The Science of Micro-Electro-Mechanical Systems Topical Conference
Room 324/325 - Session MM+VT-MoA
Vacuum MEMS and Microanalysis

Moderator: C.C. Wong, Sandia National Laboratories

2:00pm **MM+VT-MoA1 Polysilicon Sealed Vacuum Cavities for MEMS***, **J.D. Zook**, W.R. Herb,* Honeywell*; Y.C. Ahn, H. Guckel,* University of Wisconsin **INVITED**

Sealed vacuum cavities are highly useful in silicon-based micro-electrical-mechanical structures (MEMS). They serve as the reference chambers for absolute pressure sensors and provide enclosures for high-Q mechanical resonators. A process for fabricating sealed vacuum cavities in polysilicon was developed and described by Burns and Guckel in 1988.@footnote1@ The cavities are produced by the sacrificial etching of SiO@sub 2@. The vacuum is generated by the out-diffusion of hydrogen following the polysilicon sealing step. As an additional precaution the devices are coated with silicon nitride. The process was first applied to the fabrication of piezoresistive pressure transducers with a polysilicon diaphragm and a vacuum cavity used as a pressure reference. In 1989 a multi-level polysilicon process was used to fabricate resonant microbeams and to demonstrate that high mechanical Q values require a hard vacuum inside the cavity.@footnote 2@ The micromachined polysilicon resonant microbeams are sensitive strain transducers that provide the basis for temperature, pressure, strain, acceleration and vibration sensors. The polysilicon microbeams are fabricated monolithically on single crystal silicon microstructures, are sealed high vacuum shell enclosures and are characterized by high mechanical Q, typically between 20,000 and 100,000, with recent values as high as 220,000. Two devices have been running continuously for 7 years with no observable change in Q, i.e., no change in the vacuum level. The most recent use of the vacuum encapsulation process has been for fiber optic sensors which combine the advantages of silicon microfabrication with those of optical fiber communication.@footnote 3@ The microbeams are optically excited into resonance by either an optothermal mechanism or a photovoltaic mechanism. They can be driven by modulated light or can be self-resonant. The vibration of the beam modulates the light reflected back into the fiber, which is then detected using a photodetector. Fiber optic sensors also have advantages for aerospace because of their light weight and EMI immunity. A network of 16 optically resonant microbeam temperature sensors driven and read by the same laser was recently demonstrated. Optically driven self-resonant microbeams have been operating continuously for 4 years without measureable change in Q. The most recent demonstration of the vacuum integrity of the polysilicon cavities has been the high temperature operation of the microbeams. Operation up to 510 C for several hours resulted in no loss of vacuum as evidenced by the Q of the resonators after they were returned to room temperature. Thus polysilicon-based vacuum-encapsulated devices are potentially suitable for fiber-optic-based sensors that withstand harsh environments, including high temperature. The value of Q is determined not only by residual gas in the cavity but also by the end losses and by electrical losses induced by the vibrating polysilicon capacitor composed of the microbeam and the bias electrode. By measuring Q as a function of dc bias, the electrical contributions to Q can be subtracted, providing an upper limit on the partial pressure of residual gas in the vacuum cavity. @FootnoteText@ @footnote 1@D. W. Burns, Ph. D. Thesis, Dept. Mat. Sci., UW, Madison, WI (1988). @footnote 2@J. J. Sniegowski, Ph. D. Thesis, Dept. Nuc. Eng. and Eng. Phys., UW, Madiso n,WI (1989). @footnote 3@J. D. Zook, D. W. Burns, W. R. Herb, H. Guckel, J. W. Kang and Y. C. Ahn, S ensors and Actuators A52 (1996) pp. 92-98.

2:40pm **MM+VT-MoA3 Wafer Level Vacuum Packaging for MEMS***, **R.W. Gooch**, T.R. Schimert, W.R. McCardel, B.A. Ritchey,* Raytheon Systems Co.

Many types of MEMS devices require a vacuum environment for operation. Some such as uncooled bolometer IR detectors and imagers, and resonant reed devices require 10 mTorr or lower for optimal performance. Packaging cost associated with traditional materials, packages, and processes needed to achieve the vacuum requirements remains the primary barrier to high volume products. Wafer level vacuum packaging transfers the packaging operation into the wafer fab. It is a product neutral enabling technology for commercialization of MEMS for home, industry, automotive, and environmental monitoring applications. Proof of principle has been demonstrated with bolometer IR detectors on 1- inch piece parts sawed from Si wafers. The lid part contained an etched cavity and was joined to the device part with a solder seal. Less than 10mTorr pressure was measured in a cell volume of 4 cubic mm. A 120x160 IR bolometer array and a resonant reed MEMS device are being designed to be packaged in wafer form using this process. Progress toward these goals will be described. This work is supported in part by DARPA/ ETO, Elias Towe program manager and Al Pisano MEMS program manager.

3:00pm **MM+VT-MoA4 A Dual Sensor Vacuum Gauge: Advanced Micromachined Thin Film Pirani Sensor Combined with a Piezoresistive Sensor***, **D.H. Baker**, R.A. Outlaw,* Teledyne Hastings Instruments*; D. Rosenblatt,* Rosenblatt Associates

A new dual sensor vacuum gauge which employs an advanced thin film micromachined Pirani sensor combined with a B ion implanted Si piezoresistive sensor has been developed. The two sensors are mounted on a single header and welded into a small volume (2 cc), 316 stainless steel envelope which can withstand an over pressure of 1000 psi. The instrument is UHV compatible and can detect pressure from 1000 Torr down to less than 1x10@super -5@ Torr. It is shock resistant, altitude insensitive, and bakeable to 250°C. The gas composition insensitive piezoresistive sensor permits cross over to the gas composition sensitive Pirani, thus establishing the calibration of the Pirani in the gas environment at the crossover pressure. Design criteria leading to the present sensor configurations are discussed. In particular, material selection and heat transfer solutions for the fully contiguous membrane and the various suspended geometric designs are presented. Membrane stress levels characteristic of each design are also discussed. Finally, thermal and electronic noise limitations are considered to establish the ultimate sensitivity of the instrument.

4:00pm **MM+VT-MoA7 The Knudsen Compressor as a Micro and Macroscale Vacuum Pump Without Moving Parts or Fluids***, **S.E. Vargo**, E.P. Muntz, G.R. Shiflett,* University of Southern California*; W.C. Tang,* Jet Propulsion Laboratory

Microelectromechanical systems (MEMS) are rapidly becoming integral components of space missions and are finding an increasing utilization in commercial applications. Several current lander, probe and rover missions under study at NASAs Jet Propulsion Laboratory (JPL) focus on utilizing MEMS based instruments for science data gathering. These small instruments and NASAs new commitment to faster, better, cheaper missions has brought about the need for novel approaches to satisfying mission requirements. For example, a miniaturized mass spectrometer is currently under development at JPL that is designed to provide in-situ gas composition analyses of planetary atmospheres. This device utilizes a micromachined quadrupole array to provide comparable performance to a commercial large-scale unit but with much less mass, power and volume. However, the miniaturized mass spectrometer system lacks a vacuum pump that can meet future mission requirements. One attractive candidate for a vacuum pump is the Knudsen Compressor that is under collaborative development at the University of Southern California (USC) and JPL. The Knudsen Compressor is a vacuum pump that operates on the rarefied gas dynamic phenomenon of thermal transpiration, which is the development of a pressure difference between two volumes of gas via a temperature difference between the ends of small channels joining the volumes. A laboratory-scale Knudsen Compressor has previously been tested at USC@footnote 1@ with its success leading to the design and fabrication of a micromechanical version. This device has two overwhelmingly attractive features over miniaturized or mesoscale vacuum pumps - no moving parts and no fluids. The Knudsen Compressor is applicable in MEMS instruments as well as to larger, more standard pumping applications.@footnote 2@ The paper will include calculations of pumping speed, power usage, size and ultimate pressure for several applications of the Knudsen Compressor. @FootnoteText@ @footnote 1@Vargo, S.E. and Muntz, E.P. (1997): An Evaluation of a Multiple-Stage Micromechanical Knudsen Compressor and Vacuum Pump. In: Rarefied Gas Dynamics, Proceedings of the 20th International Symposium on Rarefied Gas Dynamics, Peking University Press, p995-1000, Beijing. @footnote 2@Pham-Van-Diep, G., Keeley, P., Muntz, E.P., Weaver, D.P. (1995): A Micromechanical Knudsen Compressor. In: J. Harvey and G. Lord Ed. Rarefied Gas Dynamics, Oxford University Press, 715-721.

4:20pm **MM+VT-MoA8 Novel Microvalve with Low Leakage***, M. Hirano*, *K. Yanagisawa,* Nippon Telegraph and Telephone Corporation, Japan*; S. Nakano,* NTT Advanced Technologies Corporation, Japan*; M. Shoji,* Nippon Telegraph and Telephone Corporation, Japan

Microvalve, being capable of precisely controlling fluid flow, is necessary in various industrial fields such as chemical analysis. This paper reports the novel microvalve with very low leakage, which was fabricated by silicon micromachining techniques. The valve is a micromachine constructed on a silicon substrate chip, and it uses a valve cap supported by a suspension spring and a valve seat with a 50-µmm-diameter bore to control fluid flow. Normally closed valve is obtained by applying compressive stress to the suspension spring @footnote 1@. Piezoelectric actuator bends the suspension spring, resulting in opening and closing the valve. The silicon substrate chip, on which the microvalve was fabricated, was suitably mounted on the specially designed holder, to which inlet and outlet lines are connected. The leak or flow conductance of the microvalve was precisely determined by measuring the pressure change in the gas flow system designed for precisely determining the leak and flow rate @footnote 2@. The measurements show that the valve has a very low leak rate of 5.8 x 10@super -10@ Pam@super 3@/s. This reduced leakage was due to tight contact between the cap and seat, which was obtained by nanometer-scale flat valve surfaces and self-alignment of the cap and seat-bore based on the fabrication techniques we have developed @footnote 1@. It is concluded that the flat surfaces result from the flat substrate of the sacrificial SiO@sub 2@ film deposited by RF magnetron sputtering, and from the homogeneous dry-etching at our amorphous surfaces by ion-beam milling. @FootnoteText@ @footnote 1@ K. Yanagisawa, H. Kuwano, and A. Tago, Microsystem Technologies 2. 22 (1995). @footnote 2@ M. Hirano, K. Yanagisawa, H. Kuwano, and S. Nakano, Trans. IEE of Japan 117-E, 622 (1997).

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