A Piezoelectric Microvalve for Micropropulsions

Eui-Hyeok Yang

MEMS Technology Group, In Situ Technology and Experiments Systems Section, M/S 302-306
Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109
Eui-Hyeok.Yang@jpl.nasa.gov ph: +1-818-354-7059 fx: +1-818-393-6047

MEMS technology is well suited for space applications. Reductions in mass and size of a space instrument result in nearly exponential savings in launch costs. A microvalve for micropropulsion applications requires a low leak rate of 0.005 sccm at a gas propellant pressure of up to 3000 psia, and a response time of 1~10ms within 1 W [1]. Typical micro valves are generally well within the requisite power consumption and mass requirements. However, they do not meet the requirements for pressure range [2-4], response time [5], or leak rate [6]. The Moog, Inc has developed microvalves for micropropulsions, but they need 4 Watts to open the valve [1]. Significant effort is needed for the development of microvalves to meet the micropropulsion requirements. Therefore, this abstract reports the fabrication and high-pressure test of a piezoelectrically-actuated, normally-closed, low leak valve.

The valve consists of a seat plate, a boss plate and an actuator (Figs. 1 and 2). In order to accommodate high pressures, the valve components do not contain fragile membranes. A series of 10 μm high, 1μm wide rings is fabricated on the seat plate (See Fig. 3). The piezoelectric stack has the separated active zones (Fig. 4). Application of a voltage (~50V) to the stack causes the active zones to vertically expand by 5 μm, lifting the boss center plate (bonded to the inactive zone in the center part of the stack) away from the seat plate. This action creates a channel between the two openings, allowing for the passage of fluids. Subsequently, a negative voltage (-10V) needs to be applied to the stack in order to *tightly* close the valve. Since the piezoelectric element is essentially a stacked capacitor, the actuator does not consume power when not moving, thus making it possible to achieve a zero-power, normally-closed valve system.

The fabricated valve components are bonded to stainless steel fixtures, sealed using an epoxy (Hysol E/A 9394, cured at room temperature) for flow tests at high pressures (Fig. 5). The leak test for a non-actuated valve revealed an extremely low leak rate (0.001 sccm or undetectable) at 100 ~ 1000 psig (Fig. 6). Fig. 7 depicts the nitrogen flow rates of a valve actuated with pulse width modulation at several operating frequencies (from 10Hz to 1kHz). Incorporating a smaller piezoelectric actuator in 2nd generation design will significantly miniaturize this interim design. The leak in the low-pressure regime (max. rate of 1.9 sccm at 20 psig) can be reduced by adding a check valve in the system (Fig. 8). This valve can also be used for other micro fluidics applications including JPL's LIGA gas chromatography, mass spectrometer, micro fuel cell, and bioreactor CO2 scrubber.

References

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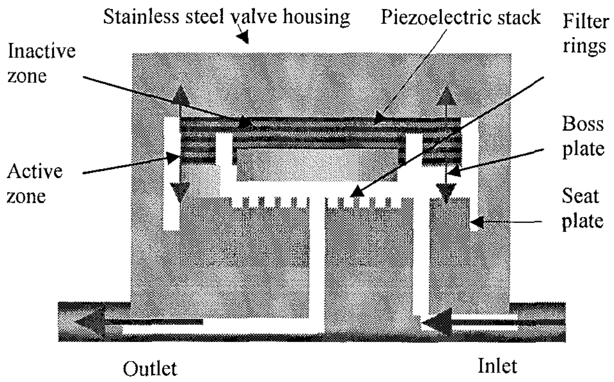
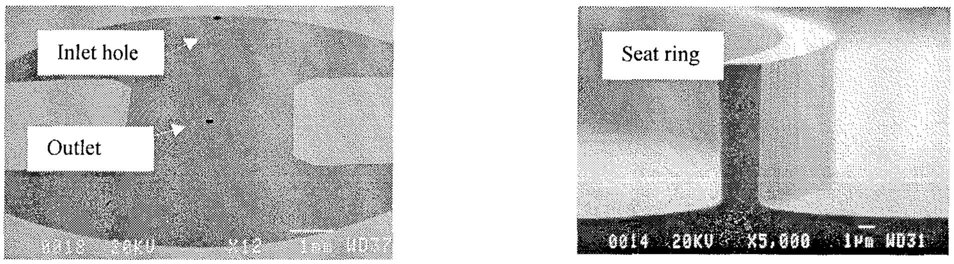


Fig. 1 The high pressure piezoelectric valve concept. The normally-closed valve is opened by a piezoelectric stack actuator. High pressure handling capability is provided by having a robust actuator construction within a rigid valve housing.



(a) (b)

Fig. 2 The SEM photographs of the fabricated valve components. This interim design is to demonstrate the operations at high pressures. *Overall size of the seat and boss plates will be significantly reduced in 2nd generation valve design, which will appear in the full paper.*

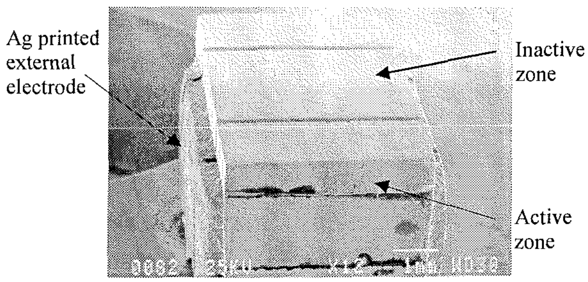
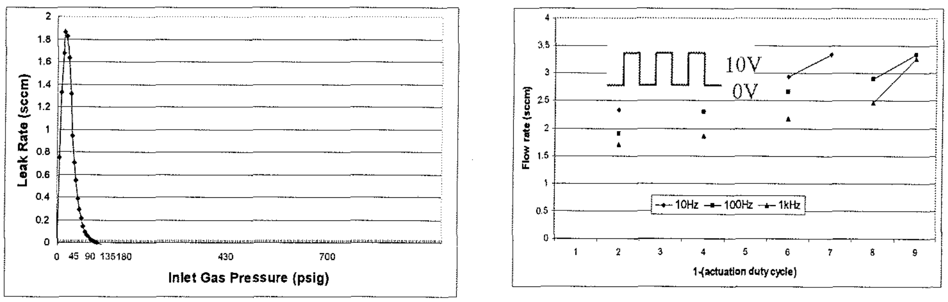


Fig. 3 The bottom view of a custom designed piezoelectric stack with mechanically separated active zones. The active zones ($5x2x5mm^3$) vertically expand by 5 μm at 50V moving the boss center plate bonded to the inactive central zone away from the seat plate, allowing the passage of fluids. Smaller piezoelectric actuator design is under development in order to miniaturize the micro valve system.



(a) (b)

Fig.4 (a) The measured internal leak rate of a non-actuated valve. The leak is undetectable (< 0.001 sccm) at inlet pressures of 100~1000 psig. The leak is reduced at higher pressures, since the inlet flow enhances the seating pressure to provide tighter seating at higher pressures. (b) The measured flow rates for a fabricated valve actuated in pulse width modulation at several operating frequencies at 20psig. A voltage of –10V needs to be applied when closed in order to reduce the leak flows. (described in the full paper.)