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On

IMPROVED PIEZOELECTRICALLY ACTUATED MICROVALVE

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JPL NEW TECHNOLOGY REPORT NPO− 30158

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Improved Piezoelectrically Actuated Microvalve

The improvements are intended to ensure less leakage and true normally-closed operation.

NASA's Jet Propulsion Laboratory, Pasadena, California

Efforts are underway to implement an improved design of the device described in "Normally Closed, Piezoelectrically Actuated Microvalve" (NPO-20782), *NASA Tech Briefs*, Vol. 25, No. 1 (January 2001), page 39. To recapitulate: This valve is being developed as a prototype of valves in microfluidic systems and other microelectromechanical systems (MEMS). The version of the valve reported in the cited previous article (see Figure 1) included a base (which contained a seat, an inlet, and an outlet), a diaphragm, and an actuator. With the exception of the actuator, the parts were micromachined from silicon. The actuator consisted of a stack of piezoelectric disks in a rigid housing. To make the diaphragm apply a large sealing force on the inlet and outlet, the piezoelectric stack was compressed into a slightly contracted condition during assembly of the valve. Application of a voltage across the stack caused the stack to contract into an even more compressed condition, lifting the diaphragm away from the seat, thereby creating a narrow channel between the inlet and outlet.

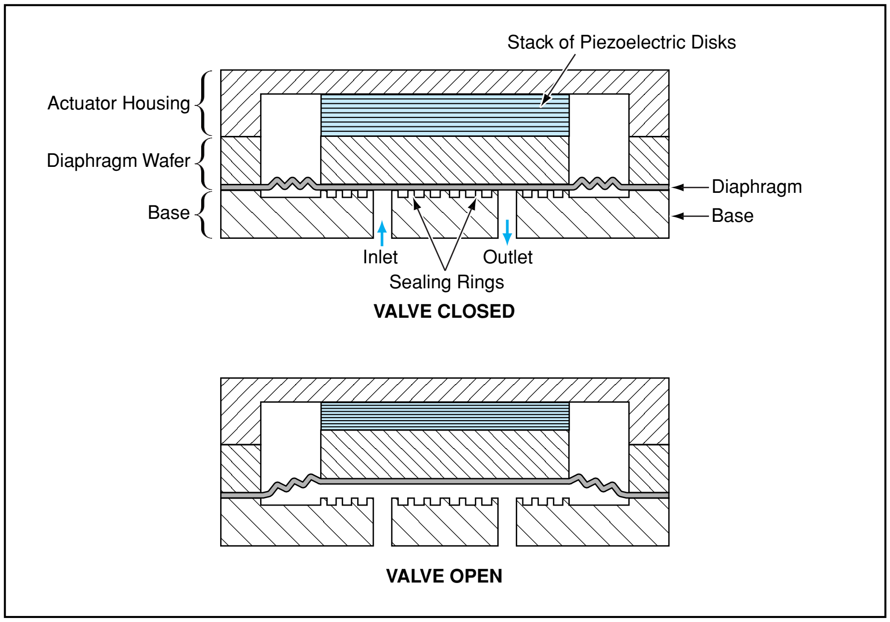

Figure 1. The **Previous Version of the Valve**, like the present version, was opened by applying a voltage that caused the piezoelectric actuator to contract slightly.

The improvements are being pursued because of the following deficiencies of the previous version of the valve:

- The valve-seat design was marginal in that dirt particles easily became stuck between the diaphragm and the tops of sealing rings, contributing to leakage.
- By virtue of the placement of the inlet orifice under the actuator, the inlet flow and pressure opposed the sealing force, thereby reducing the ability to seal against high pressure with low leakage.
- The piezoelectric actuator stack could not be machined as precisely as could the silicon parts. As a consequence, if the valve cap (the item designated the actuator housing in Figure 1) was flexible and the piezoelectric stack was thicker than the actuator housing, then the valve could not be actively opened. If the piezoelectric stack was thinner than the actuator housing, then the valve would always be open.

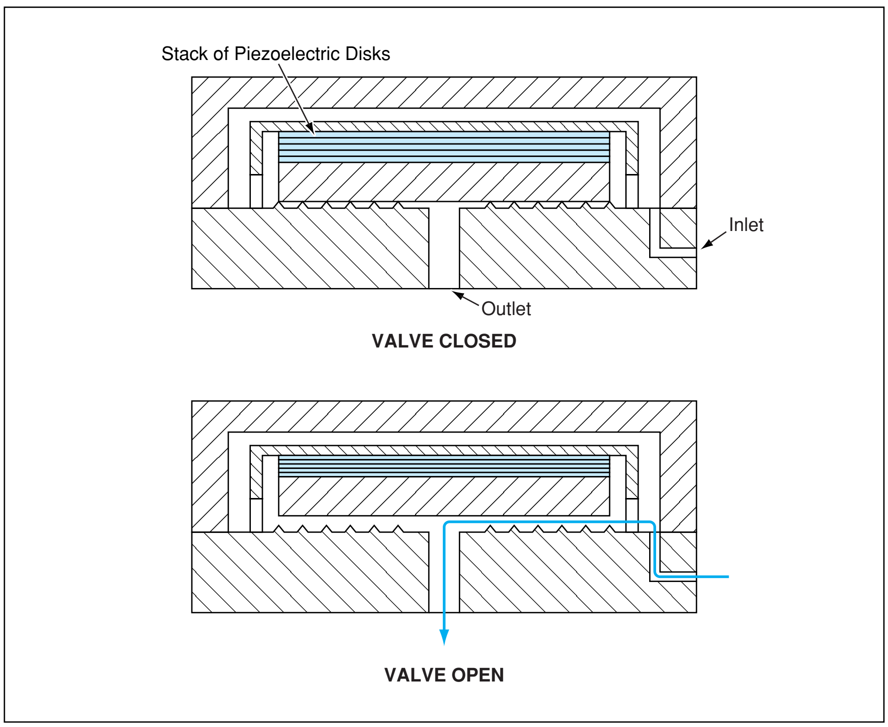

Figure 2. The **Present Version of the Valve** features a pressure-aided-sealing design and other improvements intended to overcome the deficiencies of the previous version.

Figure 2 depicts some aspects of the improved version of the valve. The inlet is repositioned from the previous version, such that now the inlet flow and pressure contribute to sealing and thus to the desired normally-closed mode of operation. The piezoelectric actuator stack, and the cap have been redesigned to conform to this pressure-aided-sealing design. The valve seat has been redesigned to replace the former blunt-cross-section sealing rings with knife-edge sealing rings that would be less susceptible to trapping of particles between the rings and the diaphragm. The micromachined parts of the improved design are assembled by room-temperature indium hermetic bonding.

This work was done by Eui-Hyeok Yang and David Bame of Caltech for **NASA's Jet Propulsion Laboratory**.
NPO-30158

NTR INVENTOR'S REPORT
NTR: 30158

PLEASE BE AS CLEAR AND SPECIFIC AS POSSIBLE, AS THIS REPORT MAY BE MADE AVAILABLE THROUGH TECH BRIEFS

Section 1 (Novelty), 2A (Problem), and 2B (Solution) must be completely fully. Your published paper may be attached to satisfy Section 2C (Description and Explanation).

1. Novelty-Describe what is new and different about your work and its improvements over the prior art.

   Typical commercial-off-the-shelf (COTS) MEMS valves do not address many of the issues listed above and are not generally designed for the space environment. They often employ thermal actuation, which requires tight control of ambient temperature and does not supply the sealing force required for a truly low leak rate. Some miniature valves use magnetic actuation, similar to the solenoids found in their larger cousins. Unfortunately, the coil is a three dimensional structure difficult to reproduce in a planar technology such as MEMS. Also magnetic force density does not scale well with a reduction in size.

   The novelty of the new valve concept includes the normally closed sealing enhanced feature as shown in Fig. 2, custom designed piezoelectric actuator for the partial actuation of the piezoelectric stack as shown in Fig. 3, low temperature indium hermetic bonding, and the new valve seat design. The seat filter design is currently under development.

2. Technical Disclosure

   A. Problem-Motivation that led to development or problem that was solved.

   Micro fluidic MEMS systems are currently being investigated for space applications, such as micro propulsion and miniature chemistry labs. All these systems will need valves for sealing and/or flow control. For the reasons stated above, many COTS valves do not fit the job. Also, The previous JPL MEMS valve design is relatively rudimentary and does not provide high sealing pressure due to its design problems as shown in Fig. 1.

   B. Solution

   We have chosen to pursue the development of a MEMS valve in house. This valve will use piezoelectric stack actuation for a superior force density, which should lead to lower leak rates. Also, particular attention is being paid to contamination and keeping them away from sealing surface.

   C. Detailed Description and Explanation

   The valve provides flow control for a wide variety of micro fluidic systems. Micro fluidic MEMS commonly target applications where a precise amount of a fluid is required. This includes aerospace technologies such as micro thrusters for micro spacecraft, medical technologies such as miniature dosing systems, semiconductor manufacturing technologies which require tightly controlled of process chemical flow, and biological and environmental monitoring systems. This valve would also be of enormous benefits to NASA. They are vital to many micro propulsion schemes currently under investigation, as well as some proposed miniature chemical labs. Miniature chemical labs are also of interest to the Department of Defense for biological and chemical weapons detection.

All typical valve devices are thermopneumatically actuated and are not suited for space applications. Several companies such as Moog and the Lee Company make very small valves using traditional machining techniques. Also, there are commercially available miniature valves which can compete with MEMS valves. These typical commercial-off-the-shelf (COTS) MEMS valves do not address many of the issues listed above and are not generally designed for the space environment. They often employ thermal actuation, which requires tight control of ambient temperature and does not supply the sealing force required for a truly low leak rate. Some miniature valves use magnetic actuation, similar to the solenoids found in their larger cousins. Unfortunately, the coil is a three dimensional structure difficult to reproduce in a planar technology such as MEMS. Also magnetic force density does not scale well with a reduction in size. Micro fluidic MEMS systems are currently being investigated for space applications, such as micro propulsion and miniature chemistry labs. All these systems will need valves for sealing and/or flow control. For the reasons stated above, many COTS valves do not fit the job. The valve proposed in this new technology report will use a piezoelectric stack for actuation. We have chosen to pursue the development of a MEMS valve in house. This valve will use piezoelectric stack actuation for a superior force density, which should lead to lower leak rates. Also, particular attention is being paid to contamination and keeping them away from sealing surface. Although there was a MEMS valve with piezoelectric stack for actuation developed at JPL (NPO-20782/0374b), this version could not provide normally closed sealing scheme. The followings are the problems of the valve design of NPO-20782.

(1) In fig. 1 (a), the valve seat design is marginal, so that dirt particles can easily be stuck in between the top of the seat and the actuator boss, making leak rate higher over time. This must be changed as shown in Fig. 2.
(2) In fig. 1 (b), the inlet orifice is not in the right position. In this design, the inlet orifice is under the valve actuator boss, so that the inlet flow direction is against the sealing force. The will reduce the sealing force, so that the valve can not provide high pressure and low leak actuation.
(3) The piezoelectric stack actuator cannot be machined as precisely as silicon. In fig. 1 (c) and (d), if the valve cap is flexible and the piezoelectric stack is thicker than the actuator die, the valve cannot be actively opened. If the piezoelectric stack is thinner than the actuator die, the valve is always opened; This is not a valve.

The novelty of the new valve concept includes the normally closed sealing enhanced feature as shown in Fig. 2, custom designed piezoelectric actuator for the partial actuation of the piezoelectric stack as shown in Fig. 3, low temperature indium hermetic bonding, and the new valve seat design. The detailed seat filter design is currently under development. Since the inlet pressure can enhance the sealing pressure, it can provide high sealing force if the actuator force is strong enough. The valve needs to open under the pressure of 3000 psia (about 20kPa) and the actuator can produce 50Mpa, which is more than enough. Currently, we are working on the custom design of the piezoelectric stack actuators. The piezoelectric stack will be bonded by using the room temperature indium bonding technique. Figs. 4 and 5 show the fabrication sequence of the valve device.

***References**

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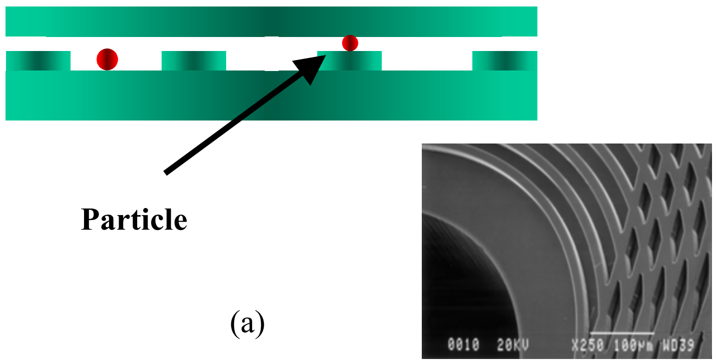
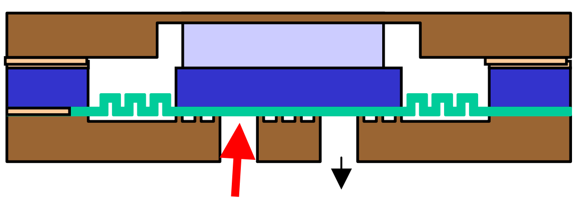
Concerns with the past JPL MEMS valve design

- **Marginal valve seat design**



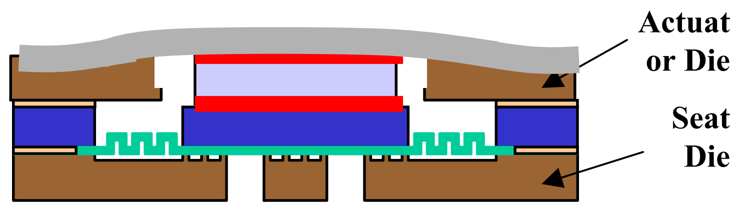
(a)

- **Flow against sealing force**



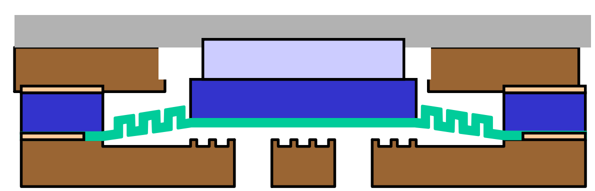
(b)

- **The valve may not actively open when the piezostack is thicker.**



(c)

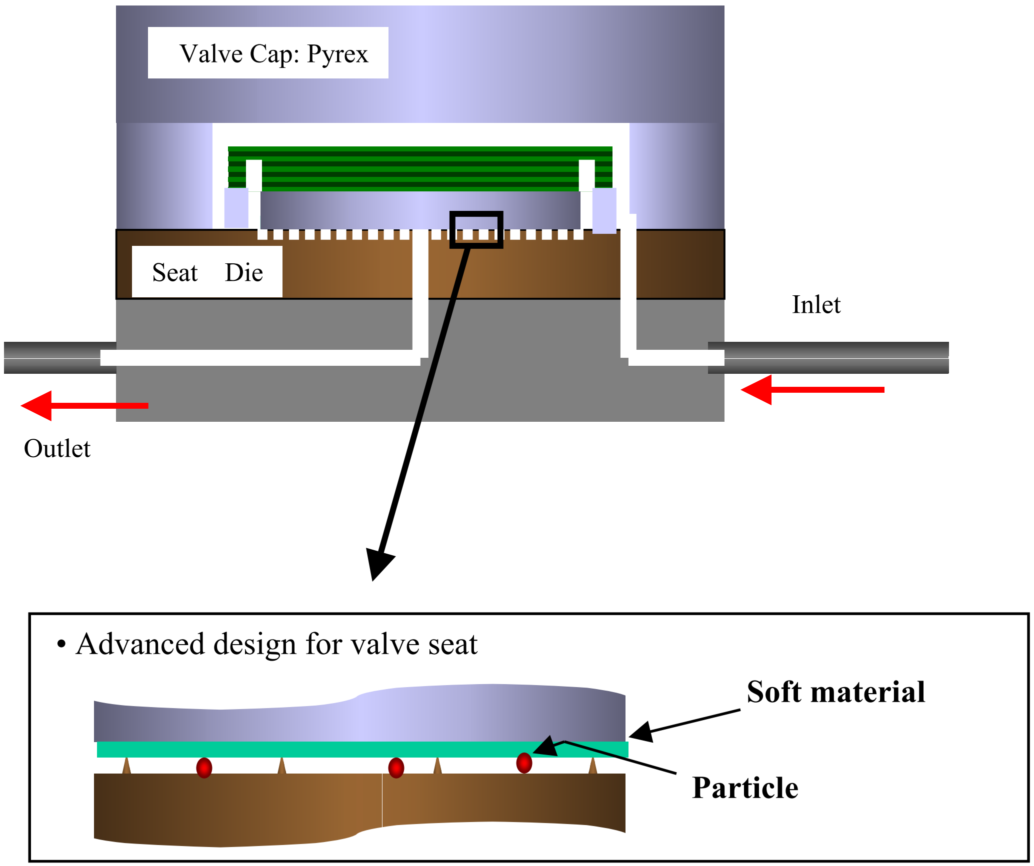
The valve may be normally opened when the piezostack is thinner.



(d)

Fig. 1

NEW DESIGN: Normally Closed MEMS Valve

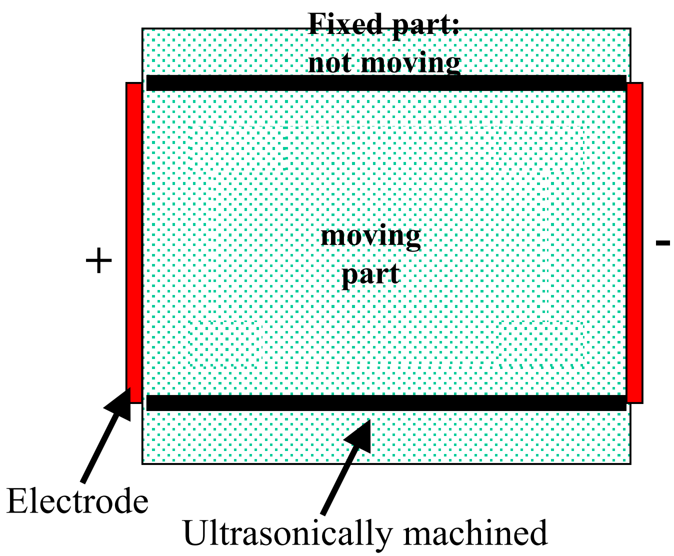


- **Normally closed sealing enhanced feature**
- **Piezoelectric actuator machined ultrasonically**
- **Need strong actuation force**
- **Low temperature bonding**
- **New valve seat design**
  - Dirt particles would be slid by the knife-edge

Fig. 2

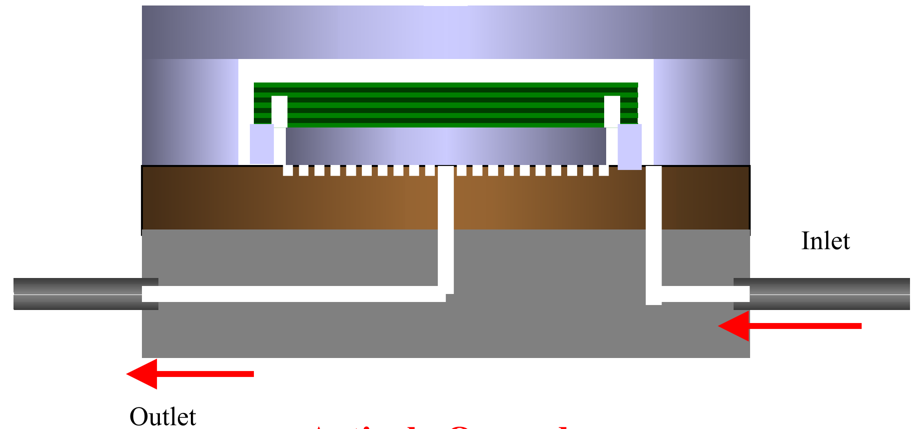
Principle of Operation

Bottom view of the piezo stack



Cross-Sectional view

Normally Closed



Actively Opened

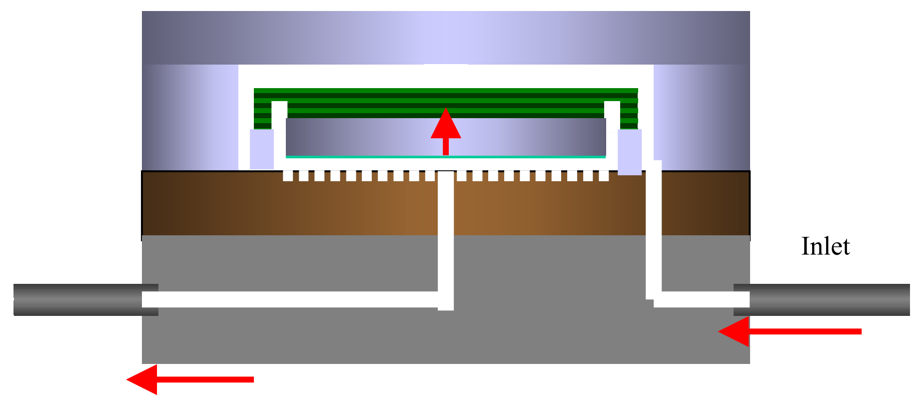


Fig. 3

Fabrication Design *Actuator part*

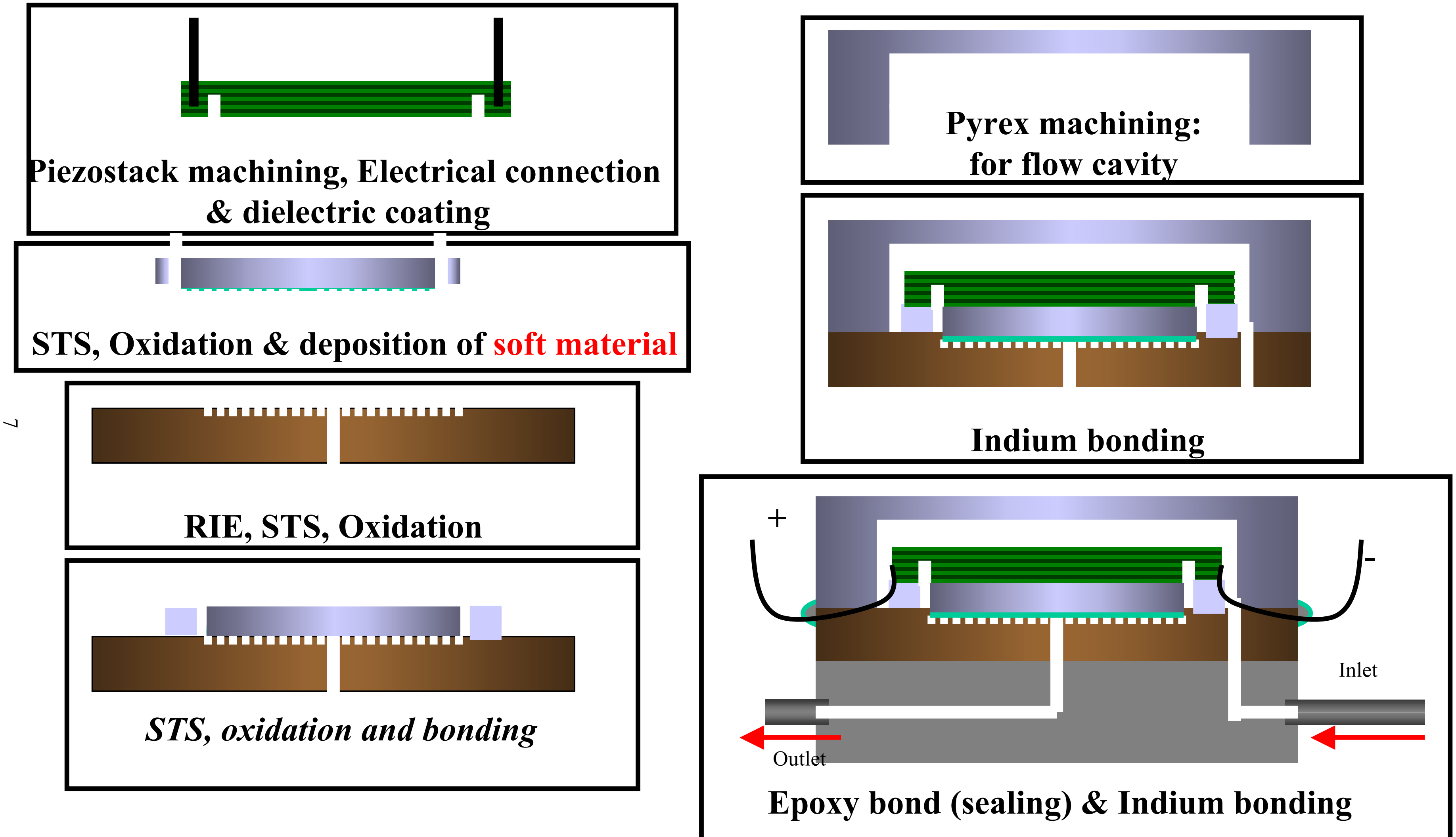


Fig. 4

“The work described here was carried out at the Jet Propulsion Laboratory, California Institute of Technology under contract with the National Aeronautics and Space Administration.”