Micro Electro Mechanical Systems (MEMS) Actuator Technologies for Future Spacecrafts

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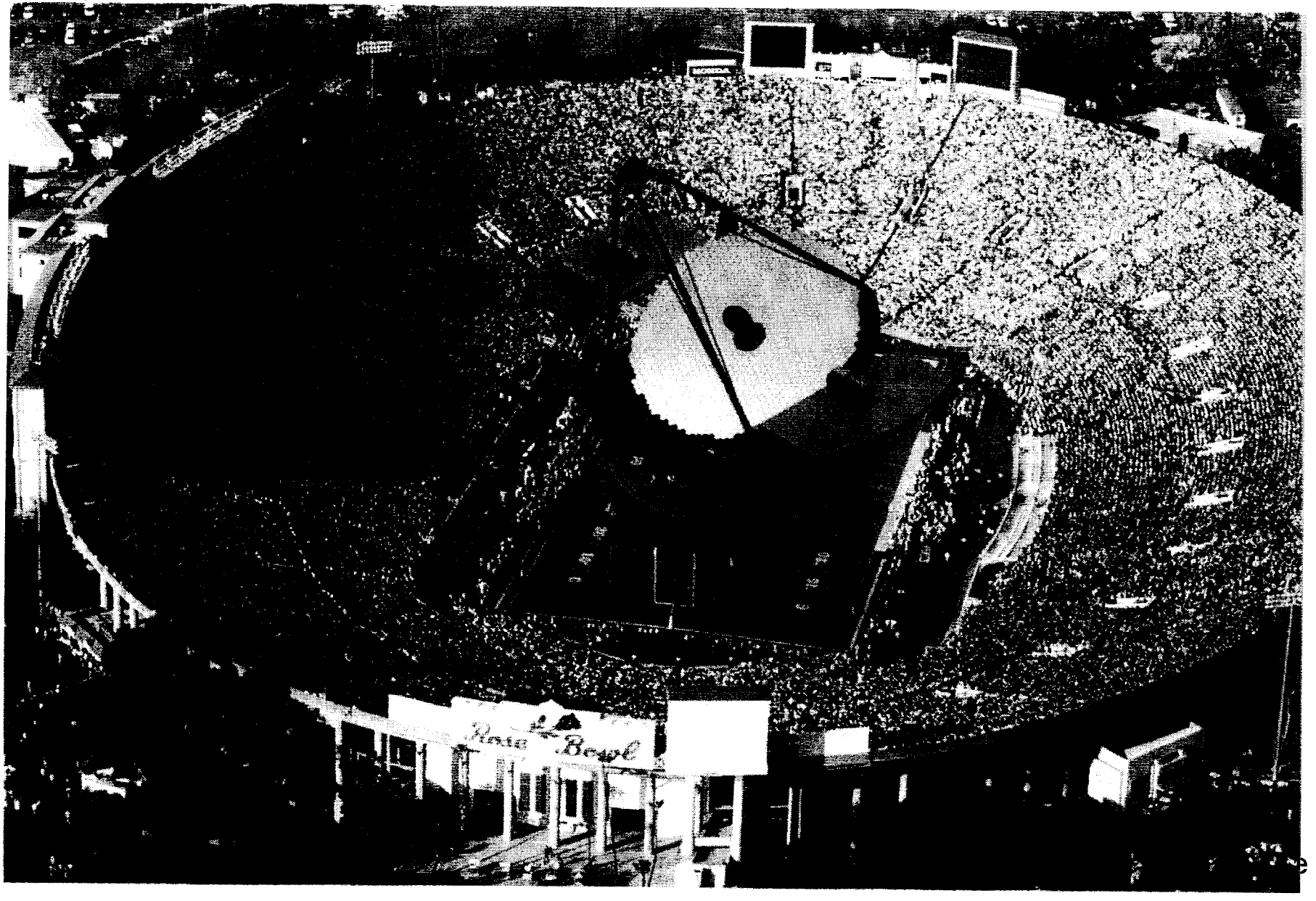
Topic I. Large-Stroke Continuous Membrane Deformable Mirror for Adaptive Optics in Space

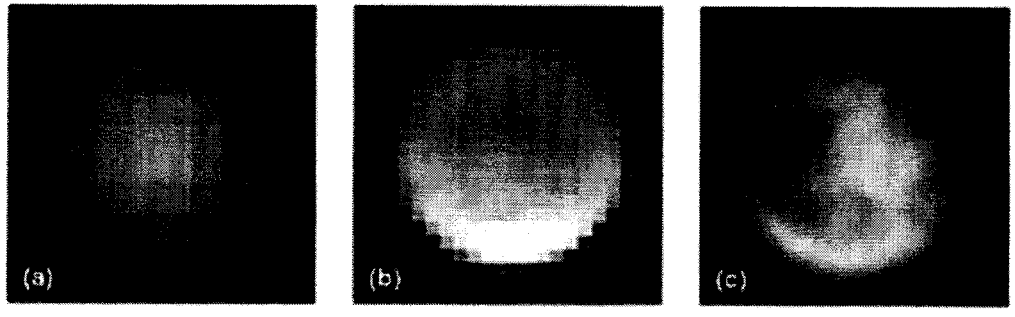
Adaptive Optics for Future Space Applications

- Ultra-large space telescopes envisioned by NASA.
- Deploying conventional mirrors is prohibitively expensive.
- Segmented or monolithic inflatable mirrors whose large wavefront errors can be corrected using adaptive optics.
- Would involve wavefront errors greater than several wavelengths.
- Need large-stroke, continuous-membrane deformable mirrors with high actuator density over large areas.

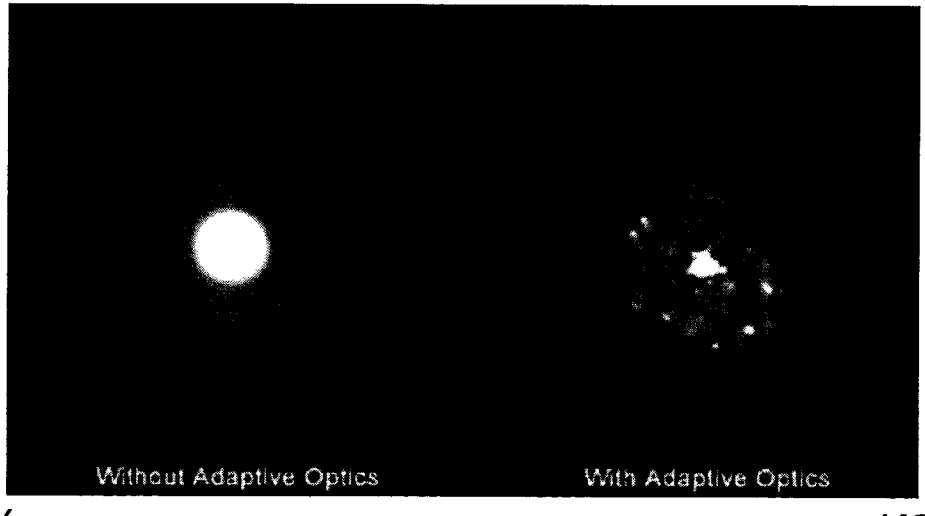

Rose Bowl

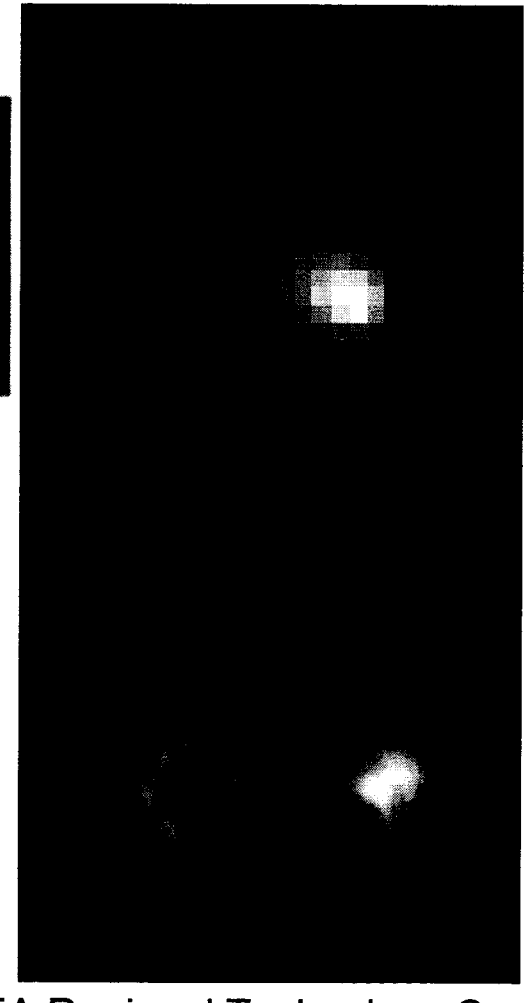
With Adaptive Optics

Titan (Saturn's Largest Moon)

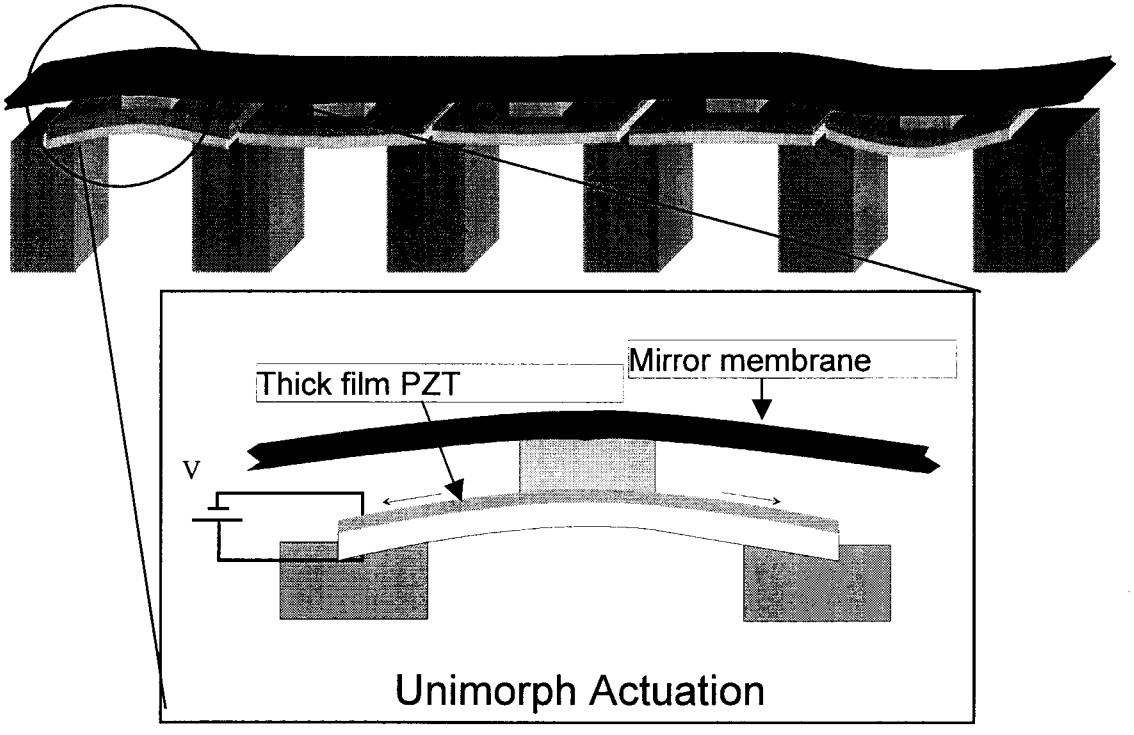


Conventional Telescope **Hubble Space Telescope** **Keck Telescope with AO**





PZT Unimorph Deformable Mirror Concept



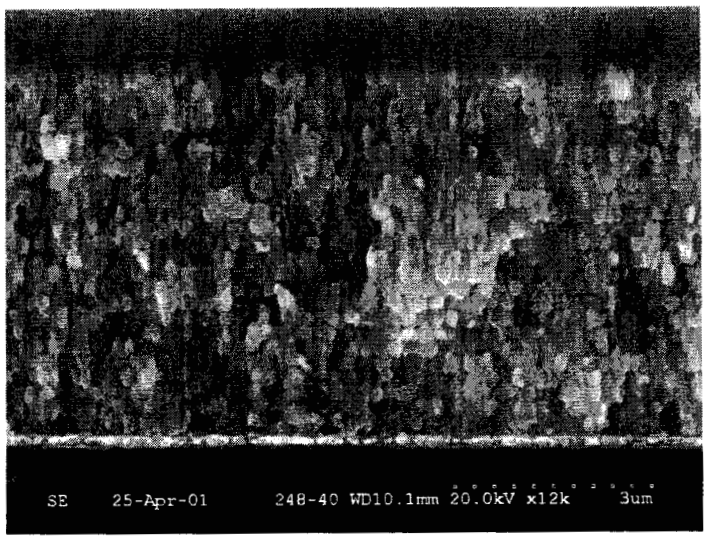
Advantage over Existing Technologies

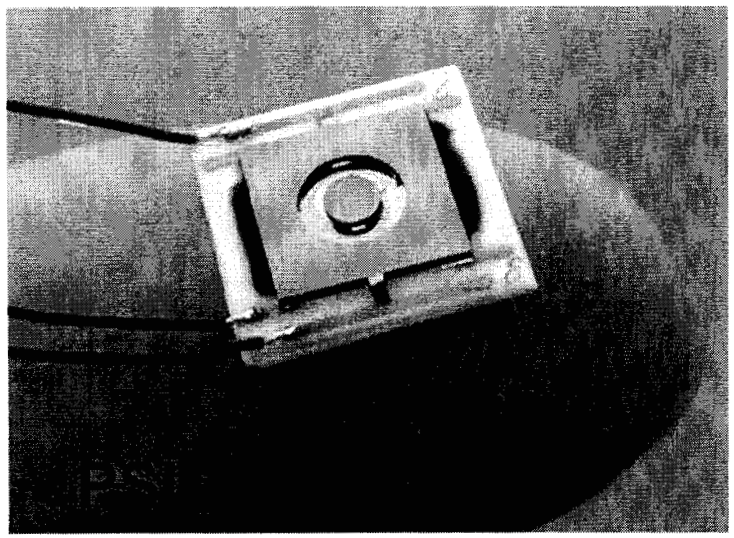
- **JPL deformable mirror meets both requirements for future astrophysical imaging applications:**

  - **Large-stroke mirror:** Unimorph actuation (actuator stroke: >10 μm)
  - **Optical quality continuous mirror:** Transfer optical quality membrane onto large-stroke actuator array

- *Competitive technologies:*
  - *PMN mirror: Limited stroke, size, scalability*
  - *Micromachined mirror: Limited mirror quality, stroke (< 6 μm)*

Thick-Film PZT Actuator Technology

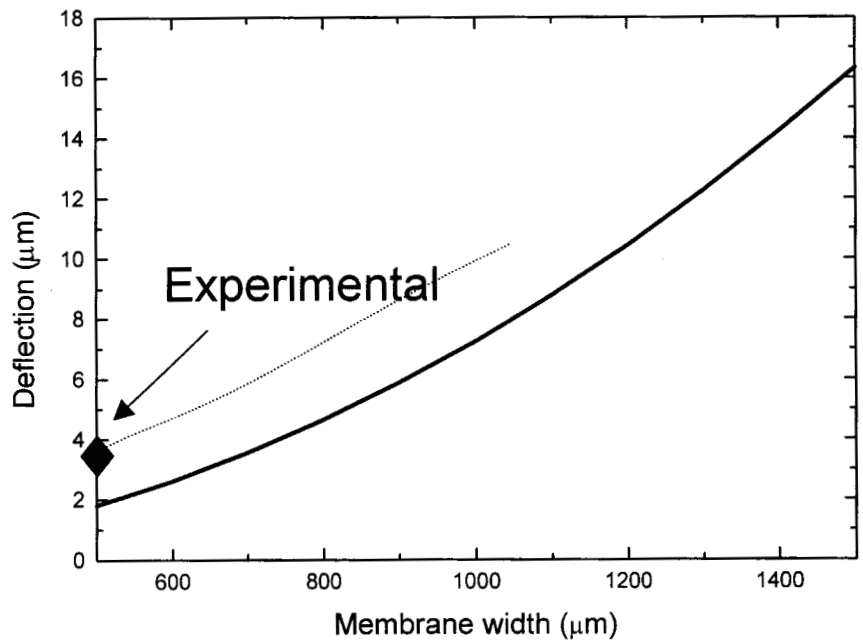




On unimorph structures with diameters of **500 μm**, center deflections of **~4 μm** have already been achieved using **1.5 μm thick** PZT films.

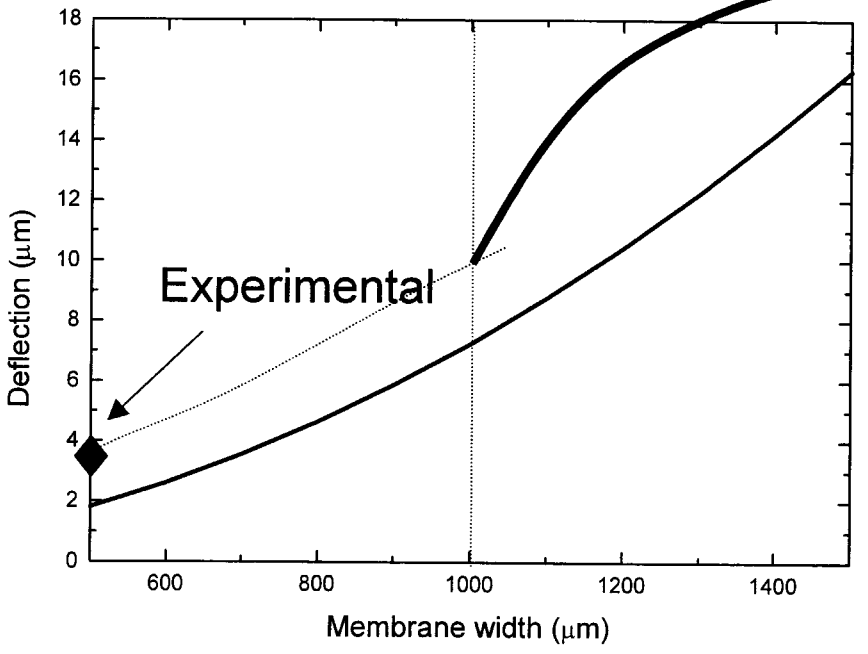
➔Currently developing **7 μm thick** PZT actuators, in order to increase the piezoelectric constant and actuator volume.

Estimated Vertical Stroke of a Thick-Film PZT Unimorph



Vertical free displacement of an actuator at 1 V/μm.
<Actuator with 2 μm thick Si_xN_y + **1.5 μm thick** PZT>

Estimated Vertical Stroke of a Thick-Film PZT Unimorph



For 1 mm² pixel size

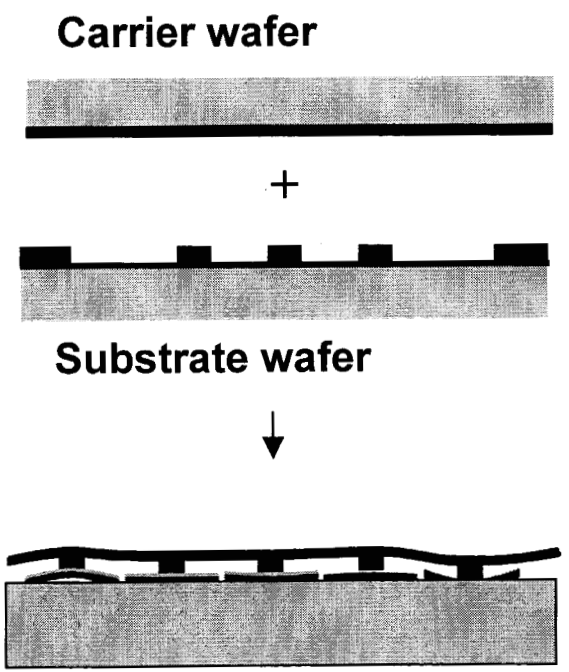
- **1.5 μm thick PZT**:

➔ Estimated actuator stroke: 10 μm

- **7 μm thick PZT**:

➔ Mirror stroke target: > 10 μm

Fabrication of Optical Quality Mirror Membrane

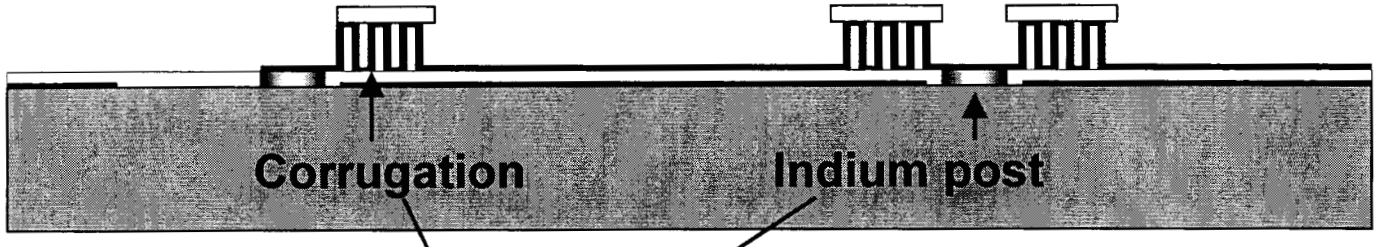


- Transfer of an optical quality mirror membrane onto large-stroke actuator array.

- Large-stroke deformable mirror with optical quality.

- Several optical materials can be transferred onto several substrates.

Transferred Corrugated Membrane Actuators

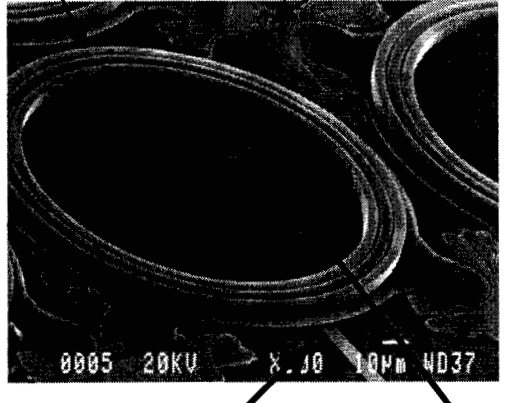


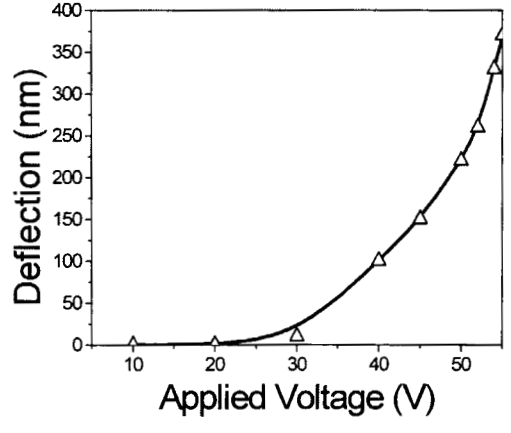
Actuator spacing: 200 μm

Membrane thickness: 1 μm

Electrode gaps: 1.5 μm

Deflection at 55 V: 0.4 μm

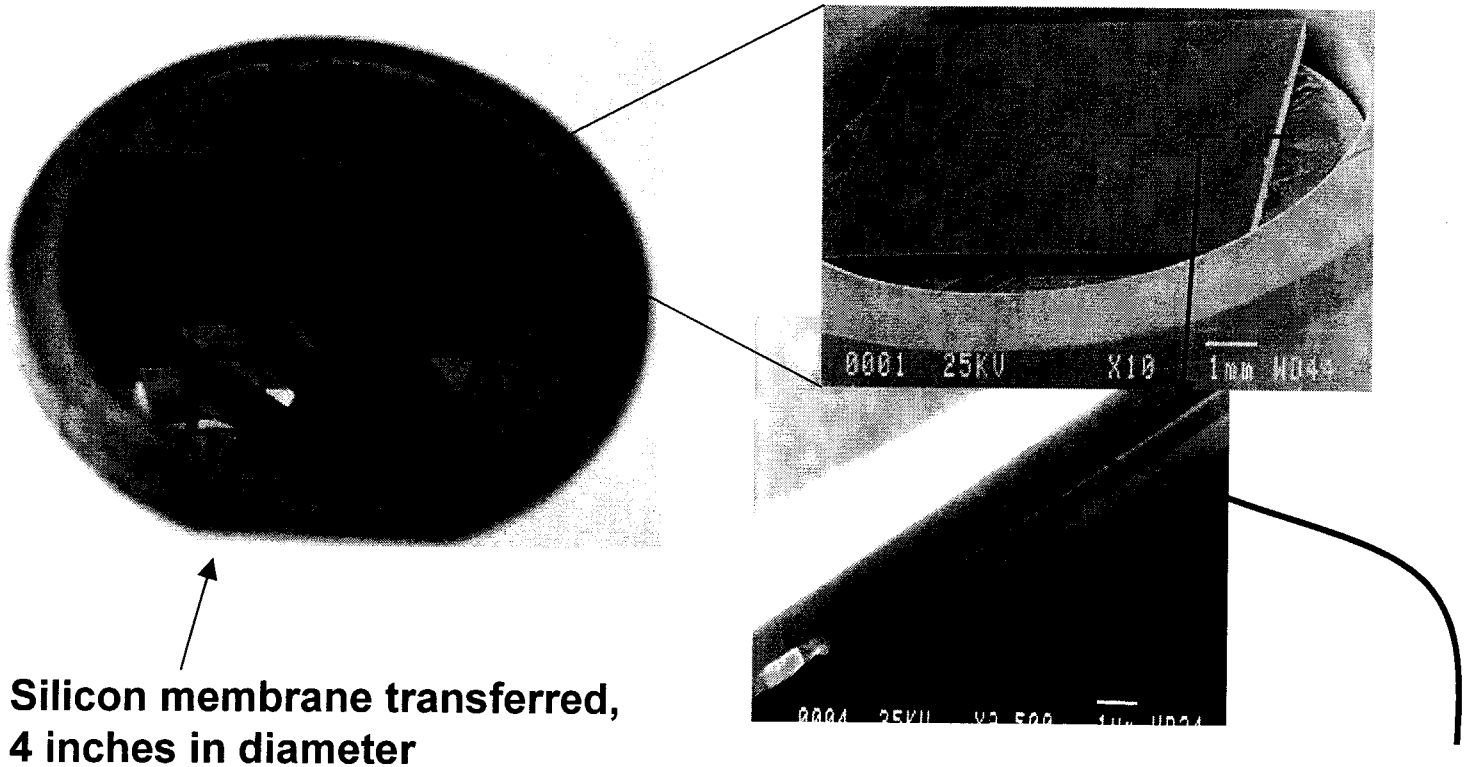




Au line **Membrane (poly-Si)**

Successful transfer of a free-standing membrane

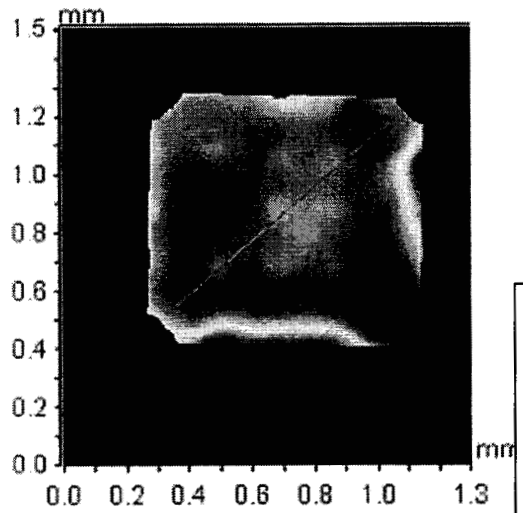
Wafer-Level Transferred Mirror Membrane

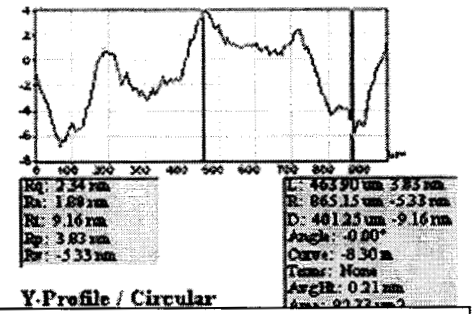


Silicon membrane transferred, 4 inches in diameter

Scanning electron micrograph view of a transferred membrane cross-section

Surface Figure of a Transferred Mirror Membrane





Obtained surface figure error of 9 nm p-v from a transferred silicon membrane (10 μm thick).

Current Status

- **Achieved**
  - Developed an optical quality membrane transfer process
  - Developed a large-stroke unimorph PZT technology.
- **Remaining**
  - Develop the deformable mirror prototype.

Topic II. Leak-Tight, High-Pressure MEMS-based Valve for Micropropulsion

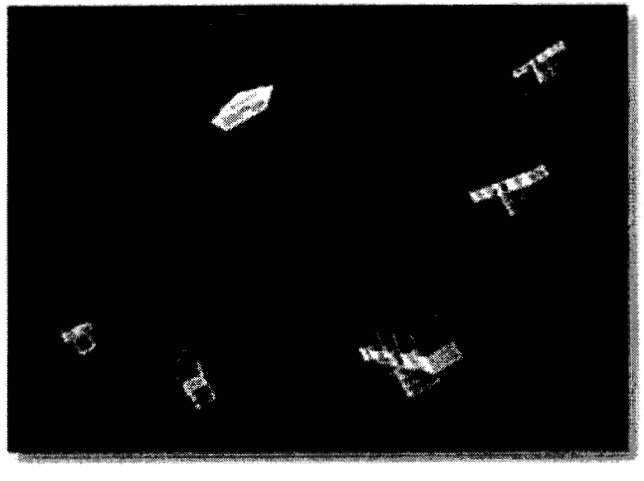
Microvalve for Micropropulsion

Develop microvalves to provide precision flow control of propellants for micropropulsion systems toward future high-visibility space missions such as

– Interferometry/Constellation missions (TPF, Planet Imager, Life Finder)

– Space Inflatable, Microspacecraft

– Advanced miniature components for conventional spacecraft



Microvalve Requirements for Micropropulsion

- Leak Rate - 0.005 sccm He
- Inlet Pressure - 300 ~ 3000 psi
- Actuation Speed - < 10 ms
- Power - < 1 W
- Package Weight - < 10 g
- Temperature - 0 ~ 75 °C

Challenge and Benchmark

Challenges

- Demonstrate leak-tight, low power, high-pressure microvalve technology.
- Integrate microvalve components with micropropulsion systems.

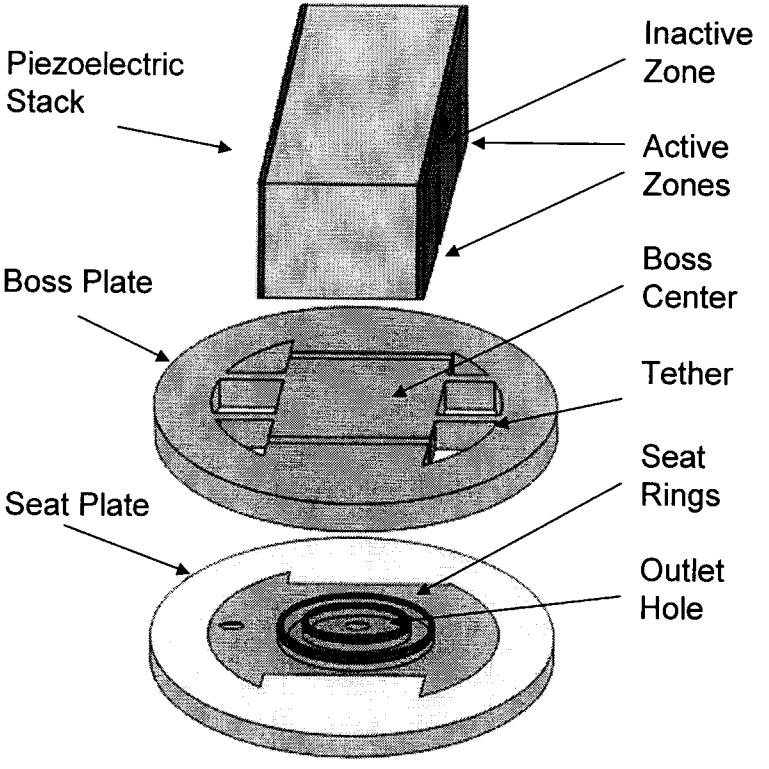
Benchmark

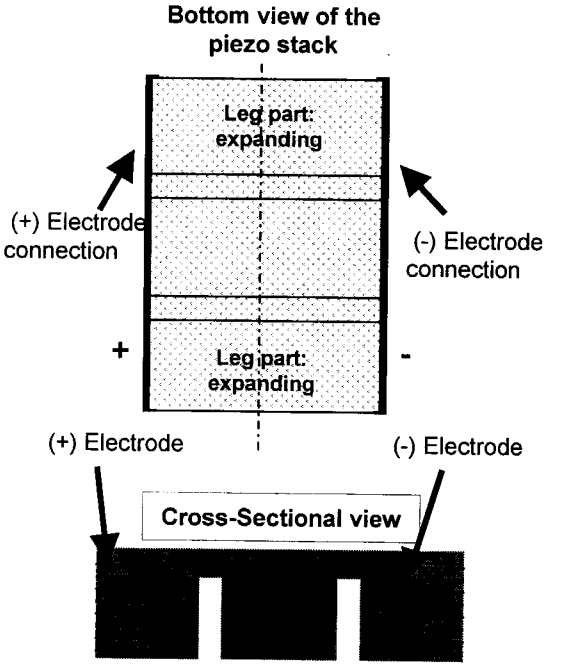
- Other approaches
  - Conventional microvalve technologies: mass/volume, power consumption
    - ➔ 3-8 W to operate
  - Typical MEMS-based valves: leak or narrow pressure range
    - ➔ Redwoods microvalve: 400 ms, 0.2 sccm (20 psi), 2 W

JPL's Microvalve

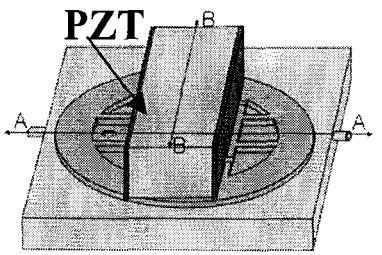
- **JPL microvalve is designed to provide**
  - **-Integration feasibility: MEMS-based technology**
  - **-Leak-tight operation at extremely high pressures: Seating configuration**
  - **-Fast, low power operation: Piezoelectric actuation**

Piezoelectric Microvalve Design





Piezoelectric Microvalve Design



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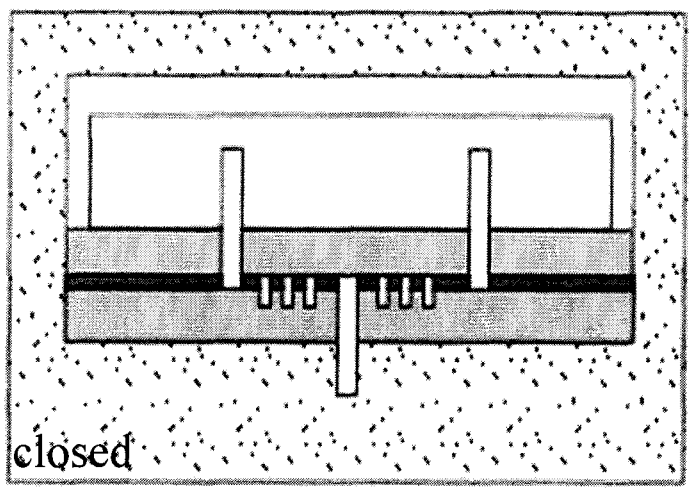

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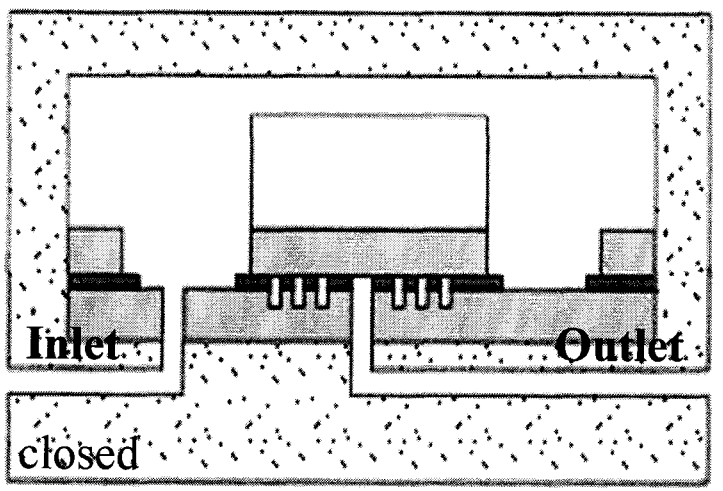
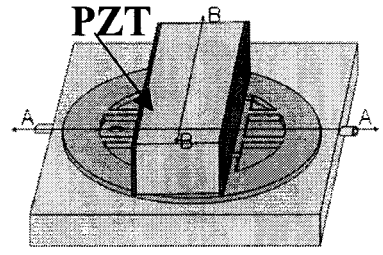


Piezoelectric Microvalve Design



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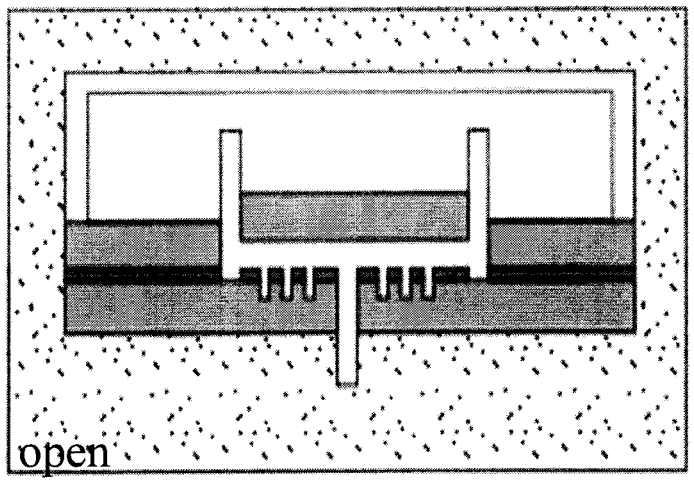

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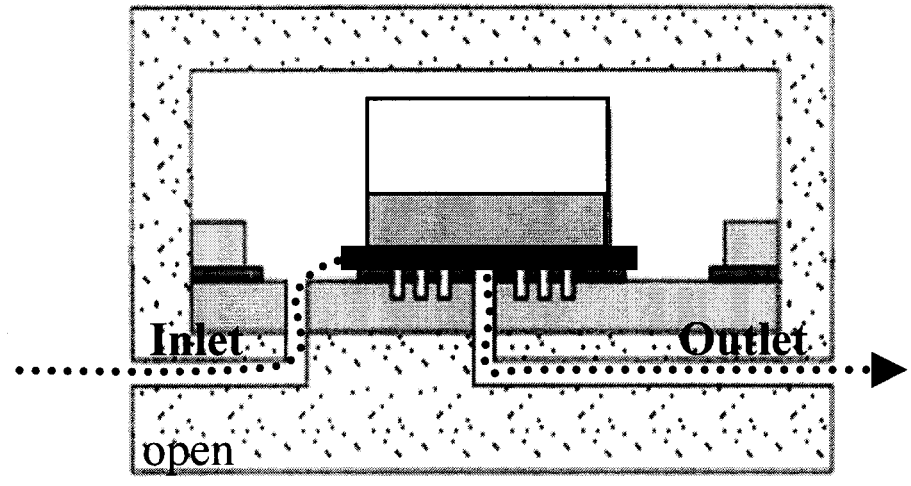
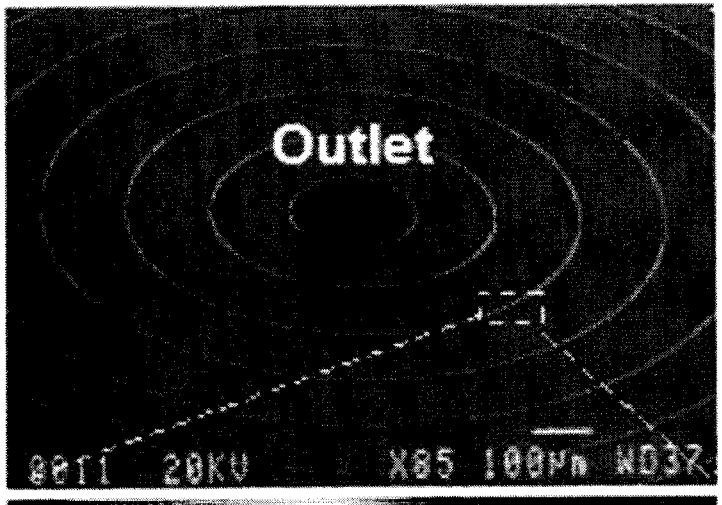
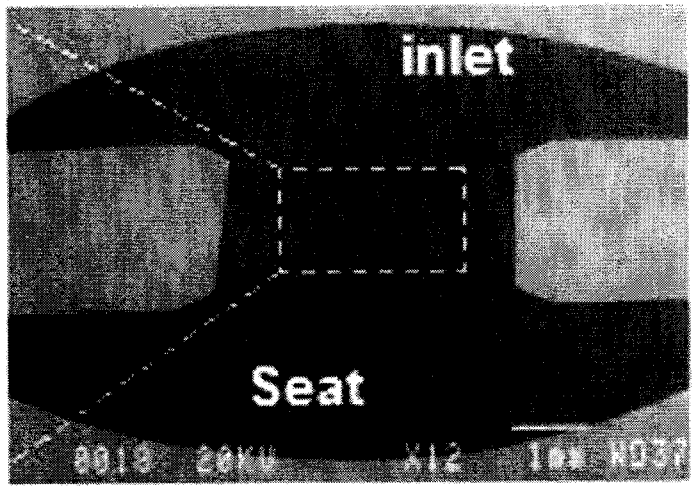
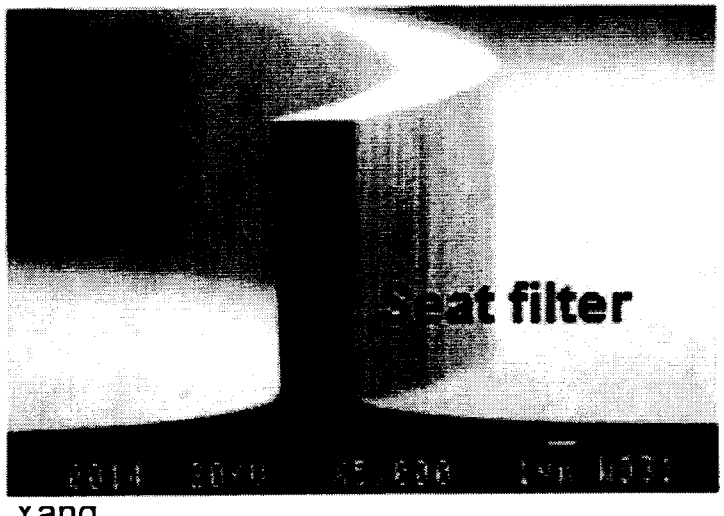
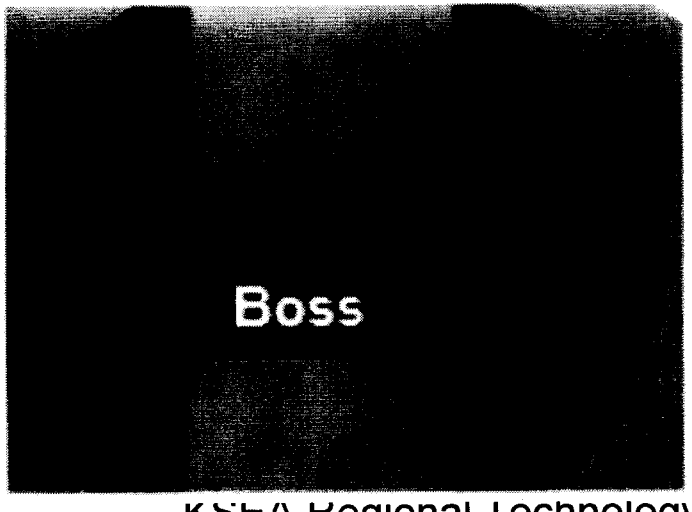


Fabricated Silicon Components

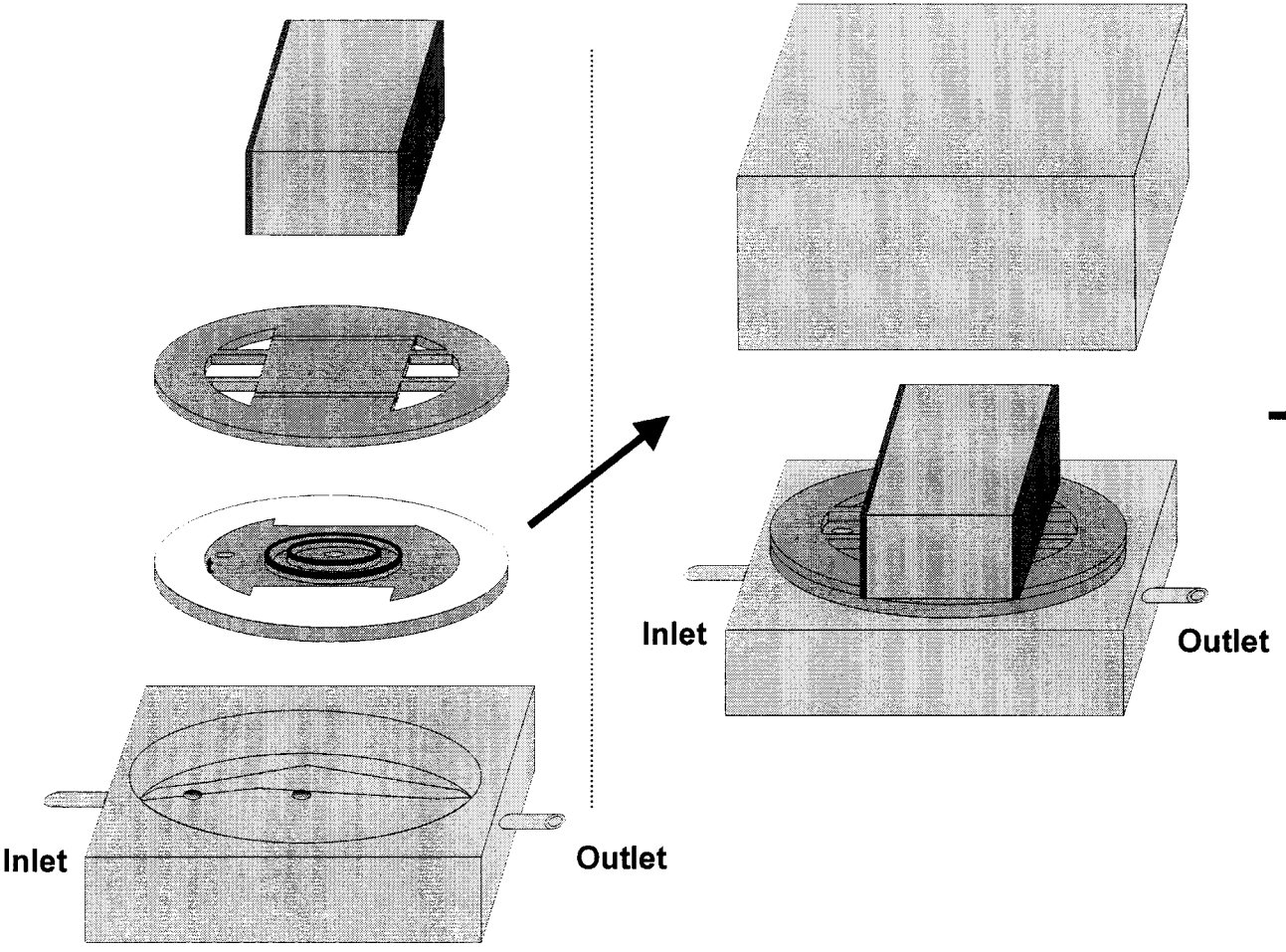


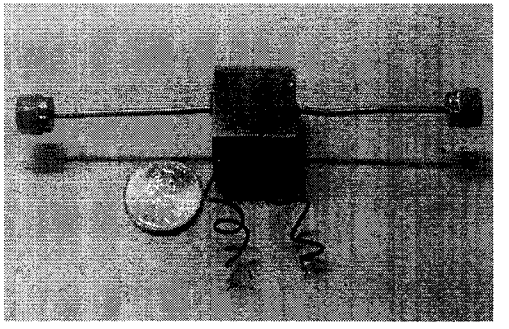






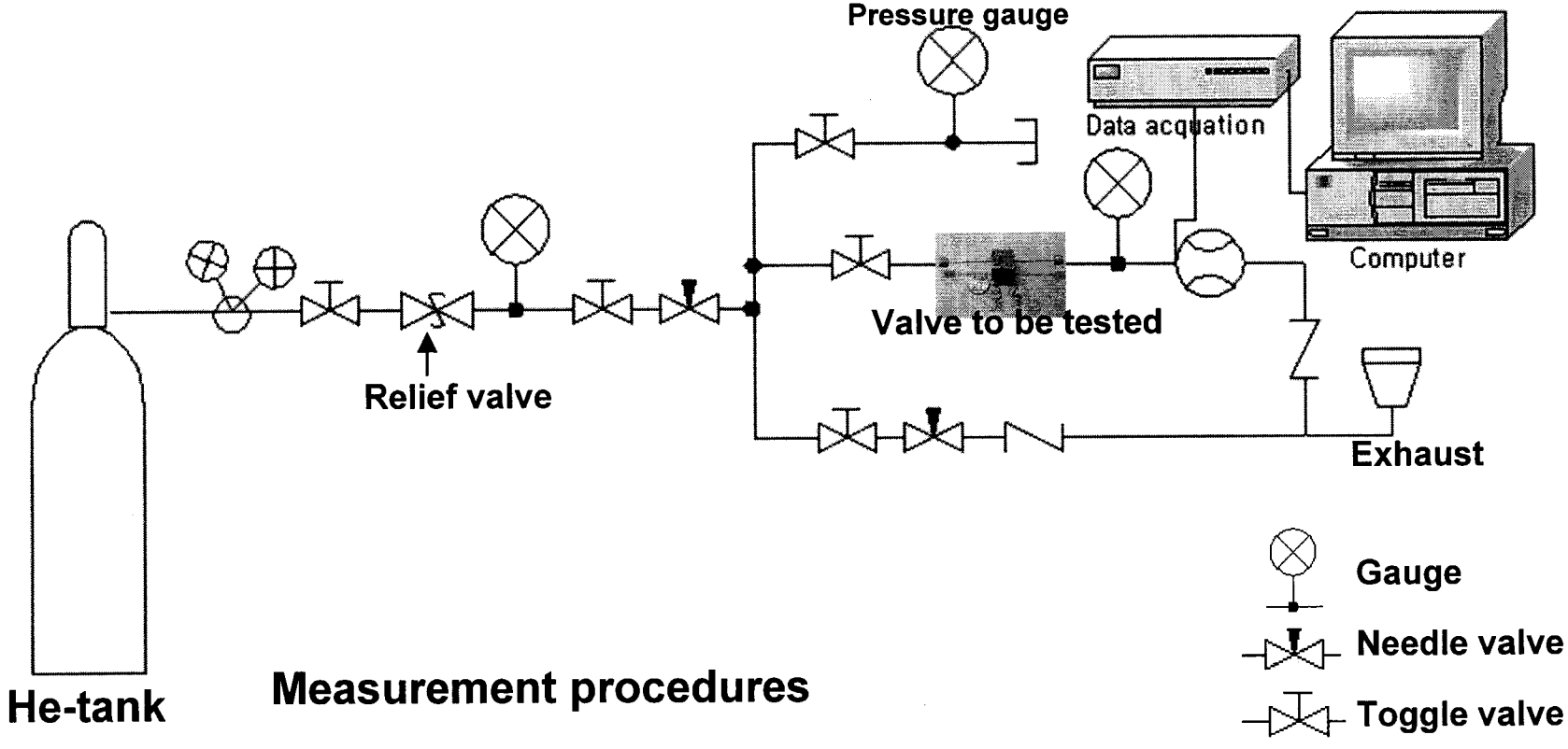
Assembly





Packaged microvalve under development

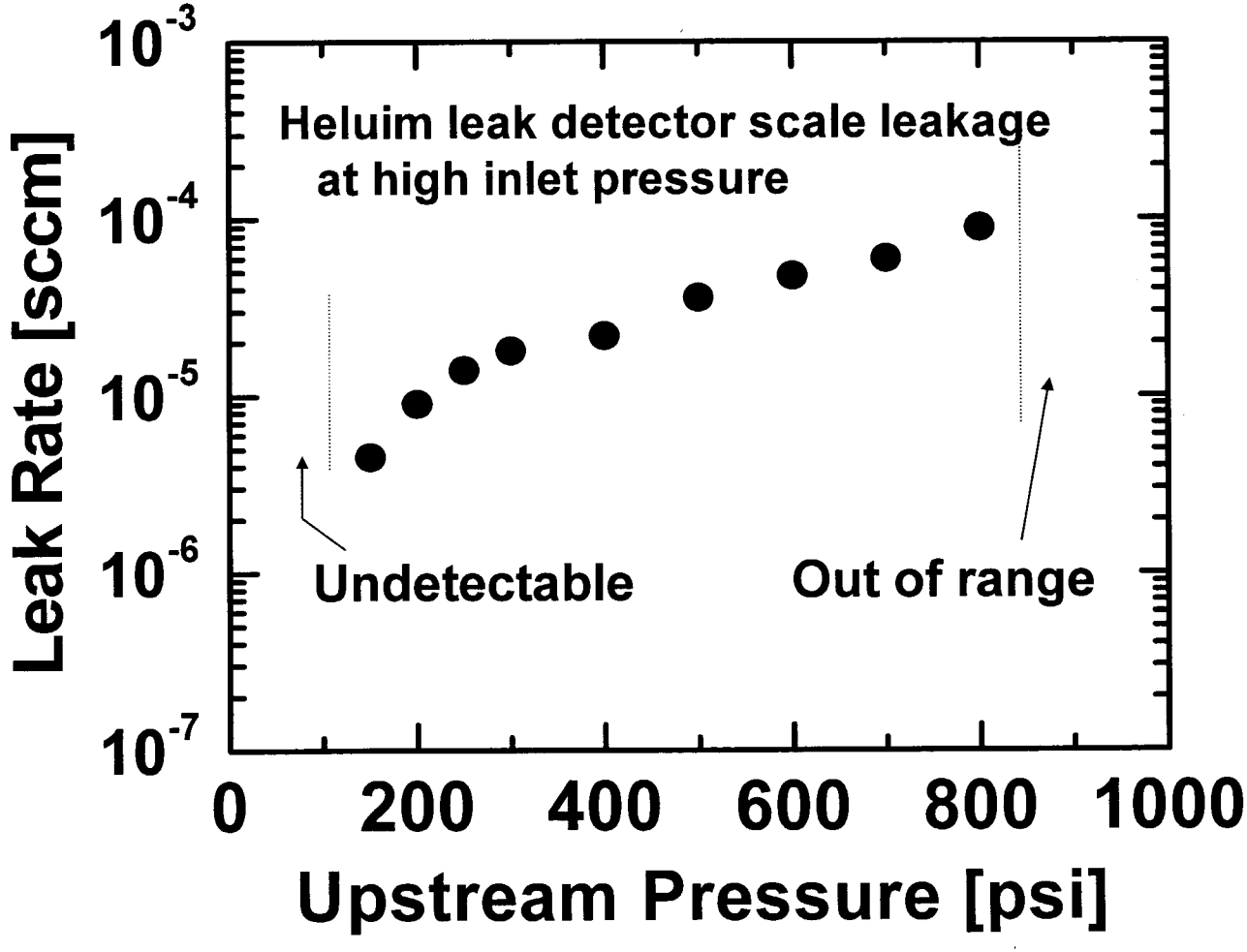
Flow Test Setup



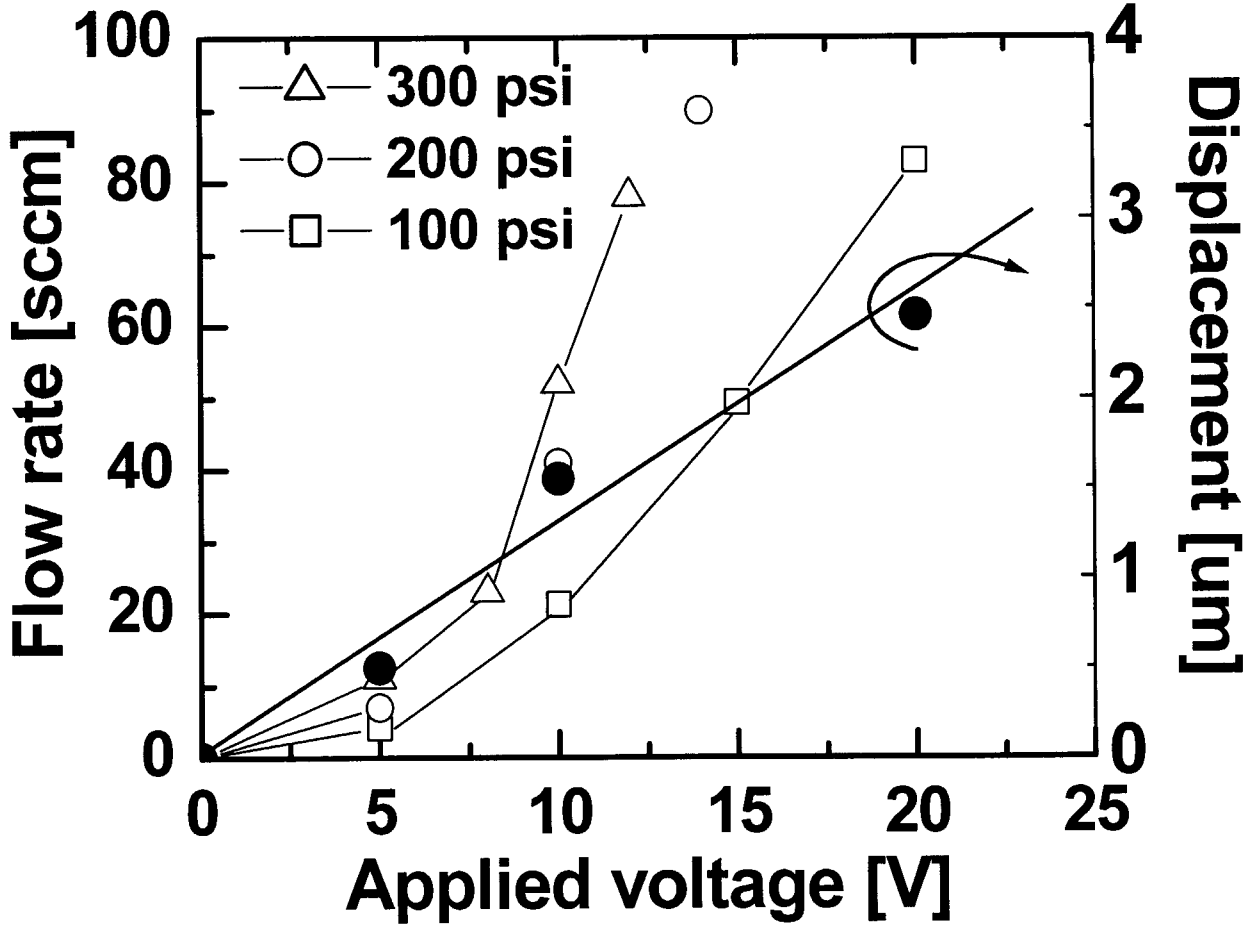
Measurement procedures

1. Connect microvalve to be tested
2. Test external leakage with He-leak detector
3. Measure internal leak and flow rates

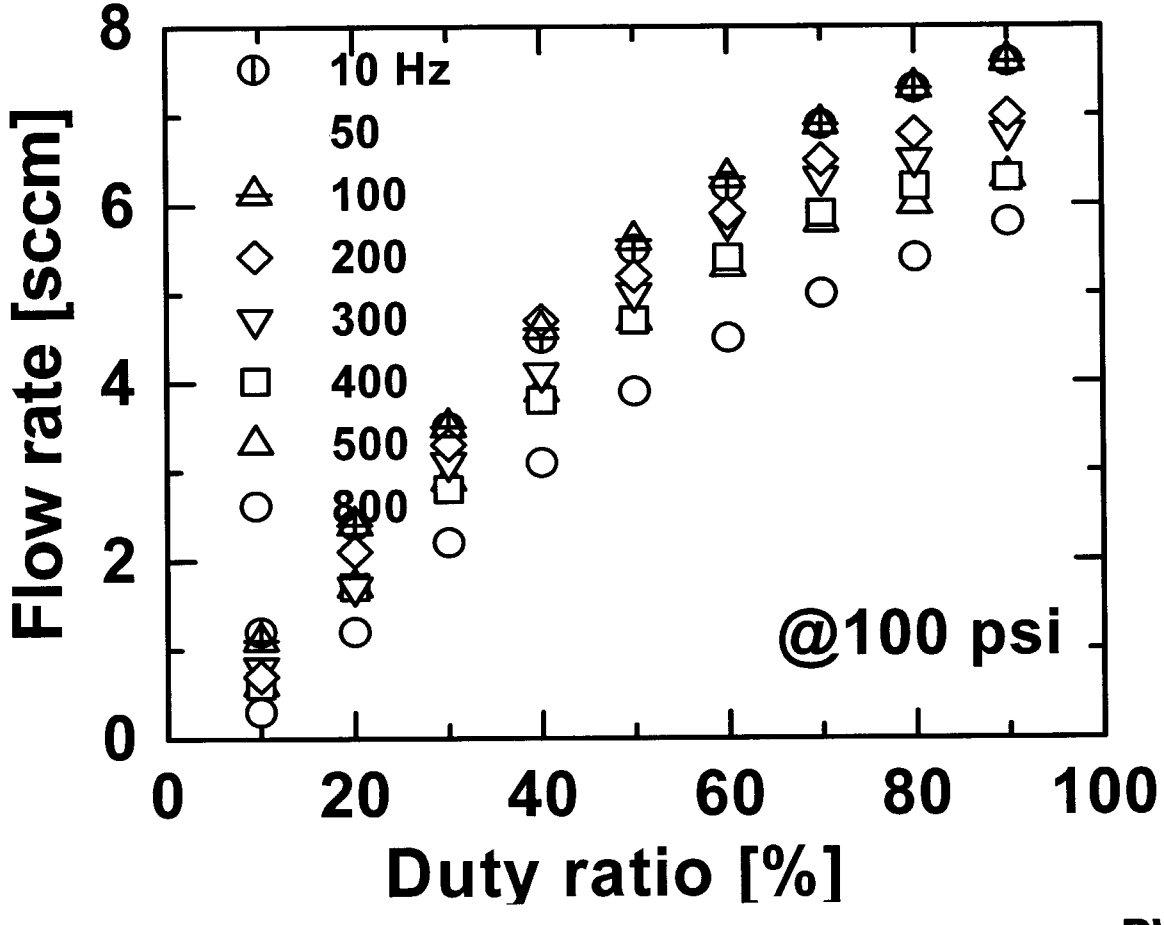
Leak Characteristics



Static Flow Characteristics

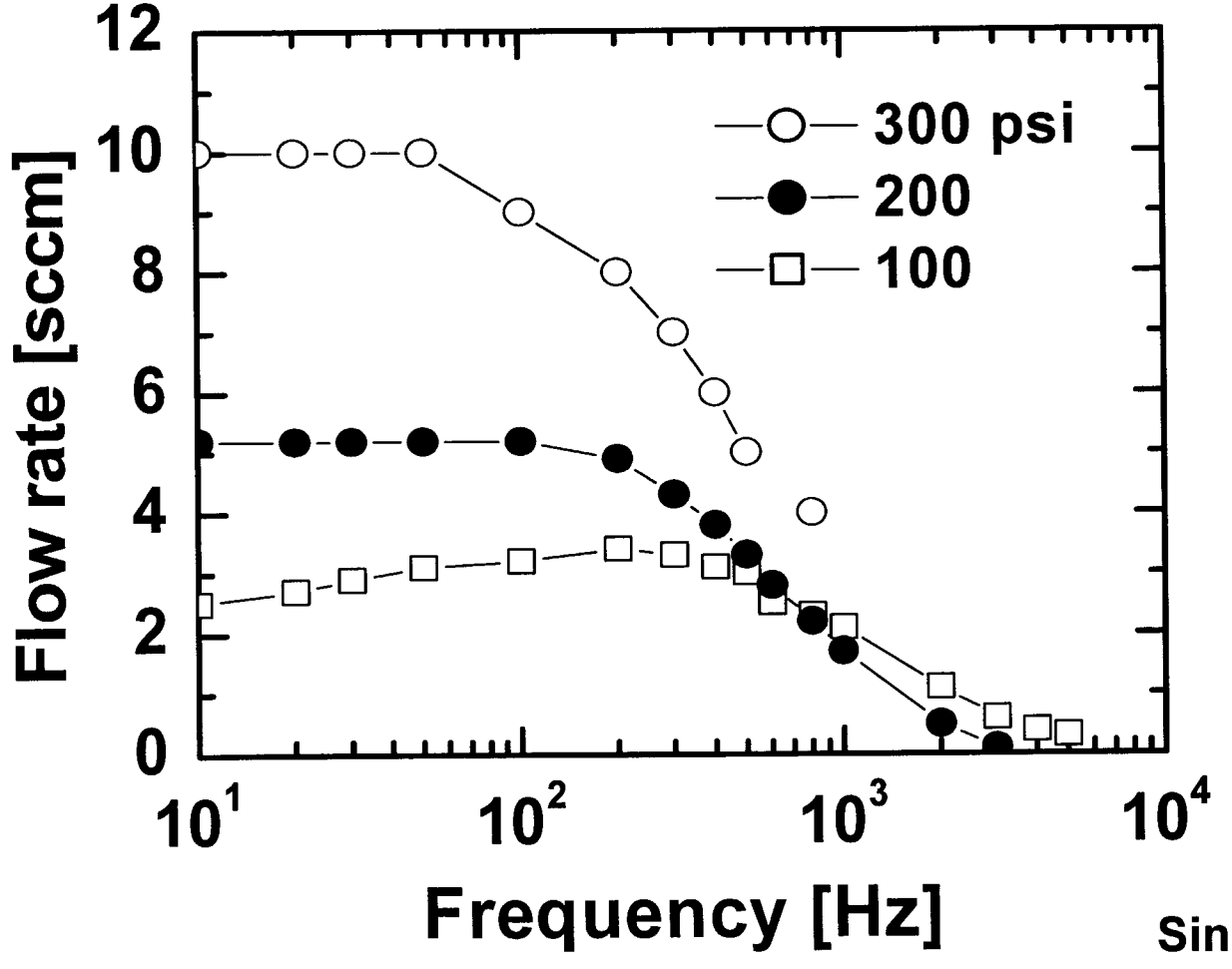


Dynamic Flow Characteristics



PWM Actuation

Dynamic Flow Characteristics



Sine wave 10V

Demonstrated Performance

Requirements	Target	Demonstrated to Date
Leak Rate	0.005 sccm/He	9×10^{-5} sccm/He @ 800 psi
Inlet Pressure	300 ~ 3000 psi	0 ~ 1000 psi
Actuation Speed	< 10 ms	< 10 ms
Power	< 1 W	180 mW @ 100 Hz
Package Weight	< 10 g	N/A
Temperature	0 ~ 75 °C	Not tested yet

Summary

- Designed, fabricated and tested the silicon MEMS-based piezoelectric microvalves for high-pressure flow control.
- Demonstrated leak-tight, high-pressure piezoelectric valve operation: 9×10^{-5} sccm at 800 psi.
- Demonstrated fast and low power microvalve operation: 180mW@ 10 ms

Acknowledgement

The research described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology under a contract with the National Aeronautics and Space Administration.