Reactive Ion Etch Lab (75 points)

Objective: The objective of this online lab is to demonstrate the dry etch process and determine the resultant etch rates of multiple materials by analyzing data obtained throughout the experiment.

The student will watch a series of videos pertaining to the dry etch process and the characterization steps used to obtain the data presented in the lab handout. After watching the videos and manipulating the provided data students will be required to calculate etch rates and answer review questions on ANGEL.

Background: The dry etch process can be used to produce an isotropic or anisotropic etch profile, depending on the processing pressure. The videos presented during this lab will discuss the difference between these two types of etch profiles and how they relate to the processing pressure. Only dry etching is capable of transferring high resolution micron, submicron, and nanometer features from lithographic resist layers. This is due to the inherent directionality of reactive ion etching, which utilizes ion bombardment. These ions possess energies ranging from tens to hundreds of eV. These charged ions physically bombard the material's surface and contribute to the anisotropic part of the etch.

The parallel plate reactive ion etch (RIE) tool is popular in the fabrication of submicron etched features. The March Jupiter III RIE, shown in Figure 1, is a good example of this design. The pressure on the system is varied from the mTorr range up to a few Torr to generate a plasma with properties needed to produce a certain etch profile.

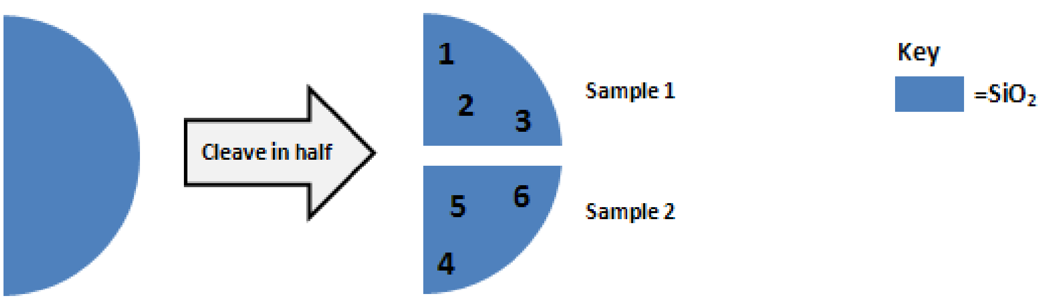
Figure 1: Image of the March Jupiter III RIE system

Experiment: Four samples will be processed and characterized. Two samples contain a photoresist pattern on a silicon dioxide substrate. These samples will be etched at 50 mT and 300 mT and characterized with the profilometer. The other two samples contain only a thin film of silicon dioxide. These samples will also be etched at 50 mT and 300 mT. These two unpatterned samples will be characterized with the ellipsometer. The data obtained during the characterization steps throughout the lab will be used to calculate the etch rates of silicon dioxide and photoresist.

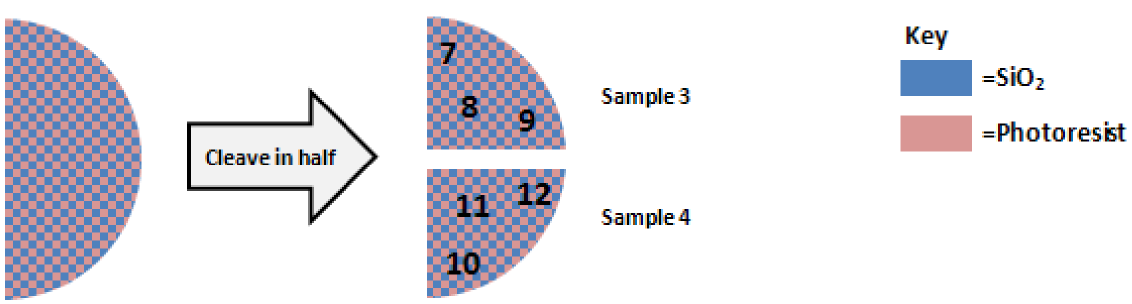
Step 1: Sample Preparation

A silicon dioxide wafer half was previously patterned with photoresist using the photolithography process. Please reference the photolithography lab for a refresher on how this wafer half was patterned. This patterned wafer half was then cleaved into two pieces, affording two quarters. An unpatterned silicon dioxide wafer half was also cleaved into 2 pieces, affording a total of 4 sample quarters. Three regions on each of these 4 quarters will be characterized throughout the process, affording a total of 12 areas to be characterized throughout the process. The unpatterned wafer will be characterized with the ellipsometer and the patterned wafer will be characterized with the profilometer. A depiction of the sample preparation and the locations of where each of the 12 measurements will be taken is shown below:

Unpatterned SiO_2 wafer half to be characterized in the 3 locations shown with ellipsometer



Previously patterned SiO_2 wafer half to be characterized in the 3 locations shown with profilometer

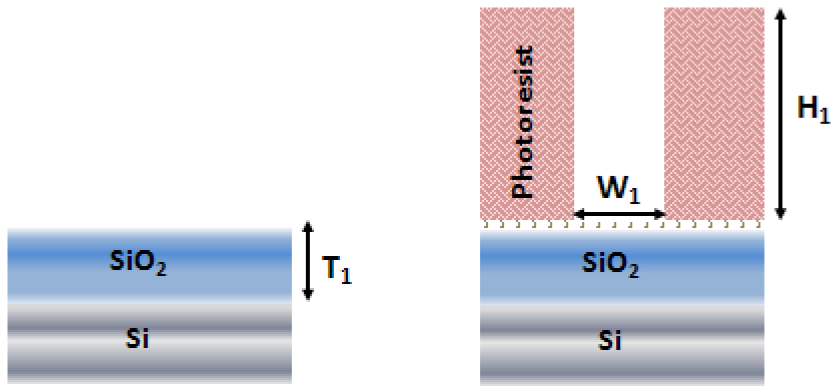


Watch the sample preparation and cleaving of the wafer at the link below:

http://www.engr.psu.edu/mediaportal/flvplayer.aspx?FileID=09225d16-5b94-43be-b8dc-6

Step 2: Pre-etch characterization steps:

Prior to etching, an initial set of characterization steps will be performed on each of the 4 sample quarters. The figure below shows a highly magnified profile view of the unpatterned sample (left) and patterned sample (right). The dimensions that will be obtained during the characterization steps are shown in the figure.



Unpatterned ellipsometer sample (Samples 1 & 2)

Patterned profilometer sample (Samples 3 & 4)

The pre etch thickness, T_1, of the unpatterned samples will be characterized first. Watch the initial ellipsometer characterization step on the unpatterned samples at the link below:

http://www.engr.psu.edu/mediaportal/flvplayer.aspx?FileID=bfc2b0dc-777b-430b-8972-6

The following results for T_1 were obtained after characterizing positions 1 through 6 on the two unpatterned samples:

Pre etch characterization data for unpatterned samples (T_1)						
Sample 1 (Å)				Sample 2 (Å)		
1	2	3		4	5	6
1618	1650	1667		1679	1688	1674

The pre etch photoresist height, H_1, and width between photoresist features, W_1, of the patterned samples will be characterized next. Watch the initial profilometer characterization step on the two patterned samples at the link below:

http://www.engr.psu.edu/mediaportal/flvplayer.aspx?FileID=61c2b727-62aa-40a7-905a-1

The following results were obtained after characterizing positions 7 through 12 on the patterned samples:

Pre etch characterization data for patterned samples							
Dimension	Sample 3 (μm)				Sample 4 (μm)		
	7	8	9		10	11	12
H_1	1.589	1.571	1.617		1.616	1.566	1.641
W_1	52	50	52		53	50	50

Step 3: Etch

Next, all 4 samples will be etched one at a time in the March Jupiter III RIE tool. Samples 1 and 3 will be etched at a processing pressure of 50 mT. Samples 2 and 4 will be etched at a processing pressure of 300 mT. All samples will be etched at a power of 100W and the gases used during all etches will be CF_4 and O_2 in a 9:1 ratio. All samples will be etched for 60 seconds.

The first part of the etch process involves turning on the March Jupiter III RIE and loading the sample onto the RF biased cathode. Next, the lid is closed and the tool is pumped down to a base pressure of about 20 mT. This step is shown in the link below:

http://www.engr.psu.edu/mediaportal/flvplayer.aspx?FileID=aed41958-44bf-4386-8836-1

After reaching the desired base pressure in the RIE chamber the next step is to introduce the etchant gases. This step requires some skill since gases must be precisely introduced into the evacuated chamber in a 9:1 ratio. The following steps can help a user determine how much gas should be added into the chamber:

Step 1) Determine the total number of parts in the gas chemistry, for a 9:1 of CF_4 and O_2 gas chemistry there are 9 parts CF_4 and 1 part O_2, thus, there are a total of 10 parts.

Step 2) Determine how many mT there are per part based on the desired processing pressure. For instance, for a desired processing pressure of 50 mT there are 50 mT/10 parts=5 mT/1 part.

Step 3) Obtain the partial pressures of each gas based on the number of parts of each gas, for 9 parts CF_4 we have: 9 parts CF_4*5 mT/1 part=45 mT in CF_4. Similarly, for 1 part of O_2 we have: 1 part O_2*5 mT/1 part=5 mT in O_2. Note that the total pressure (45 mT + 5 mT) is 50 mT, our desired processing pressure for samples 1 & 3.

Following the steps above it is straightforwardly shown that the 300 mT condition to be used on samples 2 & 4 will use 30 mT of O_2 and 270 mT of CF_4. Watch the introduction of these gases into the evacuated RIE chamber at the link below:

http://www.engr.psu.edu/mediaportal/flvplayer.aspx?FileID=b4cec3f3-3dc4-46f4-a02c-b

After introducing the proper ratio of etchant gases into the evacuated RIE chamber the next step is to turn on the RF energy source. This source will rip apart the gas molecules in the chamber and create a plasma. This plasma contains electrons, ions, free radicals, and neutral molecules. The samples will each be etched by this plasma for 1 minute. Following the plasma etch the chamber will be left under vacuum for 3 minutes to pump out harmful free radicals. Watch these steps at the link below:

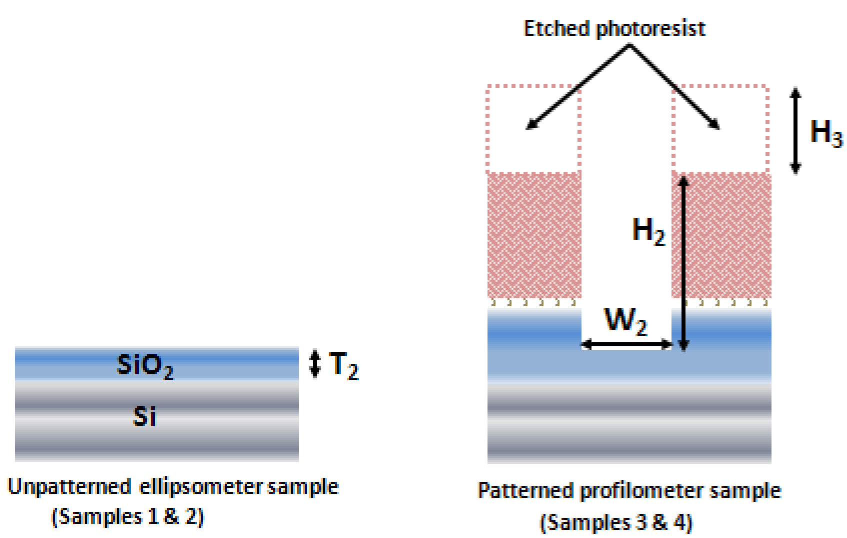
http://www.engr.psu.edu/mediaportal/flvplayer.aspx?FileID=28ff757e-1cd5-495b-9ba1-a

After etching the samples and pumping out any harmful free radicals the next step is to vent the chamber and remove the etched sample, watch this step at the link below:

http://www.engr.psu.edu/mediaportal/flvplayer.aspx?FileID=8d515d6e-6750-4b2c-9a5c-3

Step 4: Post-etch characterization steps:

Following these four etches the samples will be recharacterized with the same tools used prior to the etch (i.e. ellipsometer for samples 1 & 2 and profilometer for samples 3 & 4). The same locations (1-12) will be measured and the same feature dimensions will be measured. The figure below denotes how the cross section of the samples appears after the etching. Notice the thinner SiO_2 layer on the unpatterned sample as a result of the RIE etching away the SiO_2. Also notice that both photoresist and SiO_2 were etched away by the plasma on the patterned sample. This is a result of the physical part of the plasma.



The post etch thickness (T_2) of the unpatterned samples was characterized with the ellipsometer as shown below:

http://www.engr.psu.edu/mediaportal/flvplayer.aspx?FileID=bfc2b0dc-777b-430b-8972-6

The following results were obtained after characterizing positions 1 through 6 following the etches of the two unpatterned samples:

Post etch characterization data for unpatterned samples (T_2)						
Sample 1 (Å)				Sample 2 (Å)		
1	2	3		4	5	6
1233	1269	1263		1082	1111	1128

The etch rate is the amount of material removed per unit time. Combining the pre and post etch data for samples 1 and 2 allow the etch rate of the SiO_2 in all 6 positions above to be calculated. For instance, the etch rate of position 1 would be:

(Pre etch thickness-Post etch thickness)/Etch time=(1618 Å-1233 Å)/60 sec=6.4 Å/sec

Note that positions 1, 2, and 3 were etched at 50 mT and positions 4, 5, and 6 were etched at 300 mT. The student will need to calculate the average etch rate for each sample.

The post etch photoresist thickness, H_2, and width of the feature etched into the silicon dioxide, W_2 ,of the patterned samples will be characterized next. The same profilometer characterization step used prior to the etch is performed again as shown in the link below:

http://www.engr.psu.edu/mediaportal/flvplayer.aspx?FileID=61c2b727-62aa-40a7-905a-1

The following results were obtained after recharacterizing positions 7 through 12 on the two patterned samples:

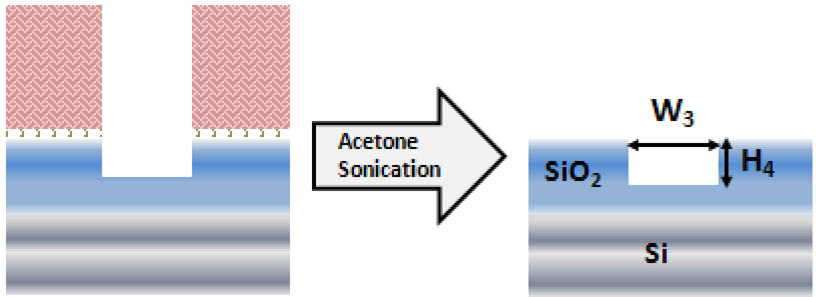
Post etch characterization data for patterned samples							
Dimension	Sample 3 (μm)				Sample 4 (μm)		
	7	8	9		10	11	12
H_2	1.412	1.397	1.443		1.505	1.464	1.535
W_2	52	51	52		52	49	49

Calculating the etch rates for the photoresist and silicon dioxide on the patterned samples is slightly more complex than the etch rate calculations discussed above for the unpatterned sample. In order to obtain all of the necessary data required for calculating these etch rates a final photoresist removal step is required in order to determine the amount of SiO_2 that was etched.

The photoresist removal step involves sonicating each of the etched samples in acetone for 60 seconds. Watch the video at the link below which demonstrates this process:

http://www.engr.psu.edu/mediaportal/flvplayer.aspx?FileID=a6d5cfc3-8405-4c1c-8903-e

A depiction of the resultant profile change of the samples as a result of this step is shown in the following figure. The figure also illustrates the locations of the final width and height measurements of the feature etched into the silicon dioxide.

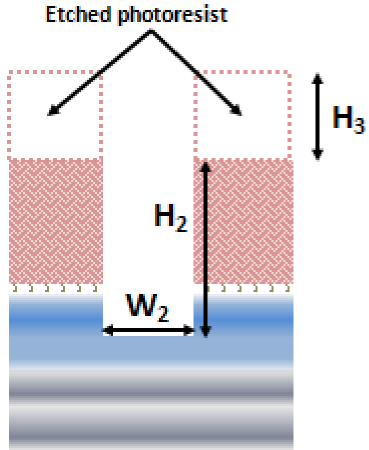


The results of this final characterization step, which were again obtained with the profilometer, are displayed in the table that follows:

Post etch & post photoresist removal data for patterned samples						
Dimension	Sample 3 (μm)			Sample 4 (μm)		
	7	8	9	10	11	12
H_4	0.0385	0.036	0.036	0.052	0.063	0.0505
W_3	51	50	50	54	56	57

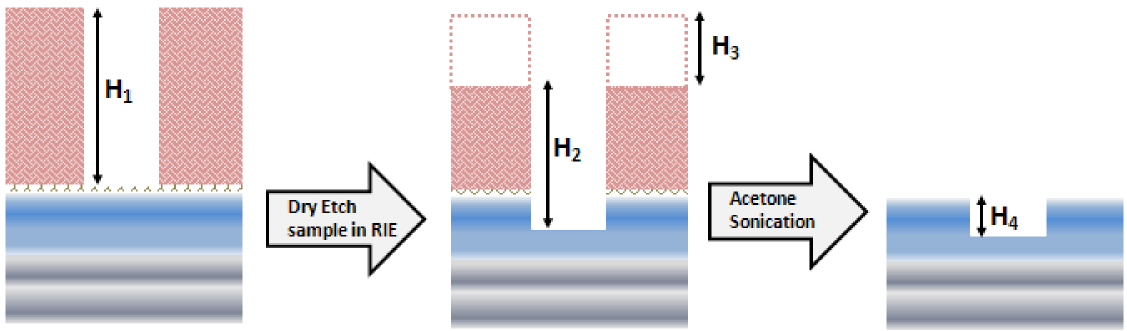
Finally, by combining the data from the 3 tables for the patterned samples, the etch rate of the photoresist and the SiO_2 can be calculated. Similar to the unpatterned sample, the etch rate of the SiO_2 is relatively simple; this calculation can be conducted using a single height dimension measured on the patterned sample and the etch time. This dimension corresponds to the thickness of the SiO_2 etched. Dividing this thickness by unit time will give an etch rate for the SiO_2 on the patterned sample.

Calculating the etch rate of the photoresist is a bit trickier. Recall the figure below which illustrates the amount of photoresist that was etched:



Patterned profilometer sample
(Samples 3 & 4)

Ideally, the etch rate would be simply calculated by dividing the amount of photoresist etched, H_3, by the etch time. However, there was no tool used in this experiment that can obtain H_3. Thus, H_3 must be deduced in terms of H_1, H_2, and H_4. A simple algebraic relationship exists between H_1, H_2, and H_4 which can be used to obtain the amount of photoresist removed, that is, H_3. Taking a look at the overall process for the patterned samples may help one deduce this relationship. This process flow is shown in the following figure. HINT: Begin by looking at the relationship between H_2 and H_4.



The student will need to calculate the average etch rate for each sample. Obtaining the correct etch rates for both materials will be critical for answering many of the questions on the assessment that follows.

Questions (3 pts each) to be answered on ANGEL (NO HARD COPY REQUIRED)

General RIE questions:

1) A gas ratio of 9:1 CF_4:O_2 is desired with a processing pressure of 250 mT. By how many mT should the pressure be increased when introducing CF_4 into the RIE?

2) A gas ratio of 13:3 CF_4:O_2 is desired with a processing pressure of 70 mT. By how many mT should the pressure be increased when introducing O_2 into the RIE?

3) Select the correct statement relating processing pressure to sidewall profile

4) Select the correct statement pertaining to the nature of the photoresist etch rate

5) Roughly, what percentage of the gas molecules in the plasma are ionized?

6) What type of power source is used in the March Jupiter III RIE?

7) Why was the sample left under vacuum in the RIE chamber for an additional 3 minutes prior to venting the system?

8) Why were the patterned samples sonicated for 60 seconds?

9) How were the locations of the features to be characterized on the patterned sample kept track of?

10) What was the base pressure in the system for the first etch?

Sample 1 & 2 (unpatterned/ellipsometer) questions:

11) What is the average etch rate of the SiO_2 on the unpatterned sample etched at 50 mT (sample 1)?

12) What is the average etch rate of the SiO_2 on the unpatterned sample etched at 300 mT (sample 2)?

13) Which unpatterned sample had a higher etch rate, the one etched at 50 mT or the one etched at 300 mT? Why?

14) What was the etch rate of the SiO_2 in position 4 (found on Sample 2) on the unpatterned SiO_2 wafer?

15) Based on the average 50 mT etch rate for sample 1, how long would it take to etch the entire SiO_2 layer (use the average pre-etch SiO_2 thickness for sample 1 for your calculation)?

16) Based on the average 300 mT etch rate for sample 2, how long would it take to etch the entire SiO_2 layer (use the average pre-etch SiO_2 thickness for sample 2 for your calculation)?

Sample 3 & 4 (patterned/profilometer) questions:

17) What was the average etch rate of the SiO_2 on the patterned sample etched at 50 mT (sample 3)?

18) What was the average etch rate of the SiO_2 on the patterned sample etched at 300 mT (sample 4)?

19) What was the average etch rate of the photoresist on the patterned sample etched at 50 mT (sample 3)?

20) What was the average etch rate of the photoresist on the patterned sample etched at 300 mT (sample 4)?

21) Based on the average 50 mT photoresist etch rate for sample 3, how long would it take to etch the entire photoresist layer (use the average pre-etch photoresist thickness for sample 3 for your calculation)

22) Based on the average 300 mT photoresist etch rate for sample 4, how long would it take to etch the entire photoresist layer (use the average pre-etch photoresist thickness for sample 4 for your calculation)

23) What is the reason for the post etch and post photoresist removal width difference between samples 3 and 4?

24) How do the dry etch rates of the photoresist in positions 8 and 9 on sample 3 compare?

25) A sample with a 3000 Å thick layer of SiO_2 is to be etched at 50 mT. Using the average etch rates obtained in this lab for this pressure, will a 2.7 μm thick photoresist layer (Shipley 1827) be thick enough to serve as an etch mask for completely etching this oxide?