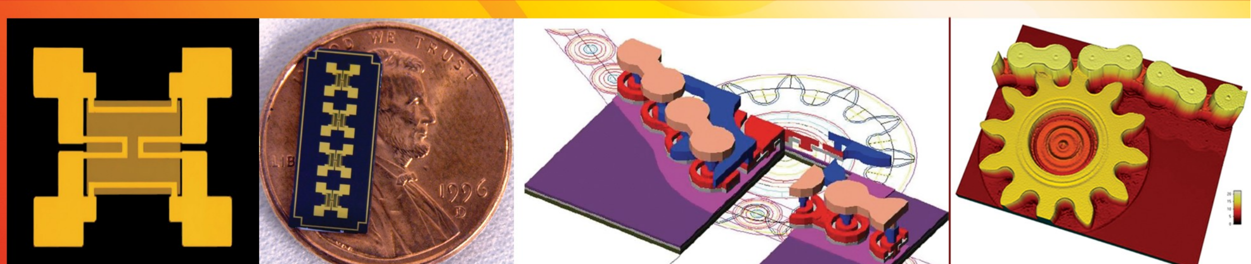
Photolithography Overview for MEMS

Learning Module Map
Knowledge Probe
Photolithography Overview PK
Activity—Terminology
Activity—Resist Thickness
Assessment - IG & PG

SCME
Southwest Center for Microsystems Education

Instructor Guide



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What is a SCO?

A SCO is a "shareable-content object" or, what we like to call, a "self-contained object". The term SCO comes from the Shareable Content Object Reference Model (SCORM), first conceived by the Department of Defense in 1999 as part of the Advanced Distributed Learning Initiative (Gonzales, 2005; Advanced Distributed Learning, 2008).

A SCO covers no more than 3 objectives that pertain to one specific topic (e.g., Material Safety Data Sheets or MEMS Applications). A SCO can be used by itself or with other SCOs with common or complementary objectives. We have grouped SCOs that support common objectives into a Learning Module.

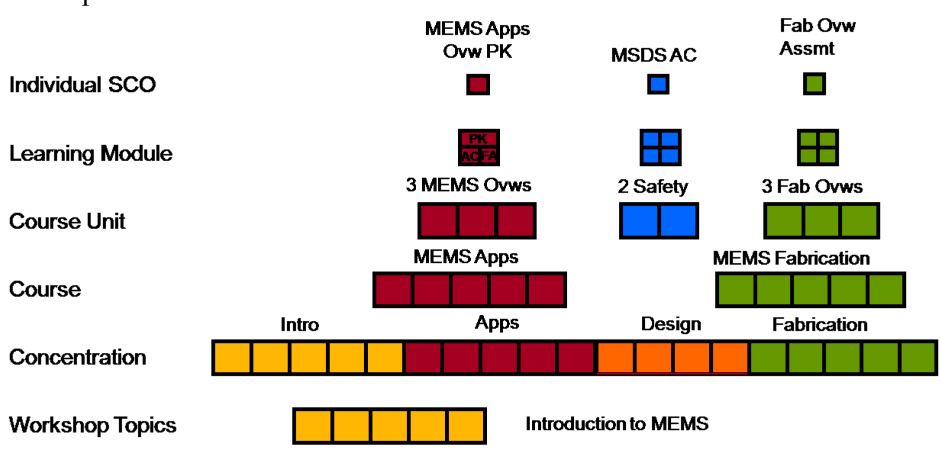
<u>Learning Module Organization</u>

Each Learning Module (LM) contains at least one of the following three types of SCOs:

- Primary Knowledge (PK) - Each LM contains at least one PK which contains the basic information supporting the objectives. Most PKs have a supporting PowerPoint presentation.
- Activity (AC) – Each LM can contain one or more activities that provide interactive or hands-on learning that supports the objectives.
- Assessment (KP, FA, AA) – Each LM contains one or more assessments that determines the student's existing knowledge (Knowledge Probe (KP) or pretest) or knowledge gained relative to a particular AC, the PK or both. (Activity Assessment (AA), Final Assessment (FA)).

Each SCO contains an Instructor Guide (IG) and Participant Guide (PG).

Each SCO is self-contained; therefore any one SCO in the Learning Module can be used without the other SCOs, depending upon the needs of the student and the instructor. The instructor or student can pick and choose individual SCOs for select topics, lessons, units, courses or workshops. The graphic below illustrates this concept:



SCME provides SCOs related to Microsystems (MEMS) Technology under many topics including Safety, Introduction to MEMS, Applications of MEMS, BioMEMS, and Fabrication of MEMS.

<u>Why SCOs?</u>

The study of microsystems incorporates many different STEM disciplines: physics, chemistry, biology, lab safety, and mathematics, just to name a few. The goal of SCME is to present MEMS-based lessons that utilize the concepts and principles of these disciplines.

The use of SCOs offers an object-oriented way of presenting materials. Since MEMS education encompasses many subjects, SCME feels that by compartmentalizing materials into small units, it provides flexibility for instructors to introduce MEMS as an application of an existing discipline, to illustrate a concept or principle, or to incorporate MEMS-based education into new or existing curricula.

Southwest Center for Microsystems Education (SCME)
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MEMS Fabrication Topic

Photolithography Overview Learning Module

This booklet contains five (5) Sharable Content Objects (SCOs):
Knowledge Probe
Primary Knowledge
Terminology Activity
Resist Thickness Activity
Assessment

The Learning Module Map is a suggested outline on how to use this learning module.

Target audiences: High School, Community College, University

Support for this work was provided by the National Science Foundation's Advanced Technological Education (ATE) Program through Grants #DUE 0902411.

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Learning Module Map for Photolithography Overview

Learning Module: Photolithography Overview

Learning Module SCOs (5):

- Knowledge Probe
- Photolithography Overview PK
- Terminology Activity
- Resist Thickness Activity
- Photolithography Assessment

Following is a suggested map on the implementation of this learning module.

NOTE: This learning module and its supporting materials are available on-line. If you are interested in the on-line materials, contact Matt Pleil (mpleil@unm.edu).

IMPORTANT STEPS	KEY POINTS	REASONS
Complete the Knowledge Probe (KP)	The KP assesses the participants' current knowledge of the Photolithography process.	By comparing the results of the KP to the results of the Final Assessment, one can determine the level of learning that took place as a result of this learning module.
Present the Photolithography Overview PK	There is a short narrated presentation that can be viewed by the participants on-line, OR you can present this learning module to the class using the non-narrated presentation. The narrated presentations can be downloaded by the participants from scme-nm.org. The instructor can downloaded the non-narrated presentation once registered with the SCME website. Participants should read the PK after viewing the presentation.	Viewing the presentation prior to reading the primary knowledge SCO provides an overview of the material to be discussed. An introduction into photolithography is needed to help participants better understand the two activities.

Complete the activity "Photolithography Terminology"	Participants should complete the crossword puzzle and answer the Post-Activity questions.	This activity helps the participants to better understand the terminology associated with photolithography processes and the steps of the processes.
Complete the activity "Resist Thickness".	Participants explore the relationship between resist thickness vs. spin speed and resist thickness vs. resist viscosity.	This activity requires the participants to be able to interpret graphs as well as construct graphs using a set of real data. The knowledge in this activity is needed to better understand problems associated with the coat process.
Complete the Photolithography Final Assessment (FA).	Have the participants complete the Photolithography Overview assessment.	Participants are evaluated on what they have learned about photolithography, its terminology and the various processes within photolithography.
Evaluate learning module's effectiveness.	If the participants took both the KP and the FA, analyze the comparative results. Please send SCME the results of your analysis and complete the SCO feedback survey on the website: scme-nm.org. Thank you!	Your analysis will determine the strengths and weaknesses of the learning module and provide SCME with feedback for module improvement and grant reporting purposes.

Adapted from Graupp, P. & Wrona, R. (2006) The TWI Workbook: Essential Skills for Supervisors. New York, NY. Productivity Press.

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MEMS Fabrication Topic

Photolithography Overview for Microsystems

Knowledge Probe (Pre-Quiz)
Shareable Content Object (SCO)

This SCO is part of the Learning Module
Photolithography Overview

Target audiences: High School, Community College, University

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Photolithography Overview for Microsystems Knowledge Probe

Instructor Guide

Notes to Instructor

This Knowledge Probe (KP) contains 16 questions to assess the participants' current knowledge of photolithography processes. This KP should be given as the start of the Photolithography Overview Learning Module.

The Photolithography Overview for Microsystems Learning Module consists of the following SCOs:

- **Knowledge Probe or Pre-assessment**
- Photolithography Overview for Microsystems
- Photolithography Terminology Activity
- Photoresist Thickness Activity
- Final Assessment Participant – multiple choice

The Participant Guide is included in the Participant Guide learning module that is available for download on the SCME website (scme-nm.org). This KP can also be accessed on-line as part of the SCME on-line Photolithography Overview mini-course.

This Instructor Guide (IG) contains both the questions and answers for the 18 questions. The Instructor Guide learning module can be downloaded by registered members from the SCME website.

An on-line version of this learning module is available. Contact SCME for access to this on-line course.

Objective of this Knowledge Probe (KP)

The objective of this knowledge probe is to determine your current knowledge and understanding of the photolithography processes used to fabricate micro-sized devices or MEMS. This KP should help you identify areas in which you need a better understanding and also assist the instructor in knowing what needs to be emphasized.

Answer the following questions to the best of your knowledge. Don't worry if you don't know the answer. Select the answer that you "think" is correct.

Photolithography Knowledge Probe

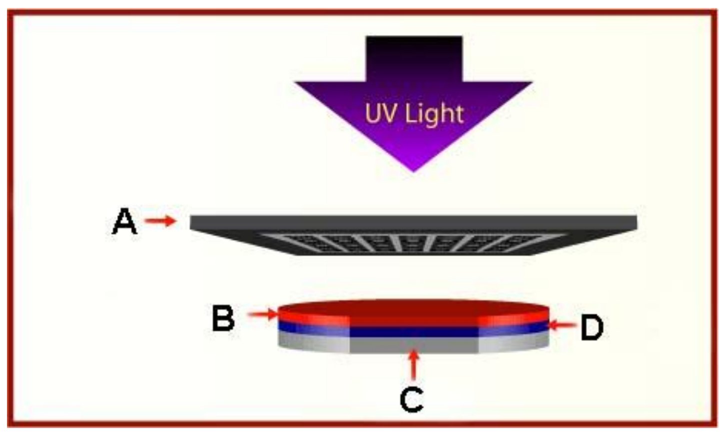
1. Which of the following **BEST** describes the photolithography process?
   a. The process step that transfers a pattern into an underlying layer or the substrate's bulk.
   b. The process step that defines and transfers a pattern into a resist layer on the wafer.
   c. The process step that deposits a resist layer on the surface of the wafer.
   d. The process step that aligns the various layers of a microsystem device to each other.

Answer: b.

2. What are the three (3) basic steps of the photolithography process?
   a. Prime, expose, etch
   b. Prime, coat, expose
   c. Coat, mask, expose
   d. Coat, expose, develop

Answer: d. Coat, expose, develop

3. What are the elements of the image labels (A, B, C, D), respectively?
   a. Mask, photoresist, film to be etched, substrate
   b. Mask, layer to be etched, photoresist, substrate
   c. Mask, substrate, photoresist, metal layer
   d. Mask, photoresist, primer, substrate



Answer: a.

4. The photoresist film is applied in which of the following photolithography steps.
   a. Prime
   b. Coat
   c. Mask
   d. Expose
   e. Develop

Answer: b.

5. Prior to applying the photoresist layer, the surface of the wafer must be conditioned. Which of the following BEST describes the purpose of surface conditioning?
   a. Remove surface particles, dry the wafer's surface, create a hydrophilic surface
   b. Dry the wafer, heat the wafer to better accept the resist, create a hydrophobic surface
   c. Clean and dry the wafer, create a hydrophobic and more adhesive surface
   d. Clean the surface, heat the wafer to better accept the resist and make it more adhesive

Answer: c.

6. What is the chemical used in surface conditioning?
   a. HMDS (Hexamethyldixalizane)
   b. KOH (potassium hydroxide)
   c. Piranha (sulfuric acid and hydrogen peroxide)
   d. PMMA (polymethylmethacrylate)

Answer: a. HMDS

7. There are two basic types of photoresist – positive and negative. Which of the following statements is TRUE?
   a. With positive resist, the exposed regions are dissolved during develop.
   b. With negative resist, the exposed regions are dissolved during develop.
   c. With positive resist, the exposed regions are hardened during develop.
   d. With negative resist, the exposed regions are hardened during develop.

Answer: a.

8. Which of the following determine the final thickness of photoresist after the coat process?
   a. The viscosity of the resist and the amount of time that the wafer spins
   b. The spin speed after deposition of resist and the amount of time that the wafer spins
   c. The amount of resist applied and the amount of time that the wafer spins
   d. The spin speed of the wafer after deposition of resist and the viscosity of the resist

Answer: d

9. During the coating of photoresist, the thickness of the photoresist ___________________ with an increase in spin speed.
   a. Increases exponentially
   b. Decrease exponentially
   c. Increase linearly
   d. Decreases linearly

Answer: b.

10. What is the purpose of the softbake after resist application?
    a. To remove residual solvent from the resist layer
    b. To correct minor uniformity problems with the resist
    c. To harden the resist for the expose process step
    d. To harden the resist for the etch process step

Answer: a

11. The expose step follows the ______________ process step.
    a. Surface conditioning
    b. Coat
    c. Soft bake
    d. Hard bake

Answer: c

12. For the expose step, some photolithography equipment, such as steppers, use a small quartz plate that contains the pattern for just a few die or fields on a wafer. This plate is called a ________________.
    a. Mask
    b. Reticle
    c. Partial mask
    d. Die plate

Answer: b

13. Which of the following two UV light sources are commonly used to expose the photoresist?
    a. Mercury Vapor Lamps and excimer lasers
    b. Mercury vapor lamps and compact fluorescent lamps
    c. CO_2 Lasers and mercury vapor lamps
    d. CO_2 Lasers and excimer lasers

Answer: a

14. After the coated wafer is placed into the photolithography expose equipment, it is ___________ prior to being exposed.
    a. Baked
    b. Cooled
    c. Aligned
    d. Coated

Answer: c

15. Which of the following could be the result of an underdeveloped resist layer?
    a. Misalignment of the resist pattern to the pattern in the underlying layer
    b. Critical dimensions in the resist layer larger than specification
    c. Overexposure of resist during the expose step
    d. Too much resist left on the wafer preventing access to the underlying layer

Answer: d. Too much resist left on the wafer preventing access to the underlying layer

16. After the develop step, the wafers are inspected. Which of the following is NOT a critical parameters for this inspection?
    a. Resist thickness
    b. Alignment
    c. Line width or critical dimension
    d. Defects (particles, scratches, etc.)

Answer: a.

17. The final test on a micro-sized accelerometer showed that the proof mass was offset from center causing the whole wafer to be rejected. Which of the following process steps is MOST likely this cause of this defect?
    a. Conditioning
    b. Cost
    c. Align
    d. Expose
    e. Etch

Answer: c

18. Arrange the following photolithography steps in the proper order from first (1) to last (12).

Order	**Process Step**
	Hard bake
	DI Rinse
	Apply HMDS
	Align
	Inspect for defects
	Initial Bake
	Coat with photoresist
	Expose
	Cool
	Develop
	Soft bake
	Nitrogen Dry

Answer:

Order	**Process Step**
11	Hard bake
9	DI Rinse
2	Apply HMDS
6	Align
12	Inspect for defects
1	Initial Bake
4	Coat with photoresist
7	Expose
3	Cool
8	Develop
5	Soft bake
10	Nitrogen Dry

Support for this work was provided by the National Science Foundation's Advanced Technological Education (ATE) Program.

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University of New Mexico

<u>MEMS Fabrication Topic</u>

Photolithography Overview for Microsystems

Primary Knowledge (PK)
SCO (Shareable Content Object)

This SCO is part of the Learning Module
<u>Photolithography Overview for Microsystems</u>

Target audiences: High School, Community College, University

Support for this work was provided by the National Science Foundation's Advanced Technological Education (ATE) Program through Grants #DUE 0402651 and 0902411.

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Photolithography Overview for Microsystems

Primary Knowledge
Instructor Guide

Note to Instructor
Photolithograph Overview is the introductory primary knowledge SCO for the Photolithography Overview for Microsystems Learning Module (LM). It is a general overview of the photolithography process use in the fabrication of microsystems as well as integrated circuits. This lesson supports the SCME Pressure Sensor Kit.

The Photolithography Overview for Microsystems LM consists of the following SCOs:

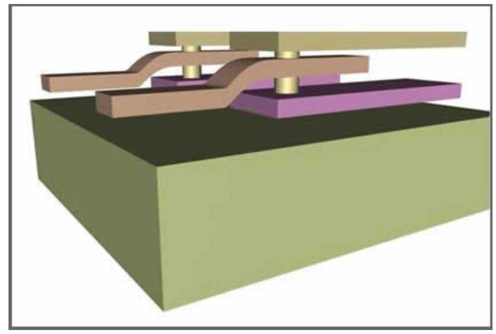
- Knowledge Probe (KP) or Pre-test
- **Photolithography Overview for Microsystems PK**
- Photolithography Terminology Activity
- Photoresist Thickness Activity
- Final Assessment – multiple choice quiz

This SCO is presented as a hand-out (participant guide - PG). A PowerPoint presentation is provided for a classroom presentation. The PowerPoint is a summary of the PG.

This companion Instructor guide (IG) contains all of the information in the PG as well as answers to the coaching and review questions at the end of the unit.

An on-line version of this learning module is available. Contact SCME for access to this on-line course.

Description and Estimated Time



Microsystems fabrication uses several layers to build devices. These layers typically consist of thin films of metal, bulk silicon, silicon dioxide or nitride, or polysilicon. The graphic illustrates the layers of a MEMS linkage assembly. Each layer is a different component of that device. Each layer requires a different pattern.

Photolithography is the process step used to define and transfer a pattern to its respective layer. The photolithography process occurs several times during the fabrication of a microsystems device as layers build upon layers. The linkage assembly would require "at least" six layers. Can you see at least six layers? (Hint: In MEMS fabrication, some layers are "sacrificial layers", meaning that they are completely removed leaving behind a void so that components can "float".) *[Linkage graphic courtesy of Khalil Najafi, University of Michigan]*

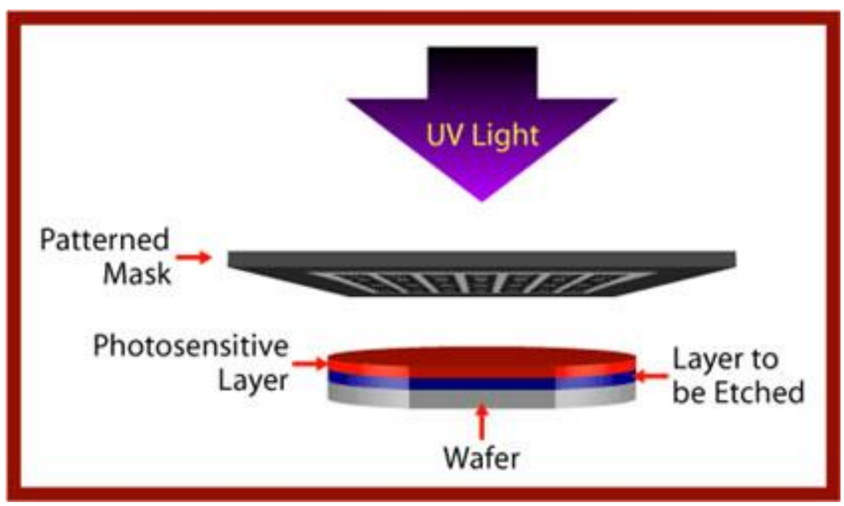
This unit provides an overview of the Photolithography process, and the basic information on each step of the photolithography process. NOTE: The definition of many of the underlined terms used in this module can be found in the glossary at this end of this unit.

Estimated Time: Allow at least 30 minutes to review material

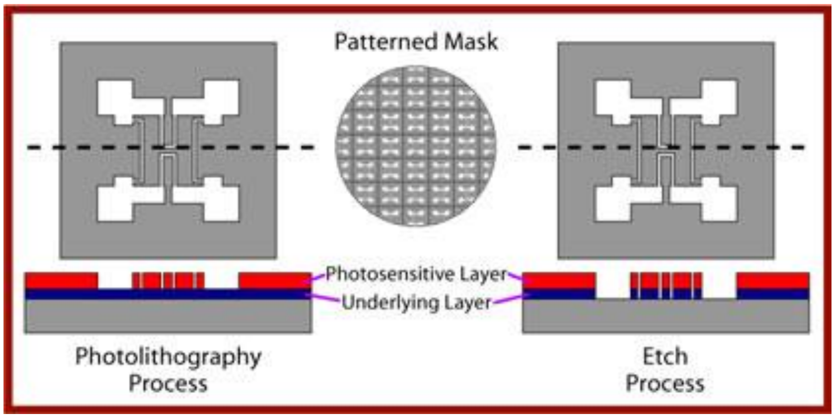
Introduction

Photolithography is the process that defines and transfers a pattern onto a thin film layer on the wafer. In the photolithography process a light source is typically used to transfer an image from a patterned mask to a photosensitive layer (photoresist or resist) on a substrate or another thin film. This same pattern is later transferred into the substrate or thin film (layer to be etched) using a different process called etch.

For some layers, the resist pattern is used as a mask for a deposition process. In such cases, the patterned resist would identify the areas that receive the deposited material and the areas that do not. Patterned photoresist is also used as a hard mask for some etch processes. The photoresist is used to protect the areas of the film that are not to be etched.



Pattern Transfer



Pattern Transfer to Underlying Layer

In the construction of microsystems, photolithography is used at any point in the process where a pattern needs to be defined on a layer. This occurs several times during the fabrication of a microsystems device as layers build upon layers. Remember the linkage assembly device? Each layer required a pattern; therefore, each layer required photolithography.

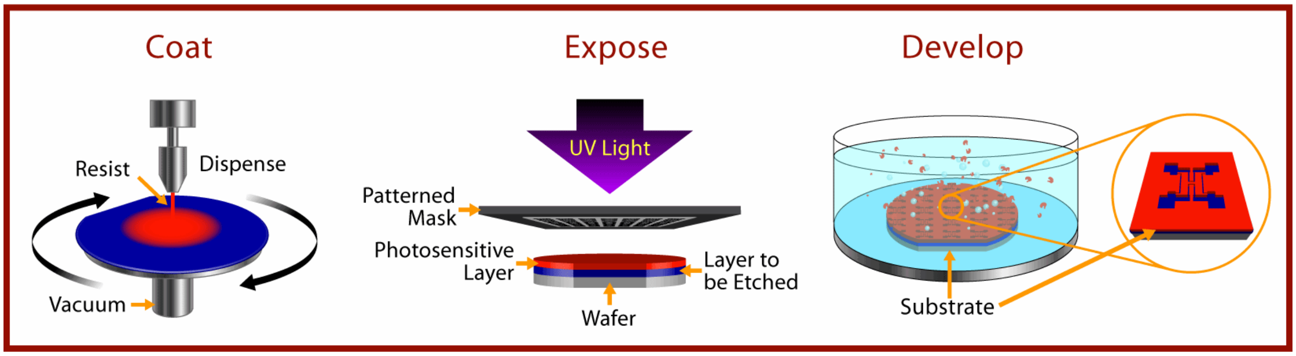
Each layer within a microsystem has a unique pattern. The initial process used to transfer this pattern into a layer is photolithography. The photolithography process transfers the pattern of a mask or reticle (depending on the method of exposure) to a photosensitive layer (resist). In the construction of microsystem devices a subsequent process step, usually etch or liftoff, transfers the pattern from the photosensitive layer into an underlying layer.

After the pattern transfer, the resist is usually stripped or removed.

Learning Module Objectives

- Develop an outline of the photolithography process.
- Briefly describe each step of the photolithography process using the correct terminology.

Steps of Photolithography



Steps of Photolithography - Coat, Expose, Develop

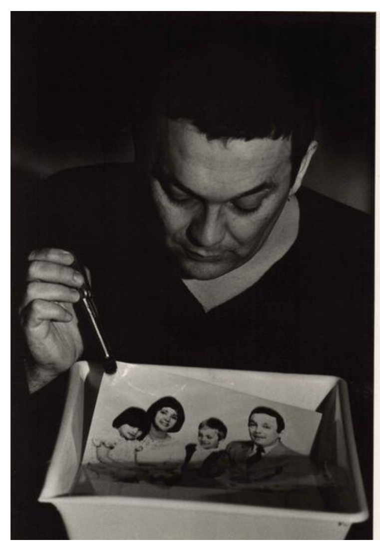
There are three basic steps to photolithography:

- Coat - A photosensitive material (photoresist or resist) is applied to the substrate surface.
- Expose - The photoresist is exposed using a light source, such as Near UV (Ultraviolet), Deep UV or X-ray.
- Develop - The exposed photoresist is subsequently dissolved with a chemical developer. The type of photoresist (positive or negative) determines which part of the resist is dissolved.

Photolithography vs. Photography

The photolithography process is analogous to a twentieth century photographic process which uses exposed film as the patterned mask (referred to as a "negative" in photography). The exposed film is removed from a camera and developed to create the patterned mask or negative. In a dark room, the negative (patterned mask) is placed between a light source and a prepared sheet of photosensitive paper.

- The paper has been coated with a light-sensitive photographic emulsion.
- The paper is exposed when the light travels through the negative.
- The exposed paper is placed in a liquid developer which chemically reacts with the emulsion, transferring the negative's image to the photographic paper.



Photographer/Painter: Jean-Pol Grandmont, shot and develop (b&W) and scanner [Courtesy of Jean-Pol Grandmont]

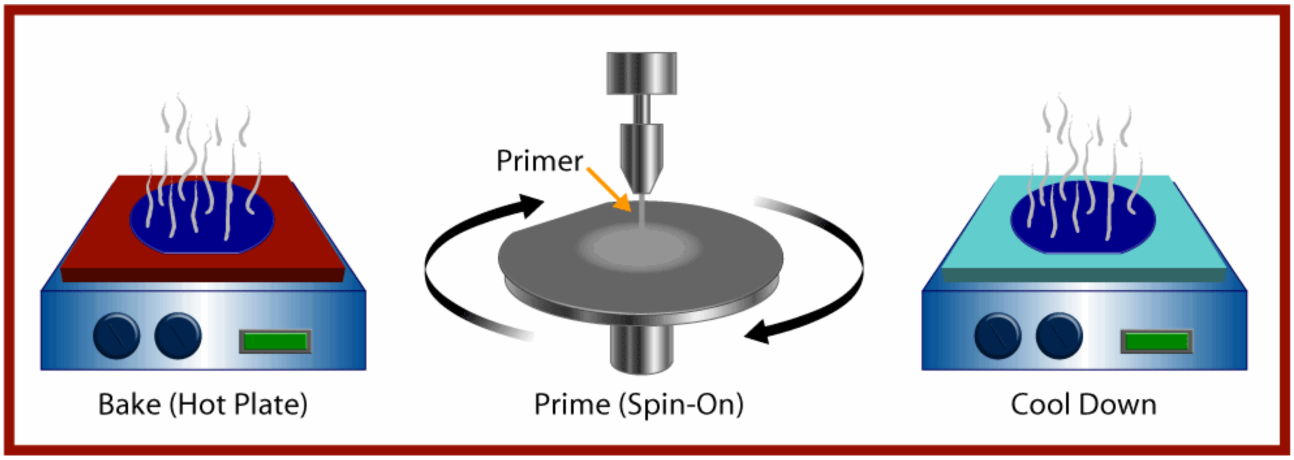
Coat Process: Step 1 - Surface Conditioning

The first step of the Coat Process is Surface Conditioning. Surface conditioning prepares the wafer to accept the photoresist by providing a clean surface, coated with an intermediate chemical (such as HMDS or Hexamethyldisalizane) that creates a hydrophobic surface which boosts adhesion of the photoresist to the wafer's surface. HMDS is the most commonly used intermediate chemical.

There are several reasons for conditioning the wafer's surface:

- The presence of other molecules or particles can create problems for resist adhesion and subsequent resist thickness uniformity; therefore, the wafer must be thoroughly cleaned and dried.
- Intermediates such as HMDS prepare the surface for adhesion of photoresist.
- Photoresist is an organic material that must interface with the substrate material which, in most cases, is inorganic. As an intermediate, HMDS allows this interface to occur.
- Different surface materials can have different surface tensions or affinity for organic materials such as photoresist. Again, as an intermediate between the underlying surface and the photoresist, HMDS acts as a buffer and promotes the adhesion of photoresist to a variety surface materials.
- Photoresist adheres best to a hydrophobic surface. A hydrophobic surface is defined as a surface which does not like (phobic) water (hydro). A layer of HMDS provides a hydrophobic surface.

Steps of Surface Conditioning



Bake, Prime and Cool

There are three basic steps to conditioning the wafer's surface: bake, prime and cool.

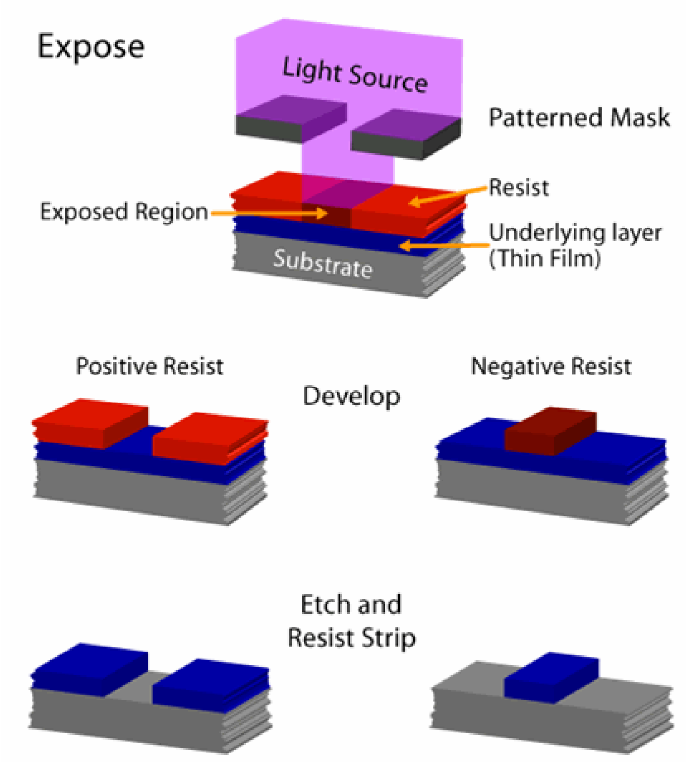
<u>Bake</u>
After the wafer is cleaned (rinsed/dried) and prior to applying a primer (HMDS), water molecules present on the wafer surface must be removed. One way is to heat the wafer to 100° C, the boiling point of water. The wafer is heated or baked in a small vacuum chamber or on a hot plate to remove water molecules on the wafer surface.

<u>Prime</u>
- HMDS is applied (prime) to create a hydrophobic surface. The hydrophobic surface prevents water molecules from re-accumulating on the surface once the wafer is returned to the environment.

<u>Cool</u>
- After the wafer is primed, it is cooled to room temperature (sometimes using a chill plate). This brings the wafer to the same temperature as the resist for the subsequent resist dispense step.

After the surface is conditioned, the wafer is coated with photoresist.

The Photoresist (Resist)



Photoresist - Positive vs. Negative resist

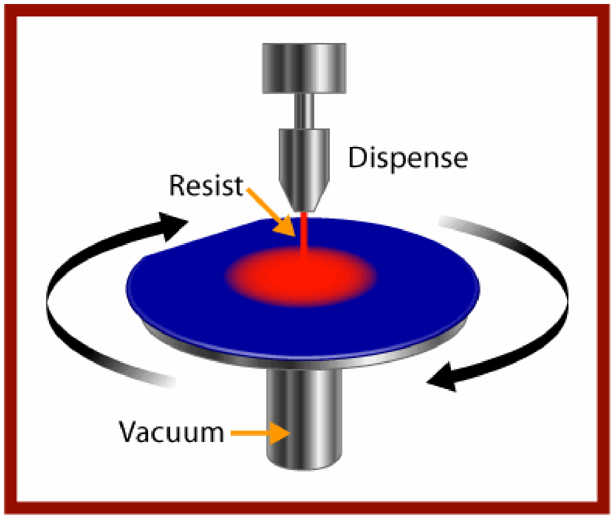
Photoresist is a mixture of organic compounds held together in a solvent solution.

There are two basic types of photoresist: negative or positive. Their primary difference is how they respond to the light source (as shown in the graphic).

Negative resist and UV: The regions of resist exposed to ultraviolet light (UV) become insoluble or harden. When developed, the hardened resist remains on the wafer and the non-exposed resist dissolves. The result is a negative resist pattern on the wafer.

Positive resist and UV: The regions of resist exposed to the UV become more soluble. When developed, the exposed resist dissolves and the unexposed resist remains. A good way to remember this is "What shows, goes". The result is a positive resist pattern on the wafer. Positive resist is more commonly used for microsystems fabrication.

Coat Process



Spin Coating

The coat process is the application of photoresist 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 must be thick enough and durable enough to withstand the next process steps. It must also be uniform in order to prevent problems during the expose process.

Spin coating is the most common methods for coating a wafer. The image below shows a spin coater. You can see the wafer sitting on the chuck and the excess resist (red) that has spun off the wafers.

- 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.

(Photo courtesy of the MTTC, University of New Mexico)

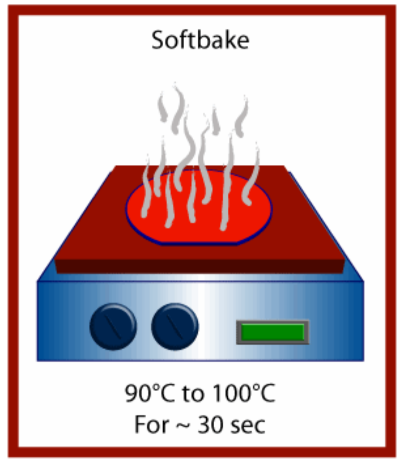
Photoresist Thickness Activity

If you need a break or would like to learn more about the coating process, you may stop and complete the activity "Photoresist Thickness". In this activity you will further explore the coat process and the factors that determine the photoresist thickness.

Softbake

After the photoresist is applied to the desired thickness, a *softbake* is used to remove the residual solvents of the photoresist.

After the softbake, the wafer is cooled to room temperature.

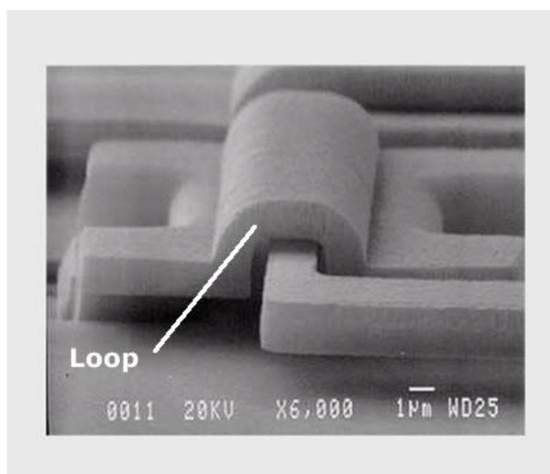


Softbake after Applying Resist

Align

The expose process consists of the align and expose steps.

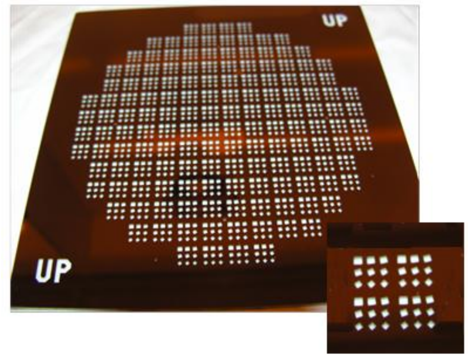
Alignment is one of the most critical steps in the entire microsystems fabrication process. Due to the microscopic size of these devices, a misalignment of one micrometer (micron or 1µm) or even smaller can destroy the entire device and all the other devices on the wafer. It is important that each layer is aligned properly and within specifications to the previous layers and subsequent layers.



Take a look at the microscopic hinge. Notice the 1µm scale in the bottom right. Using this scale we might estimate the width of the space between the hinged component and the edge of the loop to be approximately 0.5 µm or 500 nm.

What would be the result if the mask for the loop component was misaligned by 0.5 µm?

Align Procedure



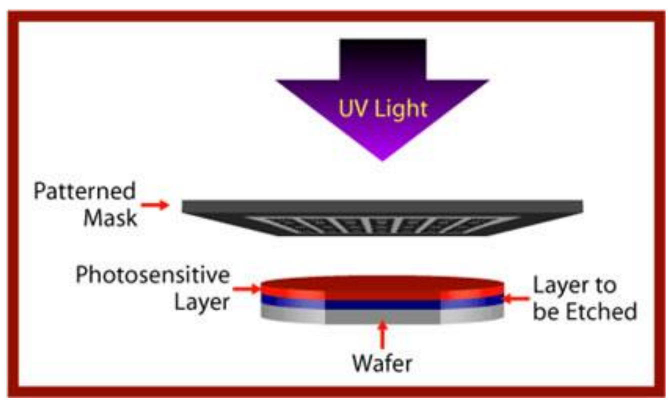
The patterned mask (or reticle) is a quartz or glass plate with the desired pattern (usually in chrome). The picture shows a mask used to expose an entire wafer. Notice that there is a repeating pattern throughout the mask. Each of these patterns is a die containing few micro-sized components, in the case shown here - 9.

Some equipment do not use masks. Instead a smaller quartz plate is used with just a few die (inset). Regardless of which is used, a mask or a reticle, the plate is locked into the expose equipment. The wafer is aligned to the mask or reticle along the x and y coordinates. The z-coordinate is adjusted to define the <u>focal plane</u> of the image.

When a mask is used, a single pulse of light will expose the entire wafer. When a reticle is used, the wafer or the reticle is “stepped” in the x, then y directions, exposing a small portion of the wafer with each step. This type of expose equipment is called a "stepper".

Expose

During expose, the photoresist layer is exposed when ultraviolet (UV) light from a source travels through the mask to the resist, exposing the resist. UV light sources normally include mercury vapor lamps and excimer lasers. The UV light hitting the resist causes a chemical reaction between the resist and the light. Only those areas not protected by the mask undergo a chemical reaction.



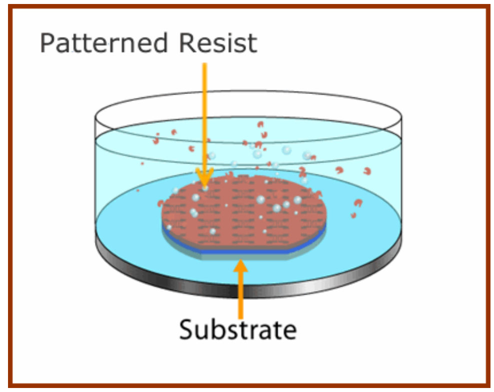
Let's see if you remember what happens when the light hits the resist. Do you remember positive vs. negative photoresist?

What happens to exposed negative resist?
What happens to exposed positive resist?

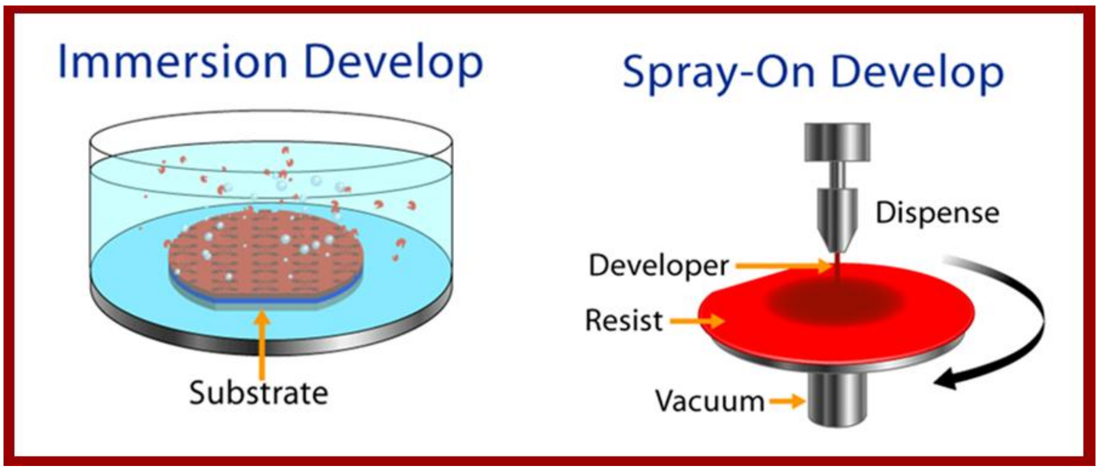
The Develop Process

In the develop process, portions of the photoresist are dissolved by a chemical developer. With positive resist (the more commonly used resist), the exposed resist is dissolved while the unexposed resist remains on the wafer. With negative resist, the unexposed resist is dissolved while the exposed resist remains.

The develop process leaves a visible pattern (seen by the naked eye) within the resist.



Develop Processes



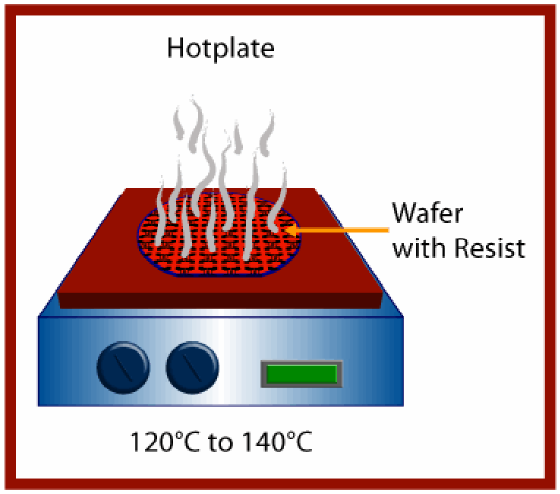
Immersion and Spray-on

Develop is usually a wet process. The wafers are physically placed in the develop solution (immersion) or the developer is sprayed onto the wafer.

The timing of this process is critical. Too long of a time leads to an "overdeveloped resist"; too little of a time leads to an "underdeveloped resist" – both of which negatively affect line width. An underdeveloped resist could prevent access to the underlying layer by leaving too much resist on the wafer.

To stop the chemical reaction of the developer with the photoresist, the wafers are rinsed with de-ionized (DI) water then spin-dried.

Hardbake



Hardbake Temperatures

A post-develop hardbake is used to harden the photoresist for the subsequent process. In order to do this, the temperature of the hardbake is higher than that of the softbake after coat. The hard bake temperature for positive resist is approximately 120°C to 140°C.

However, too high of a temperature could cause the photoresist to reflow, destroying the pattern.

After the hardbake, the wafer is cooled to room temperature.

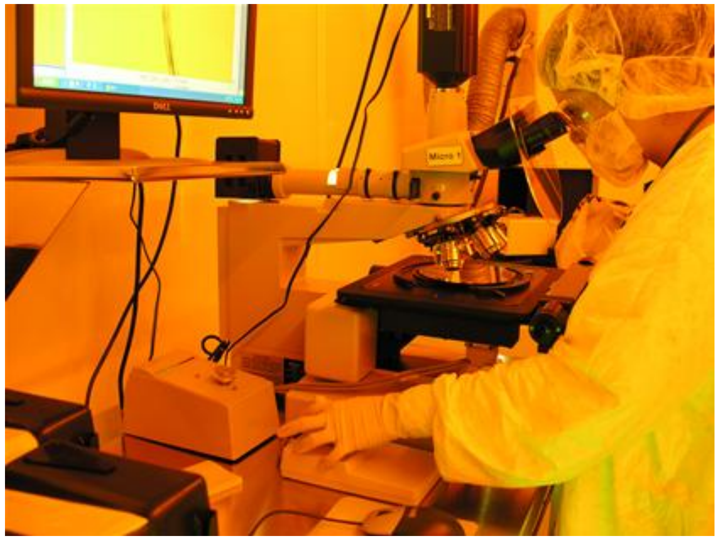
Inspect – What to Look for

Wafers are inspected immediately after the photolithography process and before subsequent processes such as etch. The inspection specifications vary depending on the product requirements.

Three critical parameters of the photolithography process are alignment, line widths and defects.
<u>Alignment</u> – the pattern must be positioned accurately to the previously layer.
<u>Line width or critical dimension (CD)</u> – the pattern images are in focus and have the correct size.
<u>Defects</u>– things that could affect subsequent processes and eventually the operation of the devices (i.e. particles, scratches, peeling (lifting) of the resist, holes in the resist, scumming (an underdeveloped or underexposed pattern))

The inspection step ensures that the pattern is properly aligned to the previous layers and that the critical dimensions are correct. Because of the 3-dimensional characteristic of MEMS devices, inspection is more challenging than with integrated circuits.

Inspect – How is it done?

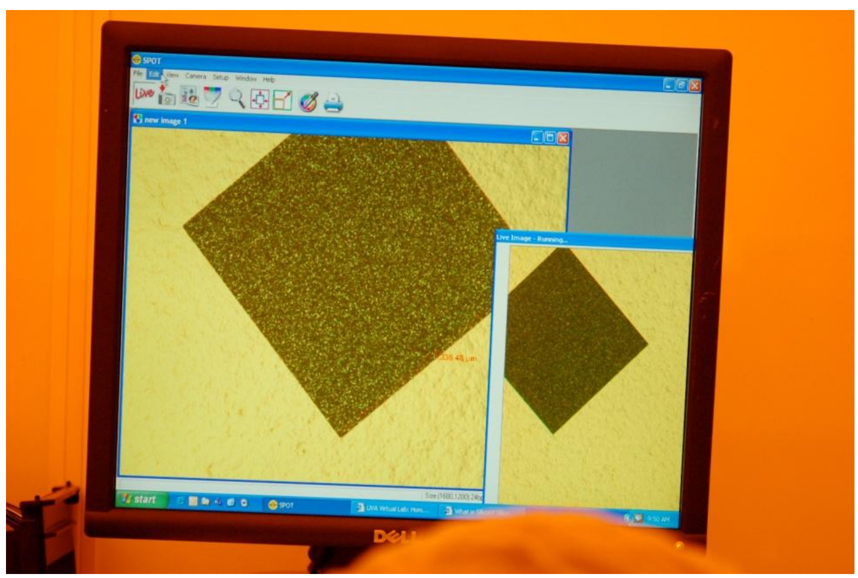


Inspecting a wafer
(Photo courtesy of the MTTC, University of New Mexico)

High powered microscopic equipment is used to inspect wafers at the end of the photolithography process. The smaller the CD's the more technologically advanced the equipment needs to be. Many tools are equipped with software that can measure the width of a printed structure and provide the information to the inspecting technician.

Alignment marks are designed into the masks and reticles and, in turn, are patterned into each layer to be used as reference points during inspect. In this way, the overlay of a subsequent step can be measured against the previous step and the misalignment can be quantified or measured.

The microscopes are powerful enough to allow the technician to see various types of defects (particles, scratches, peeling (lifting) of the resist, holes in the resist, scumming (an underdeveloped or underexposed pattern). The type of defect, if one exists, determines if the wafer can be reworked or not.



(Photo courtesy of the MTTC, University of New Mexico)

Review Questions

What are some of the critical parameters that should be inspected during the photolithography process and as a final inspection?

Critical dimensions are getting smaller. Objects are getting smaller. In microsystems technology, some objects are required to "float" above the substrate. What do you think are some of the limitations, if any, of the photolithography process described here when applied to these advancing technologies?

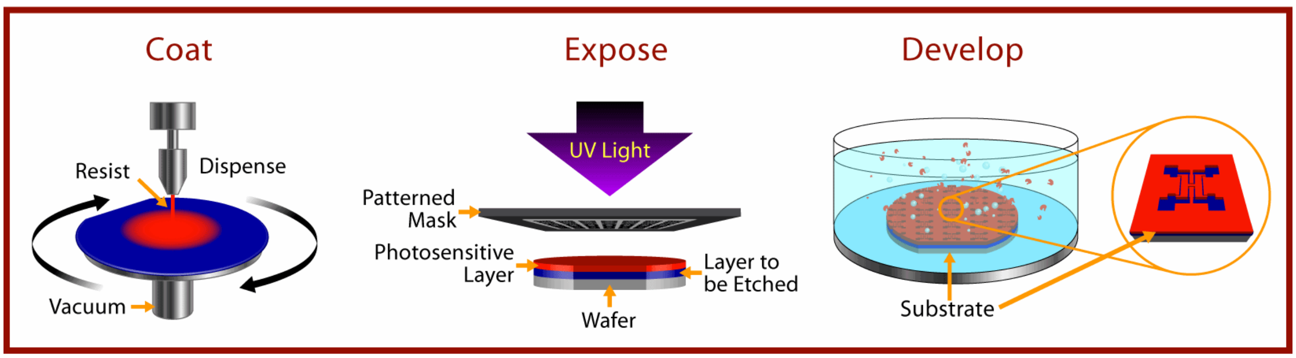
Review Questions / Answers

What are some of the critical parameters that should be inspected during the photolithography process and as a final inspection?
Answer: Photoresist thickness and photoresist coverage and uniformity should be checked after the coat process. Alignment of mask to wafer, alignment of mask to previous layers, size of critical dimensions and defects should be checked after the hardbake.

Critical dimensions are getting smaller. Objects are getting smaller. In microsystems technology, some objects are required to "float" above the substrate. What do you think are some of the limitations, if any, of the photolithography process described here when applied to these advancing technologies?
Answers will vary, but some ideas that may be mentioned are

- ***limitations to the current type of photoresist being able to handle the smaller CDs,***
- ***expose equipment / techniques being able to expose and develop for smaller CDs,***
- ***alignment with other layers.***

Summary



Coat, Expose, Develop

Photolithography uses three basic process steps to transfer a pattern from a mask to a wafer: coat, develop, expose. 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.

Glossary of Key Terms

Alignment: The ability of the alignment tool to accurately overlay the mask/reticle pattern to the wafer for transferring the first pattern.

Coat: A photosensitive material (photoresist or resist) is applied to the substrate surface.

Deep UV (ultraviolet): A portion of the electromagnetic spectrum (in the range of 100-250 nm) containing wavelengths often used to expose photoresist. It can produce smaller image widths.

Develop: The exposed photoresist is subsequently dissolved with a chemical developer.

Etch: The process of removing material from a wafer (such as oxides or other thin films) by chemical, electrolytic or plasma (ion bombardment) means. Examples: nitride etch, oxide etch.

Expose: Subjecting a sensitive material (photoresist) to light or other radiant energy (such as Deep UV (Ultraviolet), Near UV or x-ray).

Focal Plane: The plane perpendicular to the axis of a lens or optical system that contains the focal point.

Intermediate: Something that lies or occurs between two states, forms or extremes. In photolithography, HMDS is an intermediate lying between the photoresist and the previous layer.

Liftoff: A method for patterning films that are deposited. A pattern is defined on a substrate using photoresist. A film, usually metallic, is blanket-deposited all over the substrate, covering the photoresist and areas in which the photoresist has been cleared. During the actual lifting-off, the photoresist under the film is removed with solvent, taking the film with it, and leaving only the film which was deposited directly on the substrate.

Mask: A glass plate covered with an array of patterns used in the photomasking process. Each pattern consists of opaque and clear areas that respectively prevent or allow light through.

Near UV: A portion of the electromagnetic spectrum (in the range of 400 nm – 300 nm) containing wavelengths often used to expose photoresist.

Photolithography: The transfer of a pattern or image from one medium to another, as from a mask to a wafer.

Resist: Thin film used in lithography to transfer a circuit pattern to the underlying substrate.

Reticle: An exposure mask with the image of a single die, or small cluster of die (called a field). The image on the reticle is stepped across the wafer and is exposed multiple times.

Substrate: The base material on or in which MEMS components and circuits are constructed.

Thin film: Thin material layers ranging from fractions of a nanometer to several micrometers in thickness.

UV (UltraViolet) light: A portion of the electromagnetic spectrum from 250 to 400 nm. High-pressure mercury sources emit UV light for photoresist exposure. The region below 250nm is known as deep UV (DUV).

X-ray: A form of electromagnetic radiation with a wavelength in the range of 10 to 0.01 nanometers.

References

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- Photolithography. Module 40. MATEC. NSF Center. Arizona.
- "Comparing the costs of photoresist coating using spin, spray, and electrodeposition systems". Nga P. Pham and Pasqualina M. Sarro, Delft University of Technology. MicroMagazine.com. 2007. http://www.micromagazine.com/archive/05/04/pham.html
- "Photolithography". Wikipedia. http://en.wikipedia.org/wiki/Photolithography

Disclaimer

Support for this work was provided by the National Science Foundation's Advanced Technological Education (ATE) Program.

Southwest Center for Microsystems Education (SCME)
University of New Mexico

MEMS Fabrication Topic

Photolithography Overview Terminology Activity

Activity SCO (Shareable Content Object)

This SCO is part of the Learning Module
Photolithography Overview for Microsystems

Target audiences: High School, Community College, University

Support for this work was provided by the National Science Foundation's Advanced Technological Education (ATE) Program through Grants #DUE 11040000 and 0902411.

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Photolithography Overview for Microsystems Activity – Terminology
Instructor Guide

Notes to Instructor

This activity provides the participants an opportunity to better understand the terminology associated with Photolithography processing. Participants should read the PK SCO before doing this activity in order to get an understanding of photolithography terminology.

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

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

This activity is presented as a hand-out (Participant Guide - PG).

This companion Instructor Guide (IG) contains all of the information in the PG as well as answers to the Post-Activity questions.

An on-line version of this learning module is available. Contact SCME for access to this on-line course.

Description and Estimated Time to Complete

In this activity you will demonstrate your knowledge of photolithography terminology. This activity consists of two parts:

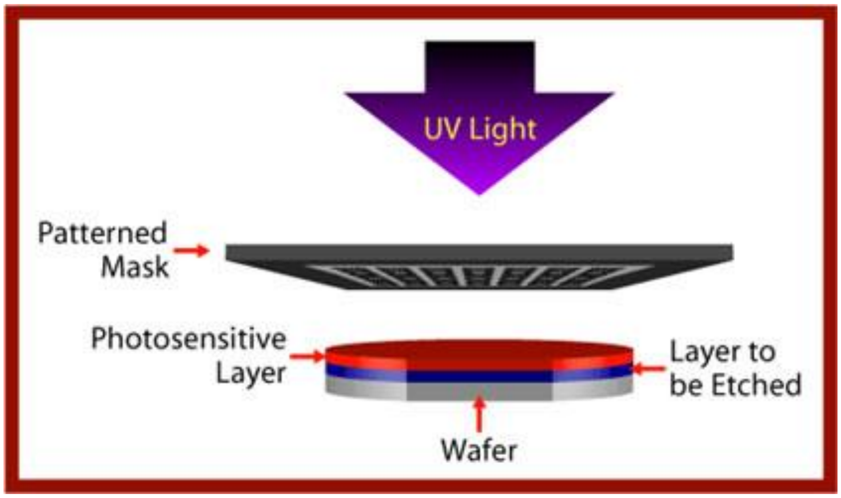
- A **crossword puzzle** that tests your knowledge of the terminology and acronyms associated with photolithography processing, and
- **Post-activity questions** that ask you to demonstrate a better understanding of photolithography and its application to MEMS fabrication.

If you have not reviewed the unit Photolithography Overview for Microsystems, you should do so before completing this activity.

Estimated Time to Complete
Allow at least 30 minutes to complete this activity.

Introduction

Photolithography is the process that defines and transfers a pattern onto a layer of the wafer. In the photolithography process a light source is typically used to transfer an image from a patterned mask to a photosensitive layer (photoresist or resist) on a substrate or thin film. This same pattern is later transferred into the substrate or thin film (layer to be etched) using a different process (etch process).



For some layers, the resist pattern is used as a mask for a deposition process. In such cases, the patterned resist would identify the areas that receive the deposited material and the areas that do not.

Activity Objective

- Identify the correct terms used for several definitions or statements related to photolithography.
- Describe the photolithography process as it applies to microsystems fabrication.

Resources

SCME's Photolithography Overview for Microsystems PK

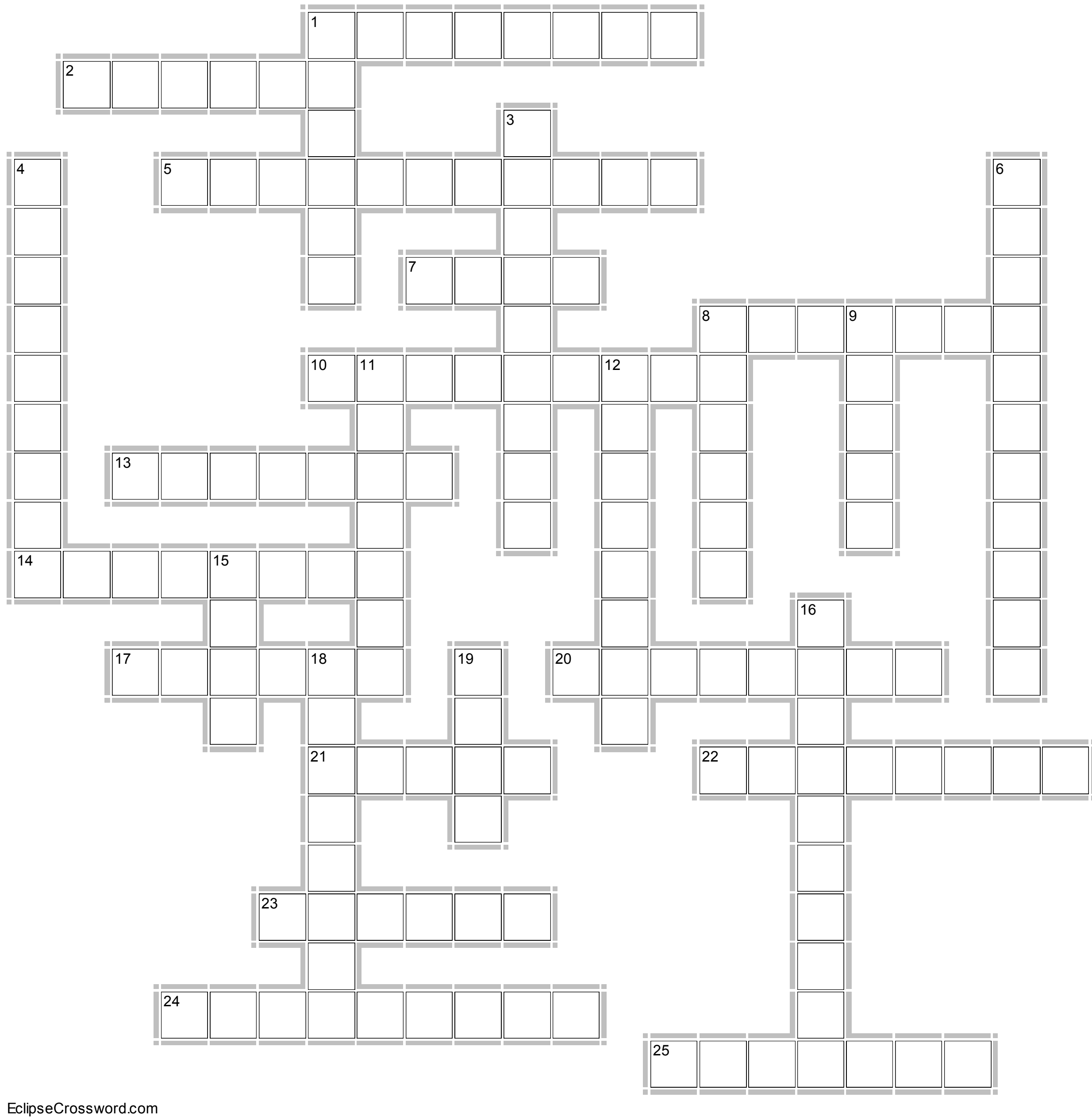
Documentation

1. Completed Crossword Puzzle
2. Questions and Answers to the Post-Activity Questions

Activity: Photolithography Terminology

Procedure:

Complete the crossword puzzle using the clues on the following page.



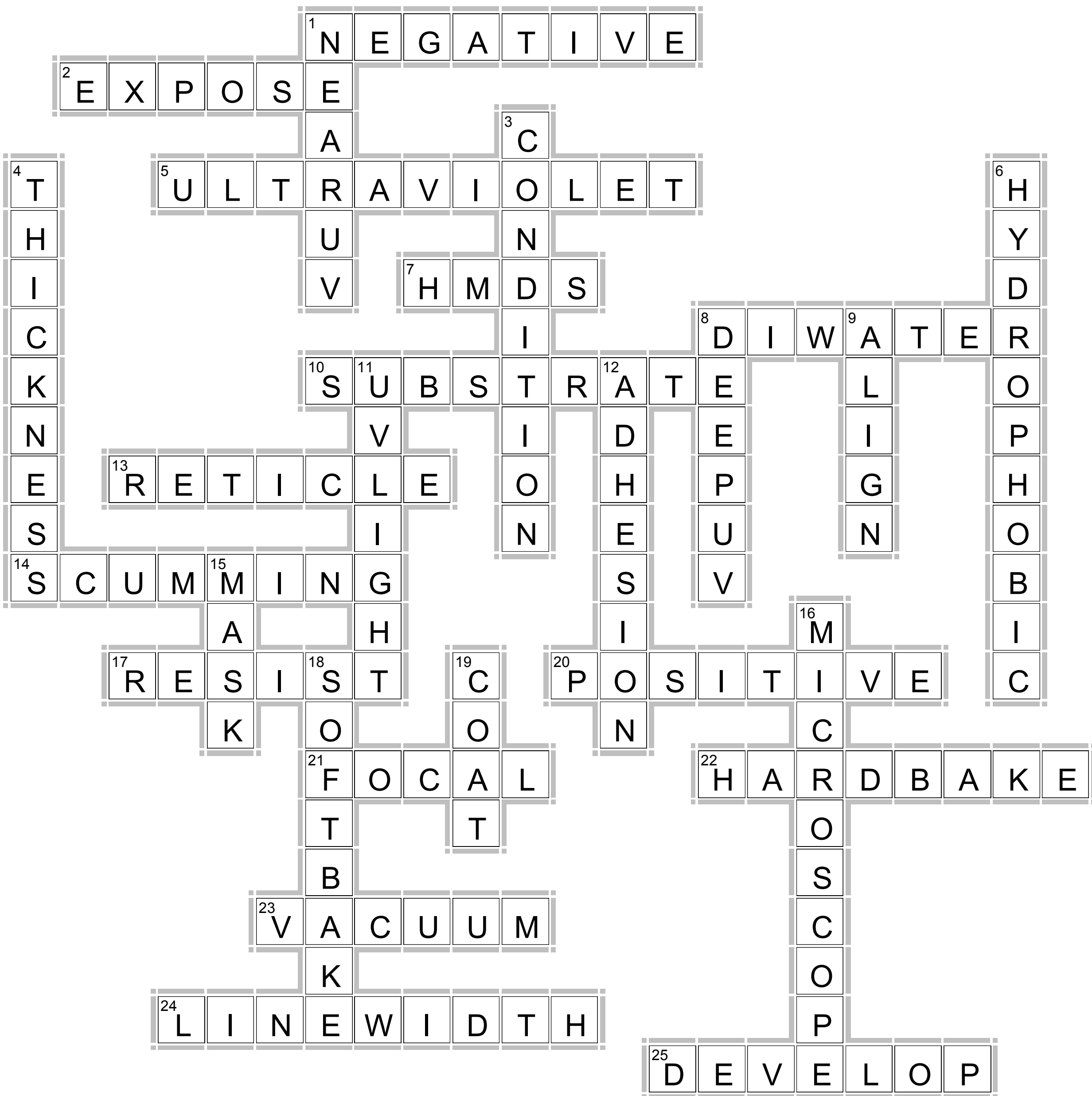
ACROSS	Answers
1. Type of resist that hardens when exposed to UV light	**Negative**
2. The photolithography step that transfers a pattern using a UV light source.	**Expose**
5. UV	**Ultraviolet**
7. Hexamethyldisalizane	**HMDS**
8. Used to stop the reaction of the chemical developer with the photoresist.	**DI water**
10. The base material or foundation on or in which MEMS components and circuits are constructed.	**Substrate**
13. A quartz plate, used in steppers, that has the pattern for one field or one or more die at one given layer.	**Reticle**
14. An underdeveloped or underexposed pattern results in this type of defect.	**Scumming**
17. A light sensitive thin film spun onto a wafer during the coat step of the photolithography process.	**Resist**
20. A type of resist that becomes more soluble in developer after being exposed to UV light.	**Positive**
21. During the exposure process, the wafer is adjusted in the z-axis and also may be tilted to adjust the ___________ plane of the image.	**Focal**
22. The photolithography process step that hardens the photoresist after it has been developed.	**Hardbake**
23. A ________________ holds the wafer on the chuck during the spin coating process step.	**Vacuum**
24. When you measure the critical linear dimension of a structure, you measure the ____________ __________ (2 words).	**Line width**
25. The removal of select photoresist material after exposure is done during the __________ process step.	**Develop**

DOWN	Answers
1. A portion of the electromagnetic spectrum (in the range of 300 nm – 400 nm) containing wavelengths often used to expose photoresist. (Hint: It is not DeepUV but ________.)	**Near UV**
3. Prepare the surface of the wafer for the coat process.	**Condition**
4. The resist parameter that is affected by rpm	**Thickness**
6. A fear of water	**Hydrophobic**
8. A portion of the electromagnetic spectrum (in the range of 100-250nm) containing wavelengths often used to expose photoresist. Due to the smaller wavelengths, this process can produce smaller structures.	**Deep UV**
9. To match (overlay) the pattern on one layer to the pattern on a previous layer.	**Align**
11. During expose, a chemical reaction takes place as the result of absorbing _________.	**UV light**
12. HMDS is used to promote the _______ of resist to the wafer's surface.	**Adhesion**
15. A quartz plate that contains the desired pattern for an entire wafer	**Mask**
16. High powered optical equipment used to inspect wafers at the end of the photolithography process.	**Microscope**
18. The photolithography process step that removes most of the solvents from the resist after the spin coat process.	**Softbake**
19. The application of resist to the wafer surface.	**coat**

Post-Activity Questions

1. Discuss the purpose of photolithography as it applies to the fabrication of microsystems.
2. Create an outline of the photolithography process.

Answer Key to Crossword Puzzle – Photolithography Terminology



EclipseCrossword.com

Post-Activity Questions / Answers

1. Discuss the purpose of photolithography as it applies to the fabrication of microsystems.

   Answer: *Answers will vary.*

   Microsystems fabrication uses several layers to build devices. These layers typically consist of thin films of metal, bulk silicon or polysilicon. Each layer is a different component of that device. Each layer requires a different pattern. Photolithography is the process step used to define and transfer a pattern to its respective layer. The photolithography process occurs several times during the fabrication of a microsystems device as layers build upon layers.

   The steps of the photolithography process ensure that the layers are correctly aligned in order for the finished microsystem to function properly. It also ensures that the wafer is ready for any subsequent process steps.

2. Create a detailed outline of the photolithography process. Include primary and secondary steps of the process. ***Answer:***

   1) *Coat Process*
      a) *Surface Conditioning*
         i) *Bake*
         ii) *Prime (apply HMDS)*
         iii) *Cool*
      b) *Spin on Resist*
      c) *Softbake*
   2) *Align and Expose*
      a) *Align*
      b) *Expose*
   3) *Develop*
      a) *Immersion or Spray-on Develop*
      b) *DI Rinse*
      c) *Spin-dry*
      d) *Hardbake*
   4) *Inspect*

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.

Support for this work was provided by the National Science Foundation's Advanced Technological Education (ATE) Program.

Southwest Center for Microsystems Education (SCME)
University of New Mexico

MEMS Fabrication Topic

Photoresist Thickness

Activity SCO (Shareable Content Object)

This SCO is part of the Learning Module
Photolithography Overview for Microsystems

Target audiences: High School, Community College, University

Support for this work was provided by the National Science Foundation's Advanced Technological Education (ATE) Program through Grants #DUE 0902411.

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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 SCO 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 activity is presented as a hand-out (Participant Guide - PG).

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

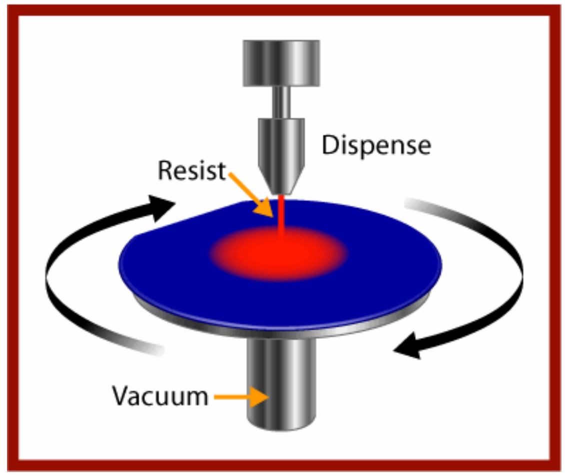
An on-line version of this learning module is available. Contact SCME for access to this on-line course.

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 will interpret and create graphs using actual process data.

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

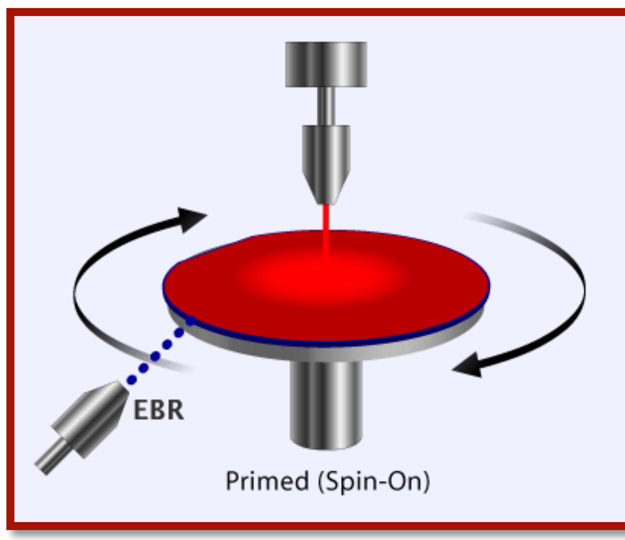
Introduction



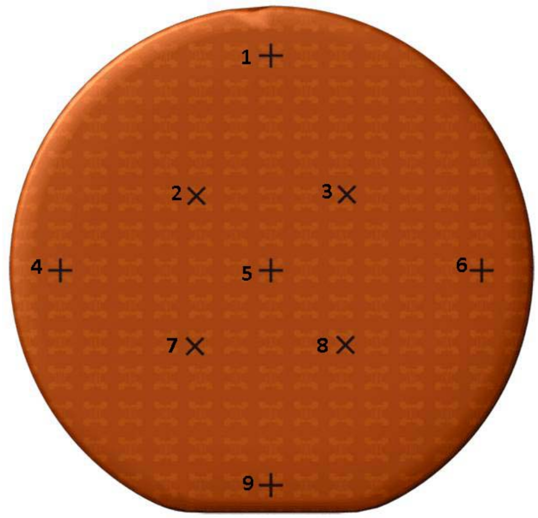
The “coat” process is the application of photoresist (also referred to as “resist”) to the wafer’s surface. There are several methods used to coat the wafer (spin, spray and electrodeposition (ED)). The goal of the coat process is to distribute a uniform thickness of resist across the wafer's surface 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 which 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?

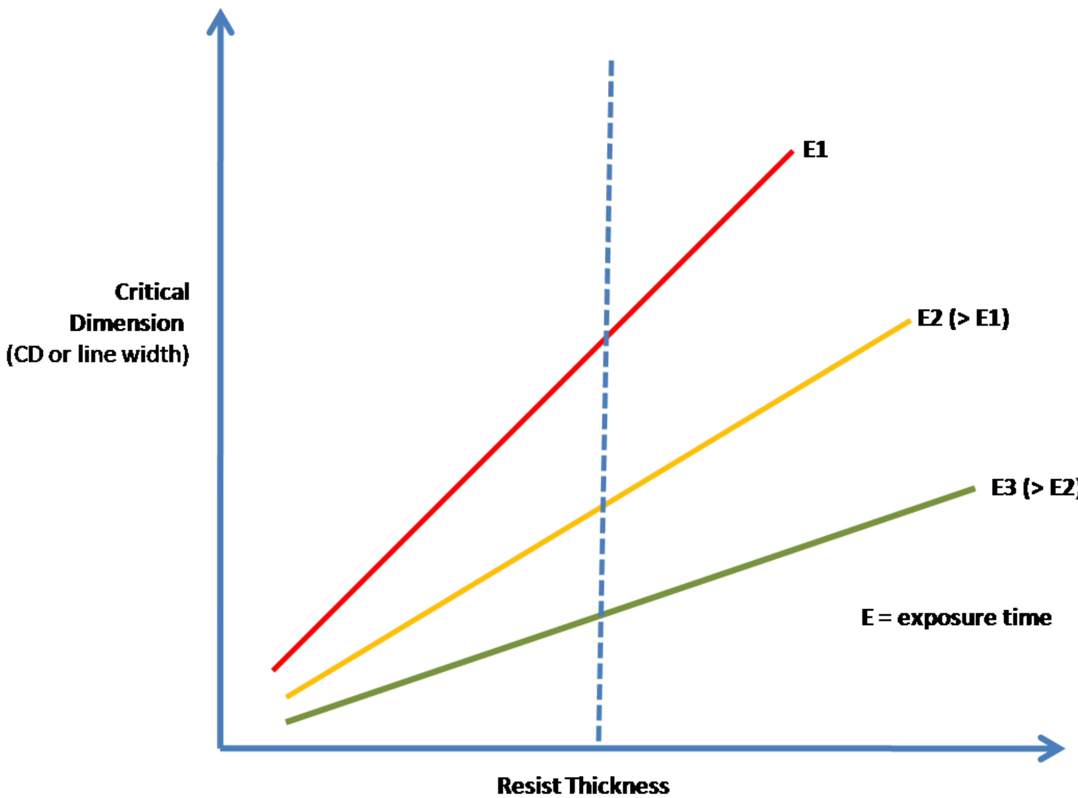
This is an important question! With positive resist,

- 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

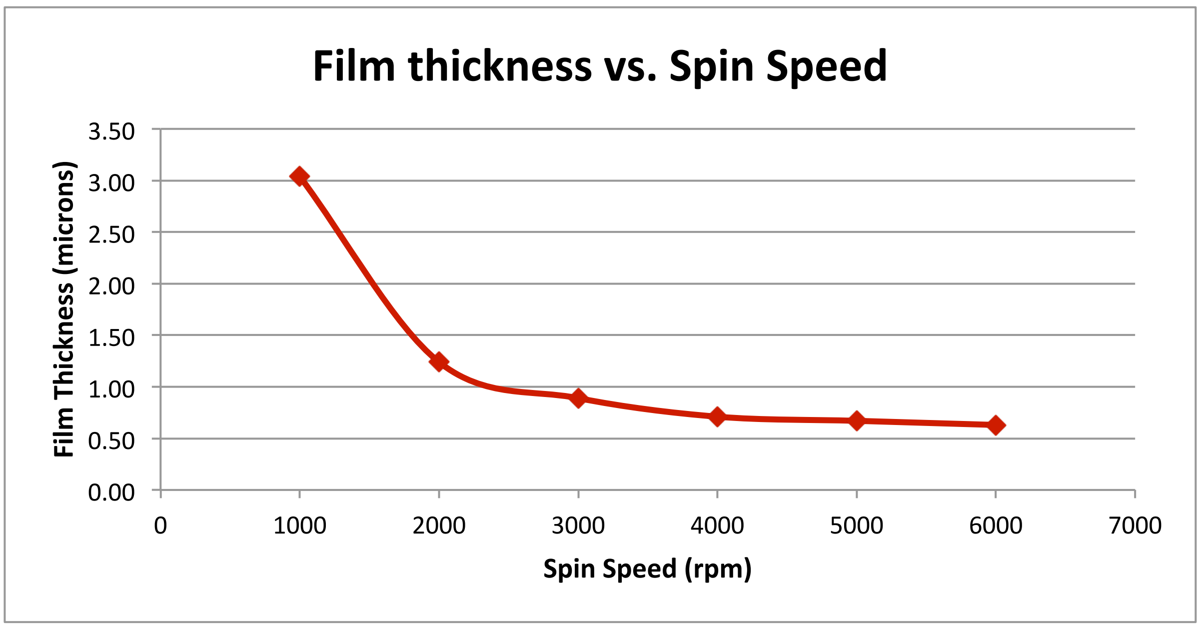
SCME's Photolithography Overview for Microsystems PK

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*

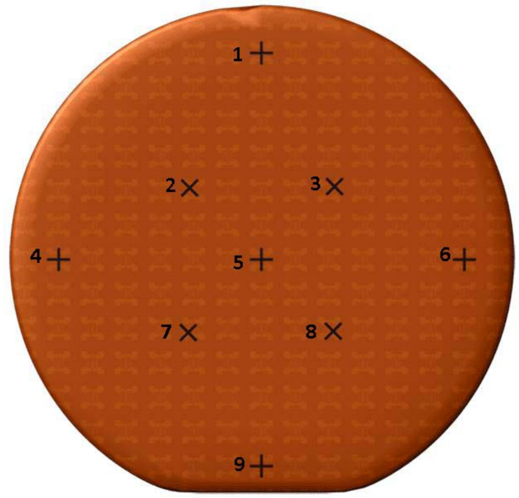
   b. *3000 rpm = ____0.89___ microns = ___8,900_____ Å*

   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)



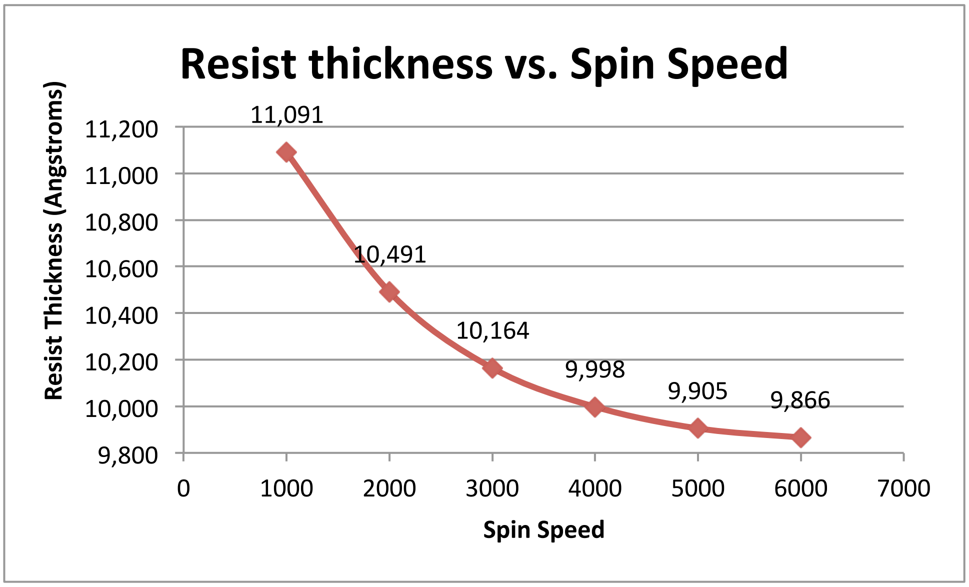
a. Plot a graph comparing the nine wafers **mean photoresist thickness vs. spin speed**. Be sure to label your graph and indicate the mean photoresist thickness for each spin speed.

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:

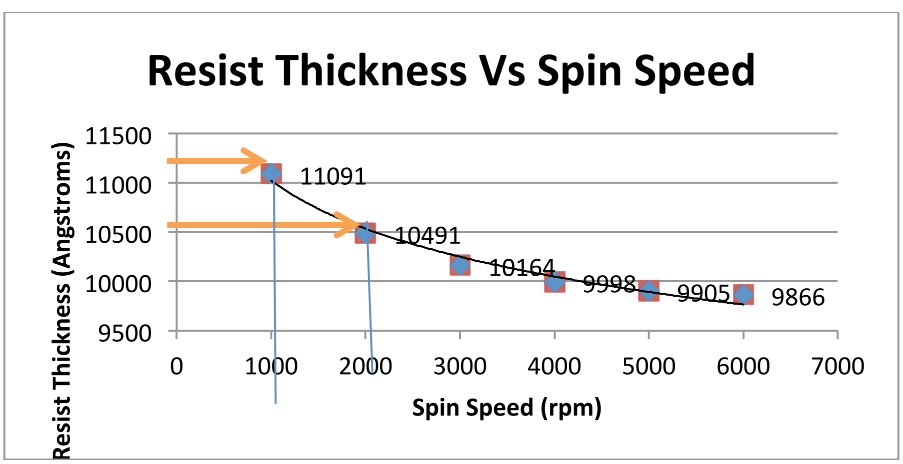


This graph shows that resist thickness decreases exponentially with an increase in spin speed.

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

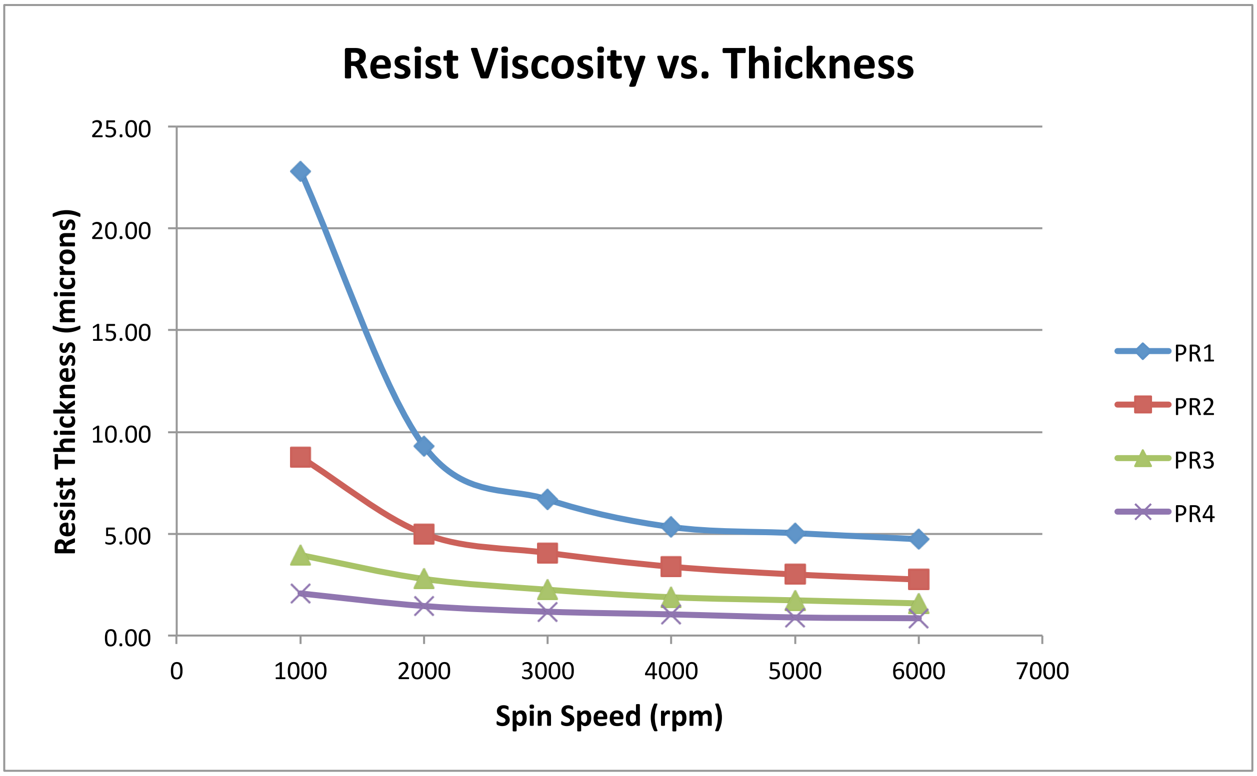
NOTE: for extra credit you could ask the participants to calculate the range, STD and 3 Sigma in addition to the mean.

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



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.
http://www.eetindia.co.in/ARTICLES/2001JAN/2001JAN01_ICP_WLP_TA.PDF?SOURCES=DOWNLOAD

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.

Support for this work was provided by the National Science Foundation's Advanced Technological Education (ATE) Program.

Southwest Center for Microsystems Education (SCME)
University of New Mexico

MEMS Fabrication Topic

Photolithography Overview for Microsystems

Final Assessment – Multiple Choice Questions

This SCO is part of the Learning Module
Photolithography Overview

Target audiences: High School, Community College, University

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Photolithography Overview for Microsystems Final Assessment – Multiple Choice

Instructor Guide

Notes to Instructor

This Final Assessment (FA) contains 18 questions to assess the participants' knowledge of the photolithography processes. This FA should be given after the completion of the Photolithography Overview Learning Module. A comparison between this FA and the KP can be used to determine the level of participant learning as a result of this learning module.

The Photolithography Overview for Microsystems Learning Module consists of the following SCOs:

- **Knowledge Probe or Pre-assessment**
- Photolithography Overview for Microsystems
- Photolithography Terminology Activity
- Photoresist Thickness Activity
- Photoresist Uniformity Activity
- Final Assessment – multiple choice

The Participant Guide is included in the Instructor Guide learning module that is available for download on the SCME website (scme-nm.org) by registered users. This FA can also be accessed on-line as part of the SCME on-line Photolithography Overview mini-course.

This Instructor Guide (IG) contains both the questions and answers for the 18 questions. The Instructor Guide learning module can be downloaded by registered members from the SCME website.

An on-line version of this learning module is available. Contact SCME for access to this on-line course.

Introduction

The purpose of this assessment is to determine your understanding of the photolithography process and how it applies to microsystems (MEMS) Fabrication.

1. Which of the following **BEST** describes the photolithography process?
   a. The process step that transfers a pattern using UV light into an underlying layer or the substrate's bulk.
   b. The process step that defines and transfers a pattern into a photosensitive film on the wafer's surface.
   c. The process step that deposits a photosensitive layer of thin film on the surface of the wafer.
   d. The process step that aligns the various layers of a microsystem device to each other in preparation for expose.

   Answer: b.

2. Which of the following sequences **BEST** represents the ordered steps of the photolithography process?
   a. Surface conditioning, align, coat, expose, etch
   b. Coat, surface conditioning, align, expose, develop
   c. Coat, expose, develop, surface conditioning, etch
   d. Surface conditioning, coat, align, expose, bake, develop

   Answer: d.

3. Which of the following represent the steps of surface conditioning?
   a. Bake, apply HMDS, cool, rinse/dry
   b. Rinse/Dry, apply HMDS, cool
   c. Rinse/Dry, bake, apply HMDS, cool
   d. Apply HMDS, cool, rinse/dry

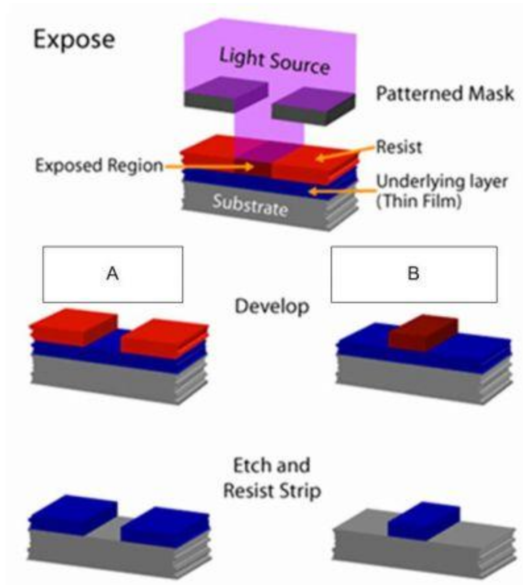
   Answer: c.

4. What is the purpose of HMDS?
   a. To clean and dry the wafer's surface
   b. To create a hydrophilic and more adhesive wafer surface
   c. To create a hydrophobic and more adhesive wafer surface
   d. To provide a more uniform and adhesive wafer surface

Answer: c.

5. Which of the following is correct in reference to this graphic?
   a. A positive photoresist was used for “A” and a negative photoresist for “B”
   b. A negative photoresist was used for “A” and a positive photoresist for “B”
   c. The photoresist determines the pattern that is etched into the underlying layer
   d. The exposed region is always hardened by the UV in the light source

Answer: a



6. Which of the following statements is NOT TRUE in reference to negative photoresist?
   a. UV light hardens the exposed resist
   b. UV light makes the exposed resist more soluble
   c. The exposed resist dissolves during develop
   d. The unexposed resist hardens during the softbake

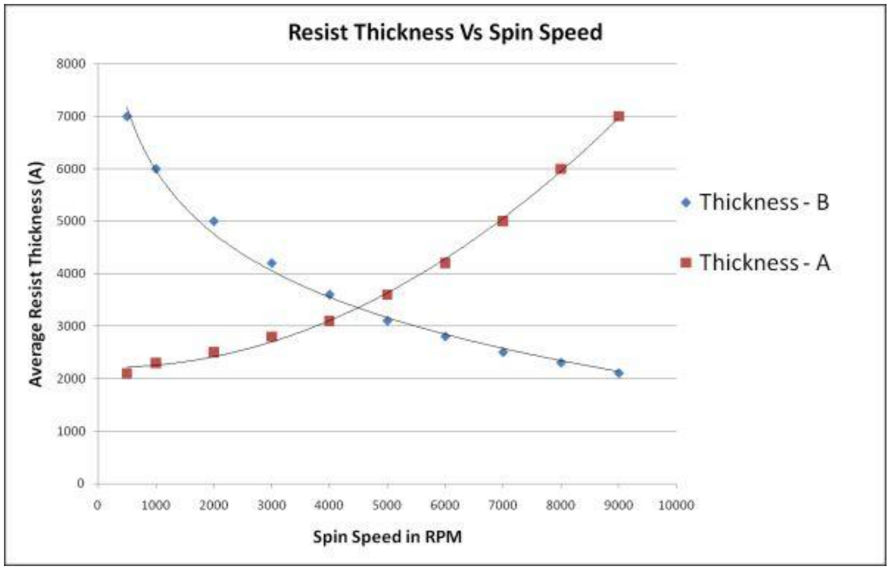
   Answer: a.

7. Which of the following determine the final thickness of photoresist after the coat process?
   a. The viscosity of the resist and the amount of time that the wafer spins
   b. The spin speed after deposition of resist and the amount of time that the wafer spins
   c. The amount of resist applied and the amount of time that the wafer spins
   d. The spin speed of the wafer after deposition of resist and the viscosity of the resist

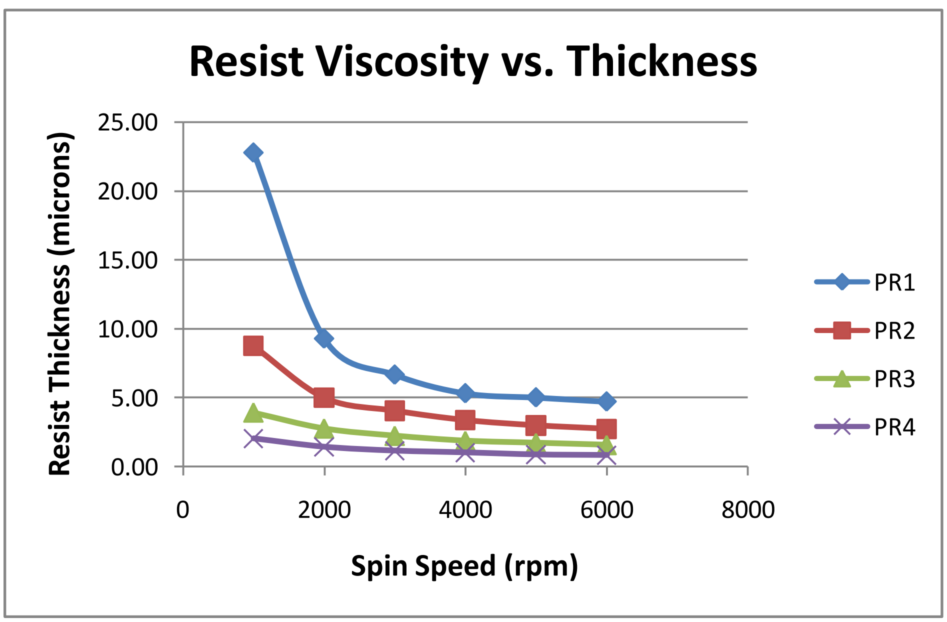
Answer: d

8. Which curve correctly represents a resist spin curve?
   a. A
   b. B
   c. Neither curve
   d. Both curves

Answer: b.



9. Which of the following curves represents the photoresist with the lowest viscosity?
   a. PR1
   b. PR2
   c. PR3
   d. PR4



Answer: d. PR4

10. A resist coat with poor uniformity could result in…
   a. an inaccurate alignment prior to expose
   b. an inability to align the wafer for a proper expose
   c. different exposures at various points on the wafer
   d. non-uniform develop of resist

Answer: *c.*

11. A soft bake is used _______________ the coat step and a hard bake is used ___________ develop.
   a. Before, after
   b. Before, before
   c. After, before
   d. After, after

Answer: *d.*

12. For the expose step, some photolithography equipment, such as steppers, use a small quartz plate that contains the pattern for just a few die or fields on a wafer. This plate is called a _______________.
   a. Mask
   b. Reticle
   c. Partial mask
   d. Die plate

Answer: b

13. What is the wavelength used to expose the photoresist?
   a. X-ray
   b. Microwave
   c. Infrared (IR)
   d. Ultraviolet (UV)

Answer: d

14. The final test on a micro-sized accelerometer showed that the proof mass was offset from center causing the whole wafer to be rejected. Which of the following process steps is MOST likely this cause of this defect?
   a. Conditioning
   b. Cost
   c. Align
   d. Expose
   e. Etch

Answer: c

15. Which of the following could be the result of an underdeveloped resist layer?
    a. Misalignment of the resist pattern to the pattern in the underlying layer
    b. Critical dimensions in the resist layer larger than specification
    c. Too much resist left on the wafer preventing access to the underlying layer
    d. Too little resist left on the wafer resulting in poor protection of underlying layer

    Answer: c.

16. The final inspection of the photolithography process (prior to going to etch) showed that the critical dimensions and lines were poorly defined (wavy, too narrow, and in some places – totally eliminated). Which of the following is MOST LIKELY the cause of this problem?
    a. A hardbake that was too long or at too high of a temperature causing the resist to flow.
    b. An expose that was too short causing too little resist to be removed in develop
    c. An expose that was too short causing too much resist to be removed in develop
    d. Too long of a develop causing too much resist to remain on the wafer

    Answer: a.

17. After the develop step, the wafers are inspected. What are the three (3) critical parameters inspected?
    a. Critical dimension (line width), alignment, defects
    b. Critical dimension (line width), resist thickness, alignment
    c. Defects, alignment, resist thickness
    d. Alignment, resist hardness, critical dimension (line width)

    Answer: a

18. Arrange the following photolithography steps in the proper order from first (1) to last (12).

Order	**Process Step**
	Hard bake
	DI Rinse
	Apply HMDS
	Align
	Inspect for defects
	Initial Bake
	Coat with photoresist
	Expose
	Cool
	Develop
	Soft bake
	Nitrogen Dry

Answer:

Order	**Process Step**
11	Hard bake
9	DI Rinse
2	Apply HMDS
6	Align
12	Inspect for defects
1	Initial Bake
4	Coat with photoresist
7	Expose
3	Cool
8	Develop
5	Soft bake
10	Nitrogen Dry

Support for this work was provided by the National Science Foundation's Advanced Technological Education (ATE) Program.

Photolithography Overview for Microsystems Final Assessment – Multiple Choice

Participant Guide

Introduction

The purpose of this assessment is to determine your understanding of the photolithography process and how it applies to microsystems (MEMS) Fabrication.

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   c. The process step that deposits a photosensitive layer of thin film on the surface of the wafer.
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   a. Surface conditioning, align, coat, expose, etch
   b. Coat, surface conditioning, align, expose, develop
   c. Coat, expose, develop, surface conditioning, etch
   d. Surface conditioning, coat, align, expose, bake, develop

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   c. Rinse/Dry, bake, apply HMDS, cool
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4. What is the purpose of HMDS?
   a. To clean and dry the wafer's surface
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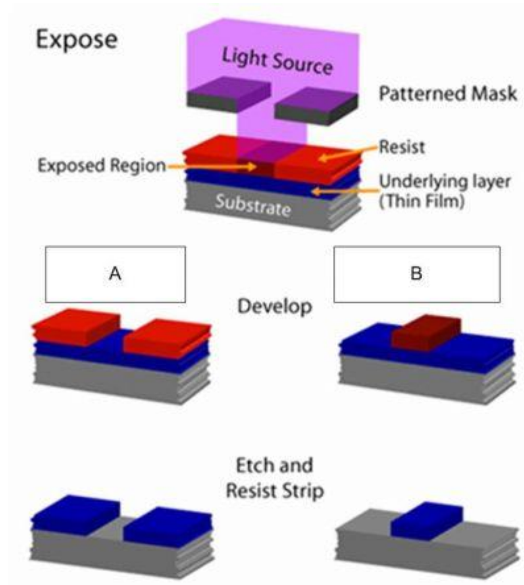
   d. The exposed region is always hardened by the UV in the light source



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   a. UV light hardens the exposed resist
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   c. The exposed resist dissolves during develop
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7. Which of the following determine the final thickness of photoresist after the coat process?
   a. The viscosity of the resist and the amount of time that the wafer spins
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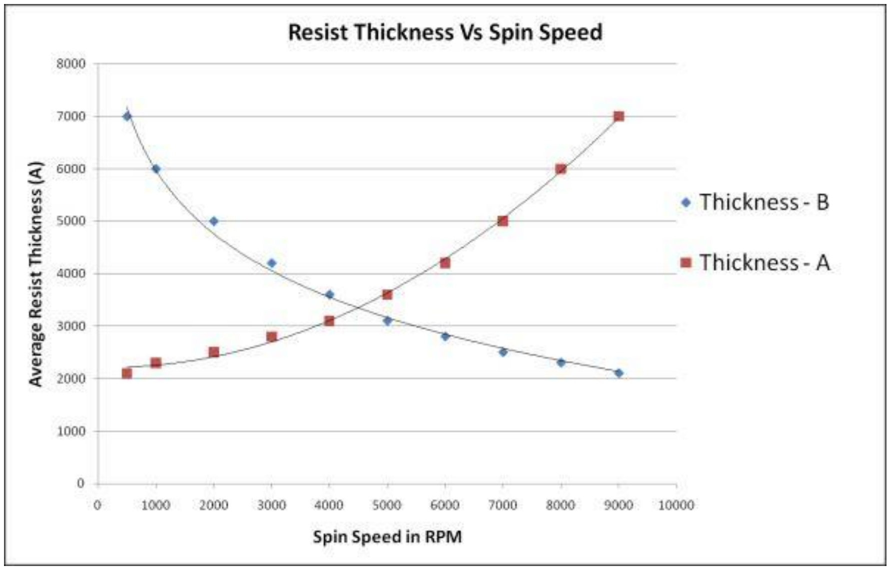

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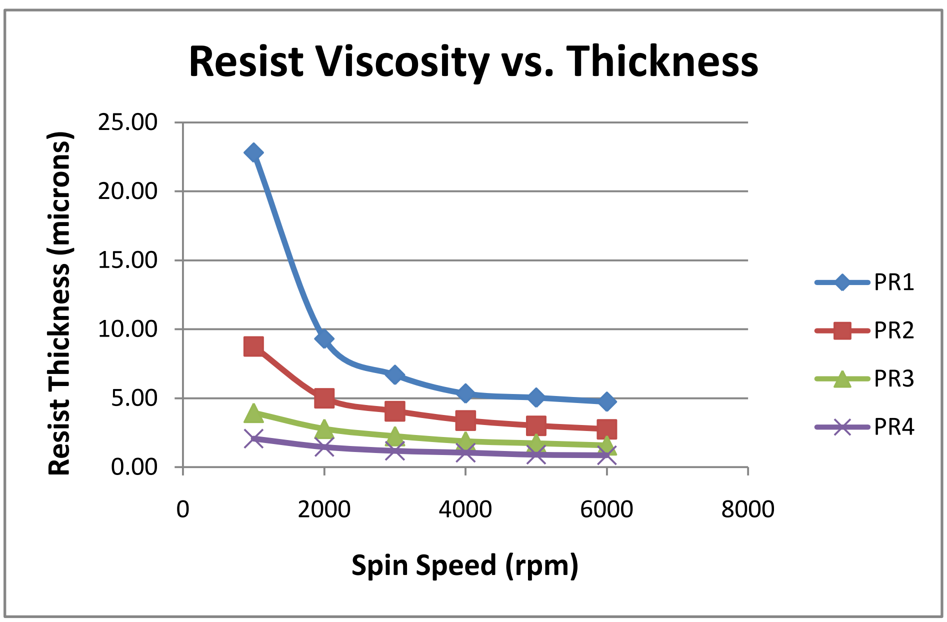

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    b. Microwave
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	Align
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	Initial Bake
	Coat with photoresist
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	Cool
	Develop
	Soft bake
	Nitrogen Dry

Support for this work was provided by the National Science Foundation's Advanced Technological Education (ATE) Program.

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<u>Learning Modules</u> available for download @ scme-nm.org

<u>MEMS Introductory Topics</u>

MEMS History
MEMS: Making Micro Machines DVD and LM (Kit available)
Units of Weights and Measures
A Comparison of Scale: Macro, Micro, and Nano
Introduction to Transducers
Introduction to Sensors
Introduction to Actuators
Wheatstone Bridge (Pressure Sensor Model Kit available)

<u>MEMS Applications</u>

MEMS Applications Overview
Microcantilevers (Dynamic Cantilever Kit available)
Micropumps Overview

<u>BioMEMS</u>

BioMEMS Overview
BioMEMS Applications Overview
DNA Overview
DNA to Protein Overview
Cells – The Building Blocks of Life
Biomolecular Applications for bioMEMS
BioMEMS Therapeutics Overview
BioMEMS Diagnostics Overview
Clinical Laboratory Techniques and MEMS
MEMS for Environmental and Bioterrorism Applications
Regulations of bioMEMS
DNA Microarrays (GeneChip® Model Kit available)

<u>MEMS Fabrication</u>

Crystallography for Microsystems (Breaking Wafers and Origami Crystal Kits available)
Oxidation Overview for Microsystems (Rainbow Wafer Kit available)
Deposition Overview Microsystems
Photolithography Overview for Microsystems
Etch Overview for Microsystems (Rainbow Wafer and Anisotropic Etch Kits available)
MEMS Micromachining Overview
LIGA Micromachining Simulation Activities (LIGA Simulation Kit available)
Manufacturing Technology Training Center Pressure Sensor Process (Three Activity Kits available)
MEMS Innovators Activity (Activity Kit available)

<u>Safety</u>

Hazardous Materials
Material Safety Data Sheets
Interpreting Chemical Labels / NFPA
Chemical Lab Safety
Personal Protective Equipment (PPE)

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