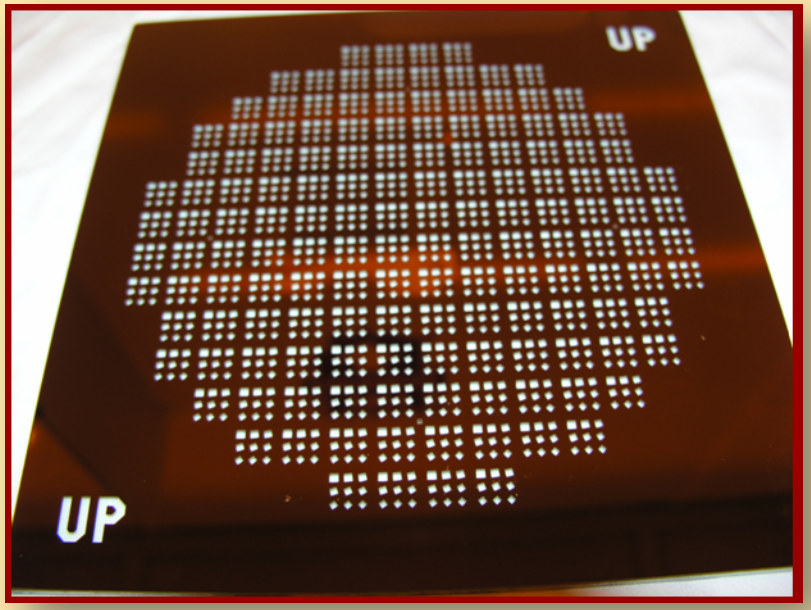
PHOTOLITHOGRAPHY OVERVIEW FOR MICROSYSTEMS



Patterned Mask for Photolithography Expose

Unit Overview

Photolithography occurs several times during the fabrication of a micro-sized device.

Micro-sized devices usually have several layers and each layer requires the photolithography step to identify the pattern for that layer.

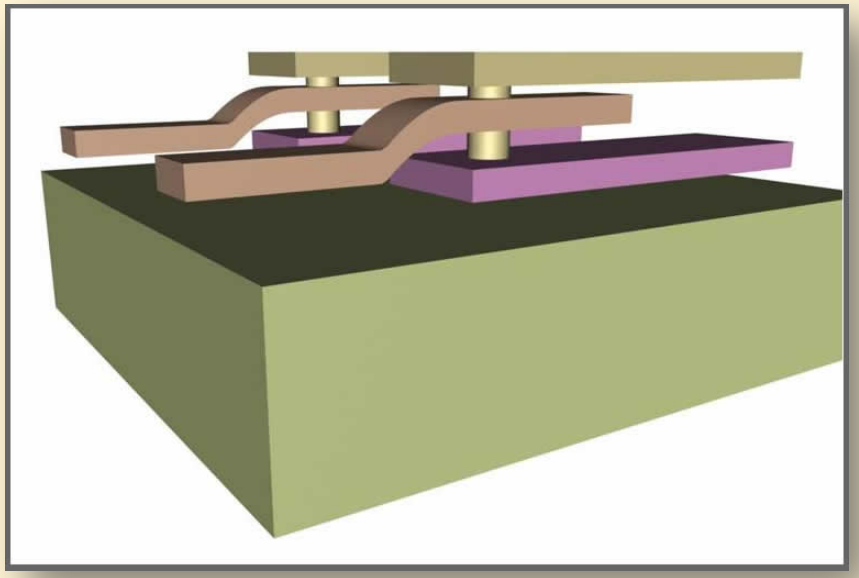
This unit provides an overview of the Photolithography process and how patterns are created for each layer.

Objectives

- Develop an outline of the photolithography process.
- Describe each step of the photolithography process.

Photolithography and MEMS

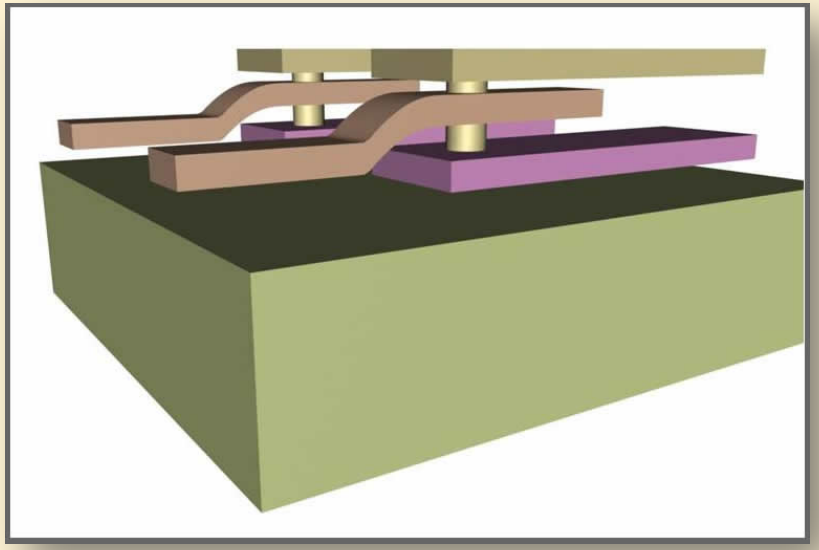
- Microelectromechanical system (MEMS) fabrication uses several layers to build micro-sized devices.
- Layers include thin films of metal, bulk silicon or polysilicon.
- This linkage assembly illustrates how each layer is a different component of the device, requiring a different pattern.
- Photolithography defines and transfers a pattern to its respective layer.



MEMS Linkage Assembly

[Linkage graphic courtesy of Khalil Najafi, University of Michigan]

Photolithography and MEMS



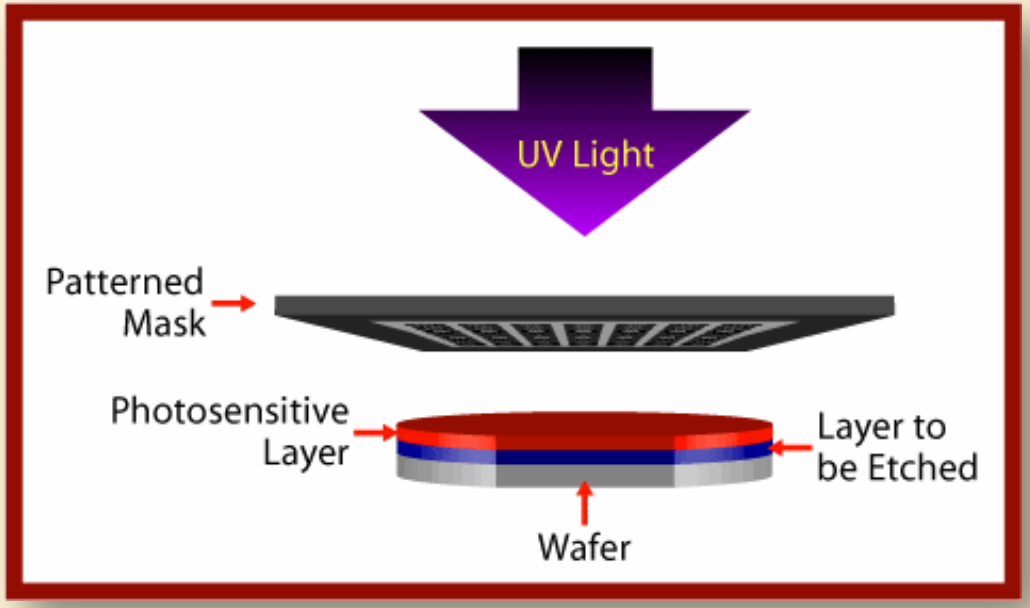
MEMS Linkage Assembly
[Linkage graphic courtesy of Khalil Najafi, University of Michigan]

This linkage assembly requires "at least" five layers.

Can you see at least five layers?

(Hint: In MEMS fabrication, some layers are removed completely leaving behind a void so that components can "float".)

Introduction – Photolithography Process



Photolithography transfers a pattern onto a wafer.

- A light source is used to transfer an image on a mask to a substrate covered with a photosensitive material.
- This same pattern is later transferred into another layer using a different process.

Photolithography vs. Photography

A twentieth century photographic process uses exposed film to create a patterned mask (negative). In a dark room, the negative is placed between a light source and a photosensitive paper.

- The paper has been coated with a light-sensitive 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. *(see picture right)*

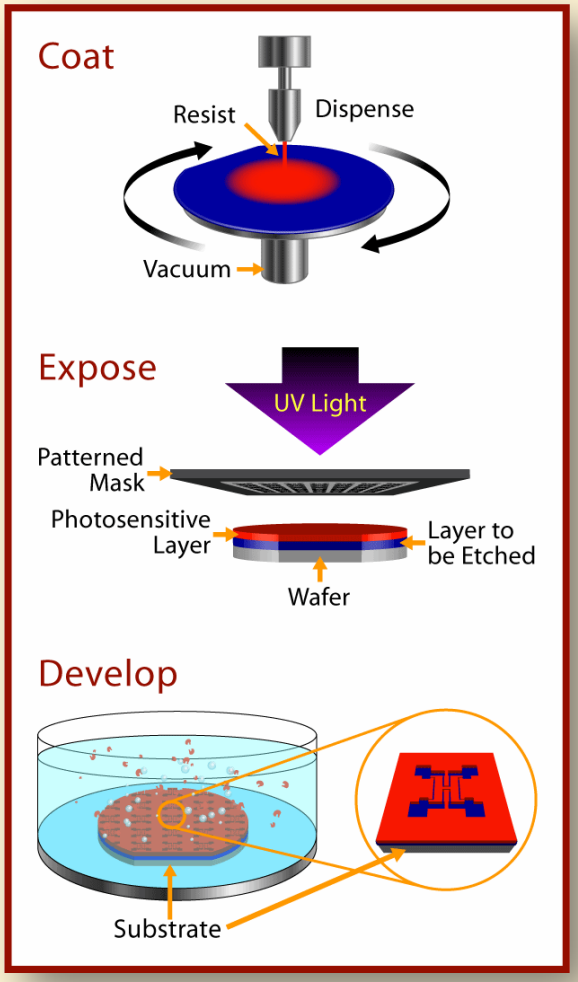
Photographer/Painter: Jean-Pol Grandmont, shot and develop (b&W) and scanner [Courtesy of Jean-PolGrandmont]

Overview of Photolithography Steps

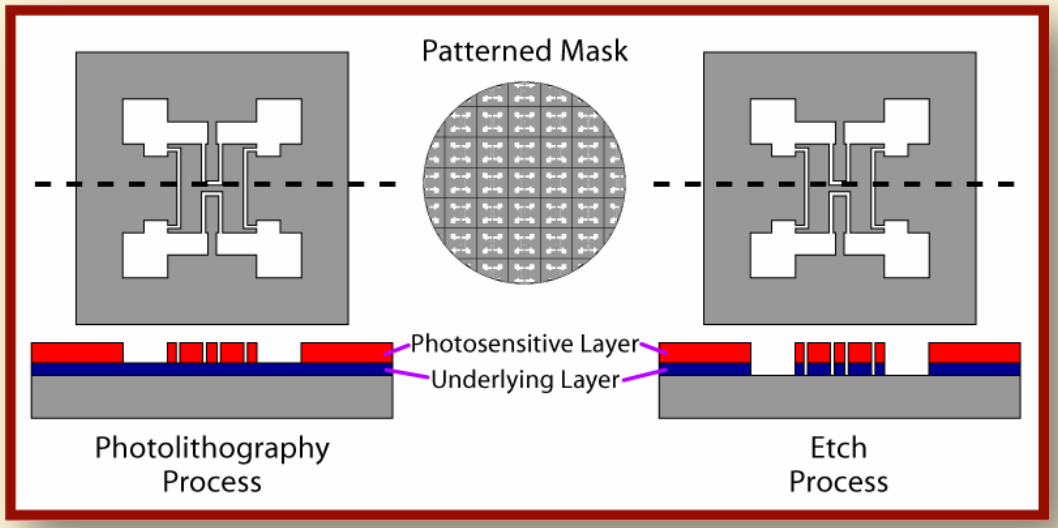
In the fabrication of MEMS, photolithography is used several times, any point in the process when a pattern needs to be defined.

This unit provides an overview of the three primary steps of the photolithography process:

- Coat
- Expose
- Develop



Pattern Transfer



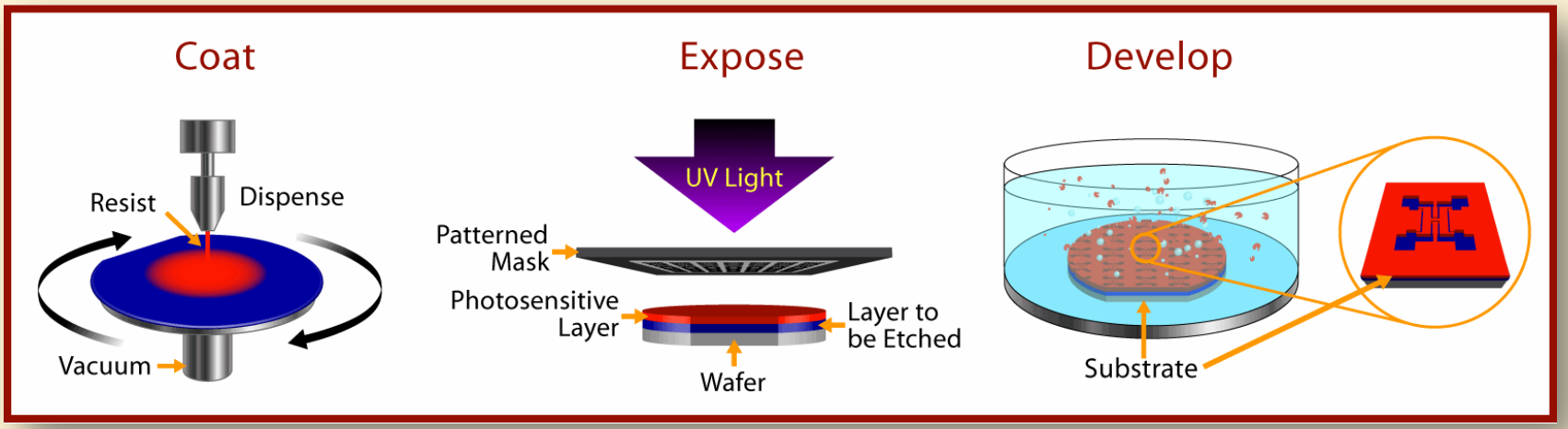
Pattern Transfer to Underlying Layer

Each layer of a MEMS or microsystems device has a unique pattern.

- Photolithography transfers this pattern from a mask to a photosensitive layer.
- Another process transfers the pattern from the photosensitive layer into an underlying layer.
- After the pattern transfer, the resist is stripped (removed).

Three Steps of 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 Deep UV (ultraviolet), Near UV or x-ray.
- Develop - The exposed photoresist is dissolved with a chemical developer.



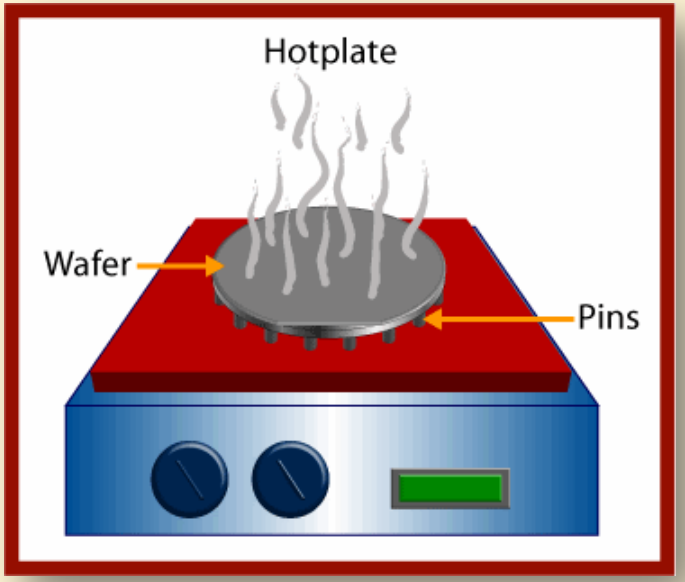
Coat Step: Surface Conditioning

In most applications, surface conditioning precedes the photoresist. Reasons for conditioning the wafer's surface:

- Presence of other molecules or particles create resist adhesion problems and resist thickness uniformity.
- Intermediates (i.e. HMDS) prepare the surface for adhesion by allowing
  - an organic material (resist) to adhere to an inorganic surface (substrate)
  - materials with different surface tensions to adhere to each other, by creating a hydrophobic surface for the resist to adhere to (which it likes to do).
- The most commonly used intermediate is Hexamethyldisalizane (HMDS).

Surface Conditioning

- Photoresist adheres best to a hydrophobic surface (a surface devoid of water molecules).
- It is the role of HMDS to provide such a surface.
- Before applying the HMDS, any water molecules present on the wafer are removed by heating the wafer to 100°C.

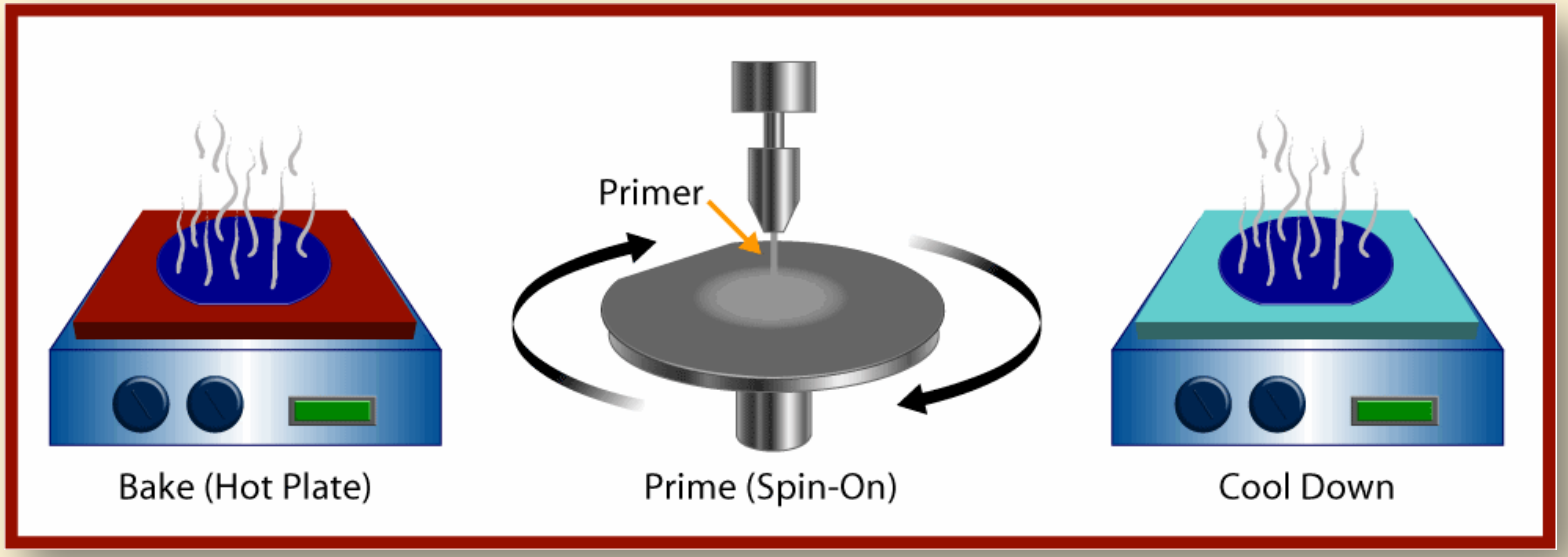


Hotplates are used to remove moisture from the wafer's surface or from coatings placed on the surface. When the wafer is placed on the hotplate, the pins lower to provide contact between the hotplate and the wafer.

Surface Conditioning

- Prepares the wafer to accept the photoresist by providing a clean surface.
- Heats the wafer to remove water molecules on the wafer surface.
- Coats the wafer with an intermediate that boosts adhesion of the photoresist to the wafer's surface. (Usually Hexamethyldisalizane or HMDS)

Surface Conditioning Steps

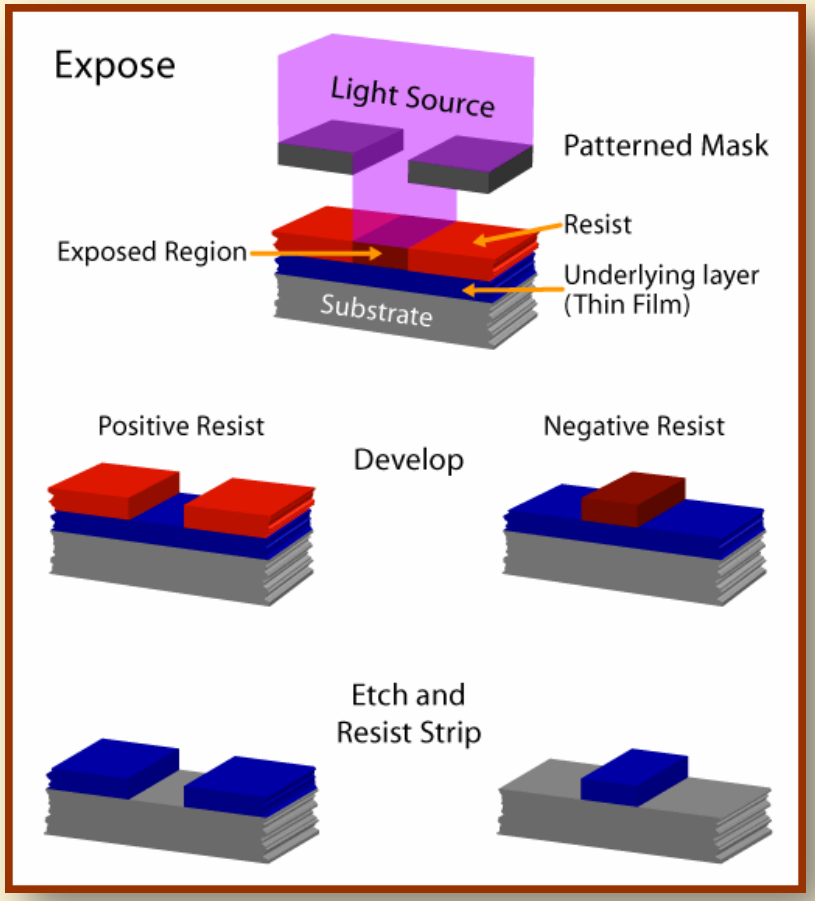


Three basic steps:

- Wafer is baked to remove the water molecules on the wafer surface
- HMDS is applied (prime) to create a hydrophobic surface
- Wafer is cooled to room temperature.

Photoresist (Resist)

- A mixture of organic compounds in a solvent solution.
- There is negative or positive photoresist (depending on how it responds to light)
- *Negative resist* - Exposed materials harden. A negative mask is left after develop.
- *Positive resist* - Exposed regions become more soluble. A positive mask is left after develop.



Photoresist - Positive vs. Negative

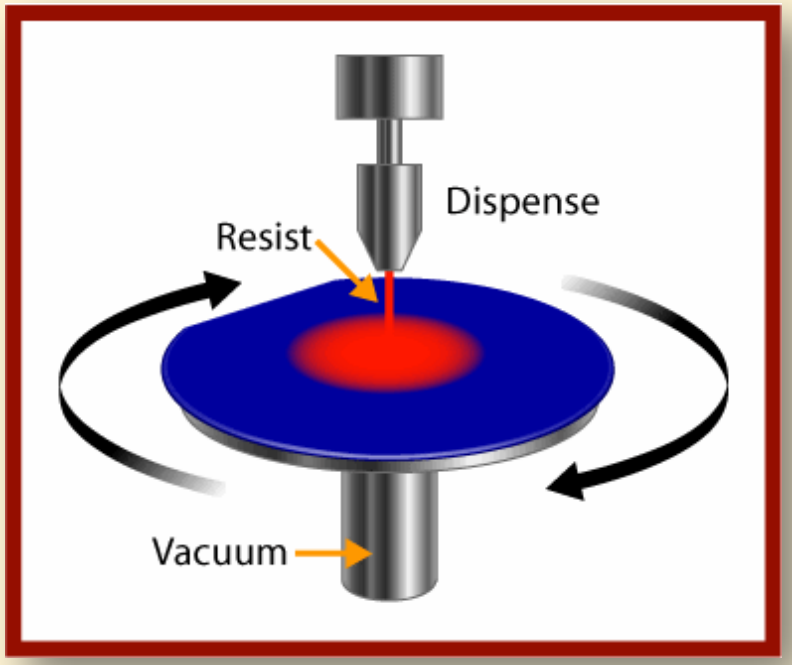
Coat Process

- The coat process is the application of photoresist to the wafer's surface.
- The resist must be
  - thick enough and durable enough to withstand the next process steps and
  - uniform (evenly distributed) in order to prevent problems during the expose process.

Spin Coating

The most common method for coating a wafer.

- Wafer is placed on a vacuum chuck
- A vacuum holds the wafer on the chuck
- Resist is applied
- Chuck accelerates for desired resist thickness
- Chuck continues to spin to dry film



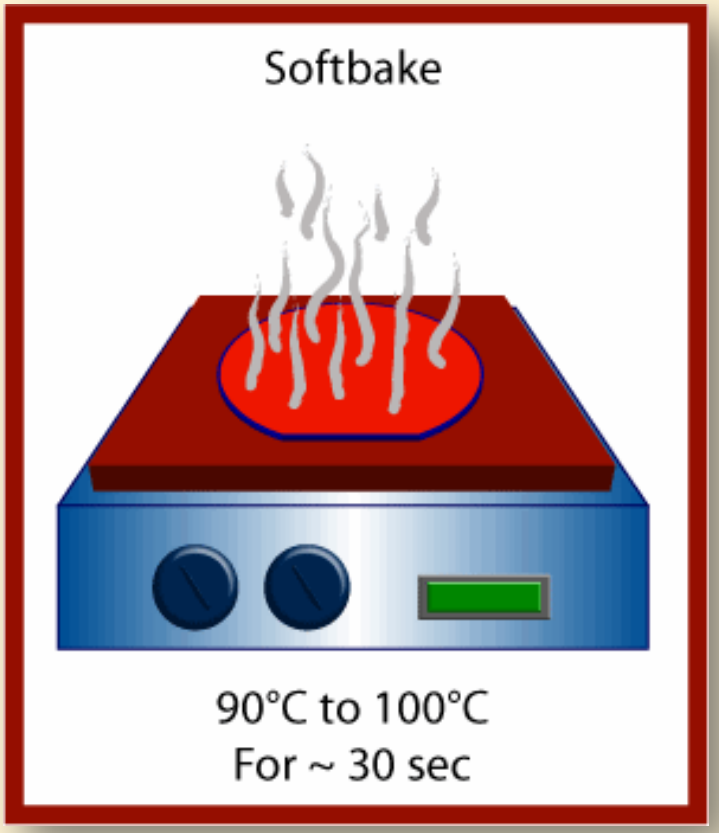
Spin Coating

Challenge Question

What could affect the uniformity of the photoresist during the coat process?

Softbake

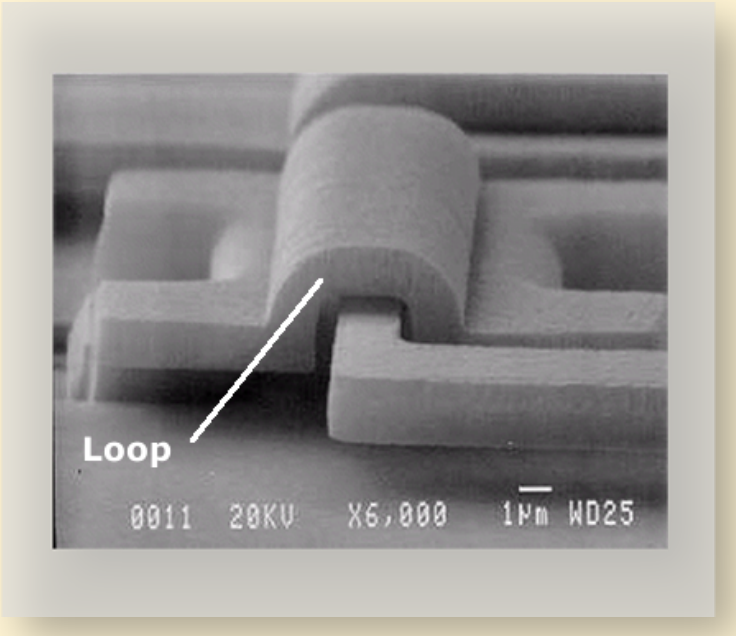
- After the photoresist is applied to the desired thickness, a *softbake is used to remove the residual solvents of the photoresist.*
- After the softbake, the wafer is cooled to room temperature.



Softbake after Applying Resist

Alignment

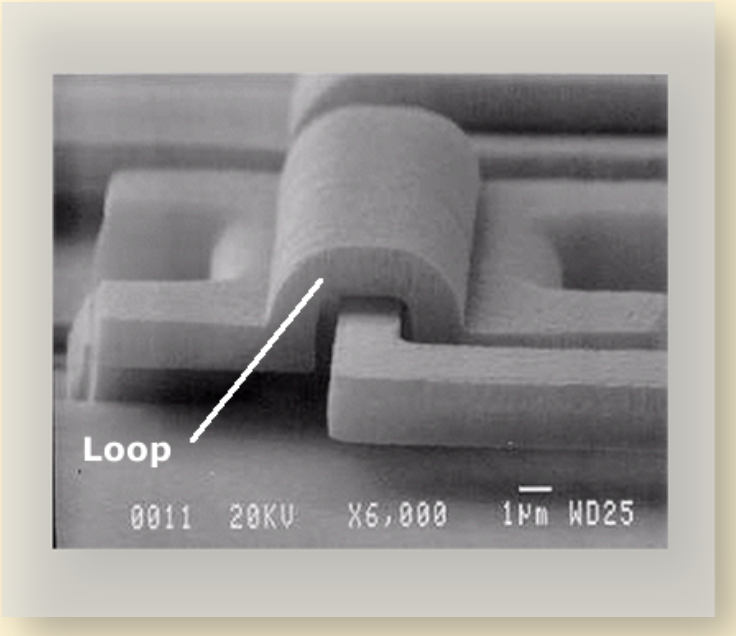
- "Align" is one of the most critical step in the entire microsystems fabrication process.
- Due to the microscopic size of these devices, a misalignment of one micron or smaller can destroy the device and all the devices on the wafer.
- Each layer must be aligned properly and within specifications to the previous layers and subsequent layers.



Microscopic Hinge
[Photo courtesy of Sandia National Laboratories]

Misalignment

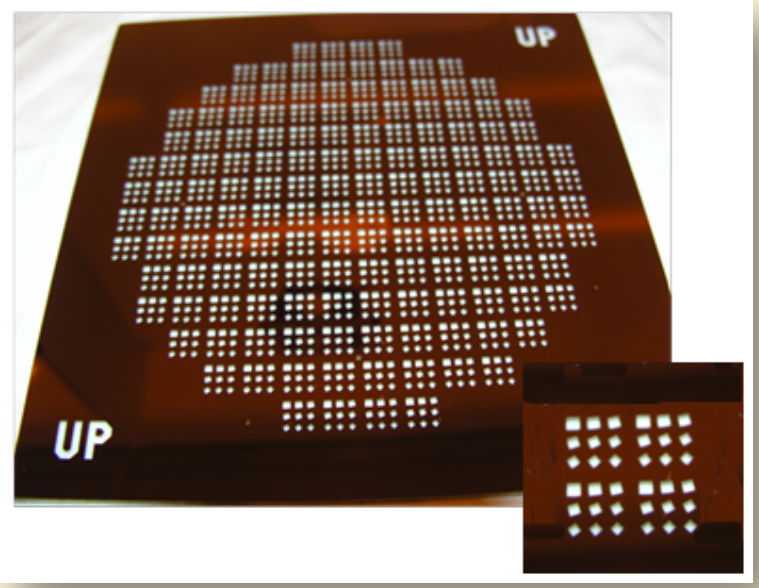
- Take a look at the microscopic hinge. Notice the 1μm scale in the bottom right. Using this scale, we might estimate the width of the space between the hinged component and its enclosure (the loop) to be approximately 0.5 μm or 500 nm.
- *What would be the result if the mask for the loop was misaligned by 0.5 μm?*



Microscopic Hinge
[Photo courtesy of Sandia National Laboratories]

Mask vs. Reticle

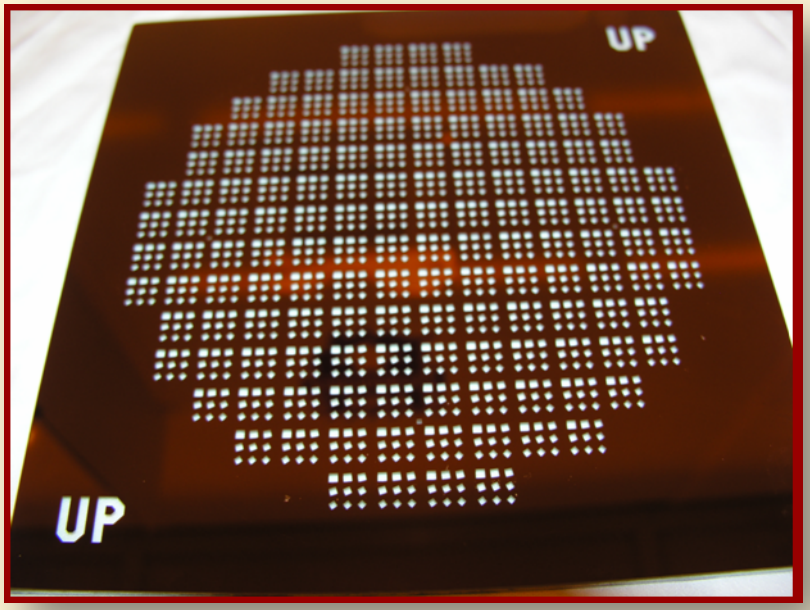
- A patterned mask (or reticle) is a quartz or glass plate with the desired pattern (usually in chrome). The picture shows a “mask” used to expose an entire wafer.
- Notice the repeating pattern throughout the mask. Each pattern is a “reticle” or pattern for one device.
- Expose equipment may use a whole mask or a smaller quartz plate with just a few reticles (inset).



Mask and Reticle (inset)

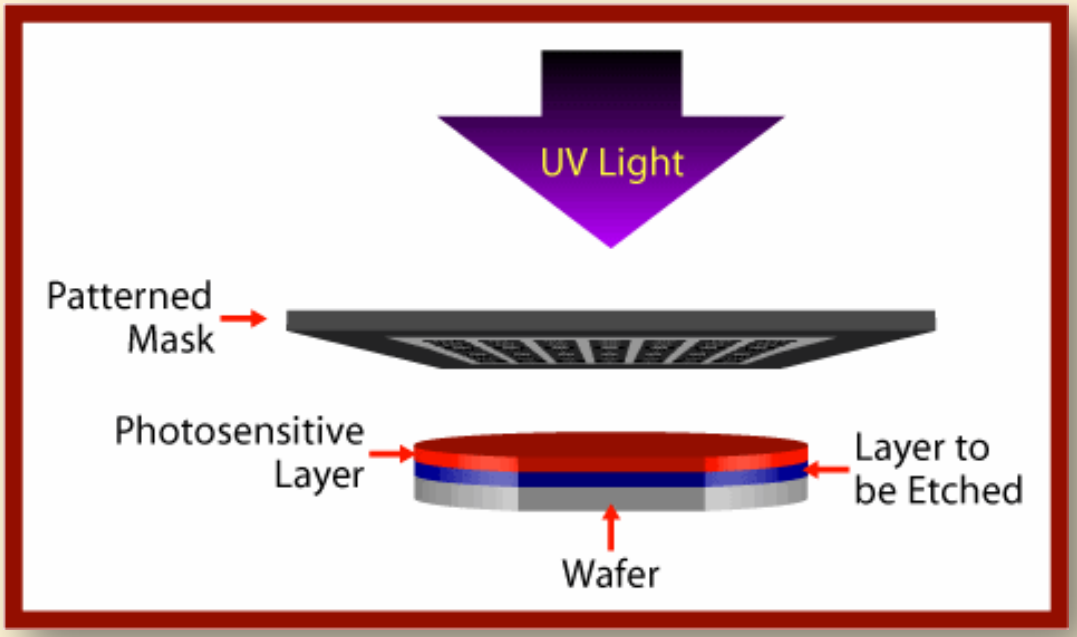
Align

- The mask or reticle is locked into the expose equipment and the wafer is aligned to the mask 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 expose the entire wafer.
- When a reticle is used, the reticle is "stepped" around the wafer exposing a small amount of the wafer with each step.



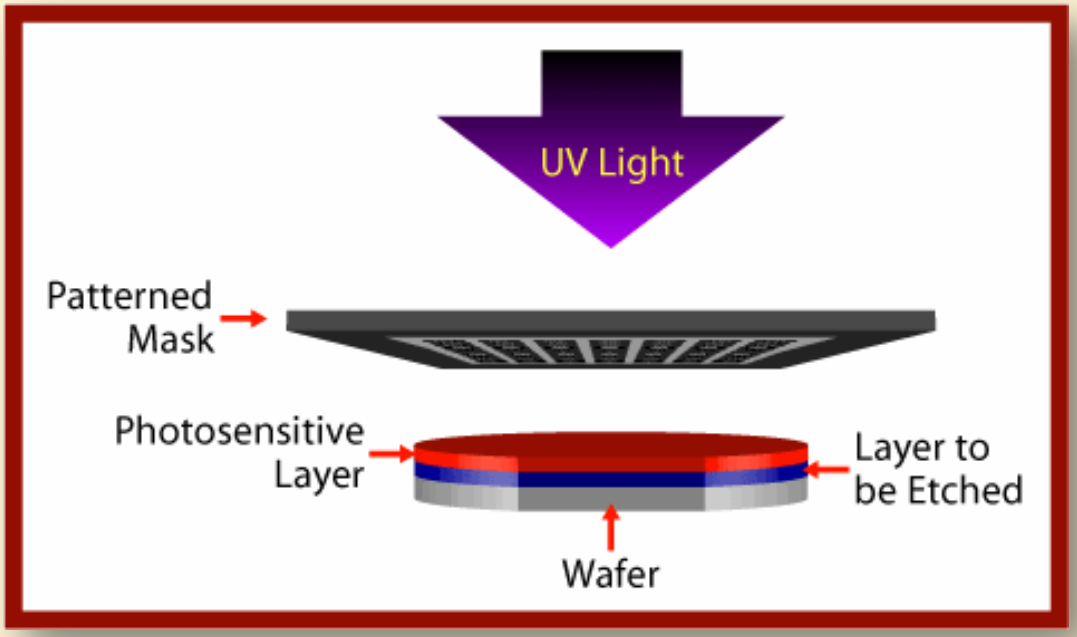
Quartz Mask

Expose



- The wafer is exposed by UV (ultraviolet) from a light source.
- UV travels through the mask to the resist.
- A chemical reaction occurs between the resist and the UV.
- Only those areas not protected by the mask undergo a chemical reaction.

Review Question



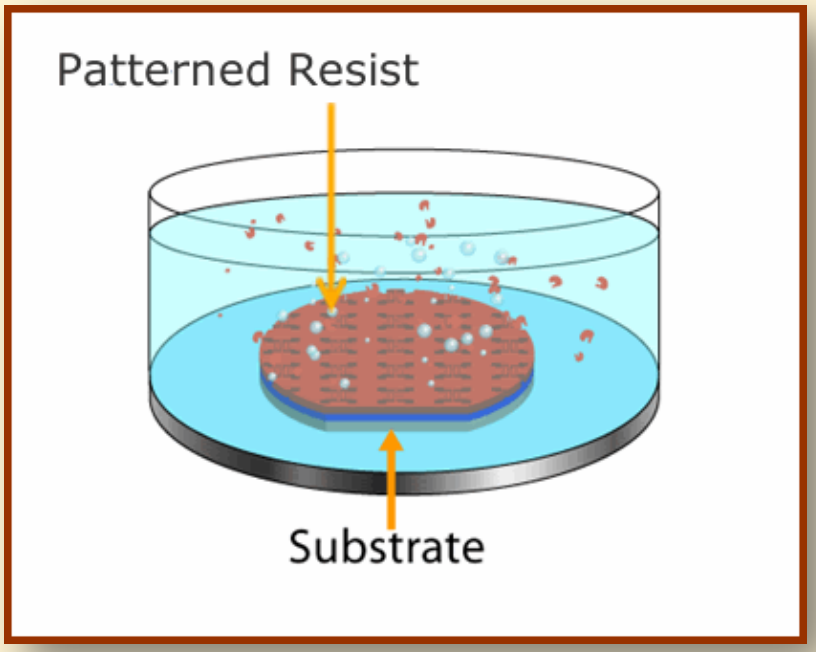
Remember positive vs. negative photoresist?

What happens when UV hits negative resist?

What happens when UV hits positive resist?

Develop

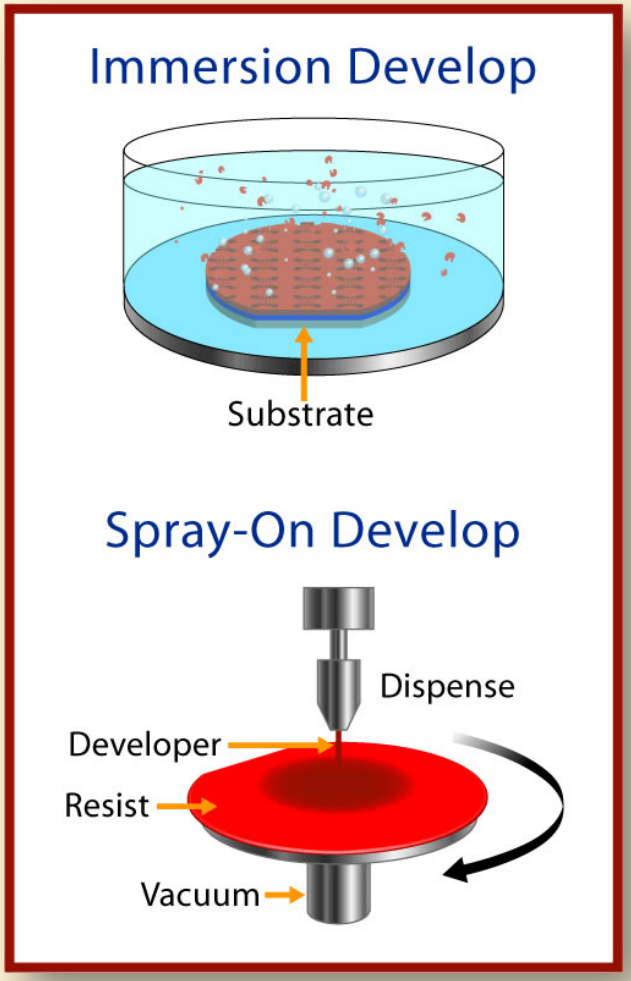
- A chemical developer dissolves portions of photoresist.
- With positive resist, the exposed resist is dissolved while the unexposed resist remains on the wafer.
- With negative resist, the unexposed resist is dissolved while the exposed resist remains.
- The develop process leaves a visible pattern within the resist.



The Develop Process

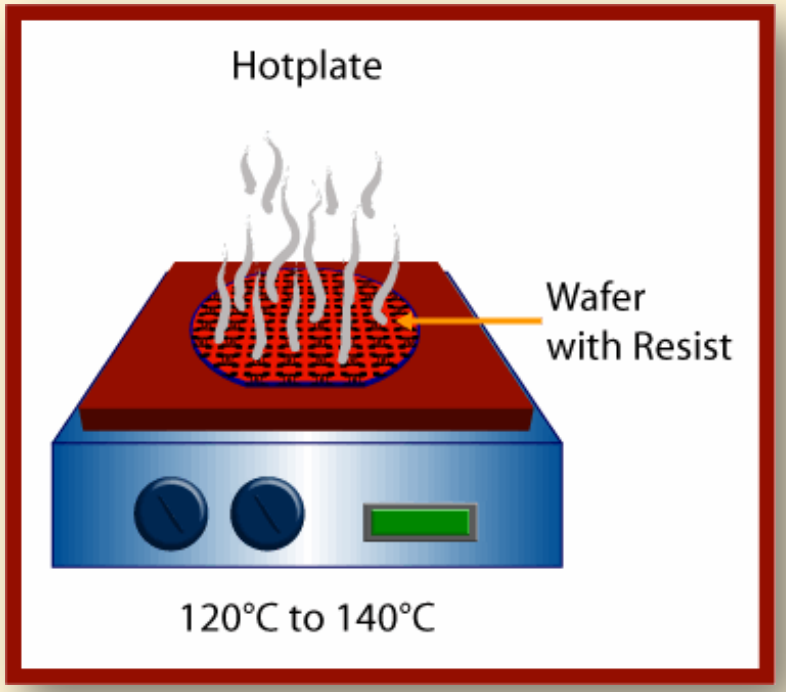
Develop

- Develop is a wet process.
- Wafers are immersed in the developer or the developer is sprayed on a wafer.
- Timing is critical. Too little or too much time could affect the critical dimensions of the pattern transfer.
- To stop the chemical reaction of the developer with the photoresist, the wafers are rinsed with DI water then spin-dried.



Hardbake

- Post-develop hardbake hardens the photoresist for the next process.
- The temperature of the hardbake is higher than the softbake after coat. 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.



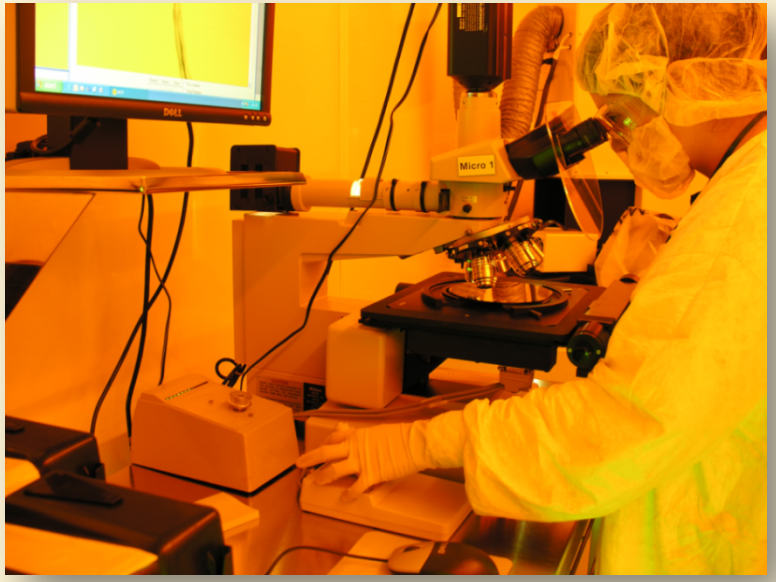
Hardbake

Inspect

- Wafers are inspected immediately after the photolithography process.
- Three critical parameters inspected are alignment, line widths and defects.
- *Alignment* – Is the pattern positioned accurately to the previously layer?
- *Line width or critical dimension (CD)* – Are pattern images in focus and have the correct size (CD)?
- *Defects* – Are there defects that could affect subsequent processes or the operation of the device?
  - e.g. particles, scratches, peeling (lifting) of the resist, holes in the resist, scumming (an underdeveloped or underexposed pattern)

Inspect

- High powered microscopic equipment is used to inspect wafers.
- Software measures the width of a printed structure and provides information to the technician.
- Alignment marks are designed into the masks and reticles and patterned into each layer as reference points during inspect. This allows the overlay of a subsequent step to be measured against the previous step to identify misalignment or CD.



Wafer Inspect
[Photo courtesy of the MTTC, University of New Mexico

Let's Think About It

What are some of the critical parameters 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

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

The pattern is transferred into the wafer's surface layer during a subsequent process.

In some cases, the resist pattern can also be used to define the pattern for a deposited thin film.

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