EPFL

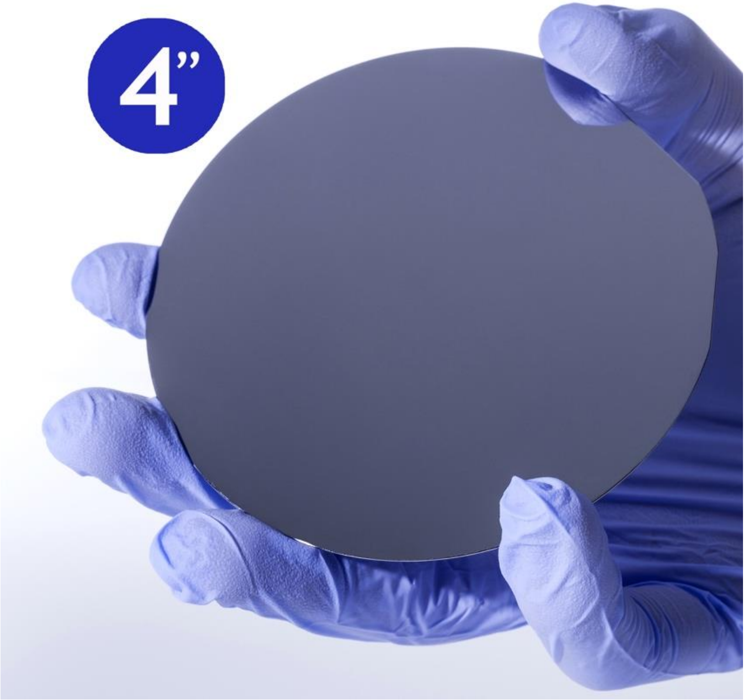
Neural Interfaces

Exercise 2

Fall 2025

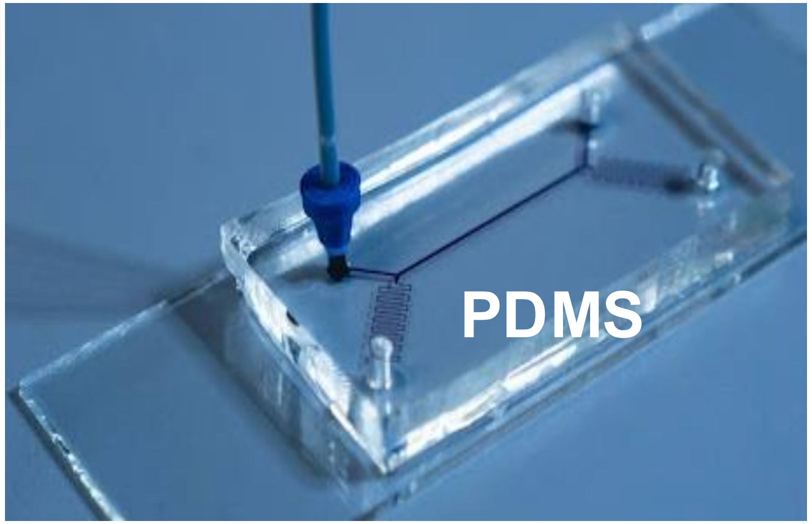
Basics: Silicon vs silicones

Silicon (Si)



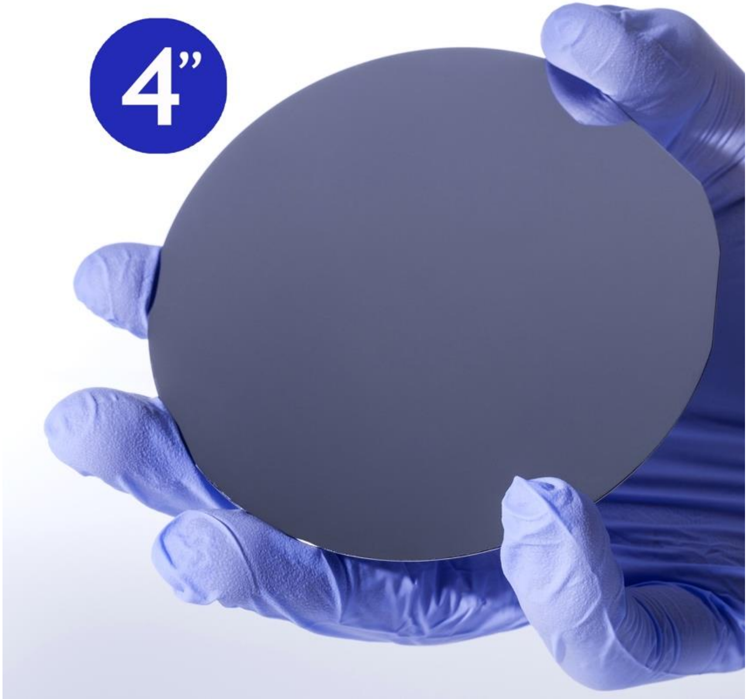
Silicon wafer

Silicones

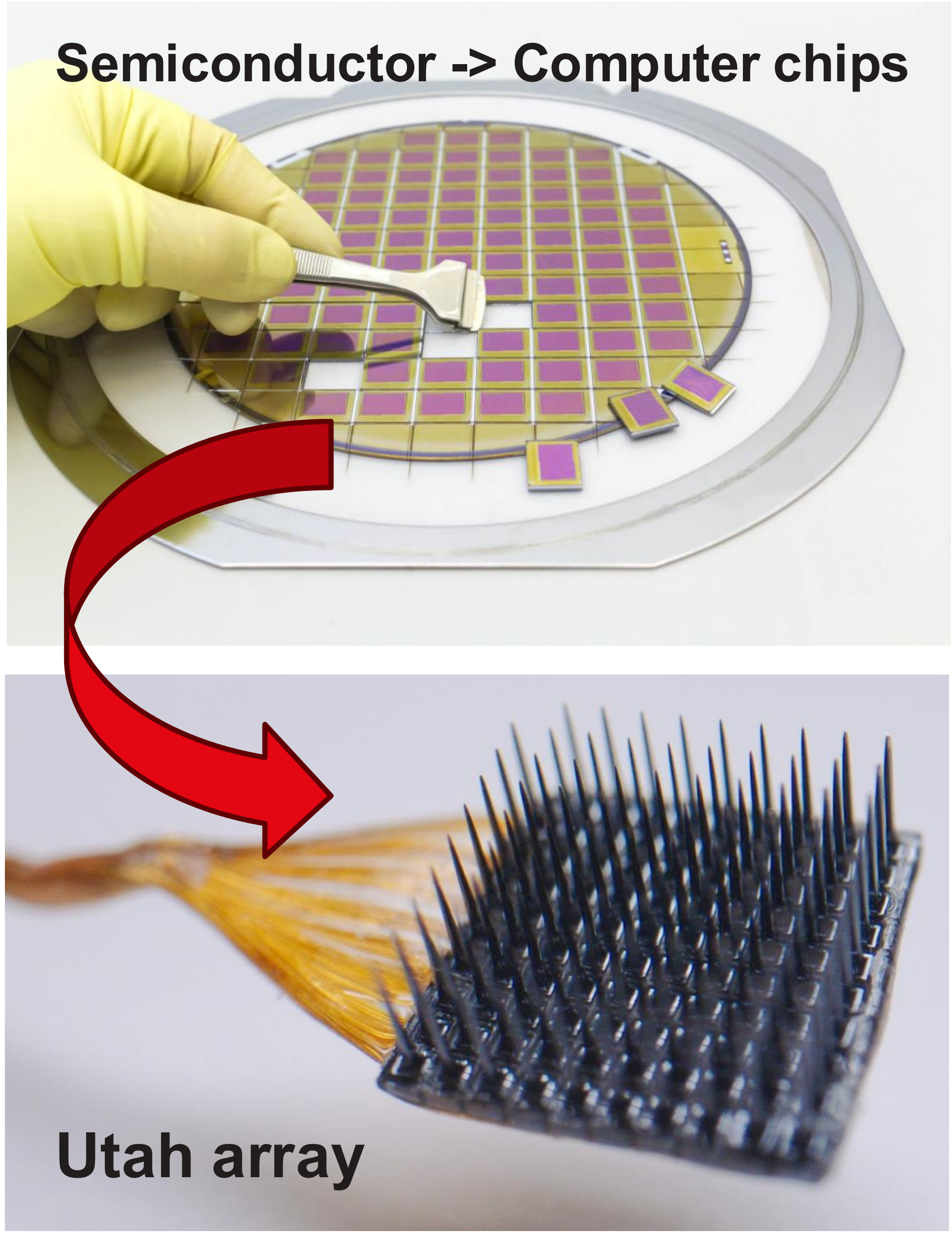


Basics: Silicon as a material

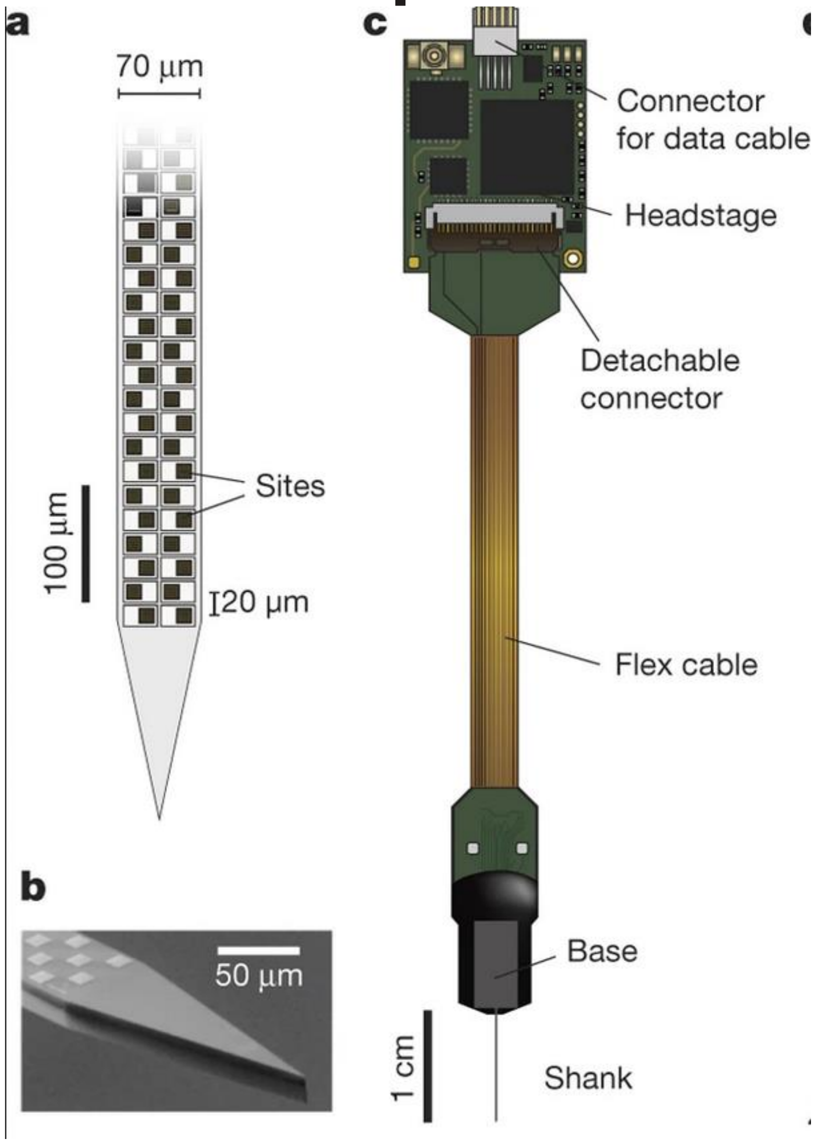
Silicon (Si)



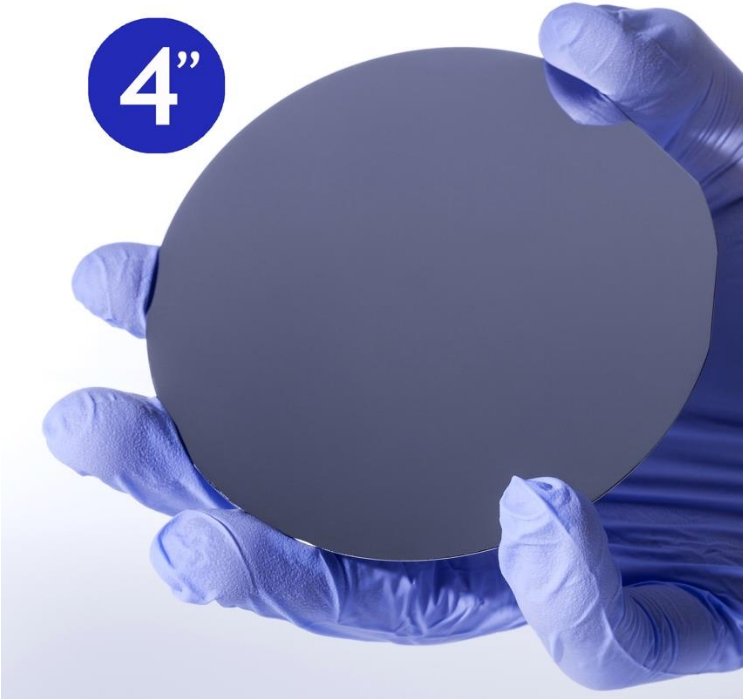
Use standard clean room fabrication processes to create neural interfaces



Neuropixels



Basics: Silicon as a substrate



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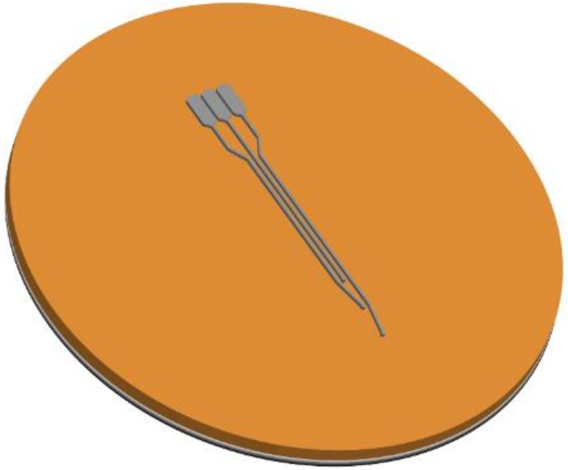
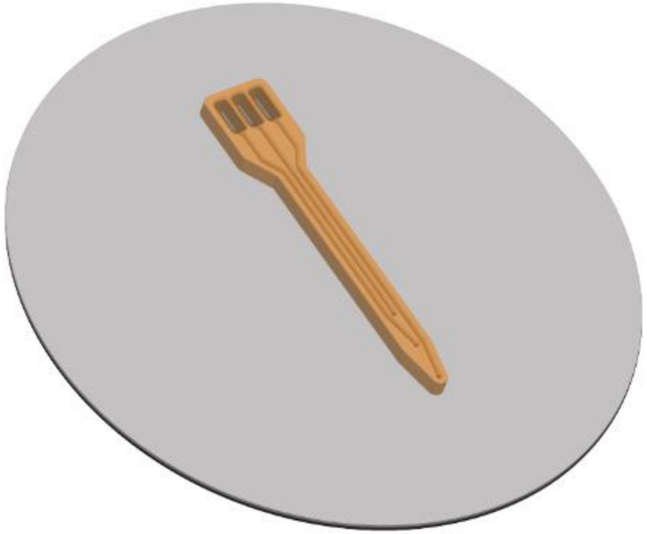
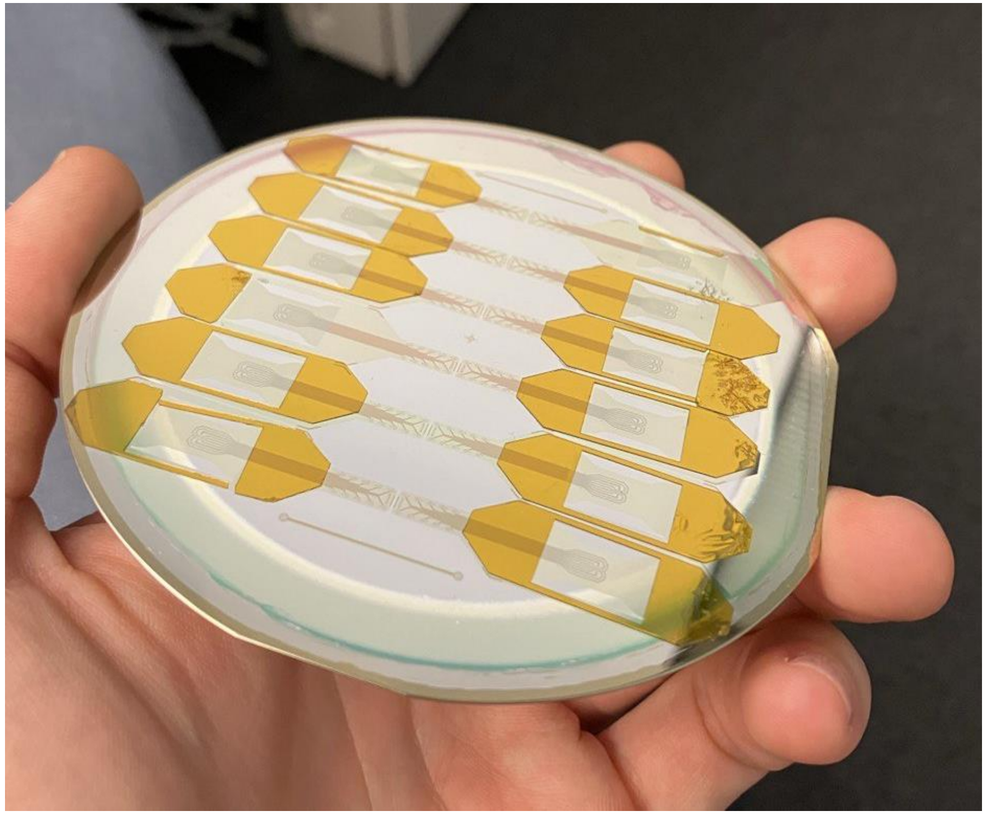
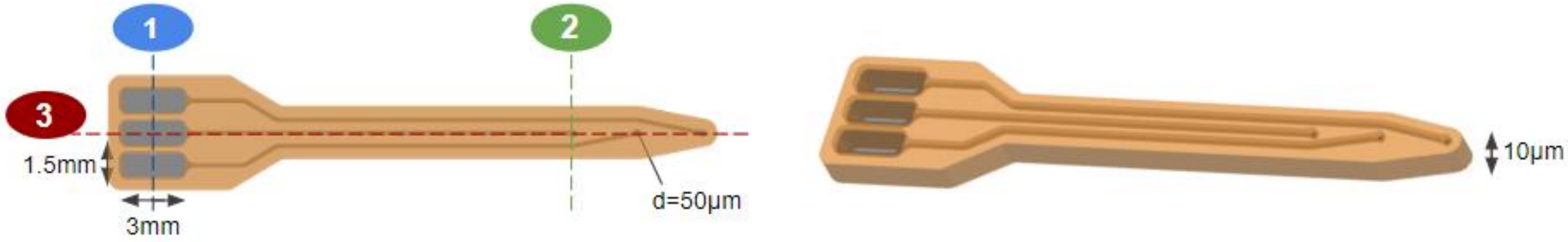




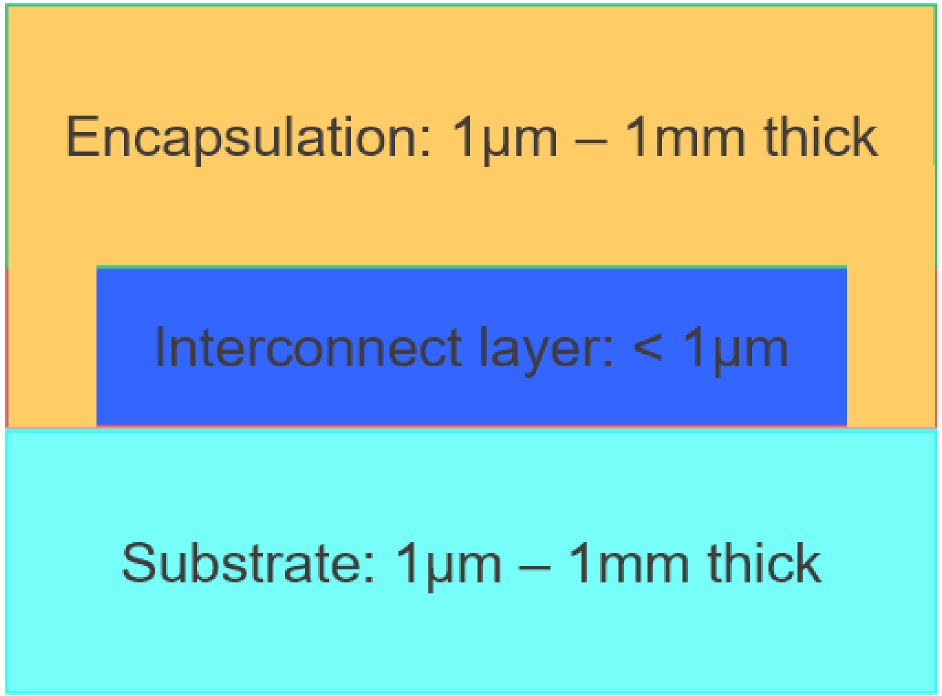
Thin film layers



Basics: Flexible neural implants



A-A' **Not to scale**

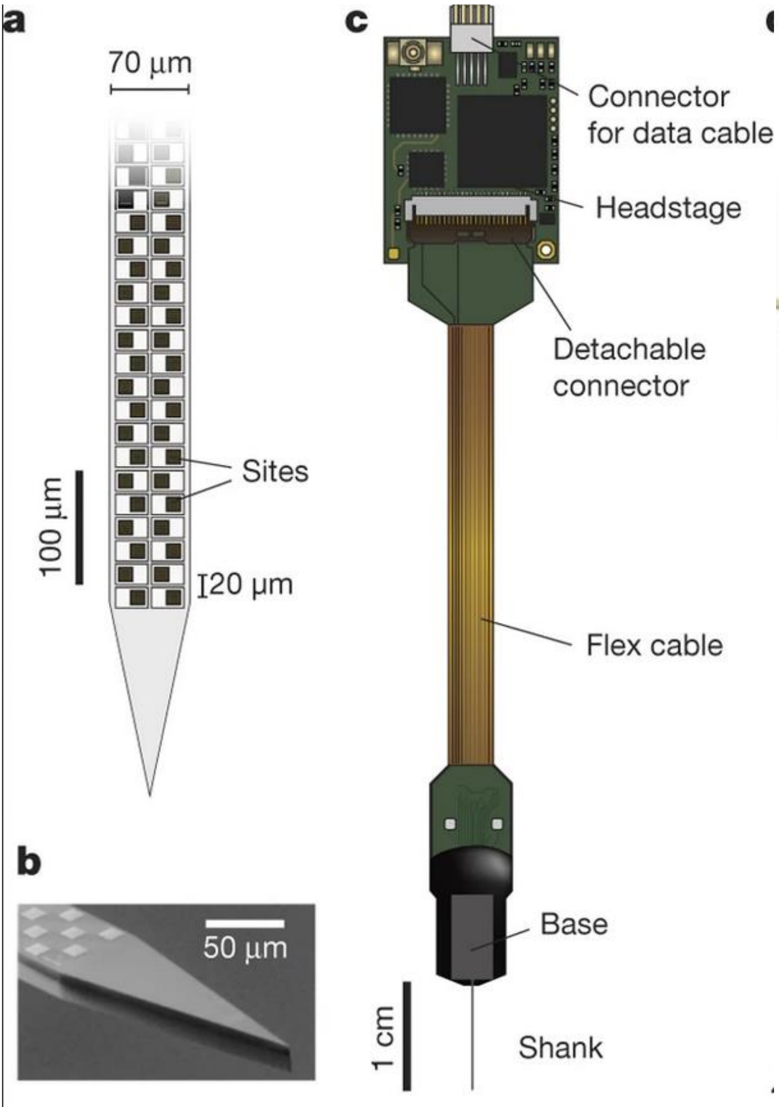


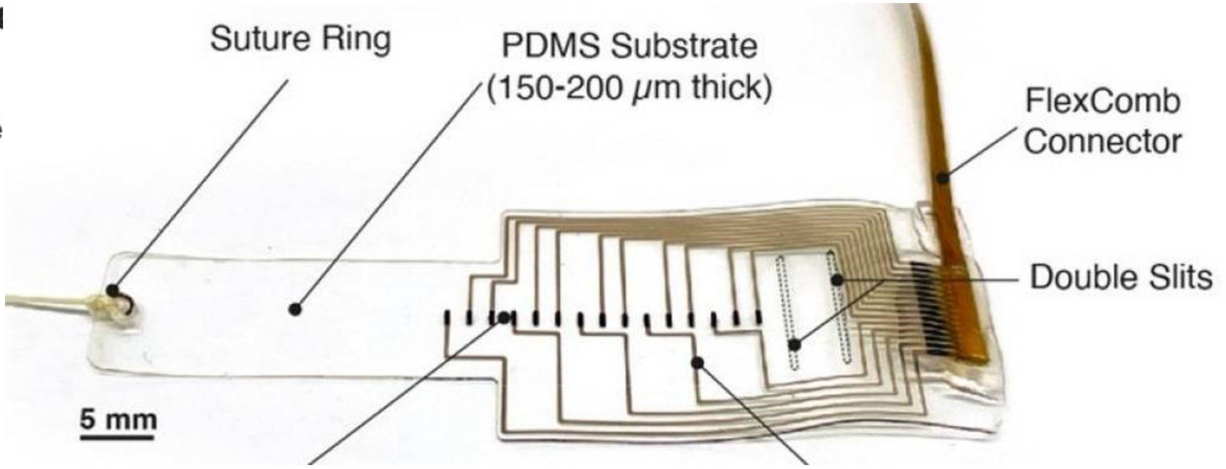
- Device
- Lead
- Implant
- Paddle

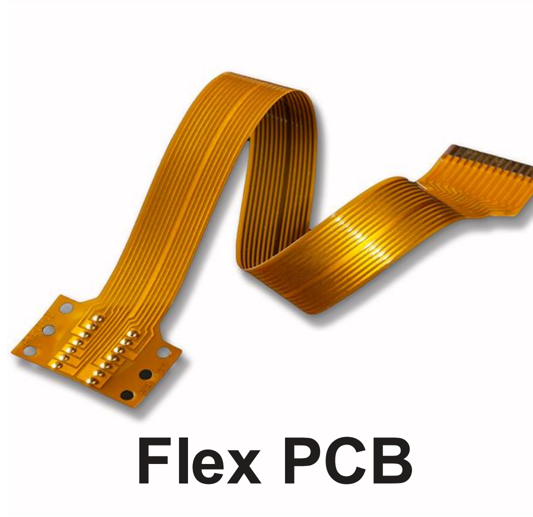
- Electrodes
- Wires
- Tracks, interconnects
- Pads

- Encapsulation (top and bottom)
- Transducer layer, metalization
- Substrate
- Wafer, Carrier

Connecting to the neural interface





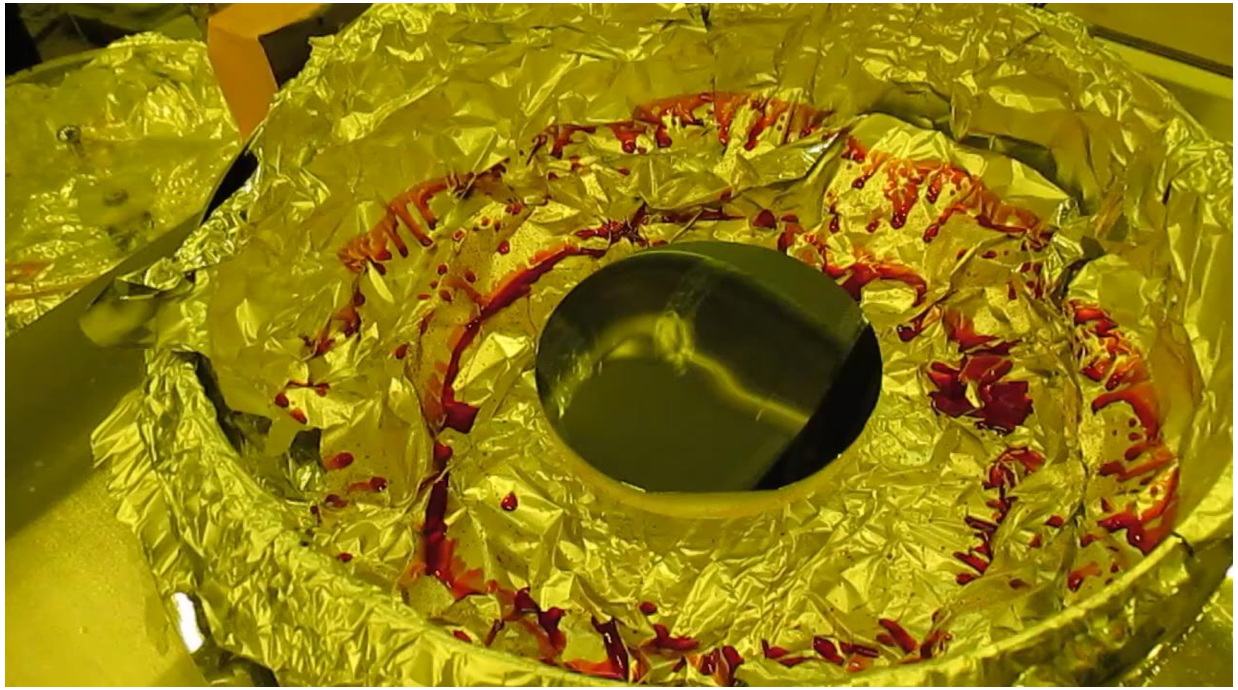


- Flex PCB, wires?
- Solder or other?
- Some epoxy?
- **Connecting to the microfabbed device**

Exercise: design of a process flow

- Design a process flow for a polyimide-based device.

Microfabrication: Spin coating

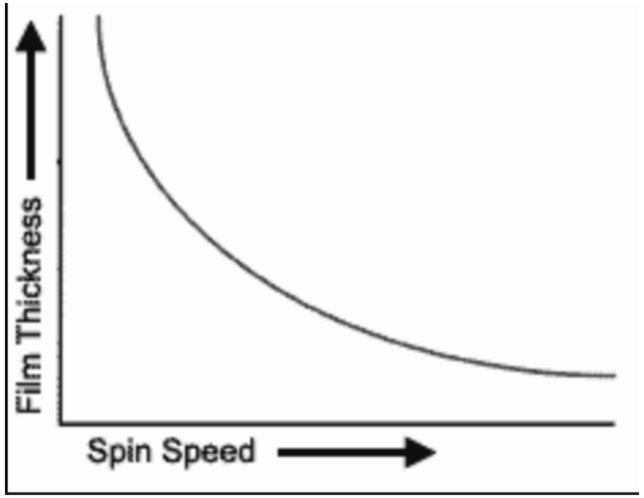


https://www.youtube.com/watch?v=uSaIRYDq-Ng

- **Photoresists (PRs)**
- **Silicones (PDMS...)**
- **PI (Polyimide)**
- **SU-8** ...

To consider:
- Possible inhomogeneity (uncoated areas, comets etc.)
- Different thickness along the radius

$$h_f \propto \frac{1}{\sqrt{\omega}}$$

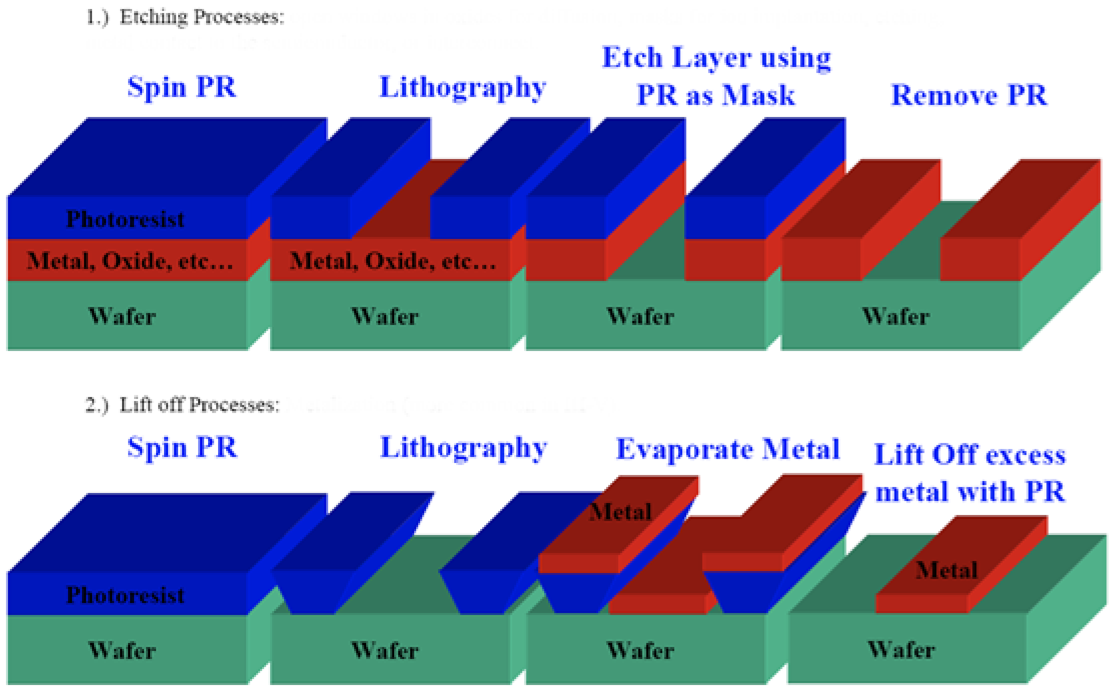


The final film thickness depends on:
- **Material concentration** in the solution
- **Solvent evaporation rate**, which is influenced by:
  - **Solvent viscosity, vapor pressure, temperature, local humidity**

spin thickness curves are typically **determined empirically**.

Microfabrication: Patterning

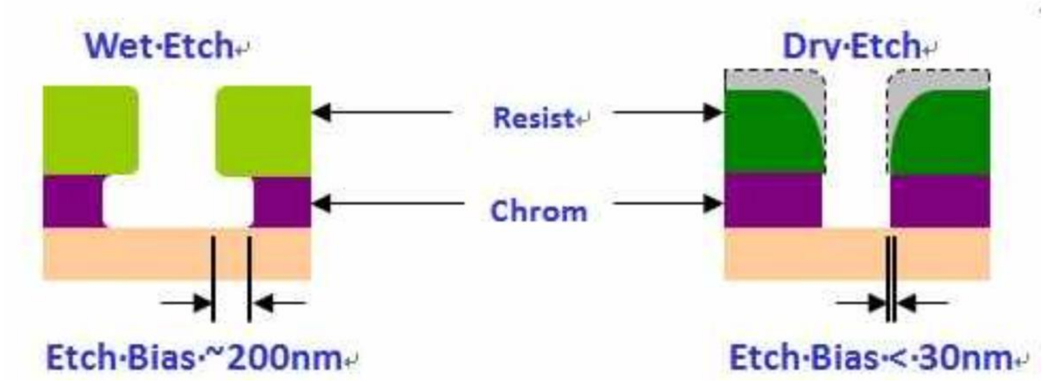
Etching vs Lift-Off



	Lift-off	Etching
Damage to substrate	Minimal	Possible, **etchant never perfectly selective**
Resolution	Limited by resist profile and mask	Limited by etchant and mask
Process complexity	**Resist profile** and deposition directionality critical	**Chemistry/plasma** must be optimized
Multi-layer structures	Easy	Different etchant per material

Microfabrication: Patterning

Wet Etching vs Dry Etching



	Wet Etching	Dry Etching
Mechanism	Material is dissolved by **liquid chemical etchant**	Material is removed by **reactive ions or radicals in plasma**
Anisotropy	Mostly **isotropic**, etches in all directions	Highly **anisotropic**
Resolution / Feature size	Limited by **lateral etching and mask undercut**	Very high, suitable for fine patterns (<1 μm)
Surface damage	Usually gentle on surface, less physical damage	Can induce roughness, or contamination
Process control	Less precise, etch rate affected by diffusion and agitation	Can precisely control etch depth and rate **Careful sizing of PR required**
Uniformity	Very good over large areas if agitation and temperature controlled	Good over small areas, may need plasma uniformity control
Material compatibility	Limited to materials soluble or reactive with etchant	**Works for most materials**, including hard-to-etch metals and dielectrics
Cost / equipment	Simple setup, low cost, chemical baths	Requires vacuum, plasma tools → higher cost

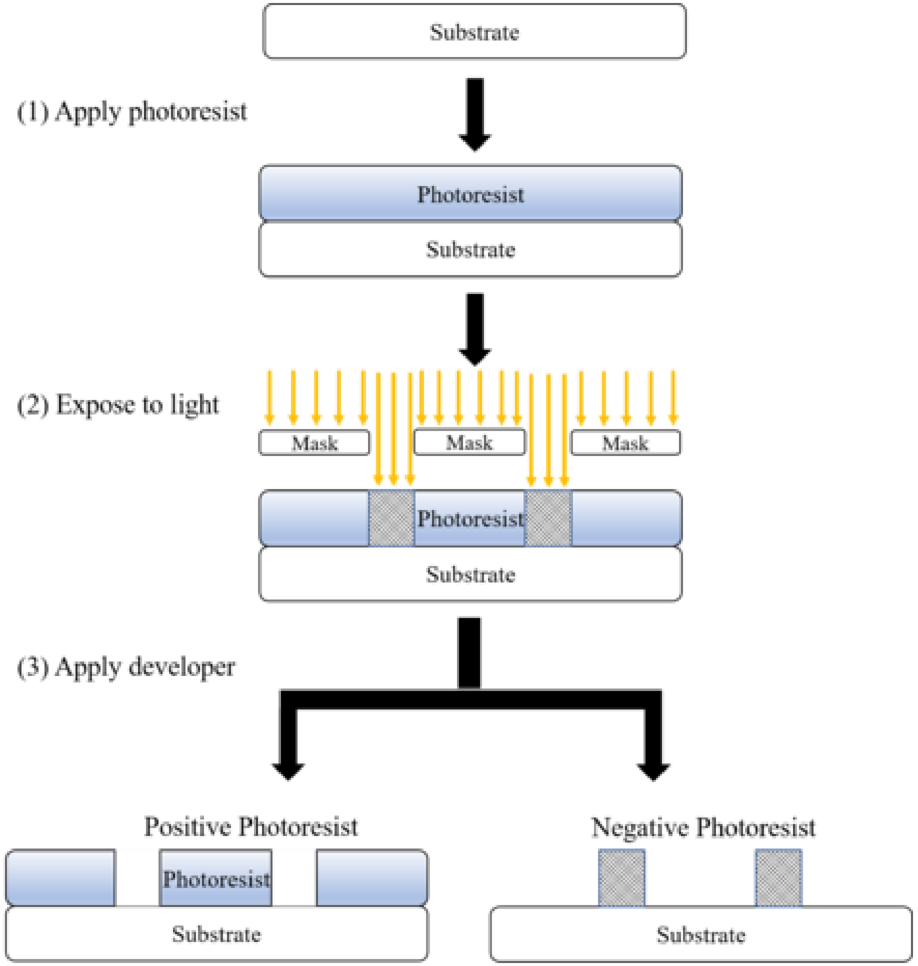
Microfabrication: Patterning

Example of dry etching rates

Material to etch	Chemistry	ICP power (W)	RF Power(W)	Etch rate (nm/min)	PR Etch Rate nm/min	Selectivity Material:Mask
Al	Ar/BCl3	800	50	60	590	1:10
Pt				20		1:28
Ti				110		1:5.3
TiN				110		1:5.3
Ti	Cl2/Ar	600	50	80	100	1:1.25
TiN				80	100	1:1.25
Si	SF6/Ar	800	100	58	1	1:8.5
SiO_2 WetOx	CHF3	800	50	233	130	1:0.6
SiO_2 Sputtered	Ar/CHF3	400	30	70	70	1:1
	CHF3	800	100	420	345	1:0.8
SiC	CHF3/Ar	800	100	100		
PDMS	CHF3/O2	500	150	800	450	1:0.8
Polyimide	O2	200	10	320	320	1:1
	O2/CHF3	500	150	1000	1000	1:1
	O2	500	150	1400	1400	1:1
Parylene				1400	1400	1:1

Microfabrication: Photolithography

Are all the photoresist the same?
Positive vs Negative photoresists

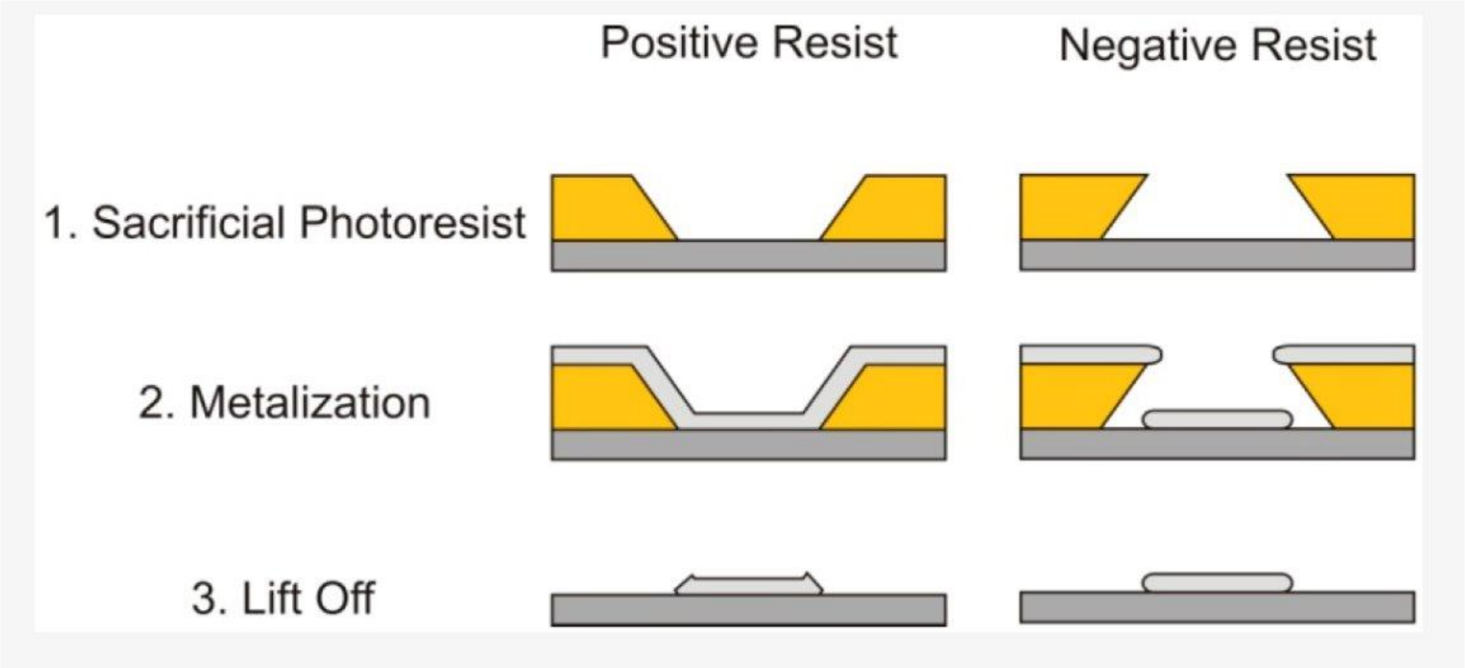


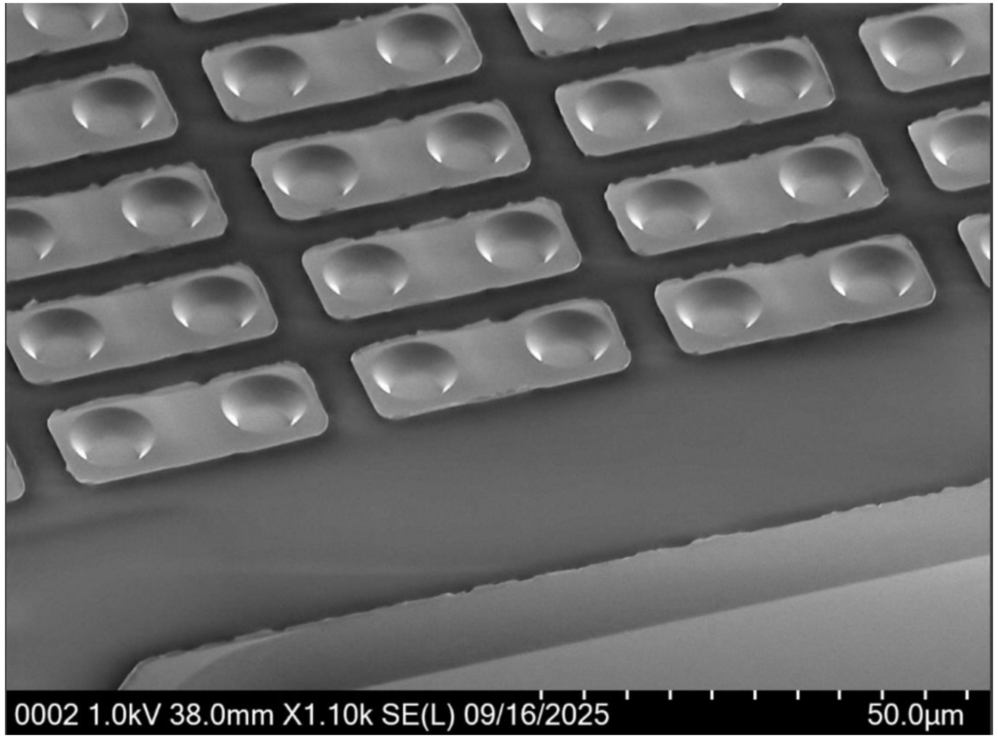
Positive photoresist = the exposed goes

*"With **pos**itive photoresist, the ex**posed** **goes**;*
*With **nay**gative photoresist, the ex**paysed** **stays**"*

Microfabrication: Photolithography

When to use a positive vs negative photoresist?





Example of Lift off with positive photoresist

EPFL

Exercise: design of a process flow

- Design a process flow for a polyimide-based device.

  Define the thicknesses of the different layers and the processes you are planning to use

  What is the total thickness of my device? Will I be able to handle it? Test/Implant it?

Exercise: design of a process flow

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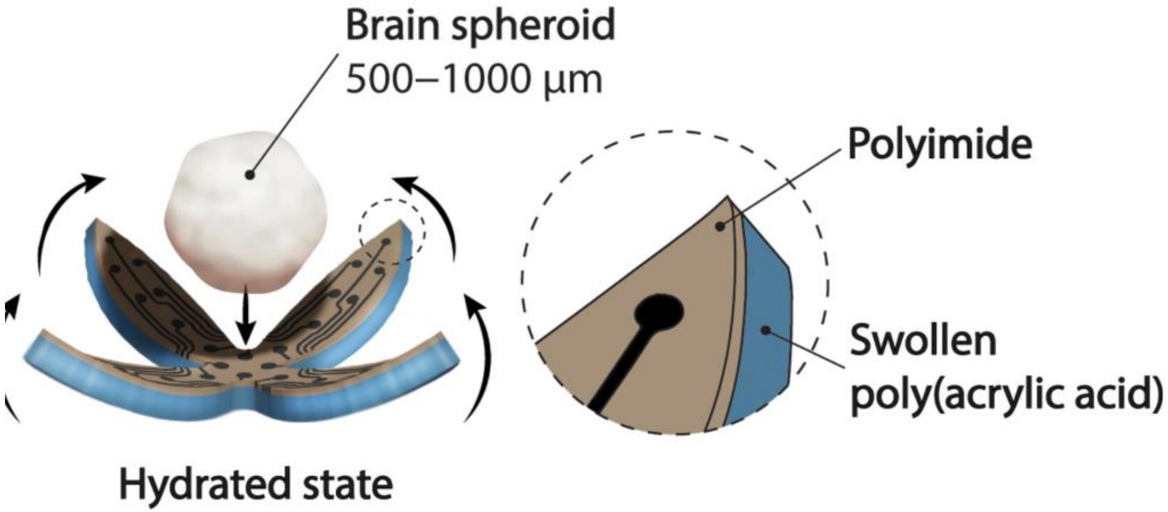
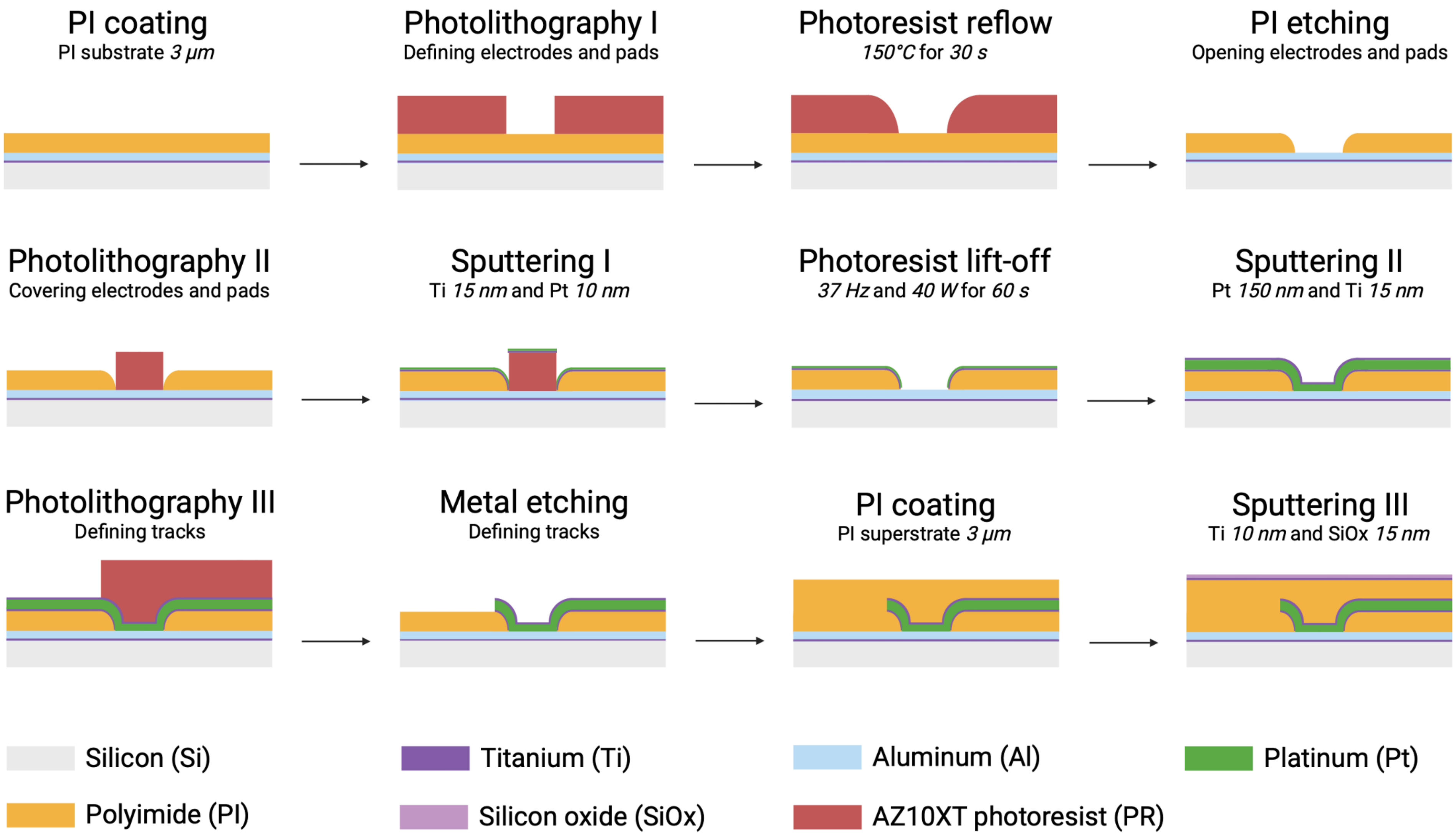
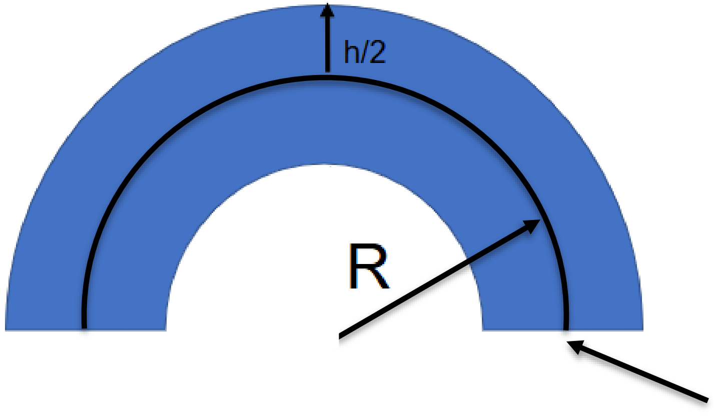
- Real case study: you want to graft a hydrogel to your polyimide-based device. How do you modify your process flow?



Example of process flow



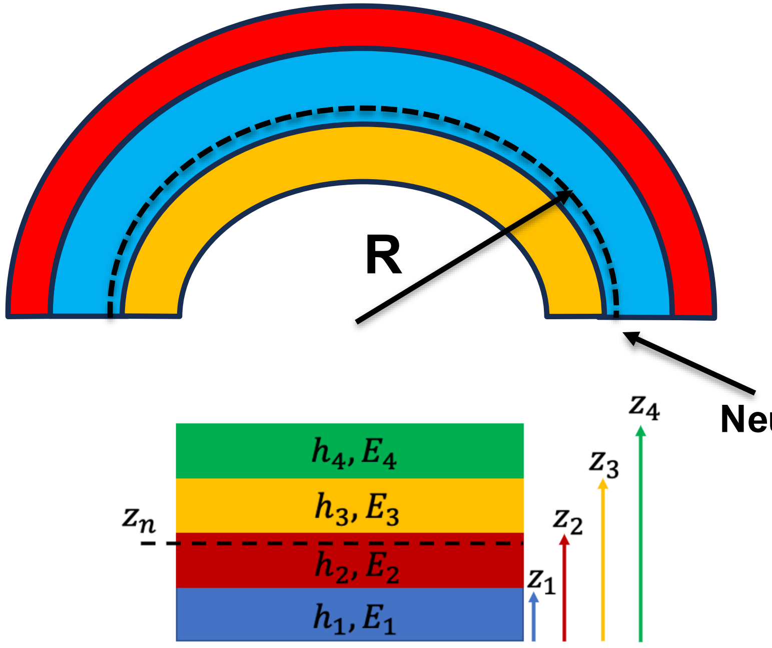
Bending radius for single foil



$$\varepsilon = \frac{h}{2R},$$

ε: *strain* (%); h: *film thickness*; R: *bending radius*

Bending radius for a stack of foils



$$z_n = \frac{\sum_{i=1}^{N} \bar{E}_i h_i \bar{z}_i}{\sum_{i=1}^{N} \bar{E}_i h_i}$$

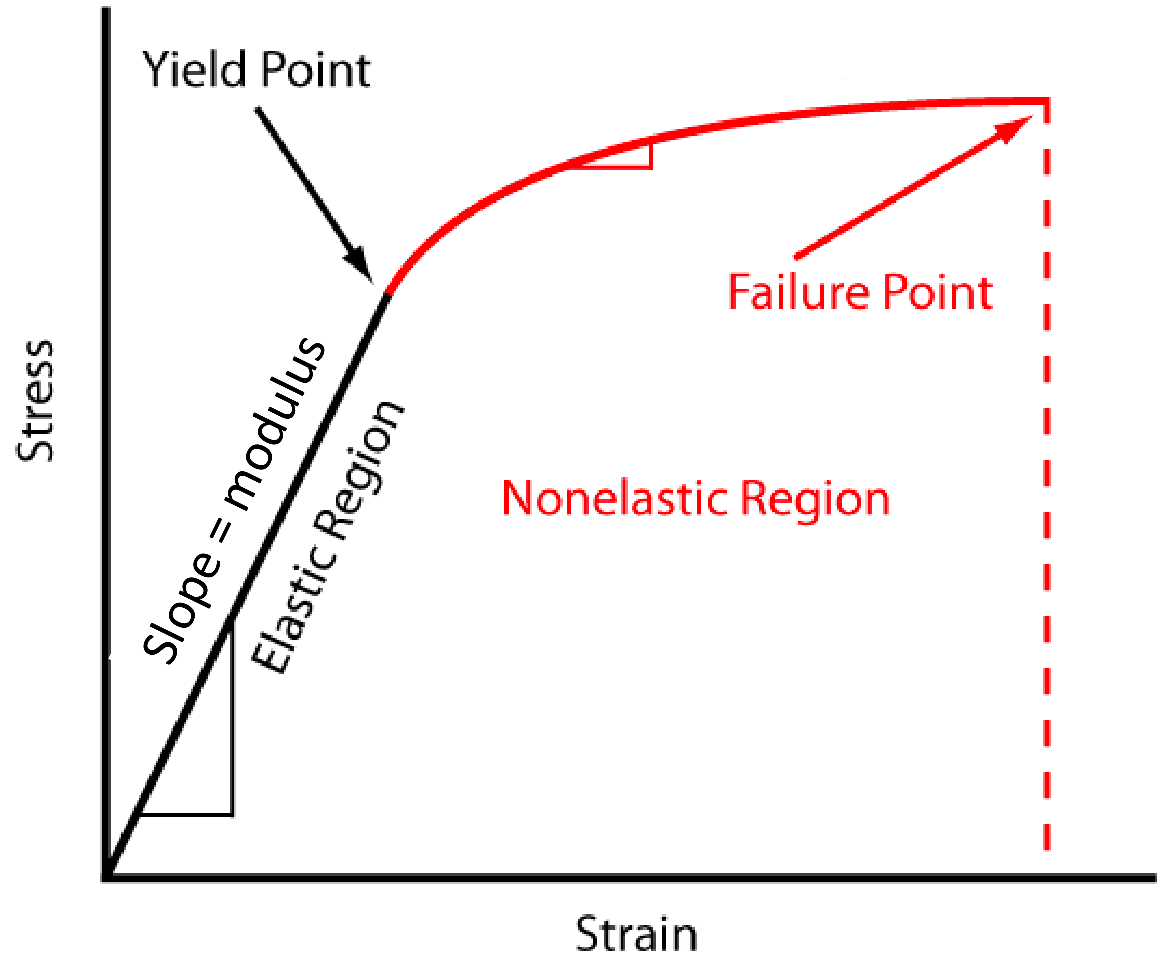
$$\bar{E}_i = \frac{E_i}{(1 - \nu^2)}$$

$$y_i = |z_{surface,i} - z_N|$$

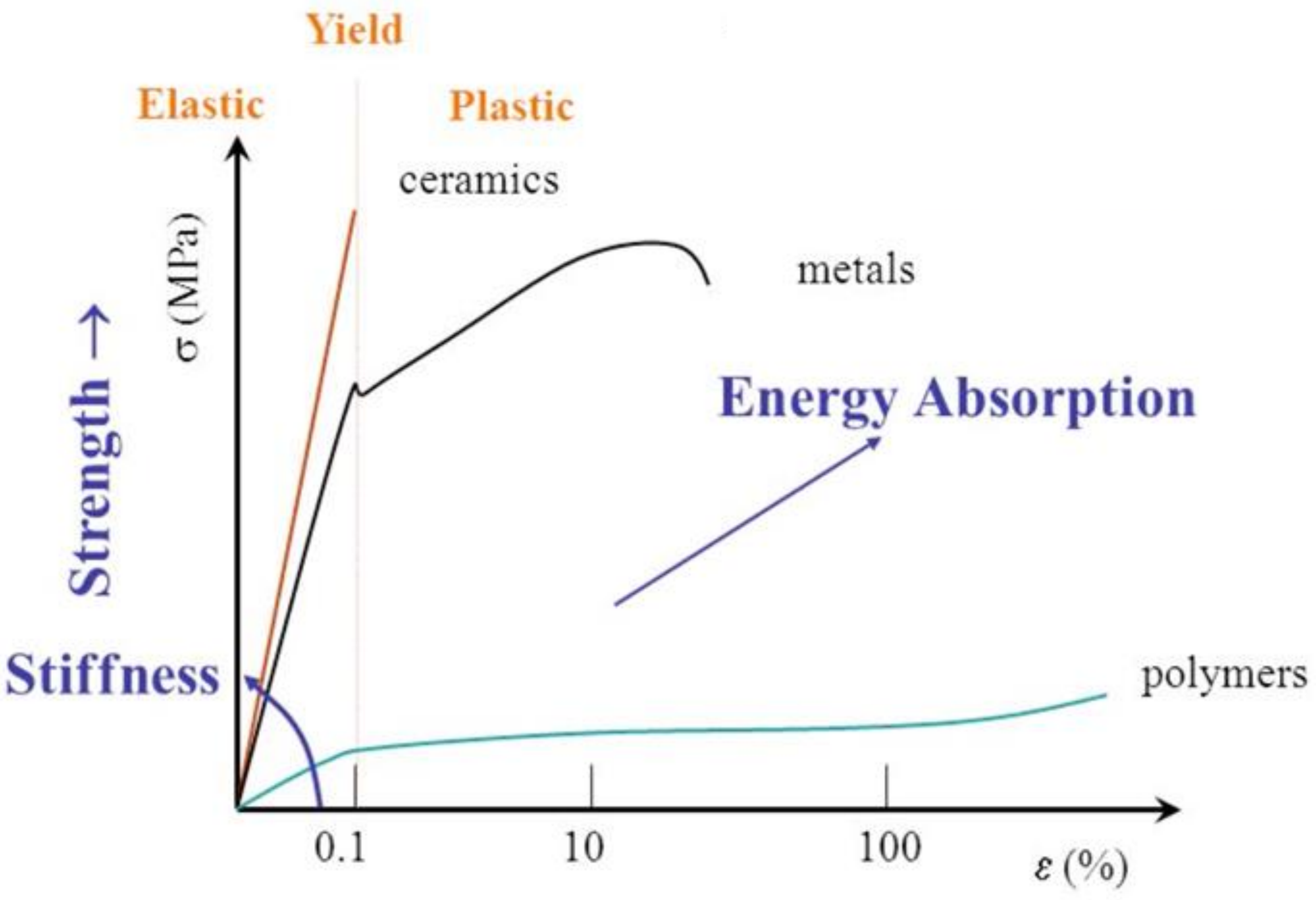
$$R_{min,i} = \frac{y_i}{\varepsilon_{crit,i}}$$

$$\varepsilon_i = \frac{y_i}{R_i}$$

Tensile test on materials



Tensile test on materials



Slope:

Stiff ⟷ Soft

Ultimate strength:

Strong ⟷ Weak

Plastic deformation:

Brittle ⟷ Ductile