

Microfabrication & Microfluidics

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- NMI Natural and Medical Sciences Institute at the University of Tübingen

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Assistant: Julia Heldmaier (***Julia.Heldmaier@med.uni-tuebingen.de***)

Summer Semester 2022

Microfabrication & Microfluidics

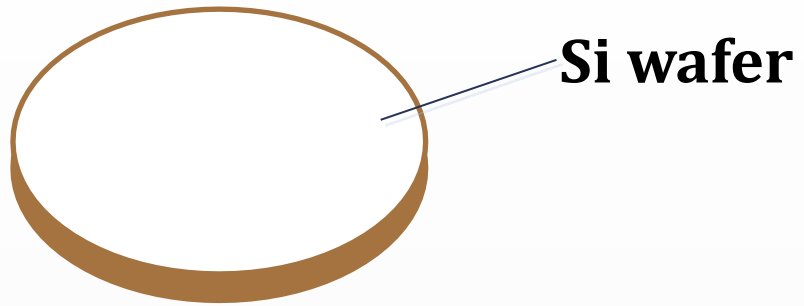
Aims for today:

- Get an understanding of the
 - general concept of microfabrication techniques
 - specific steps of photolithography
- Comprehend the fundamentals of microfluidic
 - from a Physics viewpoint
 - from an Engineering viewpoint

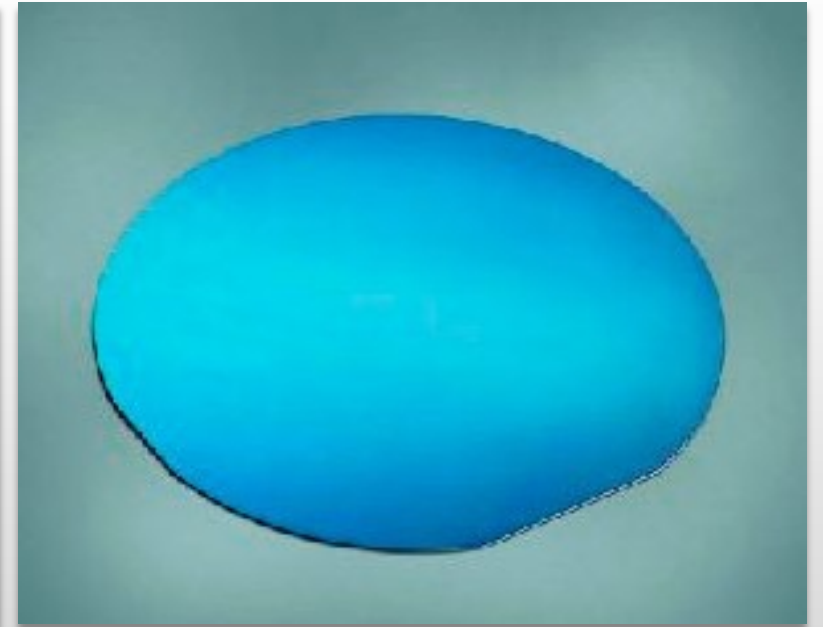
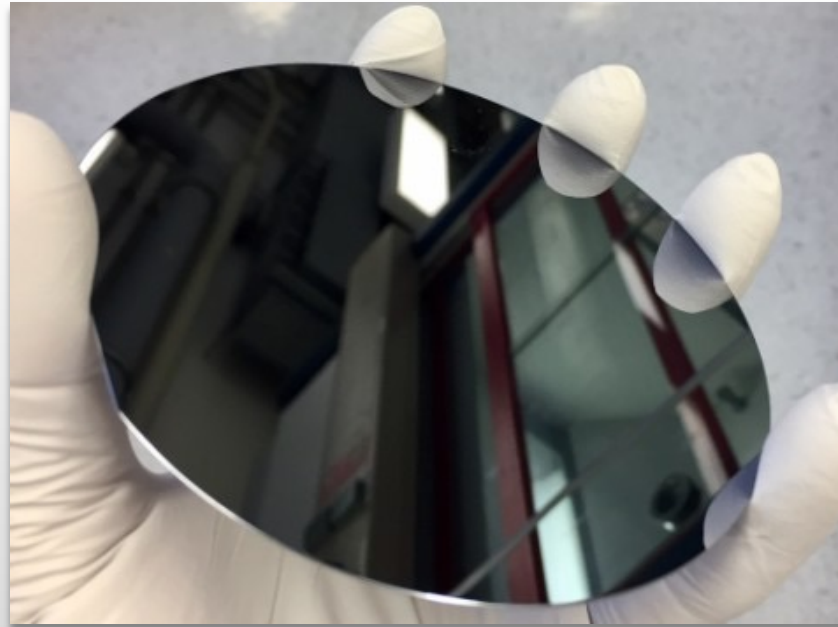
Microfabrication techniques

- Primary microfabrication (*Generation of microstructured masters*)
 - Lithographic techniques
 - Etching and deposition of materials (wet etching, dry etching, CVD, PECVD, sputtering etc.)
 - Mechanical machining (milling, drilling etc.)
 - Laser ablation & structuring
- Replication technologies (*Subsequent “mass production” from microstructured masters*)
 - Casting techniques / Replica molding
 - Hot embossing
 - Injection molding

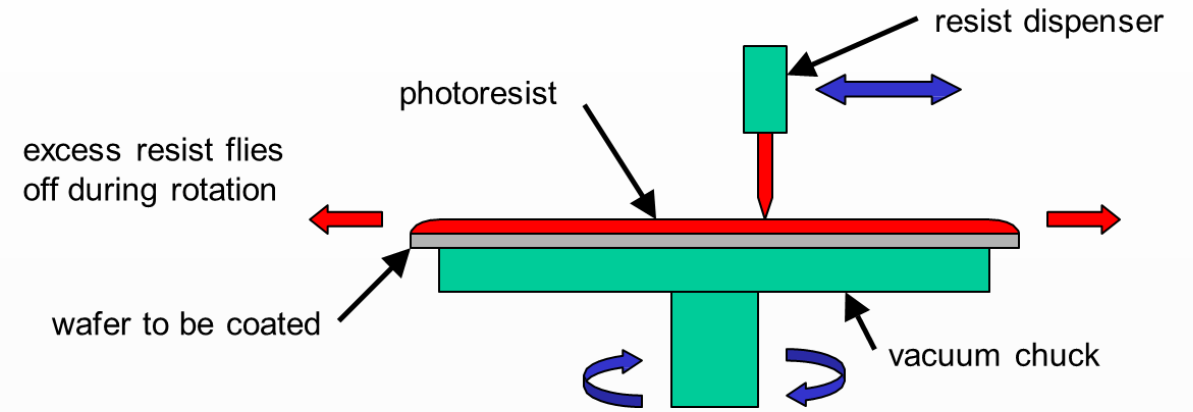
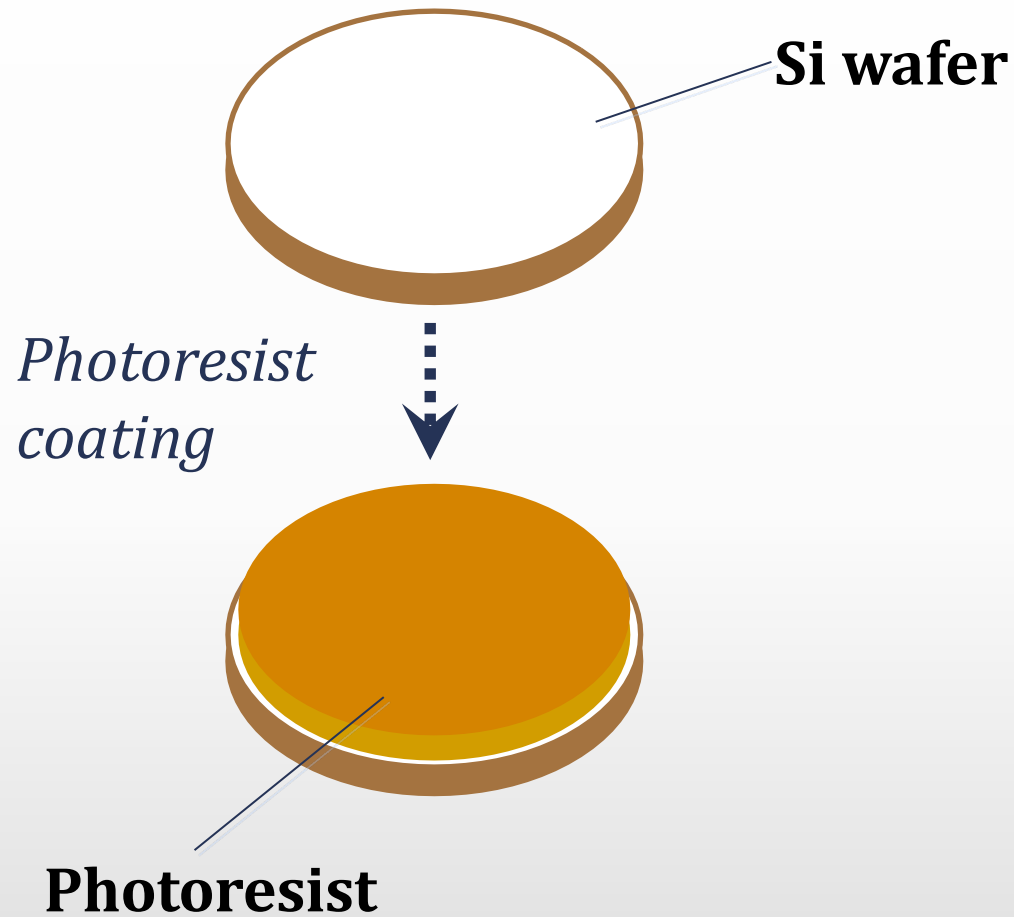
Photolithography



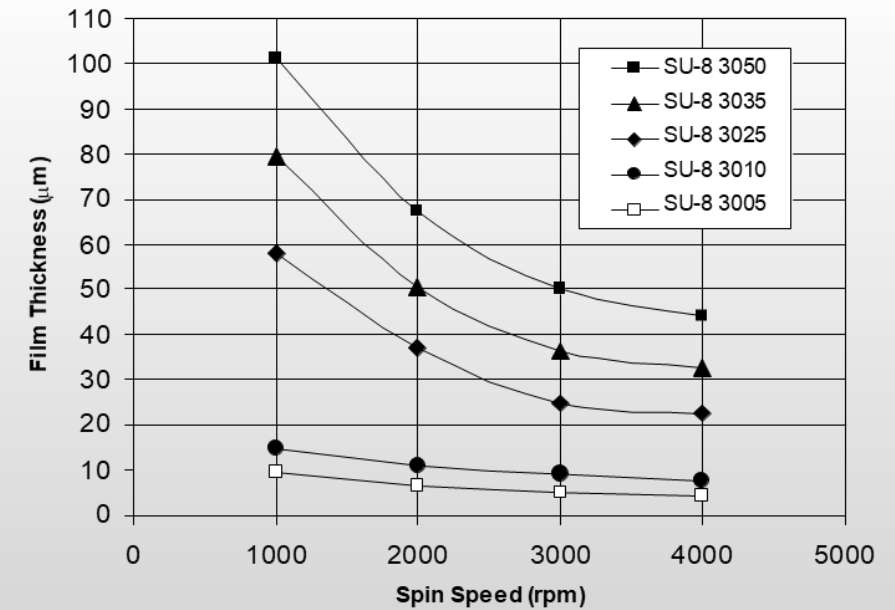
- Sub-nm roughness
- Extremely clean



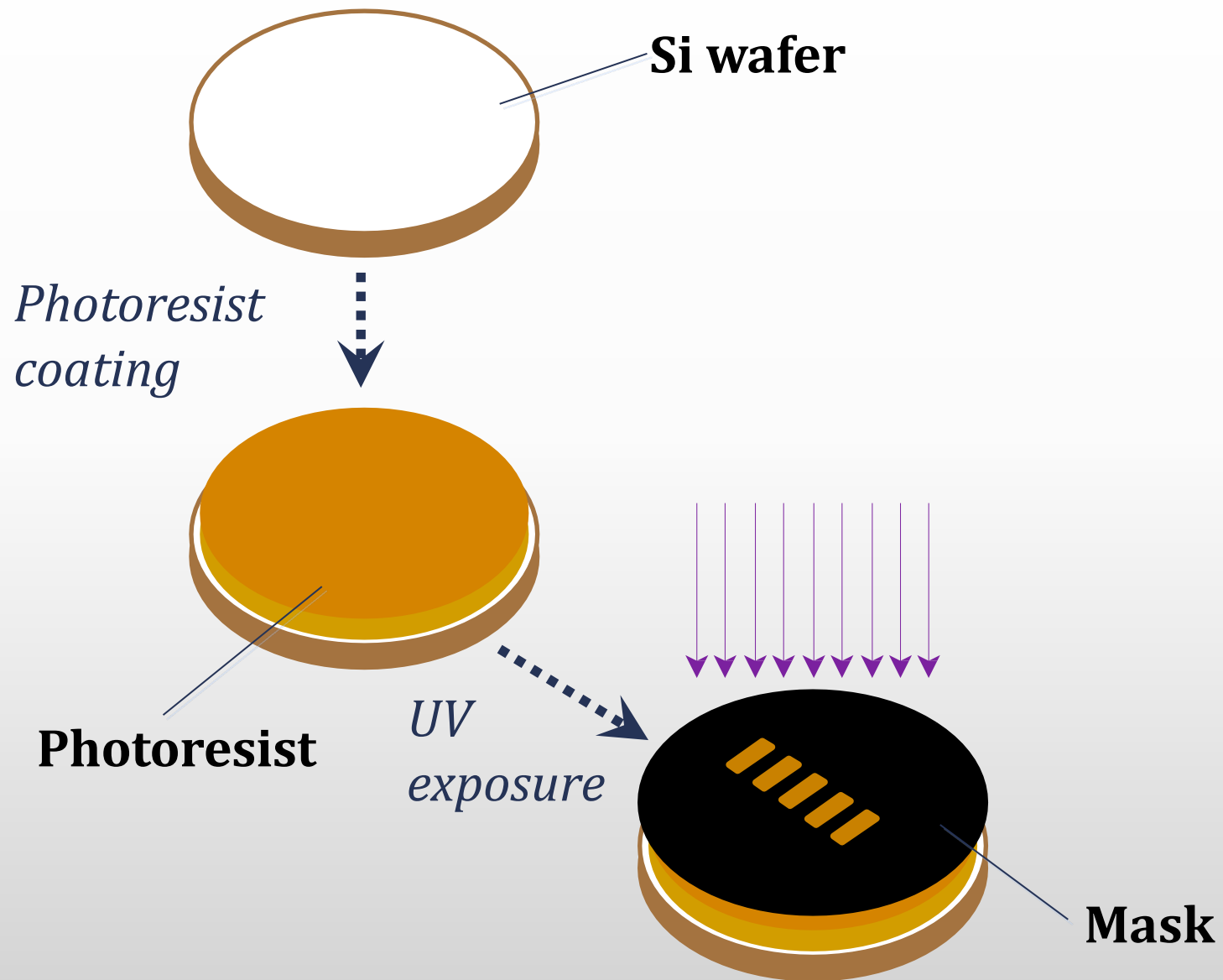
Photolithography



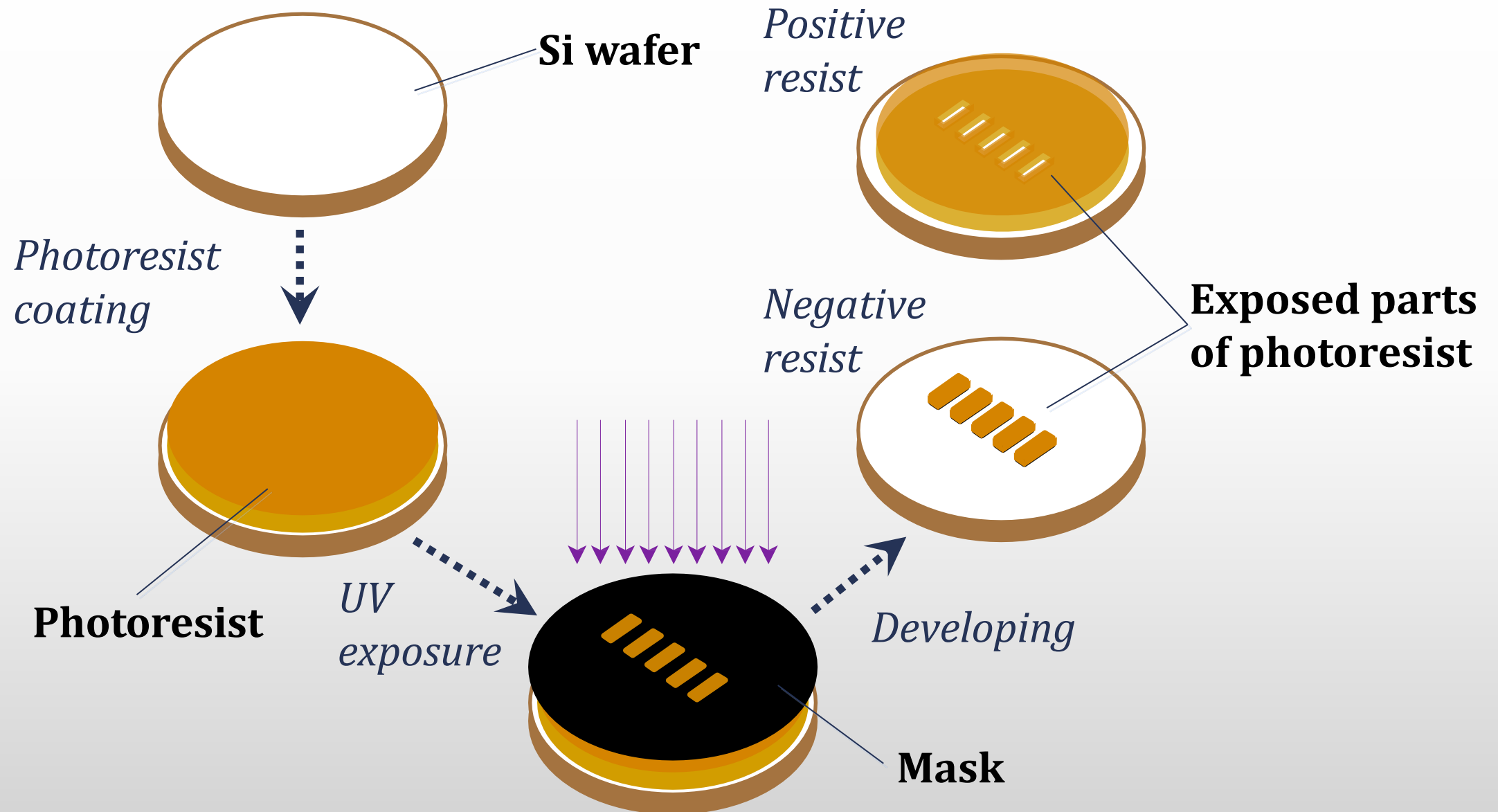
➤ Spin coating



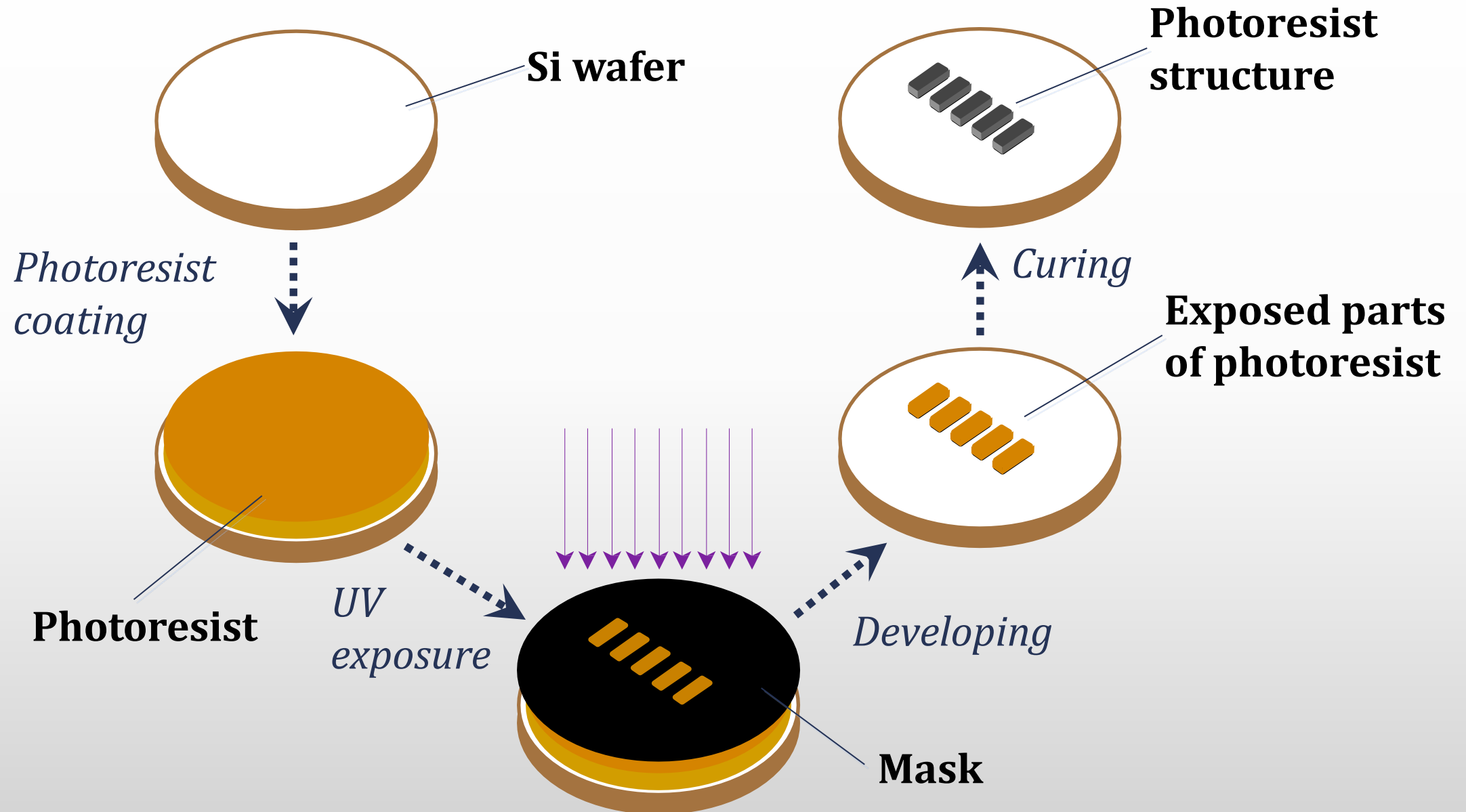
Photolithography



Photolithography



Photolithography

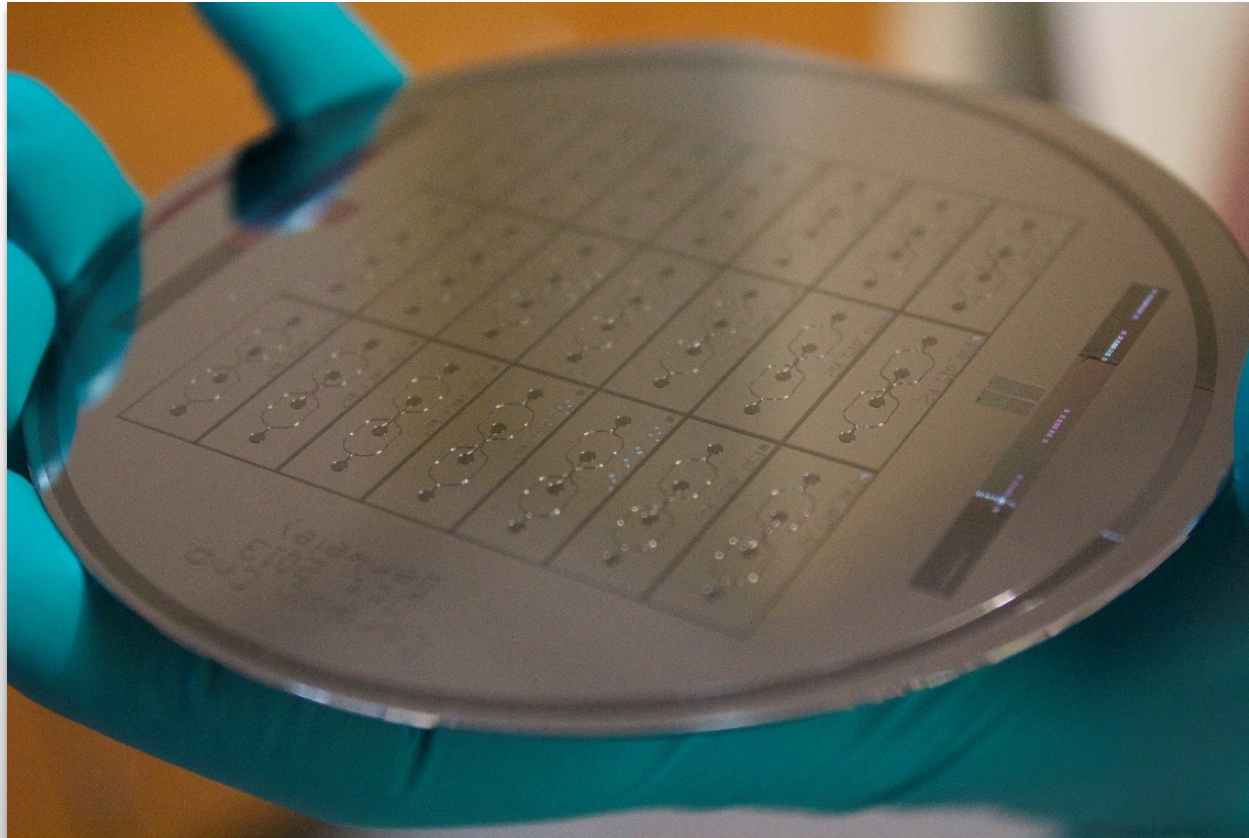
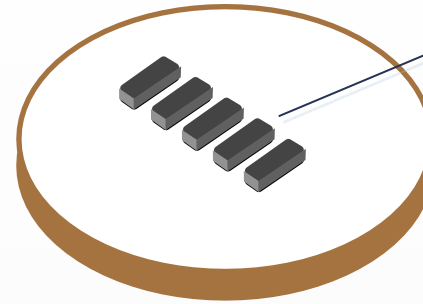


Photolithography

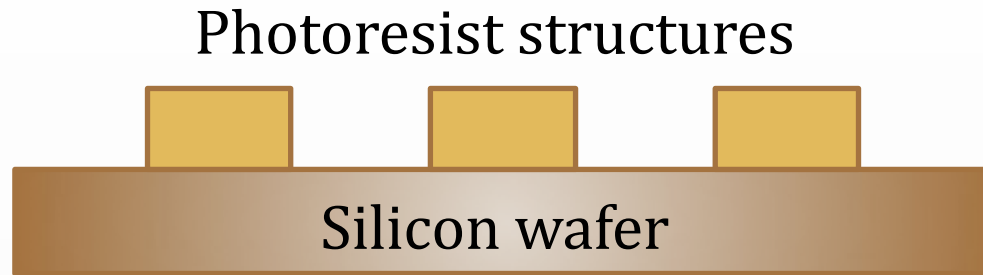
Photoresist structures



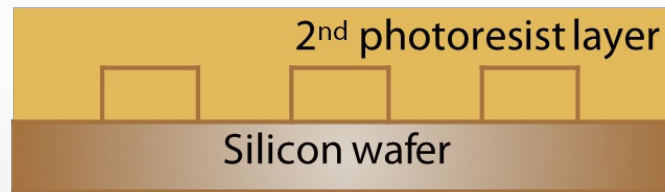
**Photoresist
structure**



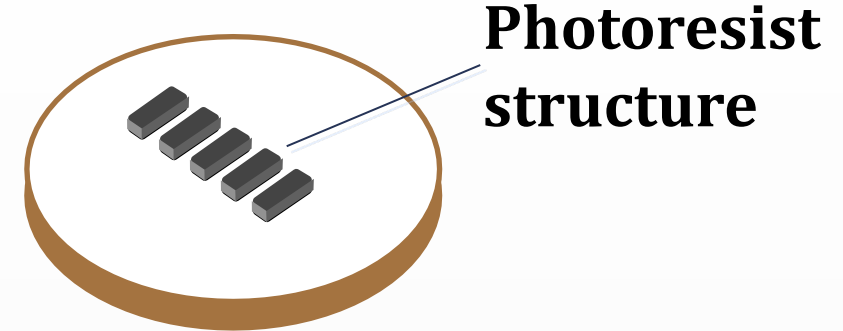
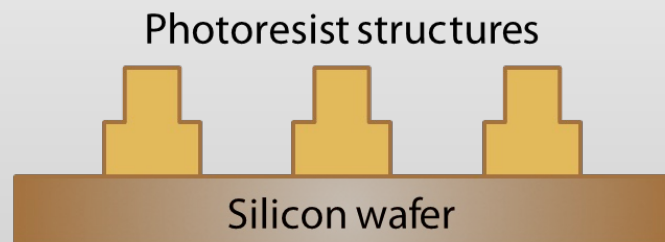
Secondary processing



Two step lithography

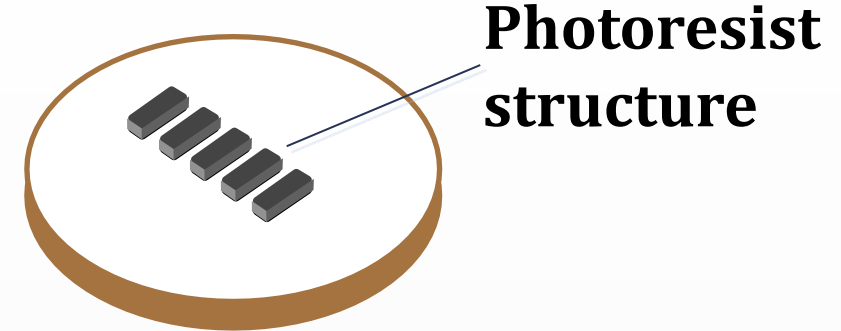


Photolithography

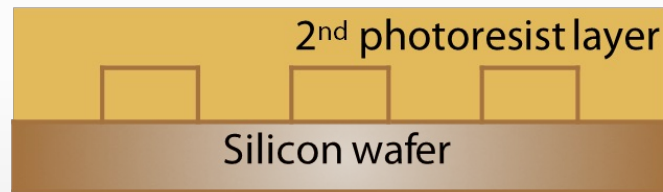


Secondary processing

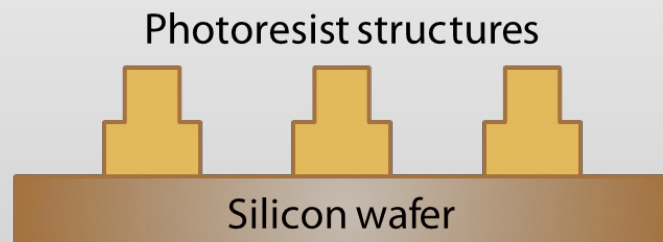
Photoresist structures



Two step lithography



Photolithography

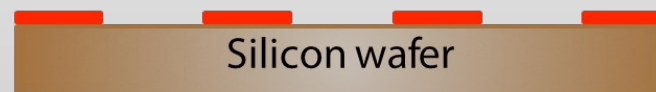
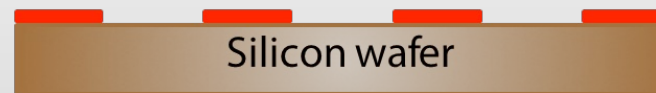


Deposition

Coating (Metall, polymer,...)

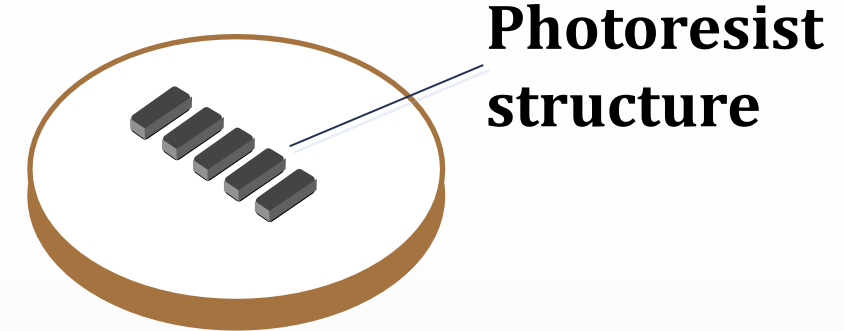


Lift off

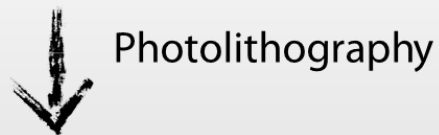
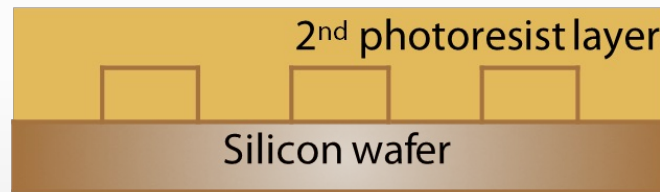


Secondary processing

Photoresist structures



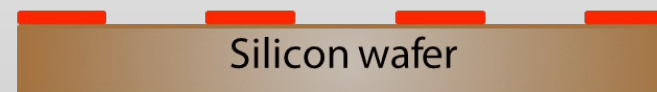
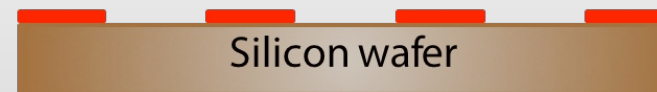
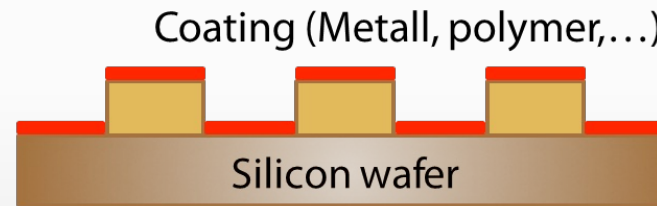
Two step lithography



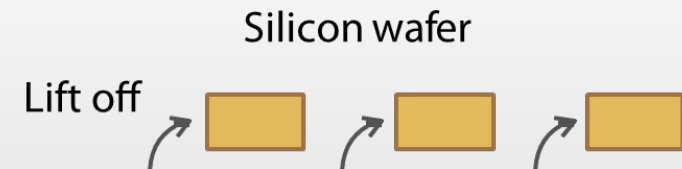
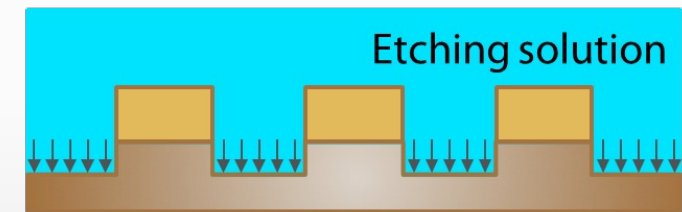
Photoresist structures



Deposition



Etching (wet, dry)

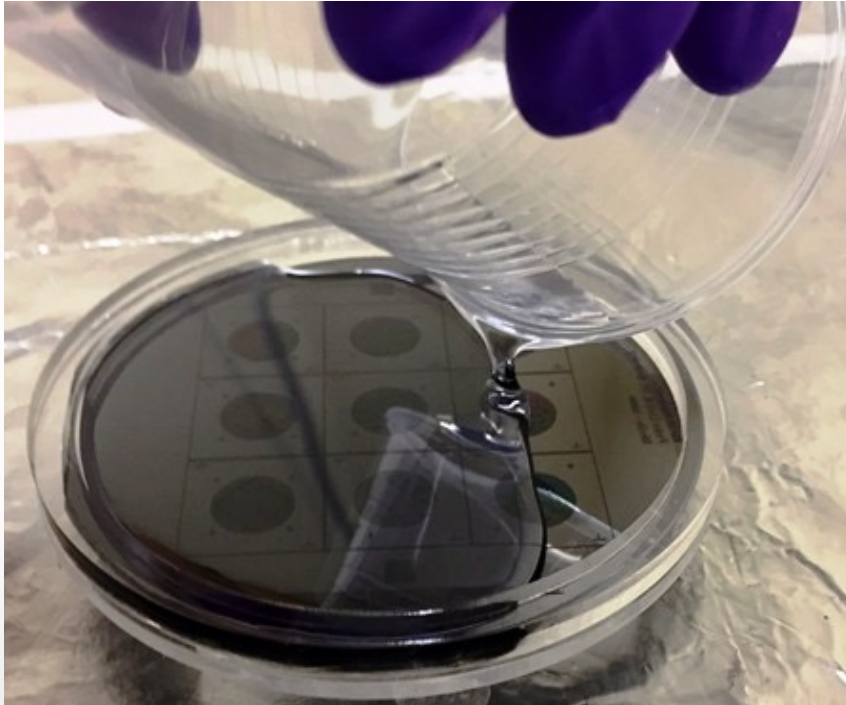


Silicon wafer

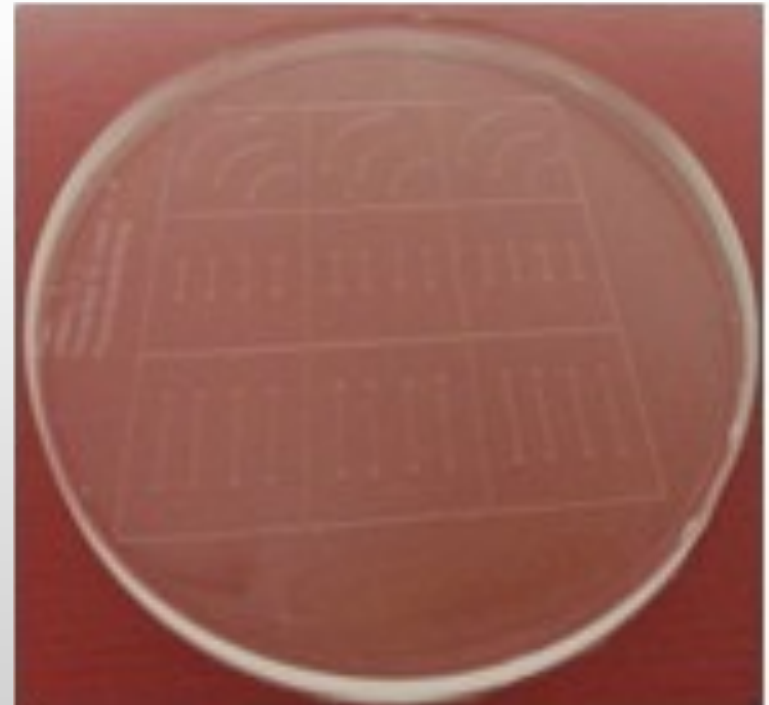
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Replica molding



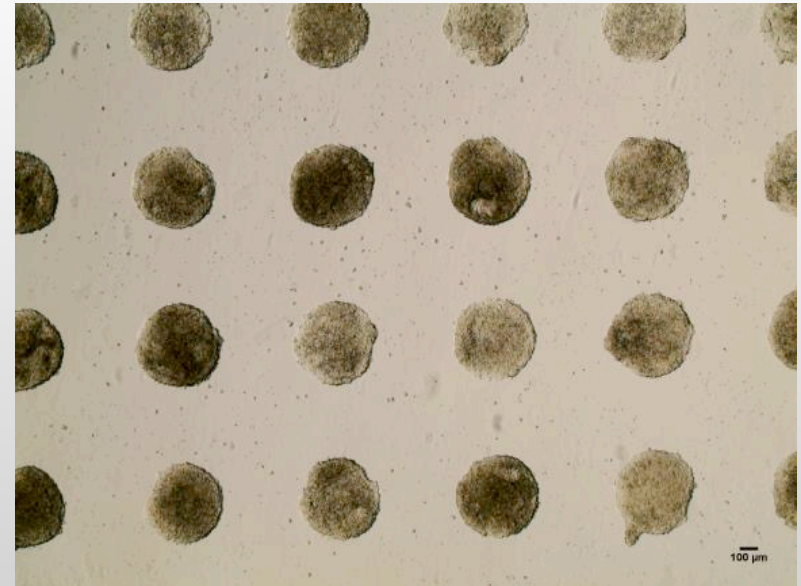
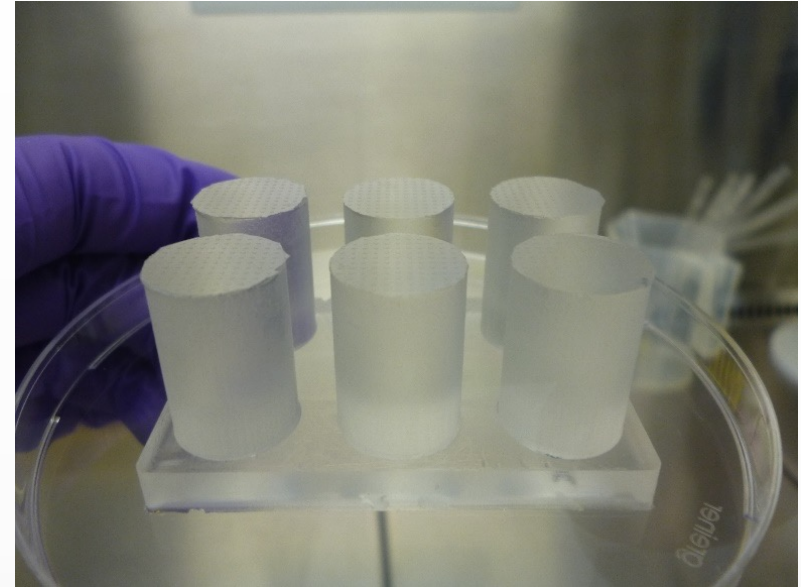
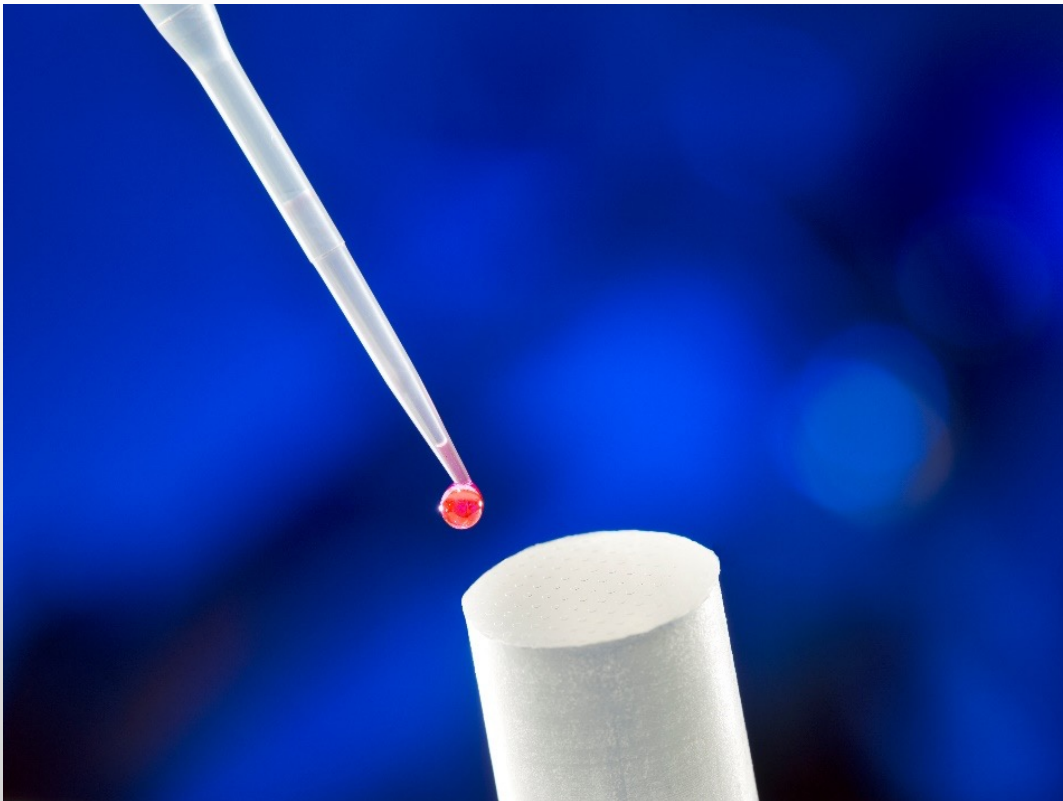
*Pouring of a
pre-polymer*



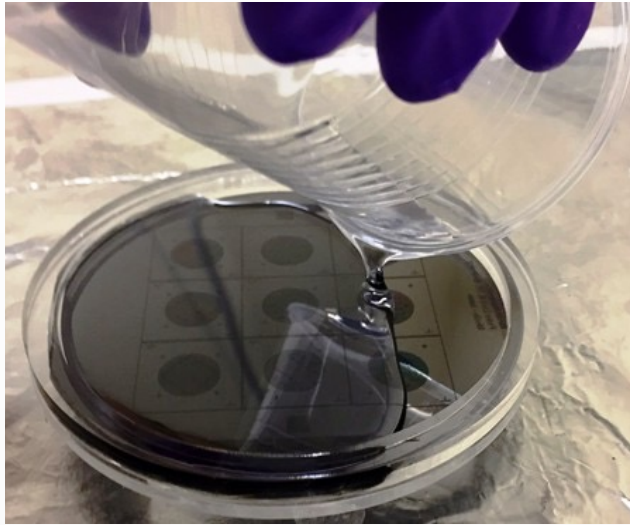
*Cured
polymer
module*

Applications – Microstructured Stamps

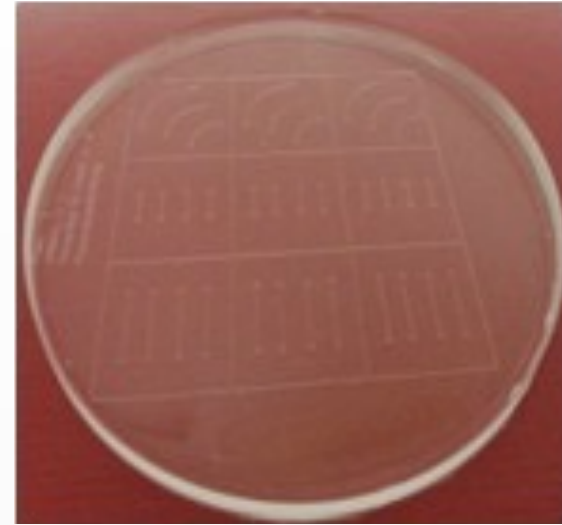
- Generation of cell patterns:
 - Micro contact printing



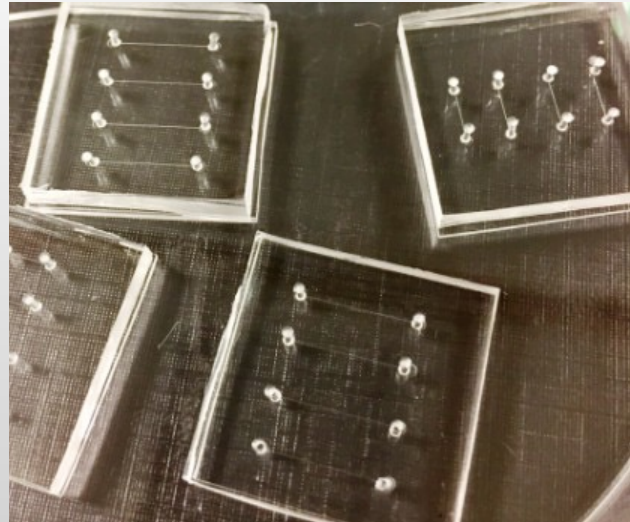
Applications – Microfluidic chips



*Pouring of a
pre-polymer*



*Cured
polymer
module*

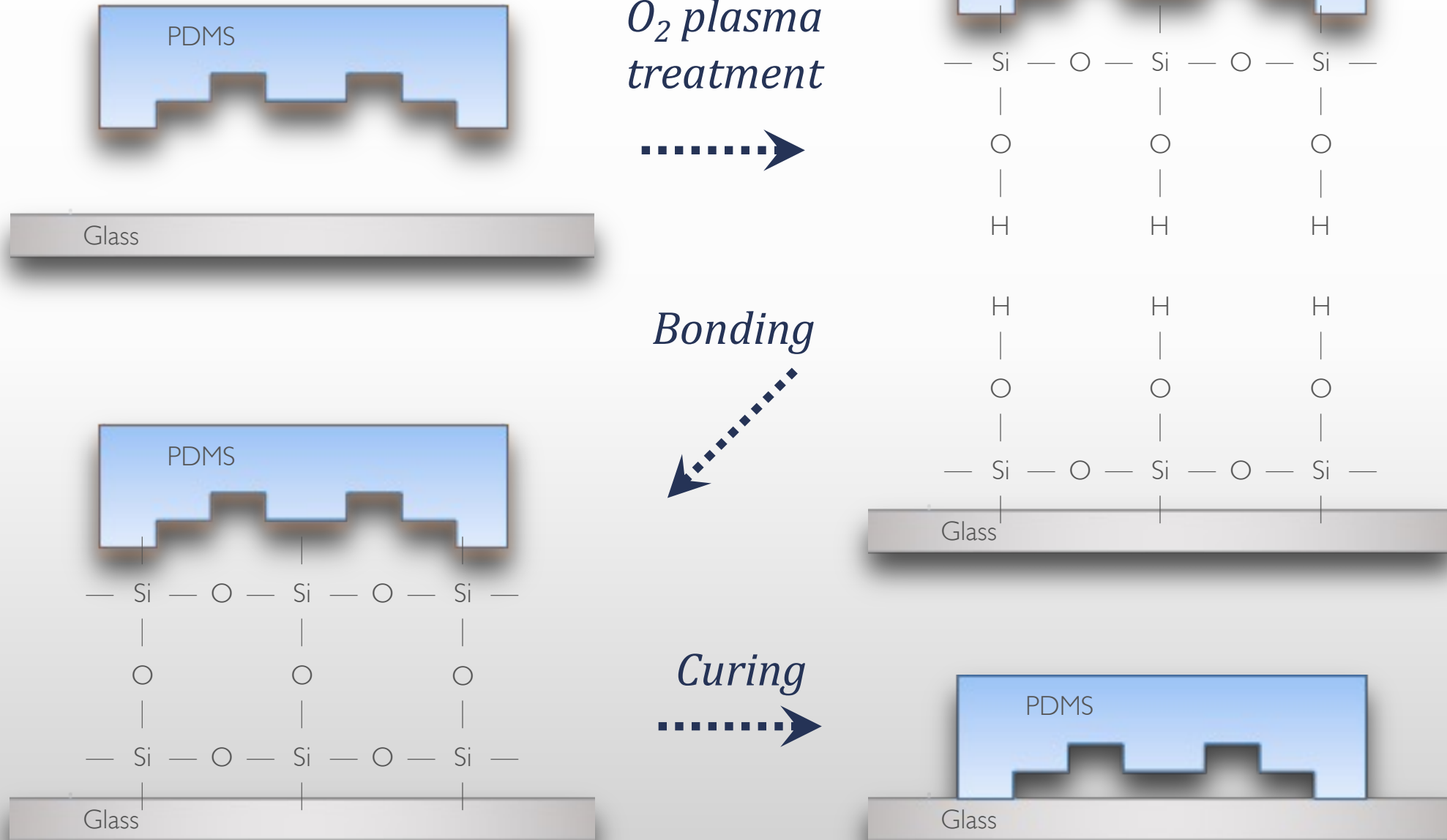


*Individual
modules*

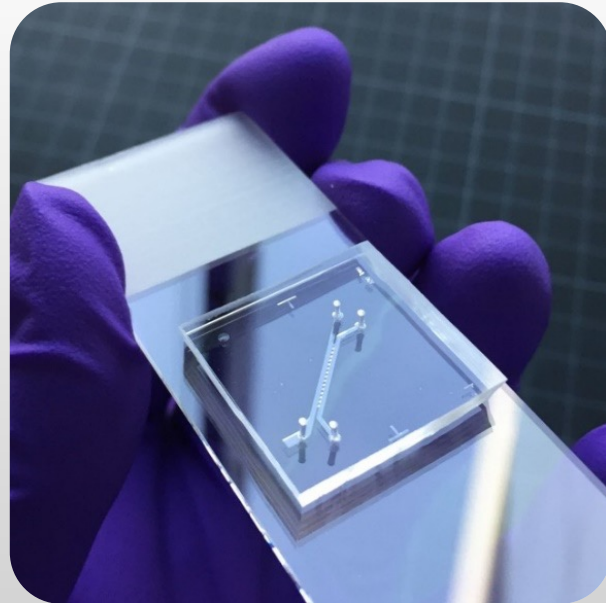
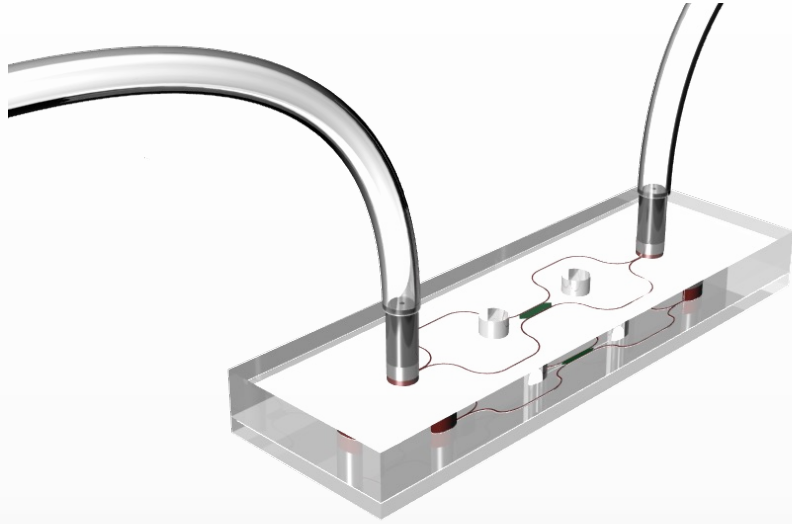


*Chip
assembly*

Applications – Microfluidic chips

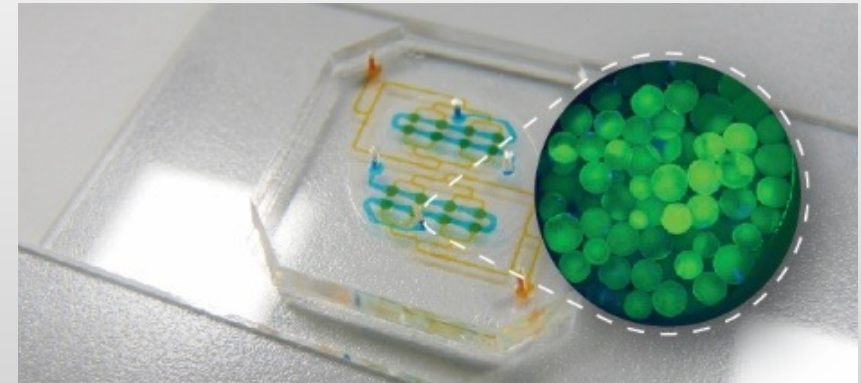
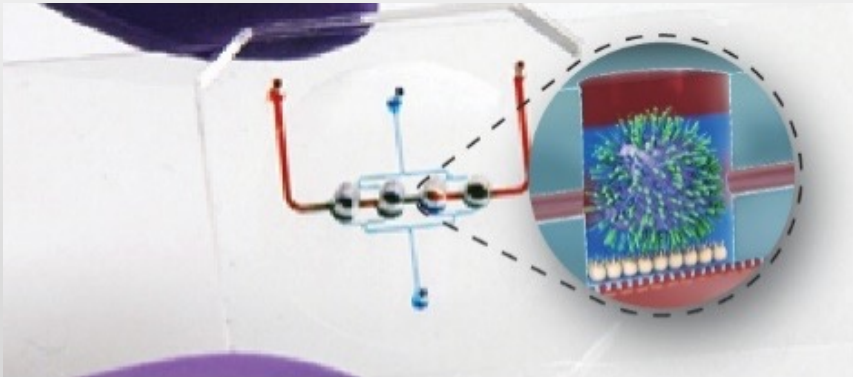
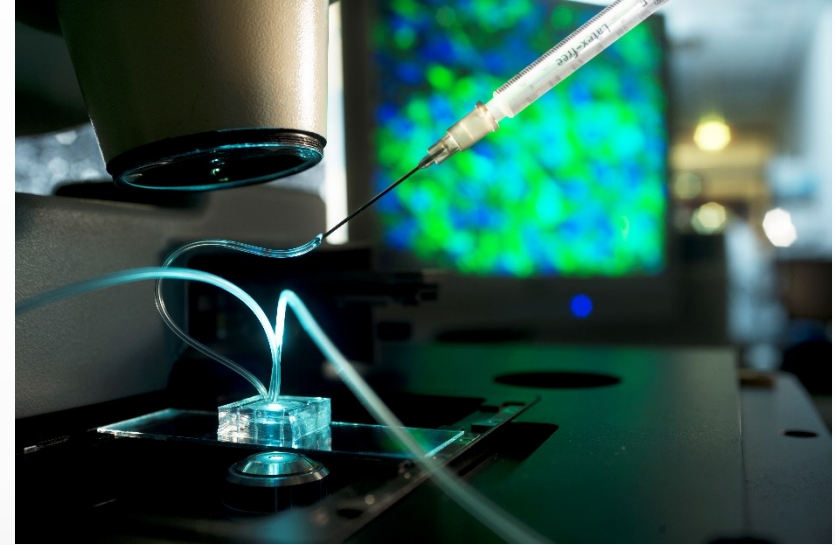


Applications – Microfluidic chips



Applications

- Microstructured Stamps
 - Generation of cell patterns
- Microfluidic chips / Lab-on-a-chip
 - Chemical synthesis
 - Diagnostic tools
 - Organ-on-chip



Microfabrication & Microfluidics

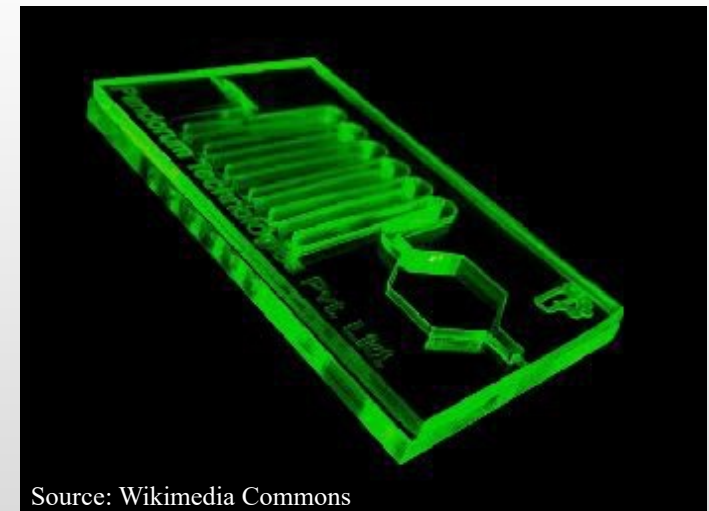
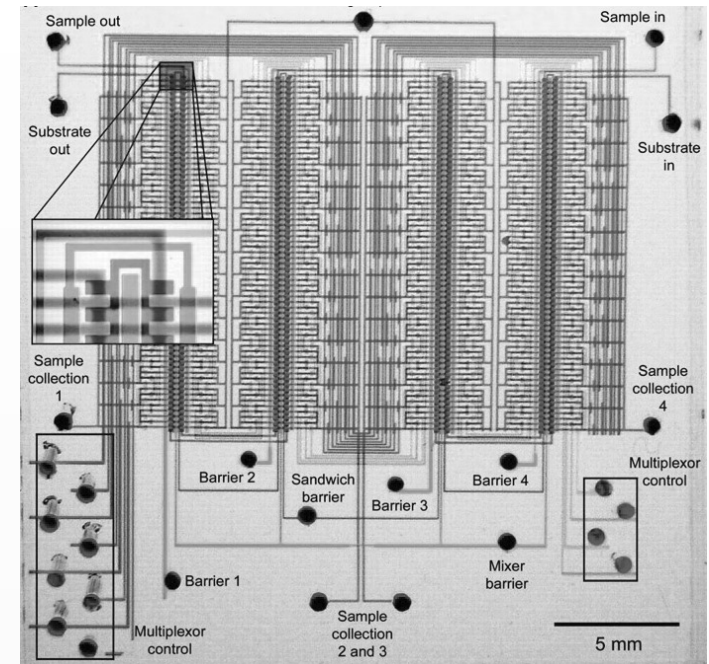
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Fundamentals of microfluidics

➤ Microfluidics:

- Manipulation of liquids on small scales (micro to nano)
- Networks of micro-channels and chambers
- Integration of valves, pumps and electrical components
- Variety of materials utilized (typically transparent): polymers, glass, paper,...



Source: Wikimedia Commons

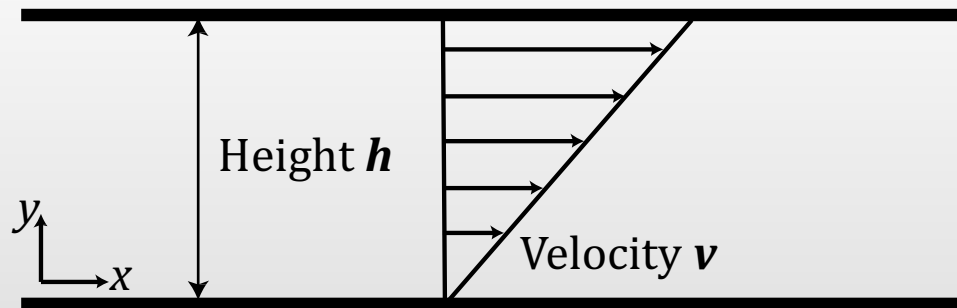
Physics of fluids

➤ Density ρ (Unit: *mass / volume*):

- Constant for incompressible liquids
 - Valid for small to medium pressure differences

➤ Viscosity μ (Unit: *mass / length / time*)

- Resistance to flow / deformation



(Tangential) Shear stress τ

$$\tau = F_{\perp} / A = \mu (v/h)$$

$$\mu_{\text{water}} \approx 10^{-3} \text{ Pa}\cdot\text{sec}$$

$$\mu_{\text{oil}} \approx 10^{-2} - 10^{-1} \text{ Pa}\cdot\text{sec}$$

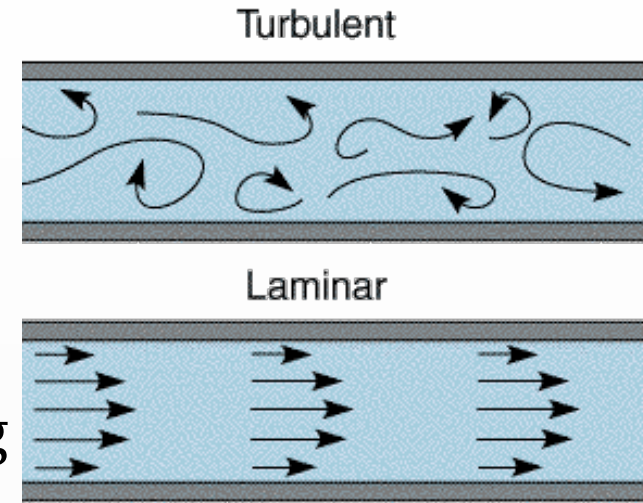
- For Newtonian liquids $\tau_{yx} = \mu \frac{du_x}{dy}$

Velocity gradient du_x/dy = Shear rate

Physics of fluids

➤ Type of flows

- **Turbulent:** Local stochastic fluctuating velocities
- **Laminar:** smooth flow in parallel layers; Layers not mixing



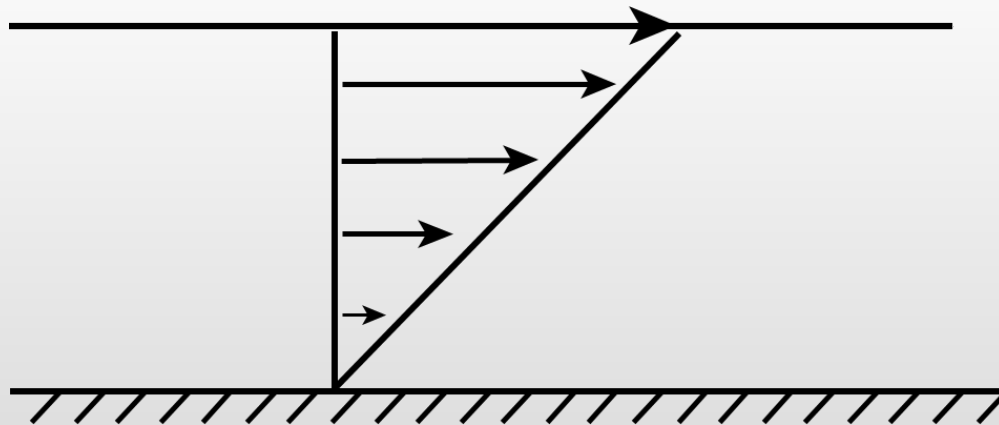
➤ Reynolds number Re

- Ratio of **inertia** and **viscosity** (*How fast is a liquid moving relative to its viscosity?!*)
- Quantitatively:
$$Re = \frac{\text{mass} * \text{acceleration}}{\text{viscosity forces}} = \frac{\rho v l}{\mu}$$
For a sphere (radius l) moving through a liquid with velocity v
- Depends on liquid (ρ, μ) and geometry (l) properties
- Small Re (<1): **laminar flow**; Large Re ($>>1$): **turbulent flow**
 - Flow in tubing: Transition at ≈ 2000

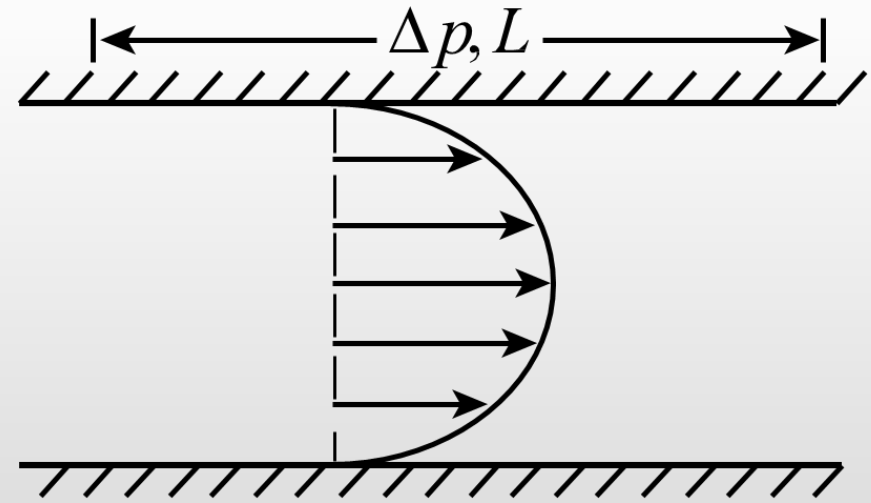
Physics of fluids

➤ Causes of flows

- **Shear strain:** Caused by the relative movement of two surfaces
- **Pressure differences:** Caused by a pressure gradient (Poiseuille flow)



Shear flow



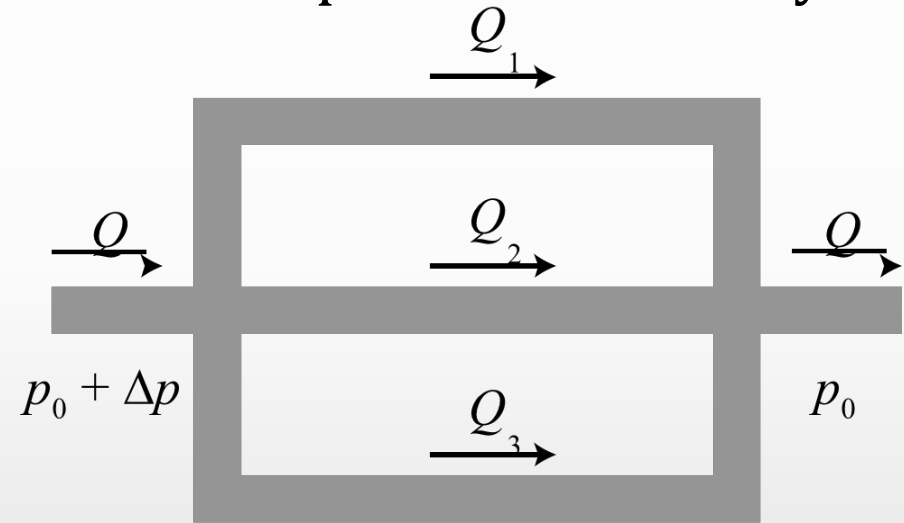
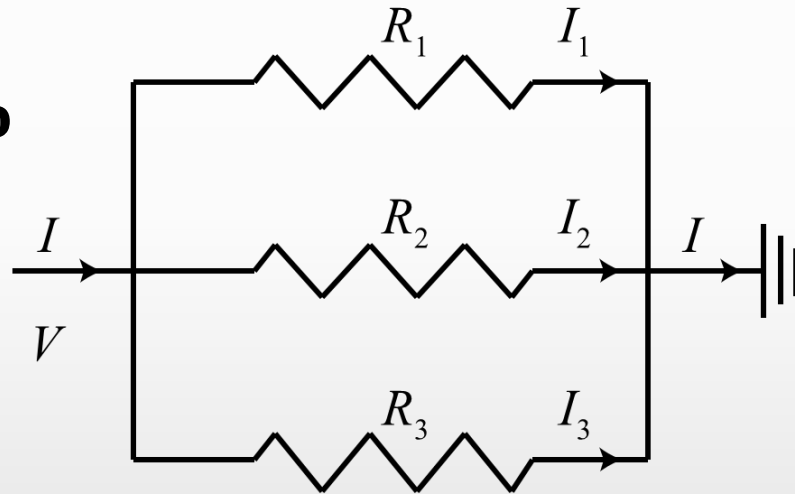
Poiseuille flow

Engineering view on fluids

➤ Network of channels

- Exact description of flows from molecular to macroscopic level extremely complex

- **Analogy to electrical circuits**



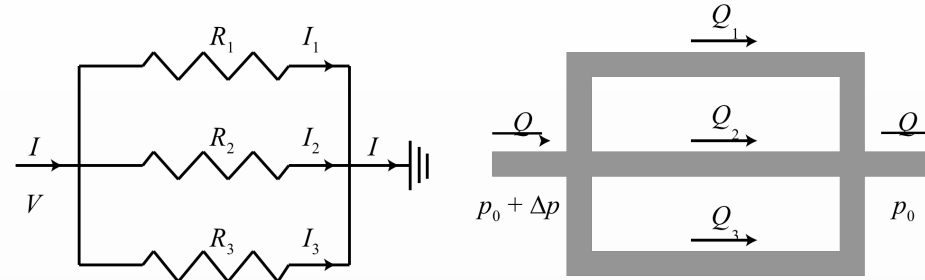
➤ Macroscopic description via relations

- Ohm's and Kirchhoff's laws
- Transferable to fluidic networks

$$\begin{array}{lll} \Delta V = I R & \& \sum I_m = 0 \\ \Delta p = Q R & \& \sum Q_m = 0 \end{array}$$

Engineering view on fluids

- Analogy of electrical and fluid mechanic relations



Electrical relation

$$\Delta V = IR$$

$$\sum_{k=1}^N I_k = 0$$

Power: $I\Delta V = I^2 R$

$$\mathbf{j} = \sigma \mathbf{E} \text{ (Ohm's law)}$$

Fluid mechanical relation

$$\Delta p = QR_H$$

$$\sum_{k=1}^N Q_k = 0$$

Power: $Q\Delta p = Q^2 R_H$

$$\mathbf{u}_{\text{avg}} = -\frac{k}{\mu} \nabla p \text{ (Darcy's law)}$$

Permeability k : depends on material properties

Engineering view on fluids

➤ Hydrodynamic resistance

- **Analytical solution** for a cylindrical tube with **radius a** and length **L**
- **General solution**
 - Can only be solved numerically
 - for a rectangular channel with height **h** and width **w** , whereby **$h < w$**

$$R_H = \frac{8\mu L}{\pi a^4}$$

$$R_H = \frac{12\mu L}{h^3 w}$$

Engineering view on fluids

➤ Channel networks

■ Parallel channels

- Inverse sum of inverse individual resistances

$$R_{\text{eff}} = 1 / \sum_{m=1}^N R_m^{-1}$$

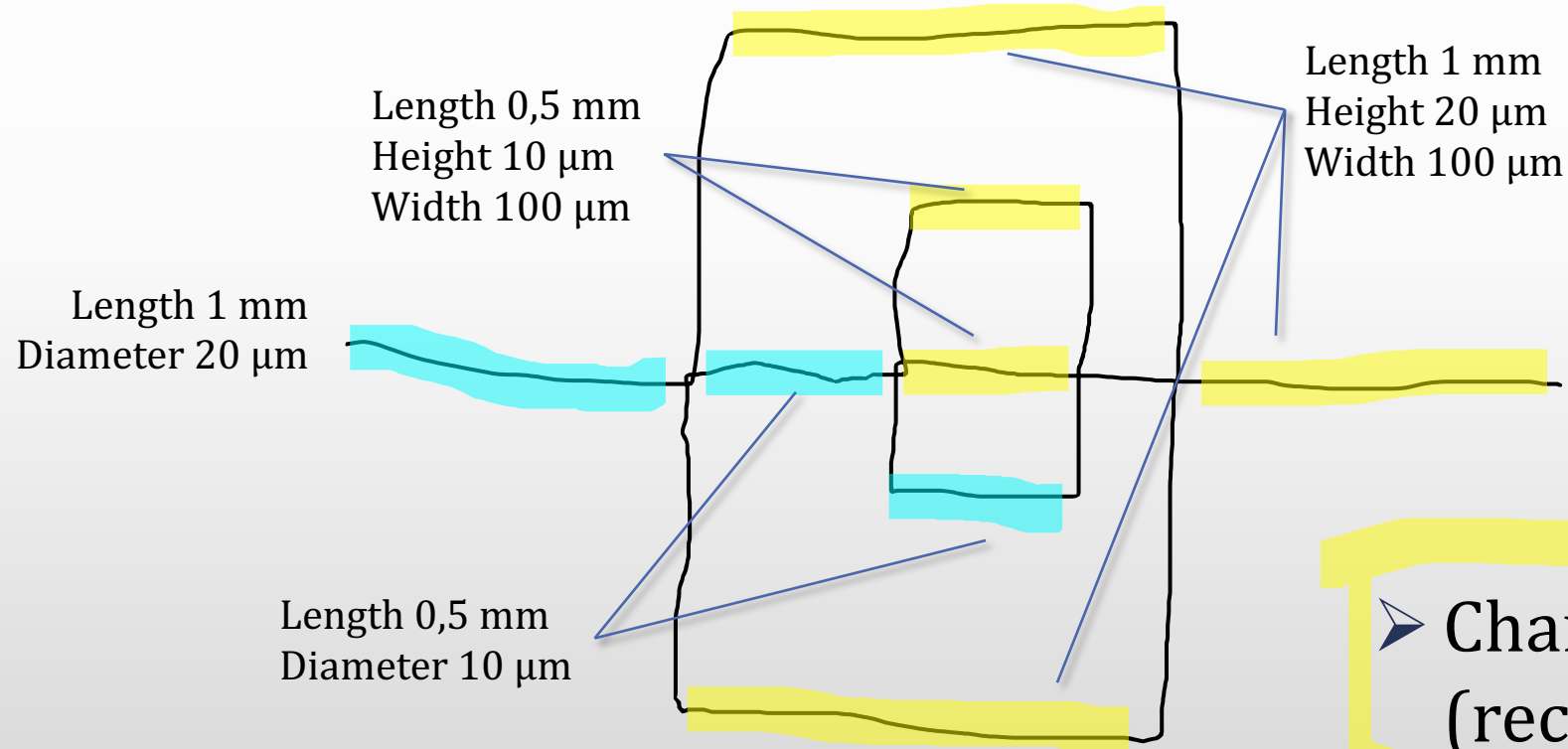
■ Serial channels

- Sum of resistances

$$R_{\text{eff}} = \sum_{m=1}^N R_m$$

Your turn: Calculate the system's hydrodynamic resistance.

➤ Tubings



➤ Channels (rectangular)

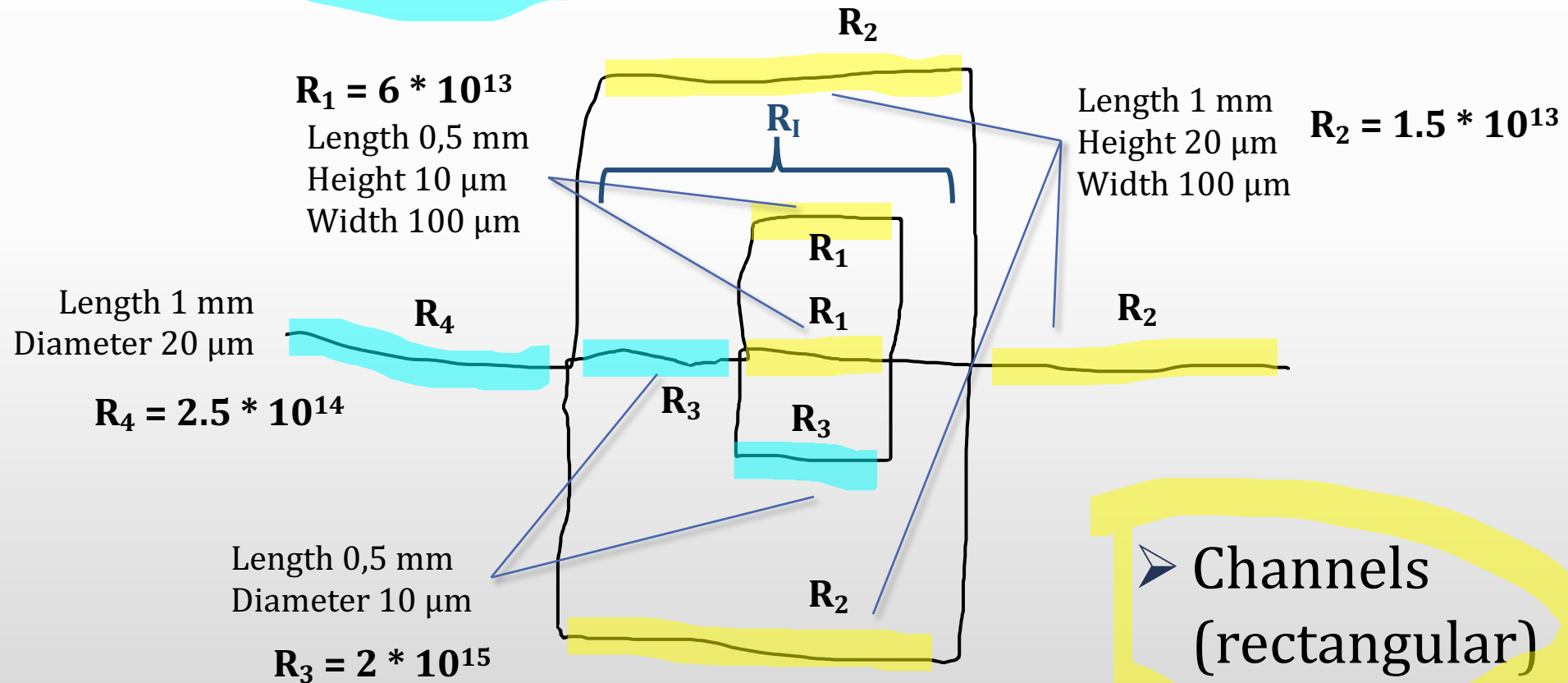
Correct solution

All R in $[\text{kg}/(\text{m}^4 \text{ s})] = [\text{Pa}/(\text{m}^3/\text{s})]$

$$R_I = R_3 + 1/(1/R_1 + 1/R_1 + 1/R_3) = 2.1 * 10^{15}$$

$$R_{\text{eff}} = R_2 + R_4 + 1/(1/R_2 + 1/R_2 + 1/R_I) = 2.8 * 10^{14}$$

➤ Tubings



➤ Channels
(rectangular)

“Almost” correct solution

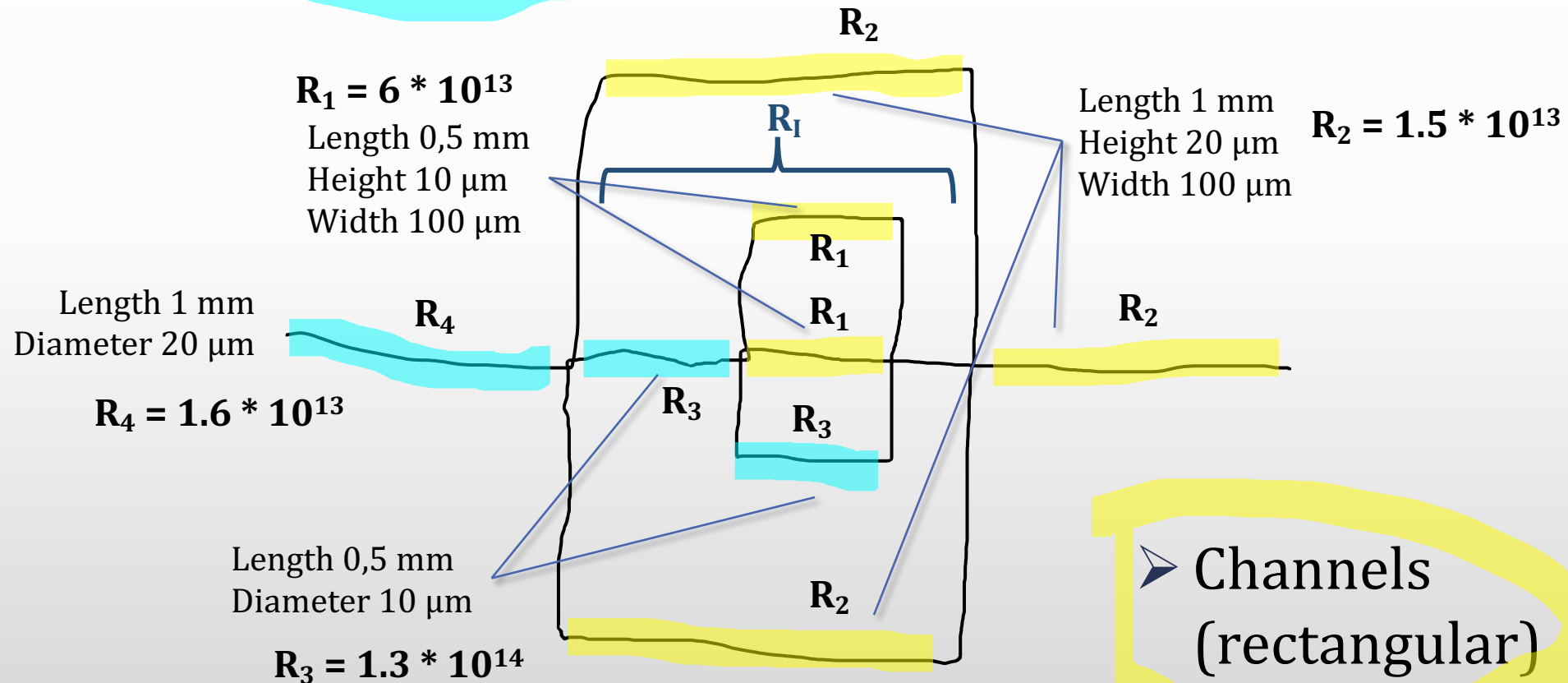
In case you used the cylindrical tube formula with diameter and not radius

➤ Tubings

All R in $[\text{kg}/(\text{m}^4 \text{ s})] = [\text{Pa}/(\text{m}^3/\text{s})]$

$$R_I = R_3 + 1/(1/R_1 + 1/R_1 + 1/R_3) = 1.5 * 10^{14}$$

$$R_{\text{eff}} = R_2 + R_4 + 1/(1/R_2 + 1/R_2 + 1/R_I) = 3.8 * 10^{13}$$



➤ Channels
(rectangular)

Thank you for your attention

Prof. Dr. Peter Loskill,
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