Micro Electro Mechanical Systems for mechanical engineering applications

Lecture 16:
Class summary: From MEMS to NEMS and Miscellaneous

Kahp-Yang Suh

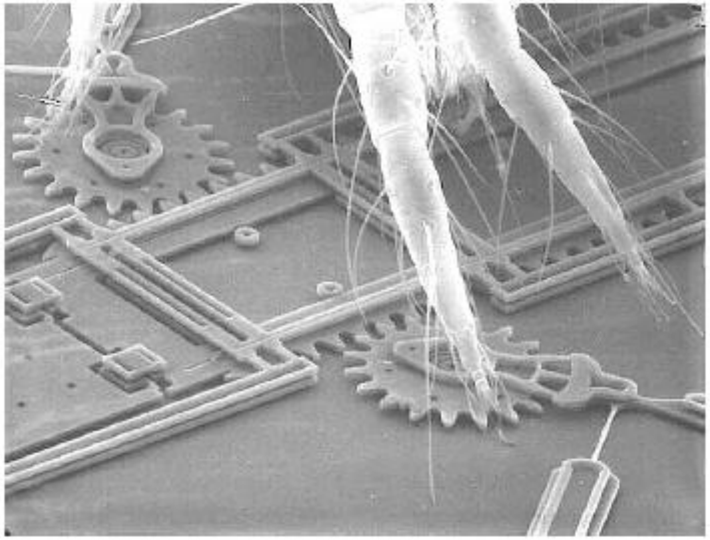
Associate Professor
SNU MAE
sky4u@snu.ac.kr

1. Introduction

From MEMS (NEMS) to BIOMEMS (BIONEMS)

‘Miniaturization engineering’ is a more appropriate name than MEMS, but the name MEMS is more popular. It involves a good understanding of scaling laws, manufacturing methods and materials. Initially it involved mostly Si and mechanical sensors (e.g., pressure, acceleration, etc). Miniaturization engineering or MEMS (NEMS) applied to biotechnology is called BIOMEMS (BIONEMS).

MEMS: MicroElectroMechanical Systems
NEMS: NanoElectroMechanical Systems



MEMS vs. BIOMEMS

MEMS

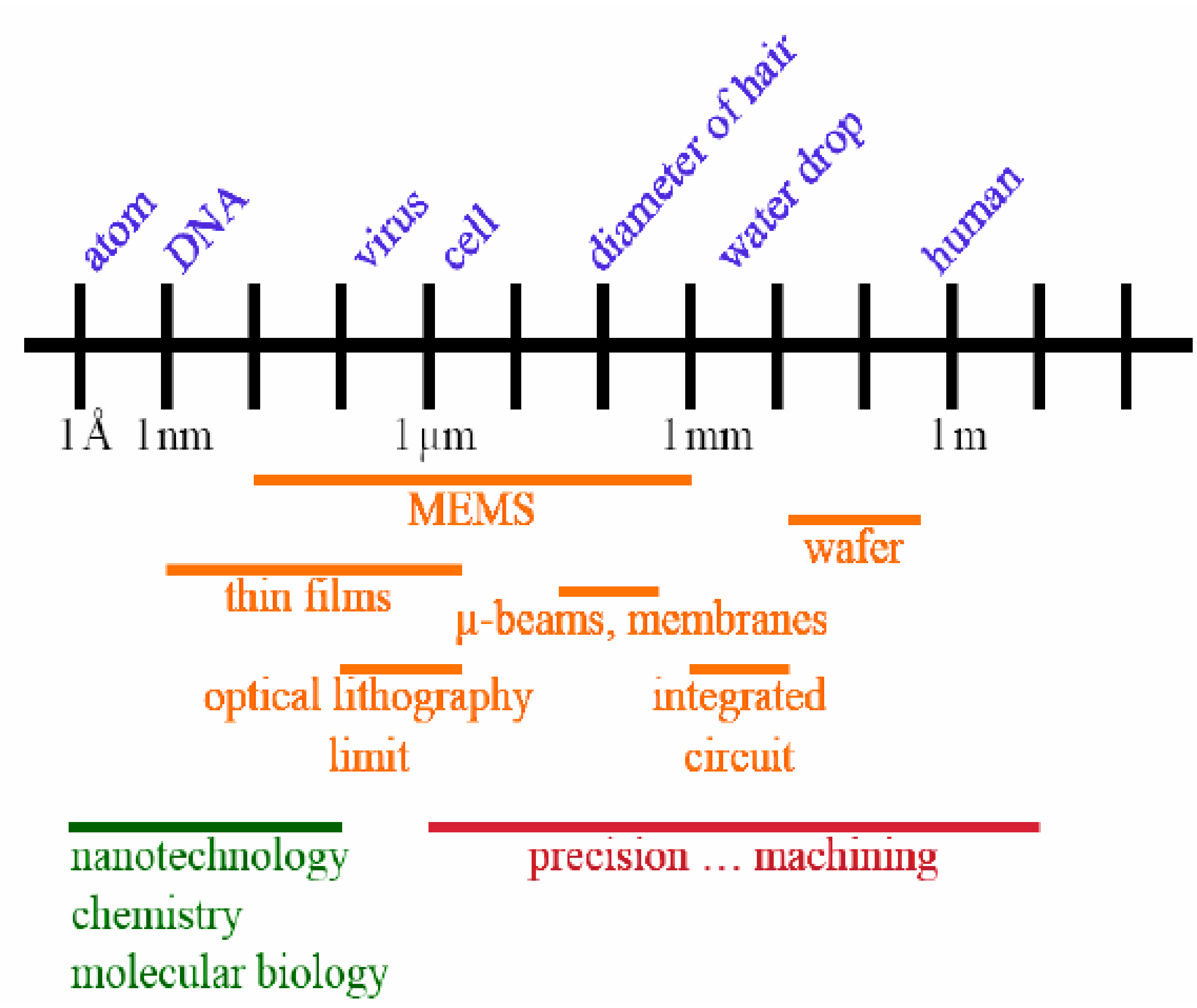
- Silicon based Material
- Electrical & Mechanical interface integration
- Moving part in micromachining system – active component

BioMEMS

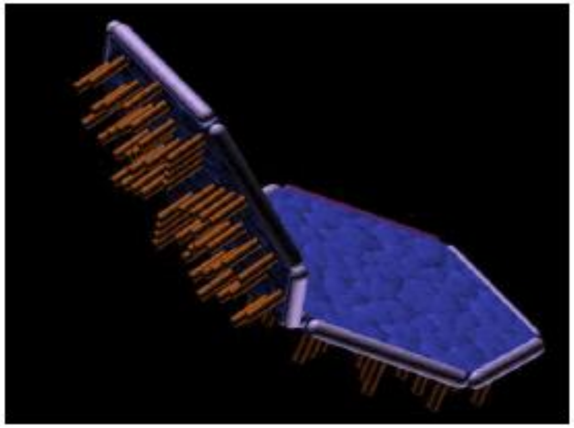
- IC incompatible fabrication process (glass, polymers, metals)
- Biomolecular & Physical parameter (electrical, mechanical, optical) transducer integration
- Moving medium in passive substrate - microfluidic driving force

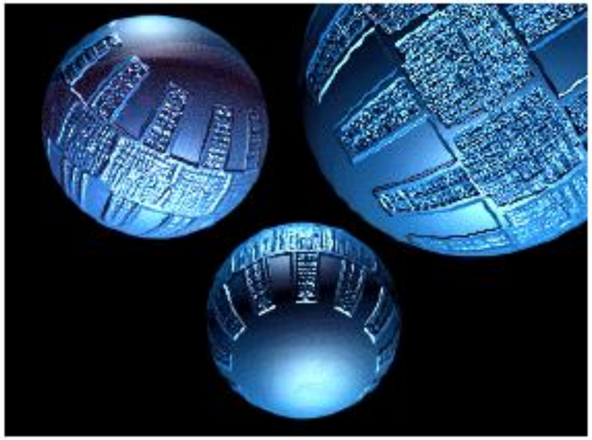
→ A different thinking process from MEMS to BioMEMS

Scale of Objects



About Scaling Laws…





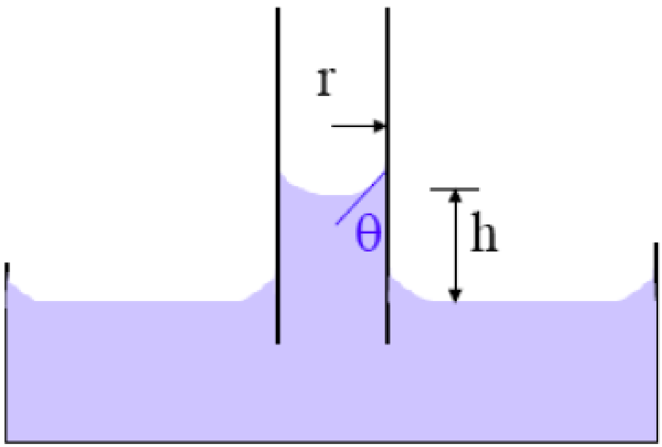
About Scaling Laws…

Assumptions

- Ignore quantum effects
- Shape is scale independent
- Speed is scale independent
- Volume is still big enough for thermodynamic quantities to be valid -- is this true in a nanoscale system?!
- Note that this treatment ignores quantum effects and statistical effect - so, it has limitations!

Scaling Laws Example

•Scaling law of surface tension force



➢ Young-Laplace equation

$$\Delta P = \frac{2\gamma}{r}\cos\theta,\ h = \frac{2\gamma}{\rho g r}\cos\theta$$

where γ_{SG} and γ_{SL} are the surface tensions at the solid/gas and solid/liquid interfaces, respectively ($\gamma = \gamma_{SG}$ and γ_{SL}).

(1) What are the scaling exponents of dimension (*l*) of Laplace pressure, surface tension force and surface tension energy? (surface tension is assumed to be constant irrespective of size).

2. Fabrication and Materials

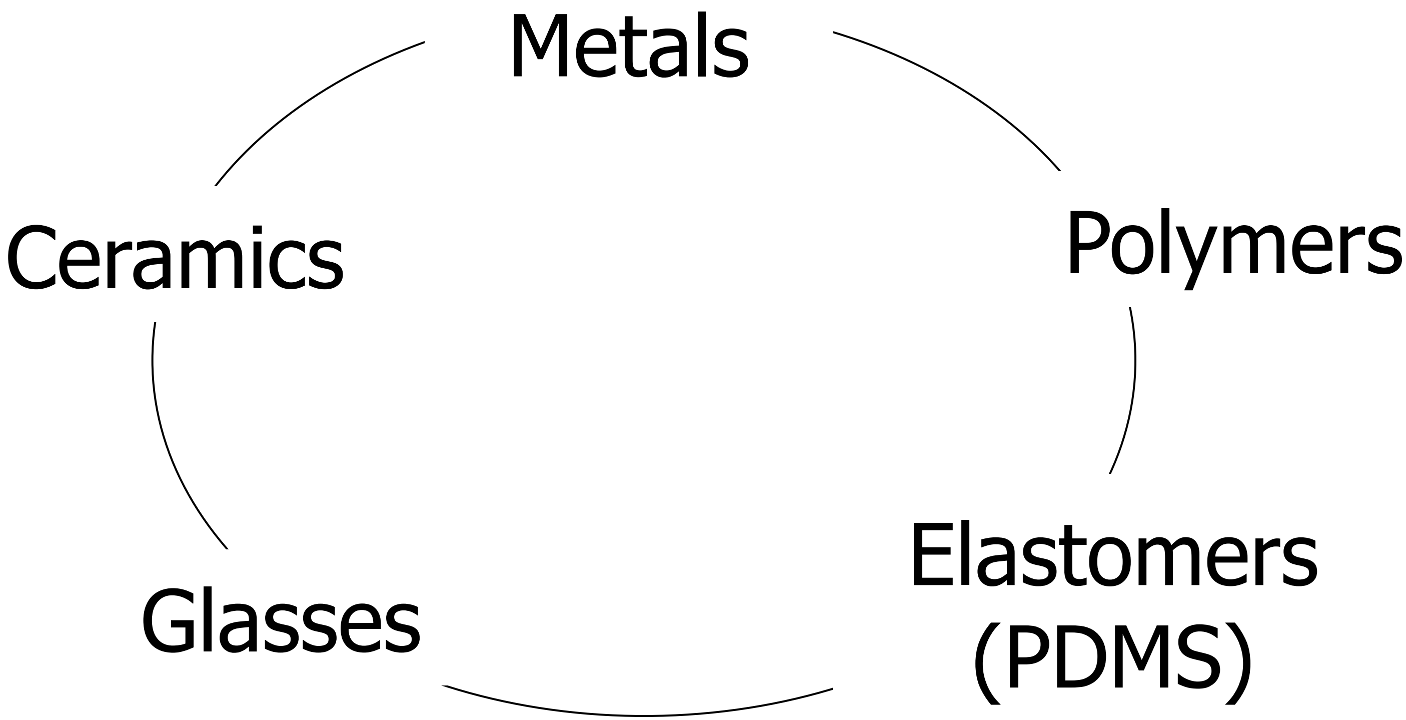
Device Fabrication

❖ What is Needed:

1. **A material to create the device – Silicon, Glass, Polymer, Metal…**
2. **A process to follow – Micromachining, Nanofabrication…**
3. **Process characteristics**
   - Reproducible
   - Scalable
   - Inexpensive
   - Environmentally friendly
4. **Tools to create the device – Lithography, Bonding…**
5. **Tools to examine and verify the device – Microscopy, Electrical analysis Optical measurement…**
6. **Packaging**
7. **Integration methods and tools**

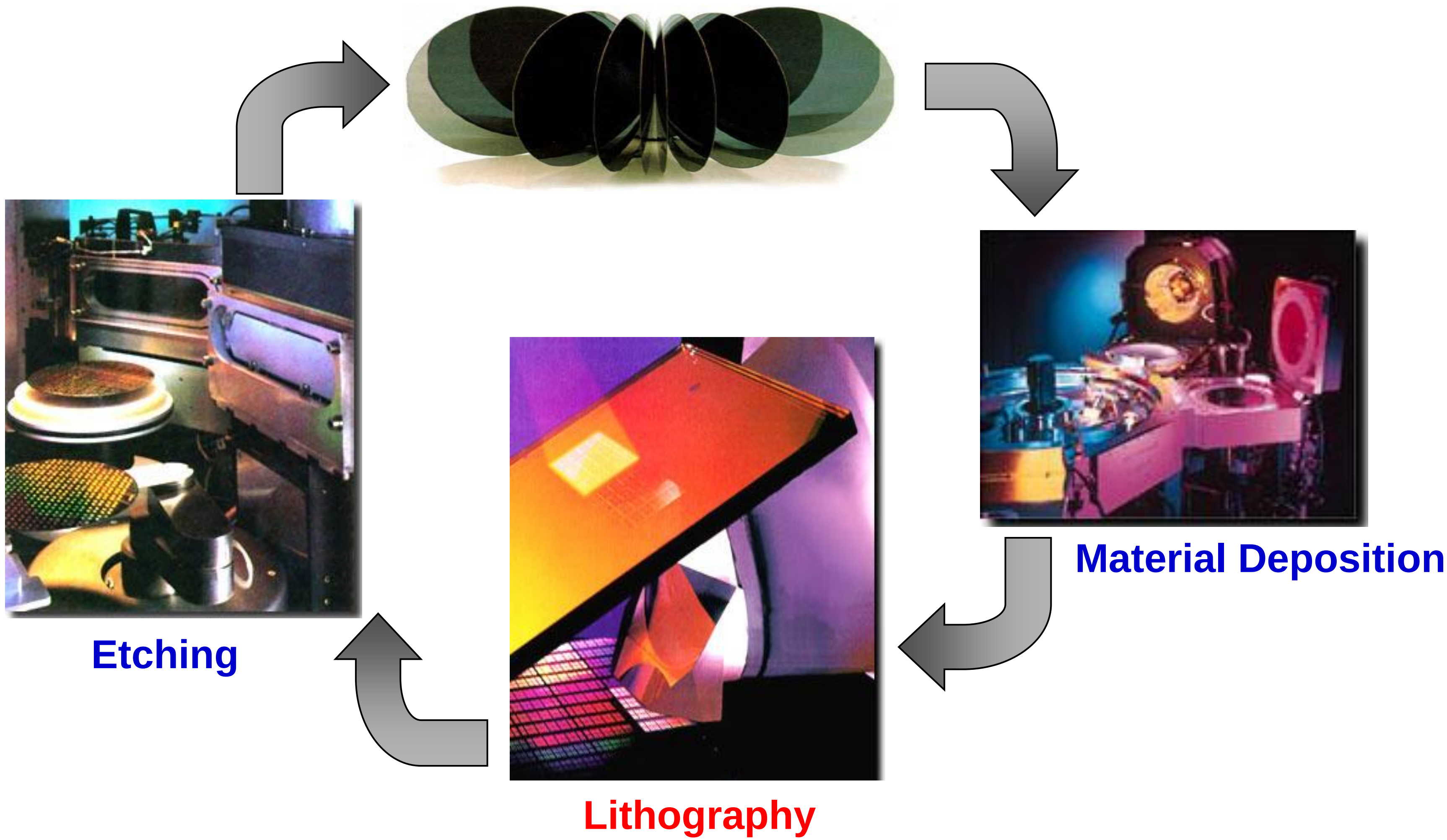
Hybrid Materials

- Materials have “domains” of properties
- Difficult to change properties by several orders of magnitudes
- Hybrid materials are now being advanced to create very difficult properties

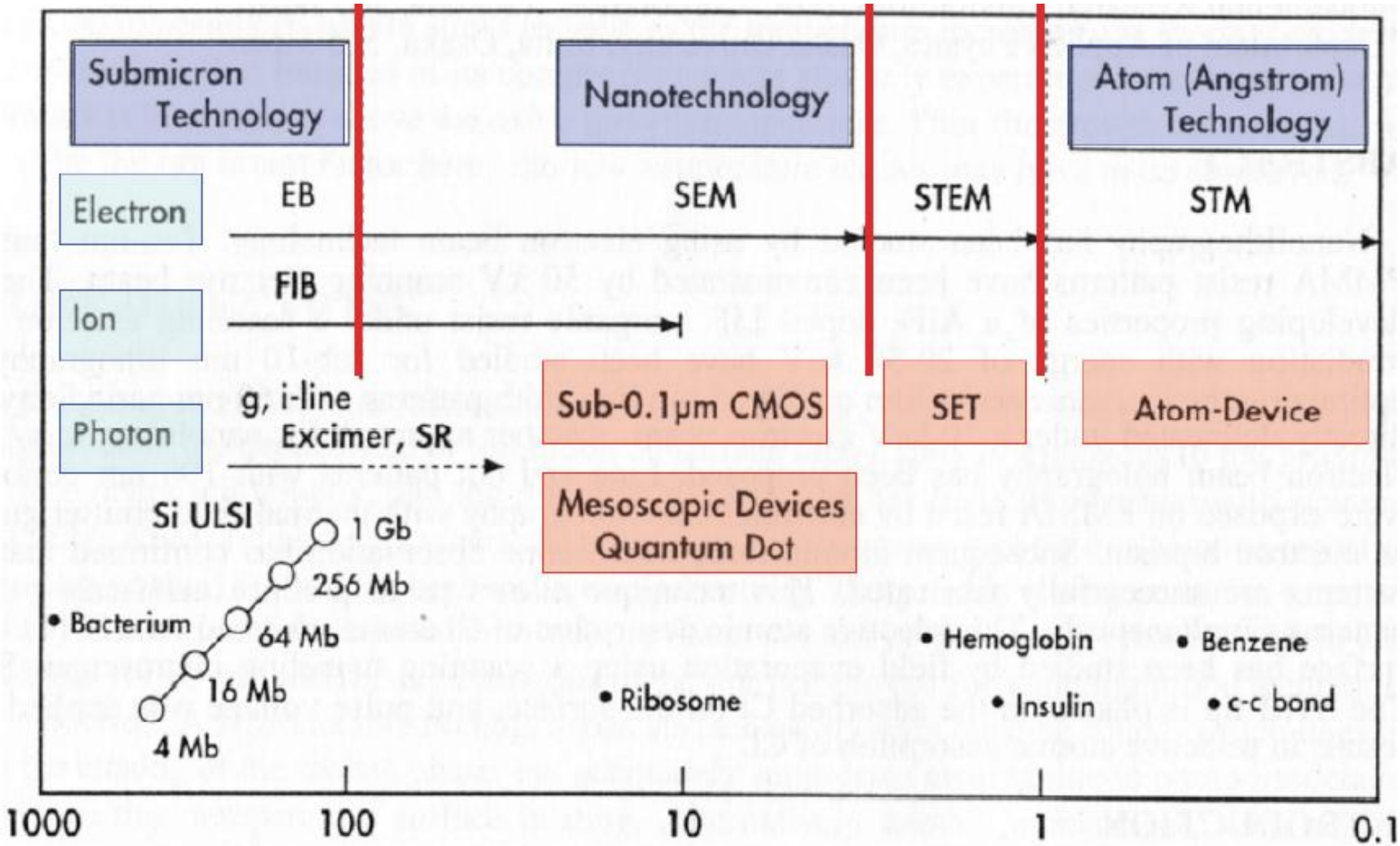


Surface Micromachining

Conventional Silicon Technology

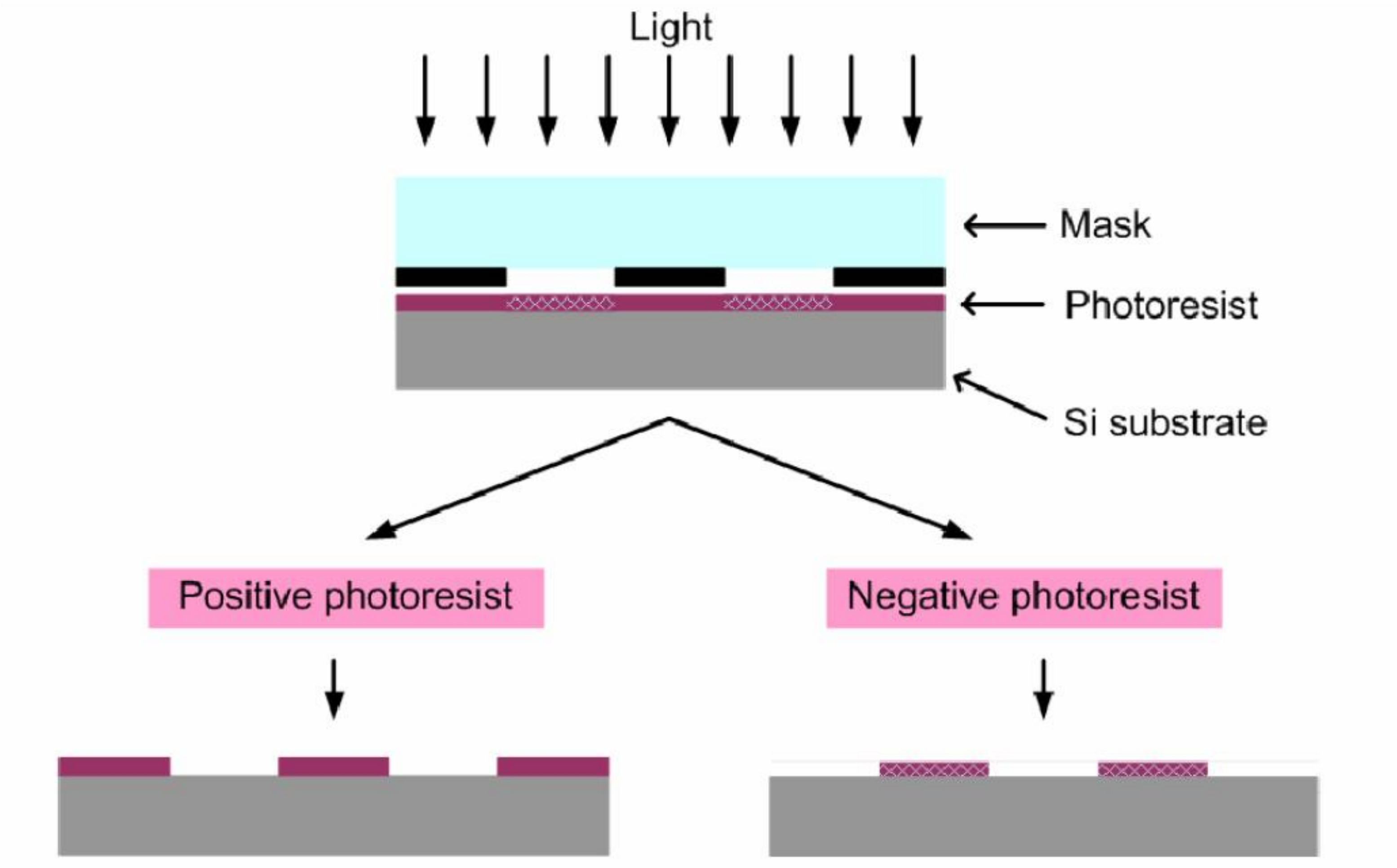


Lithographic techniques



Conventional lithographic technique

UV lithography

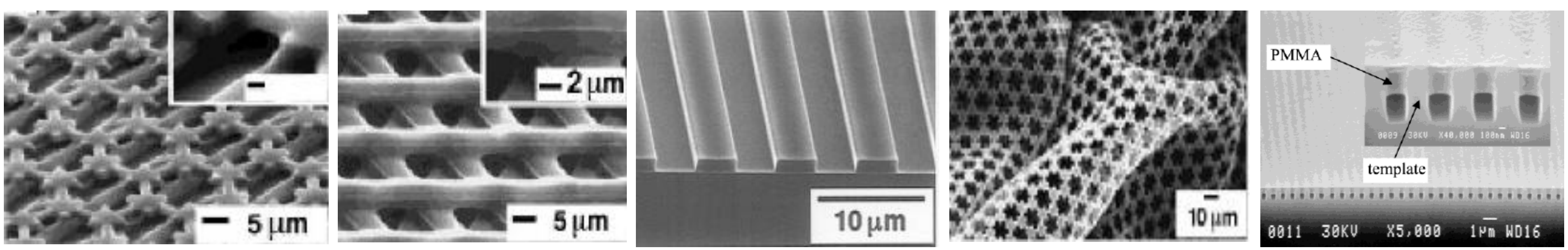


Mold-based lithographic techniques

Soft lithography

Nanoimprint lithography

Capillary force lithography

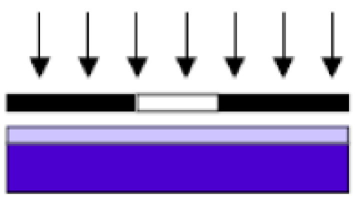


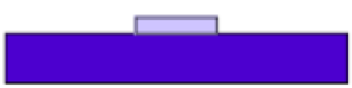
Master fabrication

In clean room:

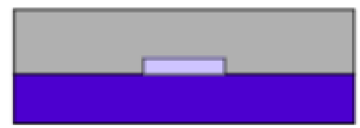

Clean Si wafer

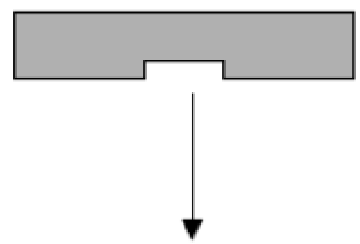

Spin coat photoresist


Exposure to UV light through mask


Develop

On lab bench:

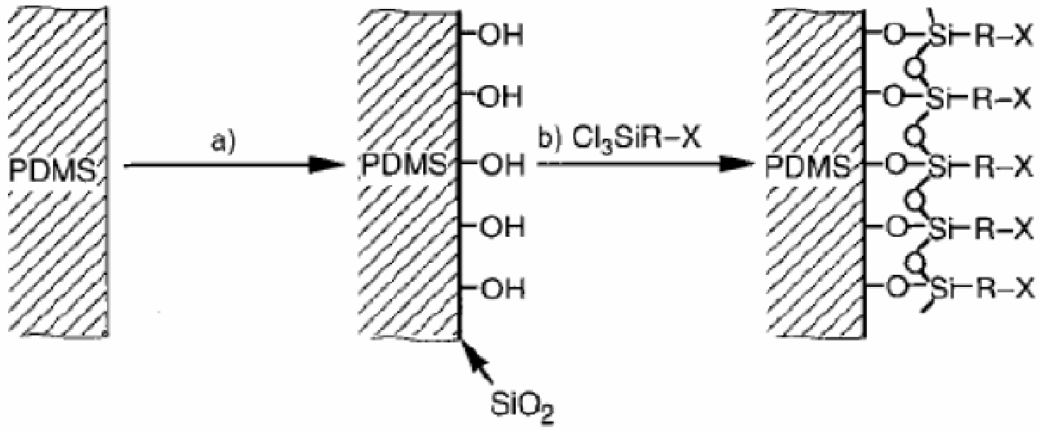

Mix and pour PDMS over master


Allow to set; peel from master

Microfluidics
Contact Printing
Micromolding
Imprinting/Embossing

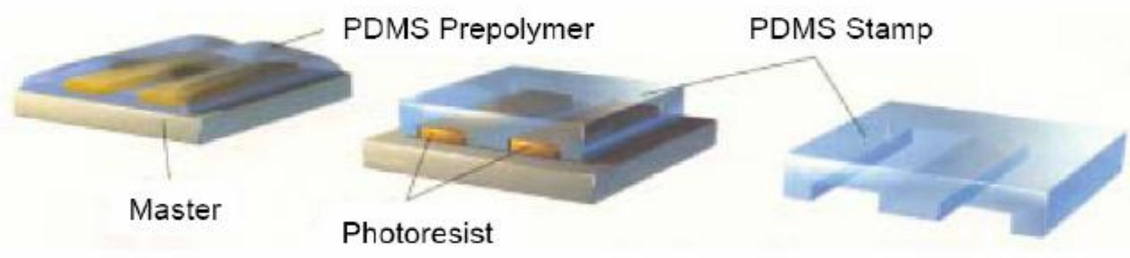
PDMS mold: wonder material for BioMEMS

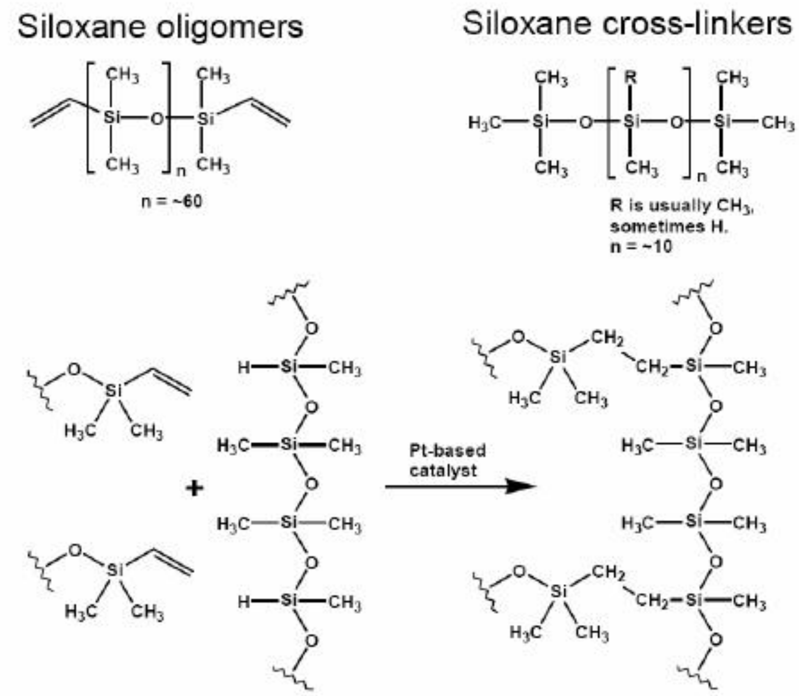
- elastomer, which means "deformable"
  - conforms to the surface of the substrate over a relatively large area
  - conformal contact achievable on nonplanar surfaces
  - be released easily, even from complex and fragile structures
- low in interfacial free energy and chemically inert
- homogeneous, isotropic, and optically transparent
- durable
- surface properties readily modified by the formation of SAMs



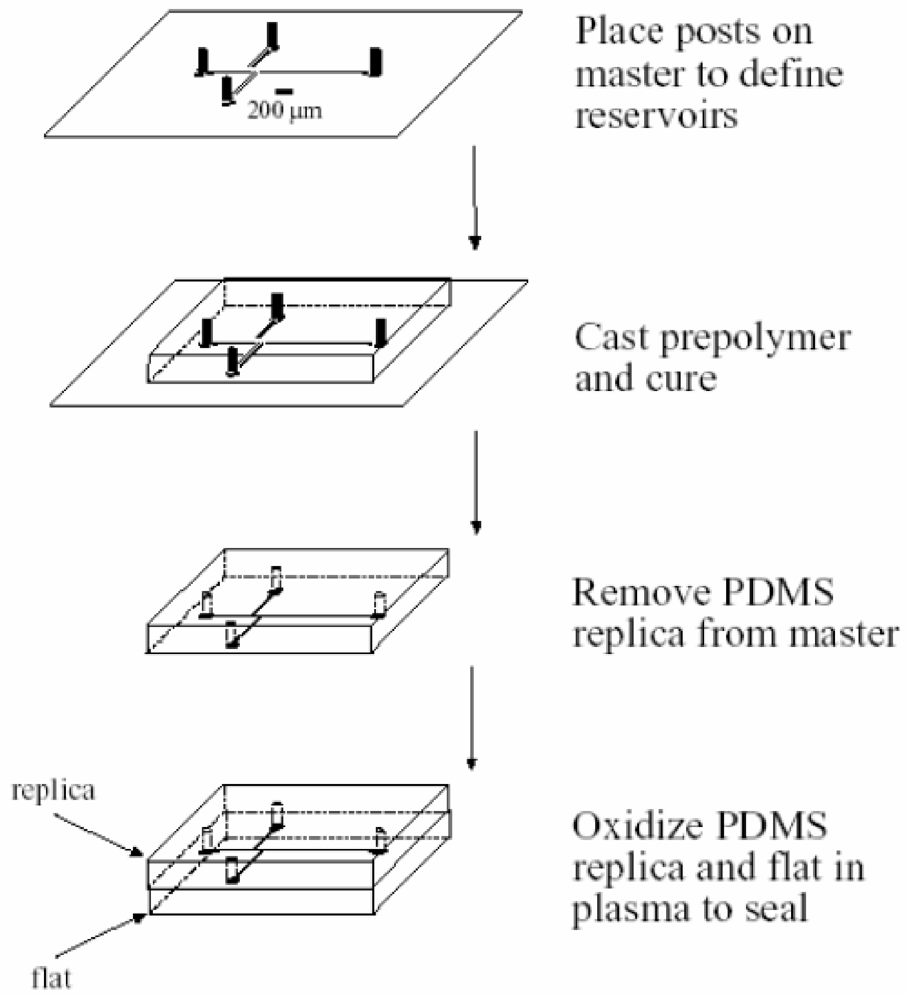
PDMS mold

PDMS Stamp





Channel Fabrication – Example



Duffy, McDonald, Schueller and Whitesides, *Anal. Chem.*, **70**, 4974 (1998).

3. Microfluidics and Nanofluidics

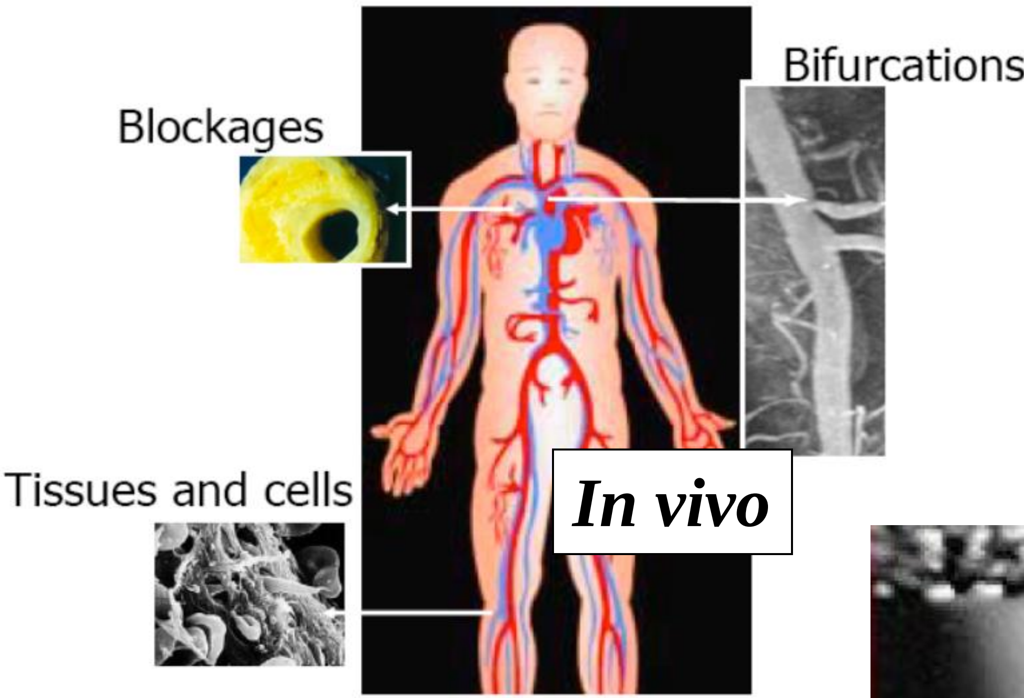
Why is Micro/Nanofluidics ?

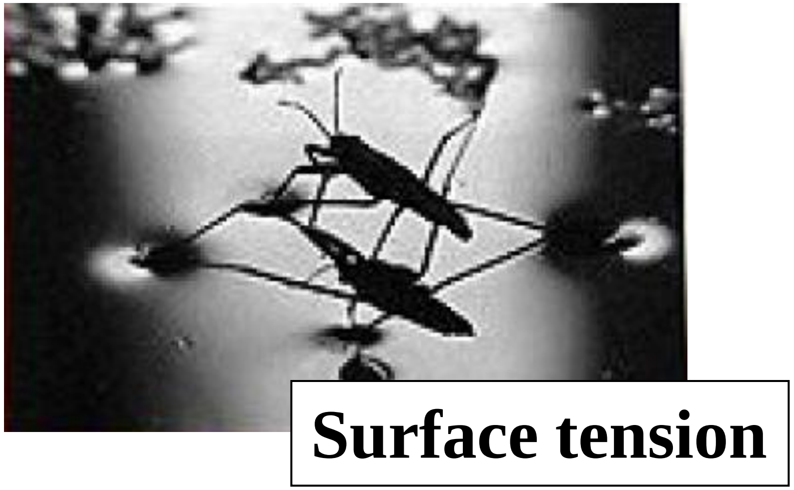
► **Micro/nanofluidics aims at investigating and developing miniature device which sense, pump, mix, monitor, and control small volume of fluids.**

► **Micro/nanofluidics has the potential to revolutionize the process and products that use fluid by high integration with a process.**

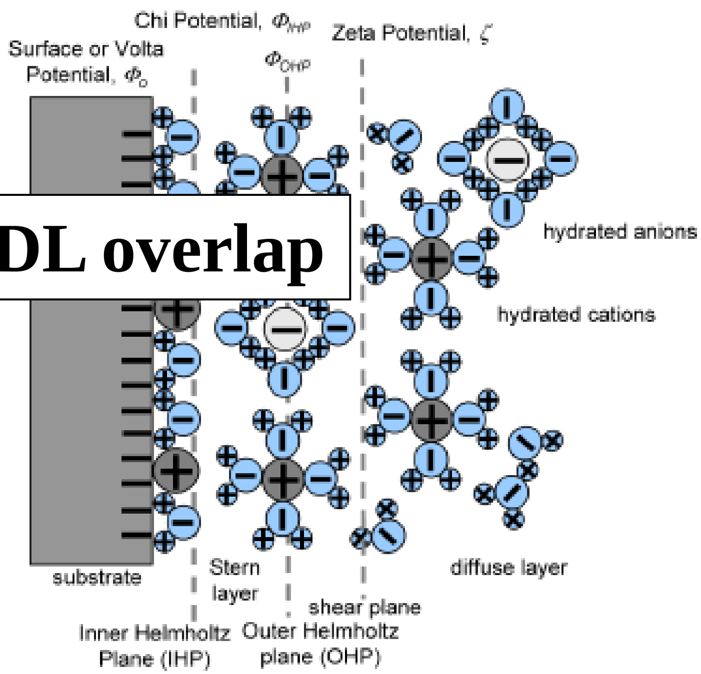
Microfluidics in Nature

Microfluidic scaling

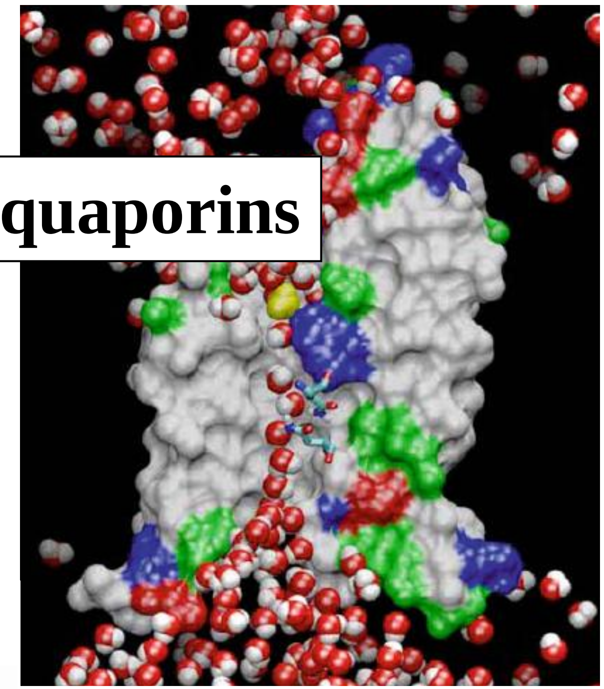




Nanofluidics in Nature

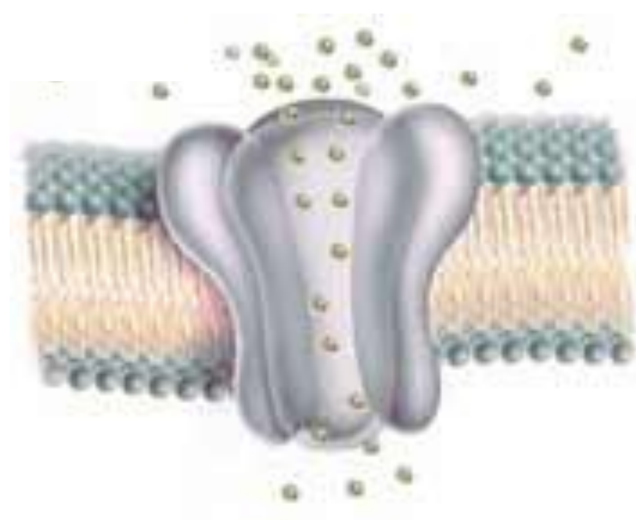


EDL overlap



Aquaporins

Ion channel



Basic properties in Microfluidics

- Conservation of Mass → Continuity Equation
- Newton's Second Law → Navier-Stokes Equation
- Incompressible Laminar Flow in Two Cases
- Squeeze-Film in MEMS

► **All flow is laminar (no turbulent mixing)**

► **Surface tension becomes significant**

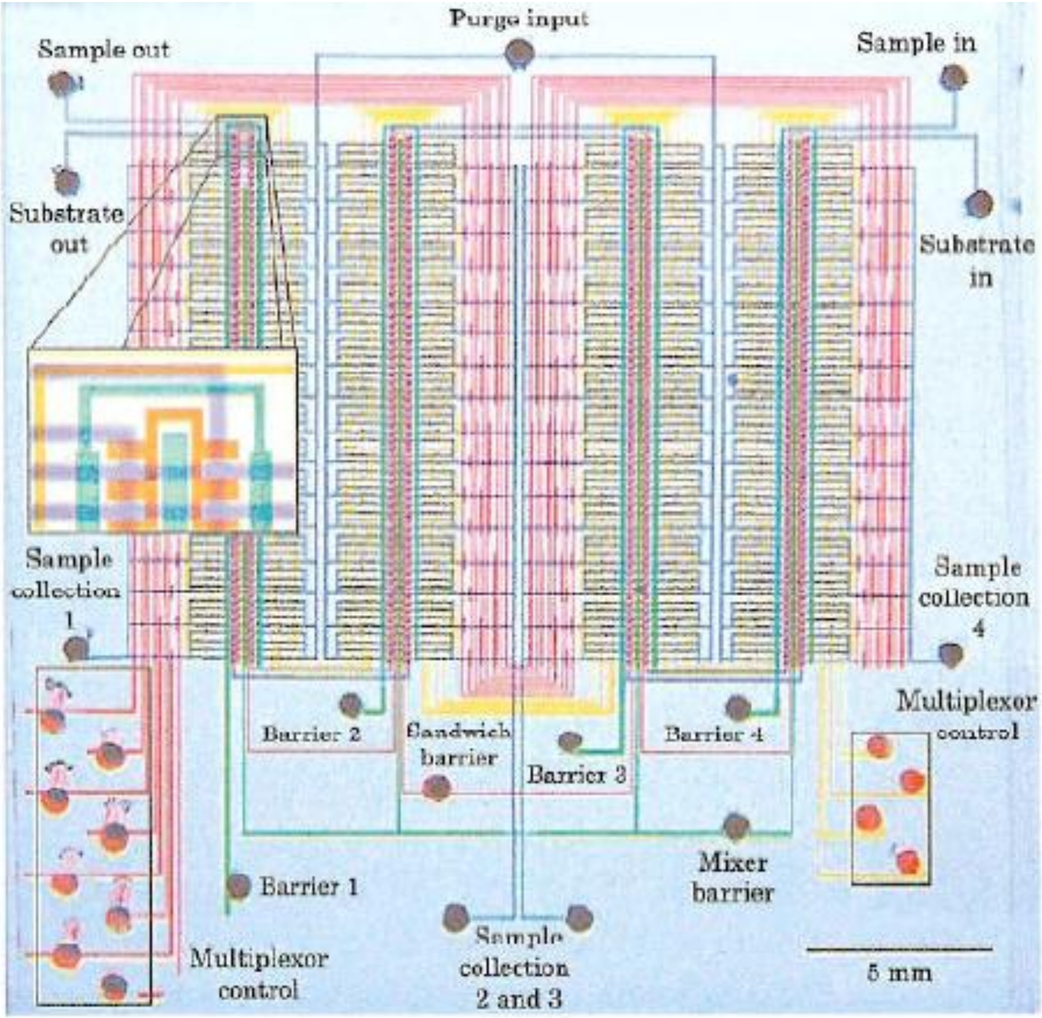
► **No inertia effects**

► **Apparent viscosity increases**

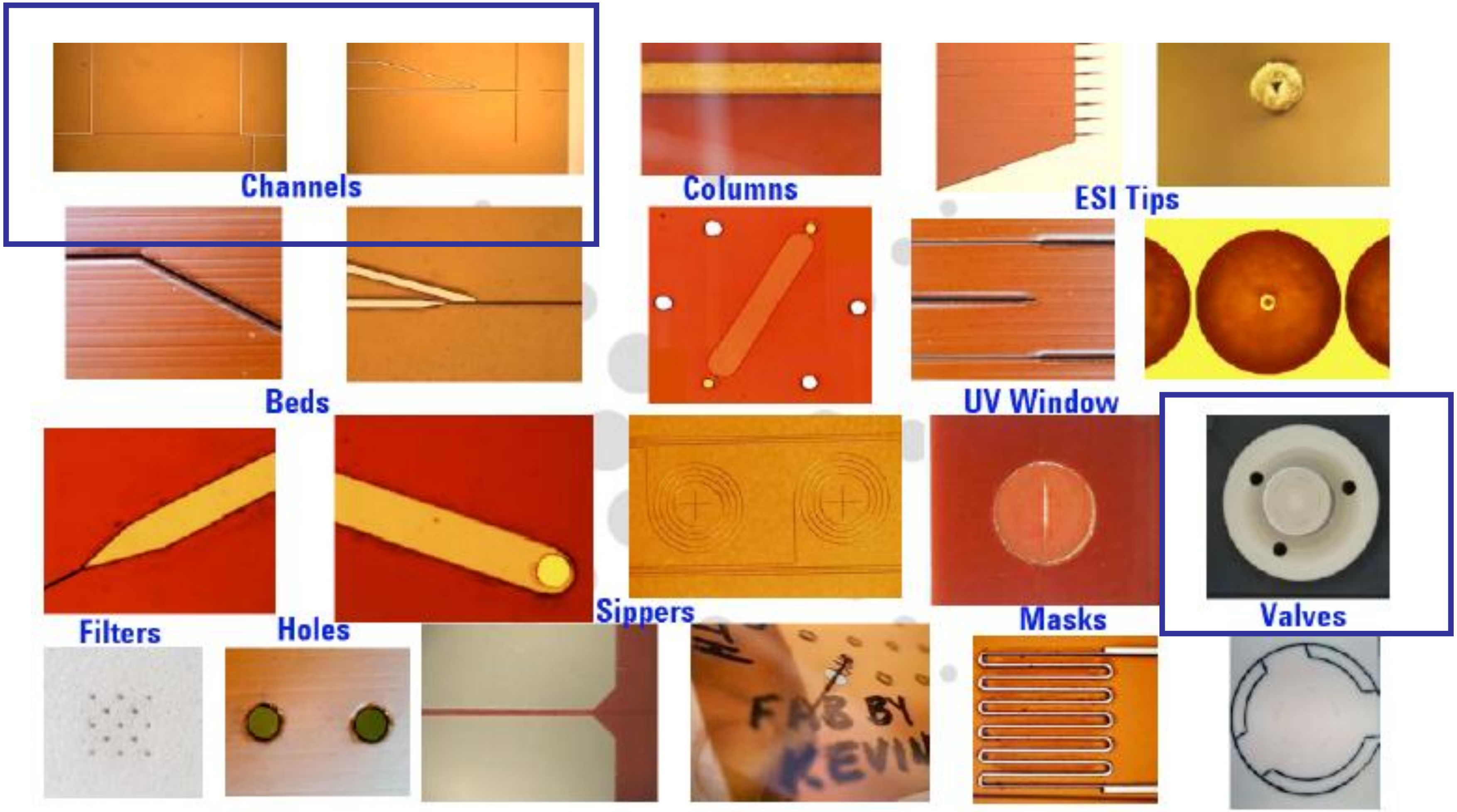
A Microfluidics system

System with a pressure actuated valves

- Thorsen et al., Science **298**, 580, 2002



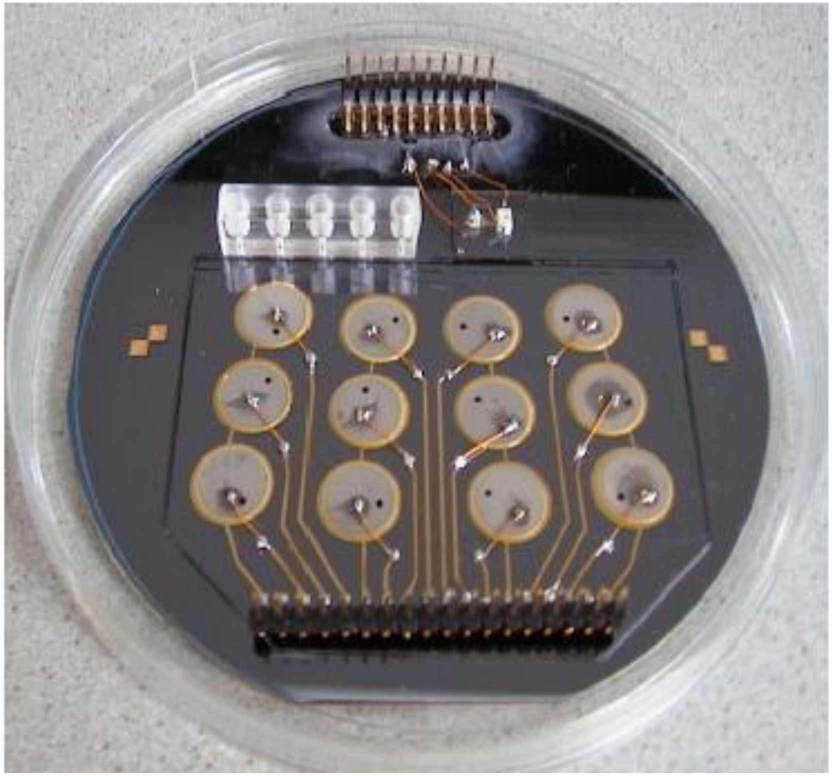
Microfluidics Elements



Integrated Microfluidic system – Example

Micro alumina flow injection analysis system

Chip has
- Micro pumps
- Micro flow sensors
- Micro mixers
- Filters
- Optical detectors



4. Sensors and Actuators

Sensors – A definition

A transducer that converts a measured parameter into a signal that carries information.

A sensor responds to stimuli such as

- Biological
  - Devices that measure biologically relevant information, e. g. Oxygen electrodes, neural interfaces, etc.
  - Devices using a biological component as part of the transduction mechanism
    - Antibodies
    - Enzymes
    - DNA, RNA
    - Whole cells
    - Whole organs/systems
- Chemical
- Physical (Acoustical, optical, magnetic, electric, thermal, radiation,..)

Sensors Performance

What is an ideal sensor?

- **Operates without affecting the "measured" parameter**
- **Has high sensitivity**
- **Has a high signal to noise**
- **Immune to external force**

→ ***Smart sensor***: An integrated device that can perform diverse tasks.
Normally it has integrated electronics and data analysis system

Sensor – Examples

Thermal Sensors

Used to control temperature of devices (example: Laser diodes) with a thermoelectric module

- Thermocouple (thermoelectric effect – Seebeck effect)

  A voltage is generated when there is a temperature difference

$$\Delta V = \alpha \Delta T$$

$$\Delta T = T - T_{ref}$$

- Thermodiode

  p-n junction, operated at a constant current, the output voltage is proportional to temperature

$$V \sim K_B T$$

Sensor – Examples

Mechanical Sensor

Acceleration (Discussed before)

- Example: An accelerometer is incorporated with pacemaker to increase heart rate with increased activity
- Cantilever beam is used to measure force (by measuring displacement)

$$F = k_m \Delta x$$

(k_m is like a spring constant)

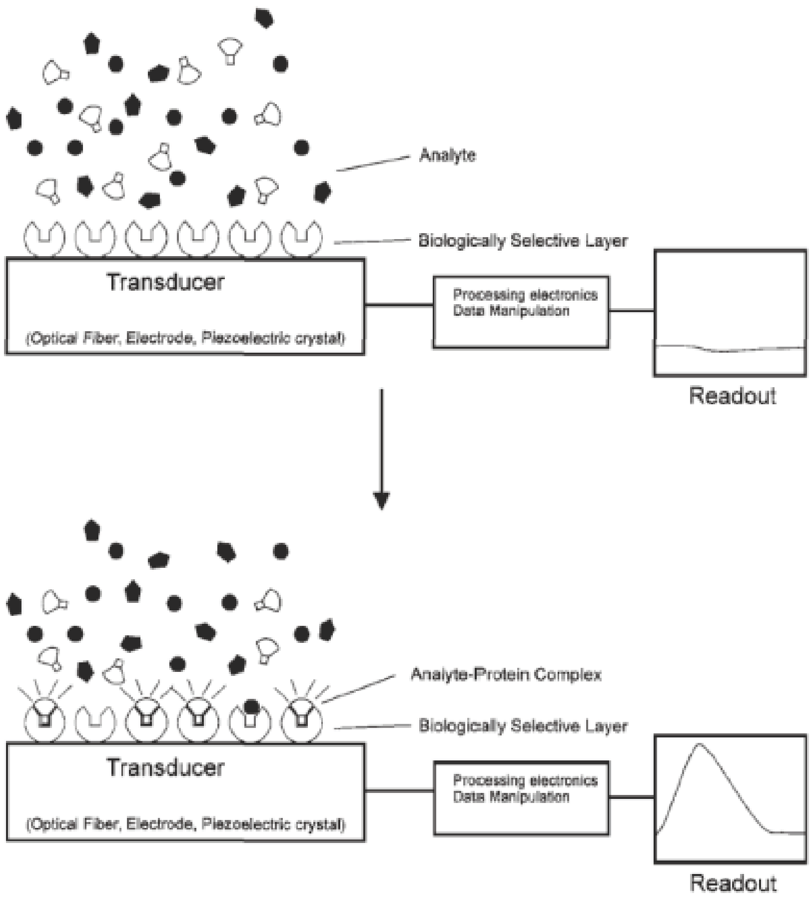
For a sinusoidal displacement

$$\Delta x = a \sin [\sqrt{\ } (F / EI)]$$

Sensor – Examples

Chemical Sensor

Selective bonding



References

- MEMS clearinghouse http://mems.isi.edu/
- MEMS links database
  http://www.nexus-emsto.com/links.html
- European Microsystems On-line
  http://www.nexus-emsto.com/
- MEMS resources http://www.trimmer.net/
- Introduction to Microengineering
  http://www.dbanks.demon.co.uk/ueng/
- Introduction to Microengineering
  http://www.dbanks.demon.co.uk/ueng/
- Lab-on-a-chip
  http://www.lab-on-a-chip.com

A few things to become a good engineer

From my personal experience and observations

- ► **Critical point of view is great but be generous and considerate**
- ► **Don't hesitate too much and be aggressive**
- ► **Communication skill is extremely important**
- ► **Be strategic and time efficient**

Thank you for your attention and participation in this class !!!