National Aeronautics and Space Administration

Robust Microvalve for Lab-on-a-Chip Microfluidics

Principal Investigator: Risaku Toda (389); Co-Investigators: Nathan Oborny (389)

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Objective

To build and test a new generation of MEMS microvalve for handling liquids in JPL's lab-on-a-chip instruments. The microvalves will be embedded in a microfluidic chip to improve instrument sensitivity by reducing dead volume. The integrated microvalve also contributes to SWaP (size, weight and power) improvement in the microfluidic instruments.

Background

The manipulation of liquid flow within small volume microfluidic devices can be challenging. **Many systems that advertise as microfluidic end up requiring large external pumps and valves to operate.** The size and mass of the required supporting equipment can limit the use of microfluidics in flight.

Currently, JPL lab-on-a-chip instruments such as **"Chemical Laptop"** and **Ocean Worlds Life Surveyor (OWLS)** systems use COTS solenoid microvalves such as those from the Lee company. The solenoid valves have the benefit over pressure actuated valves in that they do not consume large quantities of gas during operation, making them better suited for space flight. However, these solenoid valves are discrete components that needs to be individually connected to the microfluidic channel by tubing and fittings, resulting in increased dead volumes and compromised instrument sensitivity.

Significance/Benefits to JPL and NASA

In this task, we have successfully fabricated and tested a proof-of-principle microvalve chip for lab-on-a-chip microfluidic applications.

The new microvalve design offer:

- **Minimized dead volume** by eliminating external solenoid valve and tubing
- **Sensitivity enhancement** by minimizing the dead volume
- **Smaller system size and weight** by microvalve integration and elimination of pneumatic gas reservoir, pumps and valves etc.
- **Improved power efficiency** by using piezoelectric actuator

This microvalve design/concept could be useful as a new building block for NASA/JPL's planetary lab-on-a-chip instruments.

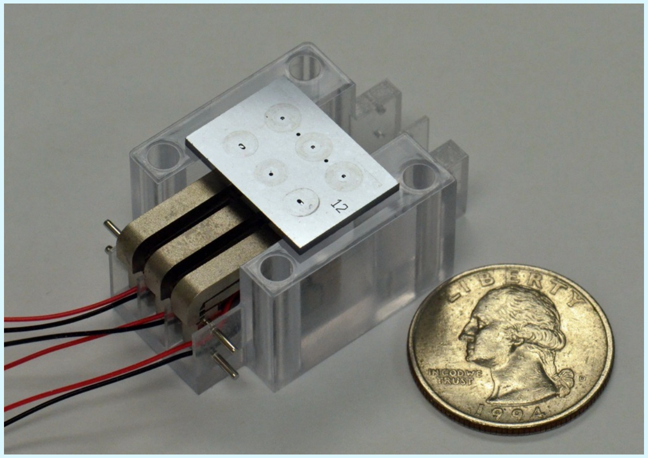

Figure 1. Microvalve assembly consisting of microvalve chip (21 mm x 15 mm), 3-D printed frame and piezoelectric flexure actuators. There are five microvalves embedded in this chip, of which three valves have fluidic channel for flow test.

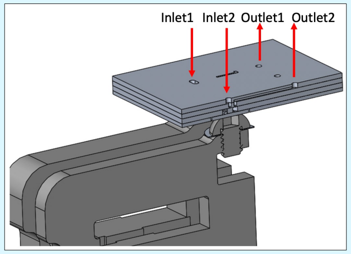

Figure 2. Cut-away view of microvalve assembly. A screw head mounted to the piezo actuator arm pushes the push-plate to exert force on membrane. 3-DOF positioning error of piezo actuators are adjusted or absorbed by shims and the push-plate mechanism.

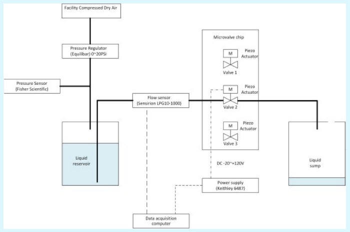

Figure 3. Flow test setup. Compressed air (regulated 0~20 PSI) pushes test liquid through a flow sensor and the microvalve chip.

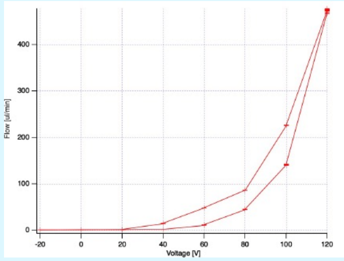

Figure 4. Water flow test result. Water inlet pressure 16psi.

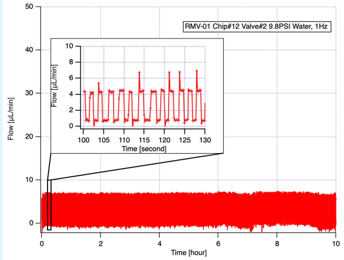

Figure 5. 10 hour flow test (ON-OFF) at 1Hz. 36,000 cycles. Water inlet pressure 9.8psi.

Approach and Results

Our approach is to quickly build and test a set of microvalve based on previously reported JPL technology concept [NTR 51670 "Robust microvalve using external actuator, R. Toda et. al. 2020]. This technology include following features:

- **Use external COTS piezoelectric actuator and its very strong force** (>1N) to actuate valves in silicon microfluidics. The strong force can overcome capillary force, viscosity and surface stiction inherent in liquid flow.
- **Unique mechanism to absorb and adjust 3-DOF positioning error of piezo actuators**. This is necessary to interface macroscopic actuator with microscopic MEMS elements.

For this spontaneous RT&D task the existing photomask design was modified and the chip was quickly fabricated at JPL's Microdevices laboratory (MDL) cleanroom. The fabrication involved four silicon wafer layers and more than 15 photolithography steps. The four wafers are bonded and diced into individual chips.

Figure 4 shows a test result for deionized water flow at 16 PSI. By varying DC voltage applied to the piezo actuator, the water flow varied accordingly. As expected, some hysteresis behavior was observed in the water flow. This hysteresis behavior is inherent in the piezoelectric actuators. Once the voltage is fixed, the water flow rate became very stable. Therefore, these microvalves may be usable not only for open/shut but also for flow rate regulation applications.

We also tested following solvents typically used in JPL lab-on-a-chip instruments and confirmed microvalve functionality:
- Acetonitrile
- Ethanol 70% / Water 30% mixture
- Methanol

Figure 5 shows an overnight flow test result with 9.8PSI water. The microvalve was cycled at 1Hz for 10 hours (36,000 switching operations) successfully.

Acknowledgements

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National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

PI/Task Mgr Contact
Email: Risaku.Toda@jpl.nasa.gov

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