Microfluidic Devices

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- Components of microfluidic devices
  - Pump
  - Valve
  - Mixer
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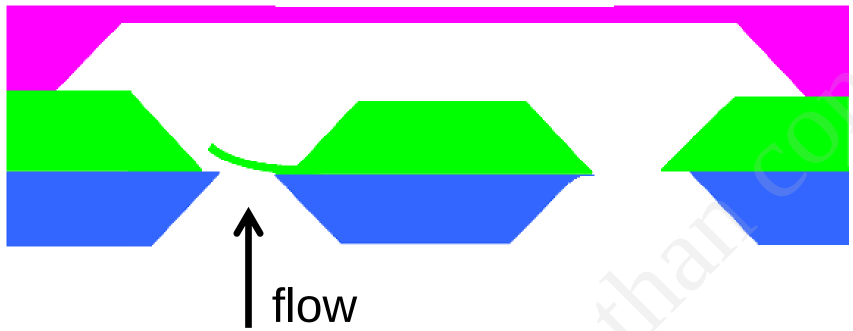
  - Design Structure and Fabrication
  - Application

Introduction

- Total analysis system (TAS): was first introduced in 1980s for analysis in chemical as well as biochemica l.
- Micro total analysis system (µTAS): was first develop ed in 1990s. µTAS combines microfluidics, mechanic al actuators, and transducers for complete analysis i n micro chip.
- Now µTAS was broaden to synthesize and other app lication. In general, it was known as Microfluidic devi ce or Lab on a chip devices.

Microvalve

- Passive valve (check valve): no actuation for control, unidirectional flow.



Depend on the strength of fl ow, we have stiffness of flap .

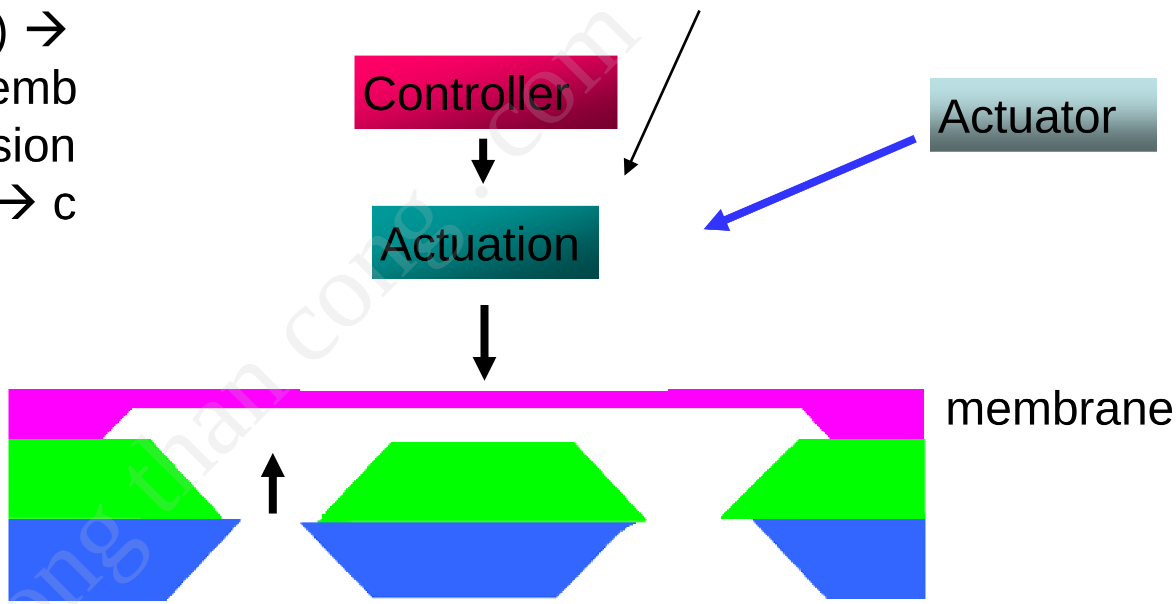
- Active valve: require an actuator to provide a mechanical action. The actuation include piezoelectric, electrostatic, electromagnetic, pneumatic, thermopneumatic actuation, bistable, phase-change.

Microvalve

Electric: static, piezo
Magnetic
Thermal expansion
Ultrasonic

Design

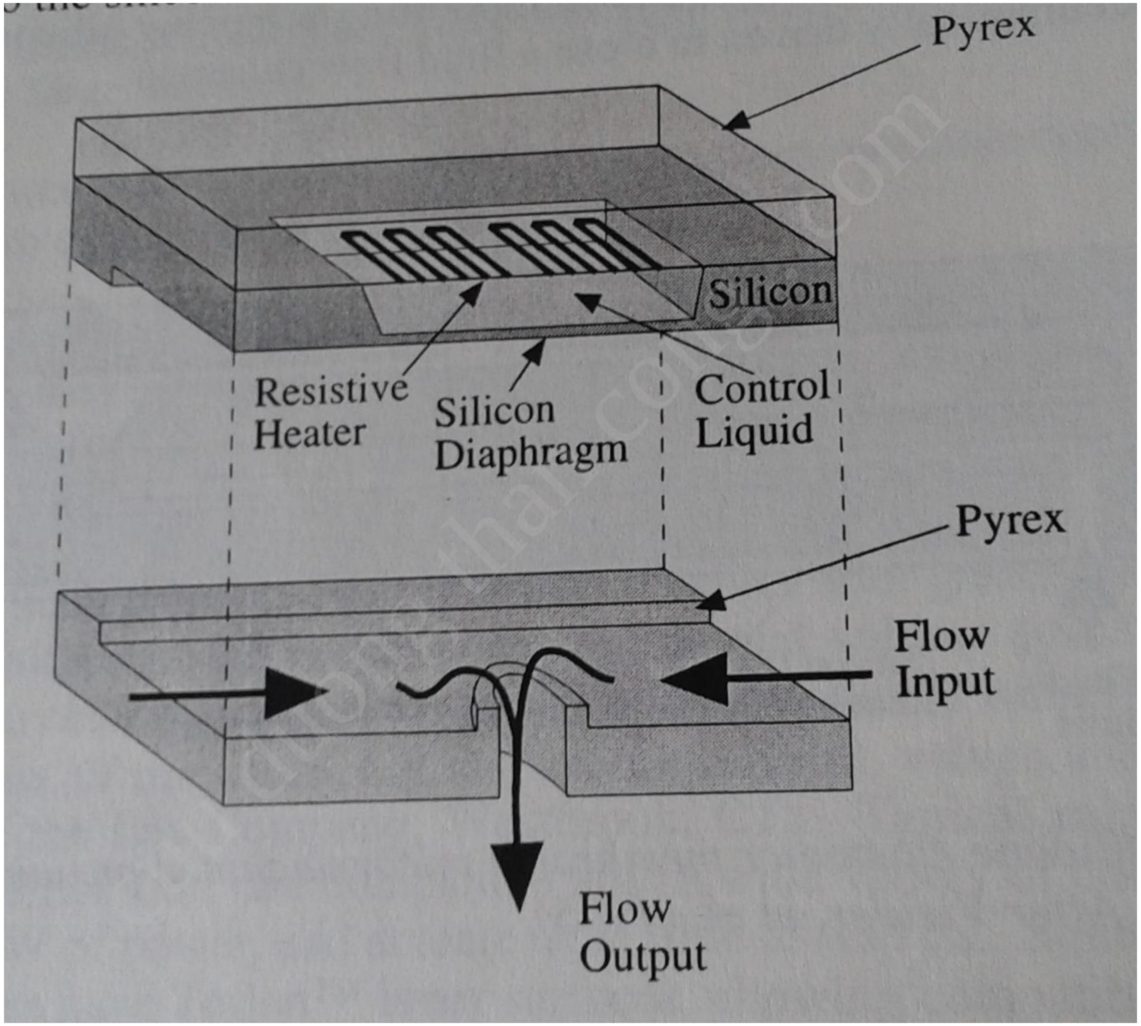
Flow rate (velocity, dimension) → size of valve → stiffness of membrane relate to material, dimension → deflection → applied force → choice the actuation.

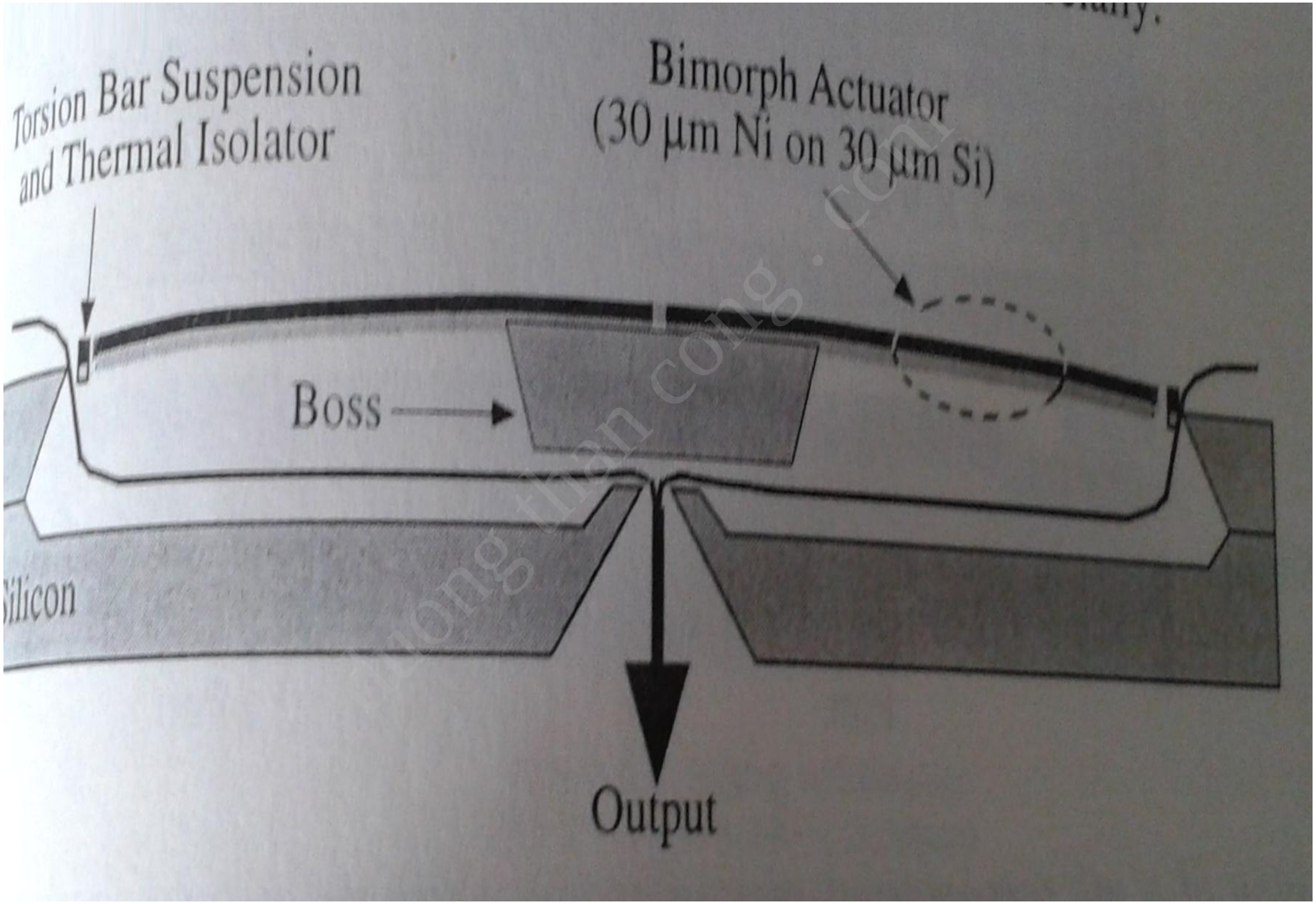


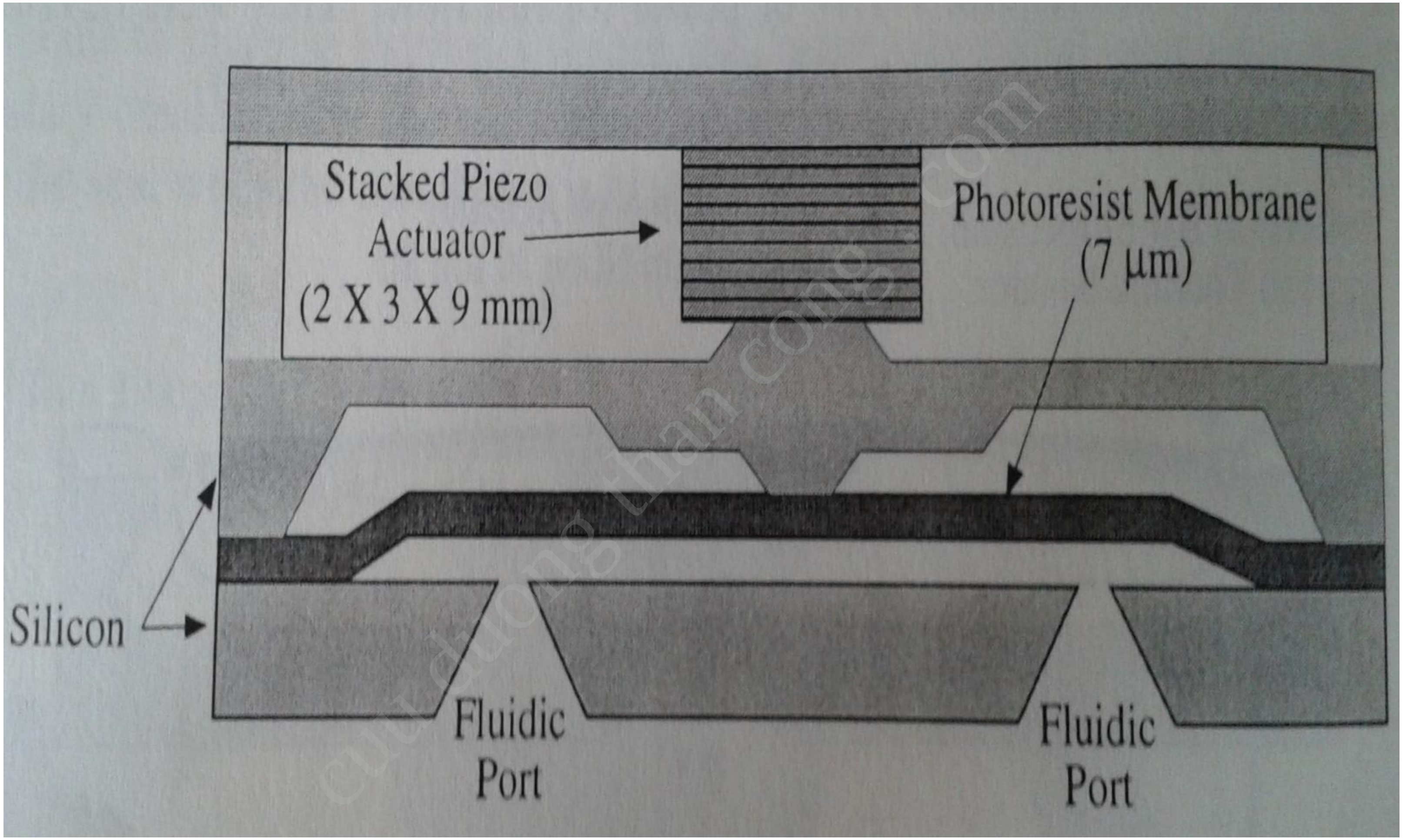
In micro fluidic:

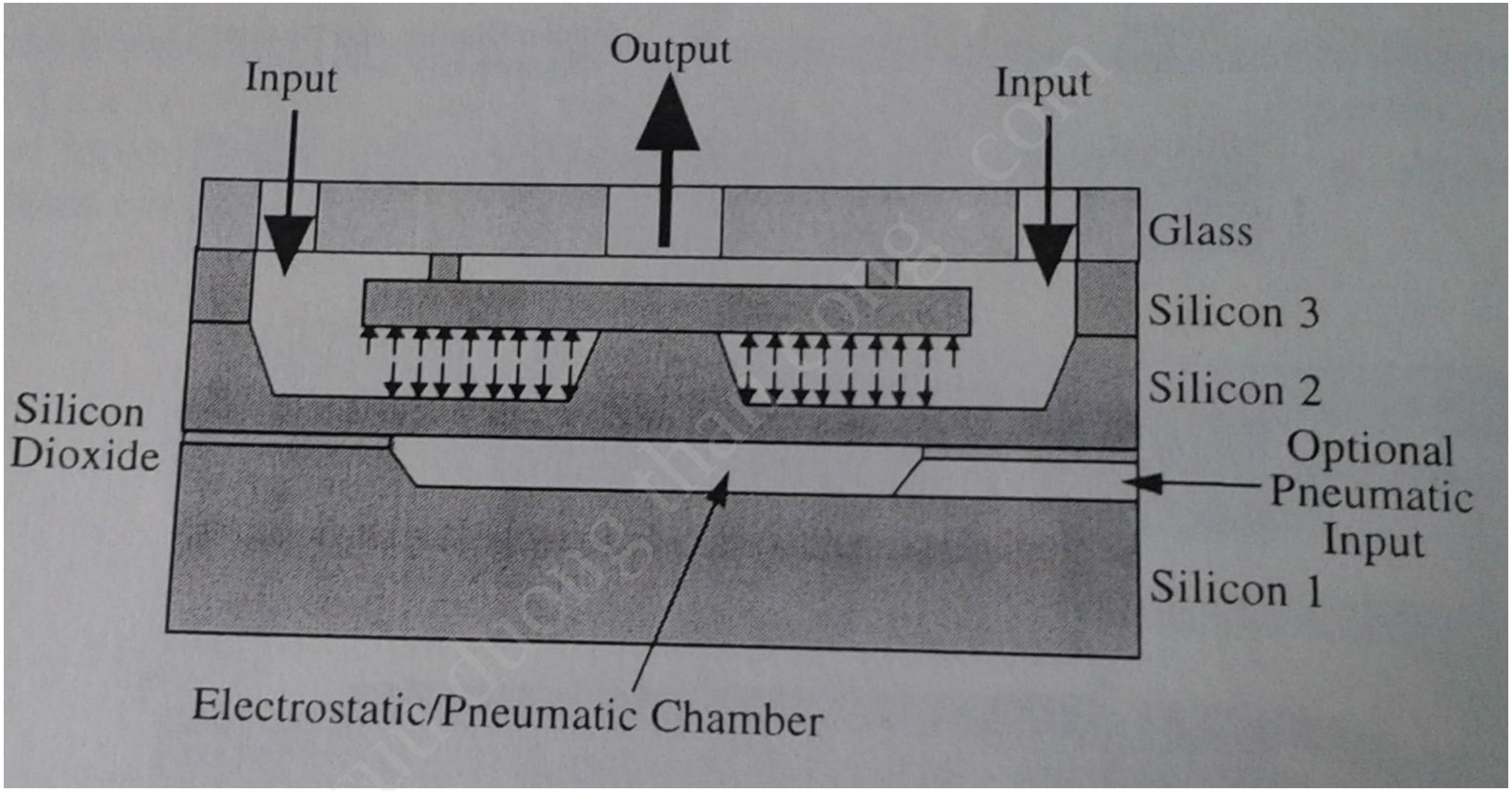
Membrane: silicon or glass (often 50 µm thickness, 2mm x 2mm), sometimes polymer.

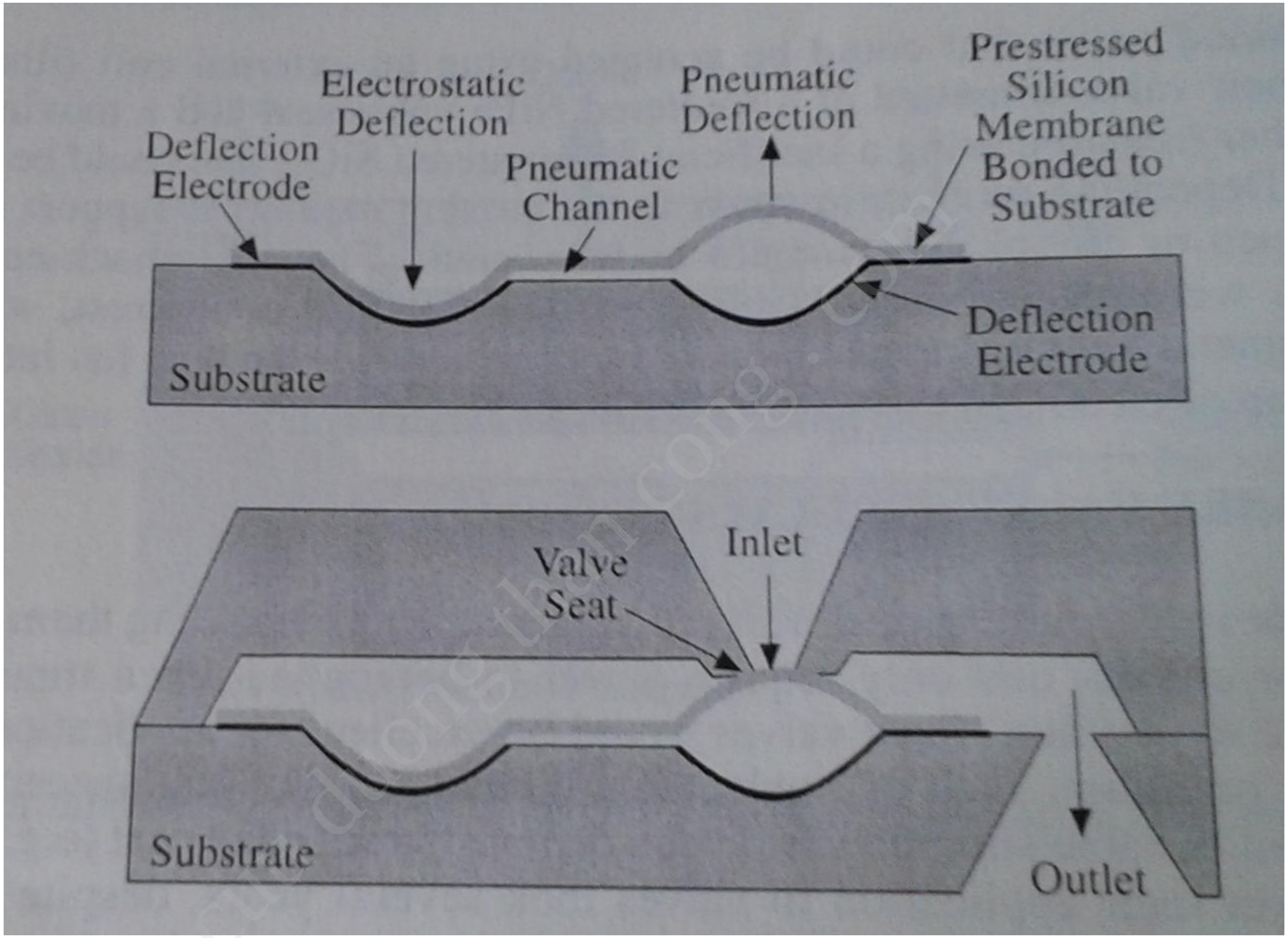
Glass/silicon were wet etching by HF/KOH or dry etching. Then they were anodic bonding.


Pyrex
Silicon
Resistive
Heater
Silicon
Diaphragm
Control
Liquid
Pyrex
Flow
Input
Flow
Output


Torsion Bar Suspension
and Thermal Isolator
Bimorph Actuator
(30 µm Ni on 30 µm Si)
Boss
Silicon
Output


Stacked Piezo
Actuator
(2 X 3 X 9 mm)
Photoresist Membrane
(7 µm)
Silicon
Fluidic
Port
Fluidic
Port


Output
Input
Input
Glass
Silicon 3
Silicon 2
Silicon
Dioxide
Optional
Pneumatic
Input
Silicon 1
Electrostatic/Pneumatic Chamber



Bistable valve

Micropump

- Micro pumps are used for pumping fluid into micro channel.
- Classified micropumps
  - Mechanical pump (reciprocate or rotary)
  - Non mechanical pumps (pressure driven, electro kinetic flow, diffuser/nozzle…).
  - Valve pumping action / Valveless pumping action.

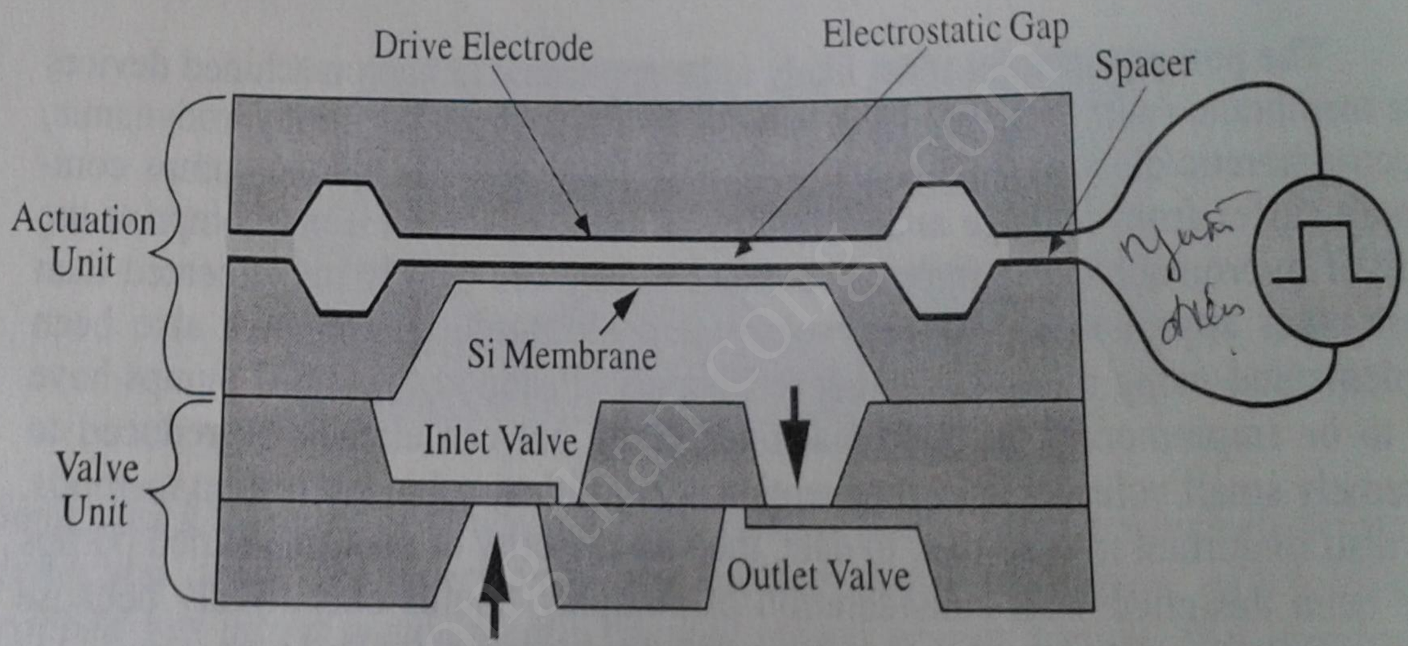


Illustration of a micromachined, electrostatically actuated, reciprocating liquid pump. After Zengerle, et al. (1995a).

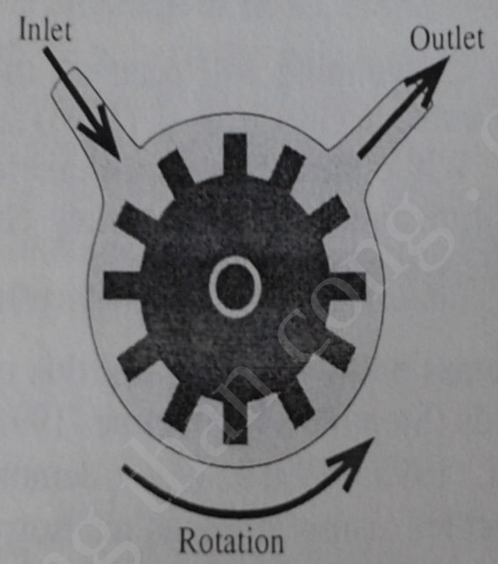
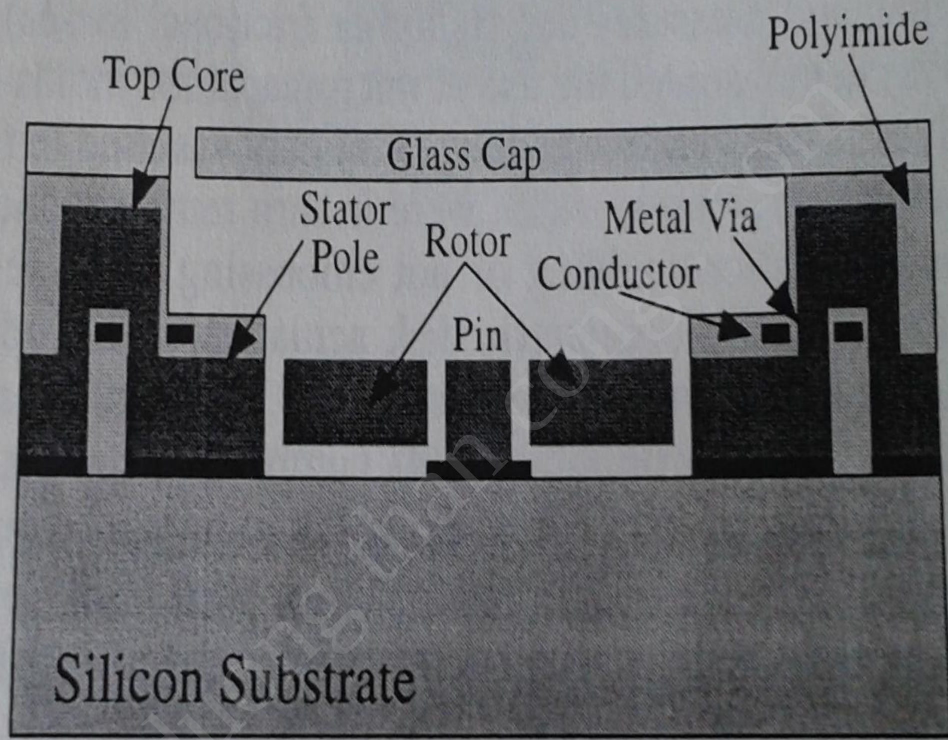
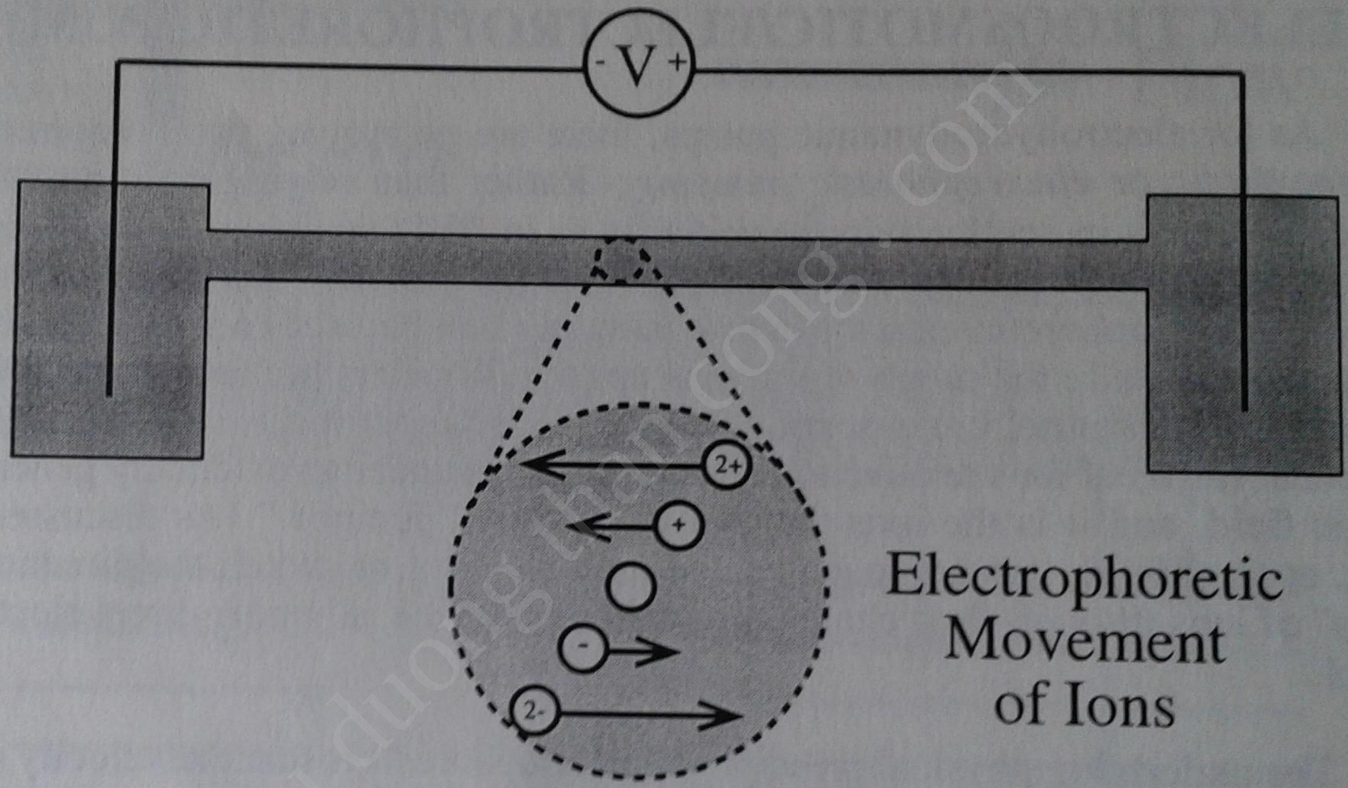


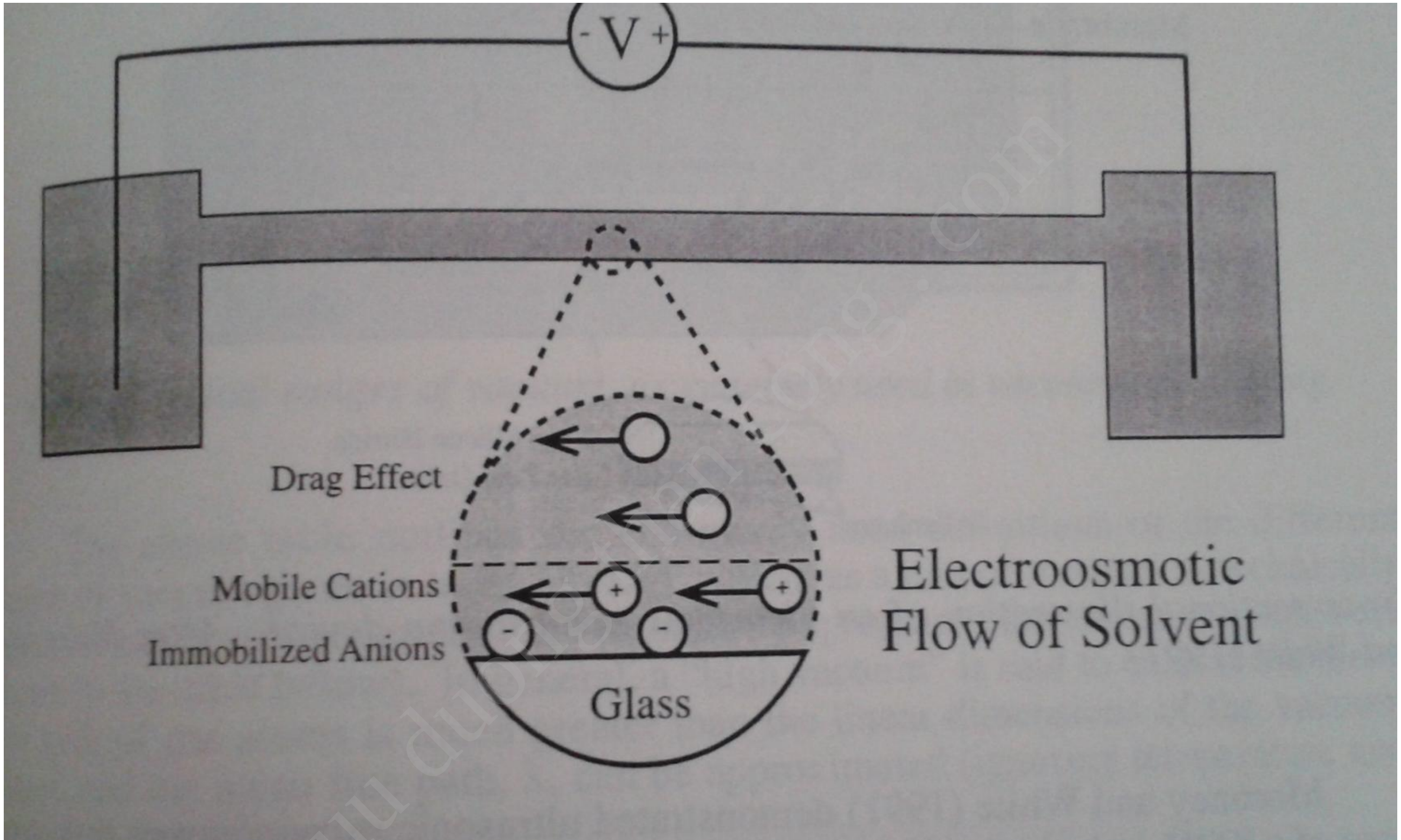
Illustration of the basic concept of a rotary "jet-type" pump. After Ahn and Allen (1995).



Cross-sectional llustration of a micromachined magnetic rotary pump. After Ahn and Allen (1995). Note that the magnetic coils were monolithically integrated.



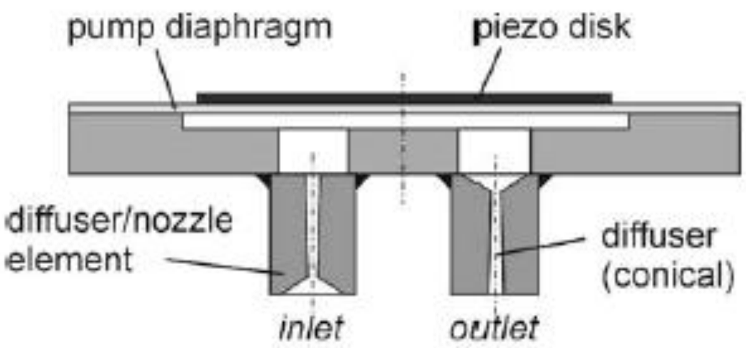
Conceptual illustration of electrophoresis. After Manz, et al. (1994).



Conceptual illustration of electroosmotic pumping. After Manz, et al. (1994).

Valveless pumping action

Diffuser/Nozzle pumps



Schematic of diffuser pump

Bernoulli: (static pressure) + (dynamic pressure) x (pressure loss coefficient)= const

So ξ is high, the energy of flow decrease fast

$$\Delta P_d = \frac{\rho v_d^2}{2} \xi_d$$

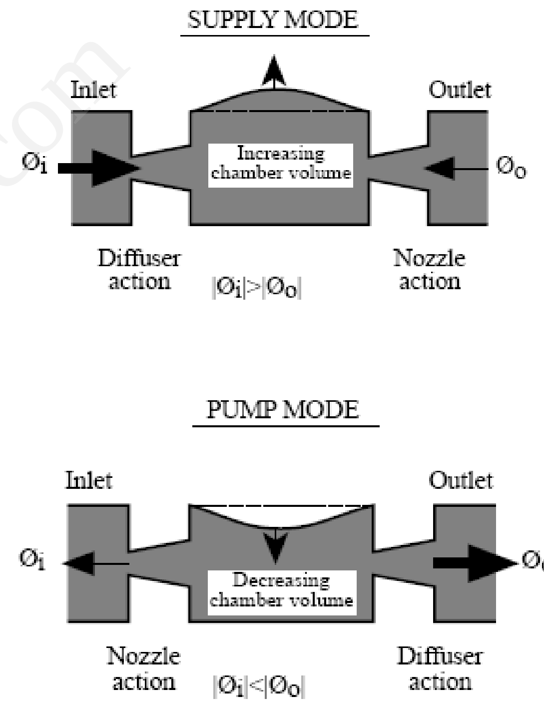
Diffusion action

$$\Delta P_n = \frac{\rho v_n^2}{2} \xi_n$$

Nozzle action

If ξn is greater ξd, pumping action will occur.

Principle working



ΔP_d , ΔP_n : pressure across the diffuser, nozzle

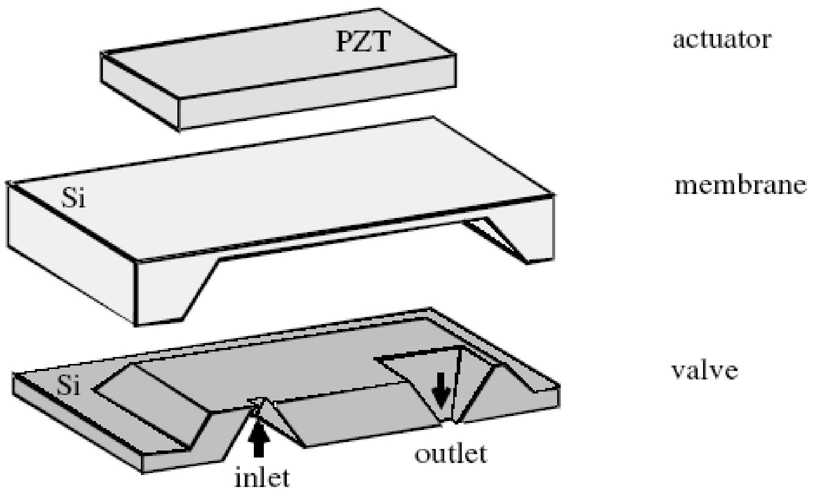
ξ_d, ξ_n : pressure loss coefficient

V_d, V_n: mean velocities

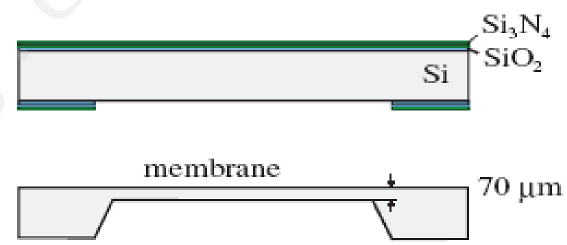
J. Micromech. Microeng. **12** (2002) 420-424

PZT: 6x6 mm^2, 250 um thickness

(PZT-5H plate from Morgan Matroc Ltd)



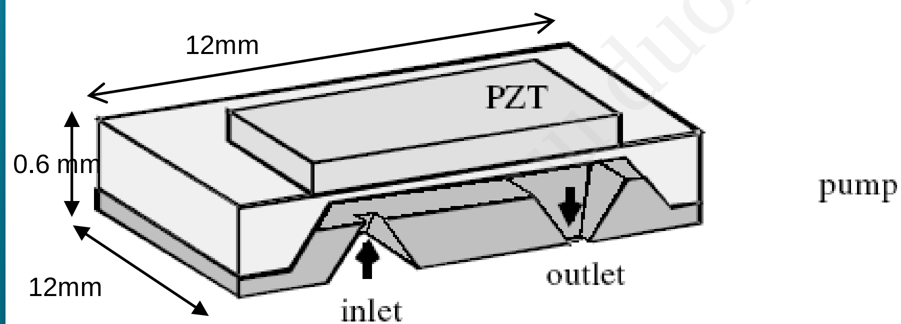
Si membrane: 7mm x 7mm x 70um

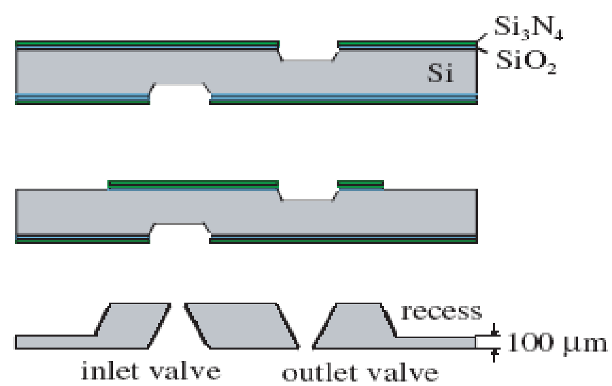


Bonding

PZT glued with Si membrane by conductive epoxy

Valve





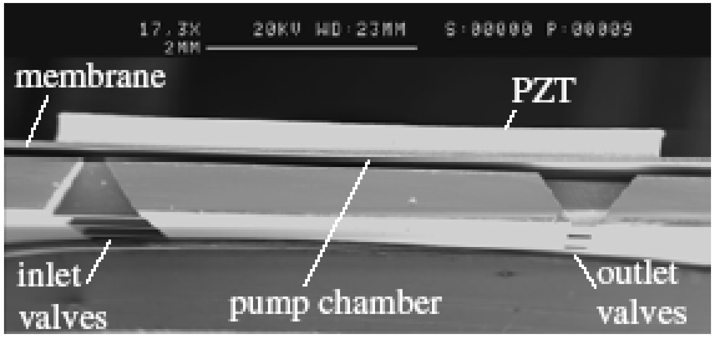
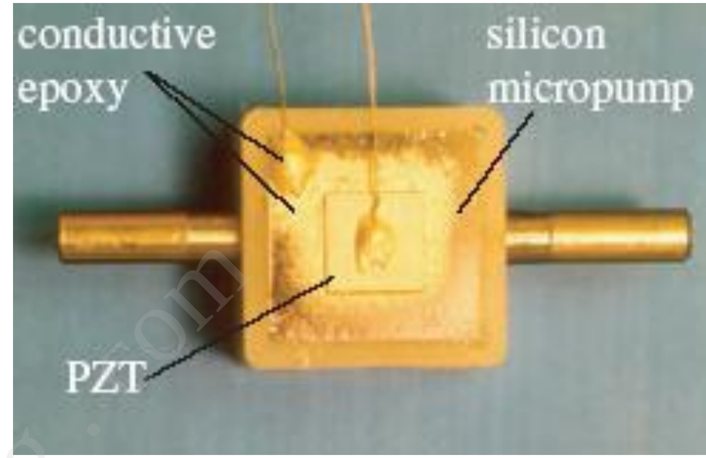


Figure 5. Cross-section of the assembled micropump.



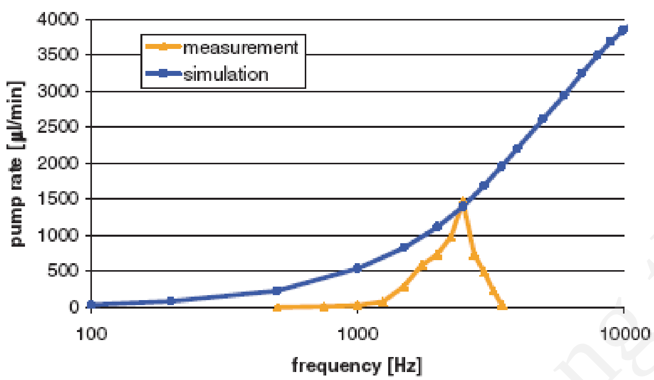
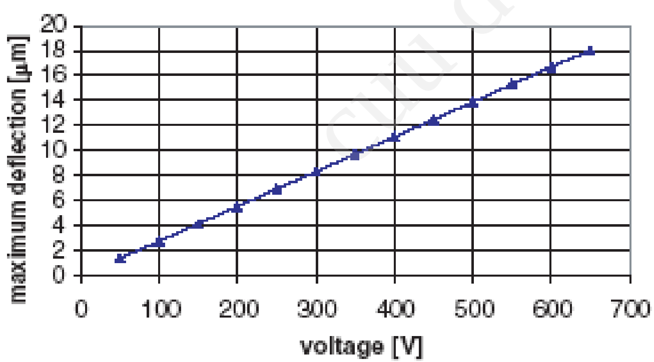


Figure 11. Pump rate of the hybrid actuated micropump for sinusoidally shaped actuation: frequency dependence; $U = 190\ V_{pp}$.



Pump connect power

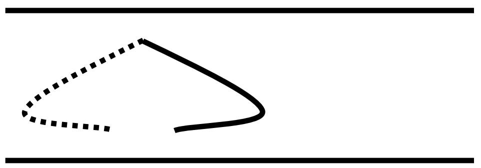
Test with ethanol, pump rate maximum 1500 µl/min at 2.5kHz, with backpressure 1000 Pa.

Real measurement difference simulation because of:

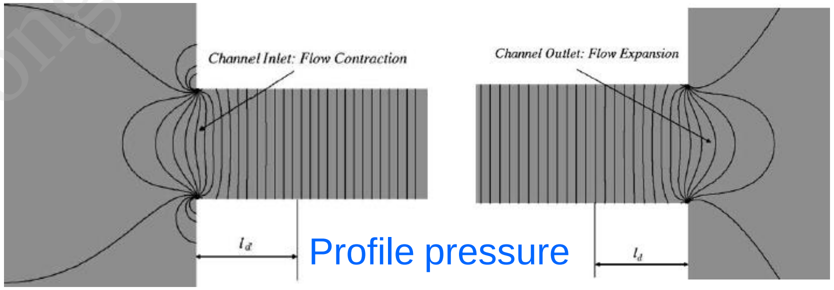
- hydrodynamic phenomena

Flow transport by pressure/electrickinetic

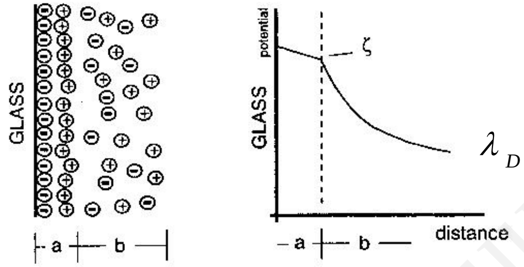
Pressure driven flow: parabolic profile velocity due to visc osity.



Electric-osmotic flow→ have band broadening due to induced pressure gradient.



Journal of Colloid and Interface Science 275 (2004) 670–678



a: fixed layer (Helmholtz or Stern layer)
b: diffuse layer (Gouy-Chapmann layer)

$$\lambda_D = \sqrt{\frac{\varepsilon RT}{2F^2 z^2 c}}$$

Schematic of electric double layer model

$$\mu_{eo} = \frac{\varsigma_o \varepsilon}{4\pi\eta}$$

$$v_{eo} = \mu_{eo} E$$

R: universal gas constant

T: absolute temperature

F: Faraday constant

z: charge number

c: concentration

ε: dielectric constant

Characteristics of fluid in micro scale

- Affected Force: capillary force (because of surface tension) inst ead of inertia in macro flow.

$$F_{cap} = 2\pi r \gamma \cos \theta$$

- Viscosity is significant effect.
- High interface to volume ratio: interaction between liquid an surf ace wall is strong → high fluidic resistance. The smaller channel si ze, the bigger fluidic resistance.

With circular cross s ection

$$resis = \frac{8\eta L}{\pi R^4}$$

R: channel radius

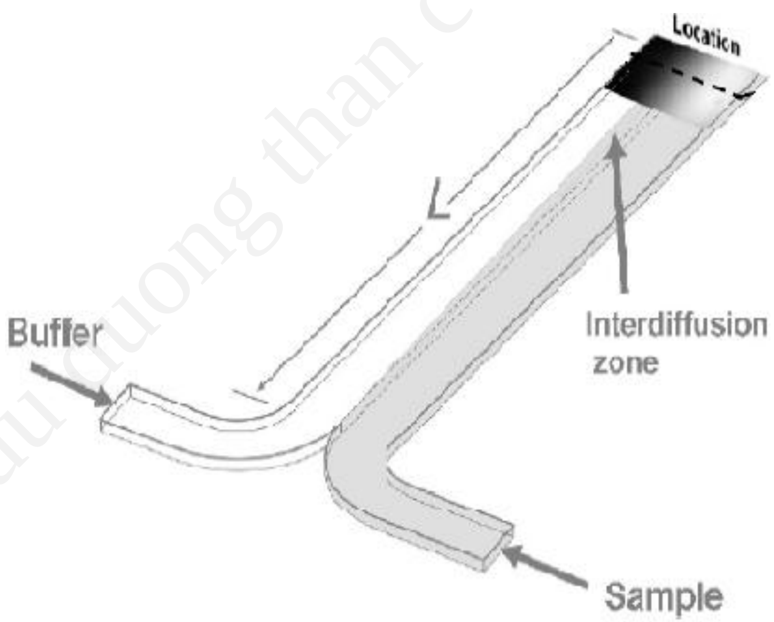
L: channel length

η: viscosity

Mixer and channel

Mixer: to attain a homogeneous of two solutions in as little time as possible.

- Passive mixer: only base on diffusion (internal energy).
- Active mixer: use external energy to induce turbulence.



Mixer and channel

How to improve the mixing?

Passive mixer:

Reduce diffusion distance → reduce time according to Einstein-Smoluchowski equation.

Split channel into an array of smaller channels → to increase the contact areas.

Form groove across the channel or block for change direction flow → induce turbulence.

E-S equation

$$x = \sqrt{2\,Dt}$$

x: diffusion distance

t: diffusion time

D: diffusion coefficient

Active mixer:

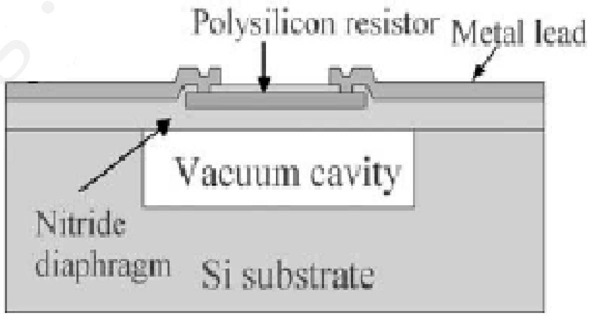
Applied voltage across the mixing chamber.

Used pump to make bubble.

Sensor

In microfluidic, we need to measure

- Flow rate (pressure, velocity) → mechanical sensor (Piezoresistive or cap acitive)
- Temperature of flow → temperature sensor
- Concentration of solution → optical sensor



Piezoresistive pressure sensor

pressure

↓

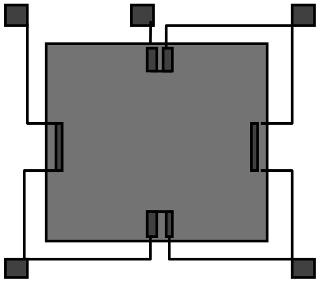
Elastic element (membrane)

+

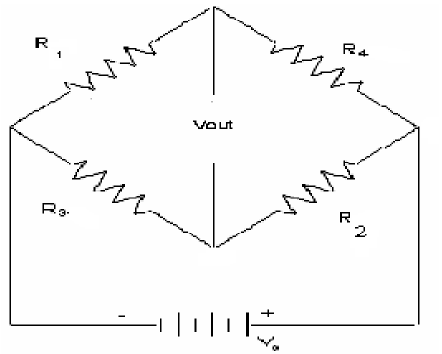
Sensitive element (resistor)

↓

Voltage



Polysilicon (0.5um) was deposited, doped.



Wheatstone bridge

Micro Total Analysis System (µ_TAS)

- To design a µ_TAS, we must answer for What is purpose o f device? Which is the fluid concern?
- Whether in chemical or in biology, device must be inert or c ompatible with fluid.

Common components of µ_TAS

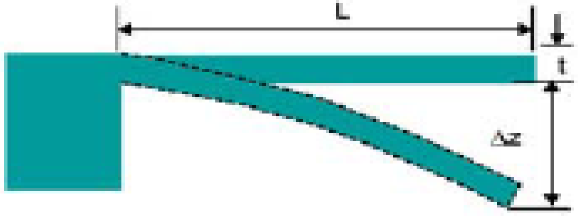
Sample preparation	+	Mixer / reactor	+	Separation	+	Detection
Injection (discrete/ co ntinuous)				Electrophoresis		Mechanical
Filter				Chromatography		Electrical
				Mass spectrocopy		optical

Sensing mechanism

- Mechanical sensing
  - – Mass sensing
  - – Stress sensing
- Optical sensing
  - - Fluorescence
  - - Luminescence
- Electrochemical sensing
  - – Potentiometric
  - – Conductometric
  - – Amperometer

Mechanical sensing

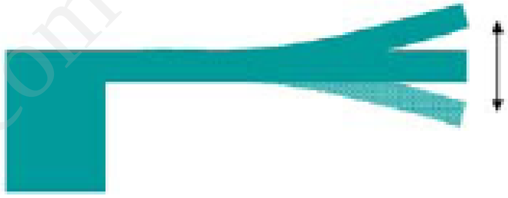
Stress sensing



$$\Delta z = 4\left(\frac{l}{t}\right)^2 \frac{(1-\nu)}{E}(\Delta\sigma_1 - \Delta\sigma_2)$$

- Δz = deflection of the free end of the cantilever
- L = cantilever length
- t = cantilever thickness
- E = Young's modulus
- ν = poison's ratio
- $\Delta\sigma_1$ change in surface stress on top surface
- $\Delta\sigma_2$ change in surface stress on bottom surface

Mass sensing



$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

$$\Delta m = \frac{k}{4\pi^2}\left(\frac{1}{f_1^2} - \frac{1}{f_o^2}\right)$$

- k = spring constant
- m = mass of cantilever
- f_0 = *unloaded resonant frequency*
- f_1 = *loaded resonant frequency*

Electrochemical sensing

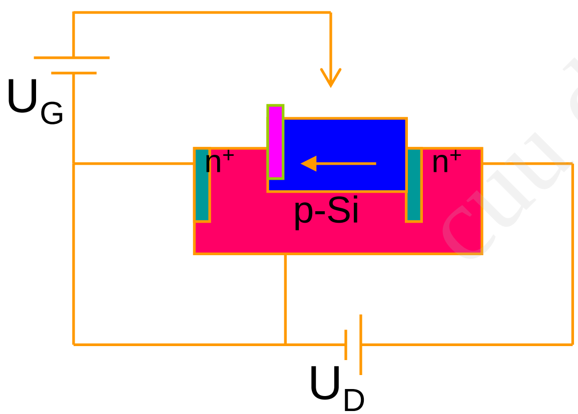
Chemical Energy, —Galvanic→ Electrical Energy,
Chemical Transformation ←Electrolytic— Electrical Signal

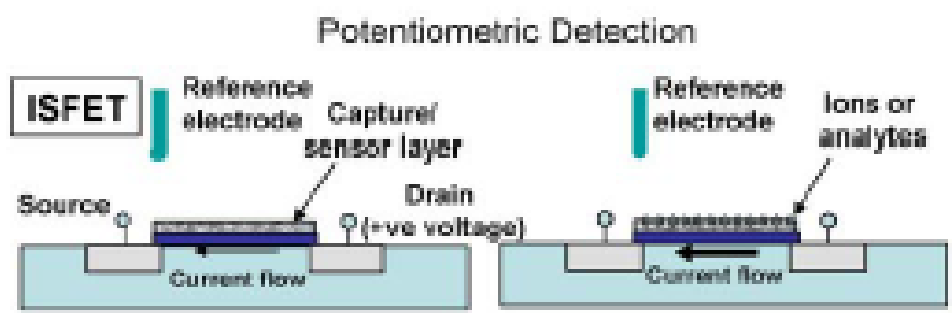
Anode	$A \longrightarrow A^{+} + e^{-}$	
Cathode	$B + e^{-} \longrightarrow B^{-}$	

$$A + B \longrightarrow A^{+} + B^{-}$$

A	B
Oxidized	Reduced
Electron donor	Electron acceptor
Reducing agent	Oxidizing agent

Potentionmetric: measure the oxidation/reduction potential.



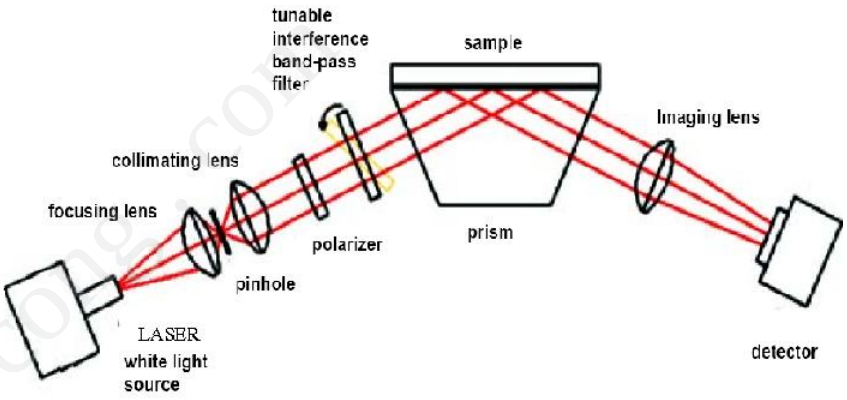


Ion selective field effect transistor (ISFET)

Optical sensing

Fluorescence: measure the different wavelength between incident and emission ligh → energy

$$E = \frac{hc}{\lambda}$$



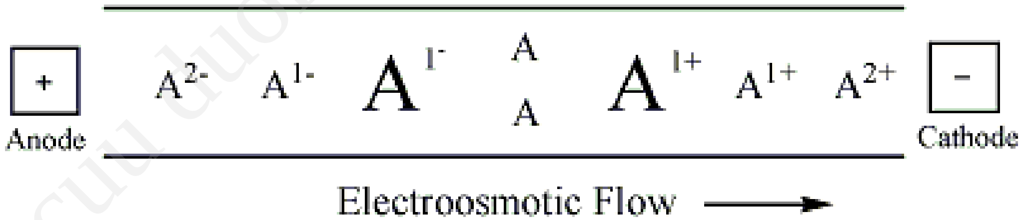
Luminescence: measure the different optical power according Lambert Beer Law → concentration

$$A(c) = \log\left(\frac{P_{solvent}}{P_c}\right)$$

Capillary Electrophoresis (CE)

CE: to separate ionic species due to their frictional forces an d charge under electric field. (base on their size to charge ratio).

CE use gel electrophoresis (agaro) to make different size por t and fluorescent dye for detection.



This method only detect the liquid have mobility and just show the size of sp ecies

Chromatography

Chromatography: techniques separation of complex mixtures rely on differential affinities of substance.

Column chromatography: mixture is mobile in the capillary which have stati onary adsorbing such as paper, gelatin, magnesia on the surface.

- Gas
- Liquid
- Gel permeation

Thin layer and paper chromatography

This method can separate almost liquid.

Micro Total Analysis System (μ_TAS)

Now μ_TAS is widely applied in many fields:

- Medicine-Biology : clinical diagnose, drug analysis.
- Chemistry: chemical compound analysis.
- Environment: water, air analysis.
- Military: explosive detector.
- Food,forensic analysis.