MEMS Fabrication Topic

Photolithography Overview Learning Module

This booklet contains five (5) units:
Knowledge Probe (Pre-test)
Primary Knowledge (Reading Material)
Terminology Activity
Resist Thickness Activity
Assessment

This learning module provides an overview of the most common photolithography process used in the fabrication of microelectromechanical systems (MEMS), photolithography terminology and basic concepts. Students explore some of these concepts in the provided activities.

Target audiences: High School, Community College, University

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Website: www.scme-nm.org
Photolithography Overview for Microsystems Knowledge Probe Participant Guide

Photolithography Overview Learning Module

This learning module provides an overview of the most common photolithography process used in the fabrication of microelectromechanical systems (MEMS), photolithography terminology and basic concepts. Students explore some of these concepts in the provided activities.

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. Do not 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.

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
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

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

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

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

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.
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

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

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

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

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

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. CO₂ Lasers and mercury vapor lamps
    d. CO₂ Lasers and excimer lasers

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
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

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.)

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

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

<table>
<thead>
<tr>
<th>Order</th>
<th>Process Step</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hard bake</td>
</tr>
<tr>
<td>2</td>
<td>DI Rinse</td>
</tr>
<tr>
<td>3</td>
<td>Apply HMDS</td>
</tr>
<tr>
<td>4</td>
<td>Align</td>
</tr>
<tr>
<td>5</td>
<td>Inspect for defects</td>
</tr>
<tr>
<td>6</td>
<td>Initial Bake</td>
</tr>
<tr>
<td>7</td>
<td>Coat with photoresist</td>
</tr>
<tr>
<td>8</td>
<td>Expose</td>
</tr>
<tr>
<td>9</td>
<td>Cool</td>
</tr>
<tr>
<td>10</td>
<td>Develop</td>
</tr>
<tr>
<td>11</td>
<td>Soft bake</td>
</tr>
<tr>
<td>12</td>
<td>Nitrogen Dry</td>
</tr>
</tbody>
</table>

Support for this work was provided by the National Science Foundation's Advanced Technological Education (ATE) Program through Grants. For more learning modules related to microtechnology, visit the SCME website (http://scme-nm.org).
Photolithography Overview for Microsystems

Primary Knowledge (PK)
Participant Guide

Description and Estimated Time

Microsystems fabrication uses several thin film 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 most common photolithography process used to fabricate micro-sized devices, 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. Two activities are provided to allow you to demonstrate your understanding of photolithography terminology and to further explores some basic concepts.

Estimated Time: Allow at least 30 minutes to review material in this unit.
**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

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 in the Introduction? Each thin film 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. These steps are illustrated in the graphic below.

This thin film to be patterned is in blue, photoresist in red. The pattern in the mask is first transferred in the photoresist (left) then an etch process transfers that pattern into the 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

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 that 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 Hexamethyldisilizane) 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 surface materials.
- Photoresist adheres best to a hydrophobic surface. A hydrophobic surface is defined as a surface that 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.

Bake
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.

Prime
- 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.

Cool
- 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

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.

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 is 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 focal plane 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

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**

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 hardbake 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.  
- **Alignment** – the pattern must be positioned accurately to the previously layer.  
- **Line width or critical dimension (CD)** – the pattern images are in focus and have the correct size.  
- **Defects** – 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?*

**Summary**

![Coat, Expose, Develop](image)

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
- Photolithography Lab.ppt, Fabian Lopez, Central New Mexico Community College
Disclaimer
The information contained herein is considered to be true and accurate; however the Southwest Center for Microsystems Education (SCME) makes no guarantees concerning the authenticity of any statement. SCME accepts no liability for the content of this unit, or for the consequences of any actions taken on the basis of the information provided.

Support for this work was provided by the National Science Foundation's Advanced Technological Education (ATE) Program through Grants. For more learning modules related to microtechnology, visit the SCME website (http://scme-nm.org).
Description and Estimated Time to Complete

In this activity you 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.
<table>
<thead>
<tr>
<th>ACROSS</th>
<th>Answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Type of resist that hardens when exposed to UV light</td>
<td></td>
</tr>
<tr>
<td>2. The photolithography step that transfers a pattern using a UV light source.</td>
<td></td>
</tr>
<tr>
<td>5. UV</td>
<td></td>
</tr>
<tr>
<td>7. Hexamethyldisilazane</td>
<td></td>
</tr>
<tr>
<td>8. Used to stop the reaction of the chemical developer with the photoresist.</td>
<td></td>
</tr>
<tr>
<td>10. The base material or foundation on or in which MEMS components and circuits are constructed.</td>
<td></td>
</tr>
<tr>
<td>13. A quartz plate, used in steppers, that has the pattern for one field or one or more die at one given layer.</td>
<td></td>
</tr>
<tr>
<td>14. An underdeveloped or underexposed pattern results in this type of defect.</td>
<td></td>
</tr>
<tr>
<td>17. A light sensitive thin film spun onto a wafer during the coat step of the photolithography process.</td>
<td></td>
</tr>
<tr>
<td>20. A type of resist that becomes more soluble in developer after being exposed to UV light.</td>
<td></td>
</tr>
<tr>
<td>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.</td>
<td></td>
</tr>
<tr>
<td>22. The photolithography process step that hardens the photoresist after it has been developed.</td>
<td></td>
</tr>
<tr>
<td>23. A ____________ holds the wafer on the chuck during the spin coating process step.</td>
<td></td>
</tr>
<tr>
<td>24. When you measure the critical linear dimension of a structure, you measure the ________ ________ (2 words).</td>
<td></td>
</tr>
<tr>
<td>25. The removal of select photoresist material after exposure is done during the ________ process step.</td>
<td></td>
</tr>
<tr>
<td>DOWN</td>
<td>Answers</td>
</tr>
<tr>
<td>------</td>
<td>---------</td>
</tr>
<tr>
<td>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 ________.)</td>
<td></td>
</tr>
<tr>
<td>3. Prepare the surface of the wafer for the coat process.</td>
<td></td>
</tr>
<tr>
<td>4. The resist parameter that is affected by rpm</td>
<td></td>
</tr>
<tr>
<td>6. A fear of water</td>
<td></td>
</tr>
<tr>
<td>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.</td>
<td></td>
</tr>
<tr>
<td>9. To match (overlay) the pattern on one layer to the pattern on a previous layer.</td>
<td></td>
</tr>
<tr>
<td>11. During expose, a chemical reaction takes place as the result of absorbing __________.</td>
<td></td>
</tr>
<tr>
<td>12. HMDS is used to promote the _______ of resist to the wafer's surface.</td>
<td></td>
</tr>
<tr>
<td>15. A quartz plate that contains the desired pattern for an entire wafer</td>
<td></td>
</tr>
<tr>
<td>16. High powered optical equipment used to inspect wafers at the end of the photolithography process.</td>
<td></td>
</tr>
<tr>
<td>18. The photolithography process step that removes most of the solvents from the resist after the spin coat process.</td>
<td></td>
</tr>
<tr>
<td>19. The application of resist to the wafer surface.</td>
<td></td>
</tr>
</tbody>
</table>
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.

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 through Grants. For more learning modules related to microtechnology, visit the SCME website (http://scme-nm.org).
Photoresist Thickness Activity
Participant Guide

Description and Estimated Time to Complete

In this activity you 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 ± 3 STD 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.

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 1.1µm to 1.05µm, making it thinner by .05µm (500Å)?

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

![Resist Viscosity vs. Thickness](image)

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 meet 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?

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?

References


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 through Grants. For more learning modules related to microtechnology, visit the SCME website (http://scme-nm.org).
Photolithography Overview for Microsystems
Final Assessment
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.

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.

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

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

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
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

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

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

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

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

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

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

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

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
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

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)

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

<table>
<thead>
<tr>
<th>Order</th>
<th>Process Step</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hard bake</td>
</tr>
<tr>
<td>2</td>
<td>DI Rinse</td>
</tr>
<tr>
<td>3</td>
<td>Apply HMDS</td>
</tr>
<tr>
<td>4</td>
<td>Align</td>
</tr>
<tr>
<td>5</td>
<td>Inspect for defects</td>
</tr>
<tr>
<td>6</td>
<td>Initial Bake</td>
</tr>
<tr>
<td>7</td>
<td>Coat with photoresist</td>
</tr>
<tr>
<td>8</td>
<td>Expose</td>
</tr>
<tr>
<td>9</td>
<td>Cool</td>
</tr>
<tr>
<td>10</td>
<td>Develop</td>
</tr>
<tr>
<td>11</td>
<td>Soft bake</td>
</tr>
<tr>
<td>12</td>
<td>Nitrogen Dry</td>
</tr>
</tbody>
</table>

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Southwest Center for Microsystems Education (SCME)
Learning Modules available for download @ scme-nm.org

MEMS Introductory Topics
MEMS History
MEMS: Making Micro Machines DVD and LM (Kit)
Units of Weights and Measures
A Comparison of Scale: Macro, Micro, and Nano
Introduction to Transducers
Introduction to Sensors
Introduction to Actuators
Problem Solving – A Systematic Approach

MEMS Applications
MEMS Applications Overview
Microcantilevers (Microcantilever Model Kit)
Atomic Force Microscope Overview
Micro Pressure Sensors and The Wheatstone Bridge
(Modeling A Micro Pressure Sensor Kit)
Micropumps Overview

BioMEMS
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 (DNA Microarray Model Kit available)
Microtechnology of Pacemakers

MEMS Fabrication
Crystallography for Microsystems (Crystallography Kit)
Deposition Overview Microsystems (Science of Thin Films Kit)
Photolithography Overview for Microsystems
Etch Overview for Microsystems (Bulk Micromachining – An Etch Process Kit)
MEMS Micromachining Overview
LIGA Micromachining Simulation Activities (LIGA Micromachining – Lithography & Electroplating Kit)
Manufacturing Technology Training Center Pressure Sensor Process (Three Activity Kits)
A Systematic Approach to Problem Solving
Introduction to Statistical Process Control
Learning Microsystems Through Problem Solving Activity and related kit

Nanotechnology
Nanotechnology: The World Beyond Micro
(Supports the film of the same name by Silicon Run Productions)

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

Check our website regularly for the most recent versions of our Learning Modules.

For more information about SCME and its Learning Modules and kits, visit our website scme-nm.org or contact Dr. Matthias Pleil at mpleil@unm.edu

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