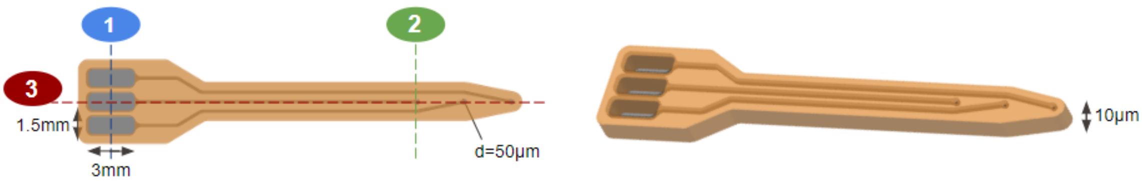
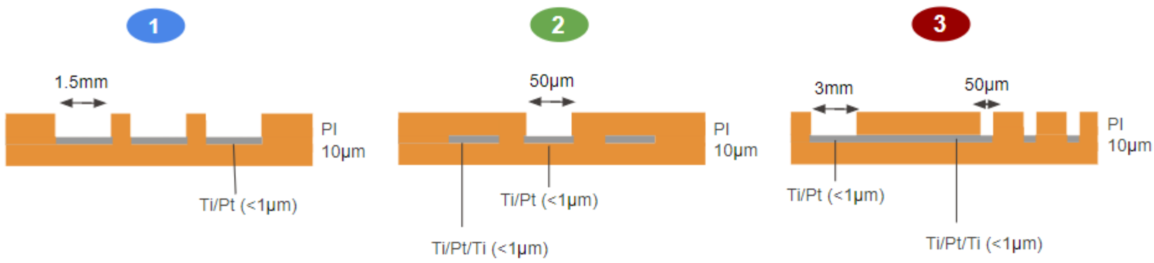
Neural interfaces - Session 2

Exercise 1 – Microfabrication of a neural implant

You want to create a flexible probe with embedded microelectrodes for acute and chronic neural recordings. The microelectrodes are made out of platinum (Pt) and encapsulated in polyimide (PI). The overall probe's geometry is depicted hereafter.



a. Draw the device cross section along line 1, 2 and 3, respectively. Assume the top and bottom encapsulation have the same thickness. How thick is usually the metal layer?



b. Outline the steps of the process flow you would use to fabricate the implant in the cleanroom. Provide the thickness of every layer at every step and justify your choices of techniques and materials (for example: etching vs lift-off).

1. We start with a 10 cm silicon (Si) wafer that we use as carrier substrate.

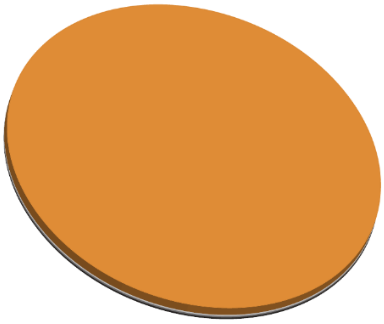
Top view **Side view**

2. **Sacrificial layer.** We sputter 25nm of titanium (Ti) followed by 100 nm of aluminium (Al). The Al layer acts as a sacrificial layer. This layer will be removed once the fabrication will be completed, therefore allowing to release the device from the wafer. Titanium is used as adhesion layer between Al and Si.

Top view **Side view**

3. **Substrate.** We spin coat 5µm of polyimide as bottom encapsulation layer (PI-2611, 3500 rpm). To define the needed spin coating speed, one has to consider the thickness after curing.

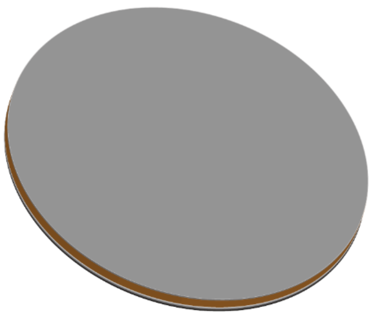
Top view



Side view

4. **Metallization.** We sputter 25nm of titanium (Ti), followed by 150 nm of platinum (Pt), and another 25nm of titanium (Ti). Titanium is introduced as adhesion layer, to insure good adhesion of the metal to the top and bottom polyimide layers.

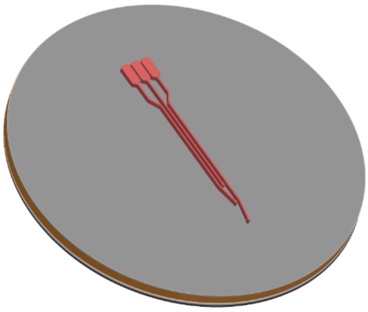
Top view

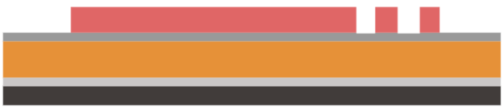


Side view

5. **Definition of the tracks, electrodes and pads.** We spin coat, expose and develop a photoresist layer (e.g. ECI3027 4µm).

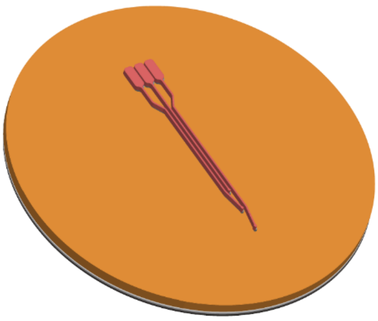
Top view **Side view**





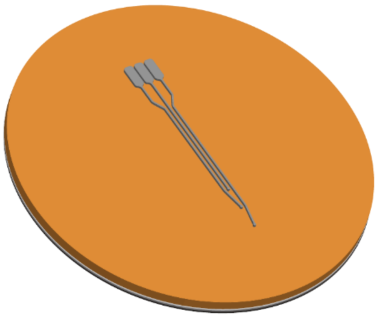
6. **Definition of the tracks, electrodes and pads.** We dry etch the exposed Ti/Pt/Ti stack. Possible options:
   a. Reactive ion etching (RIE, chemical + physical) with $Ar+BCl_3$
   b. Ion beam etching (IBE, purely physical) with Ar only.

Top view **Side view**



7. Strip the photoresist (with acetone/IPA or remover).

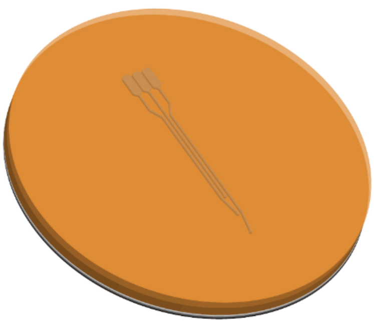
Top view



Side view

8. **Superstrate.** We spin coat another 5µm layer of polyimide for electrical insulation.

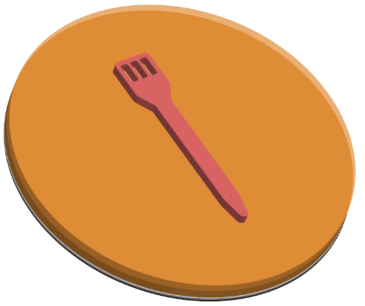
Top view



Side view

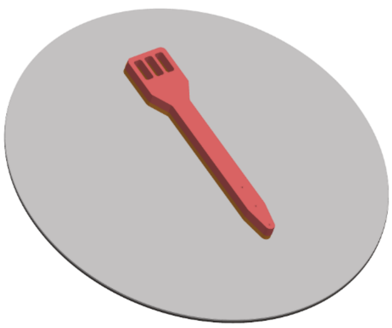
9. **Definition of the device outline and opening of the electrodes and pads.** We spin coat, expose and develop a photoresist layer (e.g. AZ10XT 12µm) on the wafer. It's essential to ensure that the photoresist layer is thicker than the entire polyimide layer intended for etching. This precaution is necessary as both polyimide and photoresist are etched using the same chemical process (O_2), resulting in a 1:1 etching ratio for both materials. Therefore, a thicker photoresist layer acts as a protective barrier for the wafer during the etching process.

Top view **Side view**



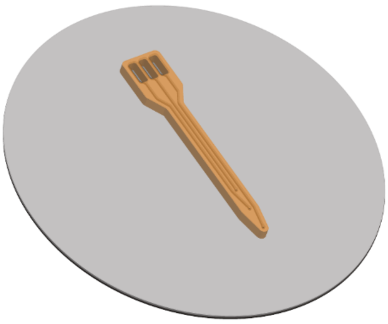
10. **Definition of the device outline and opening of the electrodes and pads.** We dry etch the polyimide layer (possibility: O_2+Ar RIE), then etch the titanium layer to expose the platinum electrodes (possibility: either Ar+BCl_3 RIE, or Ar IBE). We remove the Ti from the electrodes as, otherwise, it would oxydize.

Top view **Side view**



11. Strip the photoresist (with acetone/IPA or remover).

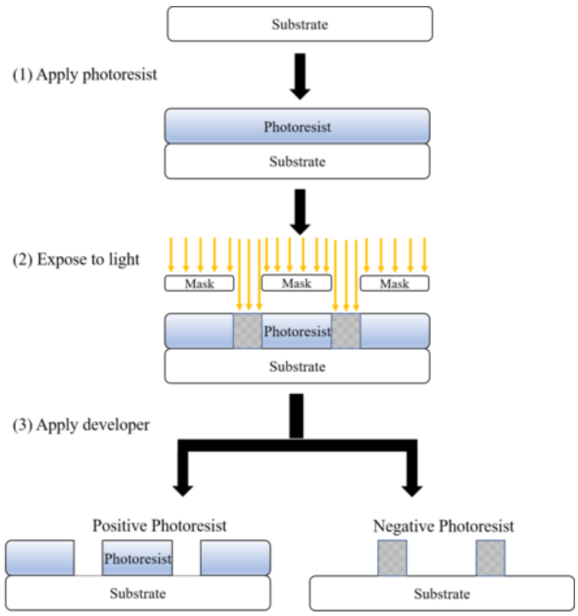
Top view **Side view**



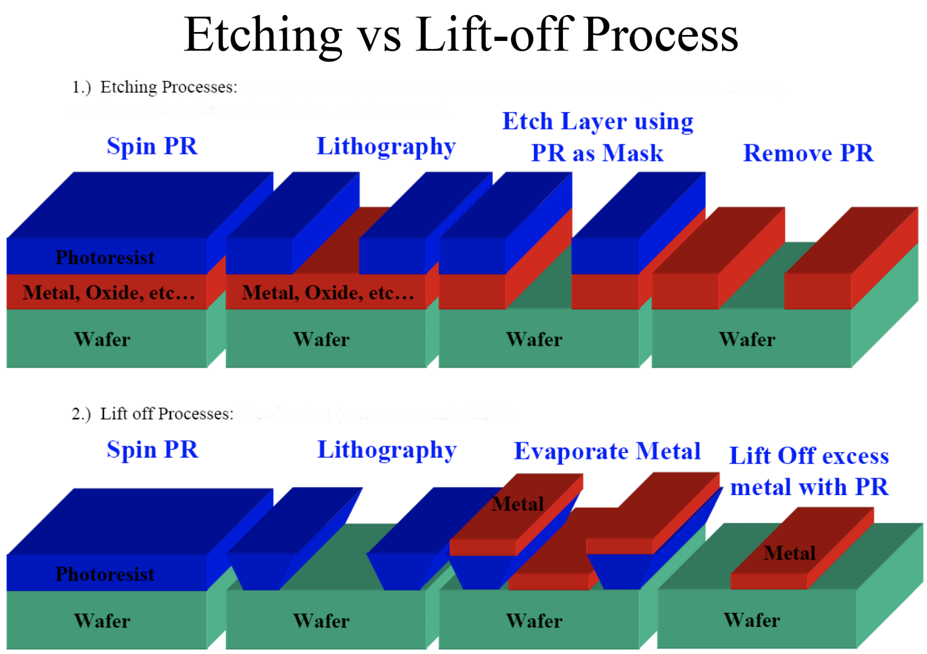
12. **Release of the device from the wafer.** We release the device from the wafer using anodic dissolution of aluminium (https://ieeexplore.ieee.org/document/1416914).

Top view **Side view**

Note: in this exercise we used standard thin-film fabrication techniques including photolithography. Photolithgrapy:



The same process flow could be envisioned using lift-off instead of etching.



Exercise 2 – Stress strain curves

a. What is the bending strain on the top surface of a polyimide film of 50 µm thickness rolled over a 1 mm diameter tube? If the same substrate is coated with a 0.5 µm thick multilayer (made of stiff, inorganic electronic materials), how will the resulting strain at the top of the structure be affected?

$\epsilon = \frac{ds}{2R} = \frac{50\times10^{-6}m}{2\times0.5\times10^{-3}m} = 50\times10^{-3}$= 0.05 = 5%

When the PI is coated with a 0.5 µm thick stiff material, the strain at the top will decrease

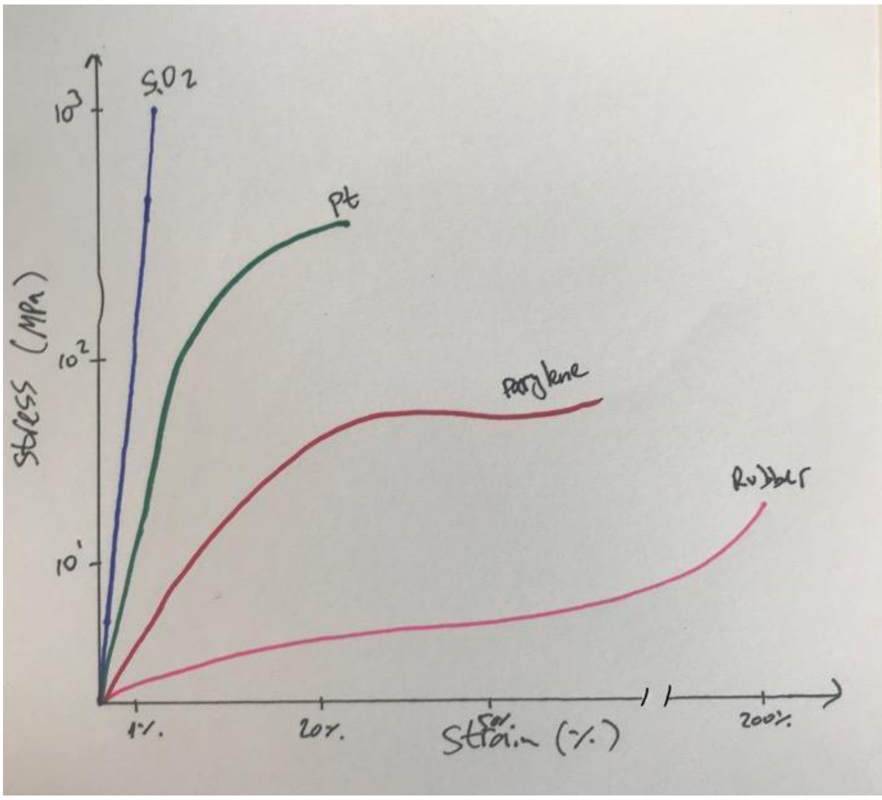
b. Knowing that the critical strain of a Cu thin film is 2%. Calculate what is the minimum bending radius such a film (with a thickness of 100 nm) can sustain when deposited on top of a 25µm parylene C substrate.

Find R giving strain of 0.02, R = 0.625mm

c. In another device, how thick should the substrate be if you want it to bend around a small human hair (diameter of 20µm)? Is this feasible?

For R=10µm, the substrate should be 400 nm thick. This is not feasible since such a device cannot be manipulated being too thin and brittle. Additionally, here the assumption that the thickness of the metallic film is negligible doesn't stand

d. Draw the stress-strain relationship for the following materials: rubber, platinum, parylene and silicon dioxide (SiO_2). Fill in the correct units, and an order of magnitude estimate of the x-y axis values.



SiO_2: Highest modulus, strongest, lowest failure strain, brittle

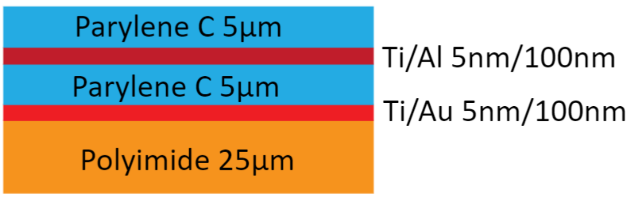
Pt: High modulus, small plastic deformation region

Parylene: Polymer, elastic + plastic deformation, ductile

Rubber: Elastomer, very low modulus, high elastic deformation, high failure strain

Exercise 3 - Neutral plane

A capacitive pressure sensor is composed of the following multilayer stack:



Young's modulus:
Polyimide 2.5 GPa
Parylene 2.8 GPa
Titanium 110 GPa
Gold 79 GPa
Aluminum 69 GPa

a. Calculate the position of the neutral plane (Assume $\overline{E_i} \approx E_i$).

$$z_n = \frac{\sum_{i=1}^{N} \overline{E}_i h_i \overline{z}_i}{\sum_{i=1}^{N} \overline{E}_i h_i} = \frac{(E_{PI} h_{PI} z_{PI}) + (E_{Ti} h_{Ti} z_{Ti}) + (E_{Au} h_{Au} z_{Au}) + (E_{PC} h_{PC} z_{PC}) + (E_{Ti2} h_{Ti2} z_{Ti2}) + (E_{Al} h_{Al} z_{Al}) + (E_{PC2} h_{PC2} z_{PC2})}{(E_{PI} h_{PI}) + 2(E_{Ti} h_{Ti}) + (E_{Au} h_{Au}) + 2(E_{PC} h_{PC}) + (E_{Al} h_{Al})}$$

$$= \frac{2.062\ Nm^2}{1.06410^5 Nm} = 19.38 \mu m$$

b. What is the bending strain on the top surface for R=1mm? And the stress? And at the top of the Au and Al layers?

$$\varepsilon_i = \frac{z_i - z_n}{R}$$

$$\sigma_i = E_i \varepsilon_i$$

$$\varepsilon_{PC2} = \frac{z_{PC2} - z_n}{R} = \frac{(35.21 - 19.38) \cdot 10^{-6} m}{10^{-3} m} = 1.58 \cdot 10^{-2} = 1.58\%$$

$$\sigma_{PC2} = E_{PC2} \varepsilon_{PC2} = 2.8 \cdot 10^9 \cdot 1.58 \cdot 10^{-2}\ Pa = 44.32\ MPa$$

$$\varepsilon_{Au} = \frac{z_{Au} - z_n}{R} = \frac{(25.105 - 19.380) \cdot 10^{-6} m}{10^{-3} m} = 5.725 \cdot 10^{-3} = 0.57\%$$

$$\sigma_{Au} = E_{PC2} \varepsilon_{PC2} = 79 \cdot 10^9 \cdot 5.725 \cdot 10^{-3} Pa = 452.28\ MPa$$

$$\varepsilon_{Al} = \frac{z_{Al} - z_n}{R} = \frac{(30.21 - 19.38) \cdot 10^{-6} m}{10^{-3} m} = 1.08 \cdot 10^{-2} = 1.08\%$$

$$\sigma_{Al} = E_{Al} \varepsilon_{Al} = 69 \cdot 10^9 \cdot 1.08 \cdot 10^{-2} Pa = 745.20\ MPa$$