Microelectromechanical Systems (MEMS)
Room: C-210 - Session MM-ThA

Fabrication, Integration, and Packaging Techniques for MEMS
Moderator: C.A. Zorman, Case Western Reserve University

2:00pm **MM-ThA1 Addressing MEMS Reliability Through Innovative Fabrication, Integration, and Packaging Techniques**, ***V.M. Bright***, University of Colorado, Boulder **INVITED**

MEMS research at the University of Colorado in Boulder (UCB) has been focused on MEMS reliability through innovative design, materials, and fabrication. The UCB has applied techniques from other fields in a novel way to solve reliability issues in MEMS. This approach has improved the reliability of more traditional silicon-based MEMS. It also has resulted in a number of innovative new MEMS designs and applications. As the silicon-based MEMS manufacturing techniques mature and products transition from the R&D phase to production, the reliability aspects of MEMS design, fabrication, and packaging become more of a reality. It is known that MEMS reliability problems are related to nano-scale interface phenomena. One approach to solve MEMS reliability challenges is through novel materials and/or fabrication methods. Another approach is to improve MEMS reliability through proper design, which takes into account interface phenomena such as adhesion or charging. The barriers to MEMS reliability include: thin film structure susceptibility to adhesion due to large contact surface area and/or dielectric charging; limited life-time of microstructure due to friction and wear at micro-scale; multilayered structure change in curvature during thermomechanical loading or fabrication/packaging processes that require temperature cycling; multilayered structure stress relaxation over time, which may result in changing device functionality. In order to build reliable devices, advanced design knowledge must emphasize interactions among thermal, mechanical, chemical, and atomic effects bridging the necessary nano- and micro-scales. The fabrication must focus on nano-scale materials synthesis, characterization, material processing and packaging technologies that are critical to assure device reliability. The technologies that this talk is focused on include: atomic layer deposition of coatings, self-assembly of MEMS using surface tension forces, flip-chip MEMS assembly and packaging.

2:40pm **MM-ThA3 Development of Individually Addressable Micro-Mirror-Array for Space Applications**, ***S.B. Dutta***, NASA, Goddard Space Flight Center **INVITED**

MEMS is a strategic technology thrust area for NASA's missions of the 21st century. It will enable development of sensors and actuators for communication, navigation, propulsion and optical subsystems with low mass and power that operate in space environment. Currently, NASA is supporting MEMS technology development for the Next Generation Space Telescope (NGST), successor of the Hubble Space Telescope (HST) to be launched in 2009. NGST would have a Near InfraRed Multi Object Spectrometer (NIRMOS) that would use programmable slits to select multiple stars and galaxies for simultaneous observation. A team at NASA, Goddard Space Flight Center (GSFC), has developed aluminum, bi-state Micro-Mirror-Array (MMA) operating at 30K that could be used as programmable slits, to support science objectives of NGST. MEMS technology permits fabrication of MMA with self-contained actuation mechanism and direct interfaces to digital electronics. 32x32 MMA has been designed and fabricated using standard CMOS and surface micro-machining processes. The unit cell of MMA contains a square mirror on 100µm pitch and tilts by ± 10 °. The MMA are built on top of CMOS driven address and driver circuit for individual addressing and a CMOS compatible MEMS process has been implemented for compact design. The tilting of the mirrors is achieved by electrostatic attraction between two parallel plate aluminum electrodes. A pair of thin aluminum torsion straps is used so that the voltage required for tilting is less than 20V. The array has been tested successfully to operate at room temperature and at 30K for over 10^6 cycles. Operation of mirror elements has been simulated extensively. Experimental data are in good agreement with model predictions. For optimal operation of MMA, different alloy materials were studied for mirror fabrication. Electro-mechanical modeling, material property studies, fabrication, packaging and optical characterization of the MMA will be presented.

3:20pm **MM-ThA5 Transformer Coupled Plasma Etching of Polycrystalline 3C-SiC Films for MEMS Applications**, ***D. Gao***, *M.B.J. Wijesundara, C. Carraro, R.T. Howe, R. Maboudian*, University of California at Berkeley

Polycrystalline 3C-SiC films were etched by oxygen-mixed sulfur hexafluoride transformer coupled plasmas (TCP) in a commercial LAM TCP 9400 etcher for MEMS applications. The SiC films were grown by single-source CVD at 850°C using 1,3-disilabutane as the precursor.[1] Low-temperature CVD SiO_2 and plasma-enhanced CVD SiO_2 were employed as etching masks, which avoided micromasking phenomena and chamber contamination commonly involved when using metals as masks in most SiC etching processes. The SiC etch rates changed slightly with O_2 percentage, reaching maximum of 3800 Å/min at 16% O_2. Etching rate ratio of SiC/SiO_2 increased with O_2 percentage, reaching 2.6 at 50% O_2. By integrating the etching process into micromachining techniques, SiC-based micromechanical structures were fabricated. The etching profile and the chemical components of etched SiC surfaces were examined by cross sectional SEM and X-ray photospectroscopy respectively.

[1] C.R. Stoldt, et al., Proceeding of Transducers 01, the 11th International Conference on Solid-State Sensor and Actuators, Munich, Germany, June 10-14, 2001, pp. 984-987.

3:40pm **MM-ThA6 MEMS-based Gray-scale Technology**, ***C.M. Waits***, *A. Modafe, R. Ghodssi*, University of Maryland

Micro-electro-mechanical systems (MEMS) fabrication technologies originated directly from integrated circuit (IC) fabrication, consisting of primarily planar techniques. Consequently, structures fabricated for MEMS devices have been traditionally designed with nominally vertical sidewalls (dry anisotropic etching), undercut sidewalls (wet isotropic etching), or sidewalls with limited angles due to the crystallographic orientation of the substrate (wet anisotropic etching). There exists a breadth of potential applications for a fabrication technique that can achieve 3-D structures (arbitrarily sloped sidewalls) in silicon suited for small and large high aspect ratio MEMS structures. A micromachining technique using gray-scale lithography along with dry anisotropic etching enables the development of 3-D structures in silicon. The gray-scale lithography allows the fabrication of a differential-height photoresist-masking layer. The key components in gray-scale lithography include (a) design of the optical mask and (b) use of a projection lithography system. A sub-resolution optical mask and a photolithography stepper system together locally modulate the intensity of ultraviolet light through diffraction. The modulated light exposes a photoresist film to specified depths where a gradient height profile remains once developed. This method results in the fabrication of differential-height photoresist masking layers with up to 22 different height levels. The masking layers are then used in Reactive Ion Etching (RIE) to successfully transfer the structures in silicon, resulting in various shaped 9-micron tall silicon structures with sloped sidewalls ranging from 5 to 90 degrees with respect to the silicon surface. The results of preliminary characterization for both gray-scale lithography and RIE etching in silicon are presented.

4:00pm **MM-ThA7 Thick and Thermally Isolated Si Microheaters for Preconcentrators**, ***W.-C. Tian***, *S.W. Pang*, The University of Michigan

Thick, thermally isolated microheaters in Si are fabricated using high aspect ratio etching technology. These thick microheaters with large surface area provide large adsorbent capacity needed for high sensitivity preconcentrators in a micro gas chromatography system (µGC). Microheaters in this work are different from previous work which consisted of mostly thin poly-Si or metal microheaters (<2 µm) on top of the dielectric membranes. Instead, thick microheaters (>500 µm) surrounded by air gaps are generated to provide large surface area and good thermal isolation, which are important for high sensitivity, low power preconcentrator in a µmGC system. A 520 µm thick Si microheater with good thermal isolation has been made and its backside is anodically bonded to a pyrex glass substrate. To provide good thermal isolation, a 500 µm wide air gap around the microheater, thin poly-Si interconnects on top of dielectric membrane, and air gap isolation from the bottom glass substrate are used. Microheaters with 500 µm air gap can be heated up 50% faster to a temperature of 270 °C compared to those with 100 µm air gap, while the power consumption is 25% less and there is a larger temperature difference between the microheater and the bonding area. Operating the microheater in vacuum results in lower power consumption. At 250 °C, 38% less power is needed at 1.2 Torr compared to atmosphere pressure. Power consumption is further reduced by minimizing the contact area with the heater support substrate. Up to 33% power reduction has been demonstrated by placing heaters on thin membrane or etching trenches in supporting substrate. This is the first demonstration of using thick Si microheaters with air gap isolation for µmGC system. These thick, thermally isolated Si microheaters can provide good power efficiency, large adsorbent capacity, and high mechanical strength as preconcentrators.

4:20pm **MM-ThA8 Silicon Nitride Micromesh Bolometric Detectors for Planck**, ***M. Yun***, *T. Koch, J. Bock, W. Holmes*, Jet Propulsion Laboratory*, A. Lange,* California Institute of Technology

We report on the design, fabrication and testing of the bolometric detectors for the High Frequency Instrument (HFI) on the Planck Surveyor, ESA mission designed to image the Cosmic Microwave Background that is scheduled for launch in 2007. The bolometric detectors consist of NTD Ge thermistors indium bump-bonded to a fine mesh of silicon nitride. The mesh is metalized to efficiently absorb mm-wave radiation. Unmetalized support becomes excellent thermal isolation from the heat sink. The absorber geometries are of 2 types: one sensitive to both linear polarizations and optimized for background-limited sensitivity at 100, 143, 217, 353, 545 and 857 GHz, the other sensitive to a single linear polarization and optimized for background-limited sensitivity at 143, 217, 353 GHz. The detectors have NEP ~ 10^{-17} W/(Hz)$^{0.5}$ and time constants of several msec.

4:40pm **MM-ThA9 Piezoelectric MEMS for RF Filter Applications**, ***A. Wickenden***, *B. Piekarski, L. Currano, J. Pulskamp, R.G. Polcawich, E. Zakar, R. Piekarz, D. Washington, J. Conrad, M. Dubey*, U.S. Army Research Laboratory

Resonator arrays for RF filter devices operating in the GHz frequency range are of interest for lightweight, low power, high precision frequency selection applications. A high quality factor (Q) is required to reduce phase noise and ensure stability against frequency-shifting phenomena. MEMS-based resonator devices offer potential advantages in size, weight, and power consumption over surface wave acoustic wave (SAW) or bulk acoustic resonators currently used for frequency filtering applications. Piezoelectric electromechanical resonator devices should demonstrate advantages over equivalent electrostatic devices for high frequency applications, since they are less sensitive to degraded coupling strength as the device dimensions are reduced.[1] Resonant frequency response is determined by both device geometry and materials properties. PZT is attractive for piezoelectric filters due to its high piezoelectric coupling coefficient, although the operating frequency of PZT resonators is limited to the MHz range by the large acoustic time constant of the material. Piezoelectric materials such as aluminum nitride (AlN), zinc oxide (ZnO), and related alloys are of interest because their fast acoustic response times translate to theoretical maximum frequencies of >100 GHz.[2] Models are being developed to predict the response of piezoelectric MEMS resonators. These models are currently being validated using PZT resonator devices with beam lengths ranging from 400µm to 20µm, with natural frequencies in the MHz regime. Deviation from standard mechanical models has been observed in the measured response of these devices having lengths less than 50µm. The fabrication, testing, and modeling of piezoelectric PZT resonator devices will be discussed, and the extension of the predictive models to alternate materials systems and submicron geometries for GHz applications will be outlined.

This work is supported in part by DARPA

[1]D.L. DeVoe, Sensors and Actuators A 88, 263-272 (2001)

[2]A. Ballato, "Micro-electro-acoustic Devices for Wireless Communication," IEEE Sarnoff Symposium on Advances in Wired and Wireless Communications (March 1999)

5:00pm **MM-ThA10 Micro-Thermal Conductivity Detector for Chemical Sensing**, ***D. Cruz***, UCLA and Sandia National Laboratories, *J.P. Chang*, University of California, Los Angeles*, F. Gelbard, R.P. Manginell, S.K. Showalter, L.J. Sanchez, S.S. Sokolowski, M.G. Blain*, Sandia National Laboratories

Microsensors are essential for detecting biological and chemical warfare agents in state-of-the art micro chemical analytical systems. We have designed and fabricated a micro thermal conductivity detector to analyze the effluent from a gas chromatography column (GC). The TCD can be integrated with a micro-GC column to form a complete "lab-on-a-chip" separation-detection scheme. The TCD consists of a two-flow cell Wheatstone bridge circuit where the resistor elements are suspended by a thin SiN_x membrane in pyramidal and trapezoidal shaped flow cells. A four-flow cell detector can also be constructed for doubling of sensitivity. Rapid computational prototyping by simulating the heat transfer in the TCD with a Boundary Element Method enables a cost-effective way of optimizing the TCD geometries yielding the greatest sensitivity. Two flow patterns, six operating temperatures, five heater sizes, and five channel widths were theoretically investigated, and the optimal geometry along with eight additional promising geometries was fabricated. The change in heat flow versus the change in gas thermal conductivity (dQ/dk) of He was first determined to verify the simulation results. Nitrogen and a carbon-fluoro-carbon were added as effluents to the He gas stream. The voltage response in the Wheatstone bridge changed by approximately 40% and 70% respectively. A four-cell detector was used, where He was flowed at 5 sccm through 2 reference resistors and a mixture of the carrier gas (He) and effluent was flowed through the other two resistors. The measured voltages yielded heat flux values that consistent with the theoretical values. In addition; results verified that convection became a dominant effect over conduction when the carrier gas was flowed at a rate greater than 10 sccm.

[1]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.

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