MEMS and NEMS

Room: 4C - Session MN-TuP

MEMS and NEMS Poster Session

MN-TuP1 Surface Potential and Resistance Measurements for Detecting Wear of Chemically-Bonded and Unbonded Molecularly-Thick Perfluoropolyether Lubricant Films Using Atomic Force Microscopy, ***M. Palacio***, *B. Bhushan*, The Ohio State University

The wear of perfluoropolyether (PFPE) lubricants applied on Si (100) and a Au film on Si (100) substrate at ultralow loads was investigated by using atomic force microscopy (AFM)-based surface potential and resistance measurements. Surface potential data is used in detecting lubricant removal and the initiation of wear on the silicon substrate. The surface potential change is attributed to the change in the work function of the silicon after wear, and electrostatic charge build-up of debris in the lubricant. It was found that coatings that are partially bonded, i.e., containing a mobile lubricant fraction were better able to protect the silicon substrate from wear compared to the fully bonded coating. This enhanced protection is attributed to a lubricant replenishment mechanism. However, an untreated lubricant coating exhibited considerable wear as it contains a smaller amount of lubricant bonded to the substrate relative to the partially bonded and fully bonded coatings. A sample subjected to shear is shown to have improved wear resistance, and this enhancement is attributed to chain reorientation and alignment of the lubricant molecules. The detection of wear of PFPE lubricants on Au by an AFM-based resistance measurement method is demonstrated for the first time. This technique provides complementary information to surface potential data and is a promising method for studying the wear of conducting films.

MN-TuP2 Wetting Behavior During Evaporation and Condensation of Water Microdroplets on Superhydrophbic Patterned Surfaces, ***Y.C. Jung***, *B. Bhushan*, The Ohio State University

Superhydrophobic surfaces have considerable technological potential for various applications due to their extreme water repellent properties. The superhydrophobic surfaces may be generated by the use of hydrophobic coating, roughness and air pockets between solid and liquid. The geometric effects and dynamic effects, such as surface waves can destroy the composite solid-air-liquid interface. The relationship between the water droplet size and geometric parameters governs the creation of composite interface and affects transition from solid-liquid interface to composite interface. Therefore, it is necessary to study the effect of droplets of various sizes. We have studied the effect of droplet size on contact angle by using evaporation studies with droplet radii ranging from about 700 to 300 µm. Experimental and theoretical studies of wetting properties of silicon surfaces patterned with pillars of two different diameters and heights with varying pitch values are presented. We propose a criterion where transition from Cassie and Baxter regime to Wenzel regime occurs when the droop of the droplet sinking between two asperities is greater than depth of the cavity. Based on the experimental data and the proposed transition criteria, the trends are explained. For the first time, environmental scanning electron microscopy (ESEM) is used to form smaller droplets of about 20 µm radius and measure the contact angle on the patterned surfaces. The investigation has shown that ESEM provides a new approach to wetting studies on the microscale.

MN-TuP3 The Effect of Sliding and Peeling Motion on Gecko Adhesion, *T.W. Kim*, ***B. Bhushan***, The Ohio State University

The attachment pads of geckos exhibit the most versatile and effective adhesive known in nature. Their fibrillar structure is the primary source of high adhesion and their hierarchical structure produces the adhesion enhancement by giving the gecko the adaptability to create a large real area of contact with surfaces. Although geckos are capable of producing large adhesive forces, they retain the ability to remove their feet from an attachment surface at will. Detachment is achieved by a peeling motion of the geckoâ?Ts feet from a surface. Recent investigations have shown that a load applied normal to the surface was insufficient for an effective attachment of seta. The maximum adhesion force was observed by sliding the seta laterally along the surface under a preload. Therefore, in this study, for the three-level hierarchical model recently developed by the authors, the sliding motion of a gecko seta is considered to understand how the sliding contributes the adhesion and friction forces. In addition, the peeling motion of a gecko seta has also modeled. The peeling force is obtained as a function of peeling angle for the gecko setae contacting with the different random rough surface. This works are useful for understanding biological systems and for guiding of fabrication of the biomimetic attachment system.

MN-TuP4 Nanotribological Studies of Platinum Coated Probes Sliding against Coated Silicon Wafers For Probe-based Recording Technology, ***K.J. Kwak***, *B. Bhushan*, The Ohio State University

Some of the new alternative information storage technologies being researched are probe-based recording techniques. In one of techniques, a phase-change medium is used and phase change is accomplished by applying either high or low magnitude of current which heats the interface at different temperatures. Tip wear at high temperature is a serious concern. For wear protection of the phase-change chalcogenide media, diamondlike carbon (DLC) film and various lubricant overcoats were deposited on the recording layer/silicon substrate. Nanotribological properties of platinum (Pt) coated probes with high electrical conductivity have been investigated in sliding against the coated media using an atomic force microscope (AFM). A silicon grating sample and SPIP software of Image Metrology were used to characterize the change in the tip shape and evaluate the tip radius. The wear tests were performed at the sliding velocity ranging from 100 µm/s to 100 mm/s. Pt-tips on the lubricant coated DLC film surfaces showed less sensitivity to the velocity and the load as compared to the unlubricated DLC film surfaces. The lubricant coatings could be used to reduce Pt-tip wear and friction between Pt-tip and DLC film surfaces. The results suggest that wear mechanism at low speed appears to be adhesive. At high speeds, the wear primarily depends on surface chemistry of the coated layers such as tribochemical oxidation.

MN-TuP5 A Microfluidic Device for the Spring Constant Calibration of Micro-Cantilevers and for Measuring Fluid Flow Velocities, ***G.V. Lubarsky***, *G. Haehner*, University of St. Andrews, UK

We present a new microfluidic device and method based on cantilever sensing technology. Utilizing an artificially created force gradient the method can be applied for the non-destructive calibration of the normal spring constant of micro-cantilevers. In contrast to the most recent efforts to advance cantilever calibration, our method can be performed in situ, is easy to use, reliable, accurate, and non-destructive, i.e., does not involve any contact between the cantilever and another surface. The method has great potential for the calibration of modified probes, bio-sensor cantilevers etc. In addition, provided the dynamic properties of the cantilever sensor are designed and clearly defined, the device can be easily incorporated in microfluidic systems to measure the velocity of fluid flows.

MN-TuP6 Improvement of Surface Roughness of Cerium Oxide Thin Film by Chemical Mechanical Polishing for Oxygen Gas Sensor, *P.-J. Ko, Y.-K. Jun, P.-G. Jung*, Chosun University, Korea, ***N.-H. Kim***, Sungkyunkwan University, Korea, *W.-S. Lee*, Chosun University, Korea

Cerium oxide (CeO2) is one of the most widely used materials for the oxygen gas sensors. Surface roughness of CeO2 thin films must be improved because the electrical and sensing properties of CeO2 thin films are determined by these characteristics. Chemical mechanical polishing (CMP) processing was selected for improving the surface roughness of CeO2 thin films. Surface roughness and within-wafer non-uniformity (WIWNU%) of spin coated CeO2 thin films were examined with a change of CMP process parameters. The optimized process condition, reflected by both the surface roughness and the hillock-free surface with the good uniformity, was obtained. The effects of the improved surface roughness on the sensing property of CeO2 thin films were also confirmed. The improved sensing property of CeO2 thin films for oxygen sensors were obtained after CMP process by the improved surface morphology. Therefore, we conclude that sensing property of CeO2 thin film is strongly dependent on the surface roughness of CeO2 thin films. Acknowledgement: This work was supported by Korea Research Foundation Grant (KRF-2006-005-J00902).

MN-TuP7 Fabrication of Body Insulated Conductive Cantilever with Metalic Nano Tip, ***S.H. Park***, Myongji University, Korea, *S.H. Kim*, Korea Electronics Technology Institute, *C.J. Kang, Y.J. Choi, J.W. Kim, Y.S. Kim*, Myongji University, Korea

Scanning Probe Microscopy (SPM) can be used to analyze specimens at sub-micrometer scale either by profiling their surface morphology or by measuring their electrical property. SPM has become one of the essential research tools in the field of biology because of its lateral resolution superior to optical microscopy. For the application to biological samples, the SPM probe should be occasionally immersed into an aqueous environment in the form of buffer solution. If we want to get electrical information of the sample in the aqueous environment with commercially available surface conductive cantilevers, electrical leakage from the cantilever body to the solution takes place, which results in poor image resolution. In this study, we fabricated body insulated conductive cantilever in order to avoid leakage current through cantilever surface. Electron Beam Induced Deposition (EBID) technique was used to fabricate well localized conductive nano probe. By optimizing the EBID tip growth condition, we could acquire probe whose base diameter and effective length are below 300nm and a few μm. Tungsten hexacarbonyl [W(CO)6] is a popular precursor material used in placing conductive deposits with the EBID method. We analyzed the constituents of fabricated nano probe by Energy Dispersive X-ray Spectroscopy (EDXS) and microscopic Fourier Transform Infrared spectroscopy (μ-FTIR) which detects element species and chemical bond. We also examined resolution of the fabricated nano probe compared with the conventional metal probe by recording topographic images and electrostatic force images (EFM) of gold electrodes simultaneously. When measuring an electric signal in buffer solution, we could reduce a leakage electric current. This result suggests the possibility of direct fabrication of high aspect ratio and conducting nano SPM probe on the body insulated conductive cantilever.

MN-TuP8 A Robust Parametrically Excited MEMGyroscope, ***L.A. Oropeza-Ramos***, *C.B. Burgner, C. Olroyd, K.L. Turner*, University of California, Santa Barbara

We present a novel scheme for a robust micro gyroscope which is actuated parametrically and is less sensitive to parameter variations. We experimentally demonstrate that using a parametric resonance based actuator, the drive mode signal has rich dynamic behavior with a large response in a large bandwidth. In this way the system is able to induce oscillations in the sense mode due to Coriolis force, despite that there is a clear disparity on the drive and sense natural frequencies. Thus we propose a scheme that reduces the sensitivity loss due to mismatching in the drive and the sense natural frequencies, which is a common problem in micro gyroscopes based on harmonic oscillators, and also increases significantly the range of frequencies where the gyroscope can operate due to its inherent dynamical properties. Rate table characterization is given. Extensive effort has been applied to gyroscopic structures based on two or more degree of freedom (DOF) harmonic oscillator.[1] For the 2 DOF type, the drive and the sense resonant modes are tuned to be equal (or nearly equal) in most cases, in such a way that the output is amplified by the quality factor Q, resulting in high sensitivities. Due to the current fabrication processes, structural asymmetries are inevitably present; therefore matching of frequencies commonly requires external trimming or implementation of control schemes. In this paper we present the realization of a novel Micro Electro Mechanical Gyroscope actuated by a set of noninterdigitated comb fingers which generate a force with time and displacement dependent stiffness coefficients. Thus, parametric resonance excitation amplifies the drive mode response over a wide set of frequencies. In this way, differences in drive and sense natural frequencies do not compromise the sensitivity in 1kHz range. The 2 DOF micro gyroscope is fabricated using the standard SOI process flow and rate table characterization is presented under 50 mTorr pressure. The sensor response is detected with a capacitive readout hybrid wire bonded to the gyroscope on a chip. Our device has demonstrated a scale factor nonlinearity of 0.8% within ±150 °/sec. Thus, in this demonstration the micro gyroscope is robust to parameter variations.

[1]Yazdi, N., et.al., IEEE Proceedings, Vol.86, No.8, 1998.

MN-TuP9 Modeling of Asymmetric Microelectrode Array and Capillary Forces for Fluidic Self Assembly in MEMS, ***A. Dang***, Netaji Subhas Institute of Technology, India, *M. Dhayal*, National Physics Laboratory, India

Modeling and quantitative design play a key role in MEMS to explore the difference parameter space that can influence the performance of micro fluidic devices. In this study the effects of actuation profile incorporated with geometrical dimensions has been investigated on self-assembly of different types of fluids in micro fluidic devices. Different types of asymmetric electrode array were designed and associated electric field profile had been modeled. The optimization of operating conditions of asymmetric field profile with controlled geometrical dimensions on self-assembly of different type of polar solutions has been investigated for different biological applications.

MN-TuP10 Effect of Au Promoter Layers on NOx Sensitivity of Indium Oxide Solid State Sensor, ***S. Kannan***, *M. Sorenson, L.W. Rieth, F. Solzbacher*, University of Utah

Stricter global emission regulations have generated an immediate need to develop high temperature compatible (>500°C) gas sensors for monitoring exhaust. Indium Oxide (In_2O_3) thin films with Au promoter layers have exhibited excellent sensitivity (S ~ 20) for detection of NO_x at temperatures greater than 500°C. Gas sensitivity results will be interpreted as a function of In_2O_3 film structure and morphology. Thin film In_2O_3 layers (~150 nm) were RF sputter deposited in an ambient of pure argon (10 mtorr, 600 W, 2.4 nm/min) on Pt inter-digitated electrodes (IDE). Au promoter layers (~3nm) were deposited on top of the In_2O_3 film in a separate sputtering system. The thin films were annealed in nitrogen, oxygen, forming gas (2% H_2 in Ar) or mixtures of nitrogen and oxygen up to 15 hours at temperatures from 700°C to 1000°C. X-ray diffraction (XRD) results reveal as-deposited and films annealed in oxygen have cubic crystallite structure with several reflections present. In_2O_3 films annealed in nitrogen show the presence of (321) (411) grains in addition to the as-deposited peaks. Atomic force microscopy (AFM) reveals as-deposited films having an average particle size of 25 nm (RMS = 1.5 nm) which increase to a particle size of up to 65 nm with annealing (RMS = 2.6 nm). These images also suggest all annealed samples with Au promoter change in morphology and increase roughness to 6.5 nm. X-ray photoelectron spectroscopy (XPS) revealed the annealed films to be In rich (45% In, 55% O). Films annealed in forming gas islanded exposing Si XPS peaks from the substrate.Four point probe measurements show the resistivity increase from as-deposited values of 0.0045 Ω-cm to larger than probe can measure(~ 7 Ω-cm) for forming gas annealed films and the results suggest the annealing ambient is important. In_2O_3 films were tested for gas sensitivity (S) towards NO_x (0-25ppm), NH_3 (25 ppm), CO_2 (1000 ppm), H_2 (5000 ppm) in synthetic air (80% N_2, 20% O_2) and nitrogen as carrier gas. In_2O_3 films with Au as a promoter annealed in N_2 at 900°C for 5 hours exhibited excellent sensitivity (S~5) operating at 500°C and S~1 at operating temperature 650°C for detection of NO_x. Sensitivity to NH_3 as well as CO_2 was low relative to NO_x at 500°C and 650°C (S~0.1).

MN-TuP11 XeF_2 Etching of Metallic Films, ***O. Celik***, *N. Shankar, A.V. Ermakov, L. Goncharova, Q. Jiang, L. Wielunski, E. Garfunkel,* Rutgers University, *X.M. Yan, A.L. Londergan, E. Gousev*, Qualcomm MEMS Technologies

The controlled etching of micro/nano structures is very important for a variety of technological applications, including MEMS fabrication. XeF_2 is an isotropic and selective vapor phase etchant used to etch Si and metals in MEMS and other devices. For better process control and device functioning, it is important to understand the etching mechanism at the molecular level. In this study we have explored the surface and gas phase chemistry of XeF_2 etching of metallic films. Down stream mass spectrometry is used to identify the gas phase by-products in the etching process. RBS and MEIS are used to measure the thickness of the films and the depth profile of near-surface species after etching. The etch rate is calculated from film thickness changes. The etched surface composition and chemical state are further investigated by XPS. Based upon the gas phase by-products during etching, surface species and their depth profiles, and the etching rate, a reaction mechanism of XeF_2 etching is proposed.

MN-TuP12 Parametric Amplification in Electromagnetically Actuated Resonant Chemical Sensors, ***K. Lukes***, *K.L. Turner,* University of California, Santa Barbara, *J. Rhoads, S. Shaw*, Michigan State University

This work presents a novel implementation of mechanical domain, parametric amplification in electromagnetic microcantilevers. Parametric amplification is the amplification of a signal due to pumping energy into the system parametrically. This class of resonators shows great potential for implementation as chemical sensors, since they exploit the induced electromotive force (emf) for sensing[1] giving potential for complete onchip integration. It is difficult to recover the sense signal because it is several orders of magnitude smaller than the drive signal. Parametric amplification offers low noise gain for signal recovery. We describe the model and experimental validation of parametric amplification. A measure of merit for the amplifier is its gain. Gain is defined as the ratio of sensor's amplified to harmonic response. Analysis of the gain function shows the response is amplified asymptotically as the pump approaches the limiting magnitude defined by the onset of parametric resonance, and depends on the square root of sin(2φ), where φ is the phase shift between the input signals. Parametric amplification is achieved by the microcantilevers. Each cantilever has metal wires deposited on the surface, making it a closed current loop. The device sits on an angled permanent magnet. An AC current, consisting of the sum of the harmonic and parametric signals, passes through the device producing the Lorentz force. The force can be broken into a normal component, the harmonic forcing, and axial component, the parametric pump. The dynamics of the resonators are measured using a single point laser vibrometer in vacuum.[2] These devices have shown the capability for emf sensing;[1] vibrometry is used for proof of concept. Experimental data confirms the expected relationship of gain to φ and pump magnitude. We have successfully shown parametric amplification in electromagnetically actuated microcantilevers. Theoretical results anticipate large gains and experimental data confirms that these gains are feasible. The ability to mechanically amplify the signal of the transducer shows potential for a complete on-chip chemical sensor.

[1] Requa, M.V. and K.L. Turner. APL, 2006. 88(26)

[2] Turner, K., Hartwell, P., MacDonald, N. in 10th International Conference of Solid-State Sensors and Actuators (Transducers 1999). 1999.

MN-TuP13 Capacitive Displacement Sensing for Comb Drive Actuators Operating in Aqueous Media, ***P. Ponce**, V. Mukundan, B. Murmann, B.L. Pruitt*, Stanford University

We present a system that is capable of measuring displacements in a comb drive actuator operating in aqueous electrolytes. Underwater electrostatic actuators are promising tools for manipulation of biological samples in media.[1,2] Optical techniques have been reported for measurement of these actuator displacements.[3] Apart from accuracy and portability, electrical measurements are beneficial in setting up feedback systems for controlled actuation. Relative changes between the capacitances of the comb drive are measured by connecting them to parallel oscillator circuits. The operational frequencies of each oscillator depend directly on its corresponding capacitance value. In order to avoid electrolysis and electrostatic shielding effects in ionic media, the oscillators resonate at high frequencies (around 2-10 MHz) and the voltages across the comb drive electrodes are limited to approximately 100 mV, peak-to-peak. A major advantage of the described system is its ability to operate in ionic media without common adverse effects, such as electrolytic breakdown and electrode corrosion. The resultant oscillating signals are multiplied with each other and filtered to obtain a sinusoidal signal whose frequency is determined by the capacitance offset between the parallel oscillators. The sine wave is then applied to a frequency-to-voltage converter that yields a DC voltage signal. The system exhibits a change of approximately 16 kHz for each pF offset in capacitance. Based on the performance of the circuitry used, these results translate into a capacitive offset measurement accuracy on the order of 10 fF. The signal that contains information of the measured comb drive displacement is a DC voltage. This purely electrical signal allows the current device to be considered as an abstract "black box" for the purposes of creating a controllable feedback system. One plausible use for this system topology is the development of a method for applying specific forces onto cells adhered to the comb drive actuator.

[1] T. L. Sounart, T. A. Michalske, and K. R. Zavadil, "Frequency-Dependent Electrostatic Actuation in Microfluidic MEMS," Journal of Microelectromechanical Systems, vol. 14, pp. 125-133, 2005.

[2] V. Mukundan and B. L. Pruitt, "Experimental Characterization of Frequency Dependent Electrostatic Actuator for Aqueous Media," presented at Solid State Sensors and Actuators, Hilton Head Island, 2006.

[3] D. J. Burns and H. F. Helbig, "A System for Automatic Electrical and Optical Characterization of Microelectromechanical Devices," Journal of Microelectromechanical Systems, vol. 8, pp. 473-482, 1999.

MN-TuP14 Assembly and Testing of Metal-based Microchannel Heat Exchange Devices, ***F.H. Mei**, J. Jiang, W.J. Meng, P.R. Parida, S.V. Ekkad*, Louisiana State University

Since Tuckerman and Pease suggested the use of microfluidic devices for high heat flux removal in 1981, intense studies of heat transfer within microchannel devices at the mm to µm length scales have been carried out over the last two decades.[1,2] A majority of studies on microscale fluid flow and heat transfer have been conducted in Si-based microchannels because of the prevalence of Si microfabrication technology[3] and the lack of suitable microfabrication techniques for metal-based microchannel devices. Metal-based microchannel heat exchangers (MHEs) have important potential advantages over Si-based devices due to their higher thermal conductivities and better mechanical characteristics. Realization of metal-based microdevices requires the fabrication of metallic high-aspect-ratio microscale structures (HARMS). We have demonstrated successful HARMS replication in Pb,[4] Zn,[5] Al,[6] and Cu[7] from HARMS mold inserts by compression molding. To form any functional metal-based microdevice from such replicated metallic HARMS, proper assembly and packaging are required. Recently, we have successfully bonded Al-based and Cu-based HARMS by using eutectic bonding with Al-Ge composite thin films as intermediate layers, utilizing the Al-Ge eutectic with an eutectic temperature of 424°C.[8] We also evaluated the bond quality through measurements of the tensile bond strength in Al-based specimens.[9] In this paper, we report successful assembly of Cu-based microchannel devices and investigation of their heat transfer characteristics. Further studies on the bond quality of Cu-based specimens will be carried out, and results of assembly of metal-based MHE prototypes and testing of their overall heat transfer performance will be reported.

[1] D. B. Tuckerman, R. F. W. Pease, IEEE Elec. Dev. Let. EDL-2, 1981, 5, 126

[2] I. Mudawar, IEEE Trans. Components and Packaging Tech., 2001, 24, 122

[3] R. Chein, J. Chuang, Int. J. Thermal Sci., 2007, 46, 57

[4] D. M. Cao, W. J. Meng, K. W. Kelly, Microsyst. Technol., 2004, 10, 323

[5] D. M. Cao, D. Guidry, W. J. Meng, K. W. Kelly, Microsyst. Technol., 2003, 9(8), 559

[6] D. M. Cao, W. J. Meng, Microsyst. Technol., 2004, 10, 662

[7] D. M. Cao, J. Jiang, W. J. Meng, J. C. Jiang, W. Wang, Microsyst. Technol., 2007, 13, 503

[8] Fanghua Mei, J. Jiang, W. J. Meng, Microsyst. Technol., 2007, 13, 723

[9] Fanghua Mei, J. Jiang, W. J. Meng, Microsyst. Technol., 2007, DOI 10.1007/s00542-007-0407-0.

Authors Index

Bold page numbers indicate the presenter