Wednesday Morning, October 27, 1999

Thin Films Division
Room 615 - Session TF+MM-WeM
Thin Films in MEMS and MOEMS

Moderator: S. Patton, Air Force Research Laboratory

8:20am **TF+MM-WeM1 Detection of Photons Using Thin Films in Semiconductor MEMS**, ***P.G. Datskos***, *S. Rajic,* Oak Ridge National Laboratory; *I. Datskou,* Environmental Engineering Group, Inc.

We report on a new method for detecting photons using the stress caused by photoelectrons emitted from a thin metal film surface in contact with a semiconductor microstructure which forms a Schottky barrier. As photoelectrons diffuse from the metal film into the microstructure they produce an electronic stress. The photon detection results from the measurement of the photo-induced bending of the microstructure. Internal photoemission has been used in the past to detect photons, however, in those cases the detection was accomplished by measuring the current due to photoelectrons and not due to electronic stress. Small changes in position (displacement) of microstructures are routinely measured in atomic force microscopy (AFM) where atomic imaging of surfaces relies on the measurement of small changes (< 10@sup -9@ m) in the bending of microcantilevers. In this work we studied the photon response of Si microcantilevers coated with a thin film of Pt. The Si microcantilevers were 500 nm thick and had a 30 nm layer of Pt. Photons with sufficient energies produce electrons from the platinum-silicon interface which diffuse into the Si and produce an electronic stress. Since the excess charge carriers cause the Si microcantilever to contract in length but not the Pt layer, the bimaterial microcantilever bends. In our present studies we used the optical detection technique to measure the photometric response of Pt-Si microcantilevers as a function of photon energy. The charge carriers responsible for the photo-induced stress in Si, were produced via internal photoemission using a 1550 nm wavelength diode laser.

8:40am **TF+MM-WeM2 Sputtered Coatings for Microfluidic Applications**, ***D.W. Matson***, *P.M. Martin, W.D. Bennett, J.W. Johnston, D.C. Stewart, C.C. Bonham,* Pacific Northwest National Laboratory

Magnetron sputter-deposited features and coatings are finding a broad range of uses in microfluidic devices being developed at the Pacific Northwest National Laboratory (PNNL). Such features have routinely been incorporated into multi-layer laminated microfluidic components where specific functionality is required and other methods for producing these features have been deemed unacceptable. Applications include electrochemical sensors, heaters and temperature probes, electrical leads and insulation layers, and chemical modification of surfaces. Small features, such as those required for the production of microsensor electrodes or miniature resistive heaters on microfluidic chips, were patterned using standard lithographic methods or with masks produced by laser micromachining processes. Use of the coating technology and its application in specific microfluidic devices, including a groundwater sensor, a piezoelectrially actuated airflow regulator, and a microchannel flow diagnostic device, will be discussed.

9:00am **TF+MM-WeM3 A Novel Thin-Film Proton Exchange Membrane Fuel Cell for Microscale Energy Conversion**, ***J.D. Morse***, *A.F. Jankowski, J.P. Hayes, R.T. Graff,* Lawrence Livermore National Laboratory

A novel approach for the fabrication and assembly of a proton exchange membrane (PEM) fuel cell system enables effective scaling of the fuel delivery, manifold , and cell stack components for applications in miniature and microscale energy conversion. Electrode materials for PEM fuel cells are developed using sputter deposition techniques. A thin film anode is formed through the deposition of nickel, followed by the deposition of a platinum catalyst layer. A proton conducting membrane electrolyte is formed over the catalyst using spin cast techniques. Finally, a thin film cathode is formed that incorporates a thin platinum layer, followed by a layer of silver. Scaling towards miniaturization is accomplished by utilizing novel micromachining approaches. Manifold channels and a fuel delivery system are formed within the substrate that the cell stack is fabricated on thereby circumventing the need for bulky manifold components that are not directly scalable. Methods to synthesize a base electrode layer to a thin-film PEM fuel cell from the electrolyte and a conductive material are developed using photolithographic patterning and physical vapor deposition. The microstructure and morphology desired for the anode layer should facilitate generation of a maximum current density from the fuel cell. For these purposes, the parameters of the deposition process and post-deposition patterning are developed to optimize porosity in the anode layer. The fuel cell microstructure is examined using scanning electron microscopy and the power ouput generated is characterized through current-voltage measurement. This work was performed under the auspices of the United States Department of Energy by Lawrence Livermore National Laboratory under contract #W-7405-Eng-48.

9:20am **TF+MM-WeM4 Thin Films in MEMS and MOEMS**, ***W.D. Cowan***, Air Force Research Laboratory **INVITED**

Micro-Electro-Mechanical Systems (MEMS) and Micro-Optical-Electro-Mechanical Systems (MOEMS) employ batch fabrication processes to construct miniature devices with macroscopic functionality. Surface micromachined MEMS structures are manufactured by the deposition and patterning of thin films. In marked contrast with conventional fabrication processes (and bulk micromachining), the thin film materials used in surface micromachined structures are formed as the device is processed. In general, the material properties of thin films are not controlled during deposition, and are only measured after processing is completed. Characterization methods include wafer curvature measurements and a variety of test structures. None of the thin film characterization techniques currently employed is entirely satisfactory and all methods rely on process repeatability to be useful. The ultimate performance of many MEMS and MOEMS depends directly on the materials properties of the thin films employed. Processing variations induce variations in materials properties that directly impact device performance. For MOEMS, residual material stresses can cause curvature of nominally flat reflecting surfaces that degrades optical performance. Recent work in which MEMS foundry processes were used to fabricate low-cost deformable mirrors (MEM-DMs) for adaptive optics illustrates the impact of residual material stress on system level optical performance. Residual material stress can be exploited in other MEMS devices to produce unique structures. More precise monitoring and control of film stress during deposition remains as a challenge for MEMS and MOEMS.

10:00am **TF+MM-WeM6 Residual Stresses in MEMS Structures**, ***B.S. Majumdar***, UES, Inc.; *W.D. Cowan,* Air Force Research Laboratories; *S. Rogers,* AFIT; *N.J. Pagano,* Air Force Research Laboratories

Residual stresses impose major restrictions on the performance of MEMS devices. Although different techniques have been developed to measure such stresses, they suffer from a number of limitations. We have focused our attention on square and circular micro-mirrors that are supported by electrically activated arms. Permanent curvature in such mirrors arise from thermal and process-generated residual stresses, and they seriously impair mirror performance. In this work, the residual stresses were estimated from curvature measurements on different sized beams using an interferometric technique, complemented by rigorous elastic analysis of composite beams. It is notable that typical analyses is based on Stoney's equation, which is not believed to be valid for the thin MEMS structures. The composite beams consisted of different grades of poly-silicon with and without gold coating, and the measurements and analysis showed consistent results for the different beams and mirrors. In an effort to de-couple the thermal and process component of the residual stresses, curvature measurements were made at different temperatures. The results and analysis technique will be presented in detail, and possible methods to reduce the residual stresses will be discussed.

10:40am **TF+MM-WeM8 Investigation and Modeling of Electrical Resistance in Polysilicon Thermal Actuators**, ***J.T. Butler***, *W.D. Cowan,* Air Force Research Laboratory

This paper reports on investigation and modeling of the electrical resistance of micromachined polysilicon thermal actuators. The availability of models compatible with commonly used circuit simulators such as SPICE are extremely useful for design of integrated microsystems which include thermal actuators. The development of a model for thermal actuators necessitated an analysis of the electrical resistance characteristics of the MEMS fabrication process in order to provide an understanding of a key material property. The thermal actuators investigated in this research were fabricated through the DARPA-sponsored Multi-User MEMS Processes (MUMPs). Hence, a TSUPREM model of the MUMPs fabrication process was created to generate polysilicon resistivity parameters which were then fed into the electrothermal SPICE model. Two types of thermally actuated devices were modeled: a lateral thermal actuator and a thermally actuated piston micromirror. The SPICE model exhibits very close agreement with the measured performance of the polysilicon thermal actuators. The MUMPs process used to fabricate the thermal actuators has three structural layers of polysilicon. The resistivity of each of the MUMPs polysilicon layers varies due to differences in fabrication. Moreover, our resistance measurements of test structures and actuators showed that the resistivity of devices formed from the various MUMPs polysilicon layers also varies based on structure linewidth. A TSUPREM fabrication model of the MUMPs process was generated which validated the empirical resistance measurements and the dependence of resistivity on linewidth. The TSUPREM simulation revealed that the diffusion of phosphorus dopant during the anneal cycles in the MUMPs fabrication process were largely responsible for the variations in resistivity due to linewidth. For small (< 10 (m) linewidth structures, the presence or absence of lateral diffusion of dopant through the sidewall can significantly alter the electrical resistance. The resistivity dependence on linewidth is significant for our thermal actuators because they are designed with elements having linewidths varying from 2 (m to greater than 20 (m. The electrothermal SPICE model augmented with the TSUPREM resistivity data accurately predicted the I-V performance of both the lateral thermal actuator and the thermal piston micromirror. The use of SPICE allows simulation of both the MEMS device and control electronics in the same analysis package and enables the designer to gain insight into the expected performance of the microsystem prior to fabrication. On-going work includes investigation of adding thermal mechanical modeling to our simulation.

Author Index

Bold page numbers indicate presenter