Photoresist Thickness Activity

Instructor Guide

Notes to Instructor

This activity provides the participants an opportunity to further explore the coat process and the relationships between photoresist thickness, spin speed, and viscosity. Participants should read the PK before doing this activity in order to get a general understanding of the coat process.

This activity is part of the *Photolithography Overview for Microsystems Learning Module*:

- Knowledge Probe (pre-test)
- Photolithography Overview for Microsystems PK
- **Photolithography Terminology - Activity**
- Photoresist Thickness Activity
- Final Assessment Participant – multiple choice

This companion Instructor Guide (IG) contains all of the information in the PG as well as answers to the questions and additional instructor notes.

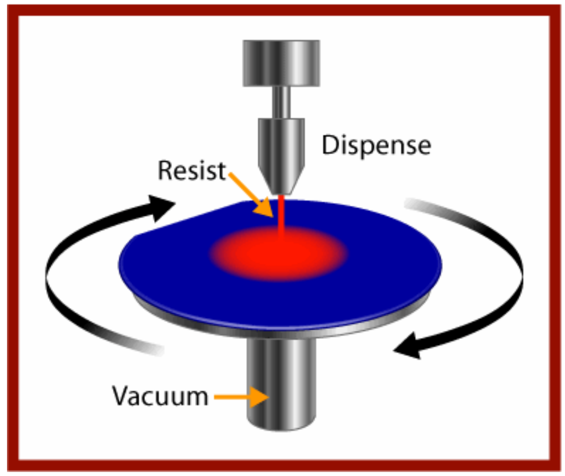
Description and Estimated Time to Complete

In this activity you will further explore the coat process and the factors that determine the photoresist thickness. You interpret and create graphs using actual process data. If you have not read the Photolithography Overview PK, stop and read BEFORE starting this activity. The PK provides the information needed to best understand the concepts explored in this activity.

Estimated Time to Complete
Allow at least one hour to complete this activity.

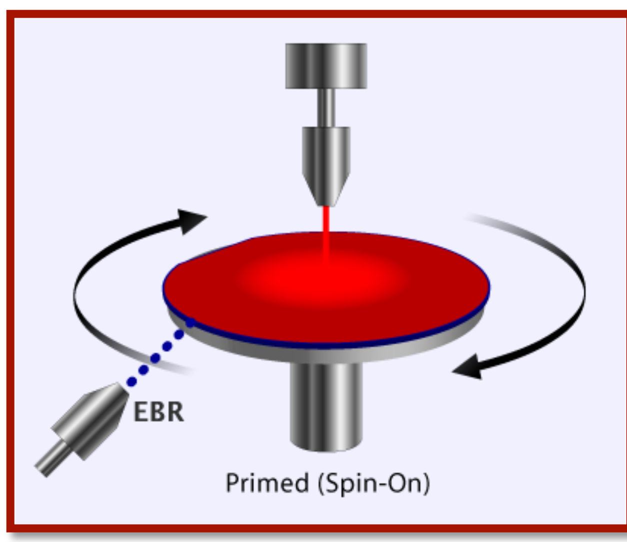
Introduction

The "coat" process is the application of photoresist (also referred to as "resist") to the wafer's surface. There are several methods used to coat the wafer (spin, spray and electrodeposition (ED)). The goal of the coat process is to distribute a uniform thickness of resist across the wafer's surface with a desired thickness. The resist thickness specification is dependent upon the device or component being fabricated. For example, resist layers for some packaging requirements "are very thick compared to the photoresists used in IC (integrated circuit) manufacturing.[1] In microtechnology resist thicknesses vary depending on the type of micromachining process (bulk or etch), the component, and even the aspect ratio of the components.

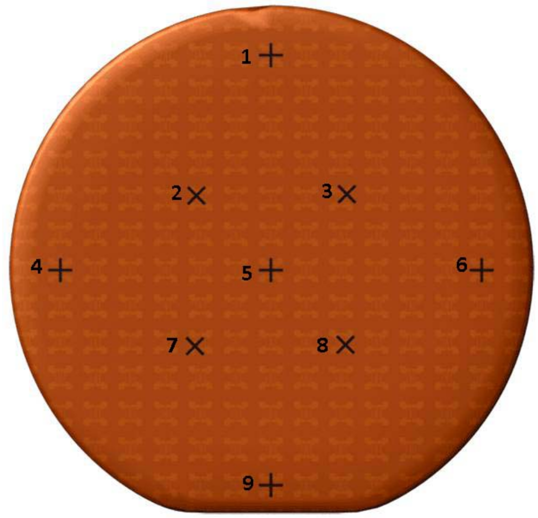


Spin coating is the most common method for coating a wafer; therefore, the data and references in this activity relate to a spin coat process. Here are the steps of that process:

- The wafer is placed on a vacuum chuck.
- A vacuum chuck holds the wafer.
- Photoresist is applied either before the chuck begins to spin (static dispense), or when the chuck starts to spin slowly (dynamic dispense).
- The chuck quickly accelerates to a pre-programmed rpm to spread the resist across the entire wafer.
- At maximum spin speed (SS) the excess resist is thrown off the wafer and a uniform resist thickness results.
- The chuck continues to spin until most of the solvents in the resist have evaporated.
- While the chuck is spinning, acetone is sprayed on the bottom edge of the wafer to eliminate resist "beading" on the wafer's edge (EBR ="edge bead removal").



The final photoresist thickness is a factor of its viscosity and the final spin speed of the chuck (the "casting speed"). After this coating process, photoresist thickness is measured to ensure that it is within specifications for mean and uniformity. In an automated test, dozens of film thickness points are measured on a single wafer. For the purpose of this activity, we acquired the data manually using an ellipsometer. Nine measurements were taken in a radial pattern across the wafer: one measurement at the center, four on a circle approximately half the radius of the wafer and four more measurements close to the edge of the wafer. The image shows a resist coated wafer and the placement of the nine test points (TP). Using these nine TPs, the thicknesses can be averaged to identify the mean film thickness of the wafer, and the standard deviation (STD) or range, can be determined. Data is usually presented and tracked as the mean ± 3STD written as $\bar{x} \pm 3\sigma$



In this activity you will be given a data set of measured film thicknesses. You will use this information to determine the relationships between film thickness and spin speed as well as film thickness and resist viscosity.

Why is Photoresist Thickness Important?

Resist thickness is very important when creating small geometries. One way to think about this is that a thin coating of film is either going to be anti-reflective or reflective. When the thickness is correct, the film is anti-reflective and most of the ultraviolet (UV) light energy during the exposure is absorbed by the photoresist. If the thickness is not correct, more of the light will be reflected, and less absorbed. Poor thickness uniformity across the wafer means that there are different thicknesses of resist; therefore, some parts of the wafer will absorb more of the light energy than other parts. The areas that absorb more light will result in thinner lines and larger spaces (holes) when using positive photoresist. Recall that positive photoresist reproduces the pattern on the photomask. In other words, the photoresist areas were light is absorbed are removed during the develop process ("What shows, goes").

How does the absorption or reflection of light energy affect the outcome?

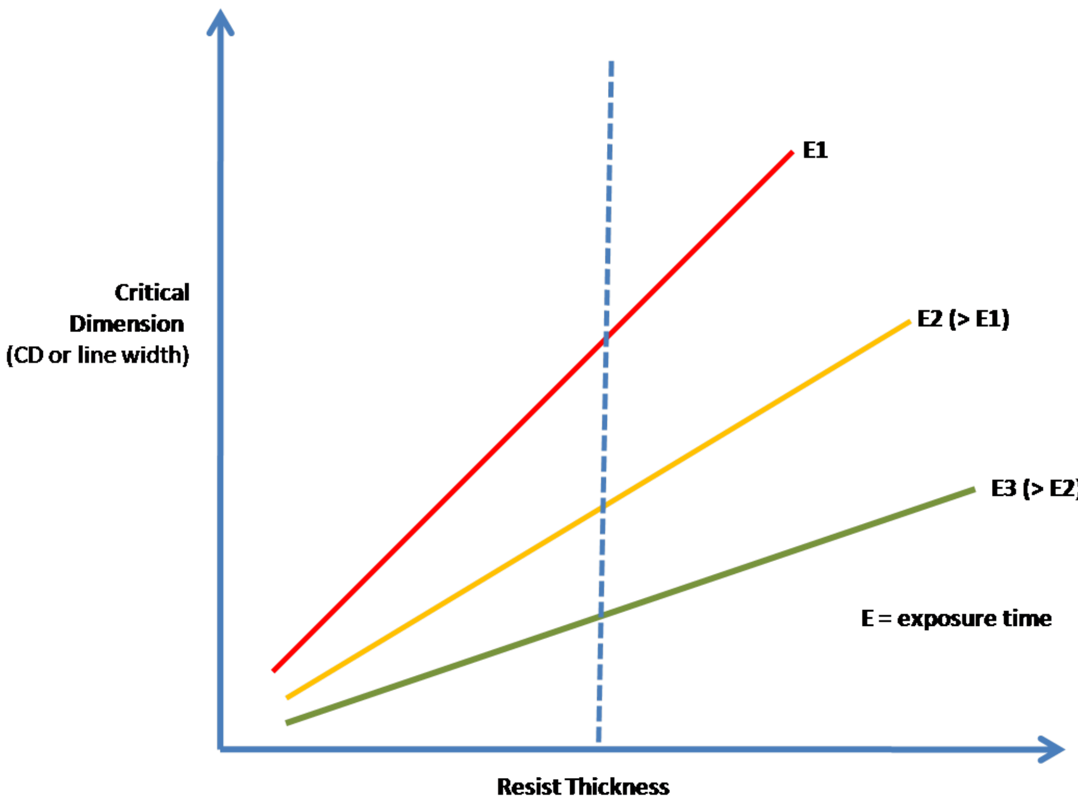
This is an important question! With positive resist,

- the areas that *absorb* more light yield thinner geometries, while
- the areas that *reflect* more light, hence, less exposure, yield wider geometries.

Since a wafer consists of hundreds of die consisting of the same components with the same specifications, it is important that the geometries throughout the wafer are consistent from location to location across the wafer. Therefore, resist thickness variation within a wafer must be negligible to prevent too much variation in critical dimensions or line widths. It is also important to maintain wafer-to-wafer resist thickness control to ensure that all wafers processed for the same devices yield the same results. The allowed *wafer-to-wafer* and *within wafer variation* specifications of resist thickness is determined by the range in the critical dimension for which the device will function correctly. The line width variation is determined by many input variables, one of which is the resist thickness.

So What is Thick Enough?

Both resist thickness and exposure dose are factors in the resulting critical dimensions (CD) or line widths. Exposure dose is the amount of light energy reaching the resist surface per unit area. Below is a graph that shows the relationships between critical dimension (CD), resist thickness and exposure dose (E). As you can see from the graph, as the resist thickness increases, so does the CD. As the resist gets thicker it takes more light to expose and develop the exposed regions; therefore, thicker resist requires a higher exposure dose to achieve the same results of a thinner resist with a lower dose. The dashed line in the middle of the graph indicates a specific resist thickness. Notice that the CD is greater for the smallest exposure dose (E1). As the exposure dose increases (E2 and E3), the CD decreases for the same resist thickness.



In addition to your desired CD, a resist thickness specification may also be determined by the subsequent etch process. A thicker resist may be needed to protect the unexposed underlying layers from being etched. The resist protection needs to last long enough for the open (exposed) areas to be etched away while the protected regions remain. The trick is to balance the resist thickness with the etch process so that some resist remains at the end of the etch process protecting the regions that are not supposed to be etched.

Now it's your turn. Complete the following activities to further enhance your understanding of resist thickness criteria.

Activity Objective

- Create and interpret a graph that shows the relationship between resist thickness and spin speed.
- Create and interpret a graph that shows the relationship between resist thickness and resist viscosity.

Resources

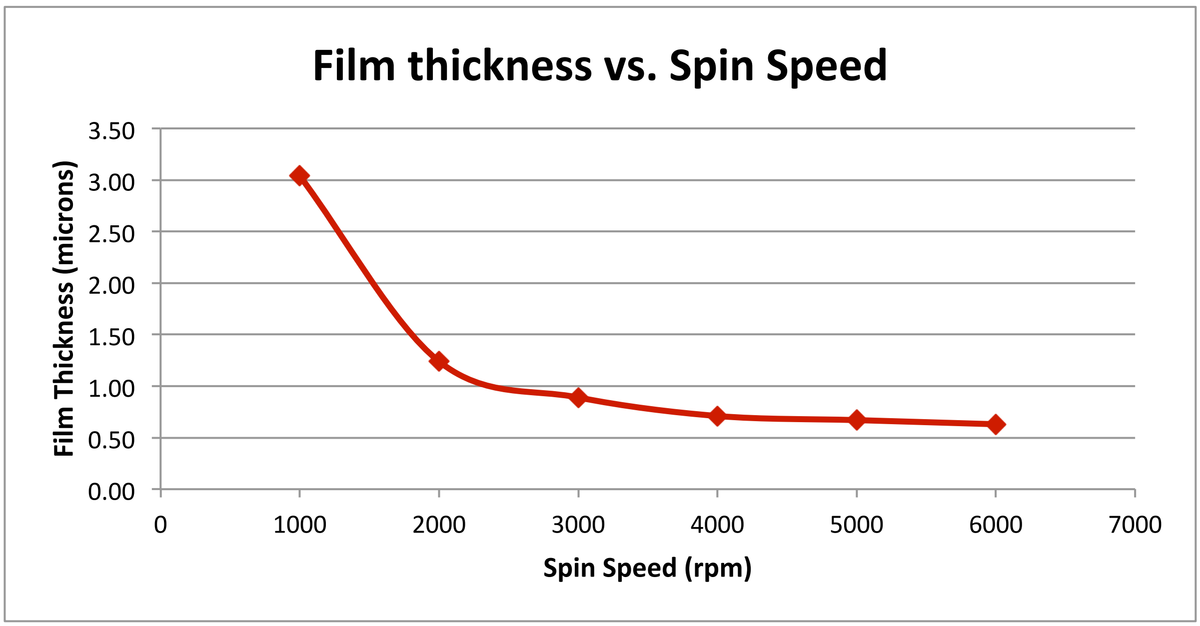
SCME's *Photolithography Overview for Microsystems PK*

Documentation

1. Create a data report with tables and explanations for both Part I and Part II of this activity.
2. Provide answers to questions in complete sentences.

Activity Part I: Film thickness vs. Spin speed (SS)

Below is a graph showing Film thickness (photoresist) vs. Spin Speed. Each film thickness data point is the mean of 49 measurements taken in an automated measurement process.



1. Using the graph, estimate the film thicknesses in microns and Angstroms (Å) for each of the following spin speeds.

   a. 1000 rpm = ____________________ microns = ________________ Å

   b. 3000 rpm = ____________________ microns = ________________ Å

   c. 6000 rpm = ____________________ microns = ________________ Å

2. Write a short description that explains the data illustrated on the above graph and describes the relationship between film thickness and spin speed for this process.

Activity Part I: Film thickness vs. Spin speed (SS) - Answers

1. *(The answers below are the actual values. Participants should be able to estimate the thickness close to these values.)*

   a. *1000 rpm = ____3.04____ microns = ___30,400____ Å*

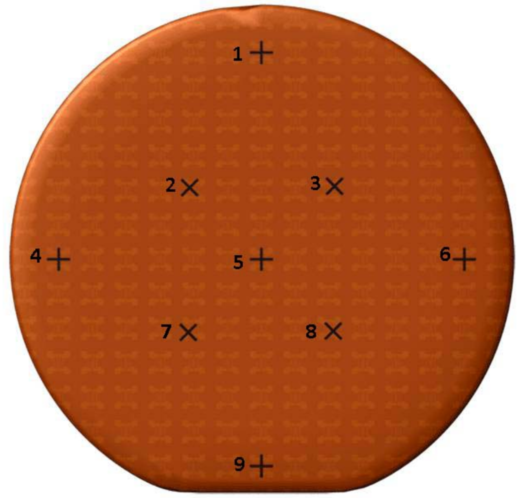
   b. *3000 rpm = ____0.89___ microns = ___8,900_____ Å*

   c. *6000 rpm = ____0.63___ microns = ___6,300_____ Å*

2. *The graph illustrates that photoresist thickness decreases exponentially with an increase in spin speed. The greatest drop in resist thickness is between 1000 and 2000 rpm. A further increase in spin speed past 6000 rpm would not greatly affect the photoresist thickness in this process.*

Plotting Film Thickness vs. Spin Speed (SS)

The following data was collected from six wafers spin coated with the same photoresist. Each wafer was coated using a different casting spin speed. The tables list the photoresist thickness at nine (9) test points (TP) on each wafer and the spin speed (SS) of each wafer. The photoresist thickness was measured in Angstroms (Å). (1 µm = 10,000 Å)



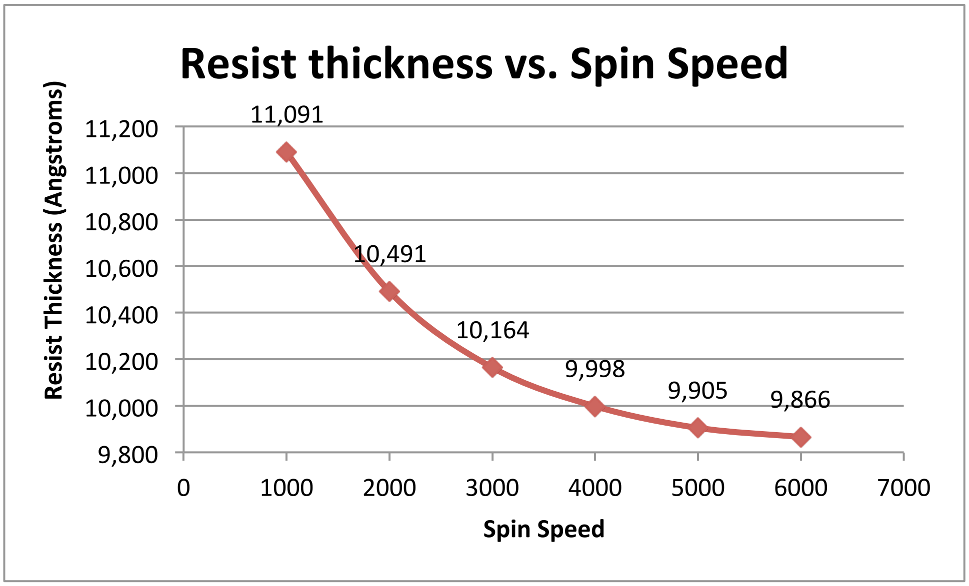
a. Plot a graph comparing the nine wafers **mean photoresist thickness vs. spin speed**. Be sure to label your graph and indicate the mean photoresist thickness for each spin speed.

b. Write a paragraph with your observations; describe what you see in the data. Hypothesize why the thickness changes with spin speed.

c. For this process, how much do you change the spin speed if you want to go from a thickness of 1.1um to 1.05um, making it thinner by .05um (500A)?

SS (rpm)	TP1	TP2	TP3	TP4	TP5	TP6	TP7	TP8	TP9
1000	11,100	11,083	11,090	11,085	11,093	11,100	11,080	11,087	11,098
2000	10,504	10,480	10,488	10,482	10,490	10,500	10,483	10,490	10,503
3000	10,172	10,150	10,161	10,155	10,162	10,171	10,164	10,170	10,173
4000	10,005	9,985	9,999	9,989	9,995	10,003	9,993	10,004	10,006
5000	9,913	9,895	9,910	9,888	9,906	9,912	9,890	9,915	9,916
6000	9,872	9,855	9,863	9,858	9,866	9,875	9,862	9,870	9,872

Answer:

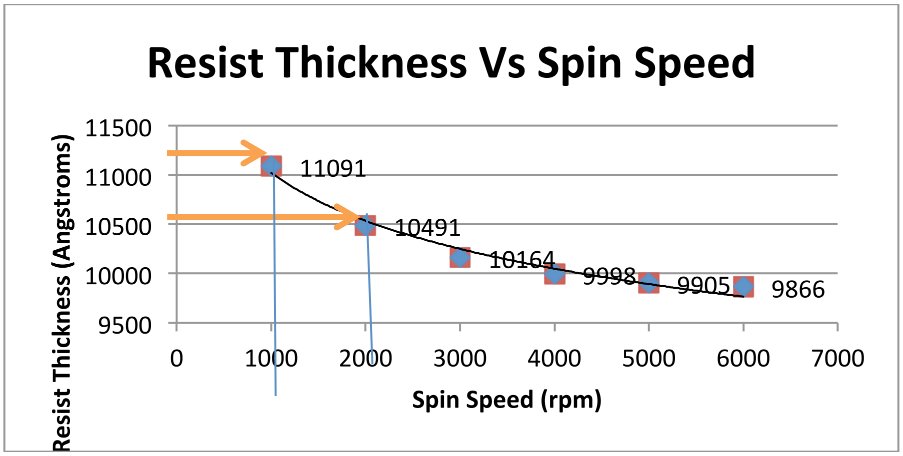


This graph shows that resist thickness decreases exponentially with an increase in spin speed.

Wafer		Wafer Resist Thickness in Angstroms			
	SS (rpm)	Mean	Range	STD	3*STD
1	1000	11091	20	7.5	22.5
2	2000	10491	24	9.2	27.5
3	3000	10164	23	8.1	24.2
4	4000	9998	21	7.6	22.7
5	5000	9905	28	11.0	33.1
6	6000	9866	20	6.9	20.6

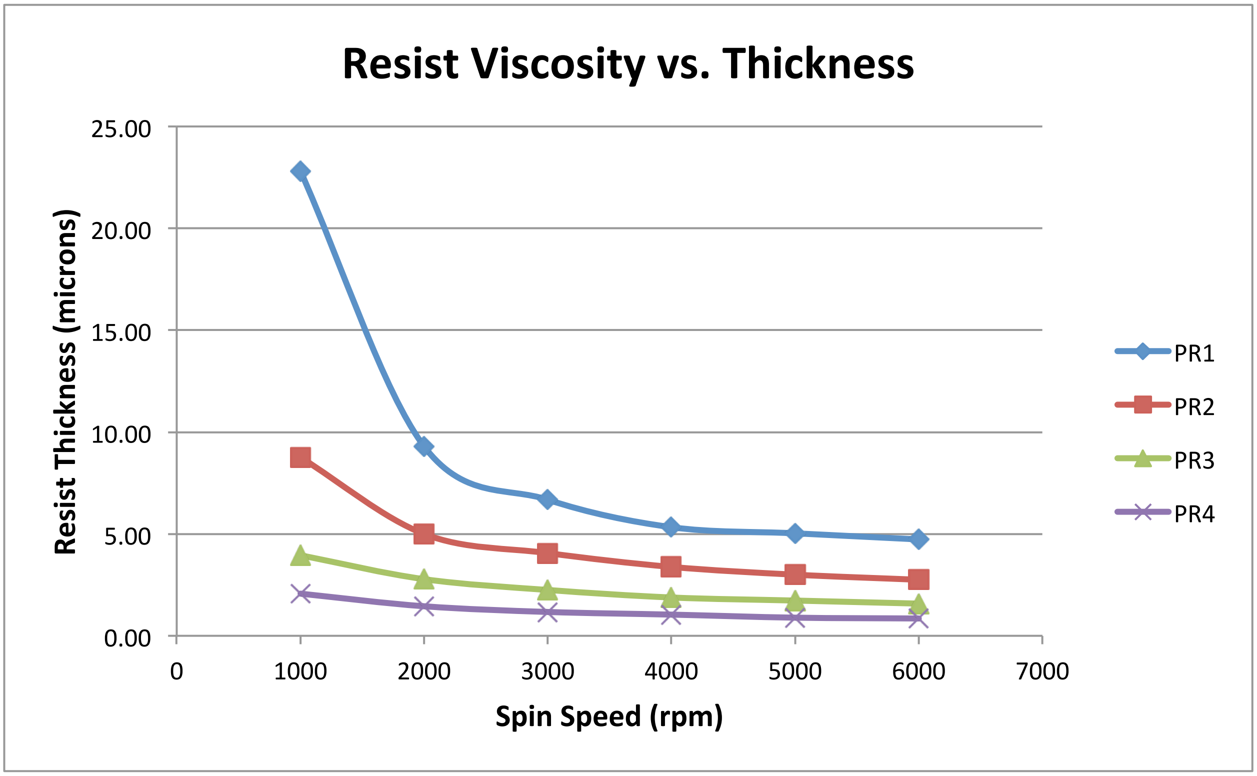
NOTE: for extra credit you could ask the participants to calculate the range, STD and 3 Sigma in addition to the mean.

d. *To change the resist thickness by 500Å, from 1.1 to 1.05um, increase the spin sped from 1000rpm to 2000rpm.*


Resist Thickness Vs Spin Speed
Resist Thickness (Angstroms)
11500
11000
10500
10000
9500
0
1000
2000
3000
4000
5000
6000
7000
Spin Speed (rpm)
11091
10491
10164
9998
9905
9866

Activity Part II: Film thickness vs. Resist Viscosity

The graph below illustrates the mean photoresist thickness vs. spin speed for four (4) different photoresists (PR1, PR2, PR3, and PR4). Each photoresist has a different viscosity.



1. Based on the graphs and your understanding of viscosity, which photoresist would you assume to have
   a. the highest viscosity? ____________
   b. the lowest viscosity? _____________

The photoresists represented in the graph have the following viscosities (cSt = centistokes):

- PR1 = 2500 cSt
- PR2 = 290 cSt
- PR3 = 45 cSt
- PR4 = 18 cSt

Note: 1 cSt is the kinematic ***viscosity*** *of water at about room temperature.*

2. Which photoresist has a kinematic viscosity closest to that of water?

3. Using the data presented in the graph and the actual viscosity values, analyze the relationship between photoresist viscosity, photoresist thickness and spin speed. Your explanation should reference the data presented. (i.e., reference specific photoresists and thicknesses)

4. Scenario: A specific process requires photoresist thicknesses that range from 2 to 4 microns. Which resist(s) illustrated in the graph best meets the requirements of this process?

5. How does the photoresist viscosity affect the resist thickness over a spin speed range of 1000 to 6000 rpms?

Answers:

1. Based on the graphs and your understanding of viscosity, which photoresist would you assume to have
   a. the highest viscosity? ____PR1_________
   b. the lowest viscosity? ______PR4___________

   The photoresists represented in the graph have the following viscosities:
   - PR1 = 2500 cSt
   - PR2 = 290 cSt
   - PR3 = 45 cSt
   - PR4 = 18 cSt

2. Which photoresist has a kinematic viscosity closest to that of water?

   PR4 has the lowest kinematic viscosity, and is closest to that of water.

Using the data presented in the graph, analyze the relationship between photoresist viscosity, photoresist thickness and spin speed. Your explanation should refer to the data presented. (i.e., reference specific photoresists and thicknesses)

Answers will vary. Below is an acceptable answer.
As seen in the previous procedures and this graph,
- *photoresist thickness decreases exponentially with an increase in spin speed;*
- *however, the viscosity of the photoresist can affect the exponential rate as well as the photoresist thickness.*
- *The higher the resist viscosity, the thicker the photoresist over the same range of rpms.*
- *The higher the resist viscosity, the greater the range of photoresist thickness over the same range of rpms*
  - *The highest viscosity resist (PR1) produces a thickness that ranges from approximately 23 microns to 5 microns (1000 rpm to 6000 rpms respectively).*
  - *The lowest viscosity resist (PR4) produces a thickness that ranges from approximately 3.0 microns to less than 1.0 microns (1000 rpm to 6000 rpms respectively).*

3. Scenario: A specific process requires photoresist thicknesses that range from 2 to 4 microns. Which of the resists illustrated in the graph would best meet the requirements of this process?

Answer: *PR3, at 1000rpm, the thickness is ~4um, and at 6000rpm, the thickness is ~2um.*

4. How does the photoresist viscosity affect the resist thickness over a spin speed range of 1000 to 6000 rpms?

Answer: *Higher viscosity photoresists yield thicker film thicknesses*

Post-Activity Questions

1. During the coat process, what factors determine the final resist thickness in a photolithography process?

2. In MEMS fabrication, what applications require the use of relative thick photoresists layers? Why?

3. What ingredient(s) alter the viscosity of photoresist?

Post-Activity Questions (Answers)

What factors determine the final resist thickness in a photolithography process?

Answer: *Spin Speed and photoresist viscosity. Soft bake which occurs immediately after the resist spin deposition step, will also affect the thickness. A longer bake, or higher temperature will affect the thickness and the sensitivity to light.*

2. In MEMS fabrication, what applications require the use of high viscosity photoresists? Why?

Answer: *MEMS devices requiring thicker resists to better protect the underlying materials during etch, as in the case of long and/or harsh etches. Also devices requiring high aspect ratios (narrow and tall structures) need higher viscosity photoresists. High aspect ratio MEMS applications require a thicker photoresist (>25 microns).Some MEMS devices use the photoresist as a sacrificial material in the process. Sacrificial layers provide space and interconnects between layers. The resist is later removed after the subsequent structures are created.*

3. What ingredient(s) alter the viscosity of photoresist?

Answer: *Solvents. Resists are made up of a mixture of many materials including solvents, photo active compounds polymers and solid materials. The solvent is the carrier of these materials and the least viscous. Adding solvent effectively makes the photoresist itself less viscous.*

References

1. "Thick photoresist patterning for WLP applications". Cullmann and Topper. EET India. January 2001.

Summary

Photolithography uses three basic process steps to transfer a pattern from a mask to a wafer: coat, develop, expose. Within each step are secondary steps that ensure the wafer is properly conditioned, the patterns are accurately aligned, and problems and defects are identified. The pattern is then transferred into the wafer's surface or an underlying layer during a subsequent process (such as etch). The resist pattern can also be used to define the pattern for a deposited thin film.

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