Jupyter Notebook exercise: PVD

You are expected to produce a metallic heater, and you have to choose materials and processes for the thin film depositions, as well as estimate the timing of the process.

Part 1: Thin film resistances and thickness

You are required to obtain a film with a total square resistance lower than 2.5 Ohm.
Remember that square resistance is calculated as:

$$R_{\blacksquare} = \frac{\rho}{t}$$

In the notebook you have some code that already can display some properties of typical metals available for the conductive layer, and also materials that can be used as adhesion layers. Considering a 10 nm thick adhesion layer (only when needed), find the conductive layer thickness to achieve the resistance requirement, and fill in this table.

Required conductor thickness table		Conductor		
		Au	Cu	Al
Adhesion	Ti			
	Cr			

HINT: you can write code that will help you to find the required thickness of conductive layer running for cycles on the materials. Remember that the two stacked layers can be treated as resistances in parallel: $\frac{1}{R_{eq}} = \frac{1}{R_{cond.}} + \frac{1}{R_{adh.}}$.

Part 2: Gathering deposition rate data

Using the CMi recipe data for the evaporator LAB600 and the sputtering tool DP650, find the fastest deposition recipes available for each material, and complete the line of code that stores the deposition rates (in nm/min). With this, find the total deposition times of the (bi-)layers of Part 1 by the two methods, and complete the table:
Remember: 10 Angstrom = 1 nm.

Deposition time Evaporation		Conductor		
		Au	Cu	Al
Adhesion	Ti			
	Cr			

Deposition time Sputtering		Conductor		
		Au	Cu	Al
Adhesion	Ti			
	Cr			

Part 3: Uniformity by evaporation.

The evaporation process can be advantageous in some cases, due to its directionality. Let us look at this process in detail.

By using the interactive plots and completing the missing parts of code, estimate the non-uniformity U in % for all possible combinations of wafer size and distance to source.

Hint: Some formulas that you might want to consider.

$$U = \left(\frac{t_{max}}{t_{average}} - 1\right) \times 100\%$$

$$t_{average} = \frac{\iint_{wafer} t\,dx\,dy}{\pi R^2} \cong \frac{\sum_{x_i^2+y_j^2<R^2} t(x_i, y_j)}{N_{\left(x_i^2+y_j^2<R^2\right)}}$$

Where $x_i^2 + y_j^2 < R^2$ refers to those points of the grid that are inside the wafer. Note that in the code, the matrix "points_outside" contains Boolean values of true for the indices that are in the outside region. $N_{\left(x_i^2+y_j^2<R^2\right)}$ is the number of grid elements that are inside the wafer (i.e. that have a false "points_outside" value) . Consider built-in methods for vector (like max, min, sum, mean) and use the "points_outside" matrices defined in the code to select wisely the indices you need.

Non- uni-formity		Wafer Size			
		5 cm	10 cm	15 cm	20 cm
Distance (cm)	20				
	40				
	60				
	80				
	100				

Part 4: Vacuum in evaporation chambers

It is necessary to pump a vacuum in the deposition chamber. Adding the necessary code to the plotting function to calculate exactly the required time to reach a sufficiently good vacuum and display it on the plot with vertical and horizontal intersecting lines.
The required mean free path needs to be greater than 100 times the distance between source and wafer. The pumping time in seconds is by rule of thumb 75 times the mean free path in m, for each of the possible distances.

Distance (cm)	Pumping time required
20	
40	
60	
80	
100	

Part 5: Process duration

a. What would be the total duration of an evaporation process for all the films proposed in the previous parts? What fraction of the time is actually employed for the deposition?

b. Assuming that the sputtering process can be done on a single wafer at a time, and it takes 15 minutes to process one wafer, how many wafers have to be processed identically so that using evaporation starts to make more sense (of course, ignoring any details about process-dependent differences in thin film quality)?

Part 6: Deposition on tapered walls

Follow the last part of the notebook to appreciate the effects of depositing on a substrate with topography and tapered sidewalls.