MEMS and NEMS

Room: 615 - Session MN-MoA

Materials Processing, Characterization and Fab Aspects

Moderator: B. Ilic, Cornell University

2:00pm **MN-MoA1 Electromechanical Resonators from Graphene Sheets**, ***P.L. McEuen***, Cornell University **INVITED**

We fabricate nanoelectromechanical systems from single and multilayer graphene sheets by mechanically exfoliating graphite over trenches in SiO2. Vibrations with fundamental resonant frequencies in the MHz range are actuated either optically or electrically and detected optically by interferometry. The thinnest resonator consists of a single suspended layer of atoms and represents the ultimate limit of two dimensional nanoelectromechanical systems. The high Young's modulus (E = 1 TPa), extremely low mass (single layer of atoms), and large surface area make these resonators ideally suited for use as mass, force, and charge sensors. We will discuss recent work on nanochambers sealed with graphene membranes. The pressure of the gas inside the nanochamber determines the pressure and damping of the graphene resonator.

2:40pm **MN-MoA3 Determination of the Density, Viscosity and Activation Energy of Small Liquid Volumes using Microcantilevers**, ***G. Hähner***, *N. McLoughlin, S.L. Lee*, University of St Andrews, Scotland, UK

The density and the viscosity are important parameters for the understanding and tailoring of many processes taking place in liquids. Their determination is generally performed with macroscopic liquid amounts and in separate measurements. In recent years some approaches have been proposed to determine these properties simultaneously. The majority of the methods applied still requires macroscopic liquid volumes and is based on macroscopic techniques. With the growing interest in microfluidic applications, however, alternative approaches for the determination of liquid properties on the microscale are desirable. We present a method for determining the viscosity and density of small liquid volumes (microliters) simultaneously from the resonance spectra of both magnetically driven as well as thermally excited microcantilevers.[1] Parameters characteristic of the resonance behavior of the system were extracted from resonance spectra recorded in a liquid of known density and viscosity. Subsequently, these parameters were used to determine the properties of further samples. In addition, temperature dependent spectra were exploited to extract the activation energy of viscous flow. The procedure we present is fast and reliable and requires no calibration of the cantilever force constant or specific knowledge of the cantilever geometry. Based around existing AFM technology the approach we propose can be easily adapted to suit a variety of microfluidic applications.

[1] N. McLoughlin, S. L. Lee, G. Hähner Appl. Phys. Lett. 89, 184106 (2006).

3:00pm **MN-MoA4 A Micromachined Ultrasound Transducer for Noncontact Nondestructive Evaluation**, *X. Wang, Y. Fan,* ***W.-C. Tian***, *H. Kwon, S. Kennerly, G. Claydon, A. May*, General Electric Co.

We report a capacitive micromachined ultrasound transducer (CMUT) for air-coupled, noncontact, nondestructive evaluation (NDE) applications. Air-coupled ultrasound is an attractive inspection technique for materials or structures that are not suitable for contact or immersion ultrasound inspections, such as the honeycomb composites used in aircraft structures. In the past CMUTs have been extensively studied for water-coupled, immersion applications.[1] In principle, CMUTs have better acoustic impedance match with air compared with piezoelectric ultrasound transducers. This makes them ideally suited for air-coupled NDE. However, they are not widely used in air inspection due to large air attenuation of acoustic power. To overcome this problem, CMUTs' transduction efficiency must be improved. We have successfully developed a large gap air-coupled CMUT. The device has a 1MHz operation frequency and can function both as ultrasound transmitter and receiver. The CMUT structure employs a large gap and a specially patterned SiO2 layer to provide large acoustic output while avoiding dielectric charging. A wafer-bonding process was used in fabrication.[2-4] In this process, a Si substrate was first etched to create cavities and oxidized. The SiO2 on the cavity floor was patterned to form pillar structures, which prevented arcing and charging in actuation. An SOI wafer was then bonded to the substrate wafer followed by handle wafer removal and metallization steps to complete the device. In our tests, CMUTs with patterned SiO2 insulation layers showed consistent operation over time. In comparison, control devices with un-patterned blanket SiO2 layers suffered from unsynchronized cell vibrations and fast signal decay due to dielectric charging. Acoustic though-transmission tests with paired CMUTs showed a loop gain of -51dB. As a comparison, a pair of state-of-the-art commercial air-coupled ultrasound transducers showed a -65 dB loop gain, 14 dB lower than the CMUTs reported here. This clearly indicates that improvement of air-coupled CMUTs is achievable and can lead to wide use of CMUTs for air inspections.

[1] X. Jin, et al., J. Microelectromech. Syst., 8, 100 (1999).

[2] Y. Huang, et al., J. Microelectromech. Syst., 12,128 (2003).

[3] Y. Huang, et al., IEEE T. Ultrason. Ferr., 52, 578 (2005).

[4] W-C. Tian, et al., US Patent Publication #2006/0004289 (2006).

3:40pm **MN-MoA6 Design, Synthesis, and Fabrication of a Biomolecular Nanovalve**, ***H. Li***, *L.E. Ocola, O. Auciello, M.A. Firestone*, Argonne National Laboratory

A device containing microfluidic and nanofluidic channels was designed and fabricated to study on the performance of a bio-nanovalve controlled by polarization of ferroelectric substrate. The microfluid channel consisting of 200 (W) x 200 (H) µm and 35 (W) x 200 (H) µm straight channels, micro-nozzles, and micro-diffusers, was designed to provide high driving pressure and low mass flow rate for fluid flow in the nanochannel. A recently developed lead-zirconium-titanate (PZT) substrate integrated with nano-electrodes was coated on the bottom of nanochannels to control the nanovalve made of biological molecules. By observing the fluid mixing behavior variation in nanofluid channels of 200 (W) x 200 (H) nm before and after the polarization of PZT substrate, the function of the bio-nanovalve would be demonstrated. The biovalve will prove useful for many applicatons including lab-on-a-chip and release-on-demand drug delivery systems. This device can also be used to study the basic science of fluid flow and heat transfer at the nanoscale with the purpose of improvement of flow and heat transfer efficiency in nanoscale devices.

4:00pm **MN-MoA7 XeF_2 Etching of Si and SiO_2 for MEMS Manufacturing**, ***J.-F. Veyan***, *Y.J. Chabal,* Rutgers, The State University of New Jersey*, M.Y. Yan, E. Gusev, A.L. Londergan*, Qualcomm

XeF_2 is used for etching a number of materials during MEMS fabrication, such as silicon,[1] and metals. Its strong reactivity with silicon and metals leads to rather violent reactions that make it difficult to characterize with typical surface science techniques under typical manufacturing conditions (XeF_2 pressure in a few Torr range). The fundamental reactions involved under these conditions are therefore harder to understand than typical elementary surface reactions in ultra-high vacuum conditions. It is therefore important to investigate etching mechanisms under such conditions. This work focuses on the characterization of gas phase, surface species, and substrate surfaces during XeF_2 etching using in-situ infrared absorption spectroscopy (IRAS) for both silicon and silicon oxide surfaces under typical etching conditions. To that end, a compact reactor has been constructed out of non-reactive materials (e.g. stainless steel, aluminum, Teflon and Kalrez o-rings), with the capability to perform IR spectroscopy. Despite these precautions, IRAS is critical to detect the presence and role of fluorinated contaminants (from reaction with molecules adsorbed on the walls) and the presence of products.[2] Thus, while XeF_2 induces a strongly exothermal reaction with Si, producing large amounts of SiF_4 gas (with a characteristic IR signature), and the incorporation of SiF, SiF_2 and SiF_3 in the subsurface region (~30Å deep) as previously observed in UHV studies, the presence of H_2O and HF gas, and CF_x and othe r adsorbed impurities can also be observed, pointing to side reactions on the walls despite thorough baking. XeF_2 etching of SiO_2 is much weaker and thereby harder to study. IRAS studies confirm that amorphous SiO_2 is etched at the rate of ~2-3Å/cycle at room temperature, where a cycle consists of 2Torr in 427cm^3 (i.e. ~ 3.10^{19} XeF_2 molecules). Although SiF_4 gas is also detected, it is not possible to exclude the potential etching of Si due to scratches. In contrast, no measurable SiF_4 gas is observed when crystal quartz is placed in contact with XeF_2, indicating that quartz does not etch. Preliminary data indicate that SiO_2 etching is highly dependent on the substrate temperature. Based on IRAS data, this talk will discuss various etching mechanisms and optimization of etching conditions for both Si and SiO_2.

[1] Harold.F Winter and I.C. Plumb J. Vac. Sci. Tech. B 9(1) 197 (1990)

[2] J. I. Steinfeld, Chem. Rev., 89, 1291, (1989)

4:20pm **MN-MoA8 Advances in Magnetometry through Miniaturization**, ***A.S. Edelstein***, *J. Burnette, G.A. Fischer,* U.S. Army Research Laboratory, *S.F. Cheng,* U.S. Naval Research Laboratory, *E.R. Nowak*, University of Delaware **INVITED**

Recent innovations will lead to magnetic sensors that are smaller, more sensitive and/or cost less than current magnetometers. Examples of this are the chip scale atomic magnetometer, magnetic tunnel junctions with MgO barriers, and a device for minimizing the effect of 1/f noise, the MEMS flux concentrator. In the chip scale atomic magnetometer researchers have been able to fabricate the light source, optics, heater, optical cell, and photodiode detector in a stack that passes through a silicon wafer. There are limits on decreasing the size of the cell, because collisions with the cell walls limit the spin lifetime. A search is underway for materials to be used as cell liners that have a smaller effect on the spin lifetime. Theoretical and subsequent experimental work led to the observation of magnetoresistance values of 400% at room temperature in magnetic tunnel junctions with MgO barriers. The large magnetoresistance occurs because electrons in the majority band can tunnel more easily through the MgO barrier than electrons in the minority band. The MEMS flux concentrator has the potential to increase the sensitivity of magnetic sensors at low frequencies by orders of magnitude. The MEMS flux concentrator does this by shifting the operating frequency to higher frequencies where 1/f noise is unimportant. The shift occurs because the motion of flux concentrators on MEMS flaps modulates the field at kHz frequencies at the position of the sensor. The concept and development of the MEMS flux concentrator will be presented.

5:00pm **MN-MoA10 Fabrication of Stationary Micro-Optical Shutter Based on Semiconductor-To-Metallic Phase Transition of W-doped VO2 Active Layer Driven by an External Voltage***, **M. Soltani**, M. Chaker,* INRS-Energie, Matériaux et Télécommunications, Canada*, E. Haddad, R. Kruzelecky,* MPB Communications Inc.*, J. Margot,* Université de Montréal, Canada*, P. Laou, S. Paradis*, Defence R and D Canada-Valcartier

At a transition temperature of T_t = 68 °C, thermochromic vanadium dioxide (VO_2) smart coatings undergo a reversible semiconductor-to-metallic phase transition (SMT). This phase transition is accompanied by an important modification of the electrical resistivity and optical properties in the infrared region. The T_t can be controlled by doping the coating with donorlike or acceptor like centers. In addition, the SMT of VO_2 can be controlled by external parameters such as temperature, pressure, photo-carrier injection into a VO_2 heterostructure, and an electric field. VO_2 smart coatings are thus excellent materials for various switching applications. Recently, we have successfully fabricated micro-optical switch device based on semiconducting and transmitting (on) state to the metallic and reflecting (off) state of W(1.4 at. %)-doped VO_2 operating at $\lambda = 1.55$ µm and driven by an external voltage.[1] This device exhibited an extinction ratio (on/off) as high as 28 dB. In addition, the electro-transmittance switching modulation of the device was demonstrated at 1.55 µm by controlling the SMT with superposition of a dc and ac switching voltages. In this paper, we present our recent results on the mico-fabrication and characterization of stationary optical shutter device based on transmittance switching (on/off) of W-doped VO_2 active layer. This shutter consists on 16 smart micro-slit arrays, which can be controlled individually by an external voltage (either a dc or ac switching voltage). This control allows to perform any desirable on-off combination of the micro-optical slits. The starting W-doped VO_2/Al_2O_3 was synthesized by reactive pulsed laser deposition. The micro-slit arrays were patterned by photolithography and plasma etching, whereas Au/NiCr electrical contacts were integrated on the top of the micro-slit by means of the lift-off process. The response of the device was investigated at 1.55 µm by controlling individually the transmittance switching of the active slits by an external voltage. The results show clearly that this device can be used as stationary Hadamard shutter to increase the sensitivity of infrared spectrometer.

[1] M. Soltani, M. Chaker, E. Haddad, R. V. Kruzelecky, and J. Margot, J. Vac. Sci. Technol. A 25(4), Jul/Aug (2007).

Authors Index

Bold page numbers indicate the presenter