Micro Electro Mechanical Systems
for mechanical engineering applications

Lecture 8:
Introduction to BioMEMS: from historical background to current research

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Definition of BioMEMS

- **From a systemic aspect:**

BioMEMS usually contains sensors, actuators, mechanical structures and electronics. Such systems are being developed as diagnostic and analytical devices.
 - Suzanne Berry, TRENDS in Biotechnology (2002)

- **From a component aspect:**

BioMEMS is the research of microfabricated devices for biological applications.
 - Tejal A. Desai, Biomolecular Engineering (2000)

- MEMS technology is an engineering solution for biomedical problems.

BioMEMS in Biomedical Field

BioMEMS encompasses all interfaces and intersections of the life sciences and clinical disciplines with microsystems and nanotechnology.

Related area:

- Micro & nanotechnology for drug delivery,
- Tissue engineering, harvesting, manipulation
- Biomolecular amplification,
- Sequencing of nucleic acids
- Proteomics
- Microfluidics and miniaturized total analysis systems (microTAS)
- Biosensors
- Molecular assembly,
- Nano-scale imaging, and integrated systems

Adapted from Cambridge Healthtech Institute
http://www.genomicglossaries.com

MEMS vs. BioMEMS

MEMS	BioMEMS
• Silicon based Material	• Biocompatible Material
• Electrical & Mechanical interface integration	• Biomolecular & physical parameter (electrical,mechanical, optical) transducer integration
• Moving part in micromachining system -active component	• Motion medium in passive Moving -microfluidic driving force

A quite different thinking process from MEMS to BioMEMS

Applications in Bioscience

- Exploit size match between cells and MEMS
- Utilize physical microscale phenomena
- Miniature, multi-component instruments
  - sensors
    - potential, pressure, force, pH, chemistry
  - actuators
    - pumps, valves, probes, grippers, ...
  - systems
    - Integrated microfluidic platforms
    - Lab-on-a-chip systems

Actuation Mechanisms of BioMEMS

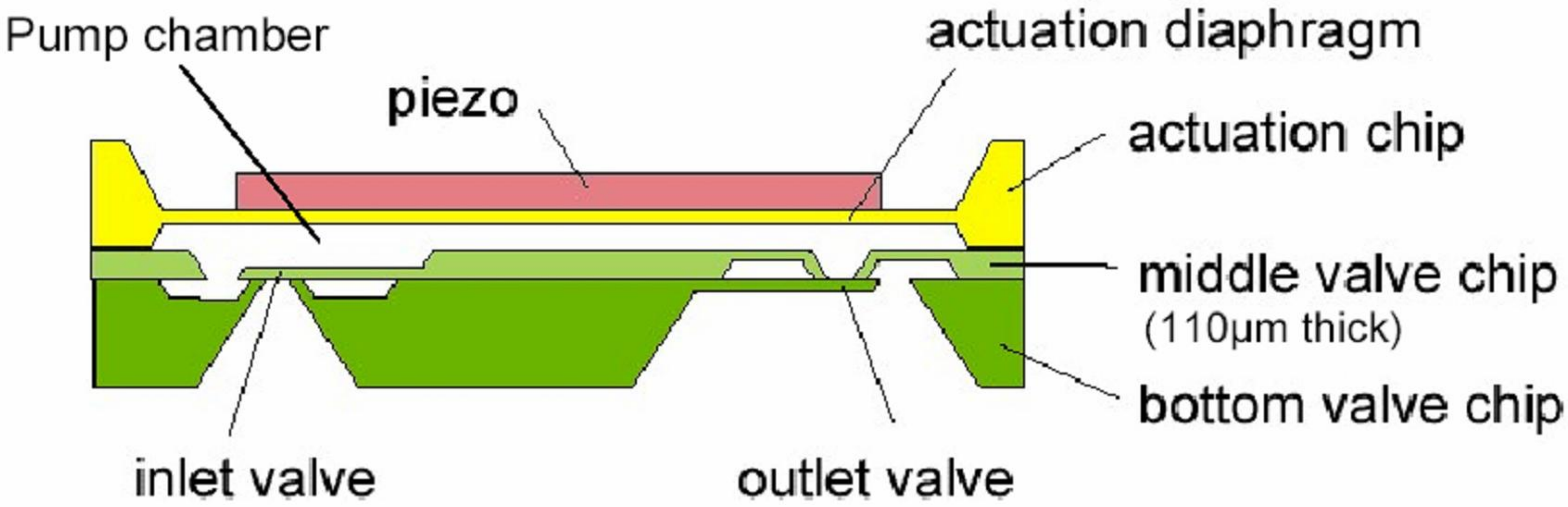
Typical MEMS actuation mechanisms for pumping:

- Electrostatic
- Thermal
- Magnetic
- Pneumatic
- Piezoelectric
- Ultrasonic

Direct fluidic actuation mechanisms:

- Fluidic phase change
- Electrohydrodynamic (EOF, electrophoresis, etc)

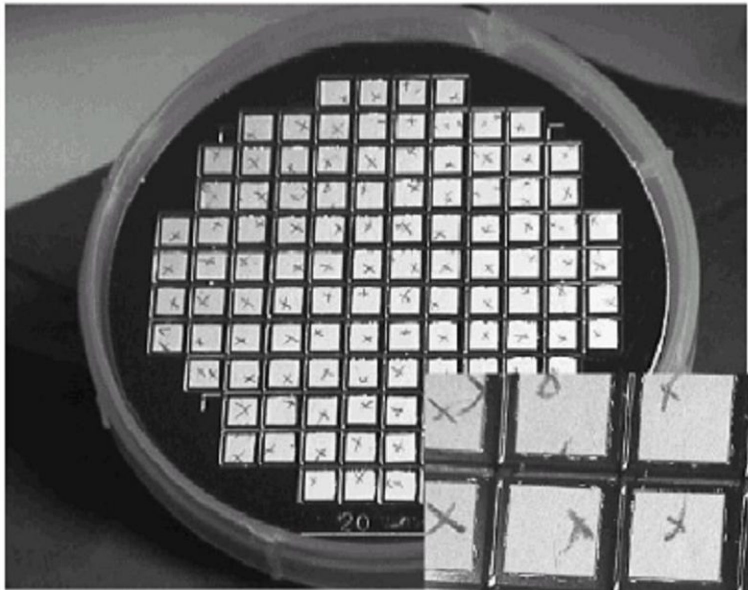
Piezoelectric Pump (1)



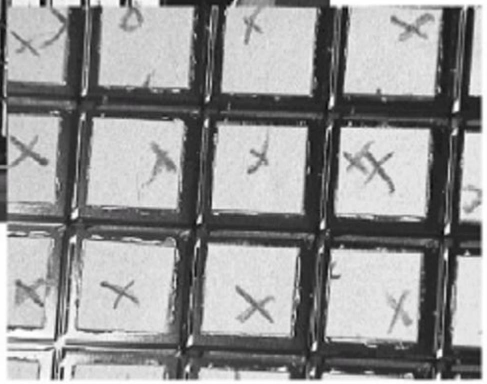
- Optimized pump is “bubble tolerant” and “self-priming.”
- Lower 2 wafers bonded via silicon fusion bonding. Top wafer later glued.
- Piezo ceramic driven by high voltage (-40V, +90V)
- At 100Hz, no back pressure, average flow rate ≈ 1600μl/min.
- Dead volume = pump chamber volume ≈ 800nl.
- Average stroke volume = 260nl.

Piezoelectric Pump (1)

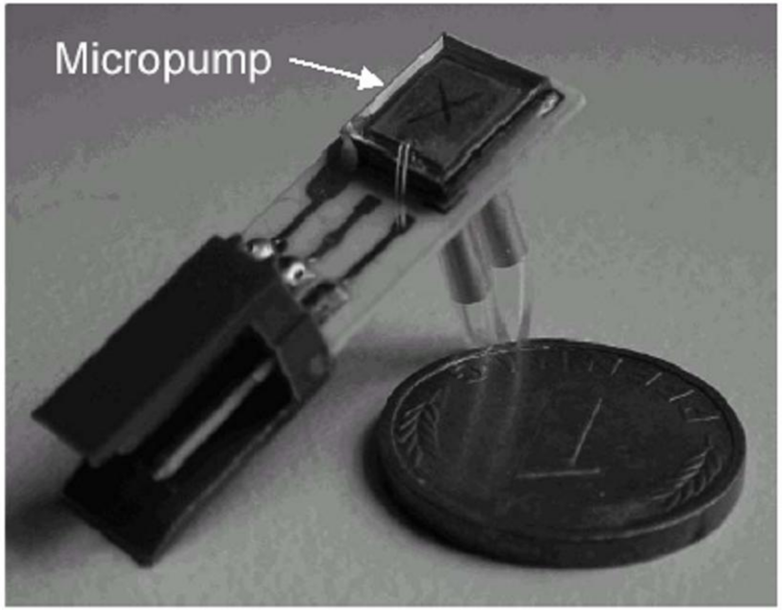
- **Packaging and Production**



4" micropump wafer stack



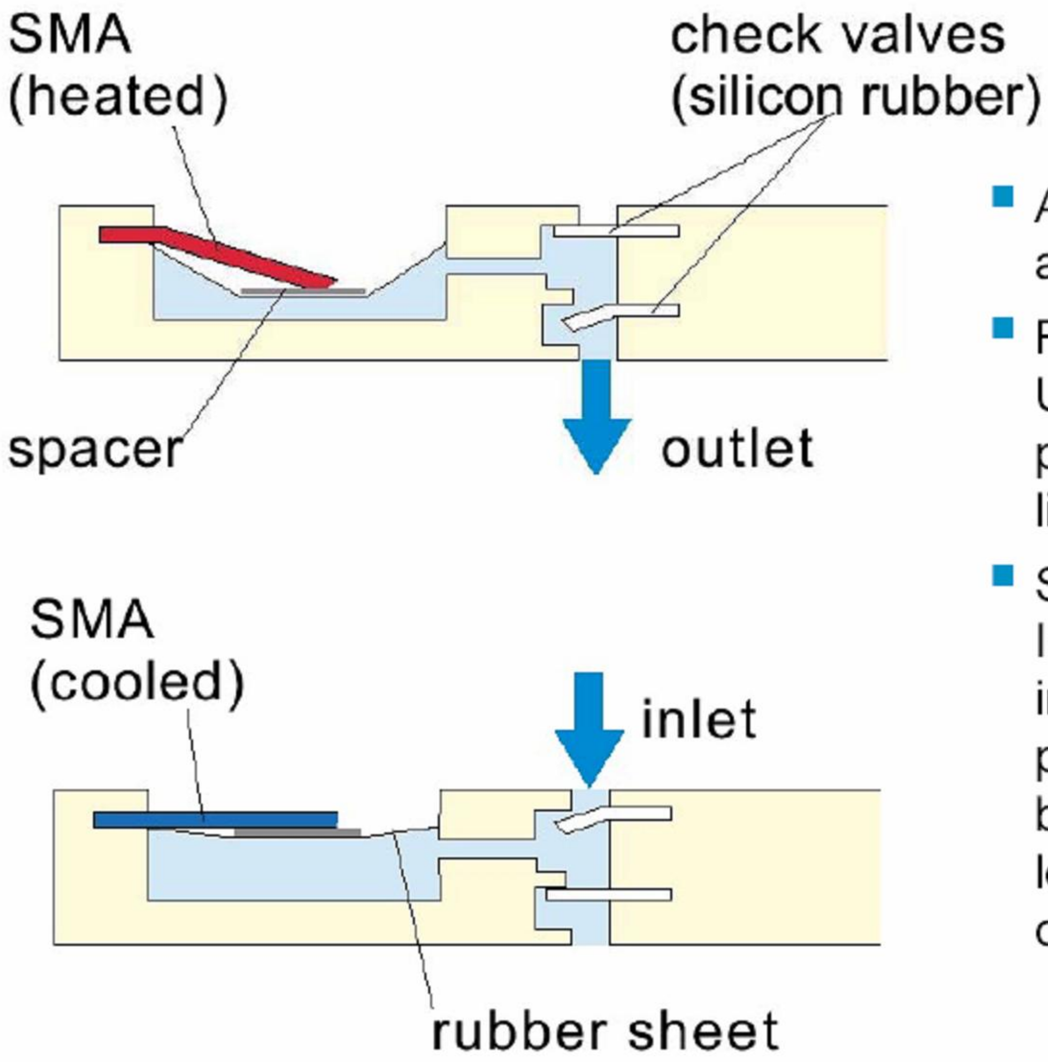
detailed view



Micropump (7mm x 7mm) is glued on a carrier with electrical and fluidic interconnects attached.

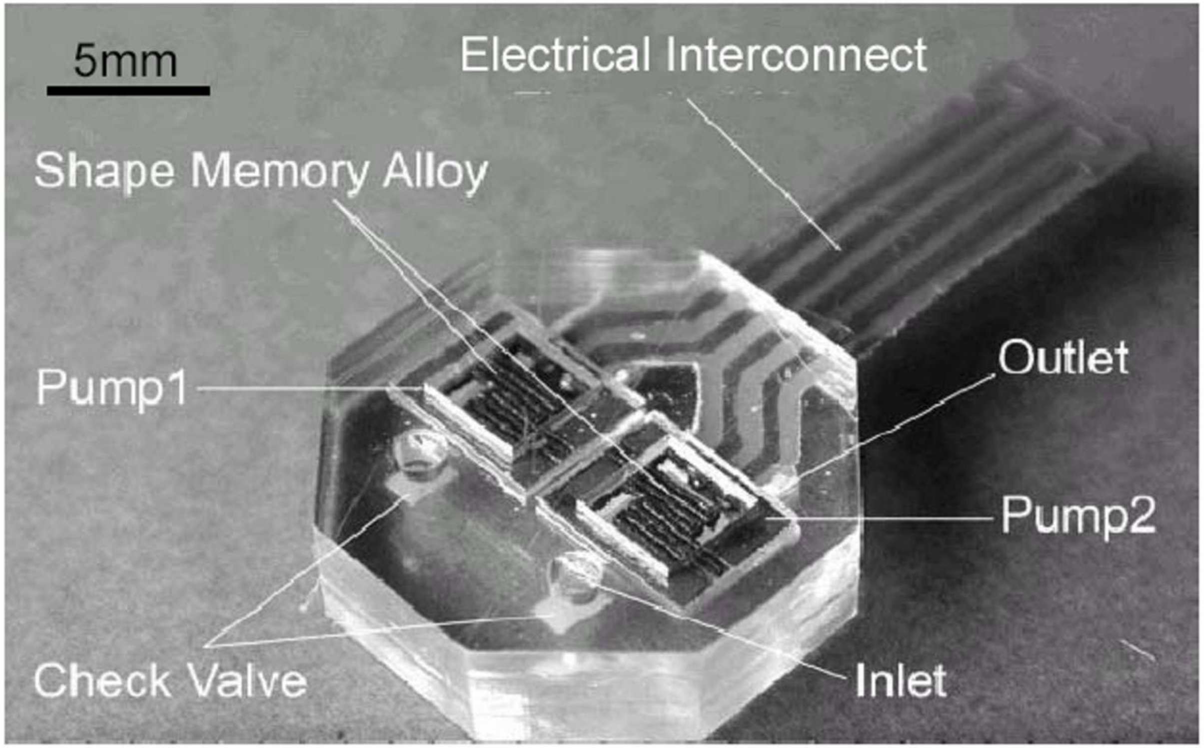
Piezoelectric crystals are attached to all die simultaneously via glue and assembly aids.

Shape Memory Alloy Pump (1)



- Also bubble tolerant and self-priming.
- Fabrication via custom UV polymerization process (micro stereo lithography).
- SMA, silicone rubber, ICs, and spacers are inserted during polymerization – No bonding needed and leak proof packaging created easily.

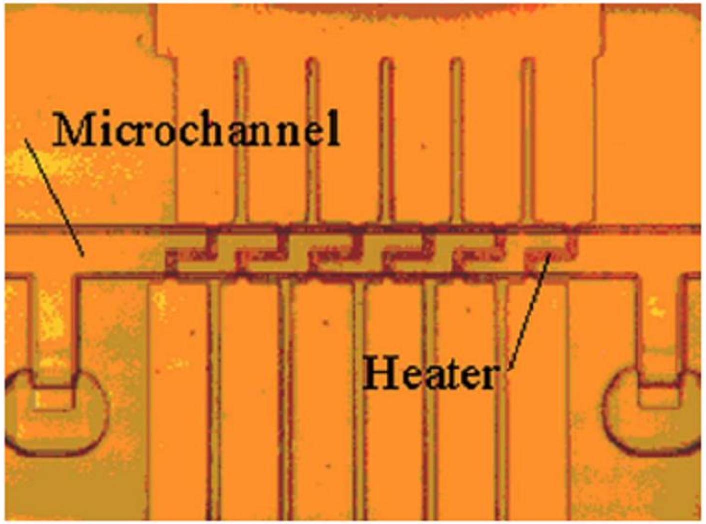
Shape Memory Alloy Pump (2)

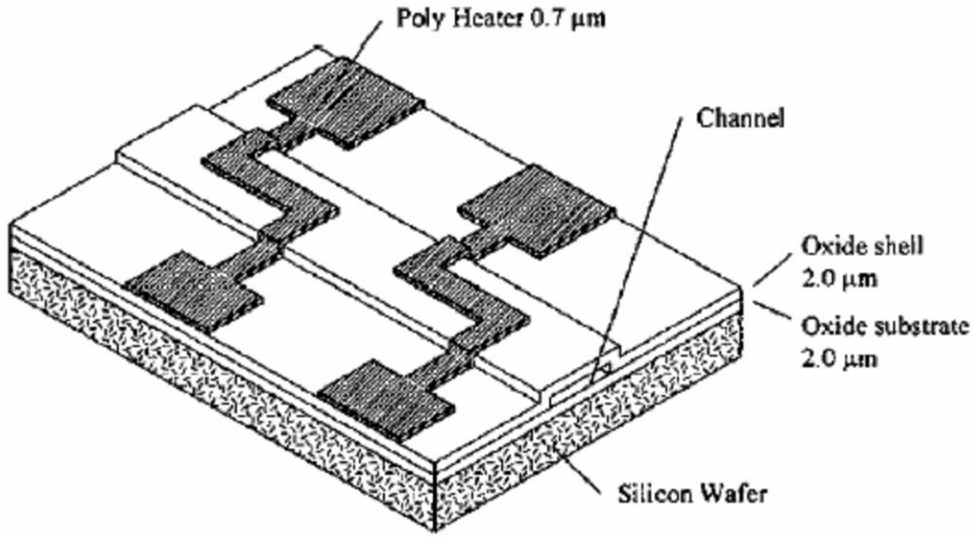


	Maximum Flow	Maximum Pressure
Liquid (water)	12.3 μl/min	25 kPa
Gas (air)	11.0 μl/min	5 kPa

K. Ikuta, T. Adachi, Nakoya University

Bubble-driven Micropump



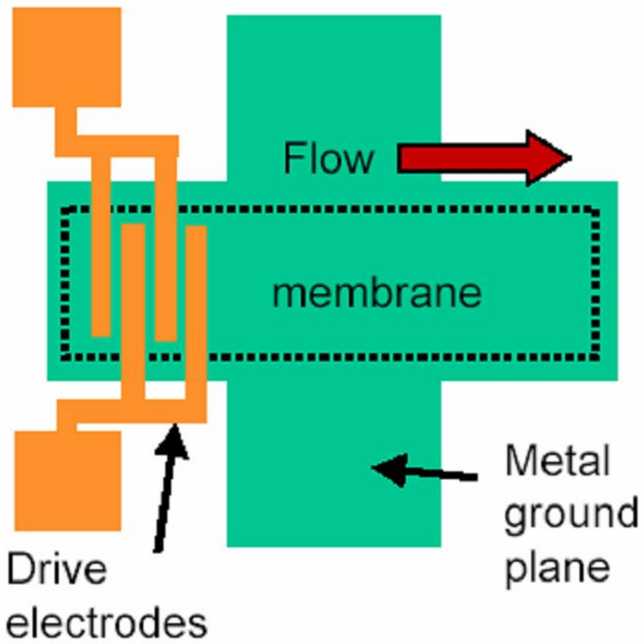


- Bubble formation induced in heater pushes fluid in the channel.
- Maximum flow rate = 0.5nl/min
- Maximum pressure head = 800Pa

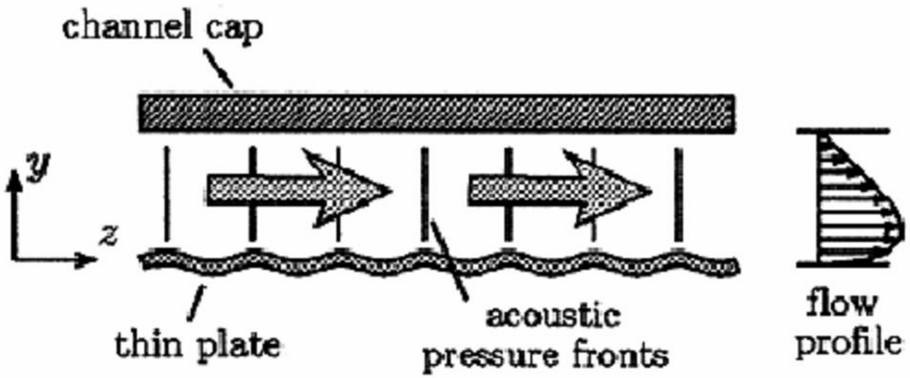
T. K. Jun and C. J. Kim, UCLA/MAE

Acoustic Pumping

TOP VIEW



SIDE VIEW

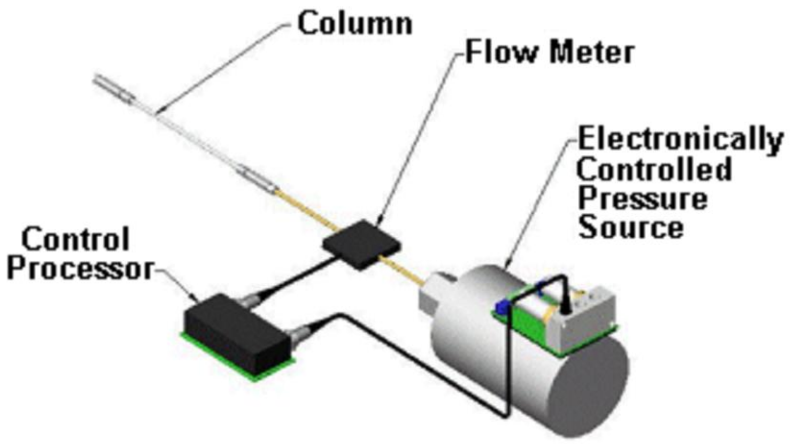


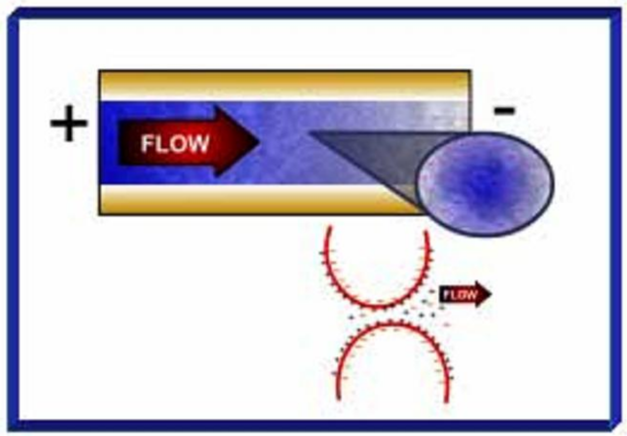
Acoustic streaming causes micron-size particles to be channeled by ultrasonic standing waves.

Electrokinetic Pump

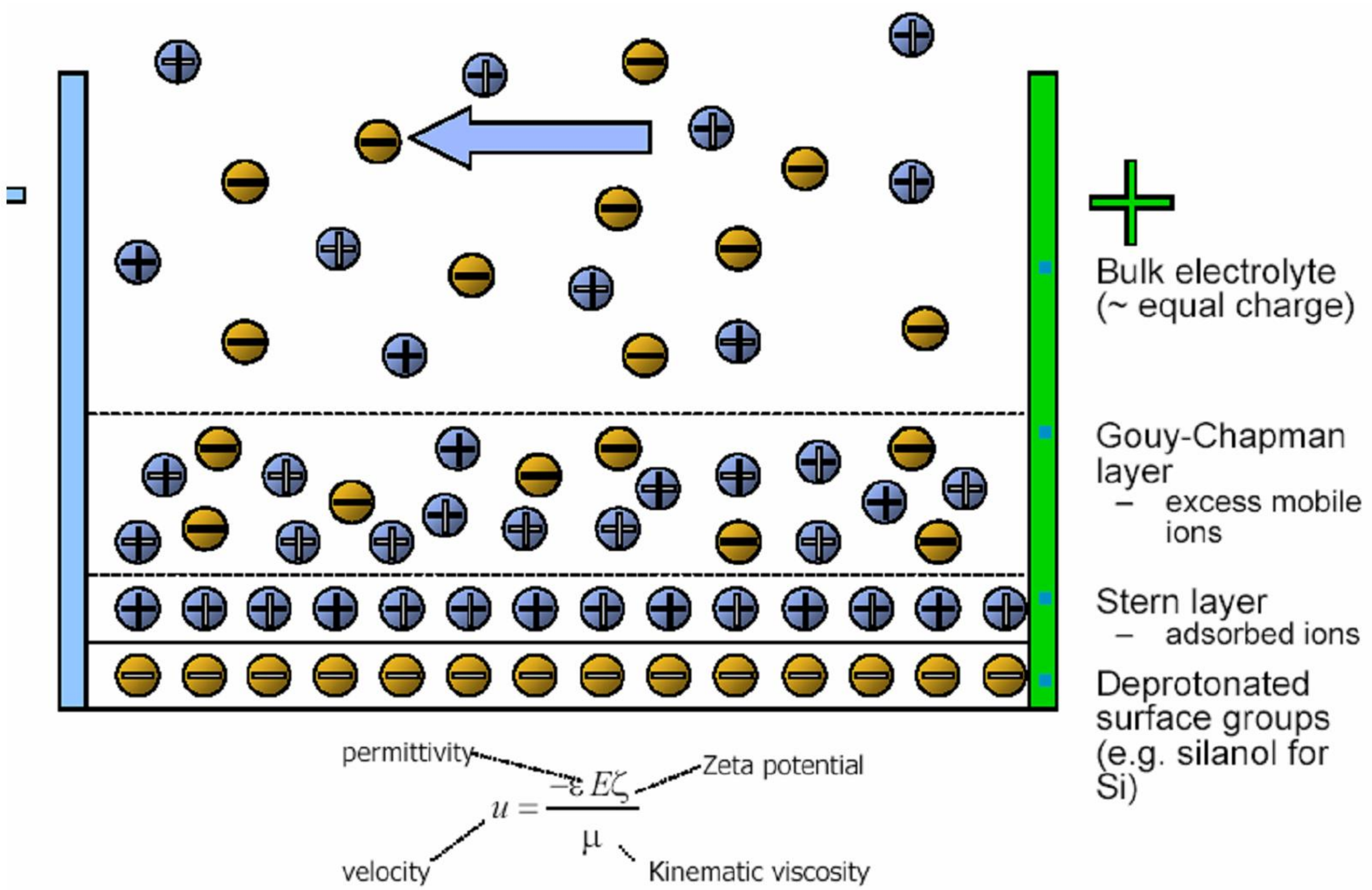
- Precise control of flow rate
- Ability to pump against substantial back pressures
- Active feedback for identification -and prediction- of leaks or blockages
- Virtually instantaneous response to step changes in flow rate setpoint

Animation: http://www.eksigent.com/tech_ekpump.htm



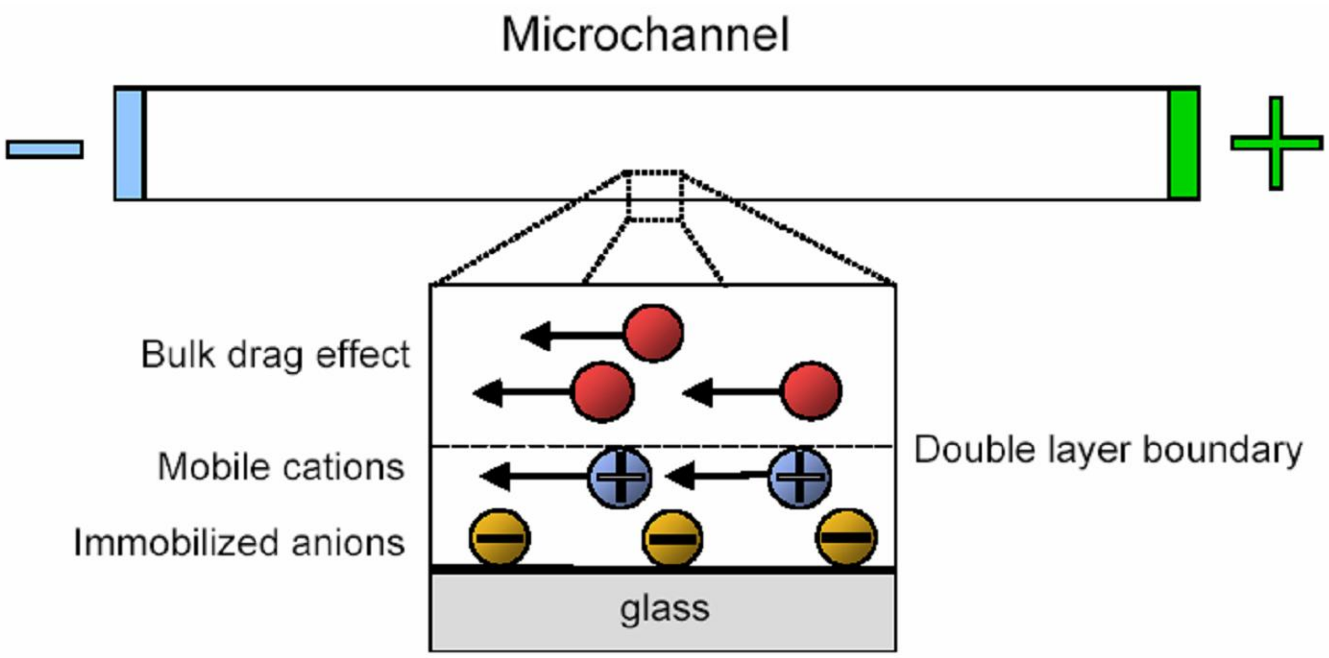


Electro-Osmotic Pump (1)



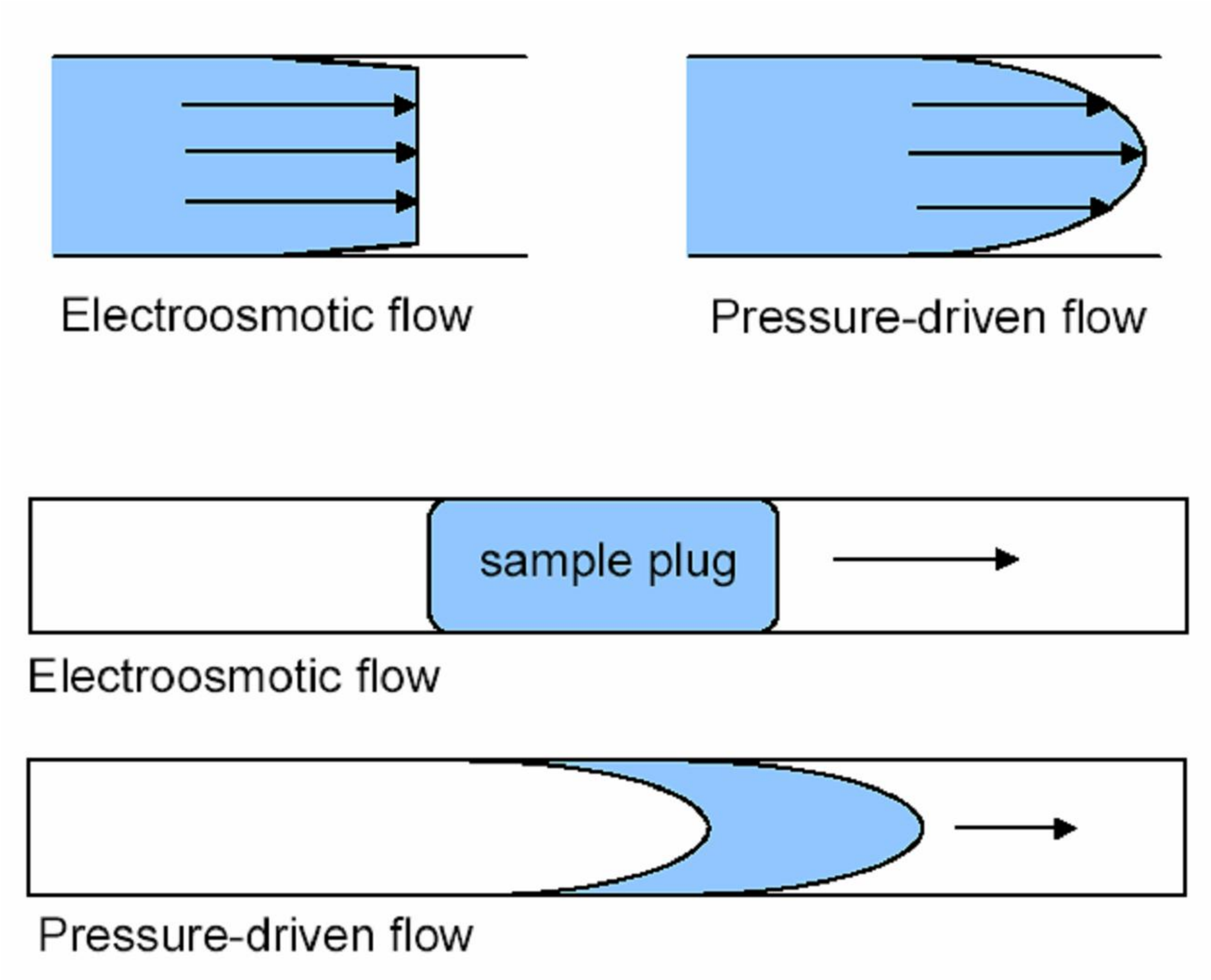
$$u = \frac{-\varepsilon E \zeta}{\mu}$$

Electro-Osmotic Pump (2)

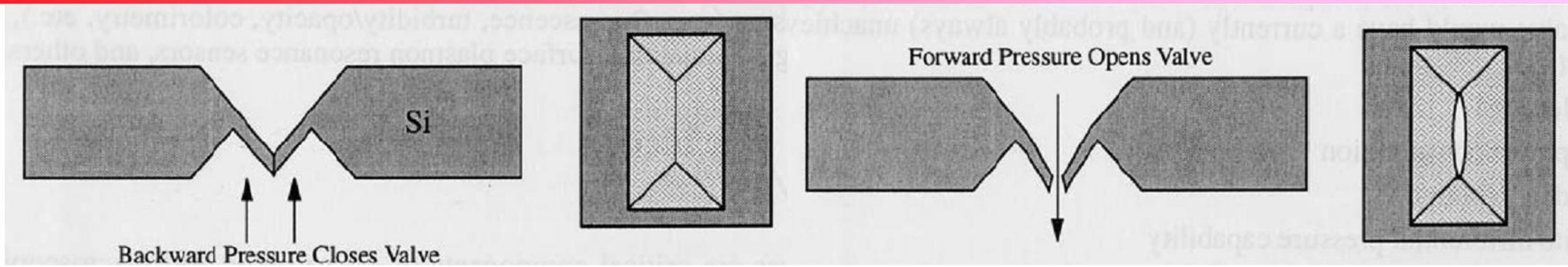


- Immobilized charges on the walls of the channels or capillary contribute to formation of double layer of opposite charges.
- The mobile charges move under the influence of the external electric field, causing bulk drag effects (flow rate is linear w/applied potential).
- Packed capillaries can generate 20atm with 2kV. (D = 530um, L = 5.4cm)

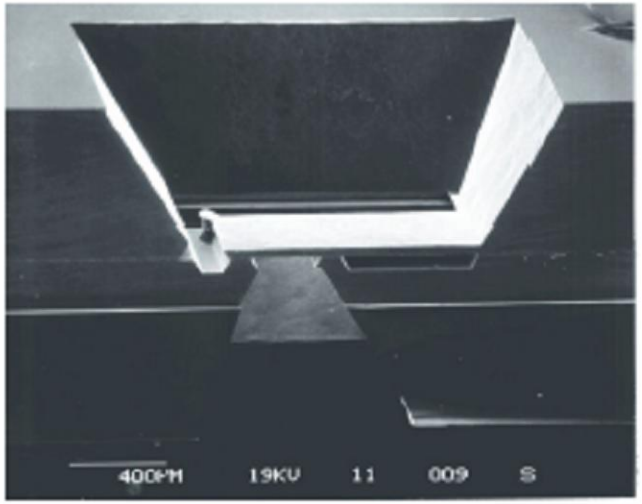
EOF Flow Profile



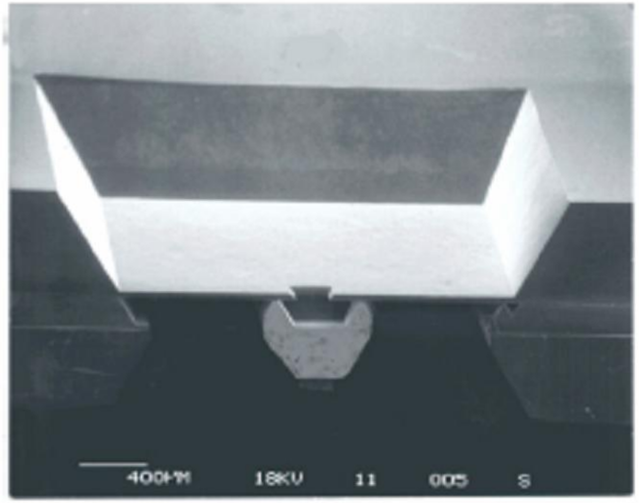
Passive Valve



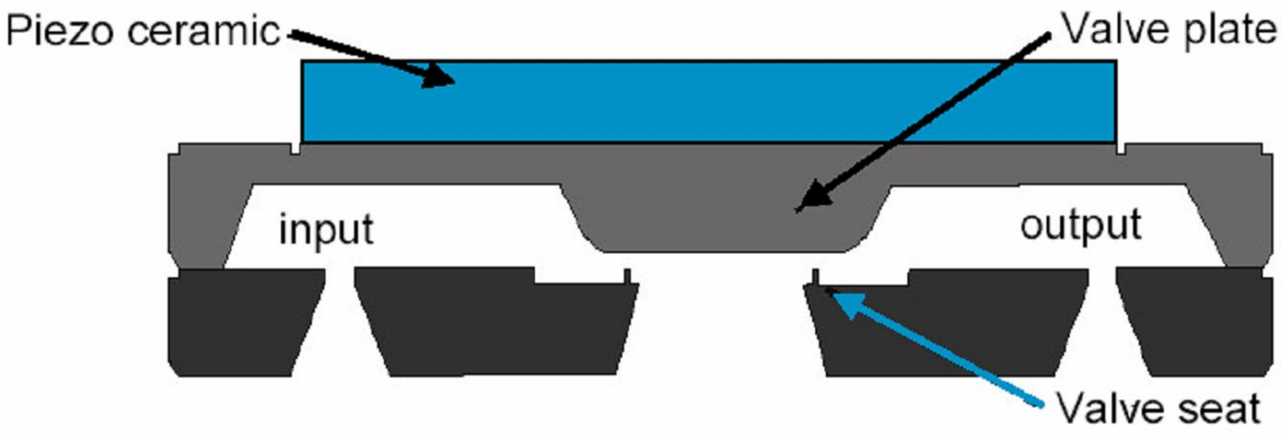
flap valve

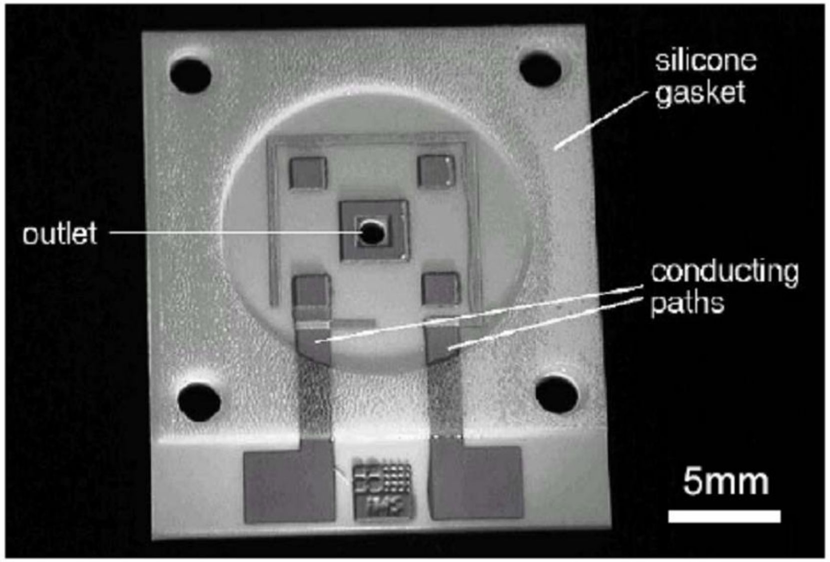


membrane valve



Piezoelectric Valve

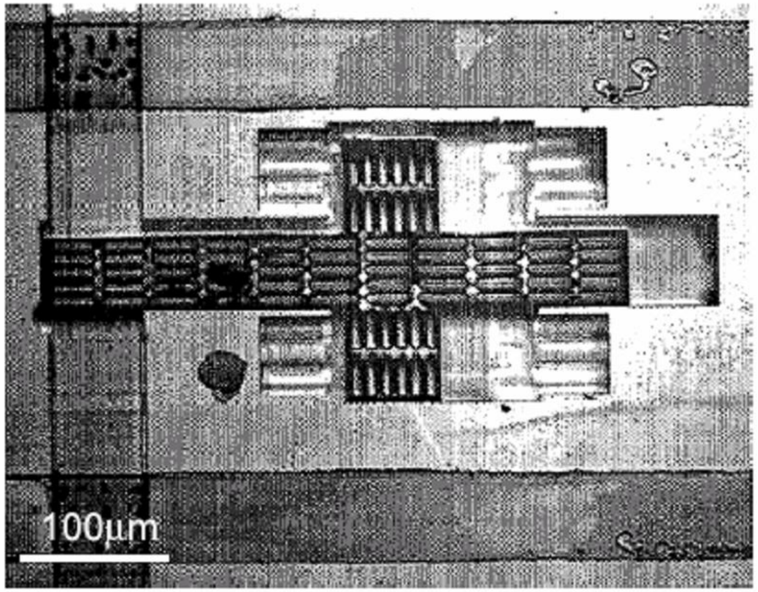




- Valve stroke = 17um (high pressure configuration)
- Leakage = 7ml/min, with 270V applied and a pressure drop of 6bar across valve.
- Valve packaged on ceramic chip carrier with silicone gasket.

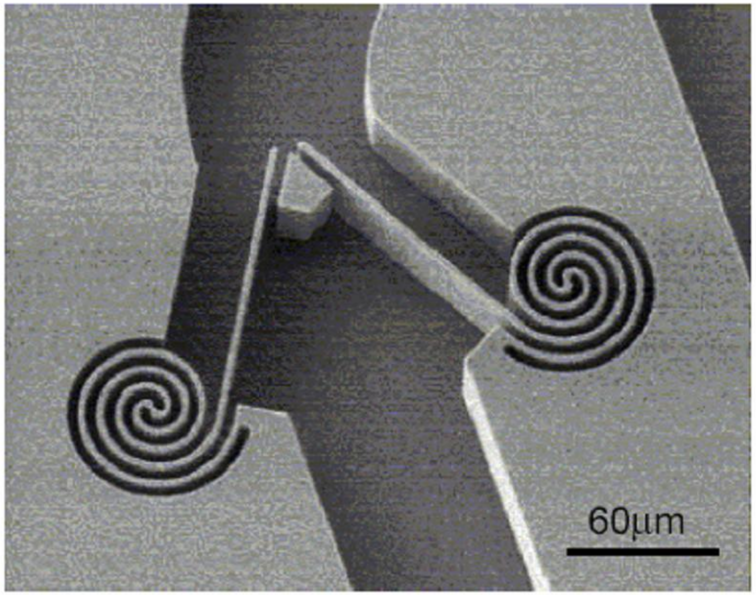
S. Kluge, Fraunhofer Institute

Planar Mechanical Valve



A. Papavasiliou (BSAC/UCB)

- **Electrolysis bubble-actuated gate valve**



J. Evans (BSAC/UCB)

- **Spring loaded check valve**

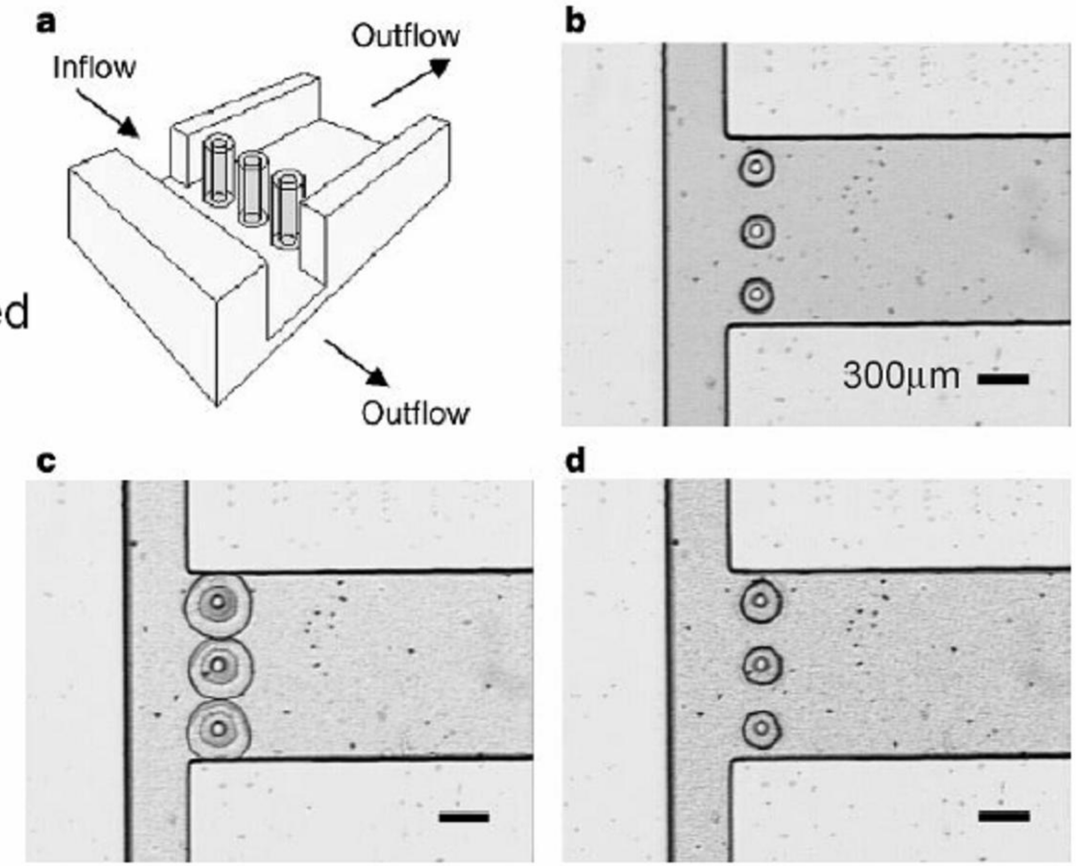
Hydrogel Microfluidic Valve (1)

Integrated within the channel, photopatterned

As fabricated

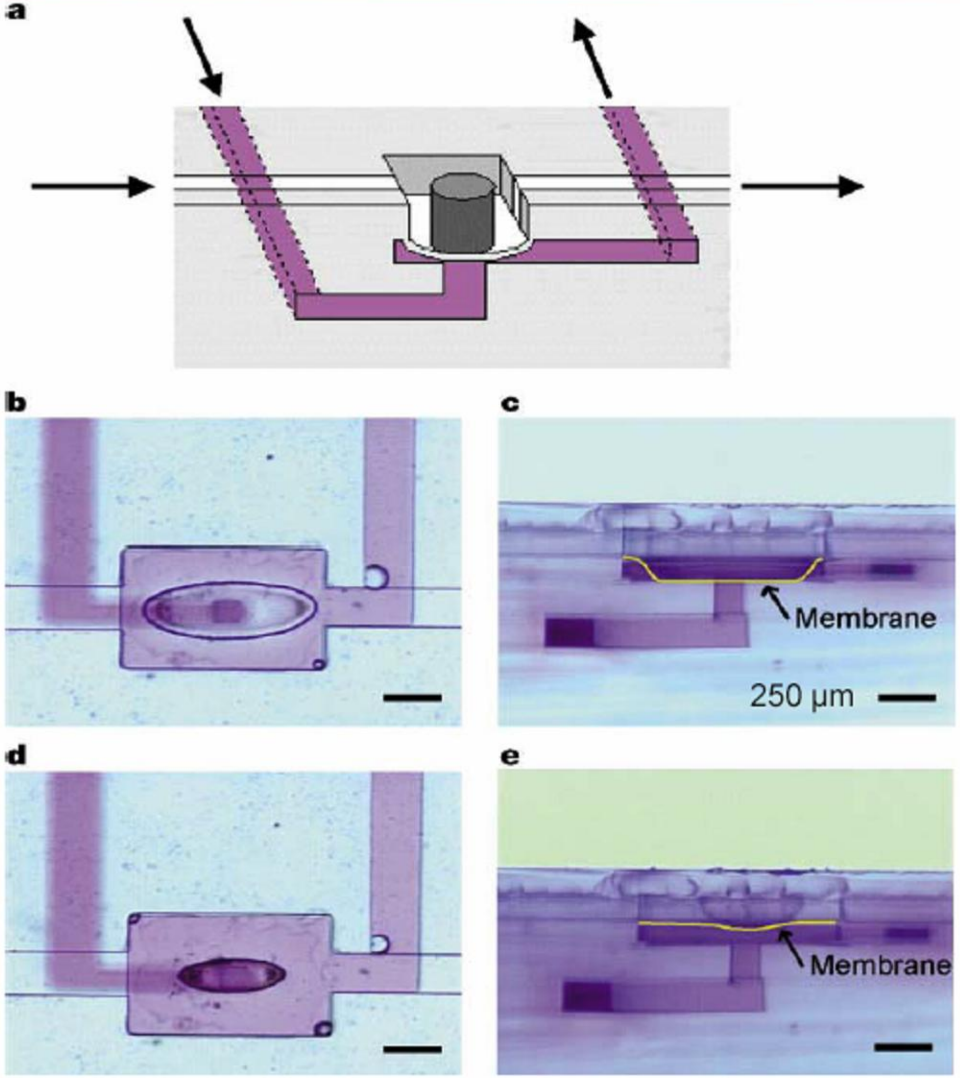
Activated in response to pH – flow is blocked

Contracted in response to pH – flow resumes



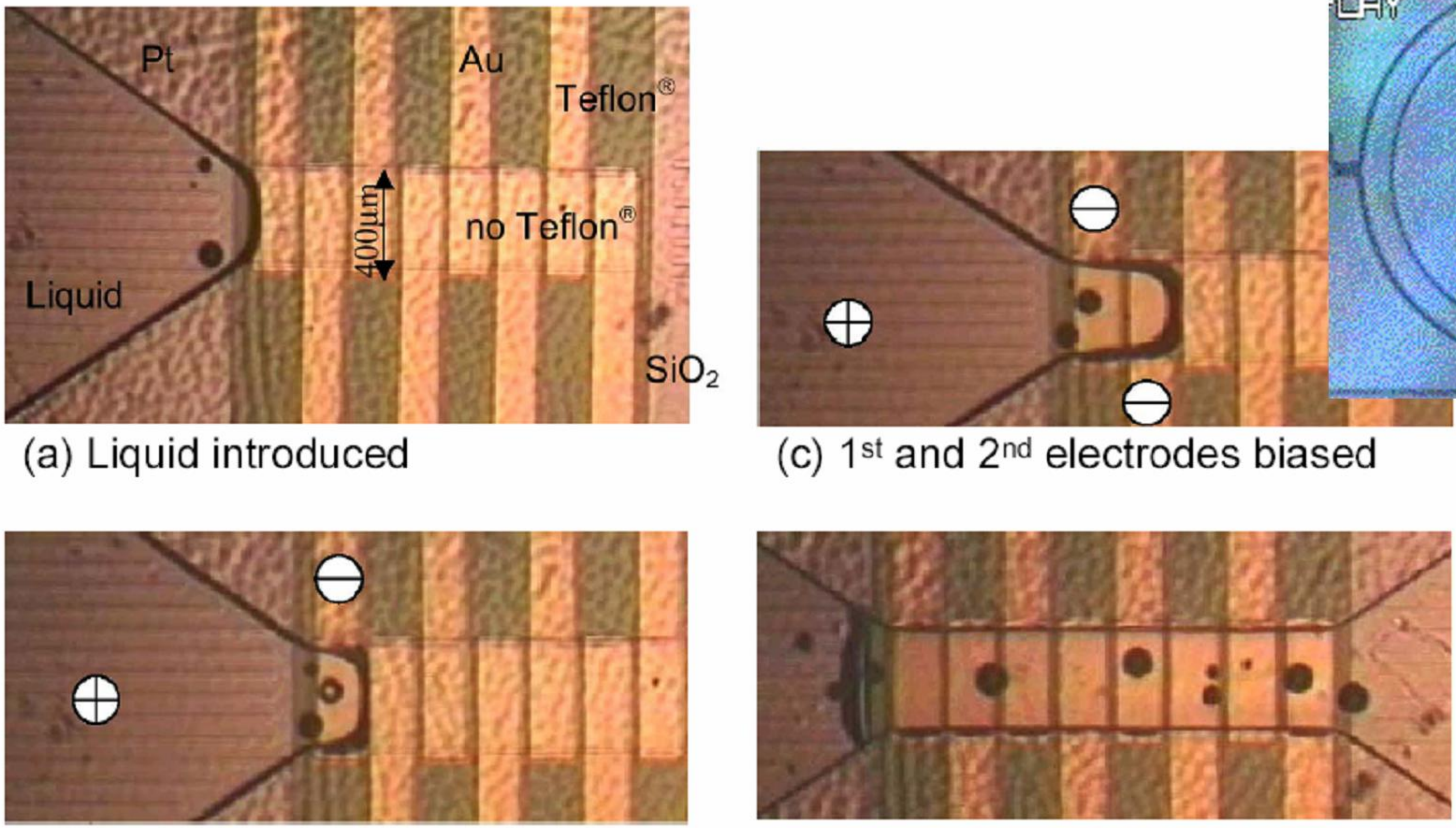
Beebe et. al., *Nature,* vol. 404, pp. 588 – 590, April 6, 2000.

Hydrogel Microfluidic Valve (2)



- In response to pH, the hydrogel structure in upper channel expands
- The membrane deforms, blocking flow in the lower channel.
- Hydrogel functions as sensor and actuator
- Stimulus can also be antigens ⇒ self regulated drug delivery, biosensing

Surface tension-based Fluid Control

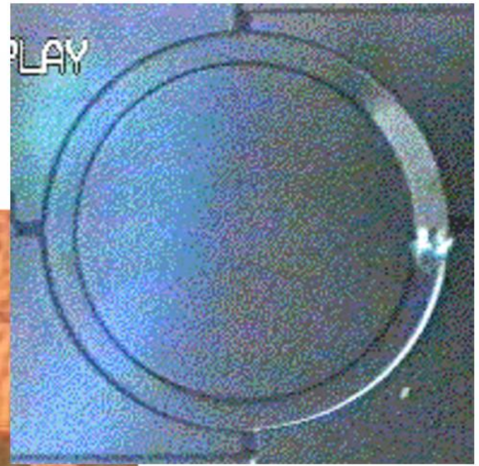


(a) Liquid introduced

(c) 1st and 2nd electrodes biased

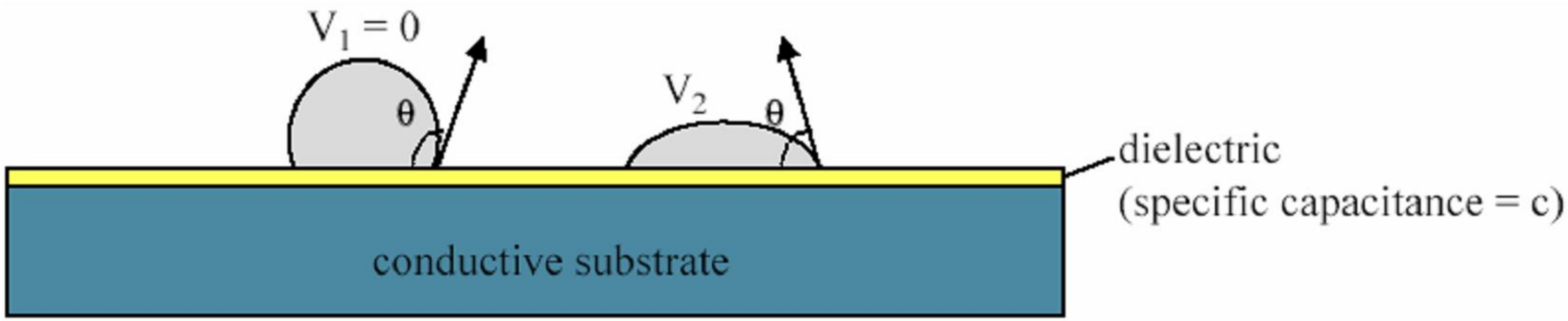
(b) First electrode biased

(d) All electrodes biased



J. Lee and C. J. Kim, UCLA/MAE

Electrochemical Wetting Principle



$$\cos(\theta) = \cos(\theta_o) + (1/2\gamma_{LG})cV^2$$

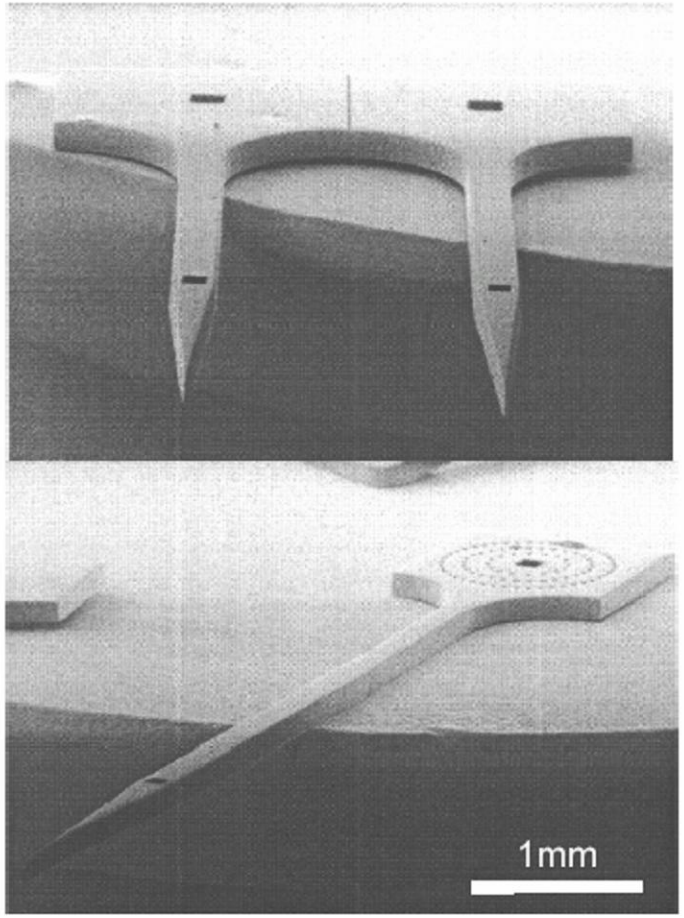
θ is contact angle

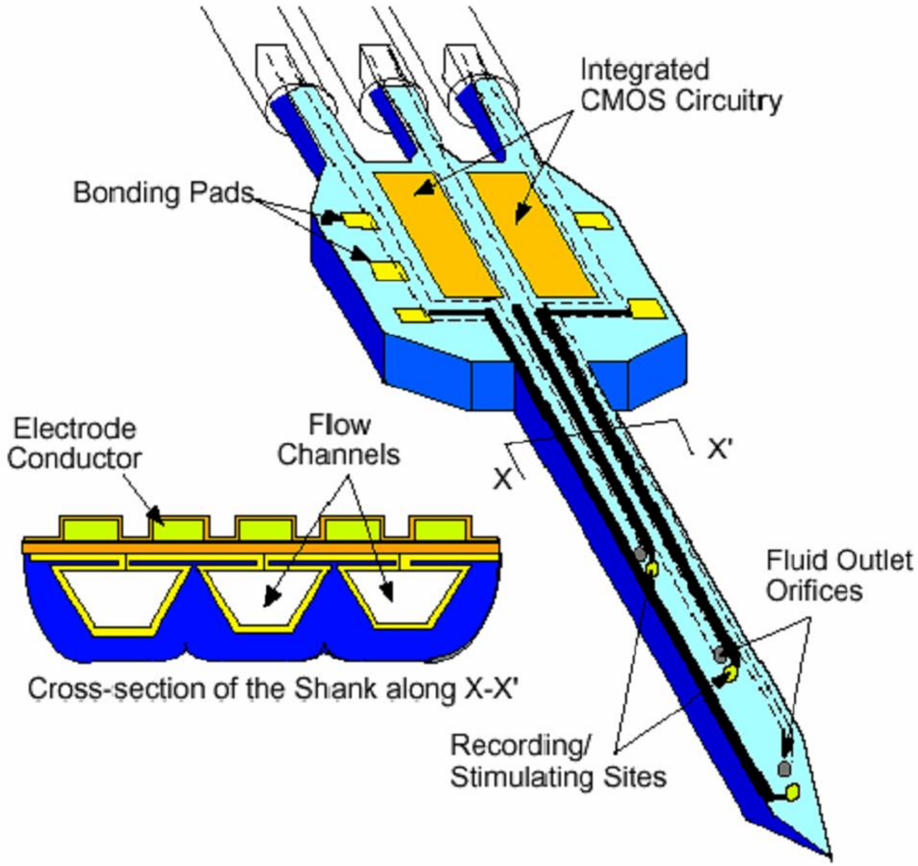
γ_{LG} is liquid-gas surface tension

c is specific capacitance of dielectric

V is applied voltage

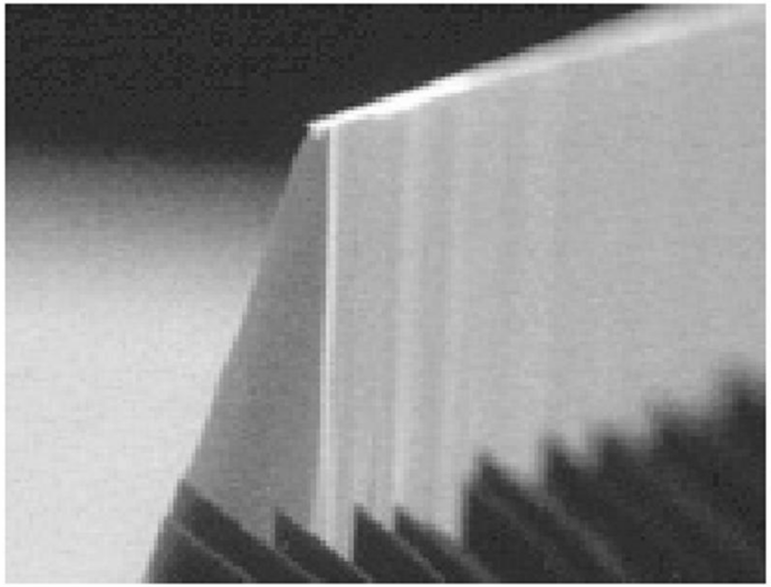
Drug Delivery Platforms

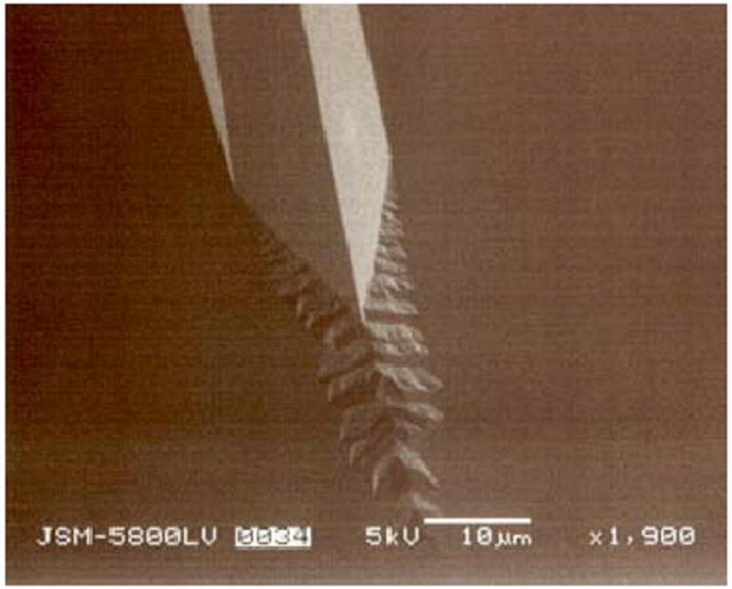




Photos courtesy of N. Talbot and A. Pisano, UC Berkeley
Diagram courtesy of K. Wise, U. Michigan.

MEMS Microblades

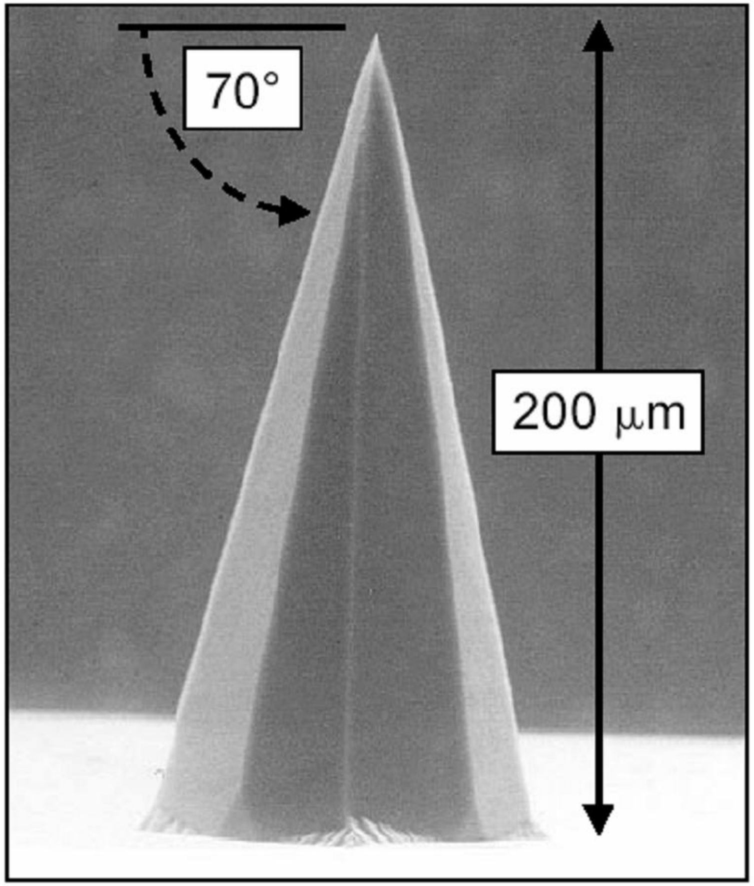


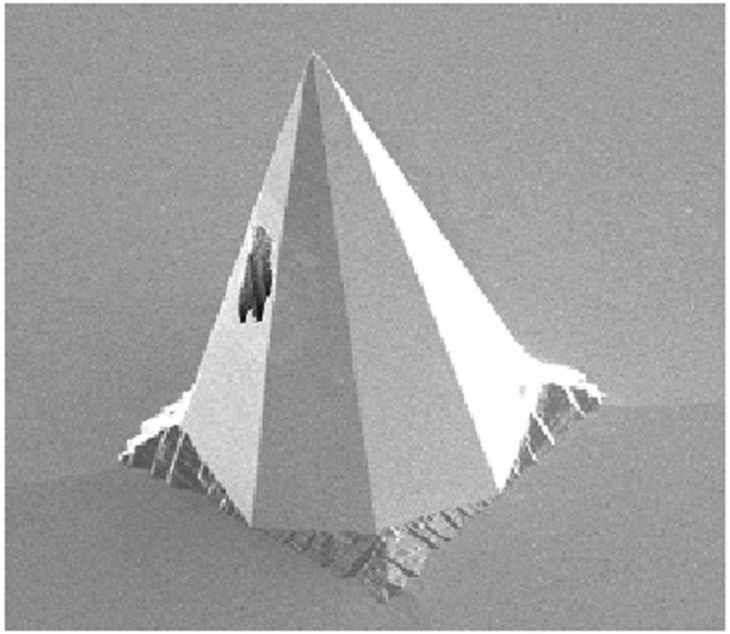


- Silicon micro-blades etched via chemical etching
- May be used for delicate microsurgery
- Microneedles fabricated in a similar fashion

Fabricated at Standard MEMS, Inc.

Drug Delivery Microneedles





- Single crystal silicon
- Bulk micromachined
- Higher order planes exposed
- Laser drilled hole

Fabricated at Standard MEMS, Inc.