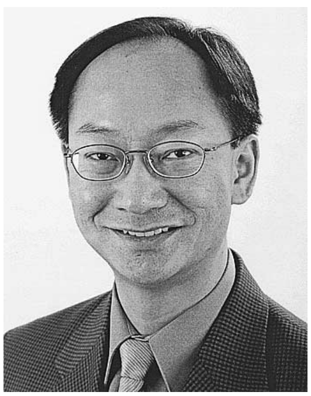
Prof. Shkel is an associate member of the ASME and SPIE. He was a member of technical committees of SPIE 2001–2003, TMS 2003, and ACC 2001. He has served on a number of editorial boards, including Guest Editor for two special issues of the IEEE SENSORS JOURNAL, Publications Chair of the 2002 IEEE Sensors Conference, and Vice General Chair and Publications Chair of the 2003 IEEE Sensors Conference. He was awarded the 2002 George E. Brown, Jr. Award and was the recipient of 2001 Fellowship of the Japanese Advanced Science Institute.



Chang Liu (S'92–A'95–M'00–SM'01) received the M.S. and Ph.D. degrees from the California Institute of Technology, Pasadena, in 1991 and 1995, respectively. His Ph.D. thesis was titled "Micromachined Sensors and Actuators for Fluid Mechanics Applications."

In January 1996, he joined the Microelectronics Laboratory, University of Illinois, Urbana, as a Postdoctoral Researcher. In January 1997, he became an Assistant Professor with major appointment in the Electrical and Computer Engineering Department and minor appointment in the Mechanical and Industrial Engineering Department. In 2003, he was promoted to Associate Professor with tenure. He teaches undergraduate and graduate courses covering the areas of MEMS, solid-state electronics, and heat transfer. His work has been cited in popular media many times. He is a Co-Founder and a member of the technical advisor board of NanoInk Corporation. He has consulted for several major MEMS companies. He has 13 years of research experience in the MEMS area and has published over 100 technical papers. His research interests cover microsensors, microfluidic lab-on-a-chip systems, and applications of MEMS for nanotechnology.

Prof. Liu is currently an Associate Editor of the IEEE SENSORS JOURNAL. He received the NSF CAREER Award in 1998 and he won a campus "Incomplete List of Teachers Ranked as Excellent" honor in 2001. In 2002, he was elected to the "Inventor Wall of Fame" by the Office of Technology Management, University of Illinois.



William C. Tang (S'86–M'90–SM'01) received the Ph.D. degree in electrical engineering and computer sciences from the University of California, Berkeley, in 1990. His seminal thesis work on the electrostatic comb drive has become a crucial building block for many microactuator and microsensor researches in the field.

He continued his contribution to the MEMS field first in the automotive industry as a Research Senior at Ford Research Laboratory, Dearborn, MI, then as the Sensor Research Manager at Ford Microelectronics, Inc., in Colorado Springs, CO. In 1996, he joined the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, where he was the Supervisor of the MEMS Technology Group, leading the pursuit of MEMS technology for space applications. In July 1999, he took on the responsibilities of the Program Manager at the Defense Advanced Research Projects Agency. He took over the MEMS and micropower generation programs and established new programs for nanomechanical array signal processors and chip-scale atomic clocks. Since July 2002, he has been on faculty as a Full Professor with the Department of Biomedical Engineering, University of California, Irvine, with a joint appointment at the Department of Electrical Engineering and Computer Science. Including the patent on electrostatic comb-drive actuators, he holds four U.S. patents and one patent pending on MEMS designs and technologies. He is the author and coauthor of over 40 conference and refereed papers in the MEMS field and is frequently invited to speak in seminars and workshops. His current research interests are in micro- and nanoscale technologies for wireless medical implants.

Dr. Tang is a Fellow and Chartered Physicist with the Institute of Physics.