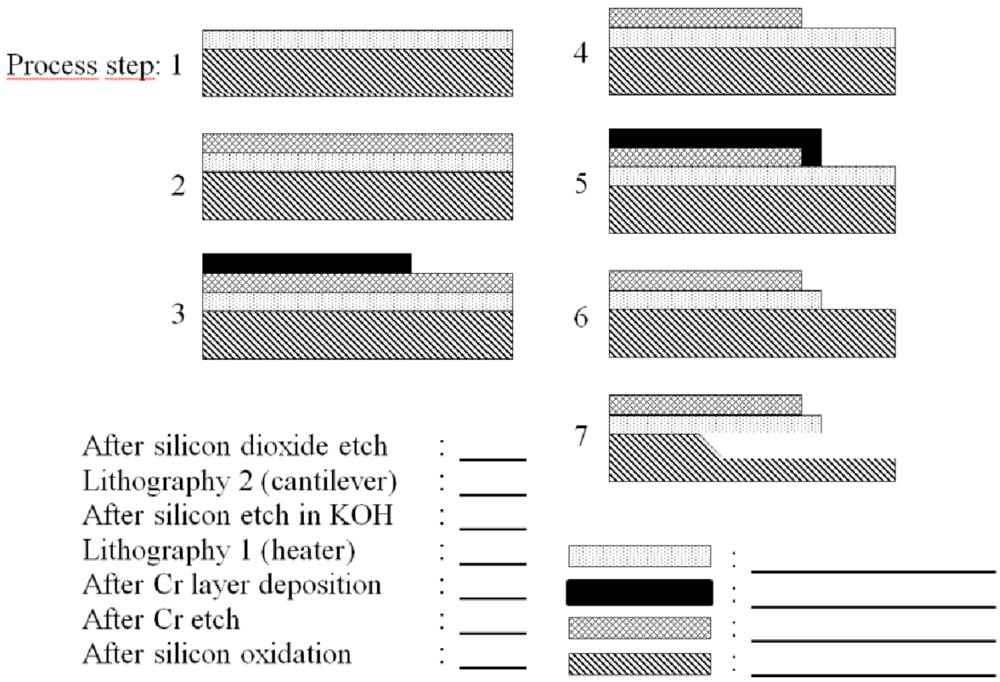
Série 3

Question 1

Below is a schematic fabrication process flow of a thermo-mechanical micro-actuator (bi-morph). Write the correct process step number in the blanks next to the descriptions of each process step, and write the name of corresponding material as well.



after silicon oxidation : 1

after Cr layer deposition : 2

lithography 1 (heater) : 3

After Cr etch : 4

lithography 2 cantiliver : 5

After silicon dioxyde etch : 6

after silicon etch in KOH : 7

white = silicon dioxyde

black = resist

light gray = chrome

dark grey = silicon

Question 2

Let us consider that we want to create a pattern via PVD of a thin gold film. This can be done by using two different strategies: (i) deposition, followed by lithography and etching, or (ii) the so-called lift-off technique. Make a schematic process flow of both strategies and explain the principle of lift-off.

i)

clean wafer
deposit thin cromium adhesion layer
deposit a gold layer
deposit photoresist
expose
etch gold
remove photoresist

ii)

clean wafer
deposit thin cromium adhesion layer
deposit photoresist
expose
remove photoresist
deposit a gold layer
remove left photoresist thus gold on it

Question 3

Lithography is typically used for pattern transfer. Consider that some microstructures have to be etched into a silicon wafer. Write (on the dashed line) the description of the necessary fabrication steps.

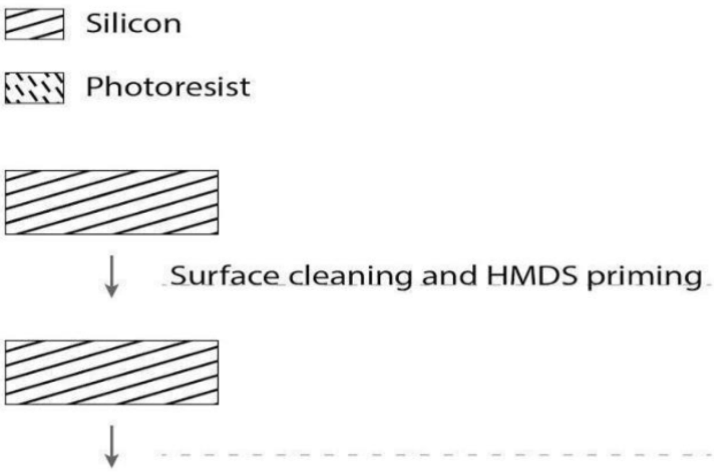
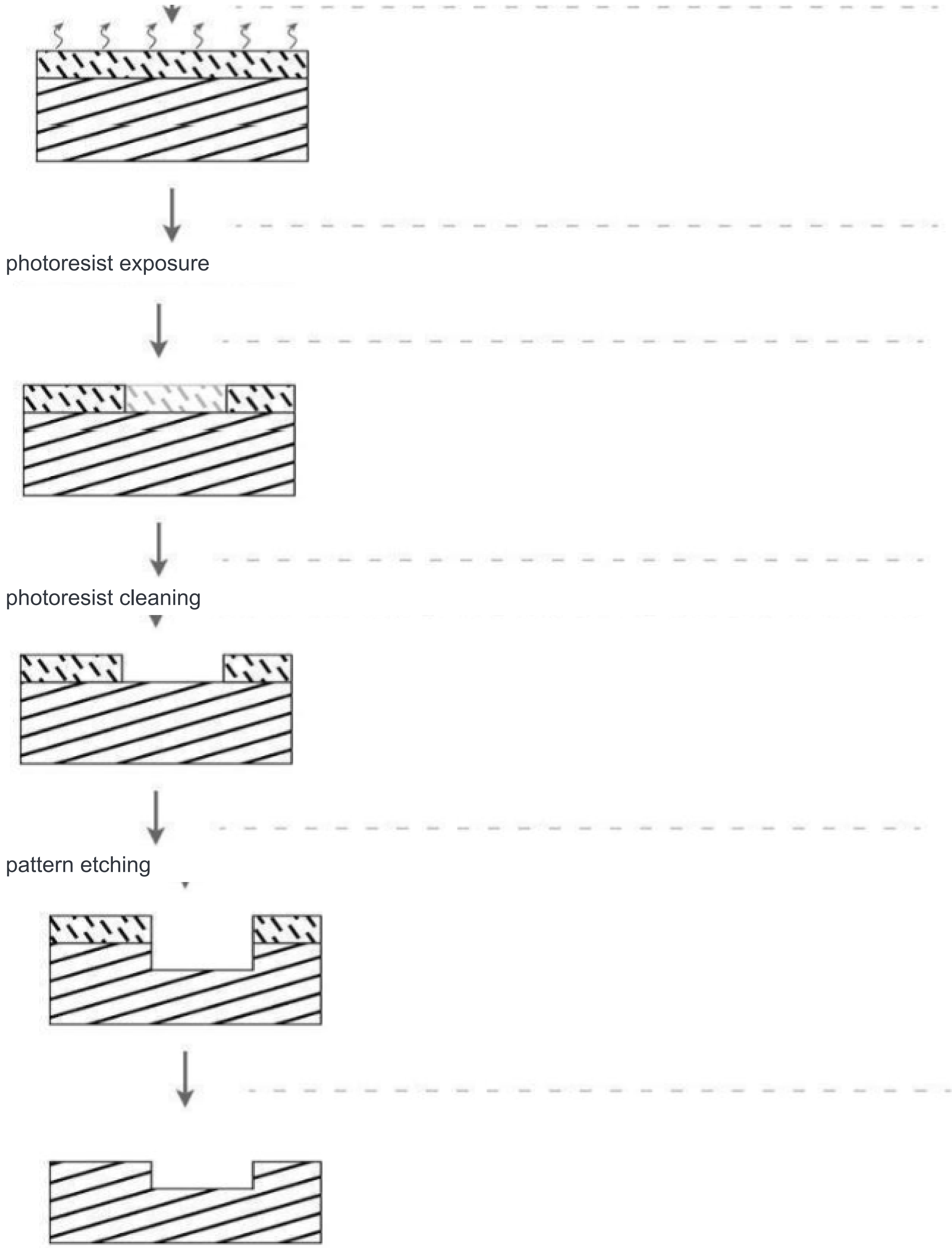


photo resist coating

photoresist baking and drying


photoresist exposure
photoresist cleaning
pattern etching

Jupyter Notebook Exercise

Objective

The aim of this exercise is to explore the nuances of photoresist coating, exposure and development. After understanding what factors affect the thickness of the obtained photoresist layer, we'll delve into how the design of a mask affects the resultant pattern upon development based on the light dose and its wavelength. An emphasis will be laid on the diffractive phenomena and its impact on the final developed pattern.

Part 1: Spin coating

The photolithography process starts with the coating of a thin photosensitive resist layer on your substrate. Follow the first part of the Jupyter notebook on spin coating.
In the text it is explained that the thickness T follows a law as a function of the spinning speed ω: $T = \alpha \times \omega^{-\beta}$.

1. With the given data pairs (ω, T) for two types of resins (LOR and AZ 1512 HS), find the best values α and β for each resin.
   Hint: use the sliders of α and β to make the green dotted line as close as possible to the data points.
   BONUS: you can write code that finds alpha and beta by regression.
2. Which of these parameters is more dependent on the resin type? Why?
3. Using the found values of α and β for AZ 1512 HS and the scaling law, find the required rotation speed for obtaining a thickness 1.5 microns.

the best fit for AZ1215 is :

residual error : 0.00014150924183749345

alpha parameter : 95

beta parameter : 0.52

the best fit for LOR 5A is :

residual error : 0.00010417873286216005

alpha parameter : 32

beta parameter : 0.5

2.

the alpha parameter is more depend because the beta barely change between the resin but alpha goes from 30 to 80

3)

The required rotation speed for 1.5 micrometer thickness is 2915.261981276865 RPM using AZ1215

The required rotation speed for 1.5 micrometer thickness is 455.1111111111111 RPM using LOR A5

Part 2: Decoding the Exposure-Development Curve

The photolithography process continues with the exposure to specially structured light, followed by a chemical removal of the resin in the undesired regions. For a positive resist as AZ 1512 HS, the regions removed are the regions exposed.

Visualize a scenario where a thick layer of resist undergoes exposure from a *uniformly distributed* light source for a set duration, followed by development. The primary graph in your notebook shows the relation between the developed depth (indicating the amount of resist removed) and the surface accumulated dose (measured in mJ/cm2).

1. **Qualitative Analysis:** Describe the form of this curve. Particularly, can you pinpoint and interpret what transpires at dose 15 to 30 mJ/cm^2 in this scenario?
2. **Practical Application:** Utilizing the data and the code provided in the notebook, determine the doses needed to fully expose resist of the specified thicknesses.
HINT: Do you remember the function interp1d from the oxidation notebook?

Thickness (nm)	Required dose (mJ/cm2)
500	
700	
1000	
1500	
2000	

1)

we can see that a small change in thickness lead to a great change in required dose

2)

best dose for target thickness of : 500

3.75 [mJ/cm^2]

with a final thickness of : 0.4998815220686531

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best dose for target thickness of : 700

6.23 [mJ/cm^2]

with a final thickness of : 0.7002582727857775

---

best dose for target thickness of : 1000

18.5 [mJ/cm^2]

with a final thickness of : 1.0000192037035416

---

best dose for target thickness of : 1500

47.0 [mJ/cm^2]

with a final thickness of : 1.4999166504582089

---

best dose for target thickness of : 2000

60.0 [mJ/cm^2]

with a final thickness of : 1.9998489600000013

Part 3: Dissecting Light Diffraction and Its Implications

When a patterned mask is introduced in the light's path, it results in a non-uniform exposure on the resist. However, due to light's wavelike nature, diffraction patterns may form for opening sizes comparable to wavelength. We have used a far-field approximation combined with Fourier transforms to model this effect. Consequently, the dose on the resist deviates from the mask's shape, forming an oscillatory profile.

For illustration of these effects, we're using a mask showcasing three distinct line widths ('mask_ThreeFingers.txt'). The notebook's code allows to calculate and visualize the dose accumulated by the resist as a function of the substrate's x,y coordinates. The markdown text in the notebook explains what is represented in each of plots. To examine the dose profile along a single line, a y_pixel slider has been implemented. Position yourself in y_pixel=300, observe how the dose varies along x. In the line plot frame, the dose function (blue) and the interpolated development function (orange) provide valuable insights. Furthermore, a dedicated procedure analyses these functions to find the boundaries between developed and non-developed areas and thus estimating developed line thickness. The resulting finger width values are printed above the line plot (only if found).

Employing these tools, populate the table below to document your findings as you transition the dose from 70% to 200% of the threshold. Capture the resultant width for each mask line width (the percentage is relative to the threshold value). Consider that sometimes you will not obtain the desired development function profile (too many oscillations may happen, or no development at all); when that happens report it in the table.

	F2 laser	ArF laser	Hg/Xe lamp	Hg lamp (i)	Hg lamp (h)	Hg lamp (g)
Line 500 nm	λ =157 nm	193 nm	248 nm	365 nm	405 nm	436 nm
Dose 70 %						
Dose 100 %						
Dose 150 %						
Dose 200 %						
Line 1000 nm	λ =157 nm	193 nm	248 nm	365 nm	405 nm	436 nm
Dose 70 %						
Dose 100 %						
Dose 150 %						
Dose 200 %						
Line 2000 nm	λ =157 nm	193 nm	248 nm	365 nm	405 nm	436 nm
Dose 70 %						
Dose 100 %						
Dose 150 %						
Dose 200 %						

4. How does the dose impact the results? How does the wavelength influence the outcomes? When do these effects become most pronounced?

	F2	ArF	Hg/Xe	Hg lamp i	Hg lamp h	Hg lamp g
500nm	157	193	248	365	405	436
70	N	N	N	N	N	N

	F2	ArF	Hg/Xe	Hg lamp i	Hg lamp h	Hg lamp g
100	T	19.4	45.3	43.2	40.8	40.8
150	89	86.4	81	70.6	66.8	68.8
200	92.9	95	86.8	82.2	79	78.2

	F2	ArF	Hg/Xe	Hg lamp i	Hg lamp h	Hg lamp g
1000nm	157	193	248	365	405	436
70	N	N	N	N	N	N
100	T	T	T	T	T	T
150	94.79	82.89	90.5	87.3	85.19	83.5
200	96.7	95.3	93.7	92	91.2	90

	F2	ArF	Hg/Xe	Hg lamp i	Hg lamp h	Hg lamp g
2000nm	157	193	248	365	405	436
70	N	N	N	N	N	N
100	T	T	T	T	T	T
150	97	96.6	95.5	93.6	92.9	92.55
200	98.4	97.9	97.0	96.05	95.6	95.5

Part 4: Experiment with Different Patterns

We have provided a bunch of text files encoding different geometries. Analyze the resultant developed patterns when varying the chosen shape or its characteristic dimension. Try triangles, stars, tightly packed fingers, etc. etc. etc. You can do this by uncommenting the corresponding line importing the files. Be careful to only make a single import at a time.