Polymer-Based Microfabrication

- Thick photoresist lithography
- Polymeric surface micromachining
- Soft lithography

Rigid Materials vs. Soft (Elastomeric) Materials

Rigid materials

Crystalline silicon, amorphous silicon, glass, quartz, metals

Advantages:

- Photolithography process is mature and well developed (eg. PR against etching)
- Bulk-etching for forming two- and three-dimensional shapes
- Batch process – compatible with IC process
- Silicon dioxide: good quality, stable chemically and thermally

Disadvantages:

- Expensive
- Brittle
- Opaque (for silicon) in the UV/Vis regions
- Surface chemistry is difficult to manipulate

Packaging/Bonding:

- Anodic bonding (Si-Glass)
- Fusion bonding (Glass-Glass; Si-Si)
- Polymer bonding

Rigid Materials vs. Soft (Elastomeric) Materials

Soft materials

PDMS, PMMA, SU-8, AZ4000 series, Polyimide, Hydrogel, etc..

Advantages:

- Inexpensive
- Flexible
- Transparent to visible/UV
- Durable and chemical insert
- Surface property easily modified
- Improved biocompatibility and bioactivity

Disadvantages:

- Low thermal stability
- Low thermal and electrical conductivity

Packaging/Bonding:

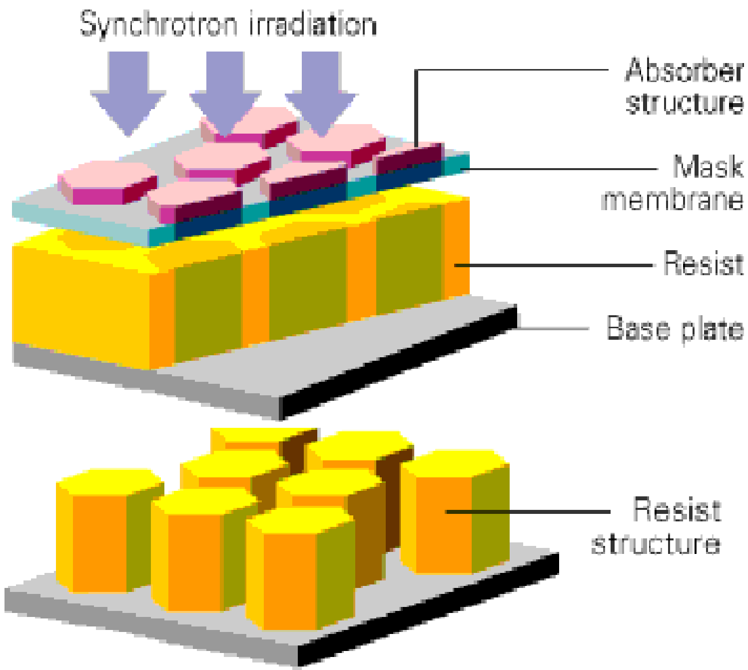
- Through surface modification – easy but not robust

Thick Resist Lithography

Polymethylmethacrylate (PMMA) Resist

e-beam, deep UV (220-250nm) and X-ray lithographic processes

- LIGA process: x-ray lithography + electroplating



X-ray Lithography

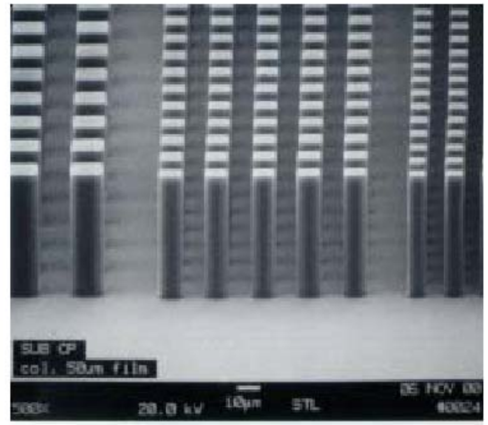
- Deposition of PMMA on a substrate
  - •Multiple spin-coating
  - •Prefabricated sheet
- Structuring of thick PMMA requires collimated X-ray (0.2 nm -2nm), which are only available in synchrotron facility.
- Require special mask substrates such as beryllium and titanium; the absorber material can be gold, tungsten, etc.
- The limited access and costs of a synchrotron facility is a major drawback; although very high aspect ration can be achieved, it has been gradually replaced by other thick PR such as SU-8.

SU-8 Resist (Microchem)

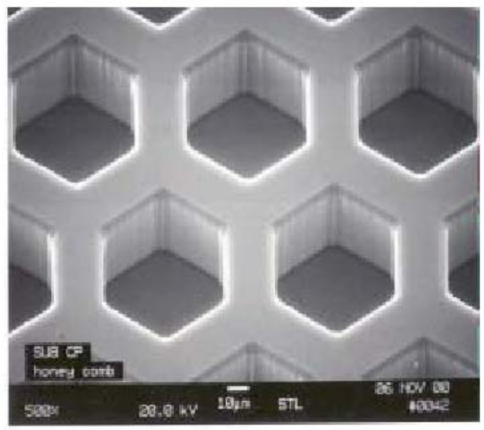
SU-8 is a negative photoresist based on EPON SU-8 epoxy resin for the near-UV wavelengths from 365 nm to 436 nm. At these wavelengths the photoresist has very low optical absorption, which makes photolithography of thick films with high aspect ratios possible.

Product Name	Viscosity (cSt)	Thickness (µms)	Spin Speed (rpm)
		1.5	3000
SU-8 2	45	2	2000
		5	1000
		5	3000
SU-8 5	290	7	2000
		15	1000
		10	3000
SU-8 10	1050	15	2000
		30	1000
		15	3000
SU-8 25	2500	25	2000
		40	1000
		40	3000
SU-8 50	12250	50	2000
		100	1000
		100	3000
SU-8 100	51500	150	2000
		250	1000

1 St(Stroke)= 1 cm^2s^{-1}

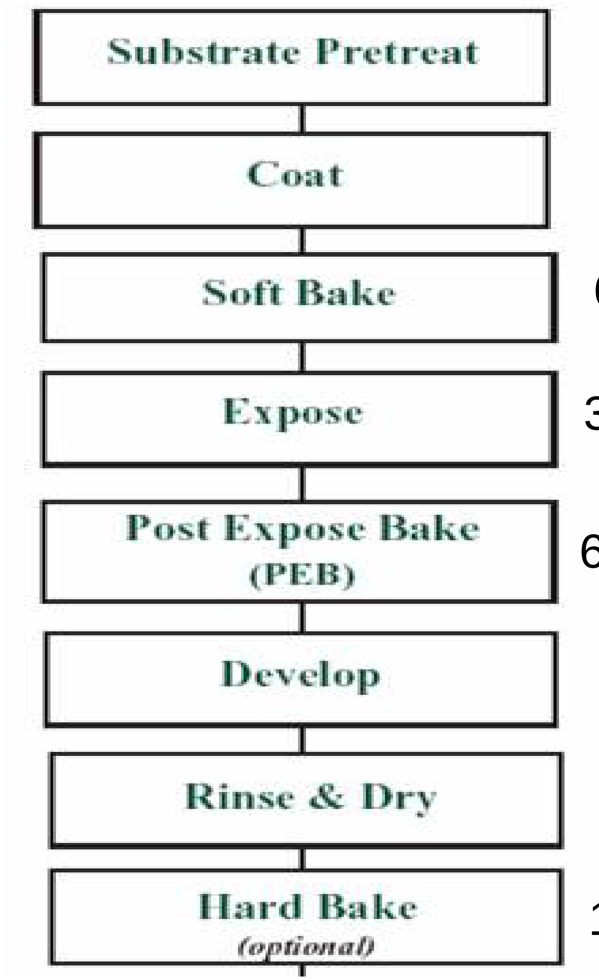


5µm, 10µm and 20µm post arrays in a 50µm thick film.



Honeycomb structure in thick SU-8 resist

- **Steps**



65-95 C

365-436 nm

65-95 C

150-200 C

Spin speed:

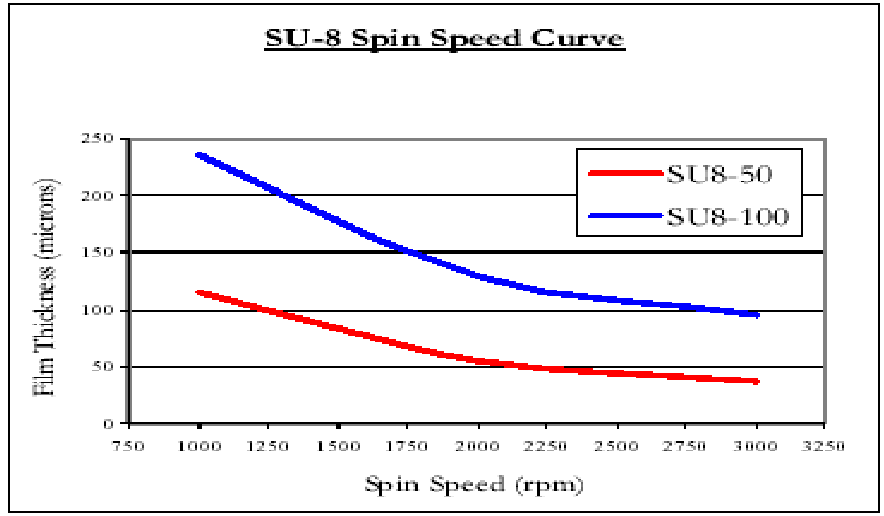


Figure 1. Spin speed vs. thickness curves for selected SU-8 resists.

Baking times (min) :

Product Name	Thickness (µms)	Pre-bake @65°C	Softbake @95°C
	40	5	15
SU-8 50	50	6	20
	100	10	30
	100	10	30
SU-8 100	150	20	50
	250	30	90

(Microchem, Inc.)

AZ4562 (Clariant)

- Positive PR
- Thickness up to 100 um
- High resistance to plasma, good adhesion properties, high-resolution capability
- Typically used as a mold for subsequent metal electroplating or as master templates for micromolding. No reports of using AZ4562 directly as structural material.

Comparison of Different Thick Film Resists

Resist	*PMMA*	*SU-8*	*AZ4562*
Exposure type	X-ray (0.2 – 2 nm)	UV (365, 405, 435 nm)	UV (365, 405, 435 nm)
Light source	Synchrotron facility	Mercury lamp	Mercury lamp
Mask substrate	Beryllium (100 μm) Titanium (2 μm)	Glass (1.5 –3 mm) Quartz (1.5 – 3 mm)	Glass (1.5 –3 mm) Quartz (1.5 – 3 mm)
Mask absorber	Gold (10 –15 μm)	Chromium (0.5 μm)	Chromium (0.5 μm)
Max. height	1,000 μm	250 μm	100 μm
Aspect-ratio	~500	20 – 25	~10
Young's modulus (GPa)	2–3	4–5	-
Poisson's ratio	-	0.22	-
Glass temperature (°C)	100	> 200	-

Polymeric Surface Micromachining

- Polymeric surface micromachining is similar to silicon surface micromachining
- Polymers are used as structural or as sacrificial material

Polyimide (PI)

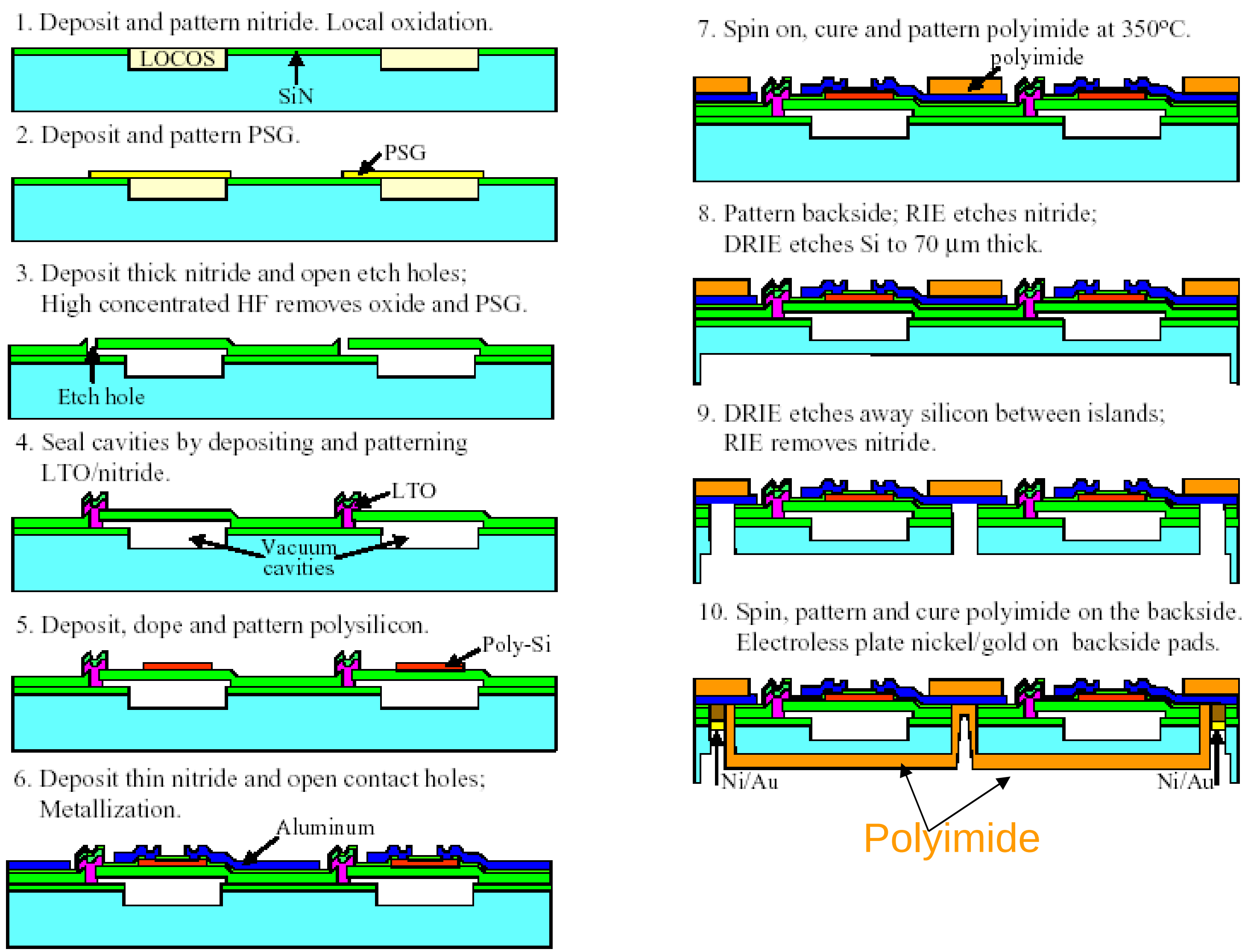
- A single spin can result in a film thickness up to 40 um.
- Photosensitive polyimide can be used for the same purpose as other thick PR
- Fluorinated polyimide is an interesting material because of its optical transparency and simple machining. In RIE processes of this material, fluorine radicals are released and act as etchants.

Parylene

- Parylane is a polymer that can be deposited with CVD at room temperature. The CVD process allows coating with a conformal film with thickness ranging from several micrometers to several millimeters.
- Parylane can be used in microfluidic devices as a structural material, which offers low Young's modulus. Such a soft material is needed in **microvalves** and **micropumps**.

- **Electrodepositable Photoresist** (e.g. ED2100, PEPR 2400 (Shipley Europe Ltd.)
  - The photoresist is an aqueous emulsion consisting of polymer micells.
  - The photoresist is deposited on wafers by electrodeposition process. In an electric field, positively charged micells move to the wafer, which works as a cathode. The polymer micelles coat the wafer until the film is so thick that deposition current approaches zero.
  - Typical thickness: 3 -10 um.
- **Conductive polymers**
  - Conductive polymers or conjugated polymers are polymeric materials, which has received growing attention of the MEMS community.
  - Conjugated polymers have alternating single and double bonds between a carbon atom along the polymer backbone. This results in a band gap and makes the polymers behave as semiconductors.
  - Doped conjugated polymers can be used as the material for electric device such as diodes, LED, and transistors.
  - The doping level of polymers is reversible and controllable. In some polymers, the changes of doping level leads to volume change –>can be as actuators. The most common and well-research conjugated polymer is polypyrrole (PPy).

Integration of Rigid and Soft Materials

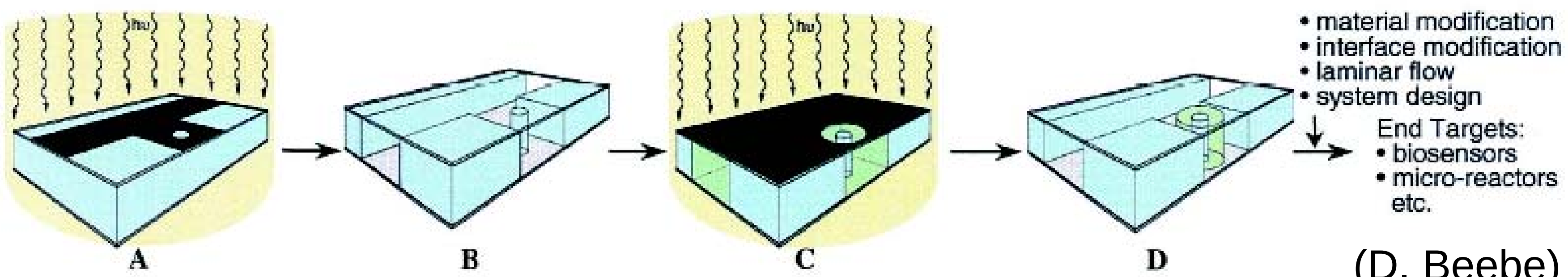


(Tai)

A flexible shear stress skin for aerodynamic applications

Hydrogel Based Microfabrication

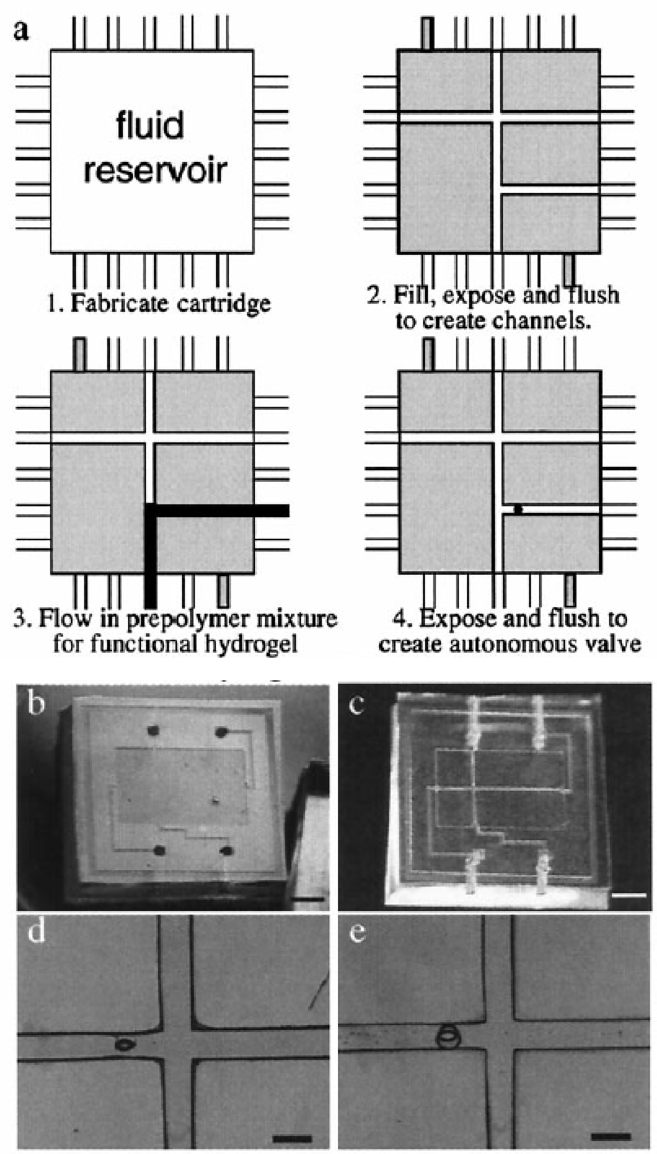
- Hydrogel Fabrication
  - Photosensitive (polarity like negative PR)
  - Liquid-phase photo-polymerization
  - Laminar flow-aided patterning
  - Functional (stimuli-responsive) and non-functional materials
  - Fabrication of fluidic channels, actuators, valves, pumps



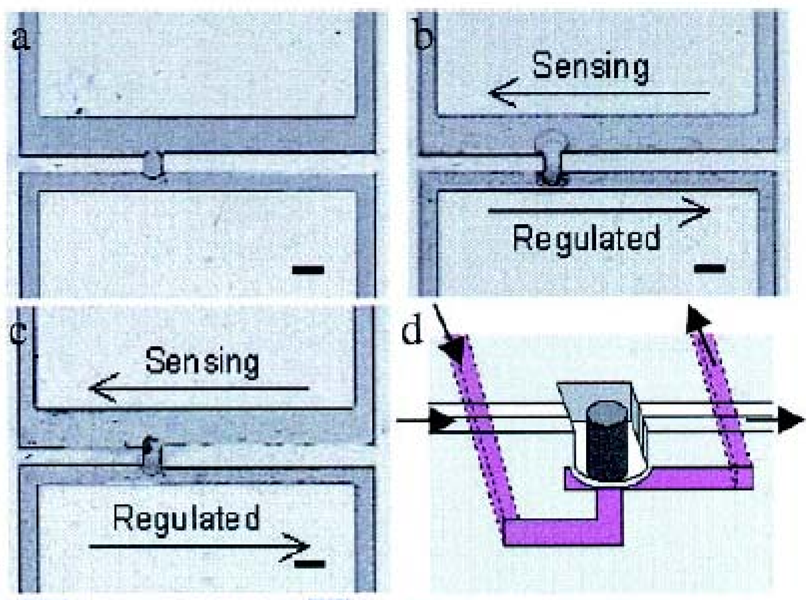
(D. Beebe)

A hydrogel jacket valve in a T channel

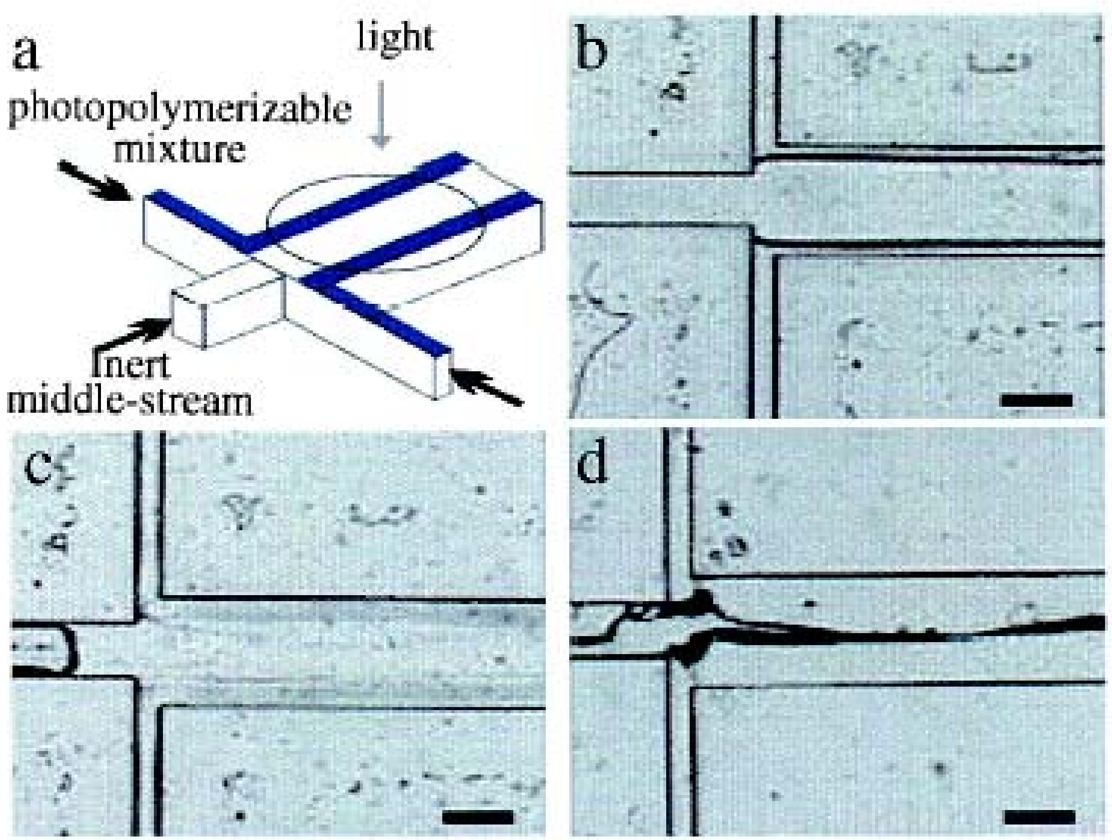
Fabrication of a valve in a Hydrogel Microchannel



2-D and 3-D micro fluidic network



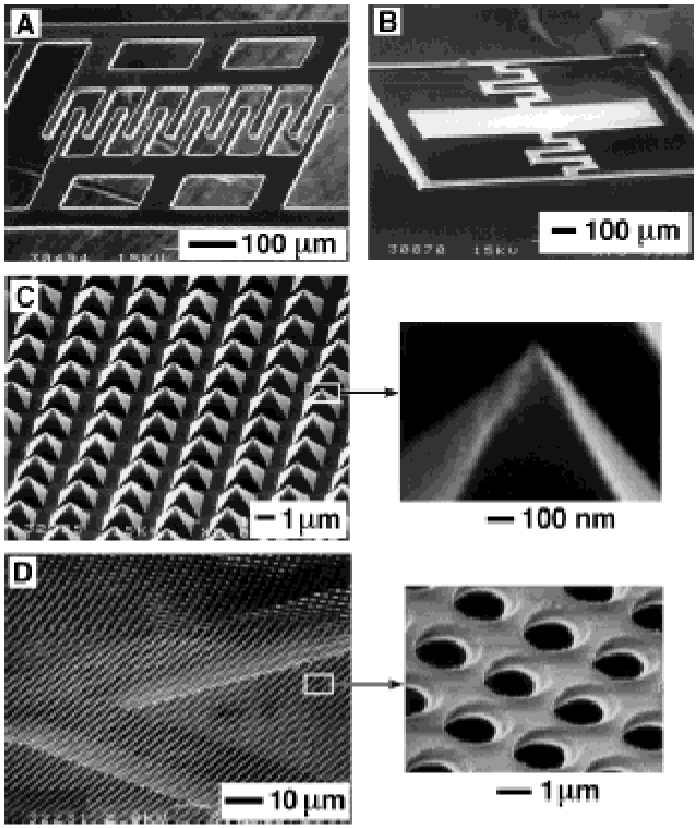
Geometry Control during Fabrication by Using Laminar Flows



Soft Lithography

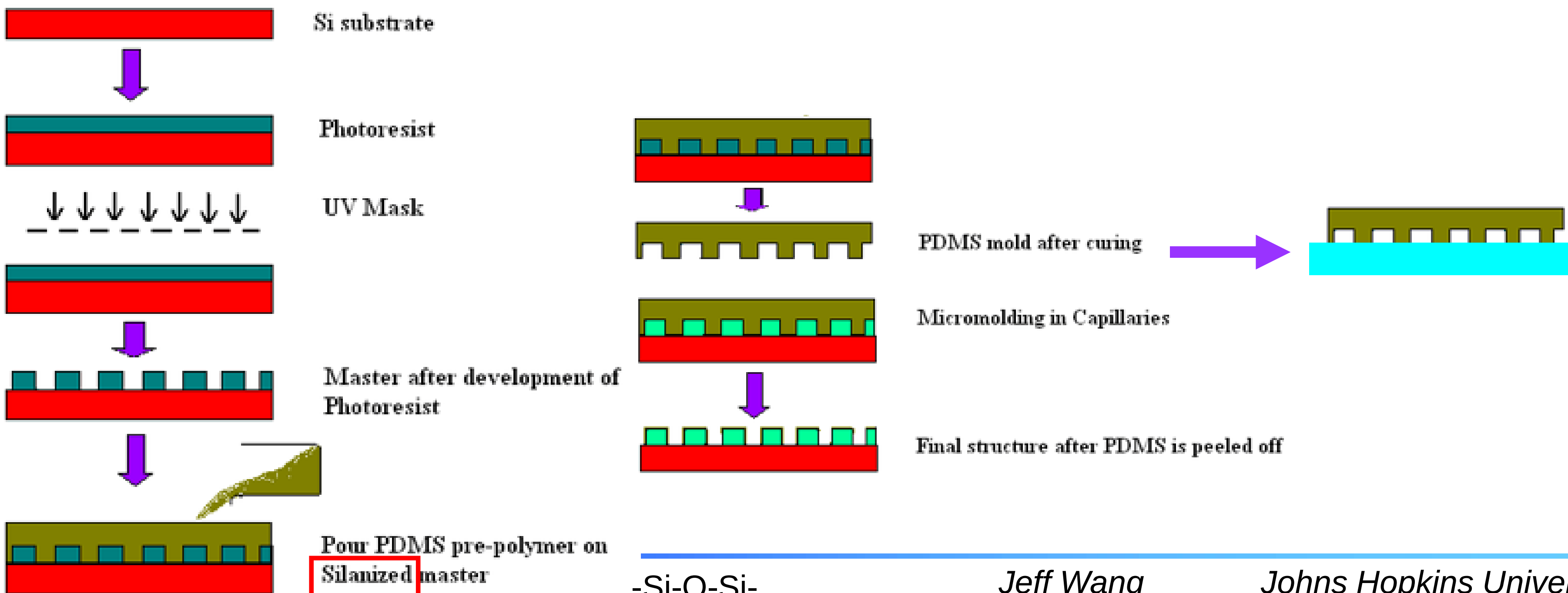
- Developed by Whitesides, et. al

  A set of techniques incorporating lithography and micro-molding for fabrication of polymer(PDMS)-based devices.

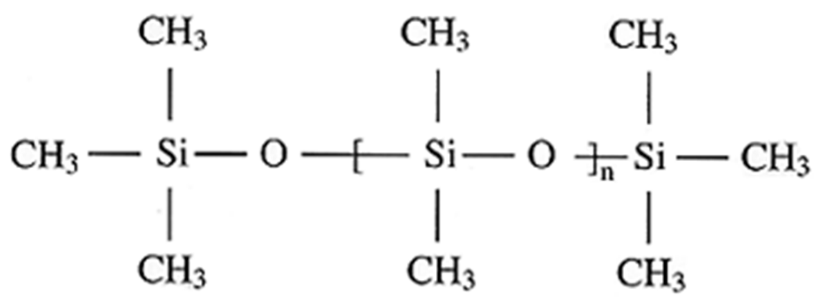


Soft Lithography Process

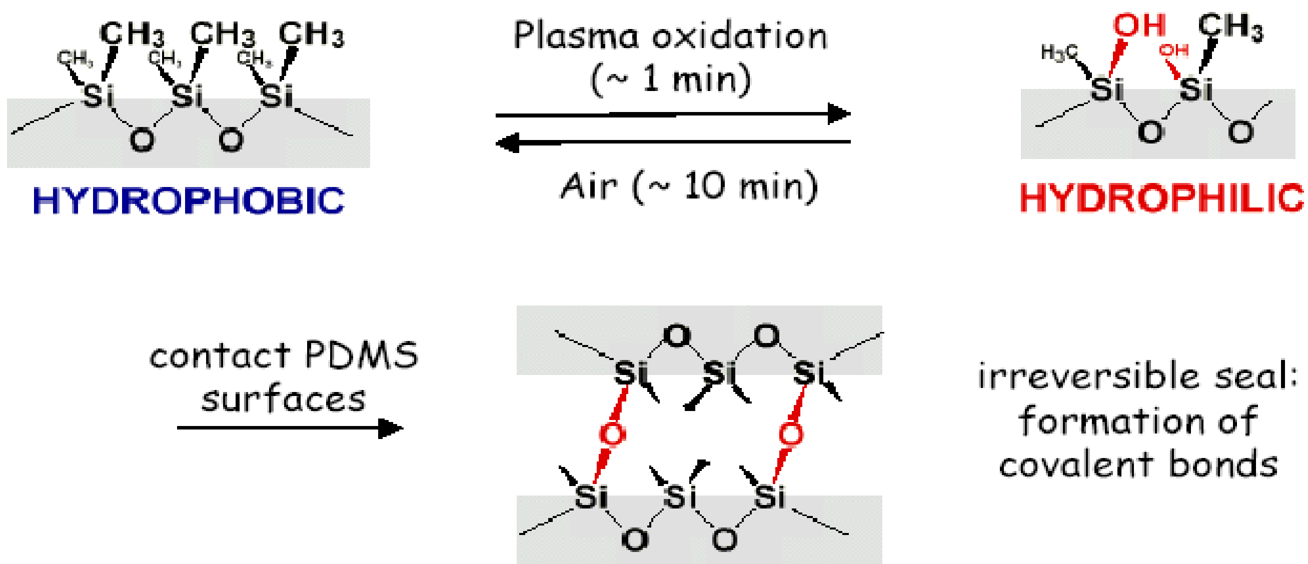
- A microfabrication process in which a soft polymer is cast onto a mold that contains a microfabricated pattern.
- Polymer materials: PDMS, PMMA, etc.
- Mold materials: SU-8, thick-film positive photoresist
- Advantages come with soft lithography:
    1. Capacity for rapid prototyping
    2. Easy fabrication without expensive capital equipment
    3. Forgiving process parameters



PDMS (Polydimethylsiloxane)



- Deforms reversibly
- Can be molded with high fidelity
- Optically transparent down to ~300nm
- Durable and chemically inert
- Non-toxic
- Inexpensive

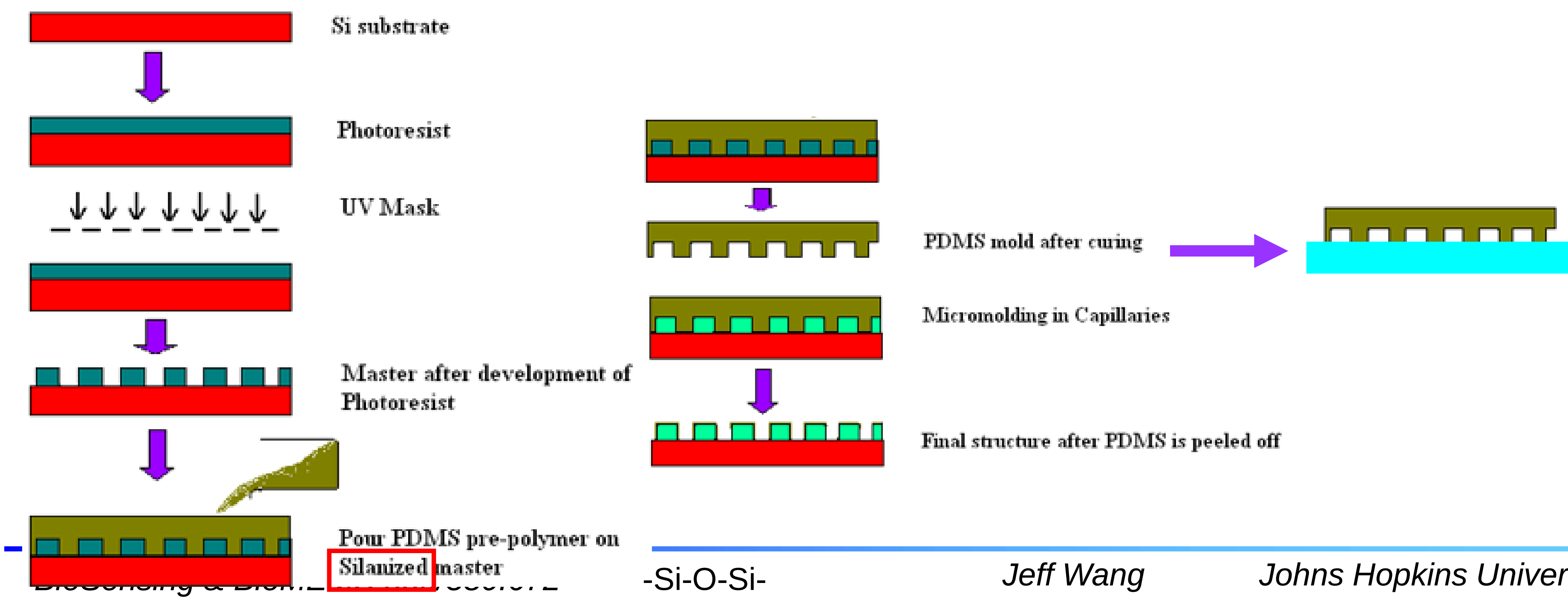


- Upon treatment in oxygen plasma, PDMS seals to itself, glass, silicon, silicon nitride, and some plastic materials

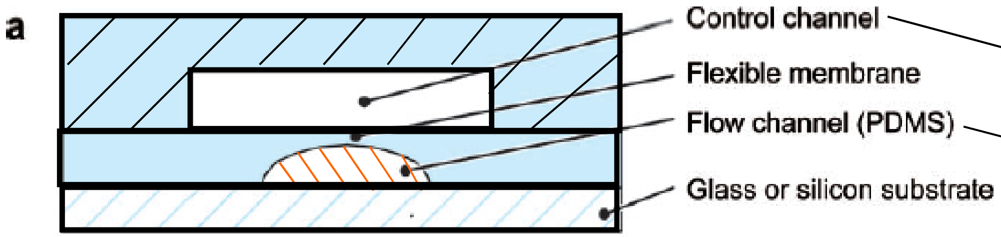
Soft Lithography Process

Advantages come with soft polymer

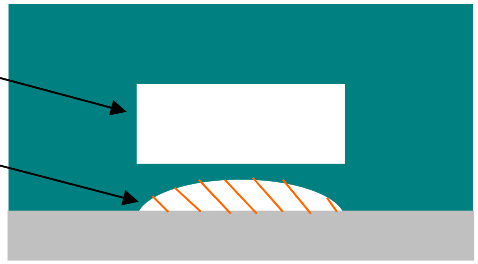
1. Excellent sealing between glass and PDMS
2. Easy for connecting a tubing adapter
3. Transparent material, great for microscopic observation
4. Permeable to gas but not to analytes or ions
5. Allow multi-layer process toward 3D networks
6. Biocompatible (?)



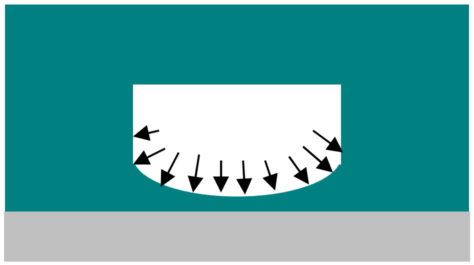
Quake's Micromechanical Valve



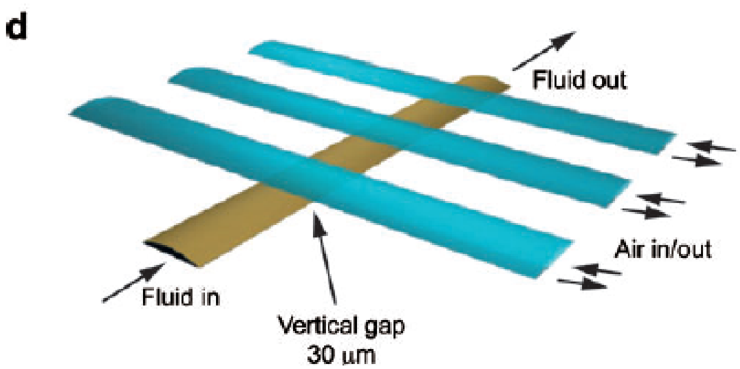
Valve open:



Valve closed:

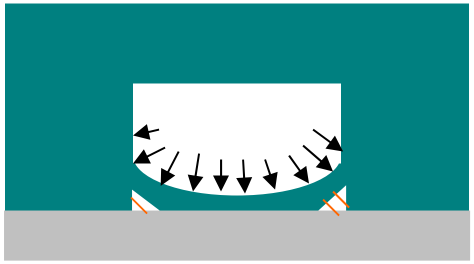


Flow channel is pinched-off.



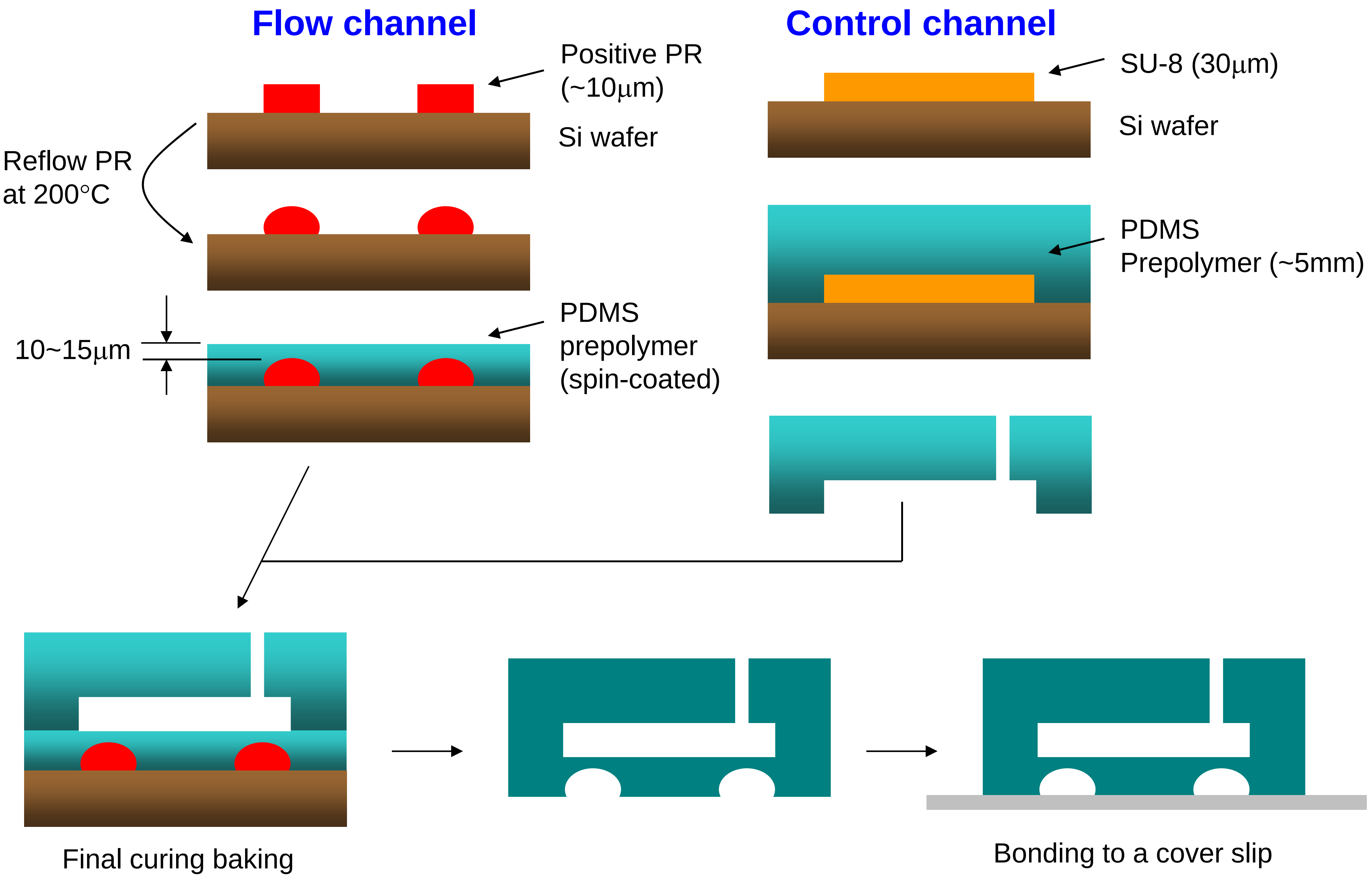
SR Quake, *Science*, 2000

Why semicircular shape?

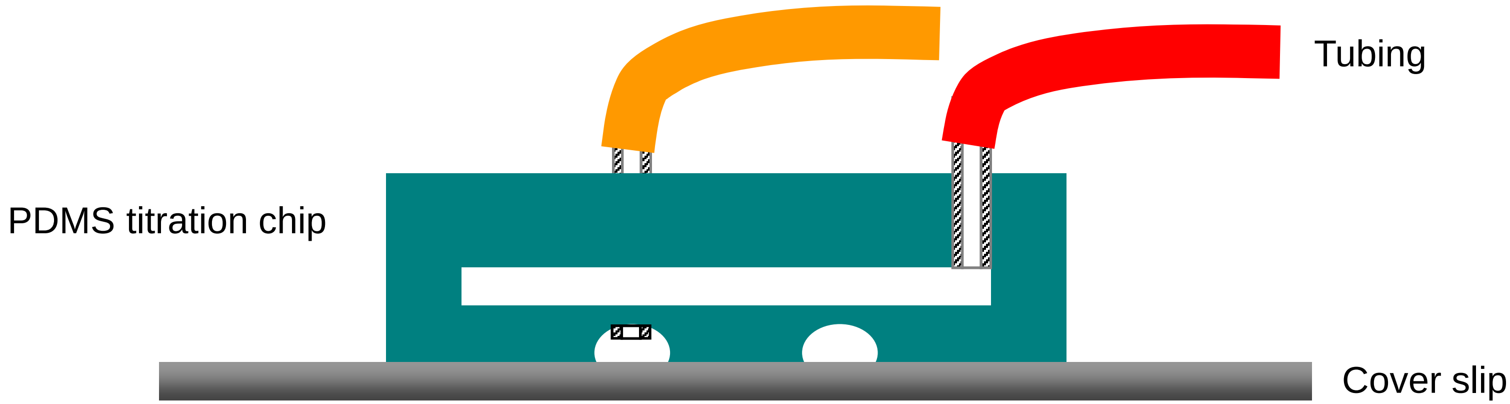


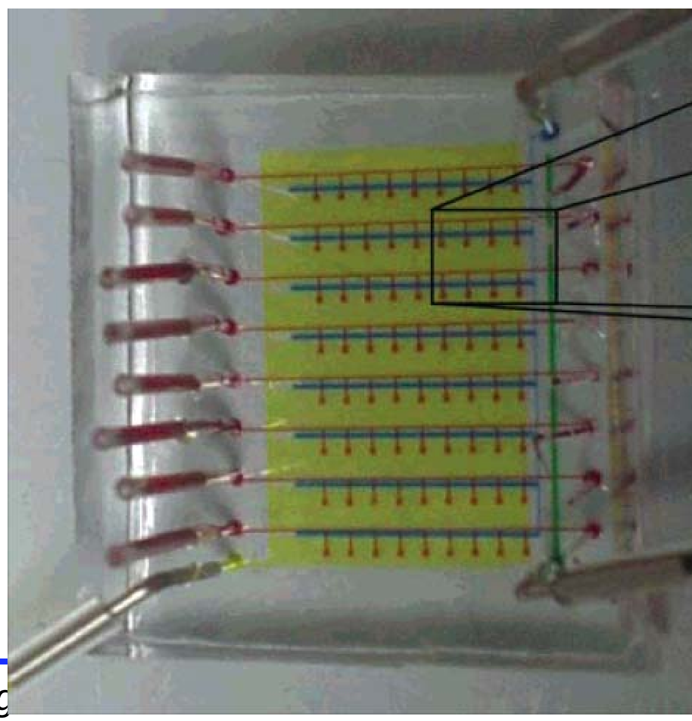
Leakage! But.....

Fabrication: Two-Layer Soft Lithography Process

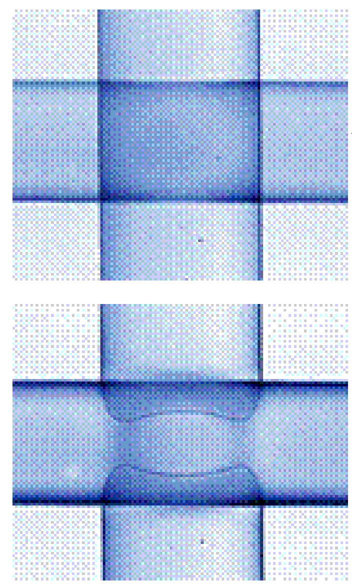


Fabrication: Two-Layer Soft Lithography Process



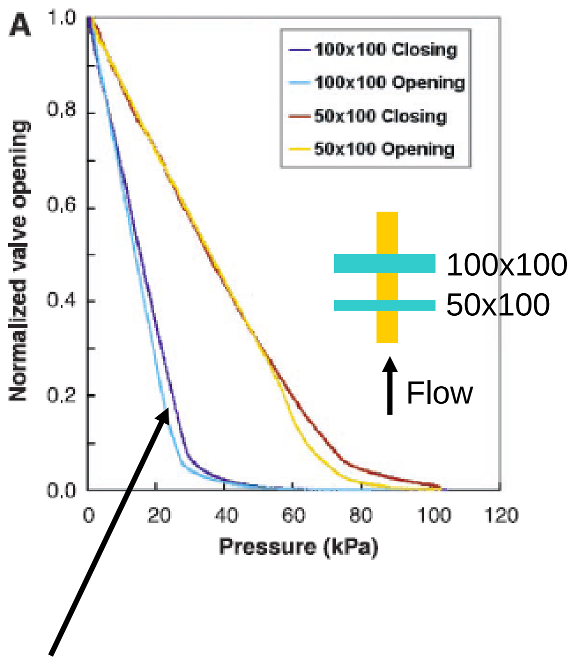


Valve open and Valve close



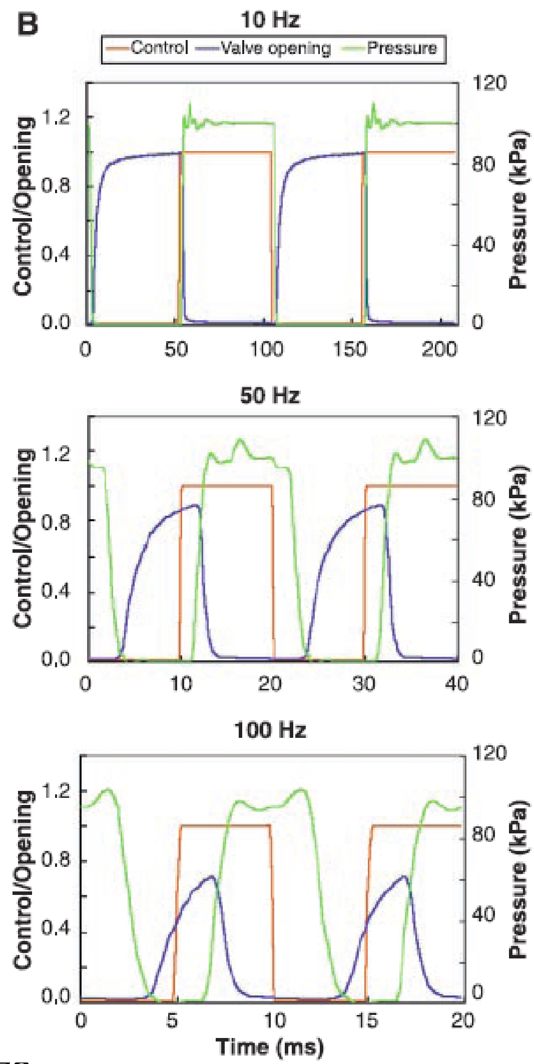
Properties and performance of Quake's valve

Frequency response

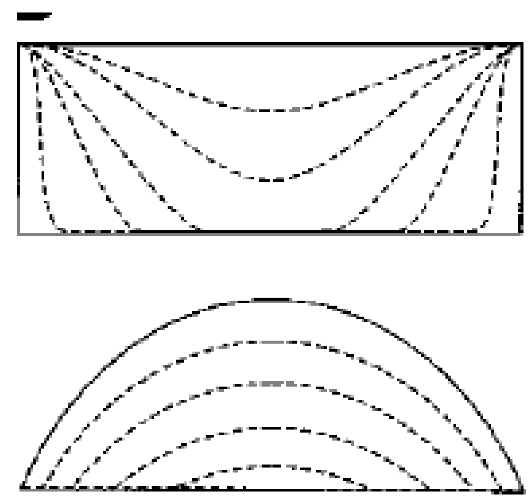


Hysteresis

SR Quake, *Science*, 2000

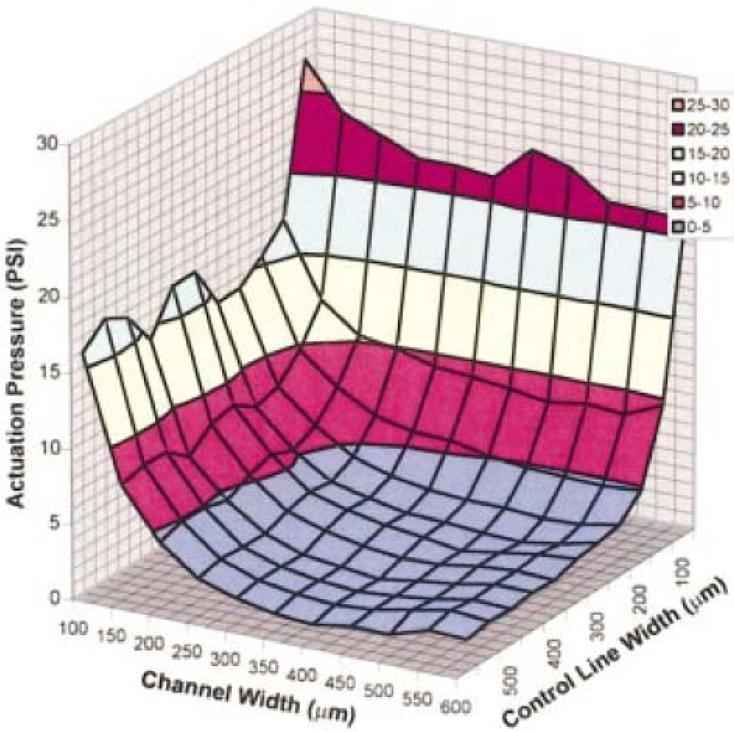


- The geometry (width, height, and thickness) of the membrane determines the valve actuation pressure
- Valve experiences little hysteresis



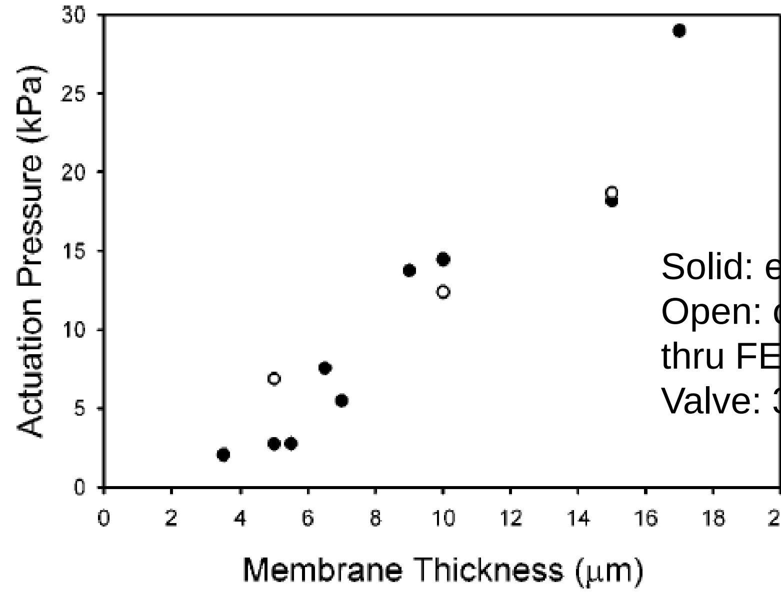
Properties and performance of Quake's valve

Driven pressure

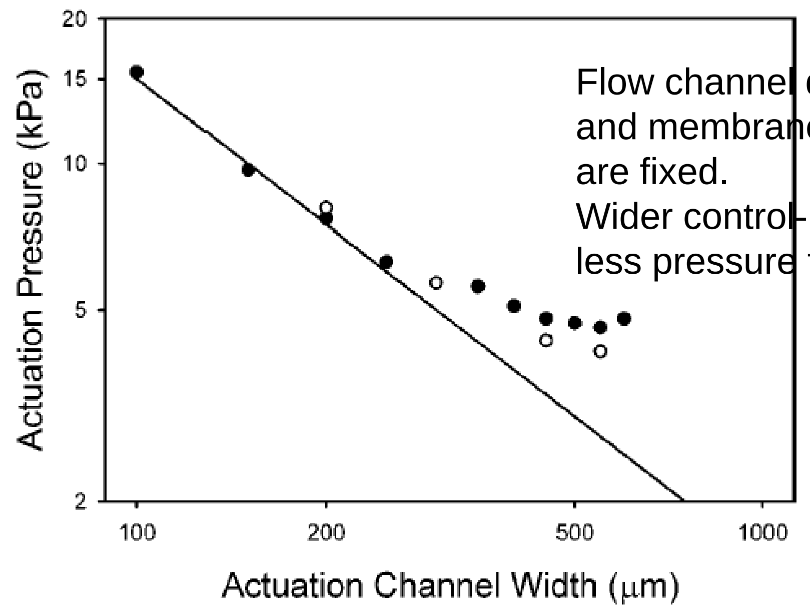


12 flow channel widths X 12 control line widths

V. Studer et al., *J. of Applied Physics*, 2004



Solid: experimental
Open: calculated thru FEA
Valve: 300x300

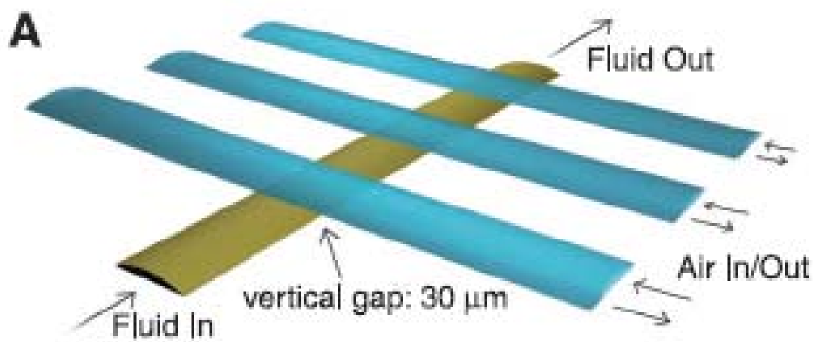


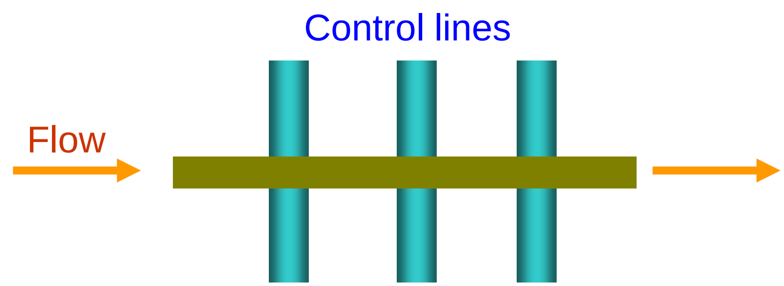
Flow channel dimensions and membrane thickness are fixed.
Wider control-line requires less pressure to close.

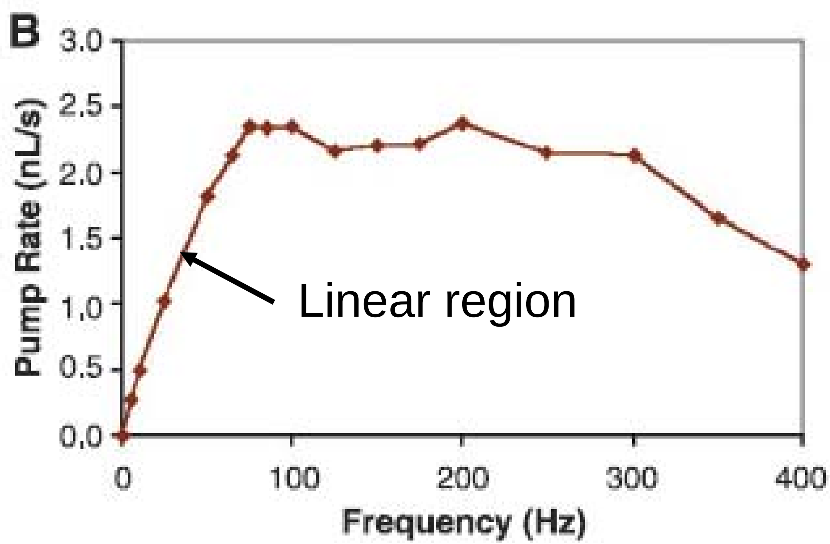
Based on valves, what are the high-level components that have be developed?

Peristaltic pump

In LSI, subcomponents: memory, comparator, counter, multiplexer







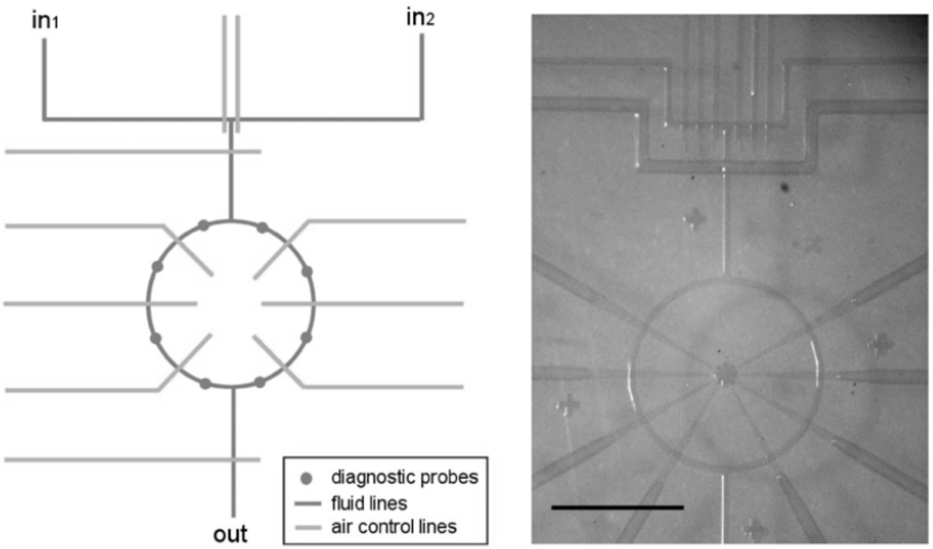
Actuation pattern

1	0	1	Trap
1	0	0	
1	1	0	Push →
0	1	0	
0	1	1	→ Push
0	0	1	

and prevent back flow

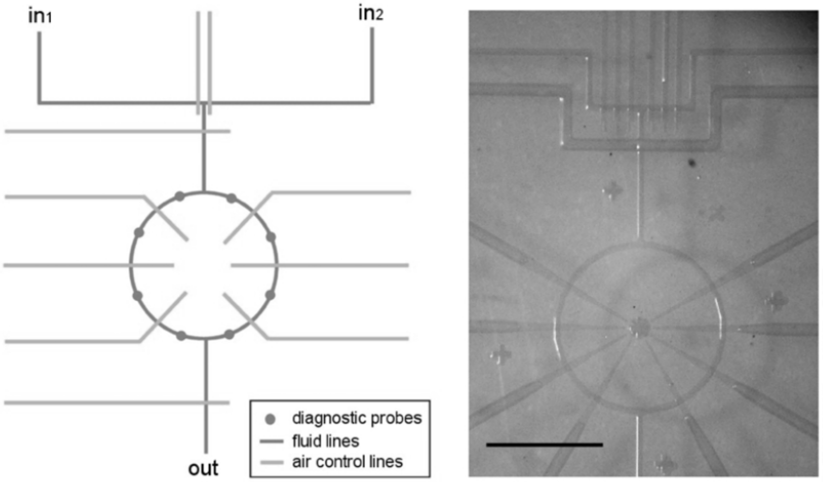
Based on valves, what are the high-level components that have be developed?

Rotary pump and mixer



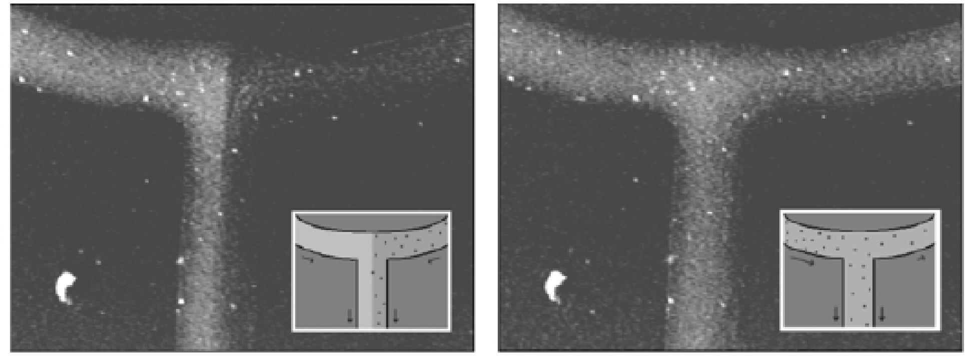
(a) (b)

Rotary mixing

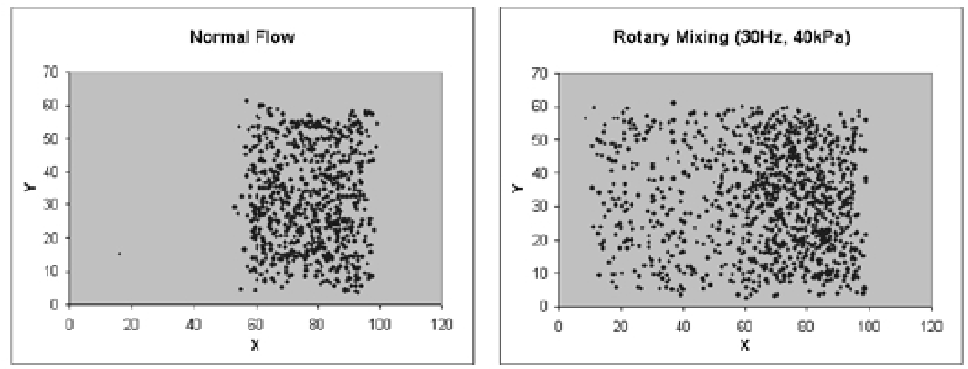


(a) (b)

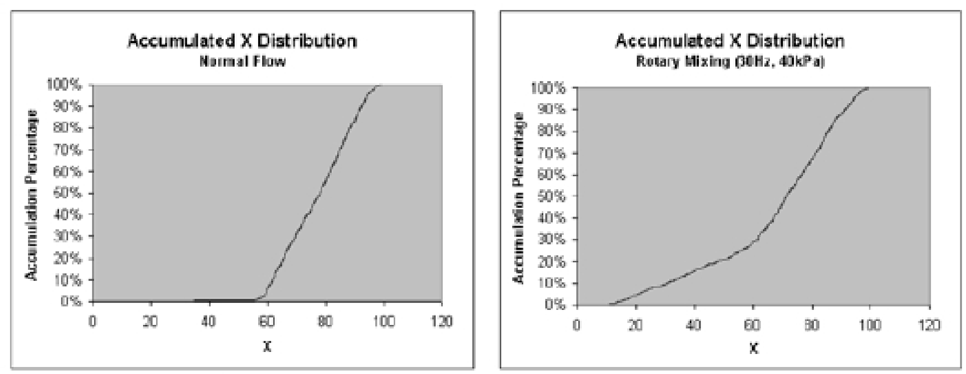
Continuous-flow mixing



(a) (b)

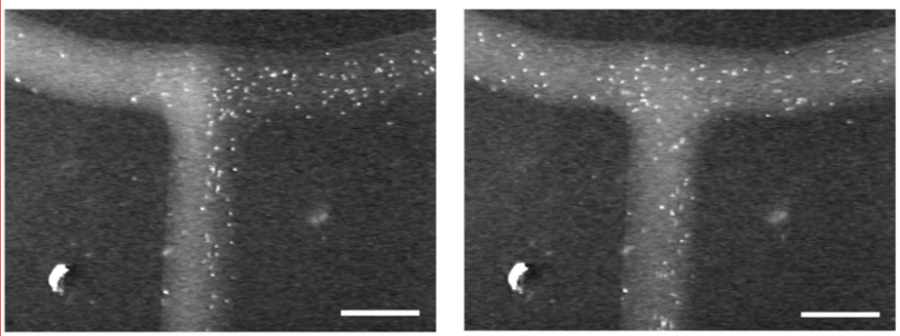


(c) (d)



(e) (f)

Fixed-volume mixing



(a) (b)

Before After