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 µm/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 polymers@footnote 1@ as well as carbon nanofibres@footnote 2@ 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 CF@sub 4@ plasma will also be investigated as a means to passivate the surface. @FootnoteText@ @footnote 1@ H.-C. Wen, et al. Surface & Coatings Technol. 200, 3166-3169 (2006)@footnote 2@ K. 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 studies@footnote 1@ 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. @FootnoteText@ @footnote 1@ M. 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 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. VanDersarl,* ***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.

MEMS and NEMS
Room 2007 - Session MN-TuM
Material Aspects of MEMS and NEMS

Moderator: C. Zorman, Case Western Reserve University

8:00am **MN-TuM1 Controlled Fabrication of Nanotube Devices using Nanotubes of Known (n,m) Indices*, J. Hone,*** Columbia University **INVITED**

Because small changes in the crystal structure (chirality) of carbon nanotubes can produce large changes in their electrical properties, it is important to understand the relationship between structure and transport properties, both for basic science and for applications. However, detailed experimental exploration of this relationship has proved elusive so far. Using a mechanical transfer technique in parallel with efforts to combine optical scattering and structural characteriztion, we have achieved the goal of placing 'the nanotube we want, where we want it.' Long suspended tubes are first grown by CVD and inspected optically. Rayleigh scattering spectroscopy can readily discern between metallic and semiconducting nanotubes, and can be correlated with direct structural probes to provide the exact (n,m) structure. After optical characterization, a chosen nanotube can be transferred to a substrate in the desired location, and devices fabricated using standard e-beam lithography techniques. We have fabricated a number of devices in this manner and are beginning to fully explore the detailed relationship between structure and transport.

8:40am **MN-TuM3 Compensation of Strain Gradient by Varying Dopant Profile during the Growth of Polycrystalline Silicon Carbide Films*, J. Zhang,*** University of California, Berkeley*; R. Howe,* Stanford University*; R. Maboudian,* University of California, Berkeley

Polycrystalline 3C-SiC (poly-SiC) films are deposited by low-pressure chemical vapor deposition on Si(100) substrates using 1,3-disilabutane and are in-situ doped by NH@sub 3@. The effects of dopant concentration on residual strain and strain gradient of the films are investigated using microstrain gauges and cantilever beam arrays. With the increase in doping level, the tensile strain increases from 0.10% to 0.21%. The strain gradient of all films is negative with values ranging from -2 x 10@super -4@ to -5 x 10@super -4@ µm@super-1@. To compensate for the strain gradient, a bi-layer deposition scheme consisting of films with different residual strain due to varying doping is developed. With this approach, a positive strain gradient of 5 x 10@super -5@ µm@super -1@ is achieved. Discussion and further optimization of this method will also be presented.

9:00am **MN-TuM4 Characterization of APCVD and LPCVD Based Polycrystalline 3C-Silicon Carbide Resonators*, W.C. Chang***, *C. Zorman, M. Mehregany,* Case Western Reserve University

Silicon Carbide is a promising material for RF MEMS due to its mechanical robustness, chemical inertness and high Young's Modulus-to-density ratio. While single crystalline SiC films are used for high quality devices, many MEMS devices do not require such high crystalline quality and therefore can use polycrystalline SiC films. Polycrystalline SiC can be grown at a lower temperature than single crystal films, (at or below 900°C by LPCVD), which makes the process more compatible with conventional MEMS processes. Furthermore, the deposition does not depend on a crystalline template, as it can be deposited on any substrate, whether single crystalline, polycrystalline or amorphous. This advantage enables polycrystalline SiC to be used in more complex micromechanical structures than single crystalline SiC. This paper demonstrates poly-SiC folded beam resonators fabricated by atmospheric pressure chemical vapor deposition (APCVD) and low pressure chemical vapor deposition (LPCVD). APCVD resonators were made from films grown at 1280°C using SiH@sub 4@ and C@sub 3@H@sub 8@ as precursors. SiO@sub 2@ and poly-Si were used for isolation and sacrificial layers, respectively. The LPCVD resonators were made from films deposited at 900°C using SiH@sub 2@Cl@sub 2@ and C@sub 2@H@sub 2@ as precursors. The resonator design used SiO@sub 2@ as an isolation and sacrificial layer. The devices were driven and measured by an Agilent 4395A network analyzer via a transimpedance amplifier under a reduced pressure of 30uTorr. The measured quality factors are about 22k and 10k for APCVD and LPCVD grown lateral resonators respectively. The quality factors of the poly-SiC flexural-mode resonators are the highest reported values by electrical measurement so far. To compare the intrinsic loss of the two folded beam resonators, XRD was used to compare the average grain size of poly SiC. The estimation for APCVD-grown poly SiC is 65nm and 43nm for LPCVD-grown poly SiC.

9:20am **MN-TuM5 NEMS and AFM Cantilevers Synthesized from Metal Nanocomposites*, C. Ophus***, Univ. of Alberta, Canada*; Z. Lee,* NCEM, Lawrence Berkeley National Lab*; E. Luber, N. Nelson-Fitzpatrick, R. Mohammadi, C. Gilkison, L.M. Fischer, S. Evoy,* Univ. of Alberta, Canada*; V. Radmilovic, U. Dahmen,* NCEM, Lawrence Berkeley National Lab*; D. Mitlin,* Univ. of Alberta, Canada

While metal films, such as Ni, Ag, Pd and Al, have been used in a variety of electronic and MEMS devices, they have had limited applications in the field of cantilever-based sensing or as AFM cantilevers. Despite several major advantages over insulators and semiconductors (optically reflecting, tough-ductile, electrically conducting), metals are notoriously difficult to pattern or release due to their high stress state, large surface roughness and low strength. We were able to overcome these limitations by using room temperature co-sputtering to synthesize nanocomposite alloy films with unique microstructures and properties. The aim of this report is to describe the device applications, the mechanical properties and the microstructure of Ni-X, Ag-X, Pd-X (where X is one or more alloy addition) and Al-Mo nanocomposite thin films. We fabricated a range of compositions and microstructures of these alloys by co-sputtering from different metal targets. Nanoindentation tests indicate that the hardness of the fabricated materials is more than an order of magnitude higher than that of conventional metal films. In addition, within a certain compositional range, the nanocomposites are under relatively low stress and possess near atomic-level smoothness. The properties of the nanocomposites are discussed in relation to the materials' microstructure, as characterized by TEM, SEM, AFM and XRD analysis. Using the microstructurally optimized versions of these alloys, we fabricated free-standing nano-scale cantilevers down to approximately 4 nm thickness. These were to our knowledge the thinnest cantilevers ever achieved both for metals and for semiconductors. We tested these devices in vibrational resonance mode, as well as further processing them into AFM-usable geometries that included both the cantilever and the tip.

10:40am **MN-TuM9 Gray-scale Technology for 3-D Static and Dynamic MEMS*, R. Ghodssi,*** University of Maryland **INVITED**

The development of gray-scale technology, a batch 3-D silicon fabrication technique, has the potential to lift the vertical design restrictions that plague MEMS designers. Gray-scale technology involves two primary steps, beginning with gray-scale lithography, where partial exposure of a photoresist film creates a gradient structure in resist after development. Next, deep reactive ion etching (DRIE), is used to transfer the gradient photoresist structure into an underlying silicon substrate, where the etch selectivity determines the vertical amplification of the gray-scale photoresist structure into a final 3-D silicon structure. Research in our group has focused on investigating the limitations and tradeoffs of the core fabrication technique, as well as incorporating this technology into the design and fabrication of both static and dynamic MEMS devices. We first created an empirical model to relate the height of a photoresist feature to the local transmitted intensity through a projection lithography system. This model enables nearly arbitrary photoresist profiles to be created by simply designating the size of individual sub-resolution pixels on an optical mask. Upon creating a precise 3-D photoresist feature, extensive etch characterization during DRIE was necessary to investigate the effects of various etch parameters on the transfer of gray-scale features into silicon. Etch variables such as silicon loading, electrode power, and oxygen content were studied as they relate to etch selectivity, enabling creation of 3-D silicon structures millimeters wide and up to 100’s of micrometers tall. Static MEMS structures developed during the course of this research have included: (1) a variable span micro-compressor towards increasing cycle performance of a micro-gas turbine generator device (in association with MIT and ARL), (2) 3-D substrate and interconnect technologies for MOSFET relay packaging (in association with Toshiba), and (3) x-ray silicon phase Fresnel lenses with precise profiles for increased focusing efficiency (in association with NASA - Goddard Space Flight Center). Dynamic MEMS devices benefiting from the incorporation of 3-D components have also been demonstrated by our group, such as voltage-tunable MEMS resonators and multi-axis optical fiber actuators for in-package alignment of fibers to edge-coupled optoelectronic components.

11:20am **MN-TuM11 Effects of Tensile Stress and Viscous Damping on the Resonance of Nanomechanical Beams and Cantilevers*, S.S. Verbridge***, *L.M. Bellan, R.B. Reichenbach, J.M. Parpia, H.G. Craighead,* Cornell University

Mechanical flexural resonators with cross-sectional dimensions on the scale of 100 nm have been studied. Devices have been fabricated in silicon nitride, covering a wide range of tensile stress values, from 0 to 1200 MPa. It is shown that the devices with the highest stress exhibit the highest frequencies, as well as the highest quality factors, for devices of a given size. The former result is expected based on traditional considerations of stressed vibrating beams, while the latter is more surprising. Quality factors as high as 200,000 have been attained at room temperature and at high vacuum for doubly-clamped nanoresonators, with MHz range frequencies. We will discuss the various loss mechanisms which might contribute to the quality factors exhibited by these resonators, and will show that the high stress state appears to be relieving certain of these mechanisms, resulting in nanoresonators with losses approaching the thermoelastic limit. We will also briefly discuss the operation of these resonators in environments in which viscous damping becomes the dominant loss mechanism, with applications for chemical and biological sensing. Resonators with 100 nm cross-sections and frequencies as high as 100 MHz have been operated in air, as well as viscous liquids including alcohol and water, using an optical drive technique.

11:40am **MN-TuM12 Piezoelectric-Diamond Hybrid Heterostructures for High Performance MEMS/NEMS Devices**, *S. Srinivasan, J. Hiller, O. Auciello,* ***A.V. Sumant***, Argonne National Laboratory

Novel microelectromechanical and nanoelectromechanical system (MEMS/NEMS) devices, including sensors and actuators represent a technological revolution similar to the microelectronics revolution of the 20th Century. Development of these new generation multifunctional devices involves new materials, dissimilar materials integration strategies, and micro and nanofabrication processing techniques for optimum device performance. Most MEMS devices are currently based on silicon because of the available surface micromachining technology. However, the poor mechanical and tribological properties of Si are not suitable for high-performance Si-based MEMS devices. On the other hand, diamond as a super-hard material with exceptional mechanical and tribological properties exhibits tremendous potential for new generation of high-performance MEMS/NEMS devices. Among various forms of diamond, ultrananocrystalline diamond (UNCD), based on a novel thin film technology using argon plasma chemistry, exhibits superior mechanical properties compared with single crystal diamond, microcrystalline diamond (MCD), and nanocrystalline diamond (NCD) in terms of properties and adaptability for MEMS/NEMS applications. Piezoelectric-based MEMS attracts much attention due to their high sensitivity and low electrical noise in sensing applications and high-force output in actuation applications. Pb(ZrxTi1-x)O3 (PZT) thin films have stimulated intensive studies over the past decade due to its potential applications in a wide variety of devices, namely piezoelectrically actuated MEMS/NEMS devices. Therefore, the integration of functional PZT thin films with the UNCD films opens up the tantalizing possibility of advanced MEMS/NEMS devices. However, the integration of PZT and UNCD is challenging, mainly due to the PZT/UNCD interface. In this research, we explore such an integration to achieve high quality devices.

MEMS and NEMS
Room 2007 - Session MN-TuA
Fabrication and Characterization of MEMS and NEMS

Moderator: R. Ilic, Cornell University

2:40pm **MN-TuA3 Fabrication and Testing of NEMS Components Made from Nanocomposite Al-Mo Films**, ***D. Mitlin,*** University of California*; Z. Lee,* Lawrence Berkeley National Laboratory*; C. Ophus, N. Nelson-Fitzpatrick, L.M. Fischer,* University of Alberta, Canada*; S. Evoy,* National Institute of Nanotechnology*; U. Dahmen, V. Radmilovic,* Lawrence Berkeley National Laboratory

Despite several major advantages over semiconductor-based NEMS components (optically reflecting, electrically conducting, tough-ductile), metal-based components with nm-scale dimensions are notoriously difficult to achieve due to their large surface roughness and grain size, high stress state, and low strength. We were able to overcome these limitations by using room temperature co-sputtering to synthesize nanocomposite alloy films of Al-Mo. We now report having successfully fabricated fully released NEMS cantilevers of various geometries from such metallic materials. At a device thickness as low as 4 nm, these are the thinnest released metal cantilevers reported in the literature to date. A systematic investigation of microstructure and properties as a function of Mo content resulted in an optimum film composition of Al-32at%Mo, with a unique microstructure comprised of a dense distribution of nm-scale Mo crystallites dispersed in an amorphous Al-rich matrix. These films were found to exhibit unusually high nanoindentation hardness and a very significant reduction in roughness compared to pure Al, while maintaining resistivity in the metallic range. A single-anchored cantilever 5 µm long, 800 nm wide and 20 nm thick showed a resonance frequency of 608 kHz, yielding a Young's modulus of 112 GPa, in good agreement with a reduced modulus of 138 GPa measured by nanoindentation.

3:00pm **MN-TuA4 Chemical Mechanical Planarization of BCB Polymer Films: Effect of Cure Temperature**, ***N. Ghalichechian**, A. Modafe, M.I. Beyaz, R. Ghodssi,* University of Maryland

We report on the chemical mechanical planarization (CMP) of a thick benzocyclobutene (BCB) polymer film with a high removal rate (470 nm/min) and a low density of post-CMP defects suitable for the fabrication of microelectromechanical devices. The effect of polymer cure temperature on Youngs modulus and removal rate of the BCB film was studied. Thick low-dielectric-constant BCB polymer (k=2.65) is used as an insulating layer to reduce the parasitic capacitances and increase the efficiency of an electrostatic micromotor. The micromotor fabrication process requires planarization of a 25-µm-thick BCB film buried in the substrate. High removal rate (hundreds of nm/min) is desired to planarize thick BCB films in an acceptable time. Polymers are generally soft (low Youngs modulus) and chemically resistant to a wide range of acids and alkali solutions; therefore, their planarization using conventional CMP processes is challenging. The removal rate of an uncured film was measured to be 3.66 µm/min; however, the CMP process induced significant film scratching, peel-off, non-uniformity, and surface roughness (188 nm/min peak-to-peak). Partial BCB polymerization can be achieved by curing the film under 250 °C. A series of experiments were conducted to measure the CMP removal rate and surface roughness of BCB samples cured at 120-250 °C. The removal rate was calculated from film thickness measurements before and after CMP steps using vertical scanning interferometer. The surface roughness of the film was measured using atomic force microscope. The removal rate at cure temperatures of 120, 160, and 250 °C was found to be 2000, 470, and 70 nm/min, respectively. An abrupt change in the removal rate was observed at cure temperature of 160 °C and is believed to be due to the change in the Youngs modulus of the film. CMP process details, measured removal rate, surface roughness, and Youngs modulus will be presented in this paper.

3:20pm **MN-TuA5 Borosilicate Glass Deep Etching in NLD Plasma by using Low GWP Gases**, ***Y. Morikawa**, T. Hayashi, A. Kelly, K. Fuwa, K. Suu,* ULVAC Inc., Japan

One of important etching technologies in MEMS device fabrication is a deep glass etching over 100 um. But the glass contains some elements that the etched products have no vapor pressure at low temperature. So etched surfaces generally show rough morphology, on which the reaction product residue of I to III group elements in periodic table is seen. The deep etching technologies for this glass were reported by X. Li, et al. and T. Ichiki. They used SF6 as an etching gas.@footnote 1,2@ However, it has not been reported that a low GWP gas was used for glass deep etching. So we first tried to etch at the pressure of 1 Pa by using C3F8 as a relatively low GWP gas, by using a NLD etching system. The result showed the rough surfaces. Therefore, we etched the glass at 0.4 Pa in order to eliminate the residue by sputtering and obtained smooth surfaces. Changing the etching gas to C3F7I(GWP < 1) , we also obtained similar smooth surfaces under the same etching condition. Furthermore, the thru hole etching from the top to bottom surfaces of the glass wafer with thickness of 1 mm was examined. This is very difficult because an extremely high selectivity to photo resist is required. Therefore, we examined to use a thin Si wafer with thickness of 50 um as the mask. The thin Si wafer was bonded on the glass by the anodic bonding method, and coated with photo resist (thickness of 50 um), and then patterned by photolithography. Finally, we obtained the etching sample whose structure was Si mask (50 um hole and thickness) / borosilicate glass (Corning 7740) with thickness of 1 mm, prepared after the thin Si etching by using a novel deep etching method.@footnote 3@ @FootnoteText@ @footnote 1@X. Li, et al : Sensors and Actuators A 87 (2001) 139. @footnote 2@T. Ichiki, et al : J. Vac. Sci. Technol. B 21 (5) 2188. @footnote 3@Y. Morikawa, et al : 51st AVS, MN-MoP5 (2004) Anaheim.

4:00pm **MN-TuA7 Molded Electromechanical Shift-Register Memories**, ***G.M. McClelland**, B. Atmaja,* IBM Research Division, Almaden Research Center

Mechanical bistability is a simple well-understood phenomenon that can be used to store information. However, most designs for mechanical memories require individual elements to be addressed, written, and read electrically. We propose a much simpler design in which bistable levers are arranged in a shift register, so that information is accessed by the simple electrostatic interaction of neighboring levers. A shift register containing > 1000 bits can be operated with only two conductors. The shift register can be molded in a single step from a single elastomeric material (e.g PDMS). In one design, the levers are conducting, and a voltage pulse from a single top electrode pulls charge to the levers, inducing repulsion, and shifting information. We have built a working 100-cm-scale memory based on this idea. In another design, which can work in a liquid, the insulating levers are charged with alternating signs to create primary and secondary components of individual memory cells. The problems of coding, initializing the memory, and recovering from errors are analyzed. A "broadcasting" scheme is described, in which the first lever is made unique, so that only it responds to a write pulse from the upper electrode, while the other elements respond to only shift pulses. These memories have been studied using both realistic finite element methods and phenomenological models. An integration scheme is proposed in which a crosspoint array of shift registers is imprinted into a series of optical waveguides. This structure can be read and written by electrical attachment to only one edge, enabling a memory system in which many layers can be "shingled" onto a silicon drive chip. This geometry, combined with simple one-imprint layer manufacturing, could allow solid state storage with the price/bit of disk drives.

4:40pm **MN-TuA9 Molecular Vapor Deposition Integration with MEMS Manufacturing**, ***B. Kobrin**, T. Zhang, N. Dangaria, J. Chinn,* Applied Microstructures, Inc.

Molecular vapor deposition (MVD) has already proved itself as enabling technique for anti-stiction prevention and yield enhancement in MEMS devices.@footnote 1,2@. We report on results of MVD process integration with MEMS manufacturing schemes. Vacuum type deposition and self-assembling nature of the coating assures excellent conformality in high aspect ratio structures and narrow air gaps between released components and a substrate. It also enables seamless integration in MEMS back-end process flow. We demonstrated successful deposition of self-assembled monolayers (SAM) through small (micron-size) openings in encapsulated MEMS package. Different selective material deposition and removal techniques (lift-off, substrate masking, UV ozone etch, oxygen plasma) allow integrating MVD process into MEMS back-end packaging and Ink-jet head assembly processes. Some examples of this integration are reported. @FootnoteText@@footnote 1@B. Kobrin , J. Chinn , W. Ashurst, Durable Anti-Stiction Coatings by Molecular Vapor Deposition (MVD), NSTI Nanotech, May 2005 @footnote 2@B. Kobrin, W. Ashurst, V. Fuentes, R. Nowak, R. Yi, Jeff Chinn, Molecular Vapor Deposition for Enhanced Monolayer Stability and Durability, AIChE2005, Nov 2005.

MEMS and NEMS
Room 3rd Floor Lobby - Session MN-TuP
Aspects of MEMS and NEMS Poster Session

MN-TuP1 Development of Accelerometer Using Multilayered Optical Bandpass Filter*, **H. Toyota**, M. Yaegashi, T. Ono,* Hirosaki University, Japan*; M. Shimada, Y. Jin,* NTT MI Labs, Japan

Accelerometer which is micro-electromechanical systems (MEMS) device has begun to be used with the cellular phone and the car, etc. In present, detection range of acceleration is limited by MEMS device structure and its range is very narrow. Therefore, it is necessary to develop the accelerometer which can be measured wide range of acceleration. We propose the accelerometer based on optical bandpass filter. The accelerometer has a membrane structure with Fabry-Perot (FP) resonator. The FP resonator is composed of air gap as cavity layer between multilayered dielectric thin films. Weight is also attached bottom layer. The input light from white light source is introduced into top surface of FP resonator. The output light is extracted from exit aperture of the weight. The output light was measured by monochromator and photo detector. When the displacement of weight is occurred by the acceleration, the thickness of air layer is changed. Then, the wavelength of output light is also changed. It is principle that acceleration can be measured by this wavelength displacement. To obtain the optical characteristics of newly accelerometer, theoretical calculation was carried out by the change of the thickness of air layer using optical simulator. The design wavelength was 780 nm. As the dielectric material, silicon oxide (SiO@sub 2@: n=1.5) and tantalum oxide (Ta@sub 2@O@sub 5@: n=2.1) were used. The peak intensity of 100% appeared at the wavelength of 780 nm. It was found that the change of output light wavelength was varied as the change of air layer thickness. Considering the linearity relation, the effective wavelength displacement was about 120 nm. Then, in order to detect gravity force from 0.1 to 100 G, the wavelength resolution of 0.1nm is required for spectroscopic measurement system, but it is easy to achieve by the use of the general spectroscopic measurement system.

MN-TuP2 Mechanical Quality Factor Measurement of Micro Structure According to Vacuum Range and Temperature Variation*, **J.S. Kim**,* Korea University*; W.B. Kim, K.D. Jung, M.S. Choi, K.W. Nam, I.S. Song,* Samsung Advanced Institute of Technology, Korea*; B.K. Ju,* Korea University, Korea

In this paper, the Mechanical quality factor of a micro gyro structure according to vacuum range at room temperature and 75°C is measured. On the SOI wafer, gyroscope structures with a comb drive are patterned with a photo-resist (PR) and vertically etched with the ICP-RIE. After the etching process, this micro structure wafer is diced into proper size and released by the oxide layer etching in BOE (buffered oxide etcher). The test circuit and diced micro structure wafer are placed in a chamber with heater that can control vacuum range and substrate temperature. The circuit board is connected with the signal analyzer(HP35670A) and the power supplier by using the feed-through of the chamber. The chamber is vacuated to the specific vacuum range, which can be controlled particularly by using the air release valve. When the vacuum is set to a specific range, the frequency and damping coefficient are read from signal analyzer and translated to the Q-factor. In this way, Q-factors as vacuum range of gyro structures are measured. The measured Q-factor and vacuum range are 3000 to 50000 and 1Torr to 50mTorr. Sample is measured at room temperature and 75°C of substrate temperature, and we found that Q-factor 4000 matched the Vacuum 740mTorr range. From these data, we can fabricate the wafer level package(WLP) gyro-chip that has the desired Q-factor range, controlled by the basic pressure of package bonding chamber.

MN-TuP3 Detection of Stimulated Proteins in KDR/VEGF-A165 System by Microcantilever Sensor*, F.S. Fiorilli, R.C. Ricciardi, P.R. Rivolo, M.S. Marasso, **B.S. Bianco**,* Politecnico di Torino, Italy*; N.L. Napione, B.F. Bussolino,* Universit@aa a@ degli Studi di Torino, Italy

To reach new and relevant insight in biomolecular sciences it is necessary to develop new tools for fine and precise measurements. To this purpose, microcantilevers-based biosensors, which can trasduce a biochemical signal into a mechanical motion with extremely high sensitivity, represent an intriguing possibility.@footnote 1@ In particular, microcantilevers biosensors may represent a great improvement of the current detection techniques in regard of "signaling transduction pathways", which allow cells to respond to external stimuli. This contribution deals with the development of cantilever biosensors to measure in a quantitative and specific way key molecules involved in the activated tyrosine kinase receptor KDR in vascular endothelial cells (EC) stimulated by its ligand vascular endothelial growth factor-A165 (VEGF-A165). KDR/VEGF-A165 system is at the heart of a network that governs differentiation, survival, proliferation and migration of EC.@footnote 2@ The basis of these measurements is the antigen-antibody reaction. The cantilevers has been coated with Protein A or G, which specifically bind to the Fc fragment of the antibody, allowing the correct orientation of the Fab fragment, responsible for the antigen interaction. The coated surface will be bound to specific antibodies and hybridized with VEGF-A165 stimulated cellular lysates. The resonant frequancy response of cantilever to binding event permits to obtain data about protein analyte concentration. @FootnoteText@@footnote 1@Fritz.J., Baller M.K. Lang H.P., Rothuizen H., Vettinger P., Meyer E. Gerber C., Gimzewski, Science, 2000, 288, 316, @footnote 2@Zachary I., Gliki G., Cardiovasc Res, 2001, 49: 568-581.

MN-TuP4 Plasma Polymerised Biomaterial for Micro-Nano Device Bonding at Room Temperature*, **M. Dhayal**,* Rajasthan University, India

In this study the plasma polymerised acrylic acid (ppAc) biocompatible films has been shown potential usefulness to bond any types of two substrate materials without applying a load at room temperature (???25 oC). To understand the bonding mechanism of plasma ppAc film at room temperature the interfacial adhesion is an important factor in determining the performance and reliability of MEMS/NEMS systems. In this paper the effect of covalent bonding between two chemically activated surfaces has been discussed. It is also know that at small roughness values at interface the adhesion is mainly due to van der Waals forces acting across extensive non-contacting areas. Therefore, the contribution of both covalent bonding and van der Waals forces at contact and non-contact areas at the interface respectively has been also discussed in this paper. Advantages of this bonding technique in fabrication of recycled and reusable MEMS/NEMS, bio-MEMS/NEMS, organic micro/nano fluidic devices, lab-on-a-chip etc. has been also discussed.

MN-TuP5 Bulk Micromachining of High Index Silicon Wafers and Possible Applications in Diffractive Elements, ***W. Calleja-Arriaga****, F.J. De la Hidalga-Wade, C. Reyes-Betanzo, A. Torres-Jacome, C. Zuñiga-Islas, M. Linares-Aranda, P. Rosales-Quintero,* INAOE, Mexico

In this project we are evaluating new approaches to develop micromirror arrays and diffractive elements which have been fabricated using squared structures on (0 0 1) silicon wafers. In this project, n-type, 2-5 ohm-cm, two inch, 300 Î¼m-thick, high index (1 1 4) and (5 5 12) silicon wafers were used, which were produced from [1 1 2] ingots. Most micromachined structures compatible in Microsystems are fabricated on (0 0 1) silicon wafers, rarely using (0 1 1) wafers and of course more rarely using high index wafers. Several sophisticated microstructures maybe fulfilled by using substrates with different crystallographic orientations. Our etching mask was designed including several polygon-like structures to analyze the resulting morphology and crystallographic planes developed during a long-time etching. One of them, an array of 10 squared structures is arranged as follows: the first square is aligned parallel/perpendicular to the (0 1 1) main flat and then the next squares were slanted ranging from 5@degree@ till 45@degree@ in 5@degree@ steps. We have developed our experimental work using different KOH-H2O dilution at 40 @degree@C. All the experimental procedure was developed at the same time on (0 0 1) and (0 1 1) silicon wafers, which were used as control samples. Our etching mask containing several polygon-like structures was transferred parallel to the main (0 1 1) flat of the low and high index wafers. We are reporting the etching of concave squared structures, watching the roughness evolution of the walls and bottom surfaces, with the main purpose of developing microstructures for integrated optics applications. At this stage we have facing some problems to develop micromirrors because the bottom surfaces developed on both high index wafers show some roughness. On the other hand we have observed a very interesting structure whose very smooth walls could be used to develop a very simple fabrication procedure of blazed diffraction gratings for infrared applications.

MN-TuP6 In Situ Characterization of Passivation Layer for Silicon Cryogenic Etching*, X. Mellhaoui, **C. Duluard**, L. Pichon, R. Dussart, P. Ranson, T. Tillocher, P. Lefaucheux,* GREMI/CNRS - Université d'Orléans, France

The cryogenic etching process that uses SF@sub 6@/O@sub 2@ plasma chemistry offers an attractive alternative to the Bosch process for etching high aspect ratio patterns into silicon, both for its high etch rate and its cleanliness. Today its use in industry is still limited primarily due to a need for more robustness, in particular a slight shift in temperature can affect the process reproducibility. Understanding the passivation mechanisms is therefore crucial to improve the passivation efficiency at low temperature and to control silicon deep etching perfectly. Previous studies have shown that a SiO@sub x@F@sub y@ passivation layer forms at low temperature and is removed when the substrate is heated back up to room temperature.@footnote 1@ Other experiments prove that this layer can also be constructed using a SiF@sub 4@/O@sub 2@ plasma, so sulphur does not seem to participate in the formation of a passivation layer.@footnote 2@ The thickness and physical-chemical properties of the passivation layer can only be known by in situ analyses. An inductively coupled plasma reactor was equipped with a spectroscopic ellipsometer to perform this characterization. In SF@sub 6@/O@sub 2@ etching plasma conditions the passivation layer is hardly observable. Nonetheless in SiF@sub 4@/O@sub 2@ chemistry a depositing regime can be achieved, which better facilitates ellipsometric measurements. Ellipsometric spectra were acquired and analyzed while varying several experimental parameters (e.g. plasma source power, substrate temperature). This parametric study will be presented. @FootnoteText@ @footnote 1@ R. Dussart, M. Boufnichel, G. Marcos, P. Lefaucheux, A. Basillais, R. Benoit, T. Tillocher, X. Mellhaoui, , H. Estrade-Szwarckopf, P. Ranson, J. Micromech. Microeng. 14, 190 (2004)@footnote 2@ X. Mellhaoui, R. Dussart, T. Tillocher, P. Lefaucheux, P. Ranson, M. Boufnichel, L. J. Overzet, J. Appl. Phys. 98, 104901 (2005)

MN-TuP8 Controlling the Silicon Micro-grass in Fabrication of Deeply Etched Silicon Structures using Adaptive Bosch Process*, **M.W. Lee**, B.S. Kim, J.H. Sung, S.B. Jo, C.H. Choi, E.H. Lee,* INHA University, South Korea*; S.-G. Park,* INHA University, South Korea, Korea*; S.G. Lee,* INHA University, South Korea*; B.H. O,* INHA University, South Korea, Korea

A deeply etched silicon structure provides an easy way to realize an embossing master, compared with a conventional Ni master. But, the silicon micro-grass which usually occurs during silicon deep etch process have to be suppressed for subsequent embossing process. We tried to control the silicon micro-grass by changing etching conditions of our silicon deep etching method, named adaptive bosch process. Etch/passivation time ratios, bias powers and other process parameters are varied, and the fabrication results are compared. Mainly, etch/passivation time ratio variation showed good control of the silicon micro-grass, and other parameters also have effect to control the micro-grass. Detailed discussions will be presented.

MN-TuP9 The Adhesion Analysis of Multi Layered Hierarchical Structure of Gecko Feet*, **T.W. Kim**, B. Bhushan,* The Ohio State University

Several creatures including insects, spiders, and lizards, have a unique ability to cling on ceiling and wall that utilizes dry adhesion. Geckos, in particular, have developed the most complex adhesive structures capable of smart adhesionâ?"the ability to cling on different smooth and rough surfaces and detach at will. The gecko feet are comprised of a complex fibrillar structure of ridges called lamellae that are covered in microscale setae that branch off into branches with nanoscale spatulae. This hierarchical structure enables the gecko the adaptability to create a large real area of contact with rough surfaces. van der Waals attraction between the large numbers of spatulae in contact with rough surface is responsible for high adhesion. In order to investigate the effect of geckoâ?Ts hierarchical structure, we consider single and multi layered hierarchically structured spring models for simulation of seta contacting with random rough surfaces. Single contact (spatula) was assumed as spherical. Rough surfaces with various roughness parameters are generated, which is a common range of most of natural and artificial rough surfaces at the scale size of gecko seta. The simulation results show that multi layered hierarchy structure has higher adhesive force than single hierarchy structure, due to better adaptation and attachment ability.

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