



## **Introduction to Micro/Nanofluidics**

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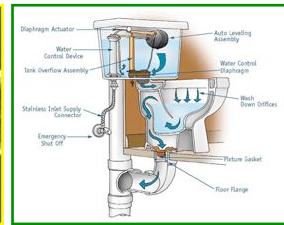
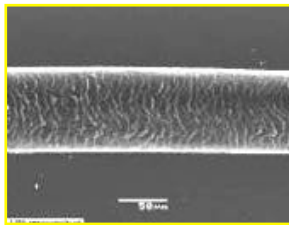
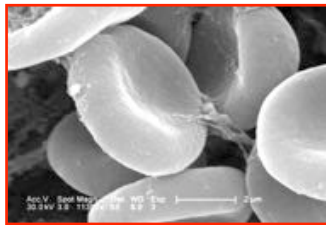
## **Outline**

- Introduction to Microfluidics
- Basic Fluid Mechanics Concepts
- Equivalent Fluidic Circuit Model
- Conclusion



## What is Microfluidics

- **Microfluidics** = Micro + Fluidics
- **Micro/Nano**:  $10^{-6}$  ,  $10^{-9}$ 
  - Small size (sub-mm)
  - Small volumes ( $\mu\text{l}$ , nL, pL)
- **Fluidics**: handling of liquids and/or gases



## Advantages of Microfluidics

- The motivation for using a microfluidic system is analogous to the argument for using integrated circuits (IC) to replace the discrete component circuits.
- Advantages:

Miniaturization: Portability (Lab-on-a-Chip)

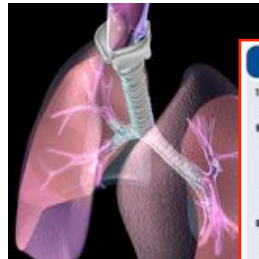
Integration: Low Costs, Batch Fabrication

Automation: Simplicity of Operation



## Microfluidics *in vivo*

- Circulating and Respiratory System



Location	Generation
Trachea	0
Bronchi	1
	2
Bronchioles	3
	4
	5
Terminal bronchioles	16
	17
Respiratory bronchioles	18
	19
Alveolar ducts	T, 20
	T, 21
	T, 22
Alveolar sacs	T, 23

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## Old School Microfluidics

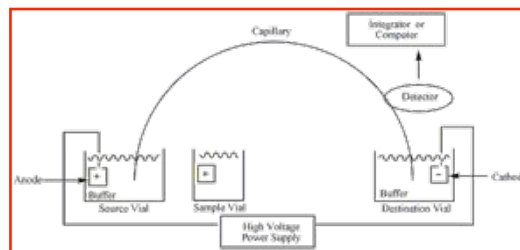
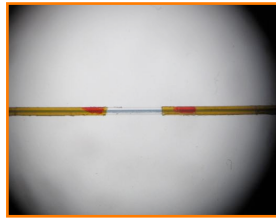
- Historical Microfluidics: Glass capillary
- Glass Capillary has been broadly exploited in labs
- Capillary Electrophoresis (CE)





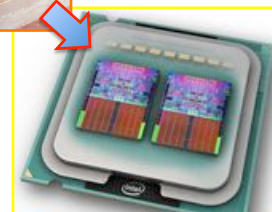
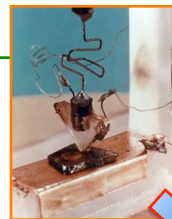
## Capillary Electrophoresis (CE)

- Introduced in the 1960s, the technique of capillary electrophoresis (CE) was designed to separate species based on their size to charge ratio in the interior of a small capillary filled with an electrolyte.



## New Era of Microfluidics

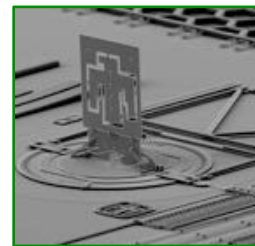
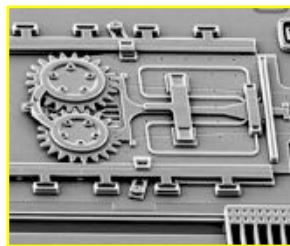
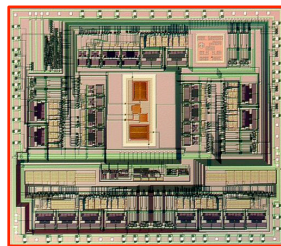
- Due to the advancement of micro/nano fabrication technology, “microfluidics” has been redefined.



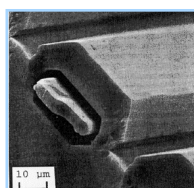


## Microelectromechanical Systems

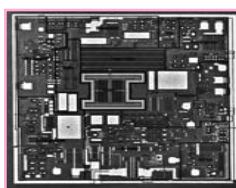
- Microelectromechanical Systems (MEMS).
- MEMS is the integration of *mechanical elements, sensors, actuators, and electronics* on a common silicon substrate through microfabrication technology.



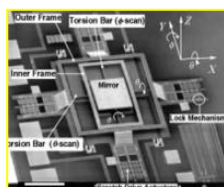
## Advancement of MEMS



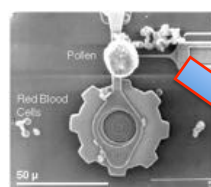
Ikeda et al. 1990 (Japan)



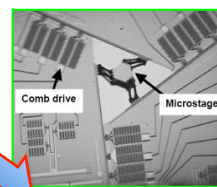
Analog Device ADXL50



Toshiyoshi et al., 1998 (UCLA)



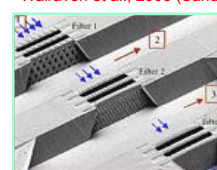
mems.andia.gov



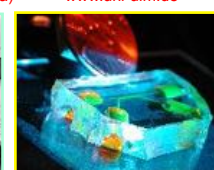
Walraven et al., 2003 (Sandia)



www.uni-ulm.de



www.mic.dtu.dk



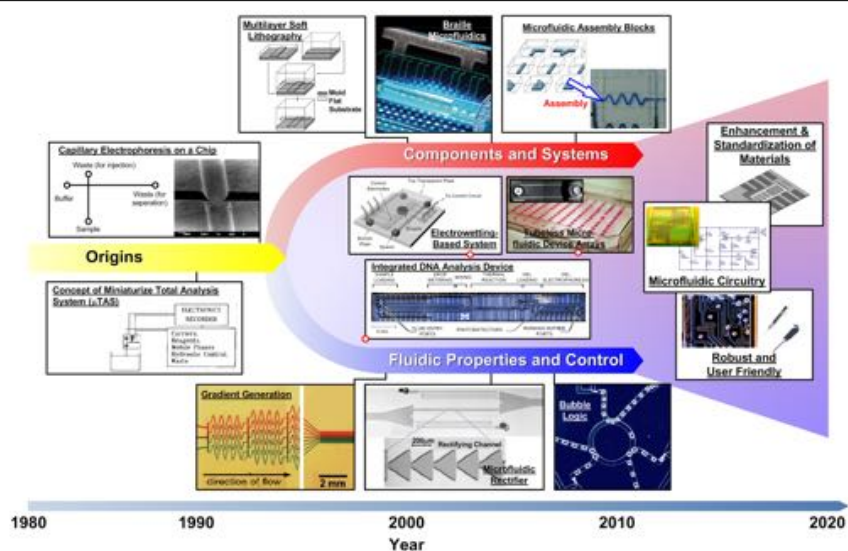
Takayama et al, 2003 (UM)

**Silicon-Based**

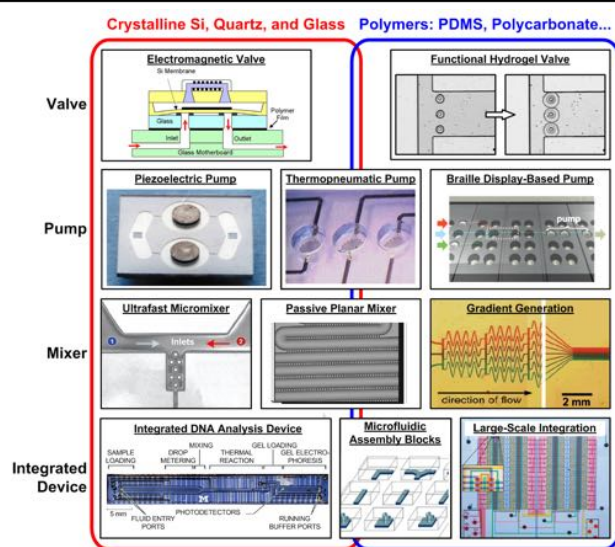
**Polymer**



## Development of Microfluidics



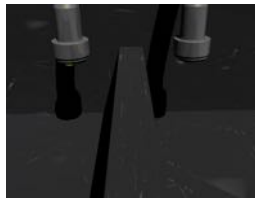
## Materials of Microfluidic Devices





## Fluid Mechanics

- **Density ( $\rho$ ):**  
Density = Mass/Volume ( $\text{kg/m}^3$ )
- **Dynamic Viscosity (Viscosity,  $\mu$ ):**  
Viscosity is a measure of the resistance of a fluid which is being deformed by either shear stress or tensional stress.



Temp (°C)	Density ( $\text{kg/m}^3$ )
100	958.4
80	971.8
60	983.2
40	992.2
30	995.6502
25	997.0479
22	997.7735
20	998.2071
15	999.1026
10	999.7026
4	999.9720
0	999.8395
-10	998.117
-20	993.547
-30	963.854

The density of water in kilograms per cubic meter (SI unit) at various temperatures in degrees Celsius.  
The values below 0 °C refer to *supercooled* water.



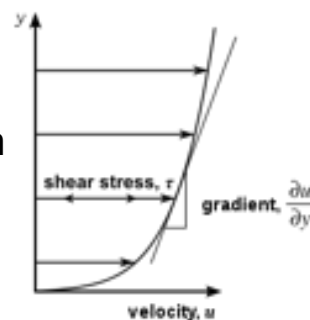
## Fluid Mechanics

- **Viscosity ( $\mu$ ) – Newton's Theory:**

$$\tau = \mu \frac{du}{dy}$$

where  $\tau$  is Fluid Shear Stress  
where  $(du/dy)$  is change of fluid velocity in  $y$  direction

- This is a constitutive equation (a reasonable first approximation).
- **Newtonian Fluids.**







## Fluid Mechanics

- **Viscosity ( $\mu$ ):**

- Unit:  $\text{kg}/(\text{m}\cdot\text{s}) = \text{Pa}\cdot\text{s} = 10 \text{ Poise}$
- Viscosity of Water at  $20^\circ\text{C}$ 
  - =  $0.01002 \text{ Poise}$
  - =  $1.002 \text{ cP}$  (centipoise)
  - =  $1.002 \text{ mPa}\cdot\text{s}$
- Viscosity of SAE 30 oil at  $20^\circ\text{C}$ 
  - =  $2.9 \text{ Poise}$

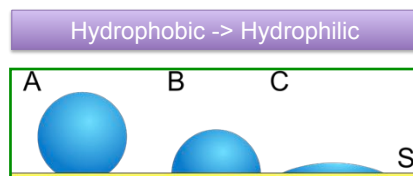
Temperature [°C]	Viscosity [mPa·s]
10	1.308
20	1.002
30	0.7978
40	0.6531
50	0.5471
60	0.4668
70	0.4044
80	0.3550
90	0.3150
100	0.2822



## Fluid Mechanics

- **Surface Tension ( $\gamma$ ):**

**Surface tension** is a property of the surface of a liquid. Surface tension is caused by cohesion (the attraction of molecules to like molecules).







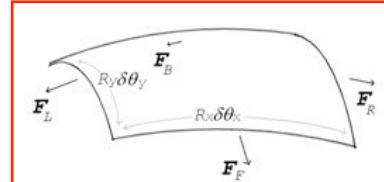
## Fluid Mechanics

- **Surface Tension ( $\gamma$ ):**  
**Young-Laplace Equation:**

$$\Delta p = \gamma \left( \frac{1}{R_x} + \frac{1}{R_y} \right)$$

Where  $\Delta p$  is the pressure difference,  $\gamma$  is surface tension,  $R_x$  and  $R_y$  are radii of curvature in each of the axes that are parallel to the surface.

Water at 25°C,  $\gamma = 71.97$  (dyn/cm)

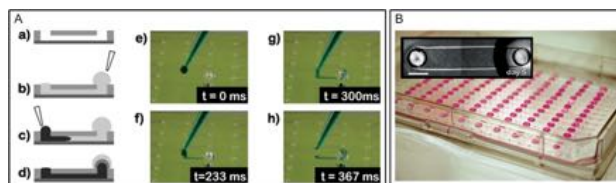


$\Delta p$ for water drops of different radii at STP				
Droplet radius	1 mm	0.1 mm	1 $\mu\text{m}$	10 nm
$\Delta p$ (atm)	0.0014	0.0144	1.436	143.6



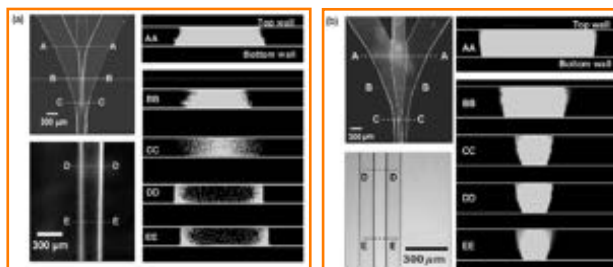
## Fluid Mechanics

- **Utilize Surface Tension in Microfluidics**



Surface Tension  
Driven Flow

Air-Liquid Two  
Phase Flow

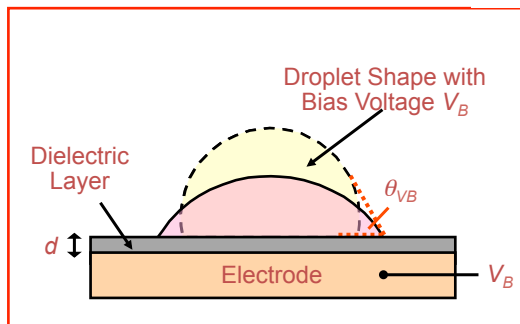




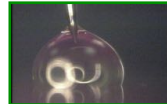
## Fluid Mechanics

- Control Surface Tension in Microfluidics: Electro-Wetting

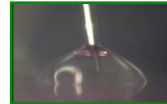
$$\cos \theta_v = \cos \theta_o + \frac{1}{2} \frac{\epsilon \epsilon_o}{\gamma_{LV} t} V^2$$



Hydrophobic Surface

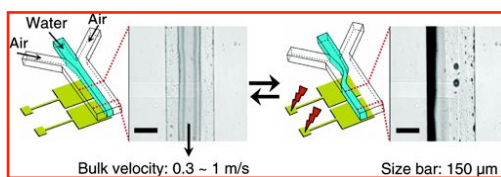


Hydrophilic Surface

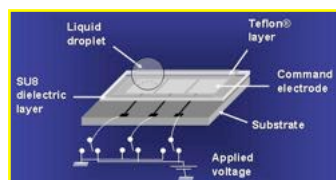


## Fluid Mechanics

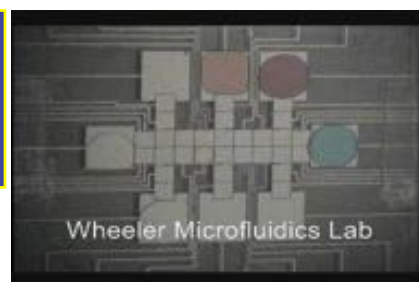
- Electro-Wetting Microfluidics



Switchable Surface for Air-Liquid Flow



Digital Microfluidics





## Fluid Mechanics

- **Reynolds Number ( $Re$ ):**

$Re$  is a dimensionless number that gives a measure of the ratio of inertial forces to viscous forces.

$$Re = \frac{\rho VL}{\mu}$$

$V$  is the mean fluid velocity (m/s)

$L$  is the a characteristic linear dimension (m)  
(traveled length of fluid or hydarulic diameter etc.)



## Fluid Mechanics

- **Reynolds Number ( $Re$ ):**

- Large  $Re$  means inertial force dominates:

**Turbulent Flow (unsteady flow stream, i.e. swirls and vortices).**

- Small  $Re$  means viscosity force dominates:

**Laminar Flow (fluid stream follows regular paths, i.e. streamlines).**

- For flow in a pipe, laminar flow occurs when  $Re < 2300$ , and turbulent flow occurs when  $Re > 4000$ .

- In the interval between 2300 and 4000:

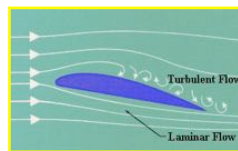
**Transition Flow.**



## Fluid Mechanics

- **Laminar Flow vs. Turbulent Flow**

- Blood Flow in brain  $\sim 1 \times 10^2$
- Blood flow in aorta  $\sim 1 \times 10^3$
- Typical pitch in Major League Baseball  $\sim 2 \times 10^5$
- Person swimming  $\sim 4 \times 10^6$



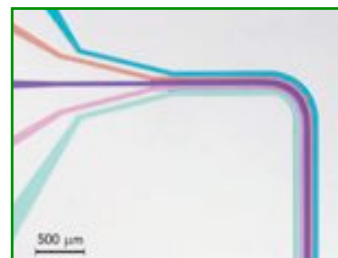
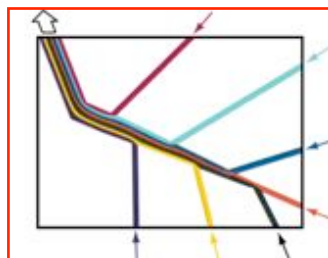
## Fluid Mechanics

- **Microfluidics (Laminar or Turbulent?)**

$$Re = \frac{\rho VL}{\mu}$$

For example:  $V = 1 \text{ (mm/s)}$ ,  $L = 100 \text{ }\mu\text{m}$

$$Re = \frac{\rho VL}{\mu} = \frac{1000(\text{kg/m}^3) \times 10^{-3}(\text{m/s}) \times 100 \cdot 10^{-6}(\text{m})}{0.001(\text{kg/m} \cdot \text{s})} = 0.1$$



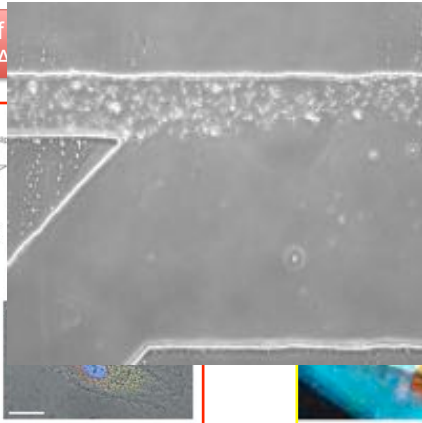
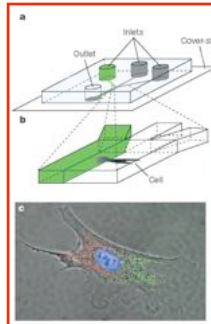


## Fluid Mechanics

- Laminar Flow in Microfluidic Channel

Partial Treatment of  
Flows (PA)

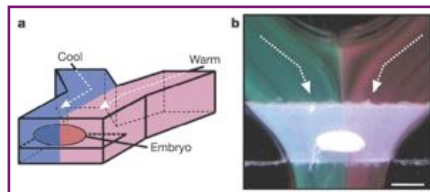
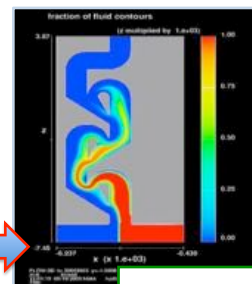
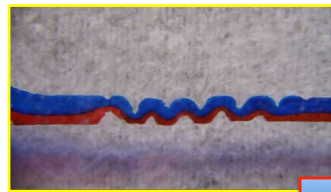
Term Sorter  
ar vs. Diffusion)



## Fluid Mechanics

- Limits in Microfluidic Channel

Gradients Generation – Difficult to Mix





## Fluid Mechanics

- **Reynolds Number ( $Re$ ):**

The ratio of inertial forces to viscous forces.

$$Re = \frac{\rho VL}{\mu}$$

- **Weber Number ( $We$ ):**

The ratio of inertia forces to surface tension forces.

$$We = \frac{\rho V^2 L}{\sigma}$$

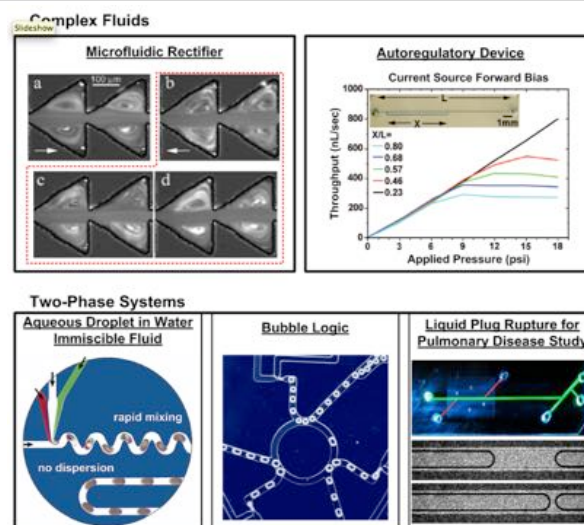
- **Bond Number ( $Bo$ ):**

The ratio of body forces to surface tension forces.

$$Bo = \frac{\rho a L^2}{\gamma}$$

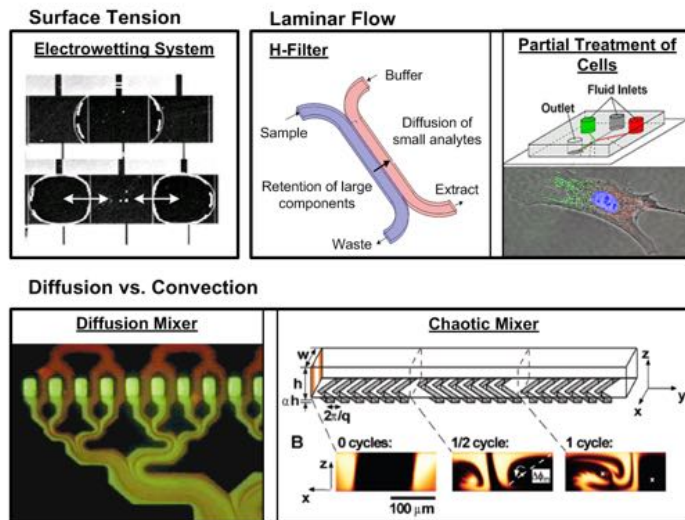


## Other Microfluidic Devices





## Conclusion



## Conclusion

- Advantages and Limitations of Microfluidics
- Challenges
- Future Directions

