Microelectromechanical Systems (MEMS)
Room 130 - Session MM-ThA

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

2:00pm **MM-ThA1 Integration of a Honeycomb Micromirror with a Surface Micromachined 2D Scanner for Improved Performance**, ***P.R. Patterson,*** University of California at Los Angeles*; G.-D.J. Su, D. Hah,* University of California at Los Angeles, U.S.A*; M.C. Wu,* University of California at Los Angeles

We have developed a novel fabrication process to integrate lightweight single crystal silicon honeycomb micromirrors with surface micromachined 2D scanners for improved optical flatness, compared to polysilicon alone, and improved response, compared to solid (higher mass), micromirrors. The honeycomb micromirrors are formed by silicon fusion bonding of two, silicon on insulator, SOI wafers allowing for precise control of the core and facesheet thickness, here we used 25 µm and 10 µm, respectively. The core SOI wafer is patterned with hexagonal cells of 100 µm long sides and 10 µm thick walls. Design flexibility is an inherent feature of the integrated process, core and facesheet for the honeycomb may be chosen from a wide range of commercial SOI, and the actuator and mirror are developed independently and subsequently bonded with a polymer. The electrostatically actuated 2D scanner with the bonded honeycomb micromirror has a mirror area of 950 µm x 950 µm and an optical scan angle of ±6°. The reduced mass bonded honeycomb micromirror shows an increase in resonant frequency, 158Hz, over an otherwise equivalent solid bonded micromirror measured at 108Hz.

2:20pm **MM-ThA2 Freestanding Microheater in Si with High Aspect Ratio Microstructures**, ***W.-C. Tian,*** *S.W. Pang,* The University of Michigan

A micromachined gas chromatography system on a chip can be used for environmental monitoring with the advantages of high sensitivity, low power, and portability. To increase sensitivity, a preconcentrator with heating elements and adsorbents is used to adsorb gases and release them at higher concentration to the separation columns. Freestanding, high aspect ratio microstructures in Si are micromachined as preconcentrators. Heat loss to the substrate is minimized by using freestanding heaters to reduce power consumption. A high aspect ratio microheater provides large volume for high adsorbent capacity and hence high sensitivity. Dry etching of Si using etch and passivation cycles has been developed to produce 240 µm thick Si microheaters with 3 µm wide wires, achieving a high aspect ratio of 80:1. This optimized dry etching technology results in high etch rate with vertical profile for thick Si microheaters up to 535 µm. A 400 µm thick Si microheater with 100 µm wide wires, 100 µm gaps, and an area of 9 mm@super 2@ has been fabricated. With the heater on 125 µm thick Si membrane, it takes 850 mW to increase the temperature by 285 °C . The power consumption is reduced to 475 mW for the same temperature raise with freestanding Si microheater. In addition, Si microheaters consist of wires and posts with different conductivity are tested for their heating efficiency. These high aspect ratio, freestanding Si microheaters can provide high power efficiency, large adsorbent capacity, and high mechanical strength as presoncentrators.

2:40pm **MM-ThA3 MEMS and NEMS Physical and Chemical Sensors: Fabrication and Integration**, ***P.G. Datkos,*** Oak Ridge National Laboratory*; T.G. Thundat,* Oak Ridge Natioanl Laboratory*; M.S. Sepaniak,* University of Tennessee **INVITED**

3:40pm **MM-ThA6 Fabrication of Novel Si@sub 3@N@sub 4@ Micromesh Spider Web Bolometer Using Deep Trench Etching on SOI Wafer**, ***M.H. Yun,*** Jet Propulsion Laboratory, Caltech-NASA*; A.M.P. Turner, J.J. Bock, J.A. Podosek,* Jet Propulsion Laboratory

Bolometers are used for sensitive detection of radiation throughout the electromagnetic spectrum, from X-ray to millimeter-wave. The sensitivity of a bolometer can be improved by reducing its base temperature, and reducing its thermal conductivity. Sub-millimeter wave bolometers have achieved a steady increase in sensitivity over the past decade. In this research, we have fabricated and developed extremely sensitive Si@sub 3@N@sub 4@ micromesh spider web bolometers for sub-millimeter astrophysics using microelectromechanical system (MEMS) techniques. The spider-web architecture provides high infrared absorption with minimal heat capacity and volume. We use silicon-on-insulator (SOI) bonded wafers, with a 2 µm of top silicon layer, a 1 µm SiO@sub 2@ insulating layer, and a 350 µm of bottom silicon layer, to fabricate the devices. Using a deep trench reactive ion etching (RIE) from the bottom silicon to the insulating layer, followed by wet etching to remove SiO@sub 2@, a 151-element polygonal spider web array was formed on the 4" SOI wafer. We also observed that the deep trench etching may result in less surface roughness and higher conductivity in the silicon nitride supports. To achieve the best accuracy performance, e-beam lithography is also employed to form contact pad layer. Several Au depositions using photolithography processes form the absorber for optimal infrared absorption, the electrical leads which define the thermal conductance, and the wiring layer for electrical readout. Another silicon wafer is patterned and etched to rest behind the array wafer, forming @lambda@/4 backshorts for maximum optical efficiency. The use of MEMS techniques in this research has improved the sensitivity and format of bolometer arrays. The fabrications of various sub-millimeter device arrays are under development at JPL/Caltech-NASA.

4:00pm **MM-ThA7 Analog Beam Steering Vertical Comb Drive MEMS Actuator**, ***J.J. Fijol,*** Standard MEMS, Inc., US*; J. Prohaska, M. Smith,* Standard MEMS, Inc.*; T. Wester,* ProcessTek, US*; G.W. Tasker,* Standard MEMS, Inc.

The design, modeling, fabrication and characterization of a vertical comb drive actuator are presented. This micro-electro-mechanical device includes a rotating platform supported by two torsion springs and an integrated vertical comb drive actuator. The comb structure was etched into the underside of the rotating platform yielding a compact three-dimensional device. An Au mirror was deposited on the rotating platform and the actuator was used for single axis analog beam steering. The vertical comb design eliminates pull-in, generates large actuation forces (>500 µN) and minimizes the footprint to dimensions approximately equivalent to the size of the mirror (1750 x 2000 µm). Device fabrication required fusion bonding of two wafers; a thick (1000 µm) Si bottom wafer and a top SOI wafer. Deep reactive ion etching (DRIE) was used to etch one half of the comb structure into the substrate wafer and the other half into the handle of the SOI wafer. The mirror platform and torsion hinges were formed in the SOI wafer's device layer using a novel dry release process that eliminated stiction. A matrix of devices were fabricated with varying comb lengths, number of comb fingers and gap spacing (between the upper and lower comb fingers). Devices were operated with a single sided displacement and rotational angles of ~13 degrees were measured for an applied voltage of 200V. Resonant frequency measurements were also performed and the primary resonances were observed between 30 to 200 Hz. Characterization of the mirror surfaces using interferometric microscopy shows the mirror flatness to be better than @lambda@/30 (at @lambda@ = 1550 nm), yielding diffraction limited beam steering.

4:20pm **MM-ThA8 An Integrated MEMS Fabrication Technology Using SU-8 Negative Resists and Conducting Polymers**, ***S. Li,*** *E. Smela, R. Ghodssi,* University of Maryland at College Park

Tall, narrow channels are necessary for many microfluidics applications, and a simple way to fabricate such channels is desirable. In addition, electrodes are frequently required for fluid pumping. Since polymers can be inexpensive, easy to pattern, and modified to be biocompatible, our goal is to make all-polymer microfluidic systems. EPON SU-8 is a light-sensitive epoxy polymer that can be patterned using conventional UV photolithography. We have previously used it to fabricate high aspect ratio microstructures, and in this work we made channels 15-micron wide and 250-micron deep on top of a patterned gold film on a silicon wafer. Surface micromachining was used (rather than, for example, deep reactive ion etching) to achieve deep channels with straight sidewalls in one simple step. For electrodes, we are investigating the use of conducting polymers such as polypyrrole (PPy). Polypyrrole, which has good biocompatibility, was electrochemically deposited onto the patterned gold electrodes in the bottom of the channel. Thus, the microfluidic channels in the SU-8 had patterned PPy electrodes embedded at the bottom. The two plastic-based MEMS technologies were successfully integrated, demonstrating materials and process compatibility. Preliminary results and a detailed fabrication process for combined SU8 and PPy will be presented.

4:40pm **MM-ThA9 Elimination of Defects on Quartz Plate Surface Induced by Deep Drying Etching and Subsequent Quartz Plate Bonding**, ***T. Fukasawa,*** *H. Ogawa, Y. Horiike,* The University of Tokyo, Japan

Two issues were studied for fabrication of a microcapillary on a quartz plate in the Bio-MEMS chip. One is generation of the cone-like defects on the quartz bottom surface which were etched deeply with fluorocarbon plasmas. The other is less tight bonding of a pair of quartz plate which is

performed at 1.3 MPa, RT and 24 hours following dipping them in a 1% HF solution. In the former issue, we noticed that defects were distributed randomly, nevertheless these diameters were almost same. Increasing RF-s elf bias voltage (Vdc) decreased the number of defects. No defect was observed on the quartz surface at high Vdc of 940V, while the masking Cr film was eroded considerably. The results imply that certain masking materials remain on the quartz surface after its finishing, while AFM and XPS measurement of the surface do not reveal the origin of materials at present. Hence, at first high Vdc of 900V added to the sample during 2 min. to remove the mask materials by sputtering, and then Vdc was decreased down to 500V to etch the quartz plate. Eventually, no defects and high etch selectivity to the Cr mask was achieved. For the latter issue, the quartz bonding mechanism was studied employing an in-situ IR-ATR spectroscopy. 10wt % HF solution was introduced between a quartz plate and a trapezoidal Ge prism whose surface was covered by a sputtered grown SiO@sub 2@ film with 70nm thickness. Elapse time dependence of IR absorption spectra was measured under 5 MPa. H@sub 2@SiF@sub 6@ was observed at the interface and this intensity decreased with increasing the pressing time. Thus the bonding mechanism was considered as follows: At first, H@sub 2@SiF@sub 6@ is produced by etching of SiO@sub 2@ in a HF solution, then it changes to SiO@sub 2@ at presence of H@sub 2@O, thereby acting as a paste layer to bind both surfaces. Based on the mechanism, high strength bonding of quartz plates was performed successfully using a H@sub 2@SiF@sub 6@ solution instead of a 1% HF one.

5:00pm **MM-ThA10 Production Plasma Etching of PZT Structures for Piezoelectric Actuators**, ***L.G. Jerde***, *J.P. Almerico, S. Marks, P.F. Werbaneth,* Tegal Corporation

Lead Zirconium Titinate (PZT) is a Perovskite structure dielectric material that is very well suited for piezoelectric actuator applications. The film growth characteristics of PZT and its need for an oxidation barrier effectively limit the choice of electrode materials for the piezoelectric actuator structure to platinum. Neither PZT nor platinum readily form soluble or volatile reaction products. This makes wet etch patterning processes impractical and dry etch patterning processes difficult for PZT based piezoelectric actuator structures. The conventional approach used to pattern these structures utilizes ion milling. The inert ion beam in an ion milling system results in defining the structure by sputter etching material from the exposed surface. The major problem with sputter etching these structures is that the edge of the previously defined PZT layer becomes coated with sputtered Pt atoms during the patterning of the bottom platinum electrode. This results in high leakage currents and limited device performance. We have developed a plasma etch process for photoresist etch masks to eliminate the limitations of ion milling and meet all the production requirements for defining PZT based piezoelectric actuator structures. This process utilizes a patented dual frequency reactor technology, magnetically confined plasma and a combination of feed gases. This technology results in synergistically combining both chemical and sputter etching to successfully meet the requirements for defining PZT based piezoelectric actuators. We shall describe this process and its performance in this paper.

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