MEMS
Room 309 - Session MM+VT-FrM
MEMS Actuators, Pumps, Power Devices, and Tribology
Moderator: R. Robbins, Texas Instruments

8:20am **MM+VT-FrM1 Micromechanical Devices for Force Measurement**, ***T.W. Kenny,*** Stanford University **INVITED**

In recent years, many researchers have adapted lithography, deposition and etching techniques from the IC processing community to the fabrication of micromechanical sensors. Many of the signals that these sensors are intended to detect are expressed as forces which stress or deflect the micromechanical structure. As sensors are miniaturized, these forces naturally become smaller, and techniques for detection are required to improve. Our research group has been engaged in a variety of activities, all of which share an interest in improving the force detection capability of microinstruments. In this talk, an overview of these activities will be presented, beginning with simple strain-gauge sensors (micronewtons), sensors based on tunneling displacement transducers (nanonewtons), AFM cantilevers (piconewtons), and ultra-thin force sensing cantilevers (attonewtons). Opportunities for exciting scientific measurements will be highlighted, and challenges for application of MEMS devices to these measurements will be discussed.

9:00am **MM+VT-FrM3 Developing MEMS Vacuum Pumps**, ***E.P. Muntz,*** University of Southern California **INVITED**

There are no satisfactory MEMS vacuum pumps; particularly unavailable are vacuum pumps that can handle the flow required for MEMS scale, continuous sampling instruments. The two obvious paths to creating such pumps, adapting current technology to MEMS scales or inventing new MEMS friendly technology, are discussed. The first path has been tried to some extent and not been successful, the second has been studied and a few possibilities are under investigation. A generic scaling study of expected trends in vacuum pumping performance as size is reduced to the MEMS scale is presented. It indicates that in practically all cases present vacuum pumps scaled to MEMS dimensions are not very attractive. New technologies that may offer more attractive possibilities are discussed. The degree of attraction is measured in terms particularly applicable to MEMS devices; the energy required per unit of upflow in the pump and the pump volume per unit of upflow. Both of these need to be sufficiently small to permit self consistency in energy use and size in order to allow local integration of the pumps with the MEMS devices that require vacuum pumping. For instance the full potential of instruments such as a MEMS sampling mass spectrometer can only be achieved if the pumps have power or space requirements equal to or preferably significantly less than the instrument itself. It is concluded that with new pumping technologies that have been identified, it may be possible to provide satisfactory MEMS vacuum pumping performance. However, this will only come to pass if a determined research and accompanying development program is created.

9:40am **MM+VT-FrM5 Miniaturized Fuel Cell for Portable Power**, ***H.L. Maynard,*** *J.P. Meyers,* Lucent Technologies, Bell Laboratories

We are developing a silicon-based miniaturized fuel cell to power 0.5-20 W portable telecommunication, computing, and personal entertainment devices. Fuel cells provide a 5-10x improvement in energy storage over advanced rechargeable batteries, allow "instant recharge" (with the insertion of a fuel cartridge), and enable sustained operation away from the power grid. The fuel cell is a methanol-based proton-exchange membrane (PEM) device. Our design is implemented in silicon to leverage advanced silicon processing technology, expertise and facilities. Applying silicon processing techniques to the fuel cell structure enables precise control over the thin-film properties and interfaces, enabling optimization of the critical three-phase region of ionic conductivity, electronic conductivity and gas and/or fluid permeability. Additionally, using a wafer-based approach minimizes production costs, instead of individually constructing and assembling the components. The advantages and disadvantages of two designs will be discussed: a two-wafer bipolar design and a single-wafer integrated monolithic structure. We discuss key integration issues including: thermal management, water control, air movement, fuel delivery, and power conditioning. We will also present preliminary experimental results.

10:00am **MM+VT-FrM6 Nanotribology and Stiction Studies of Surface Micromachined Electrostatic Micromotors Using An Atomic Force/Friction Force Microscope**, *S. Sundararajan,* ***B. Bhushan,*** The Ohio State University **INVITED**

Microelectromechanical systems (MEMS) which involve relative motion often encounter tribological problems that undermine and sometimes even prevent device operation. One such problem is that of static friction or stiction. An atomic force/friction force microscope (AFM/FFM) allows for direct measurements on fabricated devices, components and their surfaces. The AFM can be used to study tribological properties of surfaces that exhibit stiction. Nanotribological studies have been conducted on surface micromachined polysilicon micromotors for the first time using a commercial AFM/FFM. Surface roughness parameters (RMS, peak-to-valley distance, skewness and kurtosis) and nanoscale adhesion and friction properties of various surfaces of the motor were measured. Different surfaces of the motor components exhibit different surface roughness and friction properties. A novel technique to measure the stiction encountered in these motors using an AFM has been developed and is described. Using this technique, the effects of humidity and rest time on stiction in the motors have been studied. The mechanisms responsible for stiction in such devices are discussed. Meniscus forces between the mating surfaces of the motor may be the cause of the observed stiction. The real area of contact between the mating surfaces is an important factor affecting meniscus forces. The use of perfluoropolyether (PFPE) liquids as lubricants to reduce friction and stiction for such MEMS devices is investigated.

10:40am **MM+VT-FrM8 Characterizing Coupled MEM Oscillators for Array Applications**, ***R. Baskaran,*** Cornell University*; K.L. Turner,* University of California, Santa Barbara

MEM Oscillators have been successfully used as accurate sensing and actuation elements. We present a system of electrostatically coupled (by interdigital placement of the movable combfingers) torsional MEM oscillators. This design aims at studying the electrostatics of torsional systems and dynamics of variable coupling strength oscillators for distributed systems applications.@footnote 1@ The configuration allows design of elements with out-of-plane motion at locations across a large area without long springs/suspended structures, eliminating complex modes of oscillations close to operating frequencies and processing issues of large released structures. By design, each of the oscillators can be used for either capacitive sensing or actuation,like in a distributed control network. With integrated tips, the present design also lends itself to applications like AFM/STMs. We have designed, fabricated (with the SCREAM process) and characterized a 2-oscillator system. A high-accuracy(~4nm) laser vibrometry technique is used to get phase and amplitude of the displacement and velocity for various forcing voltages. Experiments have been performed to extract the electrostatic and dynamical parameters (represented by a coupled harmonic model) of the system. Experimental results show a near complete energy sharing (equal area under the Amplitude-Frequency curve) between the two oscillators in the primary resonance.'Beat' phenomenon i.e Amplitude modulation, typical of coupled systems, was observed in the impulse response as well as in the amplitude 'build up' to resonance. The phase relationship between the two oscillators will be useful to characterize the coupling mechanism and is presently under investigation. Future work involves extending the system to multiple oscillator arrays. @FootnoteText@ @footnote 1@Gabriel.K., Jarvis.J., Trimmer.W "Small machines, Large opportunities" Micromechanics and MEMS Classical and Seminal papers to 1990(IEEE).

11:00am **MM+VT-FrM9 Tunable Mechanical Oscillator**, ***M.K. Zalalutdinov,*** *B. Ilic, A. Zehnder, J.M. Parpia, H.G. Craighead,* Cornell University

It has been demonstrated that cantilever beam can resonate at various frequencies when driving force is applied locally, at different points along the beam. The tip of a scanning tunneling microscope (STM) engaged at the cantilever surface is driven in the Z-direction, acting as driving point-source with a subAngstrom amplitude. Cantilever motion was detected by the Scanning Electron Microscope incorporated into a UHV STM system and a spectrum analyzer was used to monitor the modulation of the videosignal, actuated when electron beam crosses the vibrating cantilever. Low stress silicon nitride cantilevers were fabricated using conventional bulk silicon micromachining techniques and coated with a 300Å Au/Pd film in order to provide good tunneling conditions. In this paper we present the results obtained with a 225x20x0.6 µm cantilever. When the driven STM tip was positioned above the bulk part of the sample, near the base of the beam, the conventional cantilever mode was excited with the resonant frequency

9,7kHz. When the STM tip is moved so that it engages the cantilever surface, an additional local constraint is placed on the beam's motion, altering the vibrational mode and causing the shift of the eigenfrequency. We detected a continuous increase of the resonant frequency (up to 25kHz) as the STM tip was moved along the center line from the base to the middle of the beam. This continuous variation of the resonant frequency has numerous possible applications, and was accomplished without a significant change in the Q. We have analyzed the measured deflection vs position using a model of the beam motion and found good agreement over the range we have studied. Possible realization of tunable micromechanical oscillators, based on the concept of a drive induced by the application of the local stress will be discussed.

11:20am **MM+VT-FrM10 Thermal Characteristics of Microswitch Contacts***,*
X. Yan*, N.E. McGruer,* Northeastern University*; S. Majumder,* Analog Devices*; G.G. Adams,* Northeastern University

Electrostatically actuated microswitches and relays have been developed at Northeastern University.@footnote 1@,@footnote 2@ Devices are approximately 100 @micron@ x 100 @micron@ in area and operate with an actuation voltage of 50-60 V, corresponding to a contact force of 100-150 microNewtons. The contact resistance varies less than 0.5 @ohms@ over 10@super 7@ cycles, with 4-10 mA current cold-switched. Switches have also been tested up to 10@super 9@ cycles with less than 0.5 @ohms@ variation in contact resistance, and with 330 mA of current for up to 18 cycles. The contacting bodies are a "drain" electrode approximately 0.2 @micron@ thick, and a pair of cylindrical bumps 1 µm in radius protruding from a 6 µm thick cantilever. The actual contact area is much smaller and consists of one or more small asperities. In this paper we study the microswitch contact properties at high currents. Finite element electrical and thermal models have been developed using ANSYS, and the modeled current handling limits are compared with experiments. Modeling shows that for a range of switch designs with thin-film drains, the highest temperature is located within the drain rather than at the contact interface, and this location moves further away from the contact interface as the drain thickness decreases or the length of the drain trace increases. Experiments confirm these trends, and show that switches fail catastrophically due to evaporation of the drain trace metal. SEM analysis of contact surfaces at various current densities is also presented. SEM analysis shows that even at the highest currents at which the trace metal evaporates, the contact surfaces typically show relatively little damage, mainly material transfer from one contact surface to the other. @FootnoteText@ @footnote 1@ S. Majumder, N. E. McGruer, "Study of Contacts in an Electrostatically Actuated Microswitch", Proceedings of 44th IEEE Holm Conference on Eletrical Contacts, pp 127-132 (1998) @footnote 2@ P.M. Zavracky, S. Majumder, and N.E. McGruer, "Micromechanical Switches Fabricated Using Nickel Surface Micromachining," J. Microelectromechanical Systems, Vol. 6, pp 3 (1997)

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