

MEMS and NEMS

Room 2007 - Session MN+BI-MoA

Surface and Interface Science of MEMS and NEMS

Moderator: M. Dhayal, National Physical Laboratory, India

2:00pm MN+BI-MoA1 A New Technique for Studying Nanoscale Friction at Sliding Velocities up to 400 mm/s Using Atomic Force Microscope, B. Bhushan, Z. Tao, The Ohio State University

INVITED

Micro/nanoelectromechanical devices (MEMS/NEMS) and components operate at high sliding velocities. Studies of tribological properties of materials by AFM are limited in low velocity regime (<250 $\mu\text{m/s}$) due to inherent instrument limitation of AFM. To overcome the limitation of AFM working velocity, a high velocity stage technique has been developed for tribological investigation up to 400 mm/s. A custom calibrated stage is used for mounting sample. The stage is driven by a piezomotor motor which is controlled using proportional-integral-derivative (PID) algorithm. Friction data are obtained by processing the AFM laser photo-diode signals using a high sampling rate data acquisition system. The friction data obtained from the modified setup at high sliding velocities is compared with the results from conventional AFM friction measurement. The effects of scan size, rest time, acceleration, and velocity on the friction force and adhesive force for single crystal silicon (100) with native oxide has been studied.

2:40pm MN+BI-MoA3 Novel and Direct Functionalization of PECVD SiCN for Resonant NEMS Biosensor Applications, L.M. Fischer, National Institute for Nanotechnology, Canada; N. Wilding, University of Alberta, Canada; M. Gel, National Institute for Nanotechnology, Canada; N. Yang, M.T. McDermott, University of Alberta, Canada; S. Evoy, National Institute for Nanotechnology, Canada

Specific immobilization of species is the key to a successful resonant biosensor. Such functionalization of silicon requires a coating of gold/alkane-thiol SAMs to produce stable amine groups that facilitate further binding chemistries. This introduces fabrication complexity and degradation of the resonator properties. PECVD silicon carbonitride (SiCN) has been shown to natively host stable amine groups. Our previous work involving fabrication of nano-structures and analysis of their resonant behavior has determined that SiCN is on par with silicon as a resonant material, and additionally has the advantage of tunable chemical and mechanical properties. We here use ammonia plasma to functionalize the SiCN surface for the immobilization and detection of carcinoembryonic antigen (CEA). The SiCN surface is first populated with N-H groups using a non-depositing ammonia plasma discharge. Similar methods have been used to aminate polymers¹ as well as carbon nanofibres² for biological and gas sensing, respectively. We characterize this modified surface chemistry using FT-IR and XPS, and correlate the resulting surface composition to plasma parameters (time, power, pressure). Fluorescently-tagged streptavidin is used to determine the quantity and density of stable amine groups. Anti-CEA will be immobilized onto the SiCN surface by: (a) direct binding of the antibody to the amine groups, (b) a biotin-streptavidin intermediate, and (c) a succinimide-based molecule. Binding stability and specificity of CEA by these methods will be evaluated through FT-IR and fluorescence microscopy. Fluorination of SiCN via CF₄ plasma will also be investigated as a means to passivate the surface. ¹H.-C. Wen, et al. Surface & Coatings Technol. 200, 3166-3169 (2006) ²K. Nakanishi, et al. Analytical Chemistry 68, 1695-1700 (1996)

3:00pm MN+BI-MoA4 Energy Dissipation in Chemically Functionalized Micromechanical Silicon Resonators, D. Sengupta, A.M. Richter, I.T. Clark, M.A. Hines, Cornell University

Chemically functionalized micro- or nanomechanical resonators have been proposed as the basis for low cost, high performance chemical or biological sensors; however, this application has been stymied, in part, by the relatively high rate of mechanical energy dissipation (i.e. relatively low quality factors or Q's) displayed by most micromechanical resonators. Importantly, quality factors plummet as the device size shrinks. In previous research, we showed that the Q of MHz-range micromechanical silicon resonators is sensitive to monolayer-level changes in surface chemistry; resonators terminated with a single monolayer of methyl groups have both good stability and high Q. In this talk, we report on efforts to introduce chemical functionality into these monolayers while preserving high-Q performance. In general, resonators functionalized with monolayers of

"chemically interesting" species (e.g., -COOH terminated monolayers) display poor performance, as the chemically interesting functionality prevents the formation of a close-packed monolayer. To combat this problem, we have produced resonators functionalized with mixed organic monolayers that combine the chemically resistant methyl termination with a low density of more reactive species, such as 1,3-dioxan-2-ylethyl moieties. The chemistry to produce mixed monolayers was characterized by surface infrared spectroscopy, which confirmed the presence of chemically reactive species. The mechanical properties of micromechanical resonators functionalized with mixed organic monolayers were tested. The performance of functionalized devices in different chemical environments is reported.

3:20pm MN+BI-MoA5 Role of Metal Impurities in Anisotropic Wet Chemical Etching, T. Hynninen, A.S. Foster, Helsinki University of Technology, Finland; M. Gosálvez, H. Tanaka, Nagoya University, Japan; R.M. Nieminen, Helsinki University of Technology, Finland; K. Sato, Nagoya University, Japan

Previous studies¹ have shown that great progress in understanding anisotropic wet chemical etching of silicon can be achieved by linking Monte Carlo (MC) atomistic simulations to experimental results. A key part of this effort was parameterizing the MC model according to first principles calculations. This provided a fundamental basis of high accuracy. However, that model focused exclusively on removing silicon atoms from an effectively clean surface. In reality, metal impurities are an unavoidable element in standard etchants, and their effects should be included in any comprehensive model of the etching process. In this work we use a combination of experimental and theoretical approaches to study the influence of metal impurities on the etching rates and surface morphologies, and provide an atomic scale understanding of their role. For the etching of the (110) surface, we experimentally find that copper has the most prominent effect on both surface roughness and etch rate. Lead also lowers the etch rate to some degree, but the other impurities have no effect. On the (100) surface, copper exclusively affects the surface roughness, with little influence on the etch rate. Again the introduction of lead lowers the etch rate. These results can be understood by assuming that the metal impurities act as micromasks pinning certain sites. This is supported by first principles calculations of adsorption energetics of the different metal atoms on a H or OH terminated silicon surface, which provide significant differences between the different metals and explain their influence in etching. The calculated energetics are used as basis for a full Monte Carlo model including the influence of metal impurities. ¹M. A. Gosálvez, A. S. Foster and R. M. Nieminen Appl. Surf. Sci. 202 (2002).

3:40pm MN+BI-MoA6 Interfacial Properties of Polymer Interfaces for BioMEMS/NEMS Applications, M. Palacio, B. Bhushan, N. Ferrell, The Ohio State University

Polymers are used in biological micro/nano electromechanical system (BioMEMS/NEMS) applications due to their desirable mechanical properties, biocompatibility and reduced cost relative to silicon microfabrication processes. Understanding the interfacial properties of the films that are used in BioMEMS/NEMS serves as a useful tool in obtaining higher device yield and greater mechanical reliability. In this study, two commonly used materials in BioMEMS/NEMS, polystyrene (PS) and glycidyl-ether-bisphenol-A novolac polymer (SU8) deposited on a silicon substrate, are investigated. The aim is to examine the delamination of the interfaces. Nanoindentation was employed on the PS/Si and SU8/Si film systems coated with a thin metallic layer of Cr to facilitate delamination. The interfacial adhesion energy was determined from measuring the size of the resulting delamination and the contact radius. Scale effects were investigated by comparing the behavior of systems with ultrathin (<100 nm) and thick (5 μm) PS films. In order to simulate the aqueous environment present in the human body, delamination experiments were performed on samples immersed in deionized water, and the interfacial adhesion energy was measured. To further simulate device operating conditions, delamination experiments were conducted at human body temperature by fitting the nanoindenter with a heating stage.

4:00pm MN+BI-MoA7 Nanotribological Characterization of Vapor "Phase Deposited Positively-Charged Self-Assembled Monolayers Deposited on Polydimethylsiloxane for Nanochannel Application, M. Cichomski, B. Bhushan, The Ohio State University

Surface modification of micro/nano fluidic devices by self assembled monolayers (SAMs) is very important for the controlling flow properties and protein adsorption. In this paper, vapor phase deposition was used to

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deposit four different SAMs on polydimethylsiloxane (PDMS) and identify optimum deposition conditions by measuring static contact angle. The PDMS surfaces were modified with one sulfhydryl terminated SAM and three different amine terminated SAMs. The deposited films were characterized by static contact angle and atomic force microscopy for surface roughness and adhesion. Static contact angle was monitored over time to determine stability of the SAMs. Fluorescently labeled amino and sulfhydryl groups were characterized by fluorescent microscopy to determine the surface concentration of the functional groups.

4:40pm **MN+BI-MoA9 Micro-Reservoir Arrays for Chemical Delivery**, *J.J. VanDersari, N.A. Melosh*, Stanford University

The local environment around a cell, including bound, soluble, and mechanical signals, has great influence on cellular development, function, and differentiation. In biological systems multiple signals are present at one time, and their cellular influence can change depending on concentration and method of presentation. In the simplest in vitro soluble signal assays, the signaling agents are simply added to the cell culture at a specific time. This method does not have the ability to control local signal concentration or introduction rate, and lacks any bound or mechanical signals. Ideally, all characteristics of the three major environmental factors (bound, soluble, and mechanical signals) would be well controlled. We propose a new culture platform for soluble-messenger investigations composed of an array of micro-reservoirs on a silicon based wafer with the ability to independently deliver precisely controlled (temporally and spatially) doses of soluble biochemical agents to cells in culture. Standard semiconductor processing techniques can create multiple reservoirs for each cell in culture. The flow in and out of the reservoirs is controlled by electrochemically sealing and opening the narrow reservoir entrance. The reservoirs are loaded via a solution of the desired biochemical agents and metal ions on top of the wafer surface; when a negative electrical potential is applied, the metal ions reduce at the electrode and seal the agents inside. To release the signals, a positive potential is applied causing the metal sealing the reservoir opening to oxidize, opening the reservoir and allowing the contents to diffuse into the surrounding solution.

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