MEMS
Room 309 - Session MM-WeM
Microfabricated Sensors

Moderator: C. Zorman, Case Western Reserve University

8:20am **MM-WeM1 Microfabricated Platform for Semiconducting Metal Oxide Thin Film Gas Sensors**, ***D.J. Frankel,*** *C. Silvestre, G. Bernhardt, S.C. Moulzolf, N. LeCursi, R.J. Lad,* University of Maine

A sensor platform for chemiresistive and impedance based thin film gas sensors has been developed which can be fabricated using conventional microfabrication techniques. The platform utilizes a highly polished sapphire substrate with platinum electrodes, heater element, and resistance temperature detector (RTD). The use of highly polished and well characterized sapphire substrates allows controlled growth of thin metal oxide sensing films, yielding reproducible and well-defined microstructures. Techniques have been optimized that allow for more than 400 sensing devices to be fabricated on 3" diameter sapphire substrates using liftoff technology. Delamination of metallization on the sensor platform can be problematic, particularly following high temperature annealing. Strong adhesion between the platinum electrodes and sapphire substrate is achieved with a thin Zr adhesion layer. Adhesion is such that parallel gap welding of 4 mil Pt wire can be successfully obtained with bond strengths exceeding 100 grams force. Strong bonding is achieved after fabrication and following extended anneals up to 500C. These anneals are required to stabilize the resistance of the RTD and heater elements. The platform materials exhibit stable operation after accelerated temperature cycling between room temperature and the typical sensor operation temperature of 200-400C. We have also used microfabrication techniques to fabricate sensor platforms with a variety of electrode configurations, including under and on top of the metal oxide sensing film, that explore the effect of sensor resistance measurement configuration on sensor operation while keeping substrate effects constant.

8:40am **MM-WeM2 The Use of Micromachined Arrays to Develop Processing/Performance Databases for Metal/Oxide Sensing Materials**, ***J.E. Tiffany***, *R.E. Cavicchi, S. Semancik,* National Institute of Standards and Technology

We describe the efficient study of multiple metal/oxide microsamples on micromachined platforms called microhotplate arrays. These platforms include addressable temperature control of 36 individual elements which is employed in fabricating and evaluating varied sensing films being examined for solid state conductometric gas microsensors. Each 100 micron array element consists of a suspended structure with a buried heater and surface electrodes. We present results of screening experiments (metal coverage and type, annealing and sensing temperature, gas type) designed to generate a response database of sensitivity and selectivity. Tin oxide was deposited on all array elements via a Ni seeded, self-lithographic MOCVD process. Low coverage (25-100 Å) catalytic metal s (Ni, Pd, Pt, Cu, Ag, Co, Rh, Ir, Ru) were then deposited on select elements using masked evaporation or sputtering. We describe the response of these array elements to a wide variety of gases (2-butanone, acetone, toluene, benzene, methanol, ethanol, hydrogen, and carbon monoxide). Response data was collected for bare and catalyst modified sensors. The bare tin oxide films showed a normally distributed (10%) conductance response when exposed to the test gases at fixed temperature, demonstrating the statistical stability of the screening approach. Relative sensitivities for the different metal catalysts are reported as a function of sensing temperature for each test gas. We observed, for example, that the addition of Ni catalyst decreased hydrogen response, whereas 2-butanone response was increased. Benzene response was also observed to cross over from negative to positive at a specific temperature due to competing surface reactions both with and without Ni catalyst. Such cases of increased sensitivity, selectivity and crossover response can be extracted from the materials screening response data and be used in customizing microsensors for specific tasks.

9:00am **MM-WeM3 Chemical Detection Based on Adsorption-Induced and Photo-Induced Stresses in MEMS Devices**, *P.G. Datskos, S. Rajic, L.R. Senesac,* Oak Ridge National Laboratory*;* ***I. Datskou,*** Environmental Engineering Group, Inc.*; M.S. Sepaniak, C.A. Tipple, B.C. Fagan,* University of Tennessee

Recently there has been an increasing demand to perform real-time in-situ chemical detection of hazardous materials, contraband chemicals, and explosive chemicals. Currently, real-time chemical detection requires rather large analytical instrumentation that are expensive and complicated to use. The advent of inexpensive mass produced MEMS (micro-electro-mechanical systems) devices opened-up new possibilities for chemical detection. For example, microstructures were found to respond to chemical stimuli by undergoing changes in their bending and resonance frequency even when a small number of molecules adsorb on their surface. In our present studies, we extended this concept by studying changes in both the adsorption-induced stress and photo-induced stress as target chemicals adsorb on the surface of microstructures. For example, microstructures that have adsorbed molecules will undergo photo-induced bending that depends on the number of absorbed molecules on the surface. However, microstructures that have undergone photo-induced bending will adsorb molecules on their surfaces in a distinctly different way. Depending on the photon wavelength and microstructure material, the microstructure can be made to bend by expanding or contracting the irradiated surface. This is important in cases where the photo-induced stresses can be used to counter any adsorption-induced stresses and increase the dynamic range. Coating the surface of the microstructure with a different material can provide chemical specificity for the target chemicals. However, by selecting appropriate photon wavelengths we can change the chemical selectivity due to the introduction of new surface states in the MEMS device. We will present and discuss our results on the use of adsorption-induced and photo-induced bending of microstructures for chemical detection.

9:20am **MM-WeM4 Optical Emission Study of a Microfabricated Inductively Coupled Plasma**, ***O. Minayeva***, *J.A. Hopwood,* Northeastern University

Recently, the fabrication@footnote 1,2@ and characterization@footnote 3,4@ of a micromachined 5-mm inductively coupled plasma (ICP) generator was reported. One of the applications for a microplasma source is the detection of gaseous impurities in air using a micromachined Fabry-Perot interferometer to monitor the optical emissions of the plasma. In this work the complete system that includes a microplasma generator, vacuum chamber, optical path, and lab-scale spectrometer was built and tested on several gas discharges. The goal was to maximize the electronic excitation reaction followed by the light emission from a toxic gas sample (e.g., SO@sub 2@) diluted in air (or argon). It was found that an electron temperature of ~3 eV favors the excitation reaction for SO@sub 2@. The chamber was designed to provide this value of electron temperature over an operating pressure of 0.5-1 torr. Optical paths were incorporated in the chamber in order to collimate the plasma's light emission to within 3-4@super o@ prior to filtering and detection by the interferometer. Multiple optical paths also allow one to determine the spatial structure of the plasma. The optical emission spectra were taken at different points within the micro ICP, and the results on light intensity distribution across the discharge will be presented. @FootnoteText@ @footnote 1@ J. Hopwood, "Monolitic miniaturized inductively coupled plasma source;" U.S. Patent No. 5,942,855 (August 24, 1999). @footnote 2@ Y. Yin, J. Messier, and J. Hopwood, "Miniaturized inductively coupled plasma sources," IEEE Transactions on Plasma Science, 27(5), 1516-1524, (1999). @footnote 3@ J. Hopwood, O. Minayeva, Y. Yin, "Fabrication and characterization of a micromachined 5-mm inductively coupled plasma generator," submitted to J. Vac. Sci. Technol. @footnote 4@ J. Hopwood, "A microfabricated inductively-coupled plasma generator," submitted to J. Microelectromechanical Systems.

9:40am **MM-WeM5 A Micromachined Scanning Fabry-Perot Interferometer**, ***F.C. LI,*** Northeastern University, U.S.A*; N.E. McGruer,* Northeastern University*; P.M. Zavracky, K.L. Denis,* Northeastern University, U.S.A

This work describes a novel process to fabricate a micromachined scanning Fabry-Perot interferometer (FPI) employing electrostatic actuators. The Northeastern University MEtal Micromachining (NUMEM) is used to build the electrostatic actuators, which consist of four free standing gold cantilever beams. Two highly reflective mirrors are fabricated separately. @footnote 1@ The final assembly step bonds the upper mirror to the beams and completes the device. The two plane parallel mirrors are initially separated by a gap of approximately 600nm. By applying appropriate control voltages between the beams and electrodes on the substrate, the device can be tuned to wavelengths in the visible spectrum from 450 to 750 nm. Four sense capacitors are placed underneath the upper mirror to detect the spacing between the two mirrors. The spacing information is supplied to a closed-loop control circuit which scans the upper mirror vertically and maintains parallelism. Devices fabricated with aluminum mirrors (reflectivity approximately of 85%) showed resolving powers of 26, 24 and 18.2 at the wavelengths of 525nm, 615nm and 660nm, respectively. Proposed applications of the micromachined FPI include in situ measurements of plasma composition, colorimetric, and chemical analysis. @FootnoteText@ @footnote 1@ P.M. Zavracky, K.L. Denis, H.K. Xie, T. Wester and P. Kelly, "A Micromachined Scanning Fabry-Perot Interferometer", Proceedings of SPIE-The International Society for Optical Engineering, v 3514 p 179-187, Sep 21-22, 1998.

10:00am **MM-WeM6 Passivation of MEMS Structures that are Integrated with Support Electronics*, J.R. Martin,*** Analog Devices Inc. **INVITED**

MEMS devices are susceptible to surface conditions because they are seldom passivated. For example, electrical and optical performances are affected when unpassivated surfaces adsorb or chemically react with ambient gases. Stiction can occur if shock impacts cause these high-energy surfaces to touch. Unfortunately, it is difficult to passivate MEMS wafers due to microstructure flatness requirements, metal temperature limitations and surface charging during low temperature plasma processes. Some SAM coatings are reasonable candidates. However, organics do not normally survive the cerpac process used to package ADXL accelerometers (several furnace passes in air at 430-450C). This presentation will describe a new MEMS passivation process based on a custom synthesized diphenyl siloxane. Organics with the best thermo-oxidative resistance contain phenyl rings so vapor deposited diphenyl siloxane films were evaluated on polysilicon accelerometers. Silicones (molecules with a silicon oxide backbone) were used to transport and bond phenyl rings to the sensor surface. As a result, the native oxide is modified by formation of a low-energy (organic-rich) surface that survives the packaging process. This approach also minimizes contamination concerns because any degradation products are essentially identical to the native oxide that already exists on polysilicon surfaces. A variety of deposition conditions and two types of equipment were evaluated for both electrical and stiction characteristics. Varying the type of diphenyl siloxane caused large differences in anti-stiction performance. Control of the final process is impressive. For example, 100 wafer coating runs have a thickness uniformity of +/- one angstrom. There is no practical way to measure coatings on MEMS surfaces with this level of precision. Therefore, specially prepared monitor wafers are placed in each furnace boat. Early results show that run to run uniformity is also in the +/- one angstrom range.

Author Index

Bold page numbers indicate presenter