Liftoff Lab (100 points)

Objective: The objective of this online lab is to demonstrate the liftoff process and to determine the influence using a liftoff photoresist has on feature quality by analyzing data obtained throughout the experiment.

The student will watch a series of videos pertaining to the liftoff process. The data obtained during the characterization steps throughout the liftoff process will be provided within in the lab handout. After watching the videos and analyzing provided data students will be required to answer review questions on ANGEL.

Background: The liftoff process is used to selectively deposit metals without the need for etching. This is a valuable technique because pre-existing layers may exclude some etch techniques. A pattern is defined on a substrate by utilizing steps introduced in previous labs in conjunction with the liftoff process. The liftoff process follows a lithography and deposition step as shown in Figure 1 below:

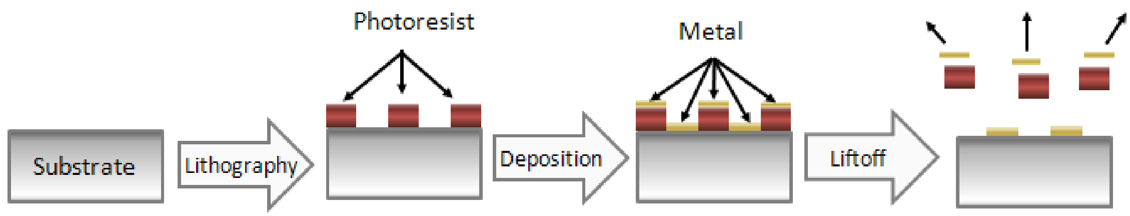


Figure 1: A depiction of the liftoff process. Here, pattern definition is obtained through a combination of lithography, deposition, and liftoff.

During the liftoff process the metal is typically "blanket deposited" meaning it covers the entire substrate. However, since the substrate has been prepatterned with photoresist one can think of this photoresist as a pseudo-shadow mask, such as that used during the introduction to thermal evaporation online lab; it is this previously defined photoresist pattern that will ultimately define the metal features on the substrate.

Lift-off is the process of choice for e-beam patterning metal lines due to its ability to define high resolution geometries since in order to obtain high resolutions an ordinary photoresist may not always be sufficient. This lab will seek to illustrate the liftoff process using both a conventional lithography and deposition technique along with a second type of lithography process utilizing a second photoresist layer. This second photoresist layer is called lift off resist, or more commonly LOR. This LOR will facilitate the liftoff of the metal features deposited onto the top of the photoresist features.

Since photolithography and metal deposition are key components leading up to the liftoff process it is recommended that students review the introduction to lithography and introduction to thermal evaporation labs prior to beginning this lab.

Experiment: Two 2" silicon wafers will be processed and characterized during this lab. Both wafers will be subjected to the liftoff process. One of the wafers will employ a layer of liftoff resist, the other will not. A hard bake will be used as an additional experimental variable. Samples will be characterized throughout the lab using the optical microscope and the profilometer.

Step 1: Wafer Clean & Dehydration bake

The first steps in this experiment are identical to those in the introduction to photolithography lab: a wafer clean and a dehydration bake. Feel free to review these two steps from the introduction to photolithography lab at the links below:

http://www.engr.psu.edu/mediaportal/flvplayer.aspx?FileID=976fee4b-a841-4a91-afd6-f

http://www.engr.psu.edu/mediaportal/flvplayer.aspx?FileID=e5abcebf-aa54-4bee-901a-9

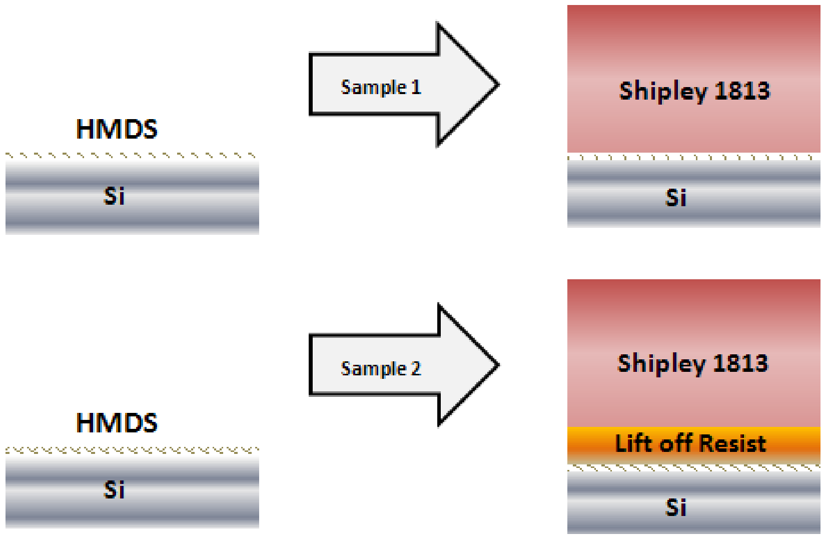
Step 2: HMDS Coating

Again, akin to the standard photolithography process, a thin layer of HMDS will be coated onto each of the two wafers in order to promote the adhesion of the photoresist. Watch the HMDS coating at the link below:

http://www.engr.psu.edu/mediaportal/flvplayer.aspx?FileID=ac567321-3da5-4b89-a12e-c

Step 3: Photoresist Coatings

Up to this point, both of the wafers have been processed identically. The photoresist coating process will be the primary experimental variable in this lab; one of the samples will be coated with only the Shipley 1813 photoresist, as usual. The other sample will first be coated with a layer of Lift off Resist (LOR) followed by a layer of Shipley 1813 photoresist (S1813). A depiction of this step is shown below:



Watch the photoresist coating process used during this lab at the link below:

http://www.engr.psu.edu/mediaportal/flvplayer.aspx?FileID=664bbf0d-b8bf-44ad-afce-f

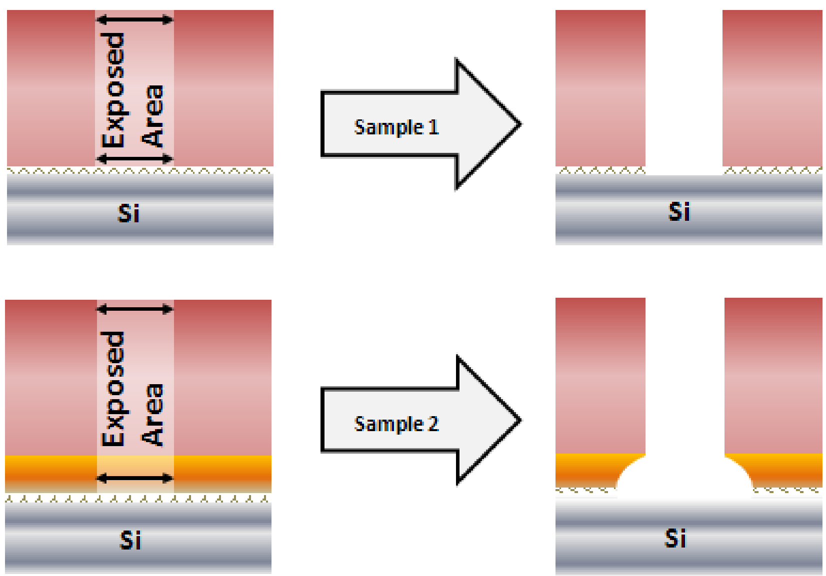
Step 4: Exposure

Next both of the wafers will be exposed. Note that the exposure tool used in this experiment is different than the one used during the Introduction to Photolithography lab.

http://www.engr.psu.edu/mediaportal/flvplayer.aspx?FileID=5eebea27-2797-4bde-a610-d

Step 5: Development

Following UV exposure through a photomask the samples are both developed. During the development an undercut is formed in the LOR layer. A depiction of the development process and the undercut formed in the liftoff resist are depicted below.



Watch the development process used during this lab at the link below:

http://www.engr.psu.edu/mediaportal/flvplayer.aspx?FileID=d45b6770-66d8-4507-b213-6

Step 6: Hard bake & First Characterization

Each sample will now be cut in half, affording 4 pieces labeled A, B, C, and D. Here, A and B are from sample 1 and C and D are from sample 2. Samples B and D will be hard baked at 120°C for 4 minutes and samples A and C will be used as controls. Next, three features on each of the four half wafers will be circled-these features will be characterized throughout the remainder of the process. Watch the cleaving of the wafers, the hard bake, and the circling of the features to be characterized at the link that follows.

http://www.engr.psu.edu/mediaportal/flvplayer.aspx?FileID=045fb124-682f-4d53-8f10-a

The widths and the heights of the circled photoresist features will then be characterized with the profilometer. The dimensions obtained during this initial characterization step are shown in the following table. The widths were measured at the bottom of the photoresist trenches since this is where the metal will be deposited and measured later in the lab. Due to this measurement location the profilometer probe tip may have a hard time accessing the precise bottom edge of the trench; this may cause a slight aberration in the form of a narrower than realistic trench width (i.e. ~40-45 μm instead of 50 μm from the photomask).

Sample ID				Average Height (nm)				Width (μm)		
Sample	Hard Bake?	LOR?		1	2	3		1	2	3
A (1)	No	No		1480.5	1520.7	1458.1		39	40	45
B (1)	Yes	No		1400.0	1388.1	1402.3		42	42	44
C (2)	No	Yes		1628.8	1577.0	1641.1		39	42	46
D (2)	Yes	Yes		1574.5	1573.0	1580.9		41	40	44

Step 7: Metal Deposition

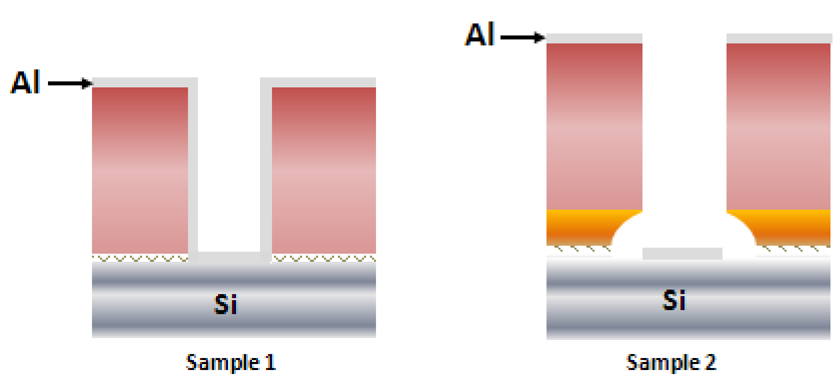
Following characterization each of these 4 samples will be loaded into the Cooke thermal evaporator for a blanket deposition of aluminum. For a complete refresher on the Cooke thermal evaporator please review the clip below:

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

Following this blanket deposition of aluminum onto the 4 samples the samples will be unloaded from the evaporator. Watch the samples processed during this lab being loaded and unloaded into the evaporator for the liftoff process at the link below:

http://www.engr.psu.edu/mediaportal/flvplayer.aspx?FileID=a24e3fa4-963e-49b9-b5d7-b

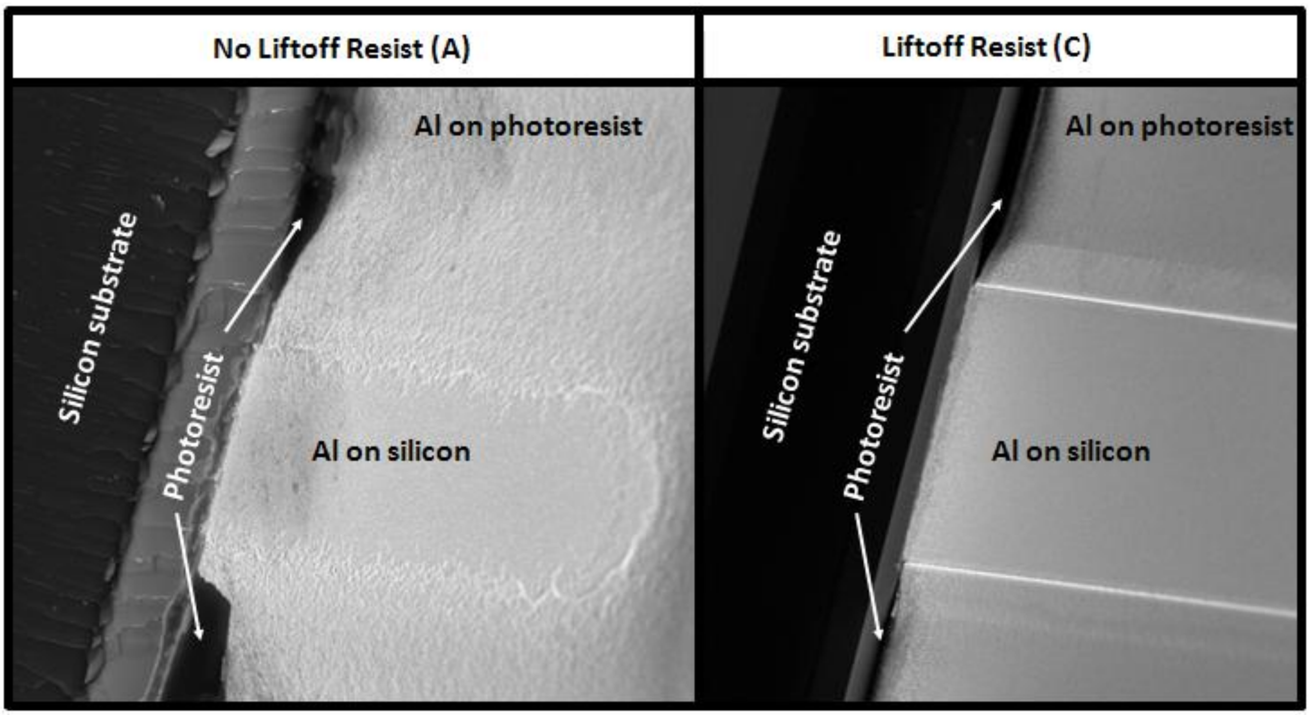
A cross section of the samples following the metal deposition is depicted below. Notice how the undercut in the liftoff resist helps create a 'break' in the metal deposition. This break facilitates the liftoff process, affording higher fidelity features.



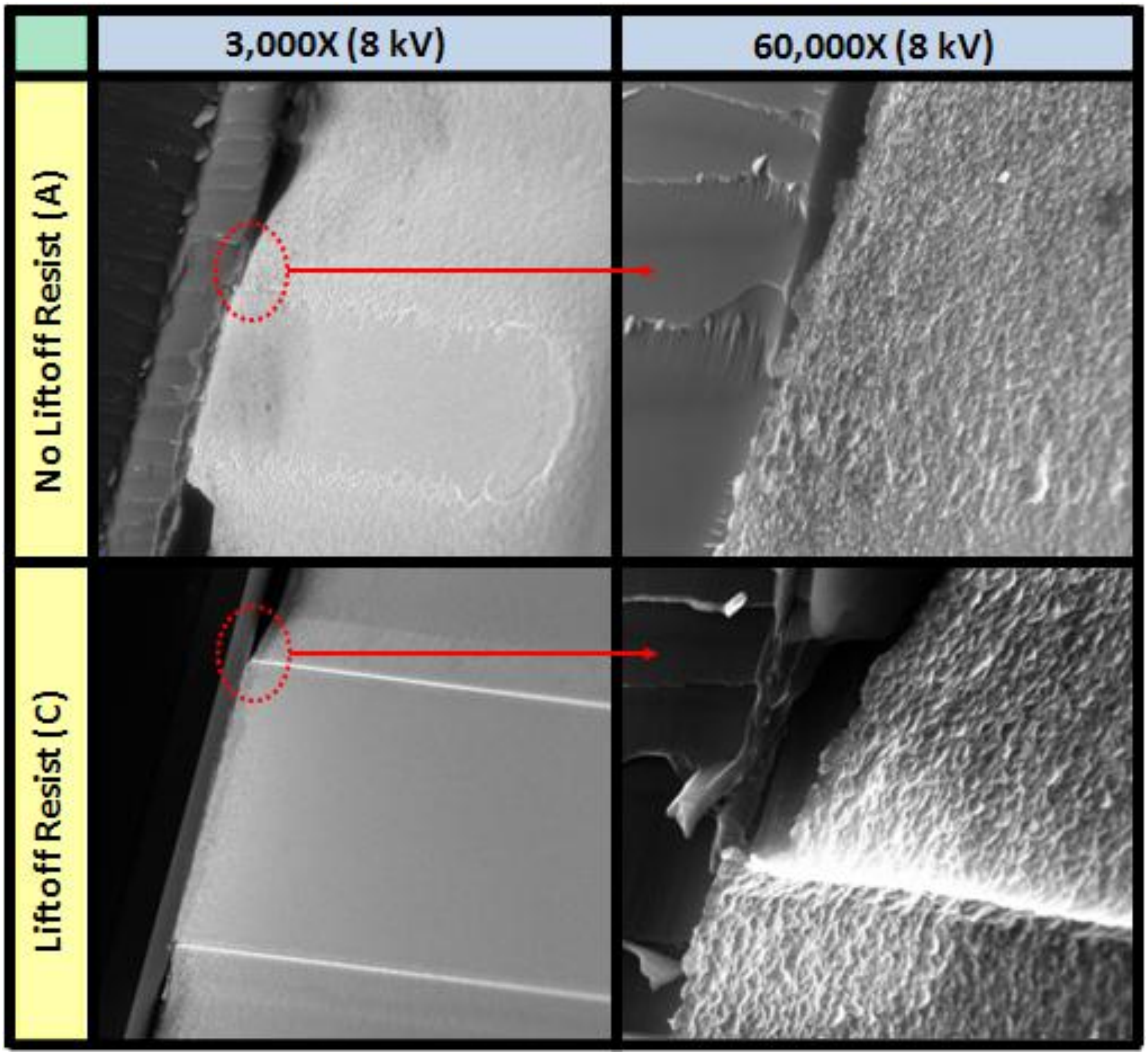
In order to get a true appreciation for the influence of the liftoff resist a field effect scanning electron microscope (FESEM) will be used to image cross sections of samples A and C. These images were obtained by cleaving a portion off of each sample immediately following the metal deposition (and before liftoff) and loading them on an angle with respect to the electron gun in the FESEM. For a more comprehensive overview on the general operation and mechanism of the FESEM feel free to visit the link below:

http://www.engr.psu.edu/mediaportal/wmvplayer.aspx?FileID=d72da32c-dc21-4bee-8d69-f

Below is a comparison image between samples A and C. Both images were taken at 3,000X magnification using the FESEM. Notice the glow around the bar that is present on sample C (right) but not on sample A (left). This glow is indicative of the fact that there is a break in the metal film on sample C, but not on sample A. Hence, the liftoff of the photoresist is expected to go smoother on samples utilizing the liftoff resist (C & D).



The interface around the Al on silicon feature was then zoomed in on using an even greater magnification of 60,000X. The left hand set of images in the following figure correspond exactly to the 3,000X images shown above. The small area circled in red on these 3,000X samples is then zoomed in on to 60,000X and shown in the right hand set of images. From these images it is clear that a step has formed on sample C and not on sample A. Therefore, the blanket deposition on sample A afforded a continuous metal film while the blanket deposition on sample C had a break in it. The reader should keep this notion in mind while watching the video of the liftoff process that follows.



Step 8: Liftoff

After the metal deposition and the FESEM characterization the metal deposited on top of the photoresist will literally be “lifted off” by the photoresist beneath it. This is accomplished by immersing the samples in a strong organic solvent that will remove the photoresist (and thus any metal on top of it) at an elevated temperature. Watch the clip below to view the liftoff process.

http://www.engr.psu.edu/mediaportal/flvplayer.aspx?FileID=0d30aae8-01c4-4d6b-950c-4

Step 9: Final Characterization

Finally, each of the 4 samples will be characterized a second time with the profilometer. This time the heights and widths of the deposited metal features will be measured. A depiction of how the samples may look following the liftoff process is shown in the following figure.

Sample 1 Sample 2

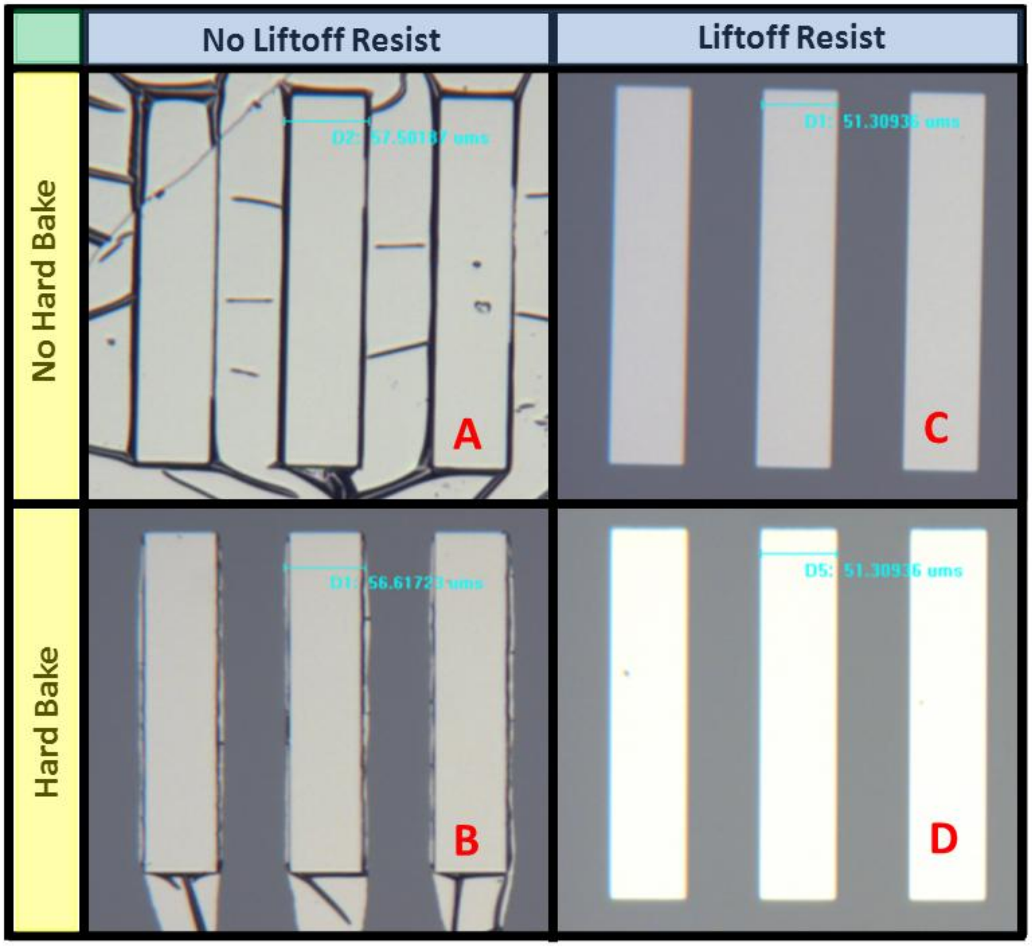
Notice the so called “rabbit ears” on the sample without liftoff resist in the Figure above. These features are undesirable as they may penetrate or puncture subsequent layers, leading to open or short circuits in electronic devices. These features can be chemically mechanically polished away or more simply avoided by employing a special type of photoresist undercut layer-such as the LOR which was used during this lab. The results obtained for the metal feature dimensions are displayed in the following table:

Sample ID			Average Height (nm)			Width (μm)		
Sample	Hard Bake?	LOR?	1	2	3	1	2	3
A (1)	No	No	42.7	42.9	43.6	51	50	53
B (1)	Yes	No	42.3	42.7	43.2	50	51	52
C (2)	No	Yes	38.3	41.2	38.0	50	51	51
D (2)	Yes	Yes	39.3	40.7	38.3	51	51	50

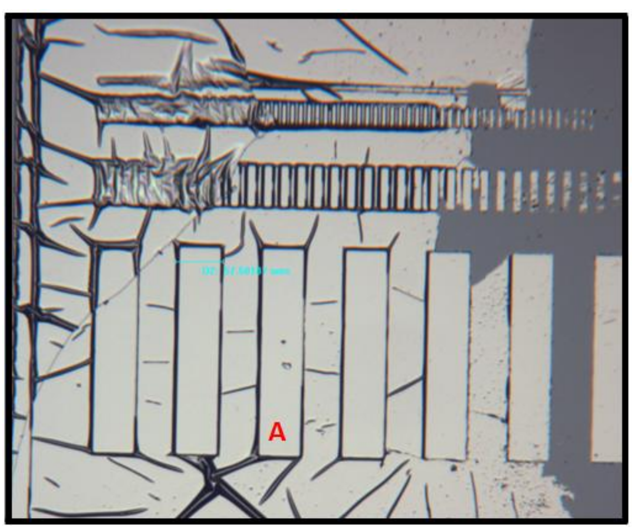
The optical microscope will also be used to view each of the 4 samples immediately following the liftoff process. The images clearly depict that a significant amount of metal was still present in undesirable areas on samples A and B, indicating some of the photoresist (and therefore metal on top of it) was not successfully lifted off. Note how this idea is consistent with the FESEM images presented prior to the liftoff process.

In order to obtain profilometer data it was necessary to sonicate samples A and B in acetone for 3 minutes in order to complete the liftoff process. The sonication served to create a break in the aluminum film on samples A and B such that the complete liftoff process could occur. All four samples were sonicated in order to eliminate the introduction of any additional variables. However, it should be noted that samples C and D did not require sonication (since they lifted off successfully the first time) and the extra treatment would only serve to damage the metal features on these samples. Thus, the LOR and Remover PG combination would be ideal for defining high fidelity features since it does not require a high energy sonication step.

100X Magnification/Bright field/Before Sonication

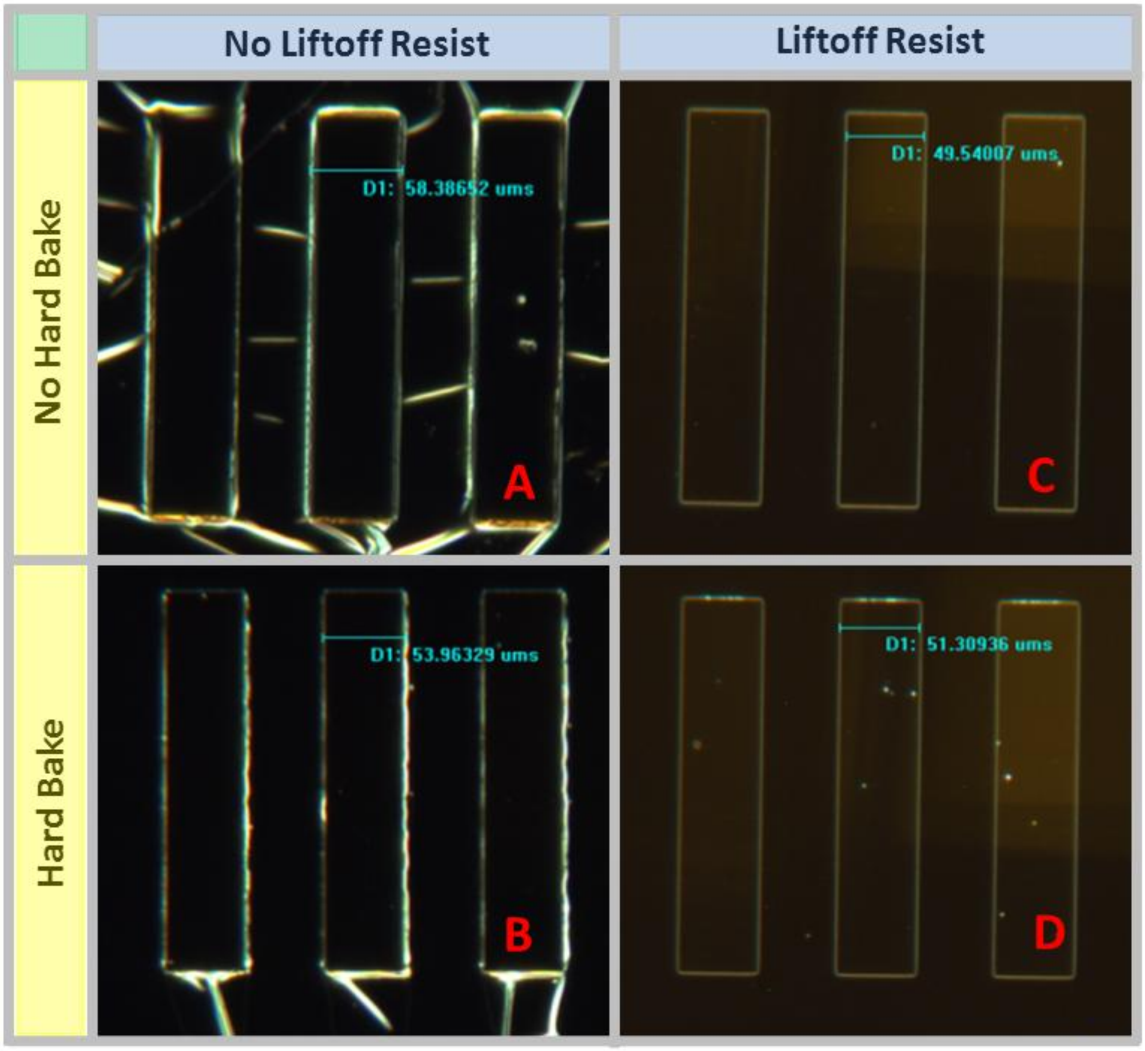


A wider field of view of sample A (100X bright field) illustrates how the metal film only partially lifted off prior to the final sonication in acetone:



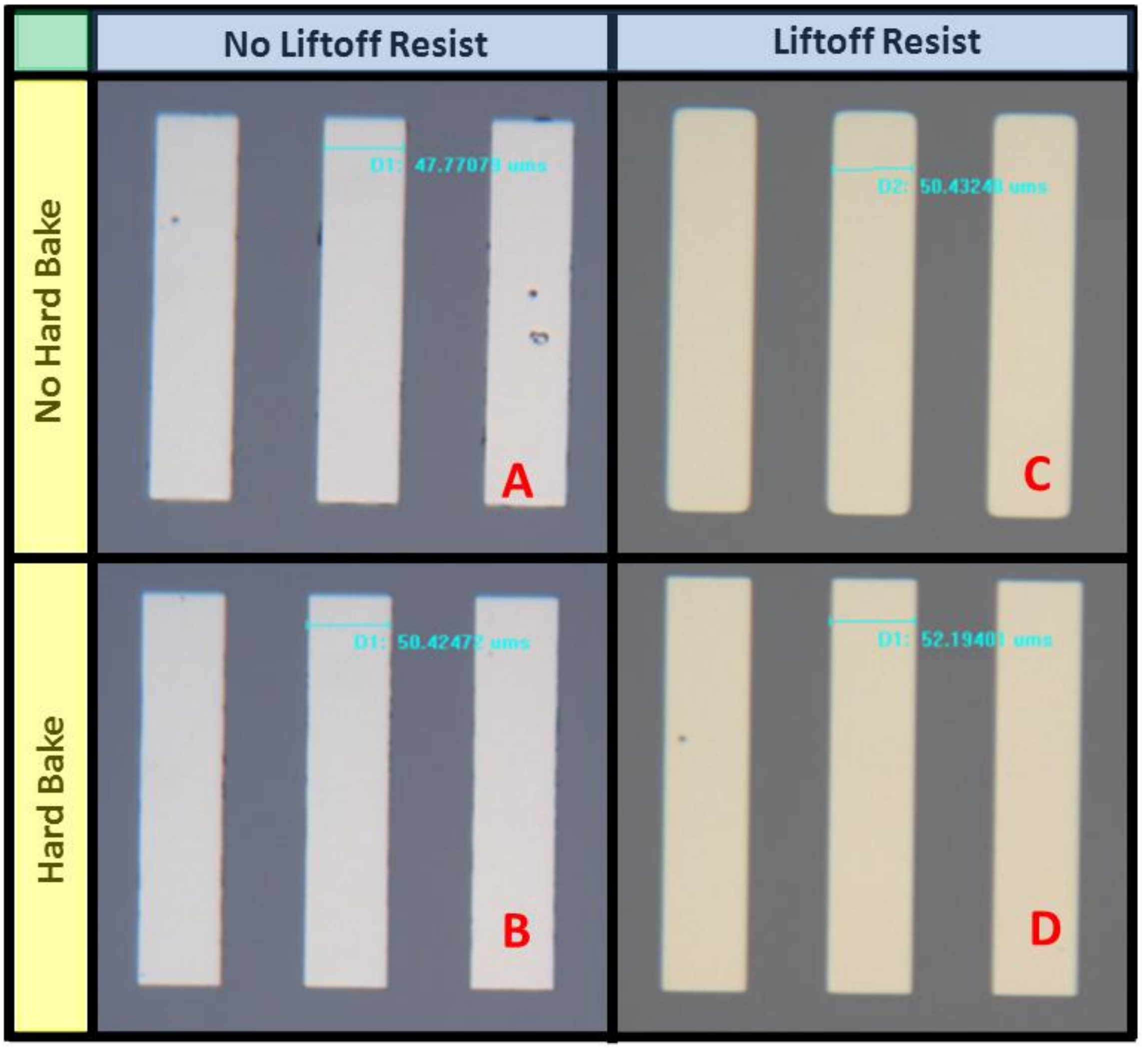
The dark field optical microscope images prior to liftoff illustrate the partial peeling off of the metal film on samples A and B. Again, samples A and B did not use the liftoff resist (LOR) while samples C and D did. This comparison image clearly illustrates the importance of using the liftoff resist when performing the liftoff process.

100X Magnification/Dark field/Before Sonication



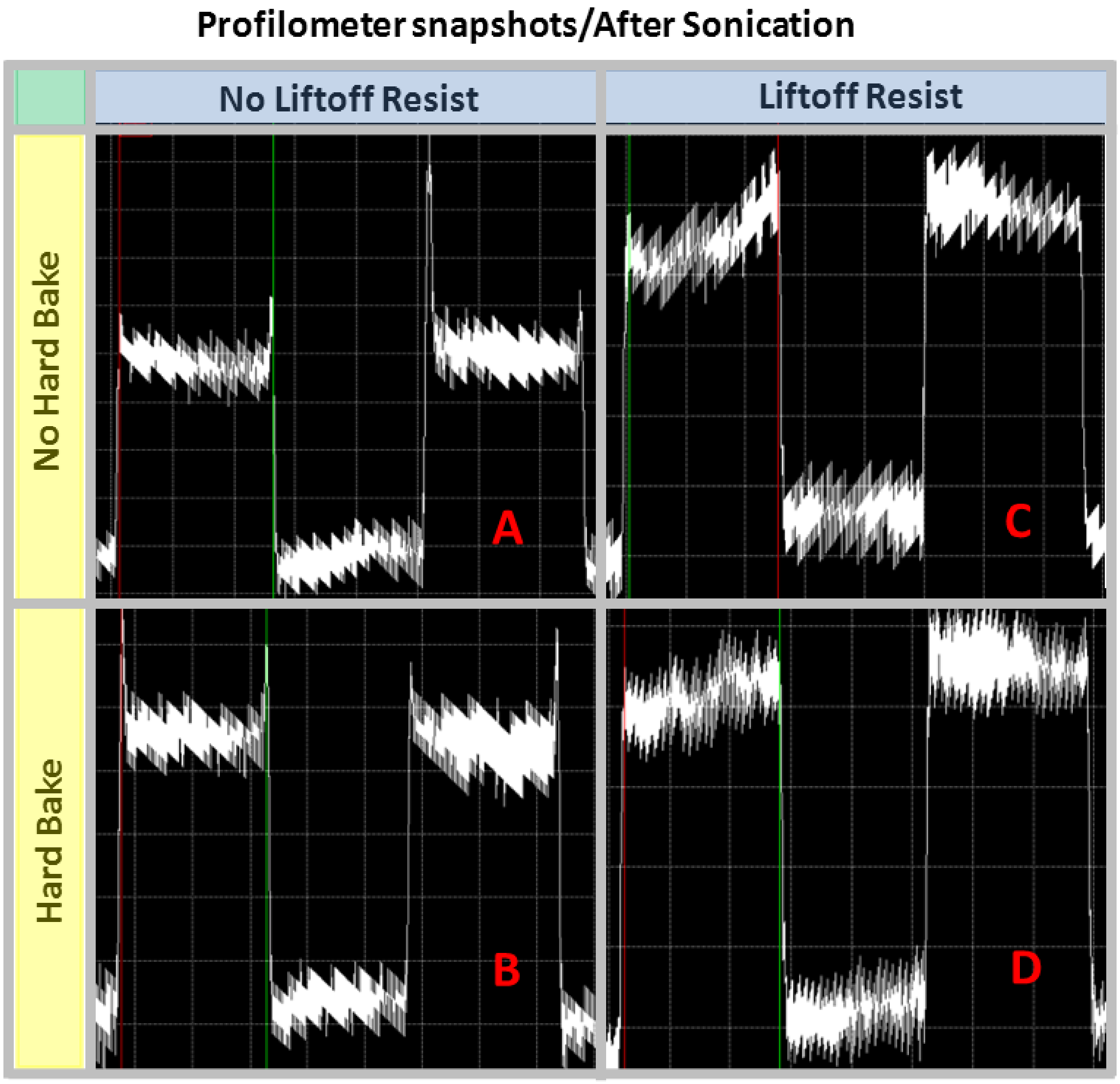
The next image comparison illustrates the same exact features at the same magnification after sonication. All 4 samples were sonicated together for 3 minutes in acetone. Following sonication samples were rinsed with IPA and DI water. The sonication served to remove the majority of the excess metal film seen above on samples A and B. This sonication was necessary in order to obtain the profilometer data for the metal features on samples A and B following liftoff.

100X Magnification/Bright field/After Sonication



Notice that even following the sonication in acetone the edges of the metal features on samples C and D are better defined and smoother than the edges of the metal features on samples A and B; which appear rougher. Recall the smoothness of the interfaces prior to liftoff shown on the FESEM images and how they are consistent with the optical microscope images following liftoff. Continuing on this point, it follows that these images are consistent with the notion of “rabbit ears” discussed earlier in the lab. In order to fully validate the notion of “rabbit ears” occurring on the samples not employing the liftoff resist the profilometer was used to obtain detailed topography data on all four samples.

From the two bars shown in each profilometer trace it is observed that samples A and B have spikes or “rabbit ears” on the edges of the metal features while samples C and D do not. Again, these spikes are detrimental to multilayer processing since they could puncture subsequent layers and destroy the device’s performance. For this reason some type of liftoff resist is very commonly employed when producing state of the art multilayer electronic devices.



At the conclusion of this lab the reader should have a strong appreciation for (1) the liftoff process, (2) the importance of the liftoff resist, and (3) how multiple characterization tools (FESEM, Optical Microscope, Profilometer, CTM) can be used in conjunction to monitor the successes and shortcomings of a sample throughout its processing lifetime. The initial production and fabrication of many cutting edge devices are produced in a similar fashion to the samples which were processed in this lab, namely, the use of multiple characterization tools throughout processing.

Prior to beginning the quiz questions it is recommended the reader feels completely comfortable with all of the lab content. A full understanding of this lab will help the student in various other labs throughout the course sequence.

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

1) What are the two experimental variables in this lab? (2)

2) What color tape was the HMDS bottle wrapped in? (2)

3) What type of photoresists were used in this lab? (2)

4) What time and temperature were used for the liftoff resist bake? (2)

5) What time and temperature were used for the Shipley 1813 resist bake? (2)

6) How long were the samples exposed for and what was the peak wavelength of the exposure tool? (2)

7) How were the samples loaded for the exposure? (2)

8) What was the name of the UV exposure tool used in this lab? (2)

9) How long were the samples developed? (2)

10) Using only the data for the hard baked samples (B & D), determine on average how thick the LOR layer was: (4)

11) What influence did the hardbake have on feature dimensions? (3)

12) The widths of all the features were measured at the bottom of the trench since this is where metal deposition would occur. Based on the photomask, these widths should be 50 um. However, the data shows they were consistently less than this. What is the most likely cause for this? (2)

13) From the data, comment on the influence of the hardbake: (3)

14) According to the video, how thick was the metal film deposited onto the samples? (2)

15) What type of shadow mask was used in this lab? (3)

16) What type of tape was used to load the samples into the evaporator? (2)

17) How does the liftoff resist help facilitate the liftoff process? (3)

18) What magnifications were used to view the cross section profiles of samples A & C in the FESEM immediately following metal deposition? (3)

19) What key detail(s) do the FESEM images reveal about the effect of the liftoff resist? (3)

20) What is the name of the chemical the samples were immersed in for the liftoff process? (2)

21) What time and temperature were used for the liftoff immersion? (3)

22) Comment on the metal flaking off from the samples during the liftoff process? (4)

23) What PPE was worn during the liftoff process? (2)

24) What is a problem with the liftoff process? (3)

25) Which samples are expected to have rabbit ears? (3)

26) How can rabbit ears be eliminated? (2)

27) What additional treatment(s) did all samples receive prior to the final profilometer characterization? (3)

28) Select the true statement pertaining to the relationship between the photomask and the substrate: (4)

29) From the microscope images, comment on the success of the liftoff: (3)

30) From the dark field microscope images, comment on the feature dimensions: (3)

31) Average step heights were used to obtain the heights of the metal features after liftoff. Why were the metal features on the samples using liftoff resist about 3.5 nm thinner on average than those not using the liftoff resist? (4)

32) Comment on the accuracy of the CTM in the evaporator: (3)

33) Use the profilometer data to determine how the widths of the metal features following the liftoff process corresponded to the widths of the features on the quartz photomask used to perform the lithography process: (4)

34) How much of the metal film initially lifted off from the non-hard baked sample using only S1813 photoresist? (3)

35) Which processing tool was not used during the liftoff process? (2)

36) Which characterization tool was not used during the liftoff process? (2)

37) From the profilometer scan snapshots, which sample appeared to be the most uniform and free from defects such as rabbit ears: (4)