MEMS and NEMS
Room: 102 A - Session MN+AS+SS-MoM

Fabrication and Multi-scale Interactions of Materials, Surfaces, and Interfaces at the Micro- and Nano-scale
Moderator: A.V. Sumant, Argonne National Laboratory

8:20am **MN+AS+SS-MoM1 Enhancing Selectivity and Sensitivity of Microfabricated Sensors using Multi-Scale Interactions**, ***T.G. Thundat***, University of Alberta, Canada **INVITED**

Achieving selectivity and sensitivity simultaneously in microfabricated chemical sensors has been a longstanding challenge. Chemical selectivity based on immobilized chemoselective receptors on sensor surfaces fails to achieve speciation in complex environments due to the generality of molecular interactions. However, by incorporating functions which can provide orthogonal signals, it is possible to achieve selectivity, sensitivity, and fast regeneration in miniature sensors. Modulating the physical properties of the surface adsorbed target molecules provides multi-scale information which can be analyzed for molecular recognition. The physical patterning of the sensor surface increases the number of target molecules adsorbed on the surface which results in higher sensitivity. I will discuss recent advances in the integration of multimodal signal generation onto a single platform in microfabricated sensors in order to achieve selectivity, sensitivity, and fast regeneration.

9:00am **MN+AS+SS-MoM3 Meso Scale MEMS Inertial Switch Fabricated using Electroplated Metal on Insulator (MOI) Technique**, *Y. Gerson, D. Schreiber,* Tel Aviv University, Israel, *H. Gerou,* Microsystems Design Center, RAFAEL LTD, ***S. Krylov***, Tel Aviv University, Israel

Micro switches triggered by inertia are widely used as safety and protection devices in airbags, arming and firing systems. These devices are typically fabricated of silicon and incorporate a movable proof mass suspended on flexure-type springs. When a sufficient acceleration is applied, the mass moves towards the fixed electrode resulting in an electrical path that triggers an electric circuit. Electrodeposited metallic devices offer an attractive alternative to silicon in the fabrication of high aspect ratio devices. Nickel is one of the most common materials used for this purpose. The Young's modulus of nickel is close to that of silicon though its density is nearly four times higher and the electric conductivity is five orders of magnitude higher than of highly doped silicon. Nickel is also exceptionally resistant to wet and dry chemical etching, aggressive chemicals and corrosion.

In this work, we report on a novel approach for the fabrication of high aspect ratio electrodeposited nickel MEMS devices. The two mask process is distinguished by its simplicity and does not require formation of anchors/vias for the attachment of the device to the substrate. In this context, similarity between this process and common silicon on insulator (SOI) fabrication paradigm can be mentioned. KMPR negative photoresist is used as a mold due to its ability to yield high aspect ratio structures (>5:1) with vertical sidewalls as well as the relative ease of removal. The devices are fabricated on a 2" single side polished wafers with 4 μm of thermally grown silicon dioxide (TOX). First, a lift-off metallization is performed to define a patterned Cr/Cu seed layer. At the second stage, a 40 μm thick KMPR 1050 negative photoresist is spun on top of the seed layer followed by electrodeposition of a 35 μm thick nickel layer. Next, the stripping of the KMPR mold is performed by ultrasonication bath of remover PG followed by etching with O_2 plasma to remove the resist leftovers. Finally, the wafer is diced into 3mm × 3mm chips and the devices are released first by dipping in a HF to etch the sacrificial oxide and then by etching the copper and chrome. The HF etch time is tailored in such a way that the anchors remain unreleased whereas the free standing elements are released by undercut. The fabricated devices were mounted in a ceramic enclosure and characterized using a drop tester. The triggering event was captured by registered the steep decrease of the resistance down to less than 10 Ω value and functionality of the device was demonstrated in the experiment. Good agreement between the designed values of the triggering time and the experimental data was observed.

9:20am **MN+AS+SS-MoM4 Fabrication and Characterization of Porous Carbon Nanotube Composite Resonators**, ***S. Noyce***, *R.C. Davis, R.R. Vanfleet, D.D. Allred, B.D. Jensen*, Brigham Young University

Porous resonators have the potential to overcome limitations in the micro-resonator field. For example, such structures with high surface area are potentially capable of higher detection limits than solid resonators when used as sensors, due to a higher mass change in a gas or liquid sensing environment. An important consideration for such resonators is the effect of thermo-elastic dampening. We present a versatile micro-resonator fabrication process in which carbon nanotubes are grown from a patterned catalyst, after which the space between the tubes is filled to various degrees of porosity with carbon through Chemical Vapor Deposition. Structural and mechanical characterization data regarding resonators fabricated with this process are presented.

9:40am **MN+AS+SS-MoM5 Fabrication of 3D Nickel Microstructures by Pulsed Electrodeposition on Carbon Coated Carbon Nanotubes**, ***L. Barrett***, *D. Barton, R.C. Davis, R.R. Vanfleet, D.D. Allred*, Brigham Young University

High aspect ratio metallic microstructures have a variety of potential applications in sensing and actuation. However, fabrication remains a challenge. We have fabricated Ni microstructures with aspect ratios greater than 20:1 by electroplating a pattern of carbon coated carbon nanotubes (CNTs). Patterned CNT forests were grown from ethylene by an atmospheric chemical vapor deposition (CVD) at 750ºC followed by a second ethylene CVD step at 900ºC. The second step coats the CNTs and the substrate with a 10nm carbon layer. This coating locks the CNTs together at the points where they touch each other and adheres the CNT forest to the substrate which prevents the forest from deforming or delaminating in the electroplating bath. This carbon coated CNT structure is approximately 95% void space. The void space was then filled with Ni by pulsed electroplating the carbon coated CNTs in a low stress nickel sulfamate bath with a 3ms on time and a 15ms off time. The off time allows the Ni ions to diffuse into the structure to improve uniformity. We will present on the development of the fabrication process and characterization of the resulting C-Ni composite 3D microstructure.

10:00am **MN+AS+SS-MoM6 Dielectric Properties of Electroactive Polymer P(VDF-TrFE-CFE) for Sensor and Actuator Applications**, ***L. Engel***, *S. Kruk, J. Shklovsky, Y. Shacham-Diamand, S. Krylov*, Tel Aviv University, Israel

The rapidly developing field of polymeric electronic and microelectromechanical (MEMS) devices has attracted much attention in recent years. Applications of polymeric MEMS devices include thin film transistors, waveguides for optical sensors, stretchable electronics as well as electroactive polymers (EAP) and dielectric elastomers actuators (DEAs). Polymeric actuators are distinguished by their very low fabrication cost, are often biocompatible, demonstrate large strain under small forces, and exhibit fast response times with relatively large actuation forces and high efficiency. The present work focuses on the integration of the recently developed relaxor ferroelectric polymer poly(vinylidene fluoride-trifluoroethylene-chlorofluoroethylene)(P(VDF-TrFE-CFE)) with MEMS/NEMS. The high electrostrictive strains, low hysteresis, and high dielectric constant exhibited by this polymer make it particularly attractive for device fabrication, however, these properties depend strongly on the dielectric nature of the polymer. Because of the coupling between P(VDF-TrFE-CFE)'s mechanical behavior and electrical properties, it is critical to device design that we fully understand its dielectric behavior in a MEMS capacity.

We report on the patterning and electrical characterization of a terpolymer of composition VF_2 : 61.3% /VF_3 : 29.7%/CFE : 9% at the micron scale. Through the use of micro-capacitor test structures, we explored the dielectric constant of the P(VDF-TrFE-CFE) as a function of temperature, frequency, and different processing conditions. The morphology of the semi-crystalline polymer under different microprocessing techniques was examined using AFM and XRD, providing a correlation between the material properties and electrical behavior of the polymer. At ~57, the dielectric constant at room temperature of this terpolymer is an order of magnitude higher than is typical for polymers, making P(VDF-TrFE-CFE) attractive for MEMS and in particular, organic electronic type sensors.

Acknowledgements

This project was supported by Arkema/Piezotech. P(VDF-TrFE-CFE) materials were supplied by Piezotech S.A.S

10:40am **MN+AS+SS-MoM8 Silicon Carbide Micro-/Nanosystems for Sensing and Energy Applications**, ***R. Maboudian***, *C. Carraro*, UC Berkeley **INVITED**

Silicon has been the dominant semiconducting material in micro-/nanosystems technologies. However, the material and surface properties of silicon impose limitations on its use in applications involving harsh environment (such as high temperature, high radiation and corrosive conditions). Silicon carbide (SiC), a wide bandgap semiconductor, is emerging as a material to address the limitations of Si as it is temperature tolerant, radiation resistant, and chemically inert. In this talk, I will present recent advances, by our group and others, in the materials science and manufacturing technology of SiC thin film and low dimensional structures. This includes deposition, metallization, and fabrication of semiconductor microdevices, with particular emphasis on sensor and energy technologies.

11:20am **MN+AS+SS-MoM10 Development of Through-Silicon via Contacts for Front Side Electrodes in ISFET Sensors**, *A. Erten*, ***S. Park***, *E. Briggs, D. Martin, Y. Takeshita, T. Martz, A.C. Kummel*, University of California San Diego

Ion-Sensitive Field Effective Transistors (ISFETs) are used for measuring the activity and concentration of ions in solutions. ISFETs are modified Metal-Oxide-Semiconductor FET (MOSFET), which utilize changes in the floating potential on the gate insulator to modulate the current between source and drain. When employed as a pH sensor, ISFETs are operated at constant source-drain current by modulating the potential of the solution via a reference electrode of ISFET. The overall potential change at gate is a direct measurement of the solution pH. Adding an additional gold electrode near the gate region of the ISFET allows the total alkalinity to be determined, which has critical applications in oceanography to study ocean acidification as well as temporary variability in the marine CO_2 system. The gold electrode is used to generate protons (H+) which react with the OH-(aq) thereby neutralizing the pH, which is being monitored by the ISFET gate. This has been successfully demonstrated by using a front side contact to the gold electrode. In a simple 0.5 M NaCl solution, the differences in total alkalinity with 1 milimolar precision were measured within 15 second as predicted by simple device models. However, for practical applications, a backside contact to the front side gold electrode is needed so that all the circuitry and wire bonds can be protected from the solution. In this study, a method for fabrication of through-silicon via contacts for front side electrodes in ISFET dies is discussed. To form backside contacts for front side gold electrodes, it requires patterning and deep etching of a chip with an extremely corrugated topology. The ISFET dies already have two backside quasi-through chip vias for backside contact to the source and drain regions, and this non-planar surface obviates the ability of conventional photoresist coating methods to form a uniform film. A new patterning technique was developed for through-chip etching on highly non-planar surfaces using a roll-on photoresist film to overcome the challenges presented by non-planar surfaces. An oxygen plasma was employed to clean the surface and enhance the adhesion between substrate and photoresist film. In comparison with spray coating and spin coating techniques, roll-on photoresist film method showed significantly improved uniformity and adhesion. This method was also employed to protect the substrate from etch plasma. Reactive ion etching was used to etch away oxide layer before gold deposition and Bosch process. Using through-silicon Bosch etching, a via could be made and gold coating could be employed to contact the front side electrode of ISFET.

11:40am **MN+AS+SS-MoM11 A New MEMS-Based Voltage Controlled Variable Capacitor for Gamma Ray Detection**, ***M. Serry***, *A. Sharaf*, The American University in Cairo, Egypt

This paper reports on a new MEMS-based technique for the rapid and highly sensitive detection of gamma irradiation. The proposed sensor detects small doses of gamma photons through changes in the mechanical and electrical properties of the MEMS structure, which consists of a voltage controlled variable capacitor coated with a gamma photons sensitive polymer. Upon exposure to photons, the polymer crystallizes, triggering a coupled effect: increased stiffness in the folded beam suspensions and altered permittivity, which result in measurable shifts in resonance frequency and capacitance. Based on these mutually reinforcing effects, the proposed design is an unprecedented method for multiplying a sensor's sensitivities for more accurate detection of gamma photons. Two preliminary devices have been fabricated and exposed to gamma radiation doses (5-35 kG) using a Co60 source; the results indicate the sensor's elevated sensitivity (1.1 pf/G), which is higher than current state-of-the-art devices. MEMS integrated devices could replace most current conventional radiation sensors, the majority of which rely mainly on one mode of detection alone—lattice defects in single crystal silicon structures that are induced by irradiation. These defects are detected through resistance or capacitance changes. The current techniques, however, have substantial drawbacks: 1) limited sensitivity; 2) high probability of error; and 3) limited efficacy (i.e., one-time usage). To overcome these drawbacks, we introduce selective electro-deposition of gamma photon sensitive polymers on the combs and folded beam suspensions of the sensors. The mechanical design of the structure yields a more responsive sensor with a stronger output signal by coupling changes in mechanical resonance due to increased stiffness with changes in capacitance as a result of alterations in the dielectric constant of the media. Both effects work together to enhance sensitivity as well as increase the accuracy of the measurements. An SOI wafer is etched on to the front and back sides of the sensor to release the shuttle mass and expose the areas that need to be selectively coated by the gamma-sensitive polymer. Preliminary structures have been employed to test the device's response under different gamma-ray dosages using a Co60 source ranging from 5-35 kG. Capacitance voltage characteristics and the loss factor through the dielectric layer versus the applied voltage across the dielectric media have been characterized. A sensitivity of up to 1.1 pF/G can be achieved.

Authors Index

Bold page numbers indicate the presenter