Thursday Afternoon, October 5, 2000

MEMS
Room 309 - Session MM-ThA
Material Science of MEMS

Moderator: C.C. Wong, Sandia National Laboratories

2:00pm **MM-ThA1 Stress Measurement in MEMS Devices*, L.A. Starman,*** Air Force Institute of Technology*; J.D. Busbee,* Air Force Research Laboratory Materials Directorate*; J. Reber,* Wright State University*; J.F. Maguire, W.D. Cowan,* Air Force Research Laboratory Materials Directorate

Due to the unique structure and small scale of Micro-Electro-Mechanical Systems (MEMS), residual stresses during the deposition processes can have a profound affect on the functionality of the MEMS structures. Typically, the material properties of thin films used in surface micromachining are not controlled during deposition. Currently, few techniques are available to measure the residual stress in MEMS devices, with each having a limited degree of validity. In this paper, Raman imaging spectroscopy is utilized to examine the residual and induced stress in silicon MEMS test structures. As MEMS structures become more complicated, images generated from Raman spectroscopy can provide valuable information on stress fields in the structure. Since the Raman methodology is directly sensitive to stress in the deposited material, the potential exists for this technology to be used both as an in situ quality control device and for the control of gradients in the batch processing. Successful implementation of this technique allows the validation of MEMS designs. We report here the mapping of the complete stress field across a micromirror flexure. Vertical displacement measurements obtained using an interferometric microscope allow the applied stress in the device flexures to be calculated as a conformation of the stress image.

2:20pm **MM-ThA2 Issues in MEMS Reliability and Characterization*, S. Brown,*** Exponent, Inc. **INVITED**

This presentation addresses MEMS failure modes that are either unexpected or judged insignificant on a macroscale. Although MEMS devices can fail from typical "macro" effects such as overload, fatigue, or corrosion, in many instances these phenomena are accentuated once one addresses micron sized devices. Examples cited include stress corrosion of silicon, creep of membrane and thin film structures, electrostatic accumulation, shock resistance, and strength reduction due to processing effects. Possible countermeasures are included with each example, and suggestions are provided for additional investigation on MEMS reliability.

3:00pm **MM-ThA4 MOCVD PZT as a Pathway to Integrated Piezoelectric MEMS*, I.-S. Chen,*** *J.F. Roeder,* ATMI*; D.-J. Kim, J.-P. Maria, A.I. Kingon,* North Carolina State University

Development of reliable actuation methods is one of many challenges in thin film MEMS devices. Piezoelectric actuation using bulk ceramic materials is well known, but widespread use in MEMS requires suitable deposition and integration methods that are compatible with large-scale manufacturing. One primary factor limiting the development of piezoelectric MEMS has been the lack of a suitable thin film piezoelectric material. PZT and its derivatives have excellent piezoelectric properties and therefore are a logical choice for MEMS applications. Metalorganic Chemical Vapor Deposition (MOCVD) offers a unique combination of precise composition control, uniformity over large areas, and relatively low process temperatures that are compatible with integrated Si processing. We have developed MOCVD processes to prepare PZT films on advanced electrodes with longitudinal piezoelectric coefficients (d@sub 33@) up to 50pm/V. Robust electrode stacks were developed to suppress diffusion of reactive / mobile species into the silicon substrate during PZT deposition. The electrode stacks are fully compatible with substrates typically used in bulk micromachining, namely silicon wafers coated with either silicon nitride or boron-doped epitaxial silicon as an etch stop. For temperature-critical surface-micromachined structures, process temperatures as low as 450 °C have been successfully demonstrated.

3:20pm **MM-ThA5 Deposition of Highly Oriented LiCoO@sub 2@ Thin Films for Use as Cathodes in Thin Film Batteries*, J.A. Ruffner,*** *T.J. Boyle, D. Ingersoll, K.P. Peters, M.A. Rodriguez, J. Liang,* Sandia National Laboratories

Presently micro-and meso-machines (MEMS) are powered by sources that are large in comparison to the actual MEMS devices. Development of small-scale power sources is critical if these devices are to reach their full usefulness. A prototype all-ceramic thin film battery that consists of a LiCoO@sub 2@ cathode, surface modified silica film composite electrolyte, and SnO@sub 2@ anode is presently under development at Sandia National Labs. Deposition of well-oriented, crystalline LiCoO@sub 2@ thin film cathodes is a critical step to achieve the highest capacities possible for these batteries. LiCoO@sub 2@ thin films deposited at ambient temperature using rf sputtering are generally amorphous in their as-deposited state. Post deposition annealing at temperatures > 300 °C results in melting and subsequent crystallization.@footnote 1@ However, it may be possible to promote crystallinity in the desired orientation [(101), (100) or (104) planes parallel to the substrate] by using a substrate or appropriate seed layer which is epitaxially matched to the desired LiCoO@sub 2@ orientation. Single-crystal metal substrates, such as Au (110), Re (100), or Ti (100), have lattices that are well-matched to LiCoO@sub 2@ lattices. However, these substrates are expensive and, in the case of Ti, readily oxidized. Instead, we deposited thin films of these metals as seed layers on more readily available single-crystal dielectric substrates (i.e. quartz) in order to test their effectiveness in promoting crystallization of subsequently deposited LiCoO@sub 2@ thin films in the desired orientation. We report on the orientation and properties of LiCoO@sub 2@ thin films deposited using rf sputter deposition versus solution chemistry. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000. @FootnoteText@ @footnote 1@ P. da Fonseca et al., J. Power Sources (1999), 81-82, 575-580.

3:40pm **MM-ThA6 Microstructure and Mechanical Properties of Polysilicon and Poly-SiC Films for MEMS*, H. Kahn,*** *A.H. Heuer,* Case Western Reserve University **INVITED**

Polysilicon films deposited via LPCVD are the current mainstay structural material for MEMS. It is well known that the microstructures and residual stresses of these films are influenced by deposition temperature. We have developed a novel processing approach (the MultiPoly process) which exploits this concept by using polysilicon multilayers in order to create flat structures, as well as structures with controlled curvatures. The effect of microstructure on mechanical properties is less well known. We have also developed a surface-micromachined electrostatic microactuator capable of generating 0.7 mN of force. The microactuator can be integrated with on-chip fracture mechanics specimens, and these devices have been used for studying strength, toughness, and fatigue resistance of polysilicon. Similar studies have also been done on poly-SiC films.

4:20pm **MM-ThA8 Comparison of In-situ Boron-doped and In-situ Phosphorus-doped Polysilicon Films for Microelectromechanical Systems*, J.J. McMahon,*** *J.M. Melzak, C. Zorman, J. Chung, M. Mehregany,* Case Western Reserve University

In order to produce thick polysilicon films for MEMS applications, a single step, high deposition rate, APCVD process was developed and used to deposit in situ boron-doped, undoped, and in situ phosphorus-doped polysilicon films at susceptor temperatures ranging from 625C to 850C. For doped and undoped films alike, the deposition rate increases with increasing susceptor temperature, with boron-doped films exhibiting the highest deposition rate at each temperature setting. The highest deposition rates occurred at 850C, with boron-doped films being deposited at a rate of 733A/min, undoped films at a rate of 716A/min, and phosphorus-doped films at a rate of 622 A/min. Spreading resistance and SIMS measurements performed on the boron-doped samples indicate that the boron concentrations are generally constant throughout the thickness of the films, with the highest boron concentrations found in films deposited at 625C. Wafer curvature measurements on boron-doped films indicate that the films are in compression over the entire temperature range, with the magnitude of the stress decreasing with increasing temperature. In contrast, the undoped films are in tension at lower temperatures, but become compressive as the deposition temperature is increased. TEM analysis shows that film microstructure strongly depends on the deposition temperature, with equiaxed grains forming at low substrate temperatures and columnar grains forming at higher temperatures. Surface micromachined cantilevers, strain gauges, and lateral resonators were successfully fabricated from 5.0 micron-thick doped films grown at 850C. The extended paper will detail the process used to deposit the doped and undoped films, present a summary of the characterization study, and highlight the performance of micromachined structures and devices.

4:40pm **MM-ThA9 Investigation of the Friction and Adhesion Properties of BPT and BPTC Self-assembled Monolayers by AFM**, ***H. Liu***, *B. Bhushan,* The Ohio State University; *W. Eck, V. Stadler,* University of Heidelberg, Germany

Self-assembled monolayers (SAMs) are considered to be good candidate lubricants for microelectromechanical systems (MEMS). It is important to understanding the relationship between the structure and tribological performance for molecular tailoring to achieve efficient lubrication. For this purpose, biphenyl-4-thiol (BPT), and cross-linked biphenyl thiol (BPTC) were prepared on a gold sublayer. The cross-linking of BPT was carried out by low energy electron irradiation. Structure characterization shows that cross-links were formed between neighboring phenyl groups. The topography, adhesion, and friction properties of Si, Au, BPT and BPTC were studied by atomic force microscopy (AFM) with silicon nitride tip. It was found that both BPT and BPTC exhibited lower adhesion and friction than Si. But the coefficient of friction of BPTC are higher than BPT. The larger coefficient of friction of BPTC is believed to be caused by its rigid cross-linked structure. The study also found that the topography of different films have different contribution to the frictions of films. For Au and BPTC, friction is affected by surface slope, but for BPT the higher surface areas have low friction. A relationship between wear resistance of the low friction phase of BPT and its size was found.

5:00pm **MM-ThA10 Viewing a Moving Surface Contact: An STM-QCM Study of Vapor Deposited Films on Metal Surfaces**, ***B. Borovsky***, *M. Abdelmaksoud, J. Krim,* North Carolina State University

With the emergence of MEMS technology and the problems of high friction and mechanical failure encountered in the operation of such devices, new experimental techniques are needed which are able to probe nanometer scale contacts under sliding conditions relevant to MEMS. By combining a Scanning Tunneling Microscope (STM) with a Quartz Crystal Microbalance (QCM), we have constructed a nanotribological test set-up in which a single asperity contact is subject to contact pressures and sliding speeds relevant to both MEMS and macroscopic devices. We have applied STM-QCM to the study of vapor phase lubricants, which may prove to be an effective, and perhaps exclusive, means of lubricating MEMS devices. The STM allows direct imaging of the surface contact under both stationary and vibrating conditions, and is able to track changes in the conductivity and mobility of molecularly thin lubricant films. Surprisingly, the amplitude and speed of the sliding contact may be directly measured using STM images of the vibrating QCM surface. We show that the QCM achieves sliding speeds over 1 m/s and senses changes in sliding friction as a function of normal load upon application of a lubricant film to a bare metal surface. Together, our nanometer scale STM-QCM results are highly suggestive of the known macroscopic lubricant properties of the applied films. By performing rubbing-and-imaging experiments with this combined apparatus, dramatic changes in the properties of the contact are observed which are highly localized to the region of rubbing. Such investigations provide evidence of possible tribochemical effects, the observation of which is associated with the realistic sliding conditions attained with the STM-QCM. Research supported by the NSF and the AFOSR.

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