The Science of Micro-Electro-Mechanical Systems Topical Conference
Room 620 - Session MM+VT-ThA
Vacuum MEMS

Moderator: C.C. Wong, Sandia National Laboratories

2:40pm **MM+VT-ThA3 Quadrupole Mass Spectrometry using MEMS***, S. Taylor,* University of Liverpool, U.K., UK **INVITED**

Quadrupole Mass Spectrometers (QMS) find a wide range of applications worldwide. The conventional QMS arrangement uses circular metallic rods as the mass filter excited electrically at voltages up to 1kV depending upon the application. If the size and voltages can be reduced then the range of applications for QMS instruments would increase. The application of MEMS technology allows the fabrication of submillimetre versions of such structures. In this paper the development of a miniature QMS is reported in which the conventional rod arrangement has been replaced with a microengineered version. The structure is made in silicon with metallised specially drawn glass fibres of length 20-30 mm and diameter 0.5 mm to act as the quadrupole rods. The correct electrode spacing and alignment are achieved through the use of V-shaped grooves etched into the silicon. This is about one order of magnitude smaller than most conventional QMS filters, with the potential for further reduction in size. The MEMS mass filter was mounted onto a commercial ion source, which was in turn attached to a vacuum flange and supplied by an electronic drive circuit modified to run at 6MHz. Mass spectra in the range 0-50 a.m.u were obtained and these were simulated numerically. The results indicate a linear mass scale with 5-10% valley separation between O2/N2 peaks and a best resolution at 10% peak height of around 2 a.m.u at mass 40. Reliable QMS operation was obtained up to pressures in the 1E-4 to 1E-3 mbar range and the highest operating pressure was felt to be a limitation of the ion source, rather than the mass filter.

3:20pm **MM+VT-ThA5 Miniaturizing an Ultra-High Vacuum Orbitron Pump***, **J.Z. Wilcox**, J. Feldman, T. George,* JPL-Caltech*; M. Wilcox, A. Scherer,* Caltech

NASA has identified the development of miniature vacuum pumps as a key future technology need. Miniature pumps will be needed for miniature instrument applications such as mass spectrometers and electron microscopes. Traditional pumps cannot be flown on microspacecraft due to their size, mass, and power requirements. This talk will discuss a novel approach towards the miniaturization of a particular type of high vacuum pump, known as the "Orbitron" pump. The Orbitron pump is an ion-getter pump that does not require magnetic confinement of the ionizing electrons. The purely electrostatic operation, coupled with a novel ring anode design under the development at JPL, enables miniaturization of the orbitron pump to sub-centimeter dimensions, and in addition may allow integration with instruments for in situ planetary exploration such as the Atmospheric Electron X-ray Spectrometer. The pumping action of the Orbitron pump is based on ionization of gas molecules by externally injected electrons which are trapped into stable helical orbits in a cylindrically symmetric electrostatic field around a positively charged anode. The ionized molecules are accelerated to the cathode and embedded in the surrounding collector. However, the conventional linear anode design does not lend itself to miniaturization very well since a minimum length of anode is required to establish stable orbits. The end losses are circumvented in the ring anode design, and in addition the "planar" geometry of the ring orbitron lends itself to miniaturization as well as ease in interfacing with other micro-instruments such as mass spectrometers, electron microprobes and electron microscopes. The goal of our effort has been to verify the feasibility and scalability of the proposed pump design. We will discuss the results of the validation experiments and modeling, impact on scaling to sub-centimeter dimensions, and compare the results with similar results for the linear anode orbitron.

3:40pm **MM+VT-ThA6 Scaling and Microfabricating a Low-Pressure Inductively Coupled Plasma Source***, Y. Yin, **J. Hopwood,*** Northeastern University

Plasmas are commonly used in many large-scale systems. For example, chemical analysis using optical emission spectroscopy relies on gaseous plasmas to electronically excite the sample. Plasmas are also used as sources of radicals and ions for materials modification and for ion propulsion. In this presentation we will describe the miniaturization of plasma sources to dimensions that are compatible with MEMS. One of the most robust methods of generating a plasma is by inductively coupling an rf field to a low-pressure gas. Inductively coupled plasmas (ICPs) can operate for extended periods in reactive gas environments because ICPs are electrodeless. In addition, the geometry of the impressed rf field creates a high density of electrons with relatively low power consumption. A large-scale planar ICP uses a 10 to 30-cm spiral-shaped coil adjacent to a dielectric vacuum window; this geometry is particularly well-suited to microfabrication as the source is scaled down to dimensions the order of 1 mm. The scaling laws associated with miniaturization have been experimentally investigated in terms of optimum frequency of operation and gas pressure. In addition, the effects of scaling the dimensions on plasma properties such as electron temperature and electron density are also measured and modeled. The decreased dimensions of the coil reduces the inductance of the coil and necessitates a higher frequency of operation. Large scale ICPs typically operate at 13.56 MHz, but 5 mm ICPs function most efficiently at 300-400 MHz. Of particular importance is fabricating a coil with a high quality factor (Q) at the operating frequency. The optimum pressure for initiating the plasma is found to scale with the operating frequency such that the electron-neutral collision frequency equals the power supply frequency. Finally, the plasma sheath, or dark space, does not scale with the source dimensions. This appears to set a lower limit on the physical dimensions of the plasma source.

4:00pm **MM+VT-ThA7 Design and Fabrication of an Electromagnetically Driven Microvalve for Micro Total Analysis Systems***, **M. Shoji**, K. Yanagisawa, M. Hirano,* Nippon Telegraph and Telephone Corporation, Japan*; S. Nakano,* NTT Advanced Technologies Corporation, Japan

Microvalves that control fluid flow over a wide flow rate range, and that are compactly assembled, are in great demand for µTAS, such as micro gas chromatographs. This paper reports on design considerations concerning the electromagnetic actuation and the fabrication of a microvalve that operates at a pressure difference of more than 1 x 10@super 5@ Pa with very low leakage. The valve is fabricated using silicon micromachining techniques.@footnote1,2@ The target specifications are a maximum flow rate of 10@super -1@ Pa m@super3@ s@super -1@, a leak rate of 10@super -9@ Pa m@super 3@ s@super -1@, a maximum power consumption of less than 0.1 W at a pressure difference of 10@super 5@ Pa, and a size of 4 x 4 x 2 mm including the actuation unit. The microvalve has a disk-shaped 1-µm-thick cap with a diameter of 100 µm. Actuation of the valve requires a force of more than 1.5 mN perpendicular to the surface of the cap and a stroke of 5-10 µm. To achieve this actuation, ferromagnetic material is deposited (electroplated) onto the cap and an electromagnet (1.3 x 1.5 x 3.2 mm) is set above the cap to generate an attractive force on the ferromagnetic material. The design parameters were determined by three-dimensional numerical analysis that took account of the nonlinear B-H curves of magnetic materials. When the deposited material was Ni with a thickness of 100 µm, and the distance from the Ni to the magnet was 20 µm, a sufficient force was attained if the formed Ni area was several times larger than the cap area. The analysis also showed that using materials with a higher saturation magnetization than Ni would increase the force, thus enabling the valve to work at a higher pressure difference. The effects of such materials will also be reported. @FootnoteText@ @footnote1@K. Yanagisawa, H. Kuwano, and A. Tago, Microsystem Technologies 2, 22 (1995). @footnote2@M. Hirano, K. Yanagisawa, H. Kuwano, and S. Nakano, Proc. IEEE Micro Electro Mechanical Systems, p. 323 (1997).

4:20pm **MM+VT-ThA8 MEMS Micro-Valve for Space Applications***, **I. Chakraborty**, W.C. Tang, D.P. Bame, T.K. Tang,* Jet Propulsion Laboratory

We report on the development of a Micro-Electro-Mechanical (MEMS) valve that is designed to meet the rigorous performance requirements for a variety of space applications, such as micro-propulsion, in-situ chemical analysis of other planets, or micro-fluidics experiments in micro-gravity. These systems often require very small yet reliable silicon valves with extremely low leak rates and long shelf lives. Also, they must survive the perils of space travel, which include unstoppable radiation, monumental shock and vibration forces, extreme variations in temperature. Currently, no commercial MEMS valve meets these requirements. We at JPL have developed a piezoelectric MEMS valve which attempts to address the unique problem of space. We begin with proven configurations which may seem familiar. However, we have implemented some major design innovations which should produce a superior valve. The JPL micro-valve is expected to have an extremely low leak rate, little susceptibility to shock, vibration or radiation, as well as a wide operational temperature range.

4:40pm **MM+VT-ThA9 Compact Fiber-Optic Pressure Sensors Using Microfabricated Sensing Membranes***, **Y.C. Cho**,* NASA Ames Research Center*; T. George, J. Tamayo,* Jet Propulsion Laboratory

Fiber optic sensors are inherently immune to electromagnetic noise, and are very sensitive, light weight, and highly flexible. A prototype optically-detected pressure sensor was successfully designed, assembled and tested. The sensing technique employed was fiber- optic Fabry-Perot interferometry. The sensing head is composed of an optical fiber terminated in a miniature ferrule with a thin, silicon-microfabricated diaphragm mounted on it. The optical fiber is a single mode fiber with a core diameter of 8 microns, with the cleaved end positioned 50 microns from the diaphragm surface. The diaphragm is made up of a 1.5 mm square, 0.2 mm thick silicon nitride membrane whose inner surface is metallized with layers of 30 nm titanium, 30 nm platinum, and 200 nm gold for efficient reflection. The measured differential pressure tolerance of this diaphragm is more than 1 bar, yielding a dynamic range of more than 100 dB. Preliminary tests have demonstrated excellent performance for this sensor. Sensitivity measurements of the sensor were compared with that for a 3 mm diameter B&K microphone and were found to be 2 to 4 dB better than the B&K microphone. This sensitivity is better than any existing fiber optic pressure sensor by at least three orders of magnitude. The frequency response of the fiber-optic microphone was steady and uniform within the 100 to 5,000 Hertz design frequency. The compact size and light weight of these sensors gives them several advantages. For measurement of air flows over flight surfaces, the flow-sensor interaction is smaller, providing more accurate measurements of dynamic pressure. Additionally, their small size could allow these sensors to be placed non-destructively on flight surfaces in contrast to present techniques. The fiber optic microphone also has the added advantage of high temperature tolerance, and a solid state preamplifier as in the case of the condenser microphone is not required.

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