PVD Uniformity Analysis (40 points)

Objective: The objective of this lab is to analyze the thicknesses of a series of aluminum thin films deposited in the Cooke thermal evaporator (Figure I). The issue of thin film uniformity when depositing from a point source will be illustrated through data analysis. This data will be obtained from the Dektak profilometer (Figure II).

Figure I: Cooke thermal evaporator

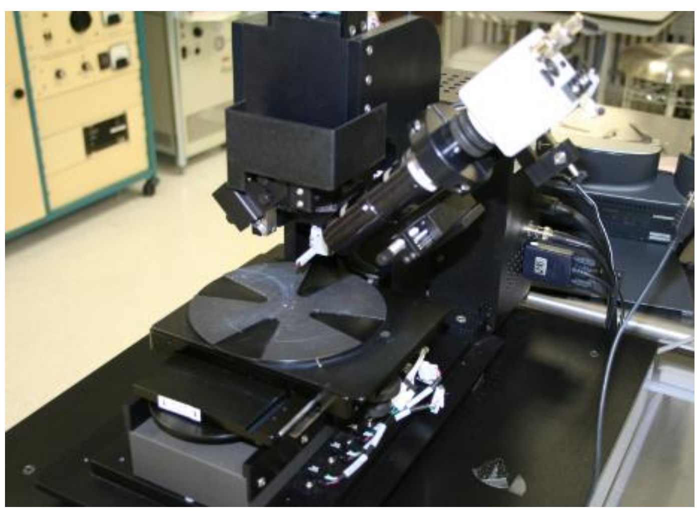
Figure II: Dektak Profilometer

Introduction: The operation of the Cooke thermal evaporator was previously shown. Feel free to review the operation of the Cooke thermal evaporator at the link below:

http://www.engr.psu.edu/mediaportal/flvplayer.aspx?FileID=8e8351bc-ecb7-42ef-aff3-b

In this lab, an array of samples will be loaded into the evaporator at varying distances from the point source. Following evaporation the profilometer will be used to obtain the thickness of each sample; in this way, the sample thickness as a function of its distance from the point source can be mathematically analyzed through data analysis.

Background: As shown in the Intro to PVD Lab, the Cooke thermal evaporator uses a tungsten basket to house the metal which is to be deposited. This tungsten basket is an example of a point source. In a point source the evaporant particles originate from an infinitely small point with a uniform mass evaporation rate. In other words, metal particles leave this point source in all directions at an equal rate; this will serve to form a cone like emission of metal atoms from the point source. A second type of source is a surface source. In a surface source the particles leave in all directions from an extended area, a good example of a surface source would be the crucibles commonly used in e-beam evaporation.

Maintaining thin film thickness uniformity is an essential requirement for many microelectronic and nanofabrication applications. This can be difficult to achieve if there are many components to be coated or the components to be coated have a large area or curved surface. Figure III contrasts an ideal, uniform, thin film, to a non-uniform and more realistic experimentally obtained thin film. The thickest portion of the film, d_1, occurs directly above the point source (boat). All other portions of the film will have a thickness that changes with position, d_n. The goal of this lab is to analyze data in order to see how the thickness of a thin film varies as a function of the positioning of the substrate with respect to the point source. **<u>This lab will require a lot of math.</u>**

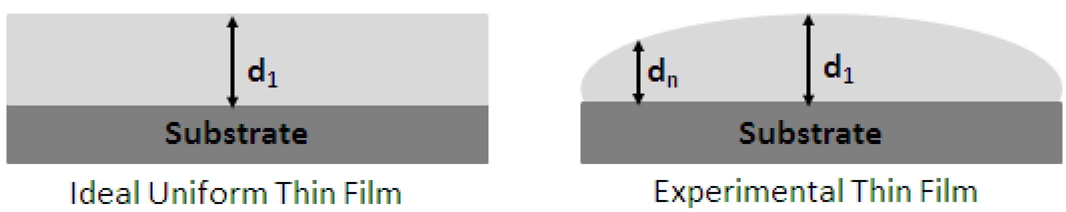

Figure III: A comparison of an ideal uniform thin film (left) to a more realistic thin film (right). The dimension d_1 is representative of the film thickness obtained directly above the point source. The dimension d_n is representative of the film thickness at any other location not perpendicular to the point source.

The thickness of a film will vary as a function of the distance the sample is from the point source. Figure IV is a general depiction of the key geometrical variables involved in this lab. The dimension h is the distance between the point source and the sample directly above it (sample 1 in this experiment). The distance ℓ_n represents the horizontal displacement of sample n from the point directly above the point source (i.e. sample 1).

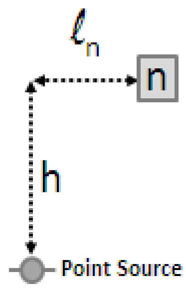

Figure IV: A Depiction of the key geometrical variables in this experiment

Experiment: Two 3" silicon wafers were cleaved into quarters and then mounted onto eight 2" shadow masks as shown in Figure V. These eight shadowed substrates were then mounted throughout the vacuum chamber of the Cooke thermal evaporator at varying distances, ℓ_n, from the point source as shown by Figure VI.

Figure V: Shadow masks and 3" wafers used for this study (left) cleaved samples (center) and cleaved samples being mounted to shadow masks (right)

Figure VI: Locations and identities of the 8 shadowed samples which were mounted at varying distances, ℓ_2 through ℓ_8, from the point source in the evaporator. The red dot in the center of the figure represents the location directly above the point source (sample 1).

An image of the tungsten boat point source and the distance between this point source and the red dot directly perpendicular to it is seen in Figure VII. Note that the distance shown in right hand portion of Figure VII is representative of the geometrical dimension h discussed in the background.

Figure VII: Point source (left) and distance between the point source and location directly perpendicular to it, h (right)

Table 1 shows some of the distances ℓ_n (refer to Figure IV) for a handful of the 8 samples shown in Figure VI. Note that the value of ℓ_1 for sample 1 is 0" since sample 1 was mounted directly perpendicular to the point source. Part of your work in this lab will be to extrapolate the distances ℓ_4 and ℓ_8 through data analysis.

Following evaporation, the shadow masks were removed from the samples. Images of completed samples and the locations of the four profilometer measurements obtained from each sample are shown in Figure VIII. Average values of the four profilometer measurements obtained from sample n, d_n, will be used during the data analysis and calculations. The operation of the profilometer was previously shown in **this** video.

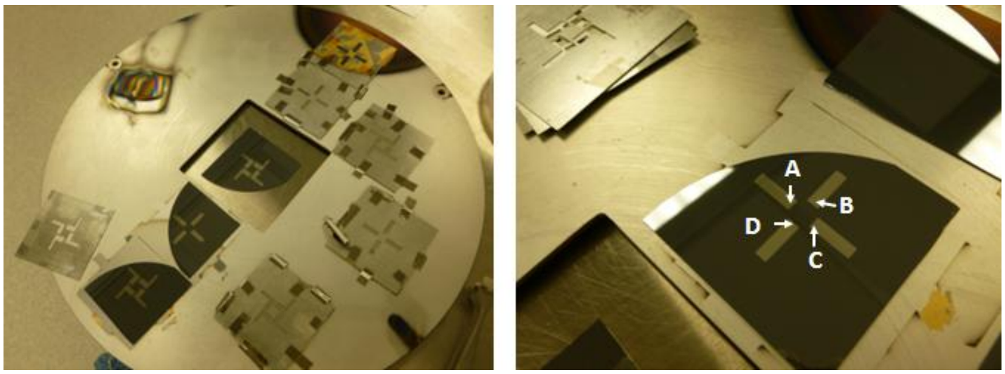

Figure VIII: Shadow masks being removed from samples (left). Locations of the four profilometer measurements taken on each of the 8 samples (right)

The data obtained with the profilometer will be analyzed to determine the relationship between the point source-substrate geometry and the thickness of a thin film. In this way, an appreciation for the commonly obtained non-uniformities over large areas shown in Figure III can be appreciated.

The thin film thickness of a point source has been experimentally determined to be given by [1]:

$$\frac{d_n}{d_1} = \frac{1}{\{1 + (l_n/h)^2\}^{3/2}} \qquad [1]$$

The values of d_n, d_1, ℓ_n, and h have all been discussed previously throughout the lab. Table 1 gives the majority of the geometric data obtained during the experiment's set up (ℓ_n values) and the majority of the sample thicknesses measured with the profilometer (d_n values). However, a few of the values in Table I are missing and need to be obtained through data analysis. Note that d_1 is the average value of the profilometer data obtained from sample 1 since sample 1 was placed directly perpendicular to the point source. Also note that the value of ℓ for sample 1, ℓ_1, is 0" since sample 1 is located directly perpendicular to the point source.

It is your job to analyze the data in Table I and utilize Equation [1] in order to determine the expected average thicknesses of samples 3 & 6, namely, d_3 and d_6, and the expected distance samples 4 and 8 were placed from the point source, namely, ℓ_4 and ℓ_8. A visual depiction of the values you will be calculating from the experimentally obtained data is shown in Figure IX.

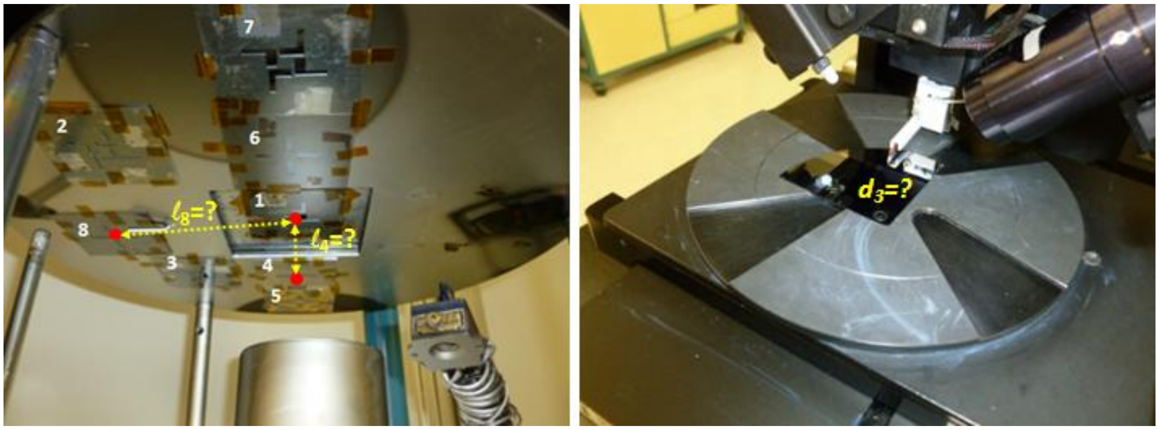

Figure IX: The distance between sample 8 and the point directly above the point source, ℓ_8, and the distance between sample 4 and the point directly above the point source, ℓ_4 (left) The average thickness of sample 3 obtained with the profilometer, d_3 (right)

Location		Thickness (nm)				
Sample	**ℓ_n (")**	**A**	**B**	**C**	**D**	**Avg (d_n)**
1	0	61	67	63	61	63
2	4	35	25	26	18	26
3	3.5	?	?	?	?	d_3=?
4	ℓ_4=?	56	46	41	57	50
5	4.625	No film deposited on Sample 5				
6	2.625	?	?	?	?	d_6=?
7	4.625	28	32	35	36	33
8	ℓ_8=?	36	46	38	45	41

Table I: Experimentally obtained data from this experiment

Questions to be answered on ANGEL-40 points (NO HARD COPY REQUIRED)

1. What is the approximate value of ℓ_4? (5)

2. What is the approximate value of ℓ_8? (5)

3. What is the approximate value of d_3? (5)

4. What is the approximate value of d_6? (5)

5. From the provided experimental data (and not the calculated theoretical data), which mathematical assertion can you make: (3)

6. No film was deposited on sample 5, what is the most likely cause for this? (3)

7. Figure VI shows samples 2, 3, and 8 were all loaded on the left hand side of the chamber while the right hand side was left vacant. What was the reason for mounting the samples in this manner? (3)

8. What is the most likely cause in the minor variance of the profilometer data obtained for a given sample? (3)

9. Can Equation [1] be used to verify the crystal thickness monitor reading of 335 Å? Why or why not. (5)

10. Why was the shutter removed from the evaporator when performing this experiment? (3)