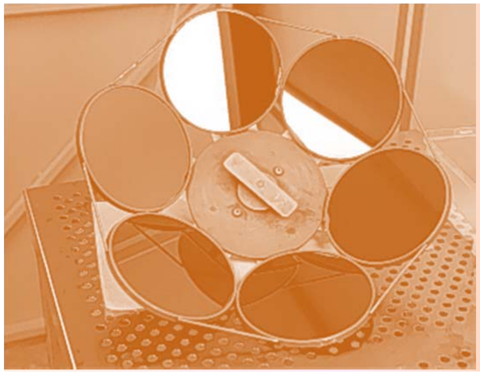

Microsystem Processes – Part II
Photolithography and Etch

Presented by

Southwest Center for
Microsystems Education
-SCME-
November 2012

Our Presenters

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SCME
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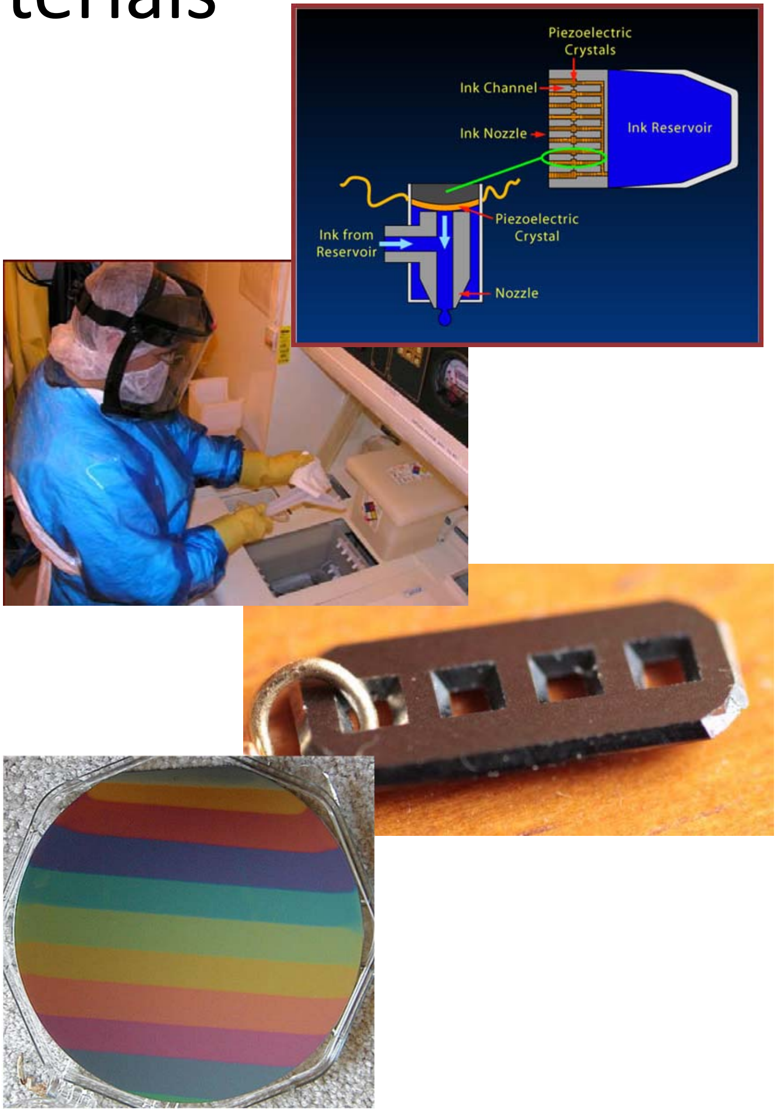
Today’s Topics

- Brief overview of what SCME can do for you
- What is Photolithography?
- Steps of Photolithography
- What is Etch?
- Types of Etch
- Photolithography and Etch in Microsystems Fabrication

Educational Materials

To date SCME offers

- 150 Shareable Content Objects (SCOs)
  - Informational Units / lessons
  - Supporting activities
  - Supporting assessments
- 37 Learning Modules in the areas of
  - Safety
  - Microsystems Introduction
  - Microsystems Applications
  - Bio MEMS
  - Microsystems Fabrication
- 11 Instructional Kits
- All are available @ scme-nm.org



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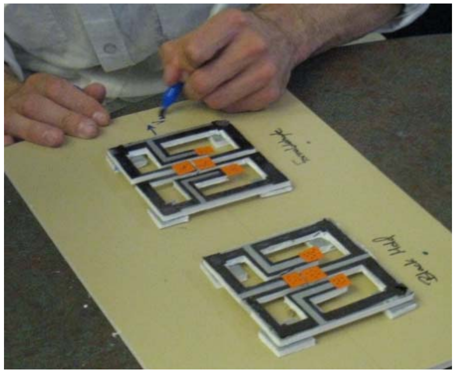
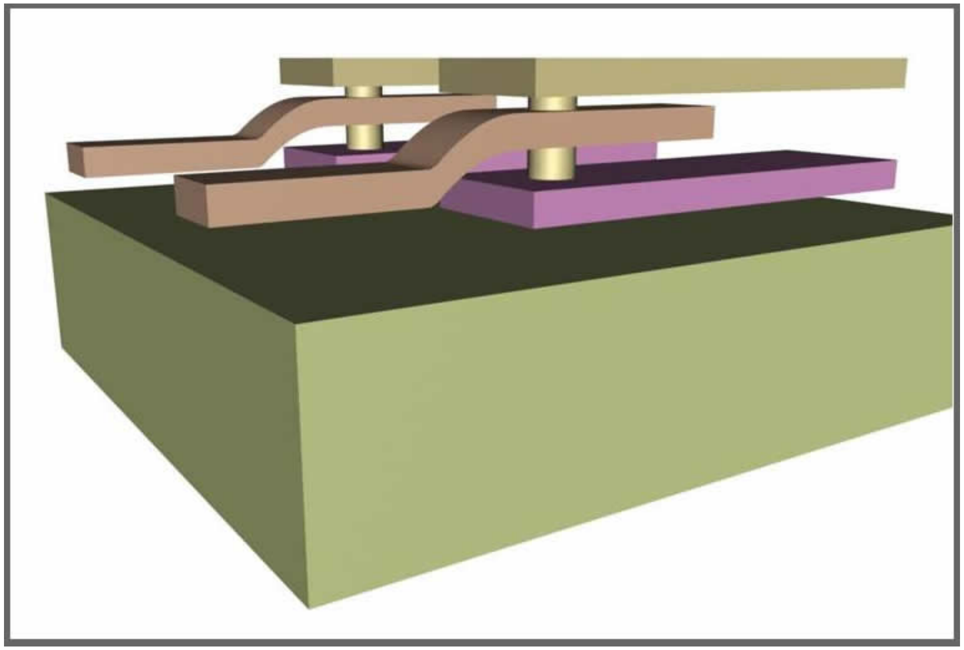
Professional Development



- 4 to 5-day workshops
- 2-day workshops
- 1-day workshop
- Conferences and conference workshops
- Create hubs at other colleges to teach our workshops
- Webinars

Photolithography and MEMS

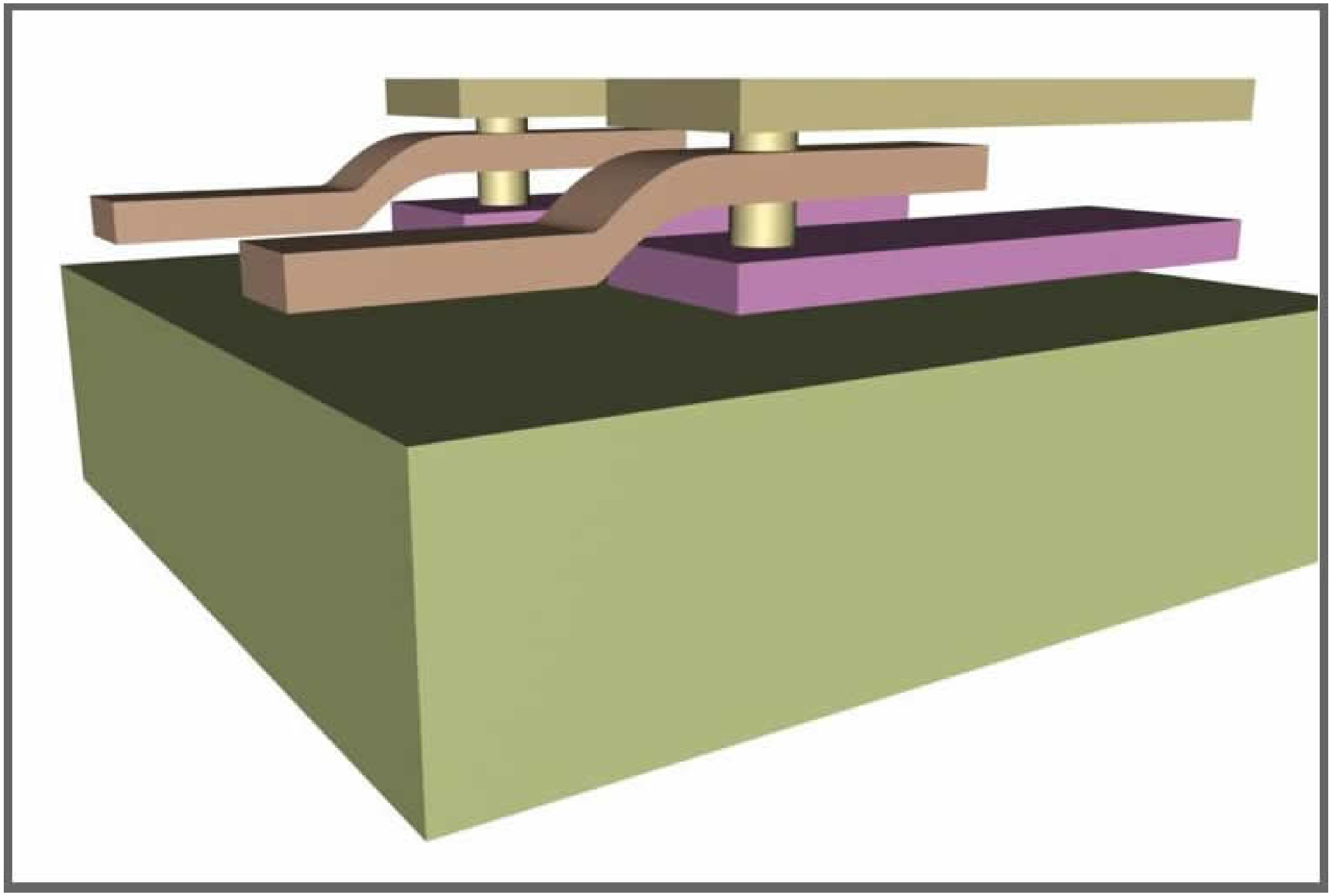
- Microsystems (MEMS) fabrication uses thin films such as polysilicon, oxide, and metals to build devices.
- Each layer of this linkage assembly is a different component of the device and requires a different pattern.
- How many photolithography steps do you think this linkage system requires?



MEMS Linkage Assembly

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

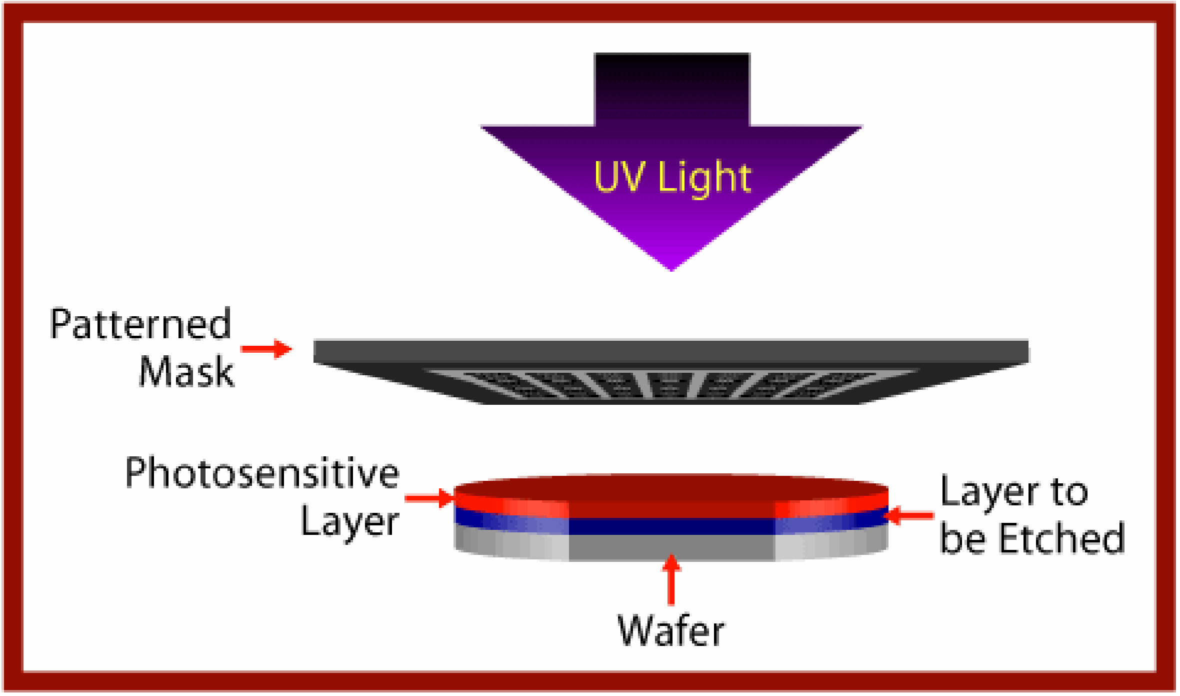
Photolithography and MEMS



MEMS Linkage Assembly

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

Photolithography Process

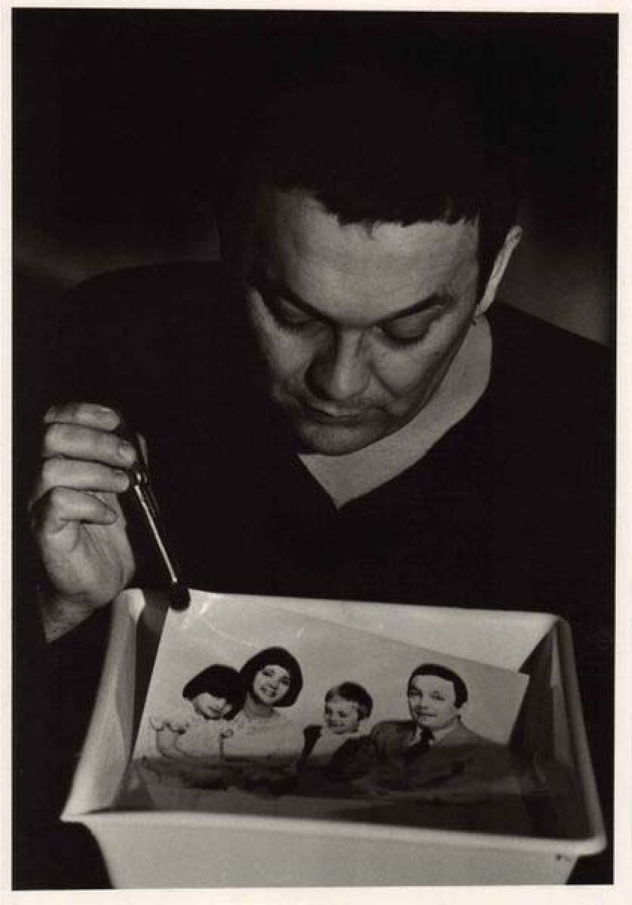


- A light source is used to transfer an image on a mask to a substrate covered with a photosensitive material.
- This same pattern is later transferred into another layer using a different process.

Photography

In a dark room, the negative is placed between a light source and a photosensitive paper.

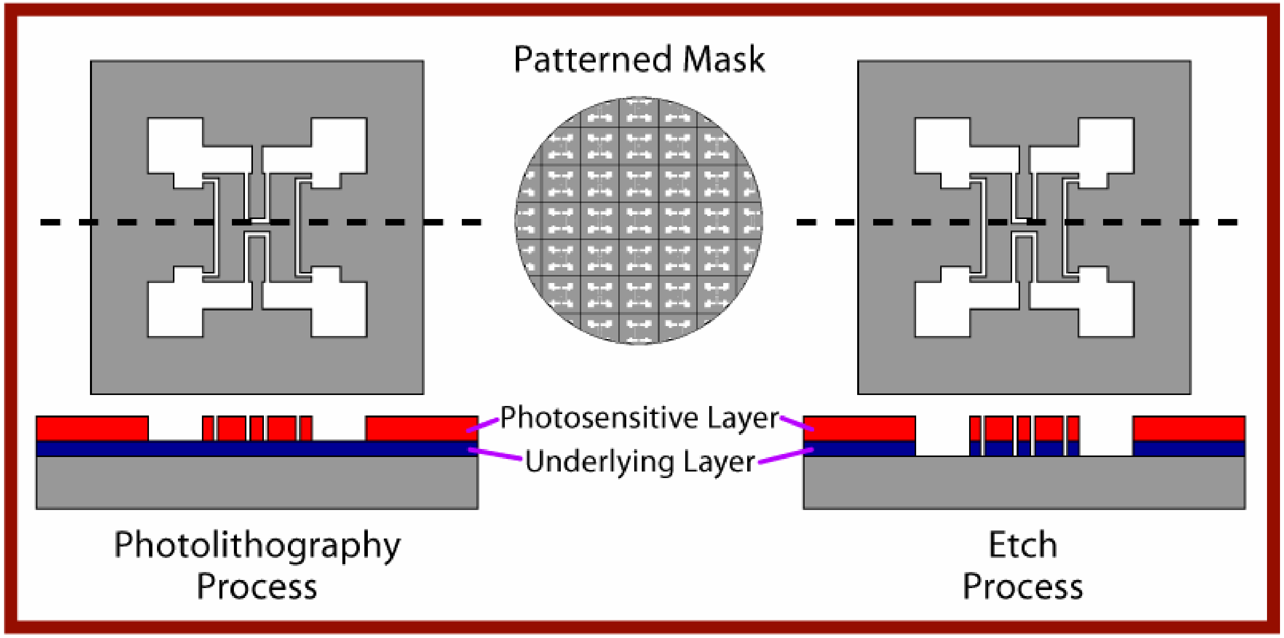
- The paper has a light-sensitive coating.
- The paper is exposed when the light travels through the negative.
- The exposed paper is placed in a liquid developer which chemically reacts with the coating, transferring the negative's image to the photographic paper.



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

[Courtesy of Jean-PolGrandmont]

Pattern Transfer

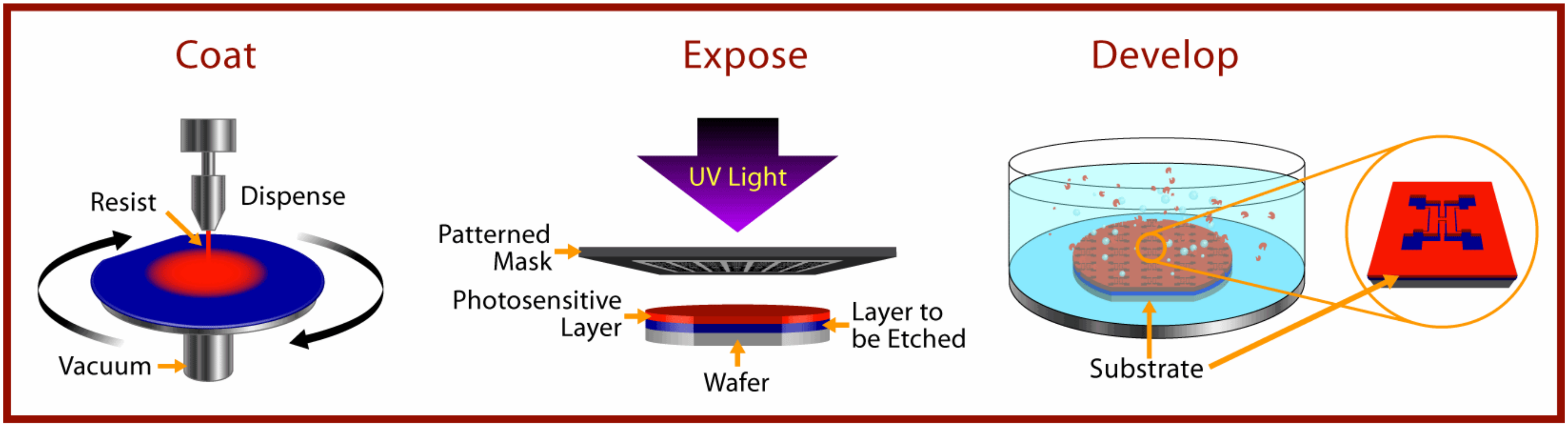


Each layer within a microsystem has a unique pattern.

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

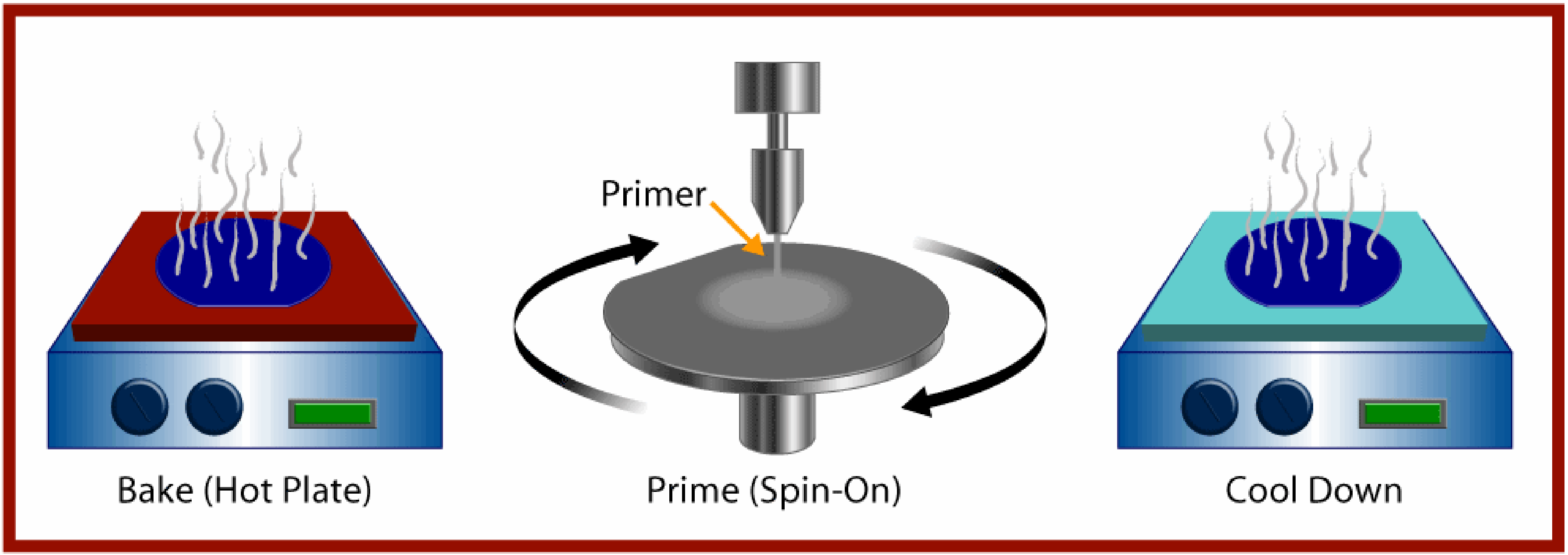
In most applications, **surface conditioning** precedes the photoresist.

Reasons for conditioning the wafer's surface:

- Presence of other molecules or particles create resist adhesion problems and resist thickness uniformity.
- Intermediates prepare the surface for adhesion . Photoresist will adhere best to a hydrophobic surface.
- The most commonly used intermediate is Hexamethyldisalizane (HMDS).

https://www.youtube.com/watch?v=41f4IkKB3zM&feature=plcp

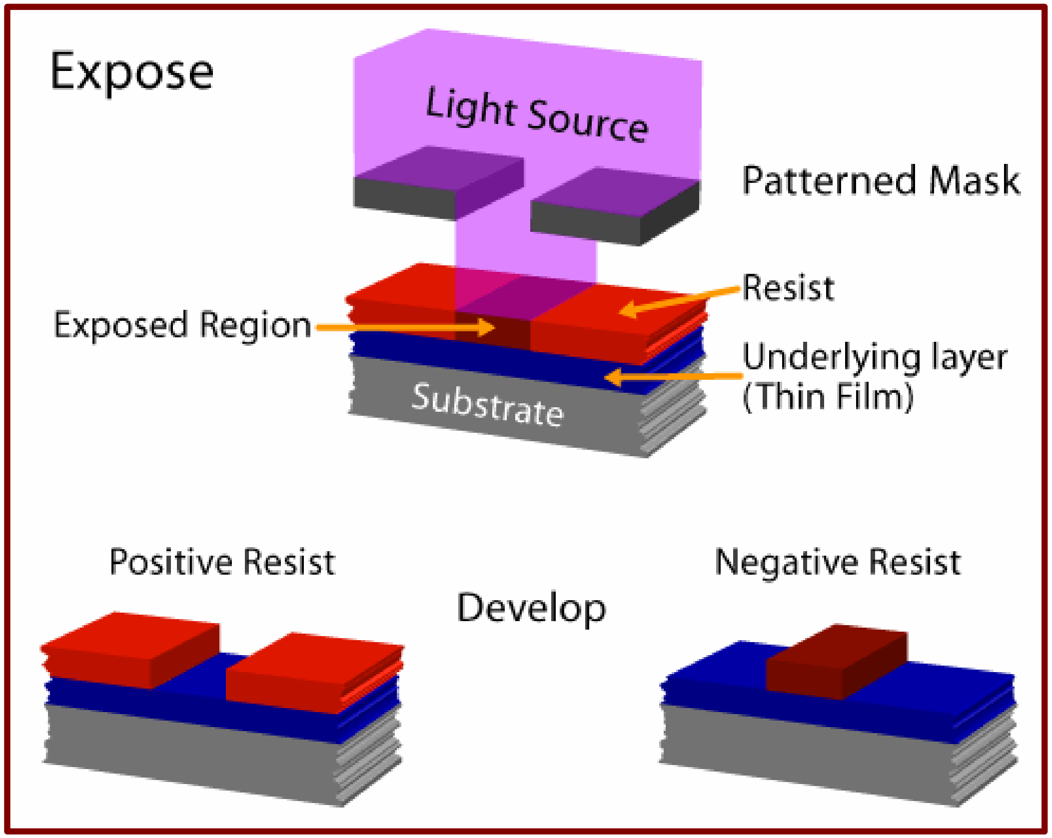
Surface Conditioning Steps



- Wafer is baked to remove the water molecules on the wafer surface
- HMDS is applied (primer) to create a hydrophobic surface
- Wafer is cooled to room temperature. This brings the wafer to the same temperature as the resist for the next process step.

Photoresist (Resist)

- Photoresist is a mixture of organic compounds in a solvent solution.
- There are negative and positive photoresists
- Positive resist - Exposed regions become more soluble. The exposed material is *removed* after develop, leaving a positive pattern.

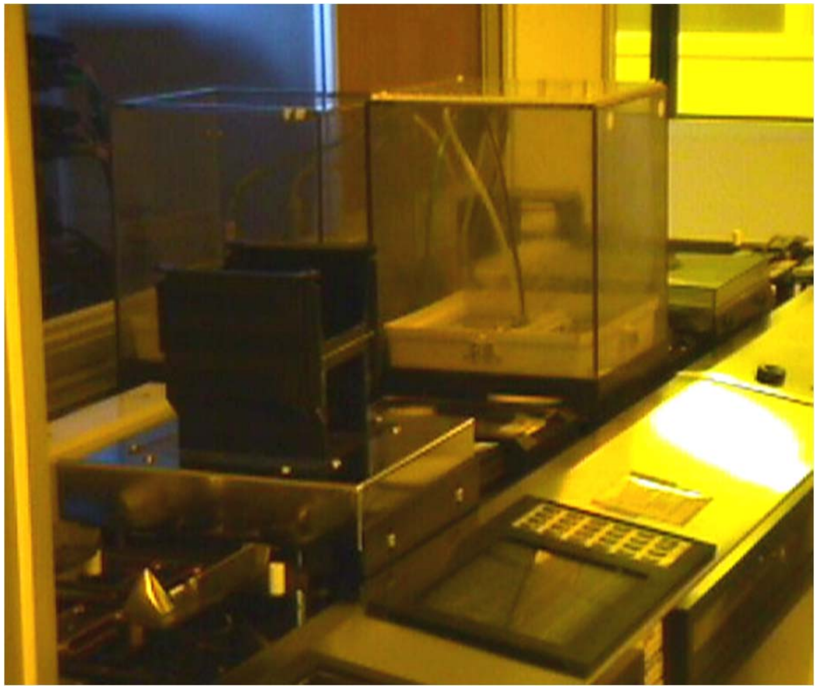


Photoresist - Positive vs. Negative

- Negative resist - Exposed materials harden. The exposed material *remains* after develop, leaving a negative pattern.

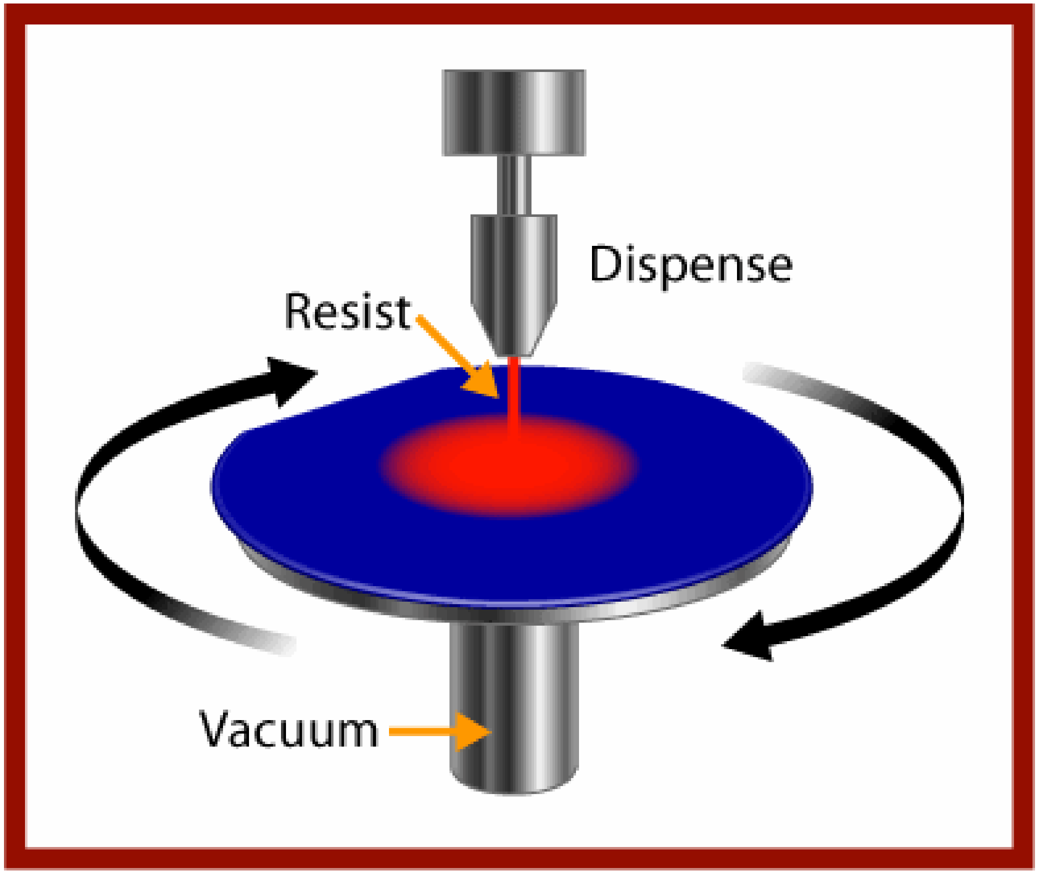
Coat Process

- The coat process is the application of resist to the wafer’s surface.
- The resist must be thick enough and durable enough to withstand the next process steps.
- Resist must be uniform in order to prevent problems during the expose process.

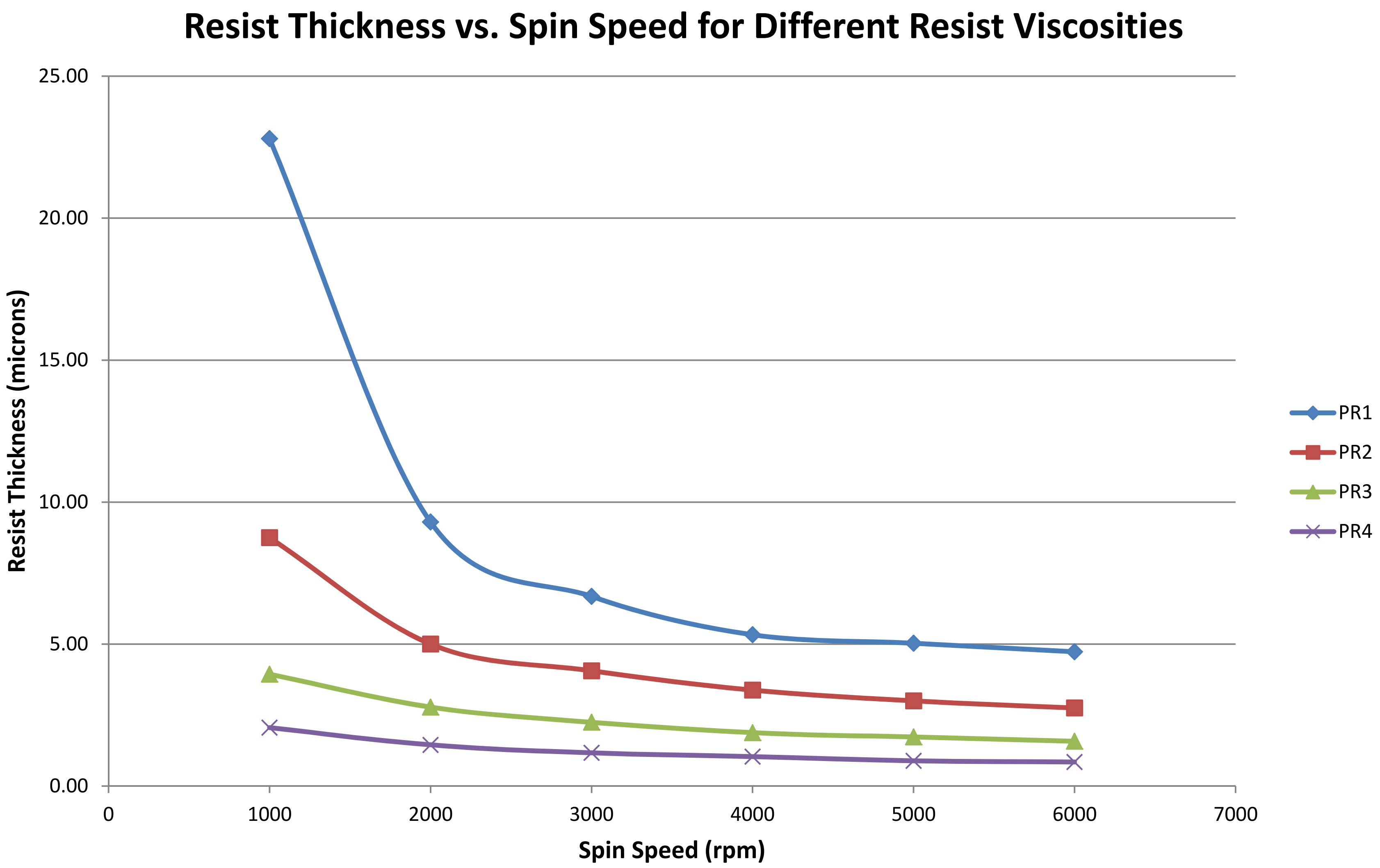


Spin Coating

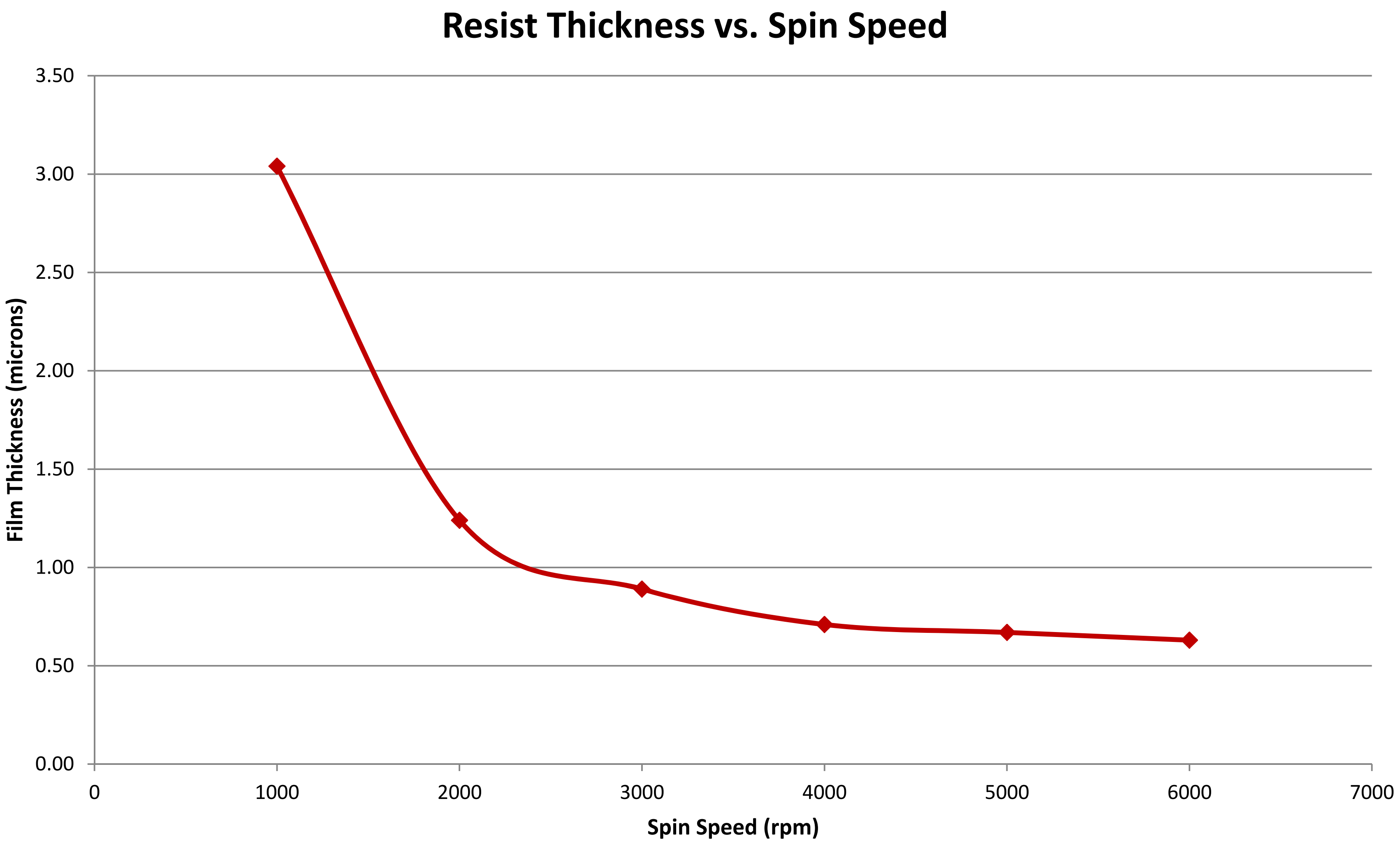
- Wafer is placed on a vacuum chuck
- A vacuum holds the wafer on the chuck
- Resist is applied
- Chuck accelerates for desired resist thickness
- Chuck continues to spin to dry film



Resist Viscosity

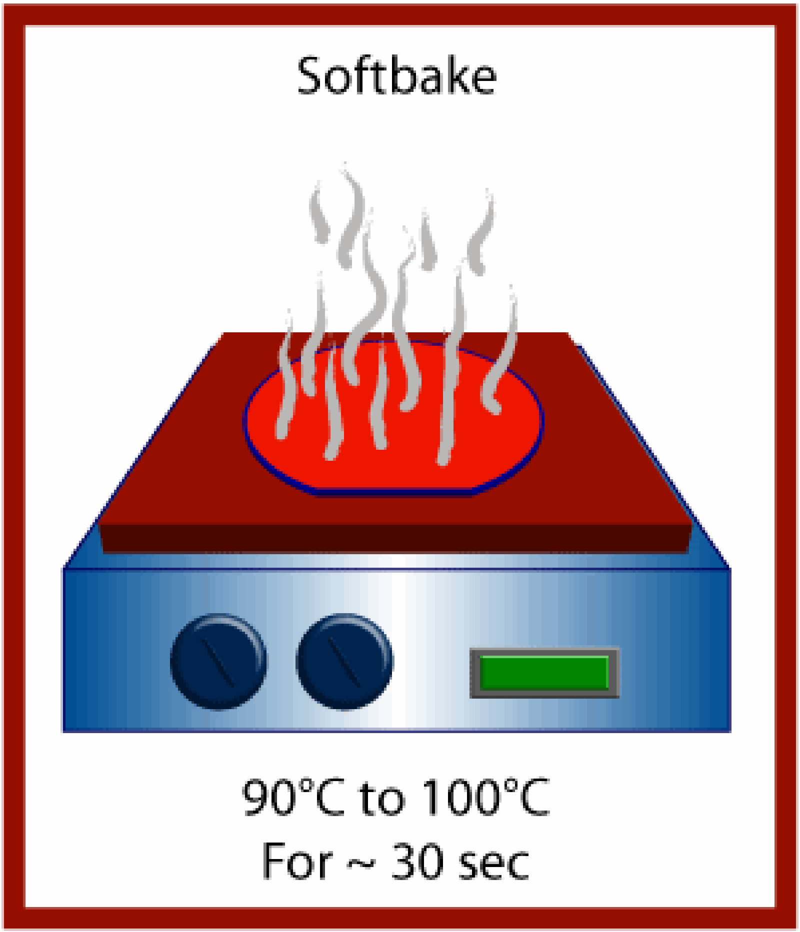


Spin Speed

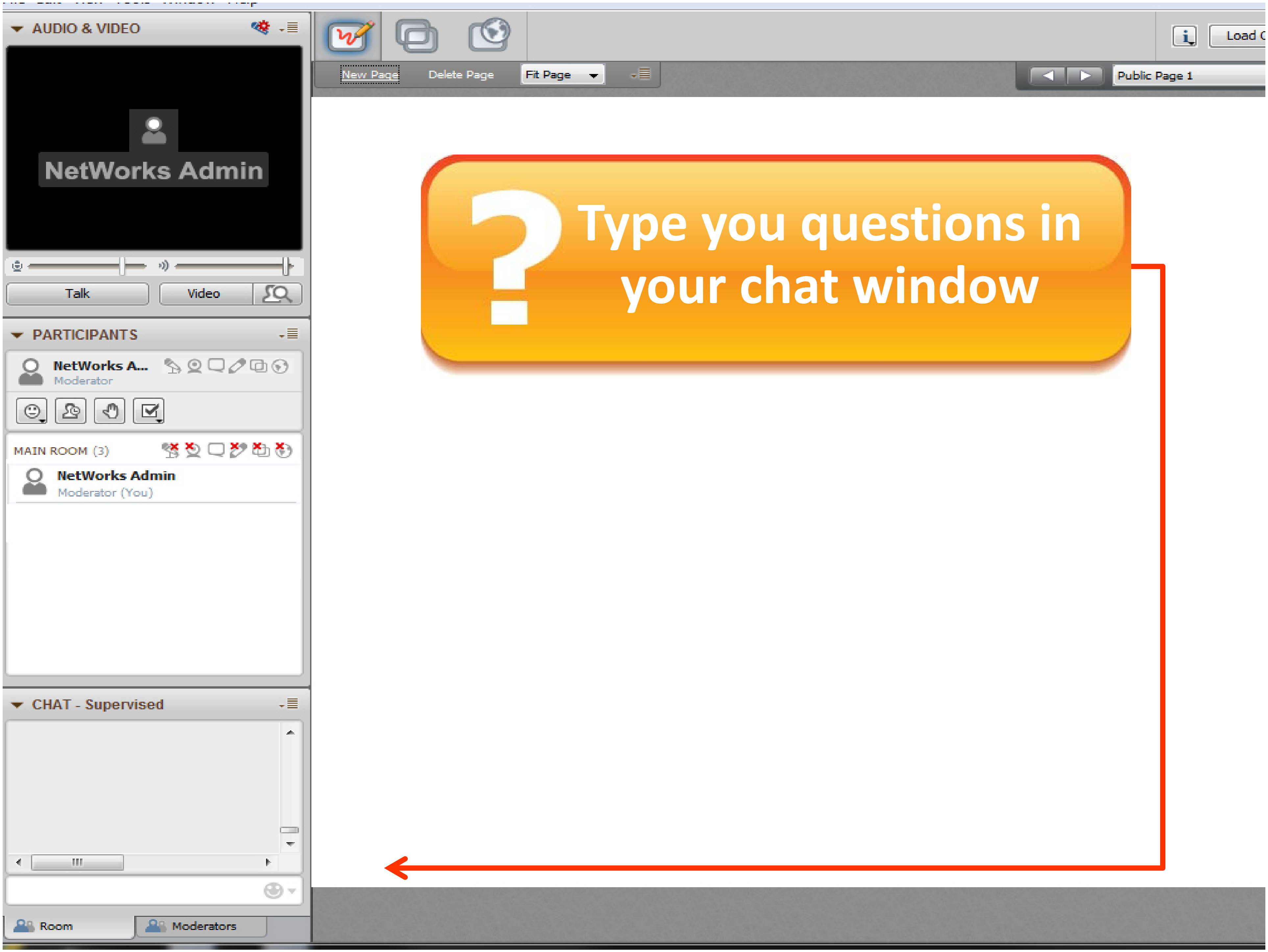

Resist Thickness vs. Spin Speed
Film Thickness (microns)
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0
1000
2000
3000
4000
5000
6000
7000
Spin Speed (rpm)

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.



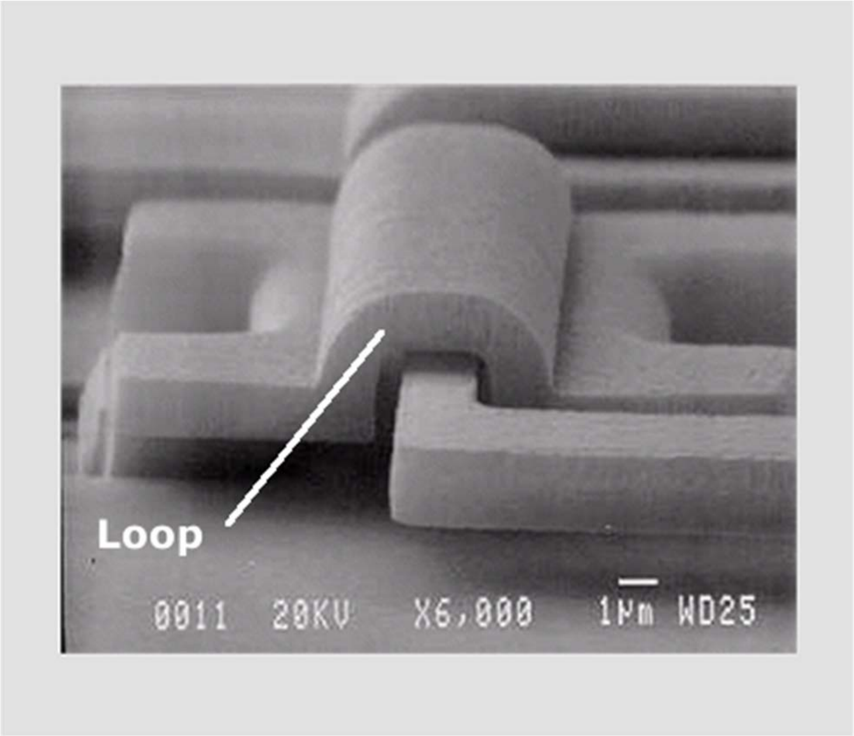
Softbake after Applying Resist



? Type you questions in your chat window

Alignment

- One of the most critical steps in microsystems fabrication.
- A misalignment of one micron or smaller can produce drastic defects, rendering the device unusable.
- Each layer must be aligned properly and within specifications to the previous layers and subsequent layers.

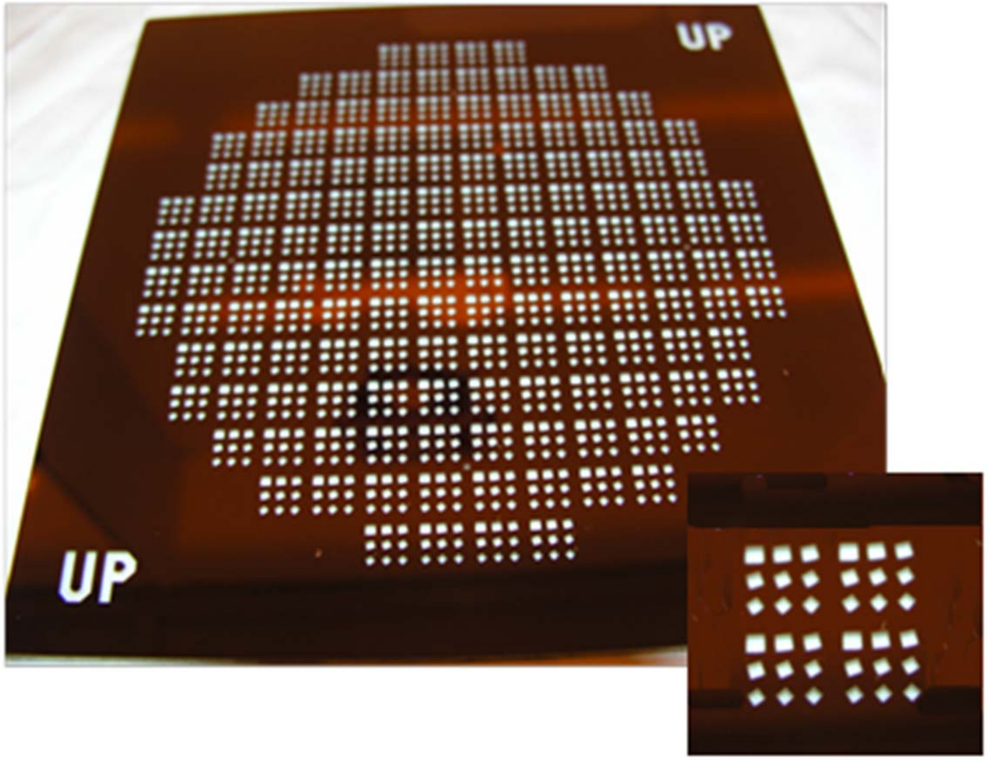


Microscopic Hinge

[Photo courtesy of Sandia National Laboratories]

Mask vs. Reticle

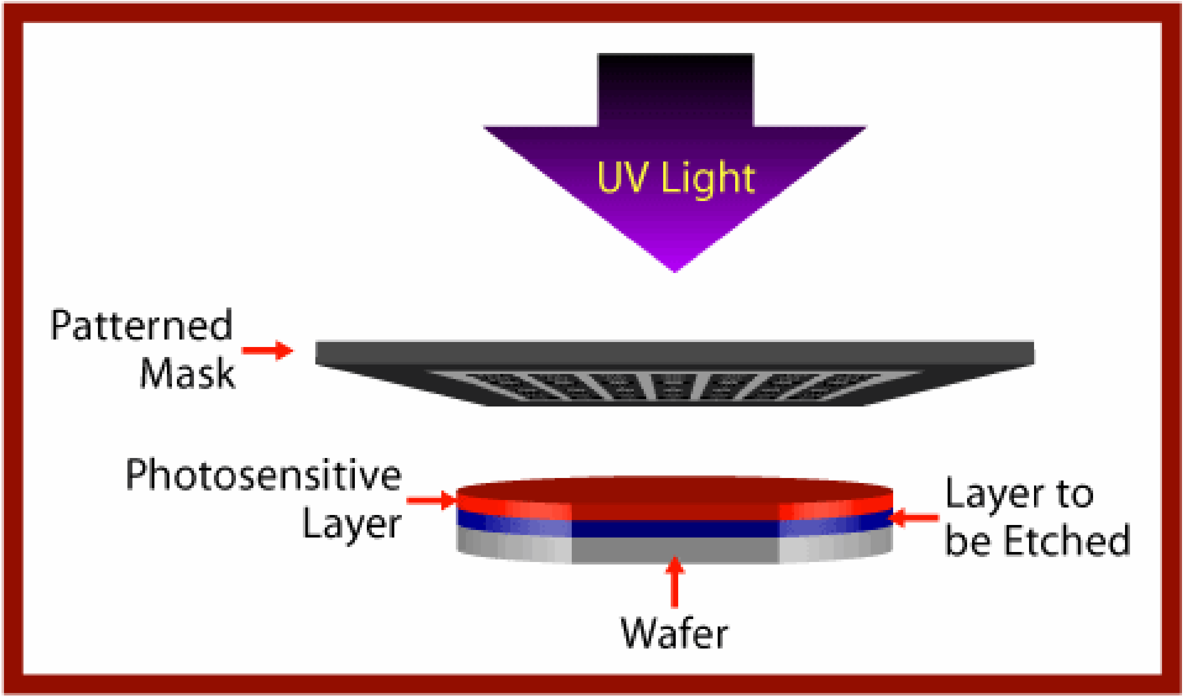
- Both Masks and Reticles are quartz or glass plates containing patterns to be transferred to a substrate.
- Mask: One single pulse of light will expose the entire substrate.
- Reticle: The pattern needs to be stepped and repeated to expose the entire substrate.
  - Reticles are often used to make masks.



Mask and Reticle (inset)

- The mask or reticle is locked into place and the wafer is aligned to the mask along the x and y coordinates.
- The z-coordinate defines the focal plane of the image.

Expose



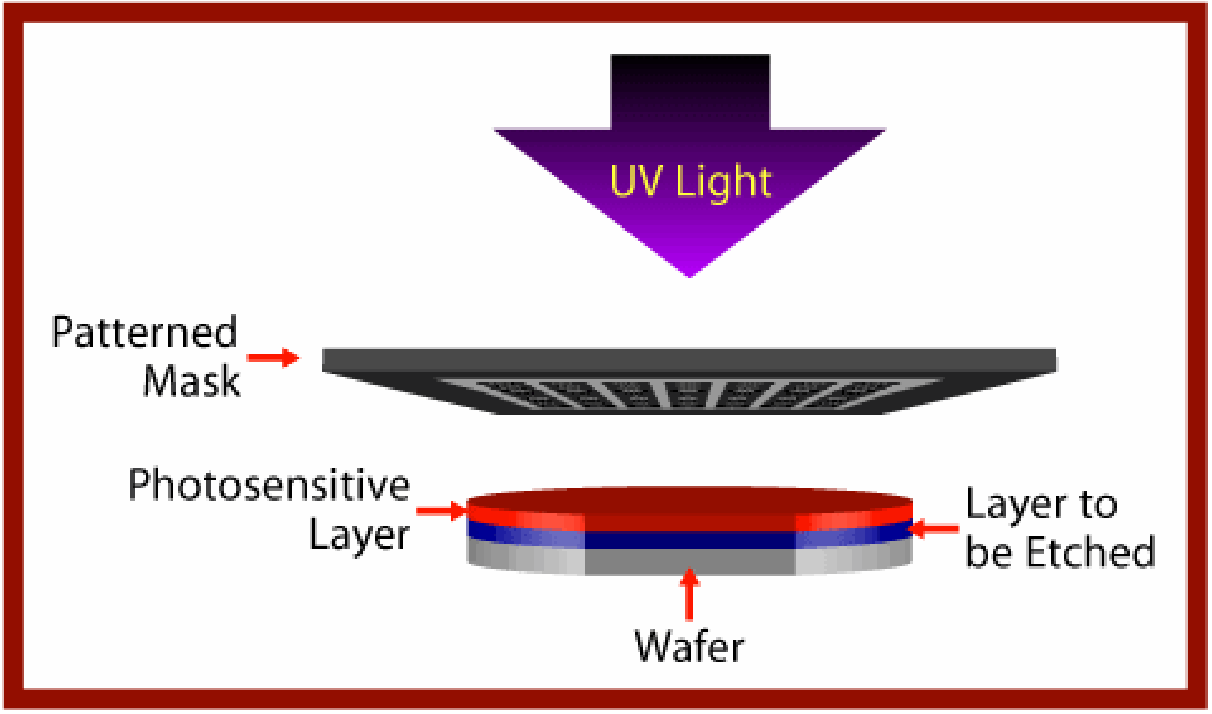
- The wafer is exposed by UV (ultraviolet) from a light source traveling through the mask to the resist.
- A chemical reaction occurs between the resist and the light.
- Only those areas not protected by the mask undergo a chemical reaction.

Question

During the expose process, which resist (positive or negative becomes soluble when exposed to UV as opposed to insoluble?

a. Positive

b. Negative

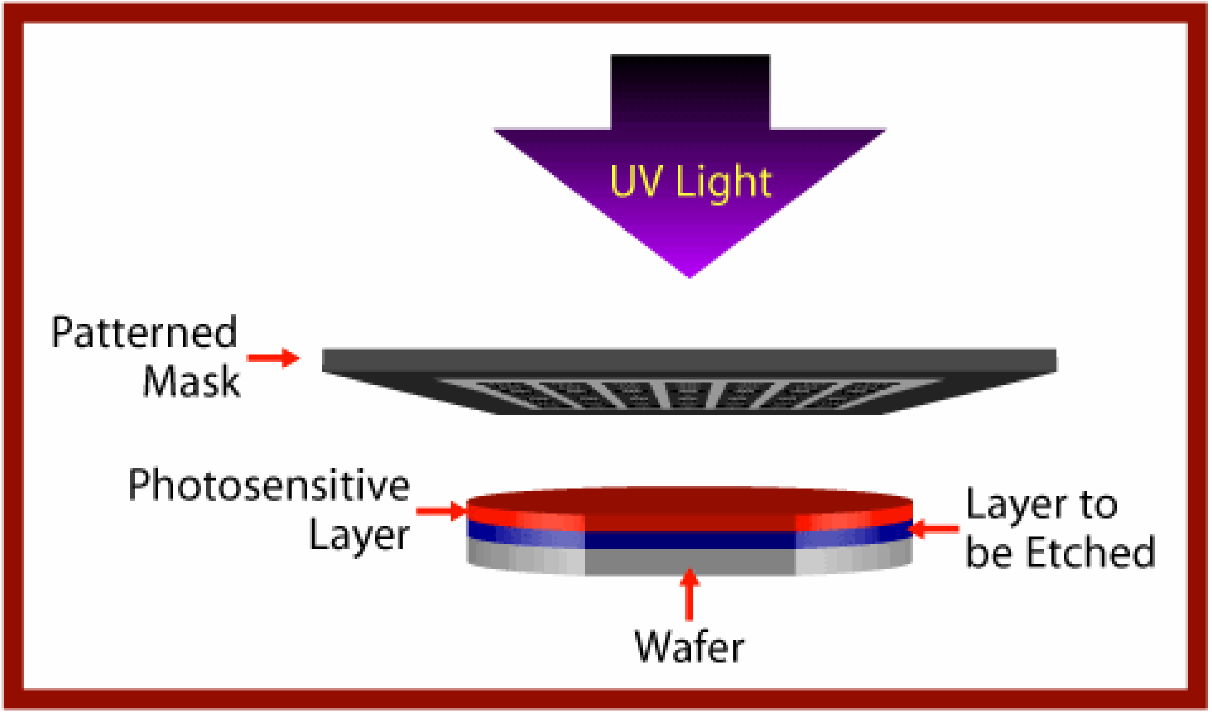


Question

During the expose process, which resist becomes soluble when exposed to UV as opposed to insoluble?

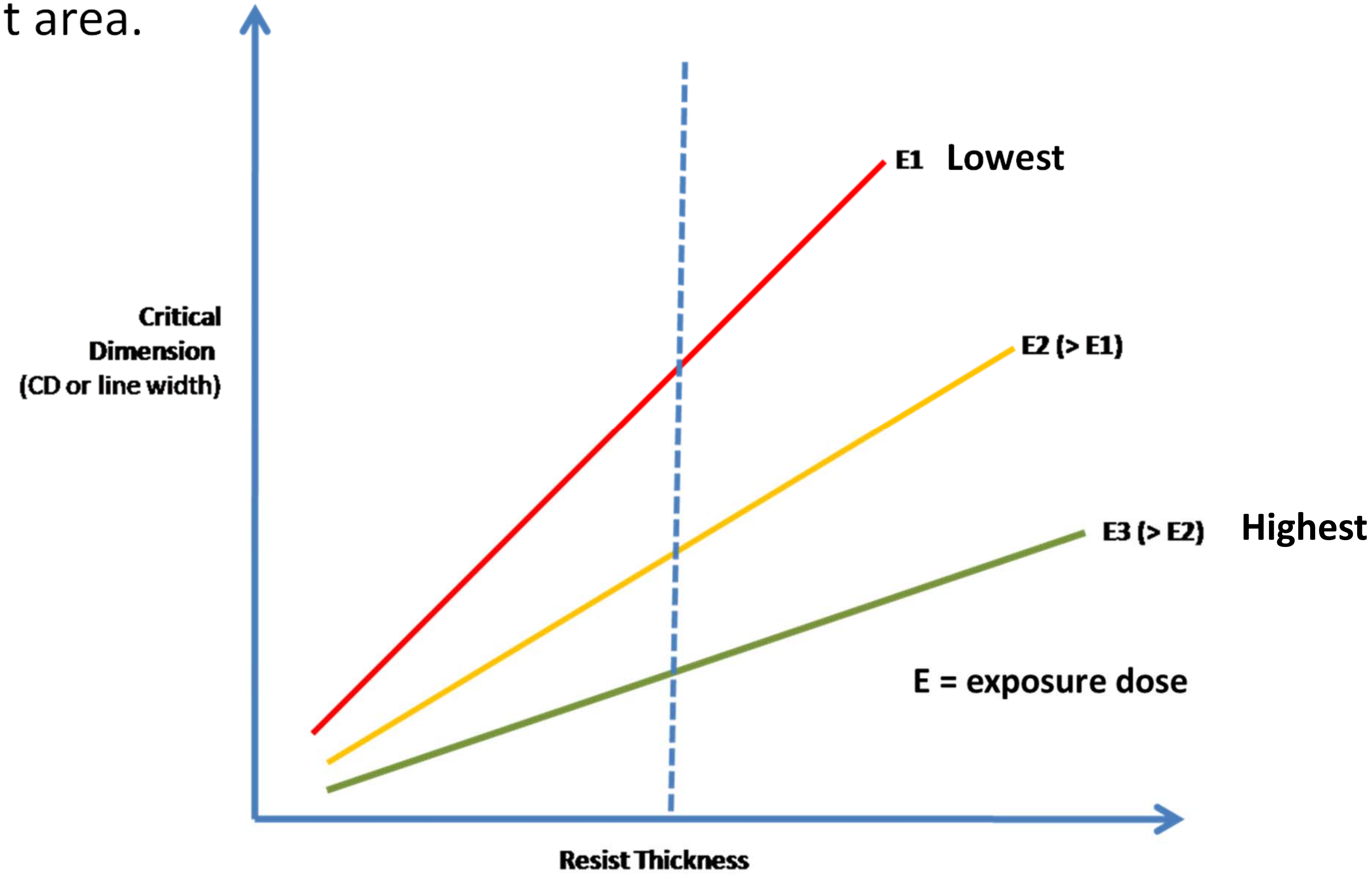
a. Positive (ANSWER)

b. Negative



Exposure Dosage

Exposure dose is the amount of light energy reaching the resist surface per unit area.



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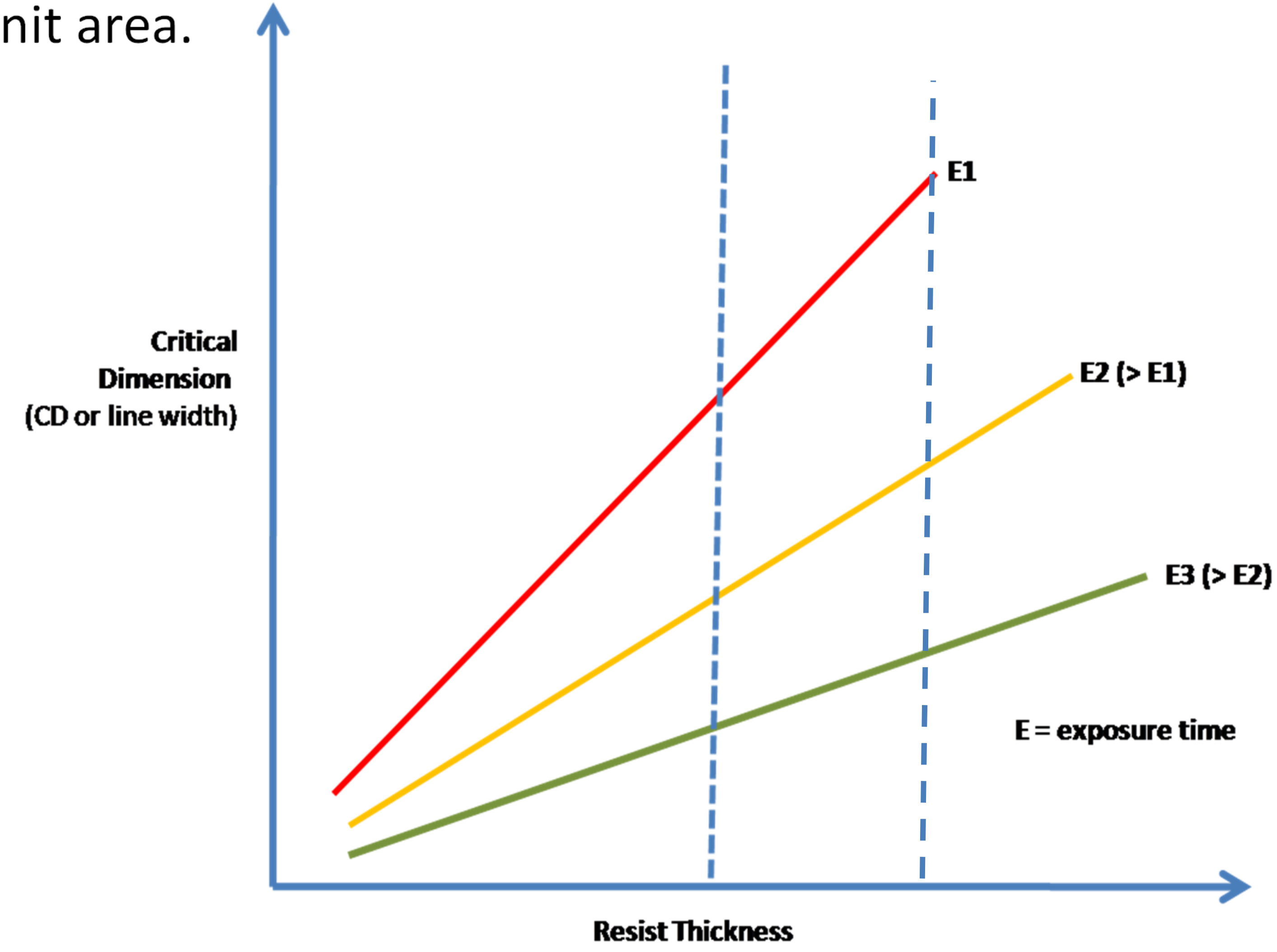
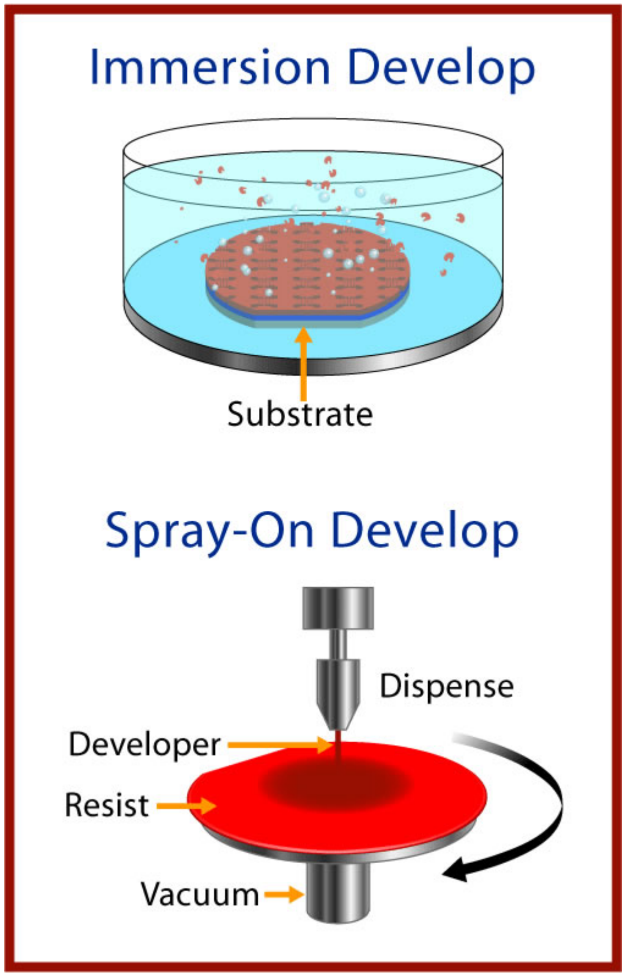


Develop

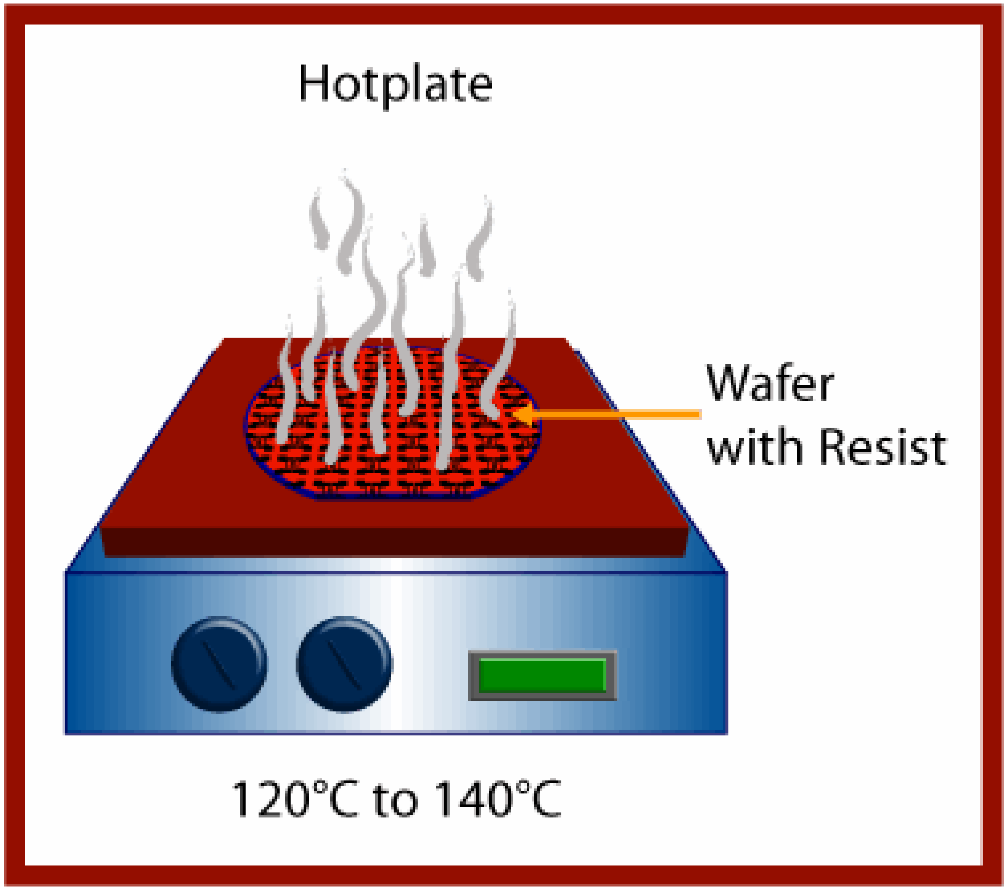
- Portions of the photoresist are dissolved by a chemical developer.
- Positive resist - the exposed resist is dissolved while the unexposed resist remains on the wafer.
- Negative resist - the unexposed resist is dissolved while the exposed resist remains.
- The develop process leaves a visible pattern within the resist.



The Develop Process

Hardbake

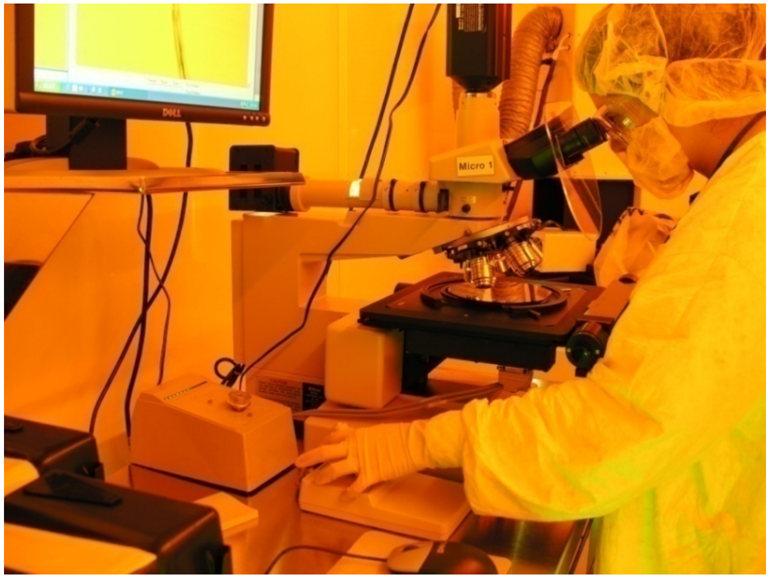
- Post-develop hardbake hardens the photoresist for the next process.
- Temperature is higher than that of the softbake after coat.
- After the hardbake, the wafer is cooled to room temperature.



Inspect

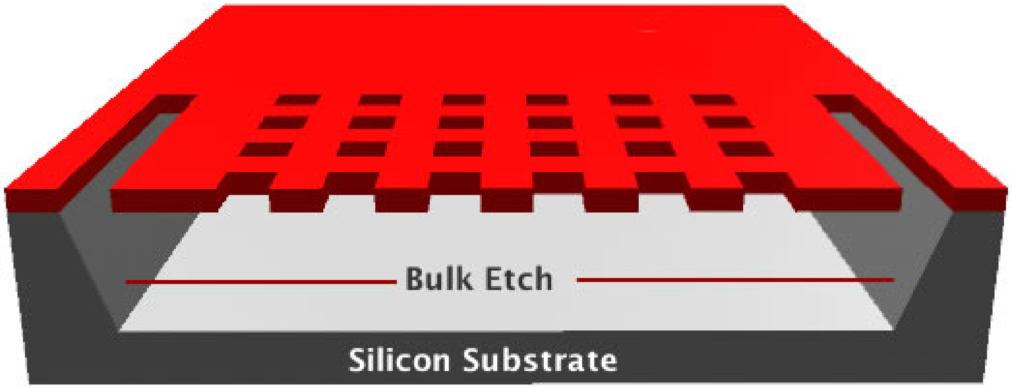
Three critical parameters:

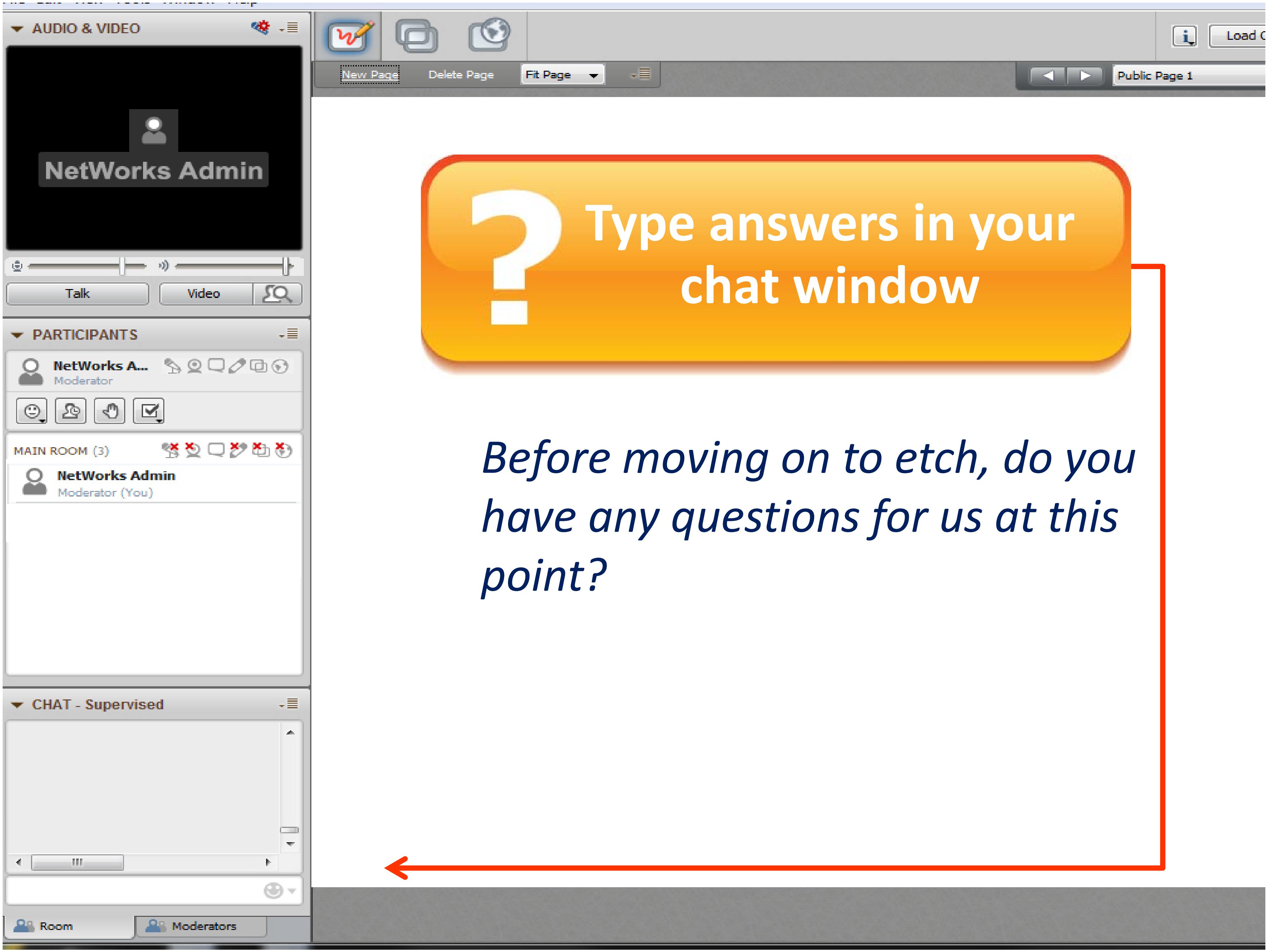
- Alignment – pattern must be positioned accurately to the previously layer.
- Line width or critical dimension (CD) – patterned images are in focus and have the correct widths.
- Defects – things that could affect subsequent processes



Wafer Inspect

[Photo courtesy of the MTTC, University of New Mexico





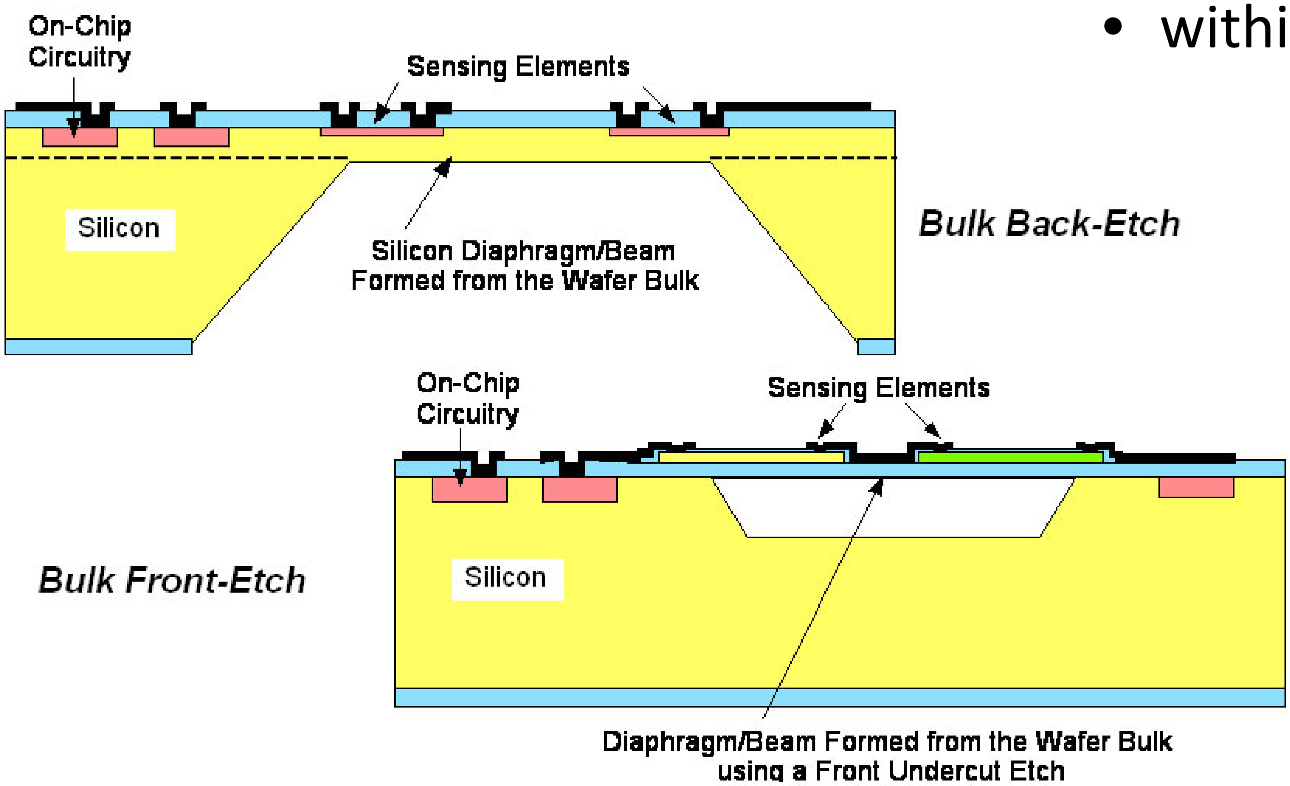
Type answers in your chat window

Before moving on to etch, do you have any questions for us at this point?

Microsystems Etch Process

Etch is a process that removes select materials from

- the wafer's surface
- below the wafer's surface
- within the substrate



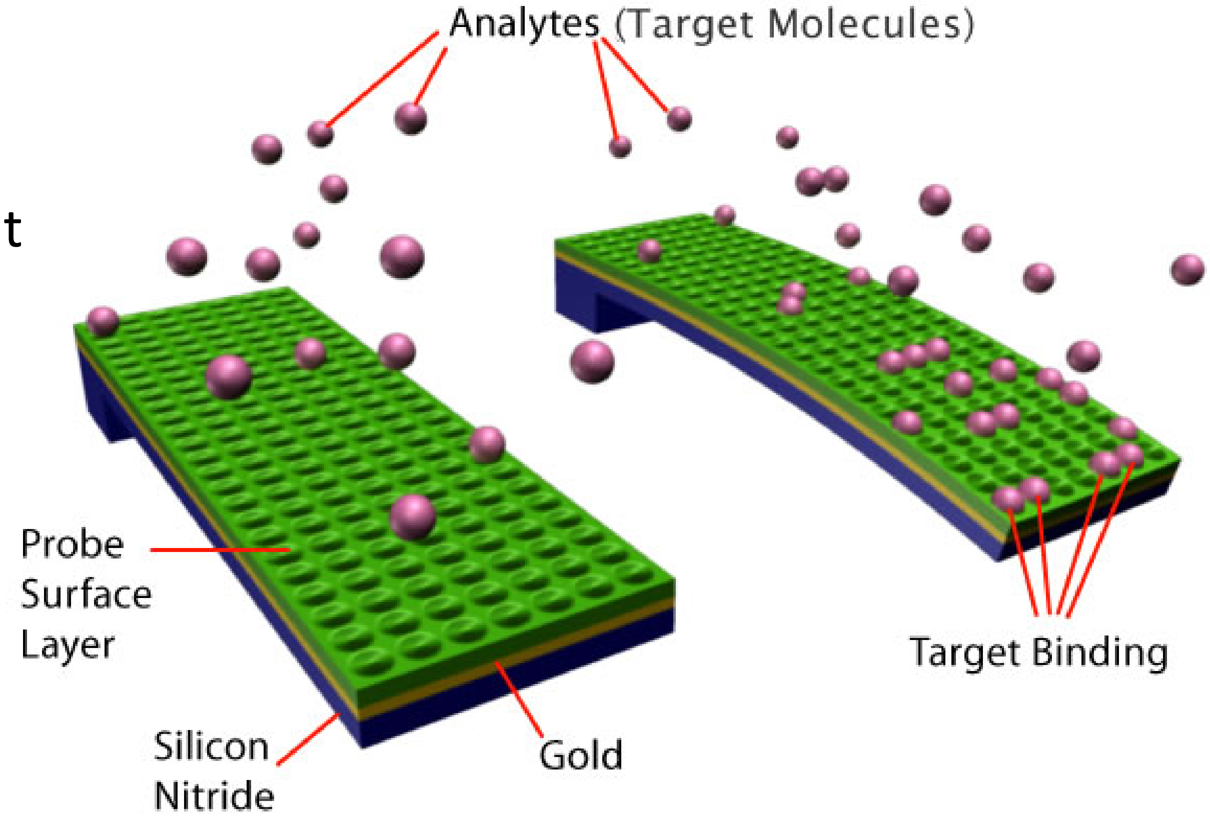
A combination of these etch processes allows for the construction of electronic and mechanical devices on the same microchip.

[Graphic courtesy of Khalil Najafi, University of Michigan]

Different Microsystem Layers

Microsystem Layers

- Insulator
- Conductor
- Structural component
- Transducer layer
- Sacrificial layer



Cantilever sensor

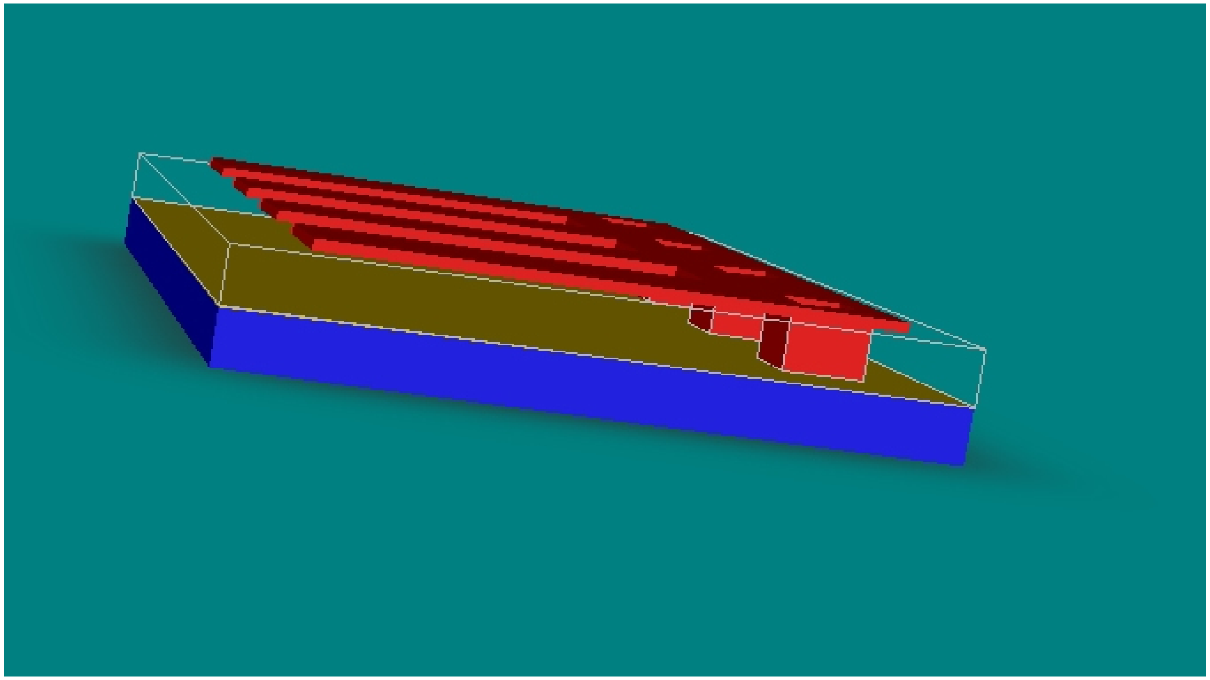
Silicon nitride - structural layer

Gold – chemically inert primer and piezoresistive layer

Probe layer – chemically selective layer

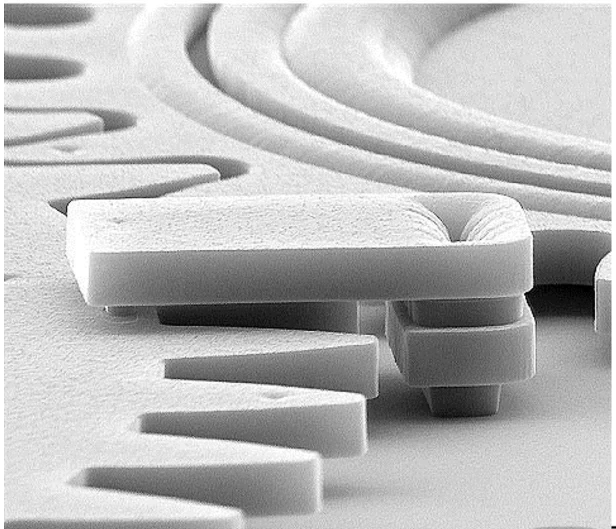
Sacrificial Layer Etched

Removal of the sacrificial layer in a cantilever sensor array.



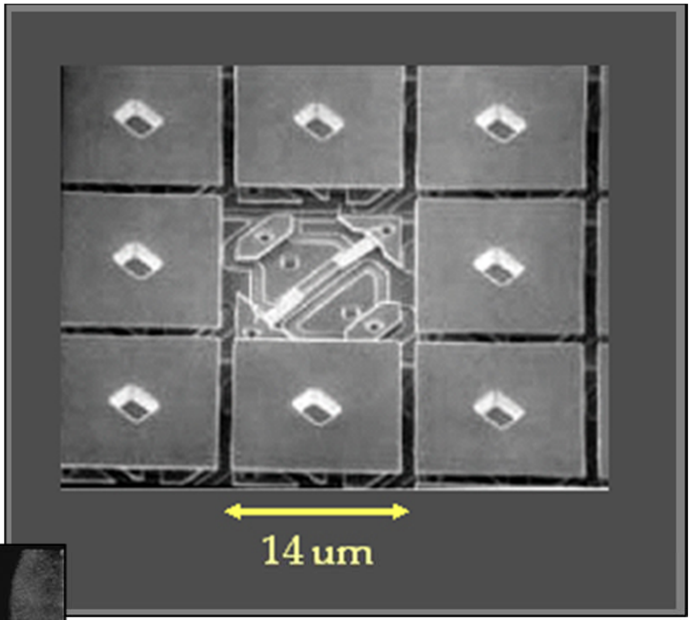
https://www.youtube.com/watch?v=dnXPLDQwFFk

Etch Processes for Microsystems



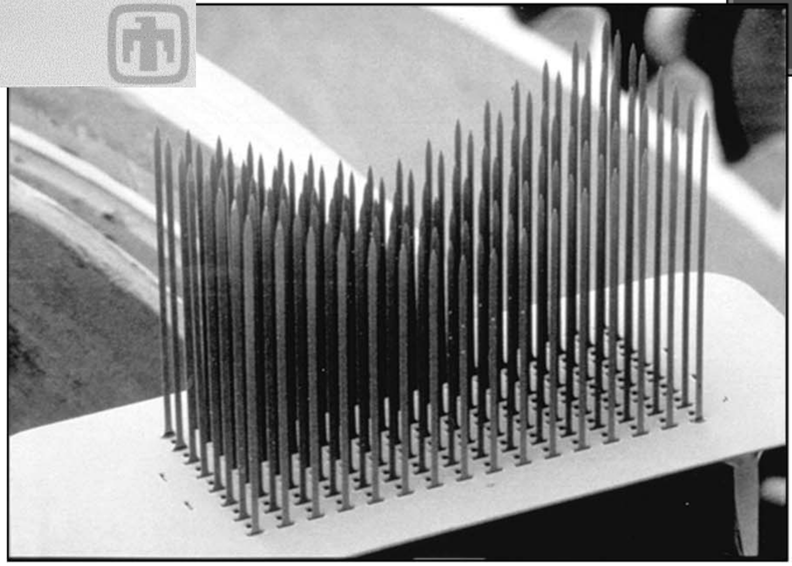
Microgear and alignment pin

[Courtesy of Sandia National Laboratories]



Optical Mirrors

[Courtesy of Texas Instruments]

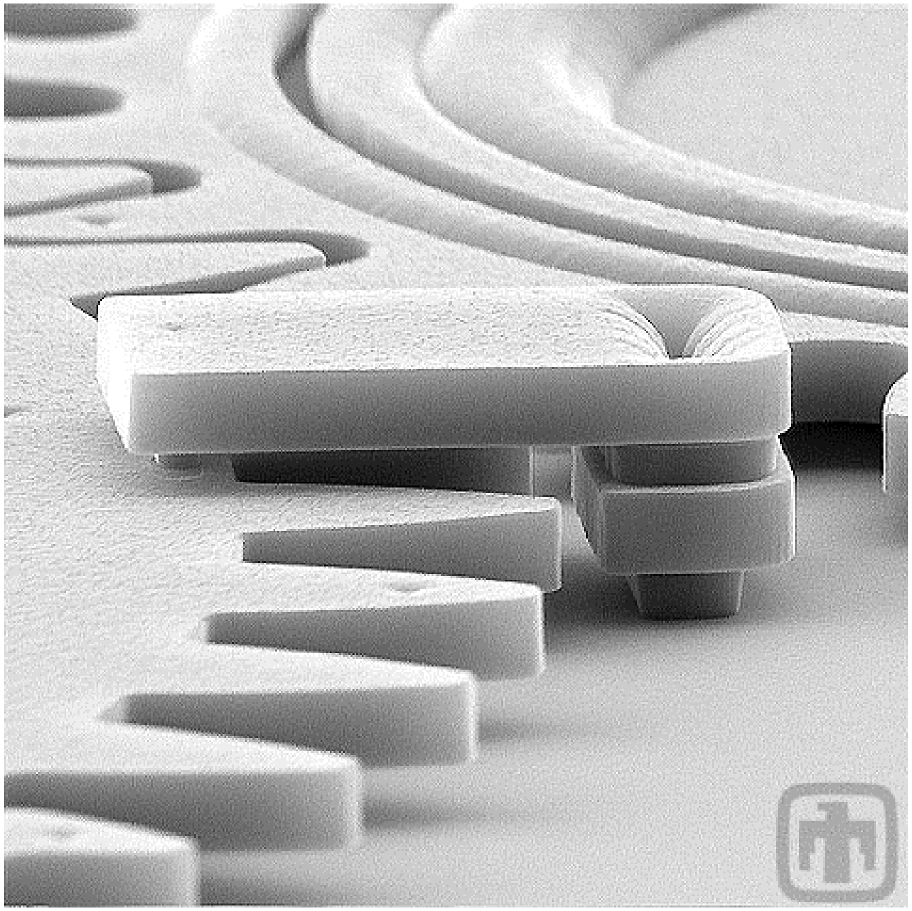


Neural Probes

[Courtesy of of Khalil Najafi, University of Michigan

Surface Etch

Surface etch removes selected regions on one layer of the wafer to create either a structural pattern or to expose an underlying layer of a different material.

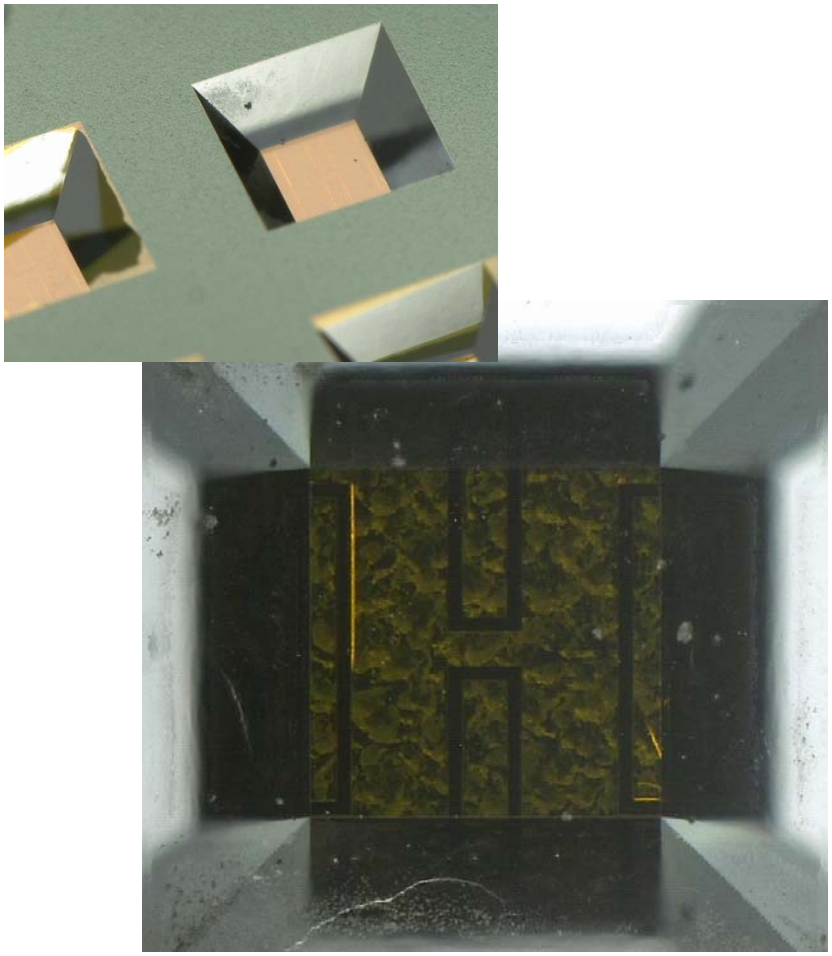


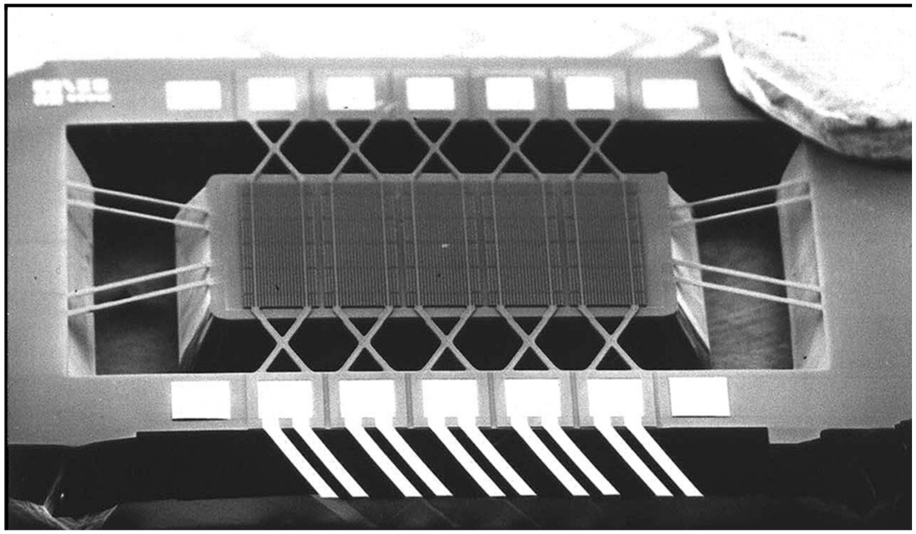
Part of a Gear Train built using Surface Micromachining Technology. Sacrificial layers were etched (removed) in order to create released or moveable devices.

[Image courtesy of Sandia National Laboratories, www.mems.sandia.gov]

Bulk Etch

<u>Bulk Etch</u> - used to remove material from underneath the mask or from the backside of the wafer.



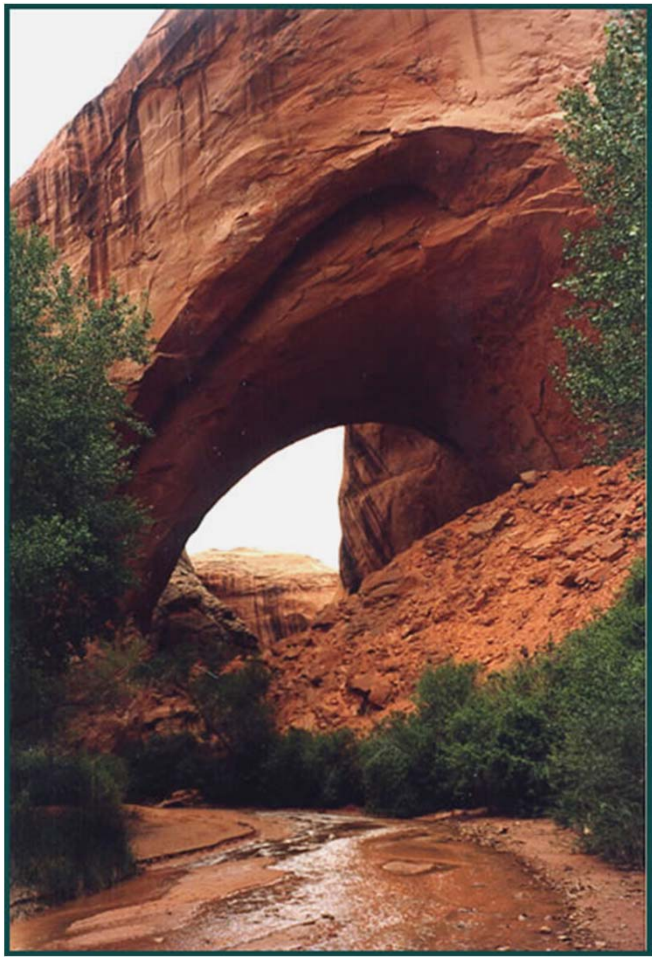


[Image courtesy of Khalil Najafi, University of Michigan]

[Images courtesy of the MTTC, University of New Mexico]

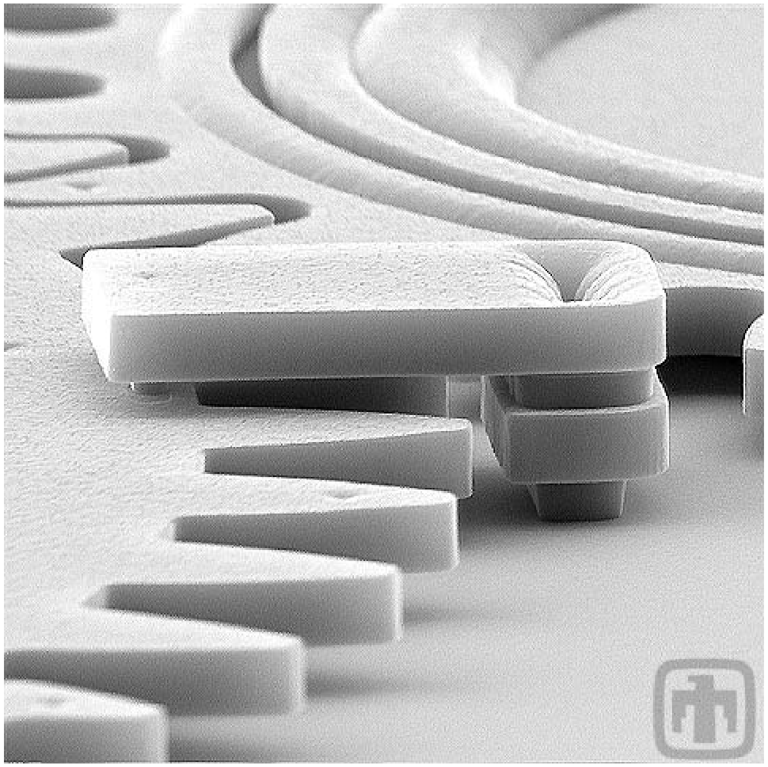
Natural Bridges

Examples of bulk etching in nature include natural bridges and arches. These structures are formed when the material underneath is etched by wind, rain, water, and natural erosion.



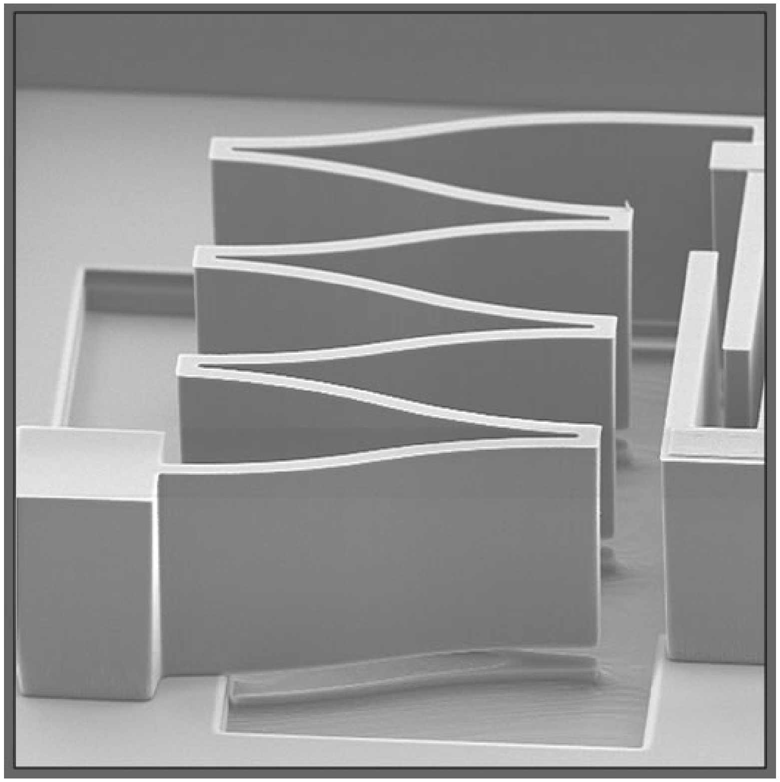
Natural Arch - Coyote Canyon, Utah [Photo courtesy of Bob Willis]

Release Etch



Part of a Gear Train built using Surface Micromachining Technology. Sacrificial layers were etched (removed) in order to create released or moveable devices.

[Image courtesy of Sandia National Laboratories, www.mems.sandia.gov]



Leaf Spring - expands and contracts above the substrate

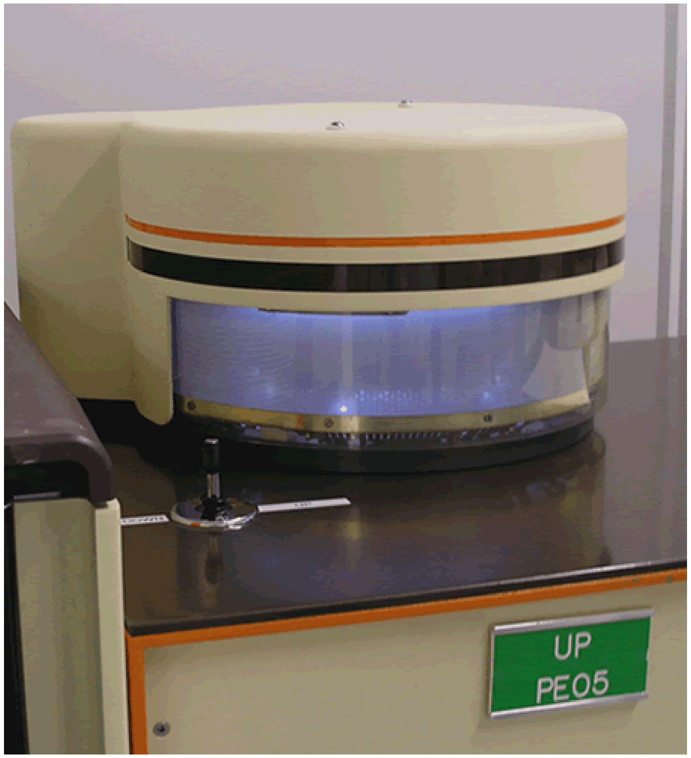
[SEM courtesy of Khalil Najafi, University of Michigan]

Etch Processes

Wet etch removes the material through a chemical reaction between a liquid etchant and the layer to be etched.

[Wet Etch pictures courtesy of MJ Willis]

Dry etch removes the material through a chemical reaction and/or a physical interaction between etchant gasses and the exposed layer.

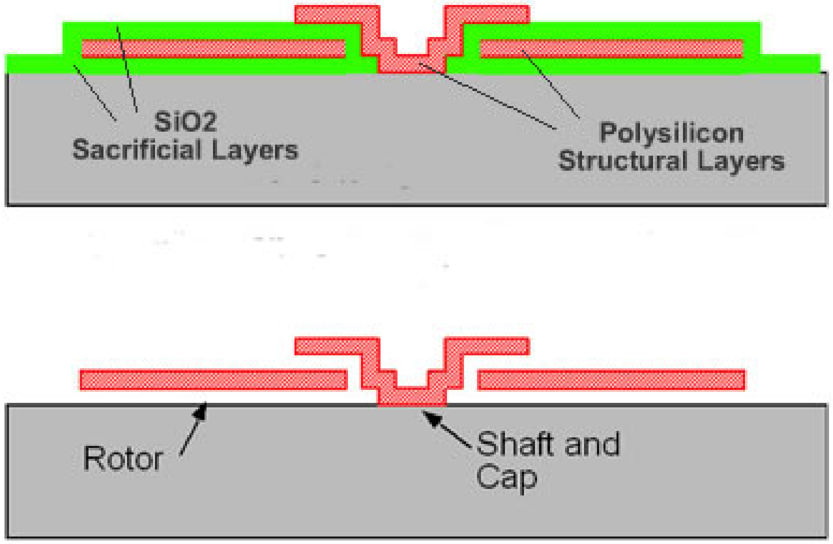


Etchants

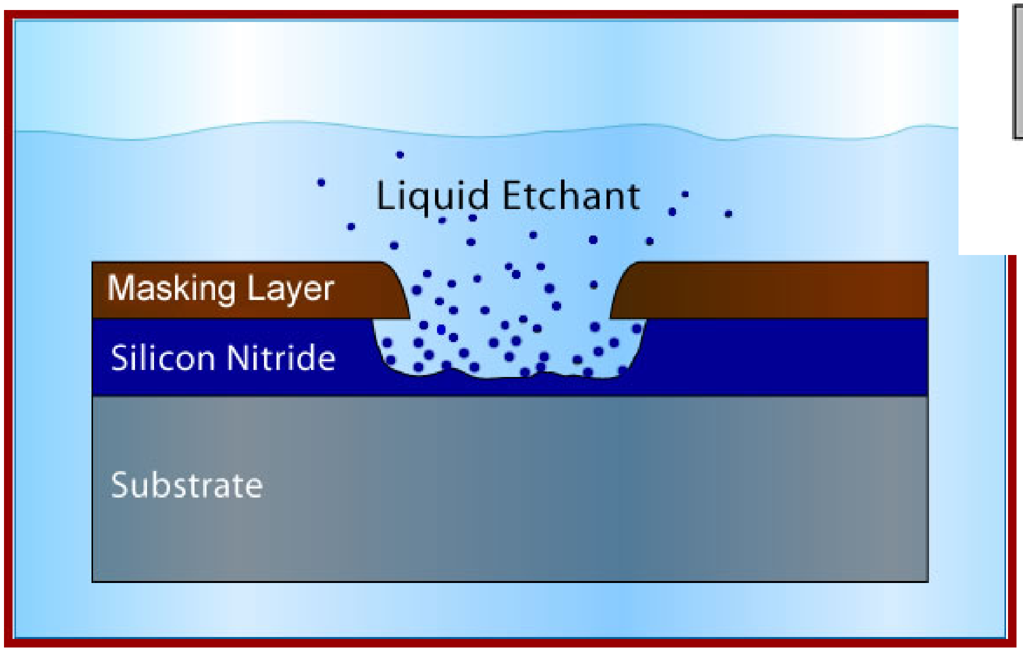
- Potassium Hydroxide (KOH)
- Hydrofluoric Acid (HF)
- Sulfur Hexafluoride (SF_6)
- Boron Trichloride (BCl_3)

Isotropic Wet Etch

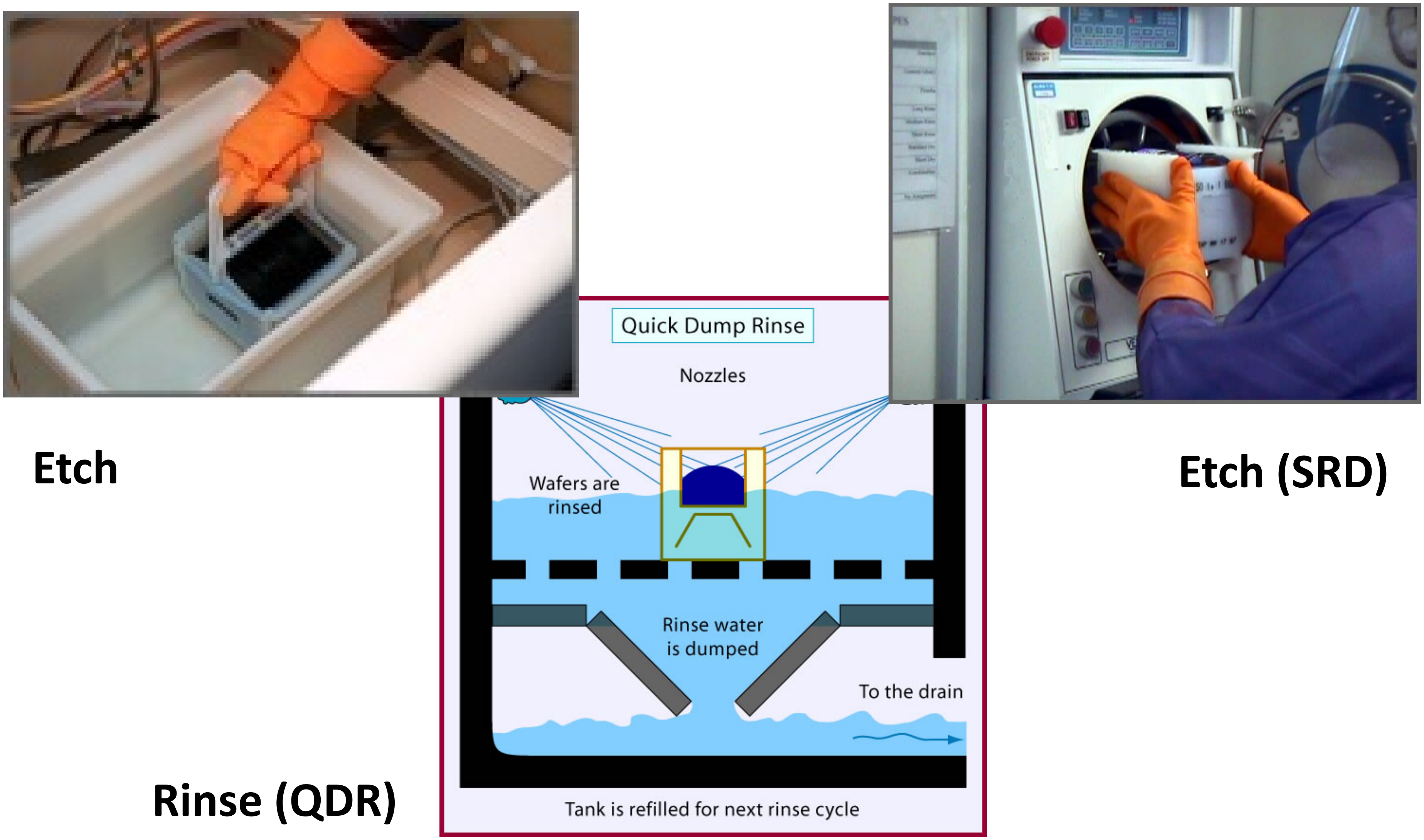
- A chemical etch that etches the selected layer in all directions.
- Etches vertically as well as horizontally (undercutting the masking layer).



A selective wet etch removes the SiO2, leaving the polysilicon layers intact.



The Wet Etch Process



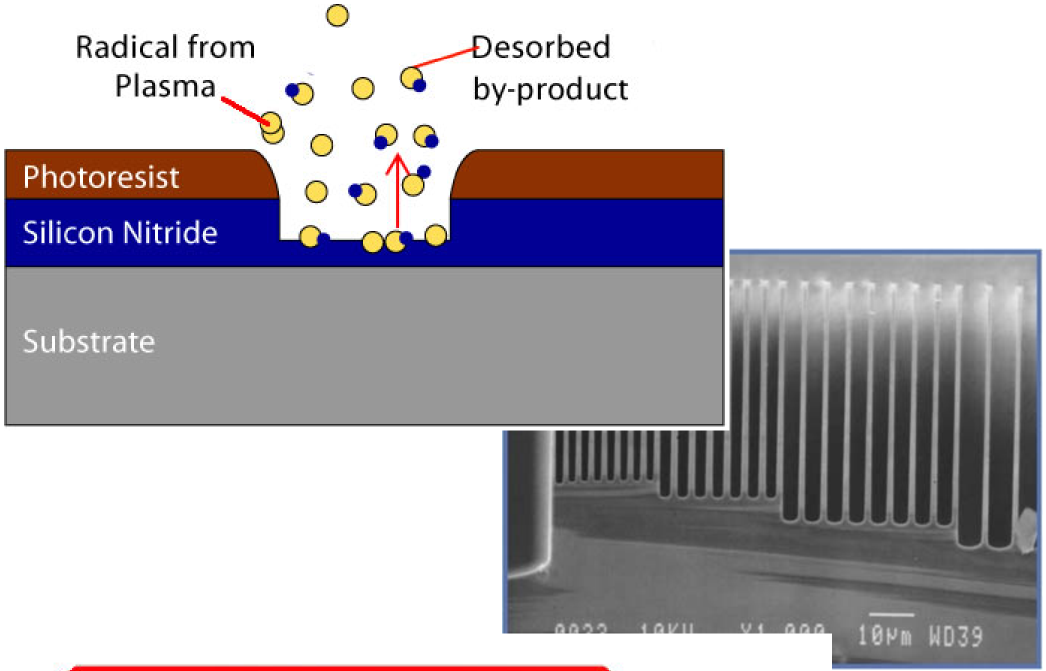
Etch

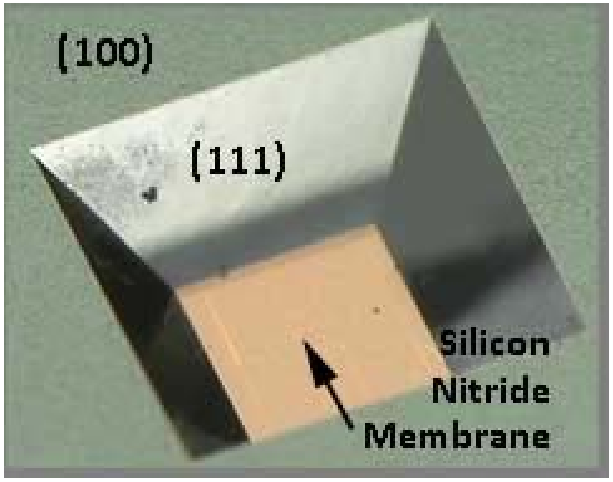
Rinse (QDR)

Etch (SRD)

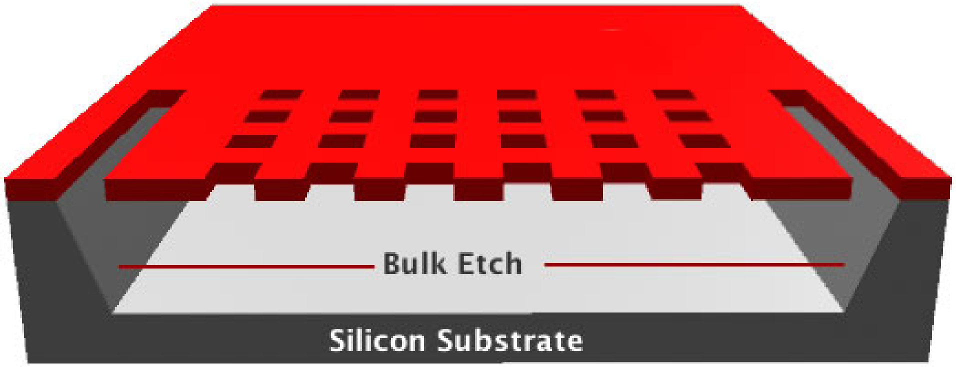
Anisotropic Etch

- Selective etch which creates a straight wall edge
- Edge can be either vertical or at an angle
- Etches along the crystal plane



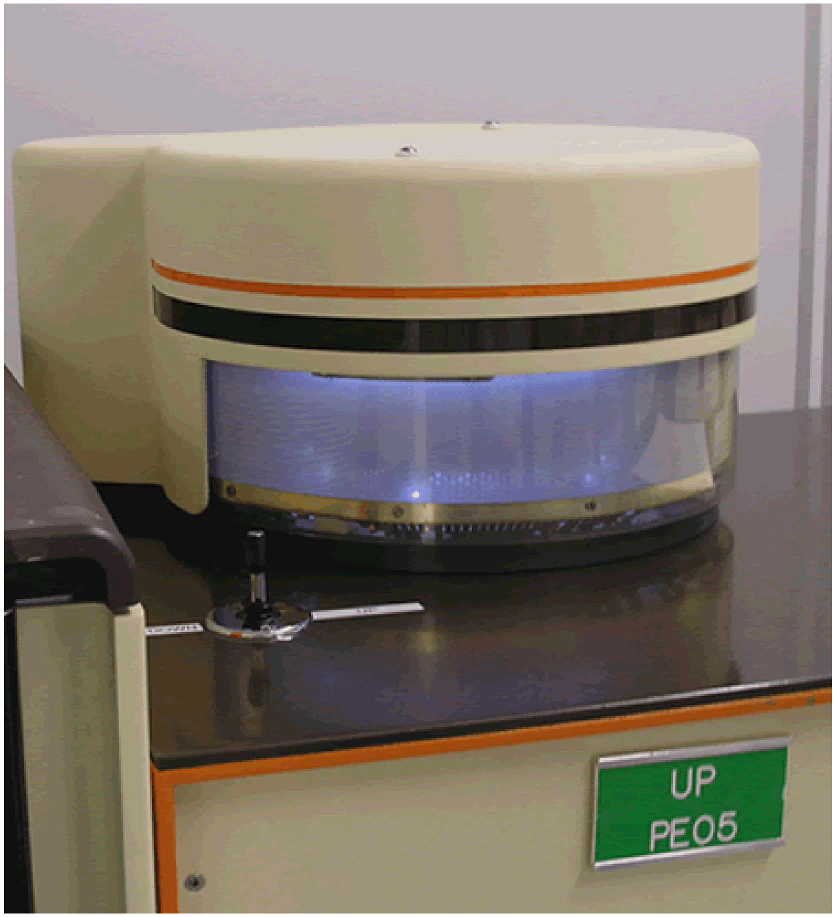


Backside of MTTC Pressure Sensor illustrating anisotropic etch

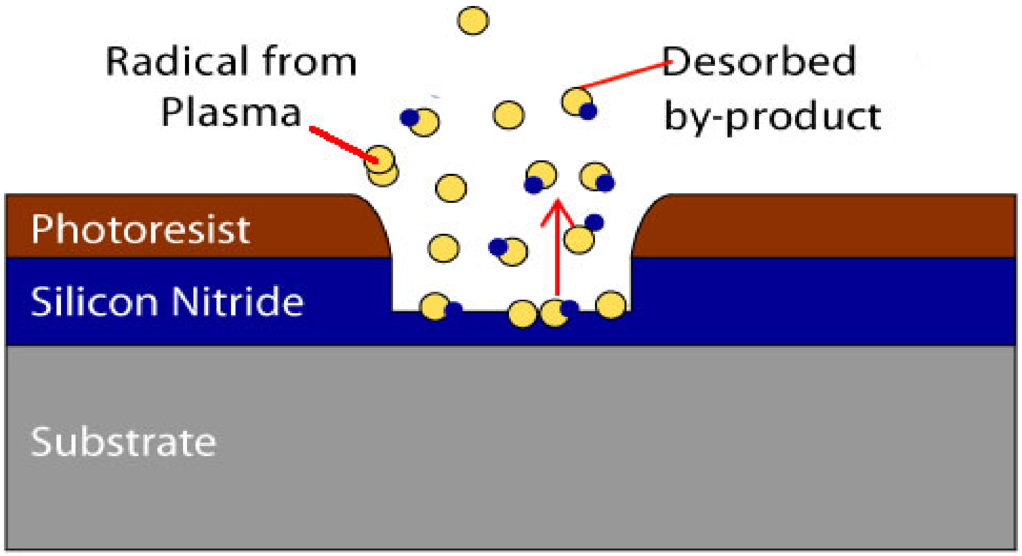


Dry Etch Process

- In dry etch the wafer is exposed to a gaseous etchant suspended in a RF (radio-frequency) energized plasma.
- Collisions between the gas molecules and energized electrons create a "soup" made up of electrons, ions and radicals.



Physical Etch

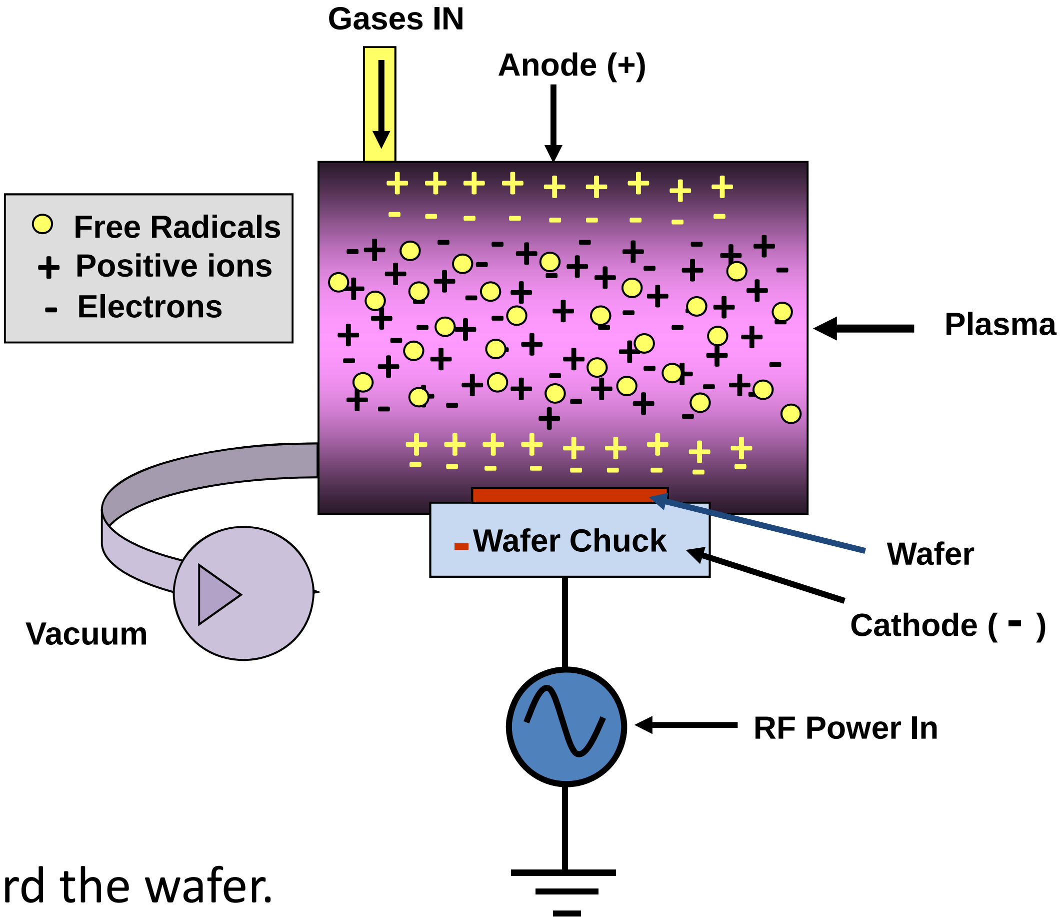


Physical Dry Etch
uses ions to sputter molecules from surface

- Physical etch is entirely physical
- No chemical reaction occurs
- Physical etch is referred to as "ion beam etching", "sputtering" or "ion milling".
- Ions bombard the surface of the wafer, causing molecules to sputter off the surface.

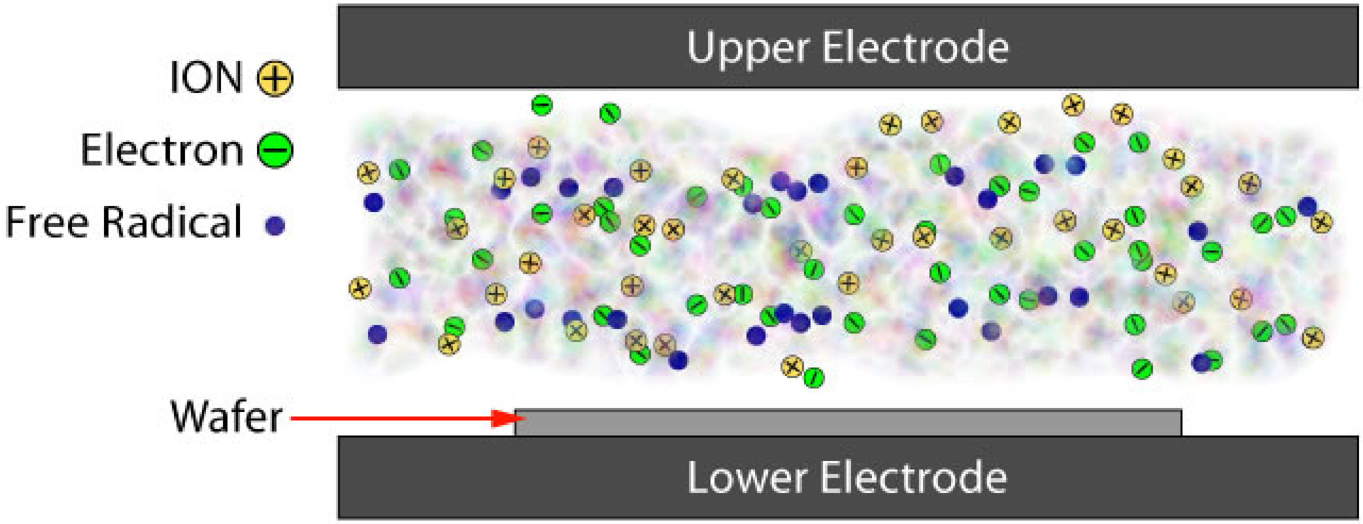
Dry Physical Etch

- Wafers are placed on a cathode.
- Gas is introduced
- Chamber pressure is reduced
- RF is turned on
- A plasma is ignited
- Gas molecules enter the plasma and collide with high energy electrons resulting in positive ions and radicals.
- Ions are attracted to the negatively-charged wafer.

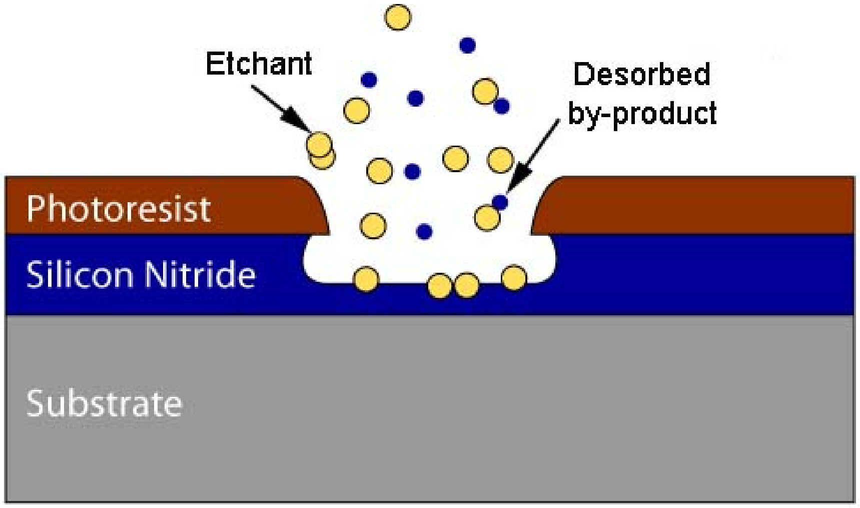


- Ions accelerate as they move toward the wafer.
- Ions hit the wafer, sputtering molecules from the surface.
- Process continues until pattern is etched exposing the underlying layer.

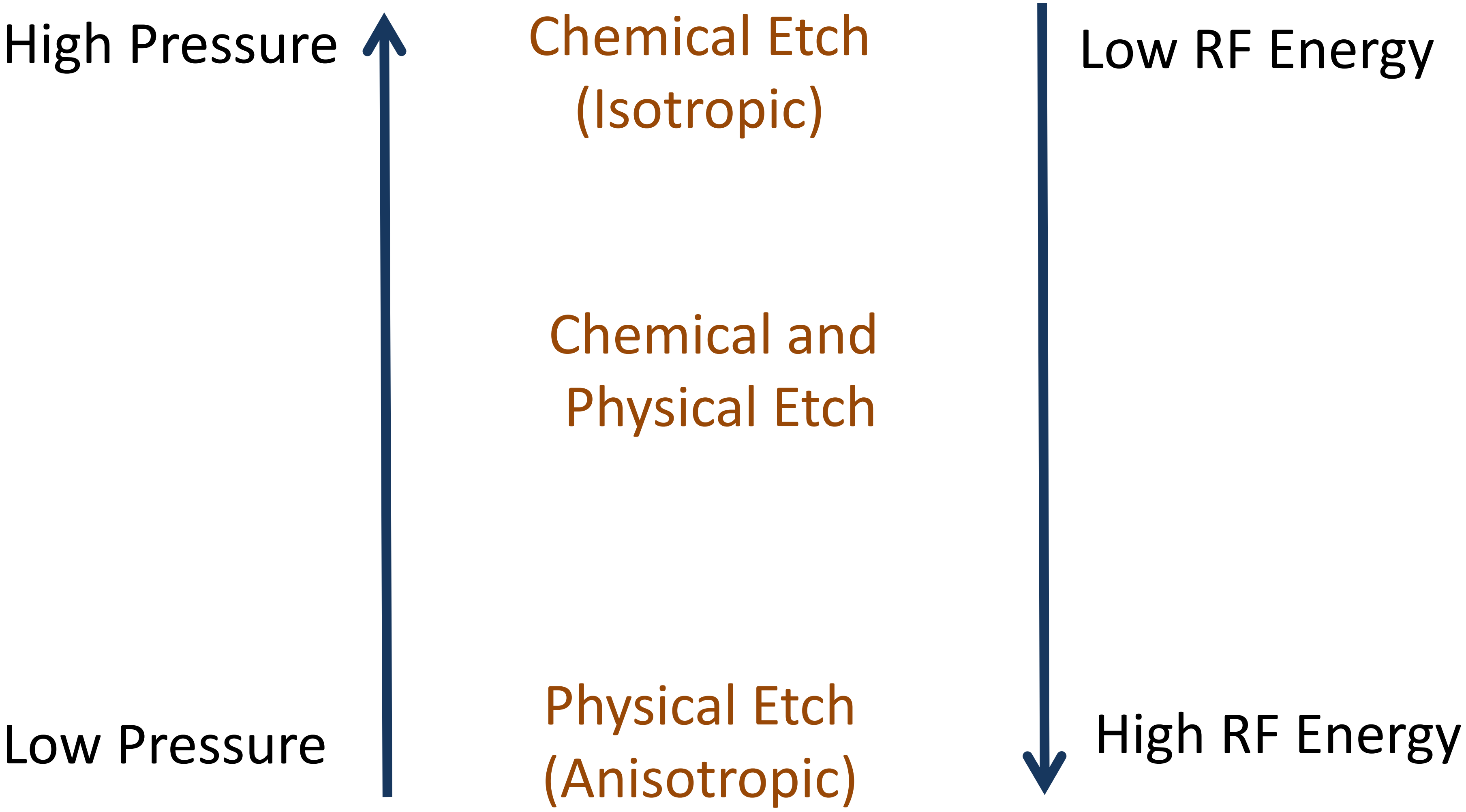
Dry Chemical Etch



- Free radicals are formed by particle collisions within the plasma.
- Free radical are adsorbed at the surface where a chemical reaction takes place causing the desorption or removing of surface molecules.



Dry Etch Process Parameters



High Pressure

Low Pressure

Chemical Etch
(Isotropic)

Chemical and
Physical Etch

Physical Etch
(Anisotropic)

Low RF Energy

High RF Energy

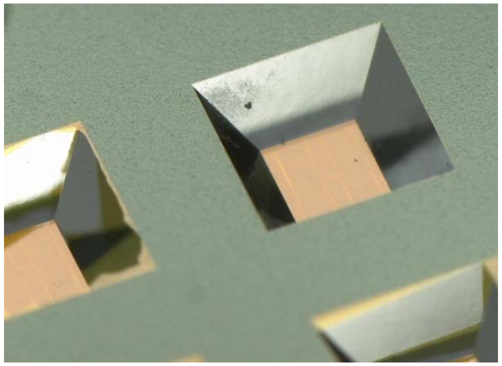
Factors Affecting Etch Quality

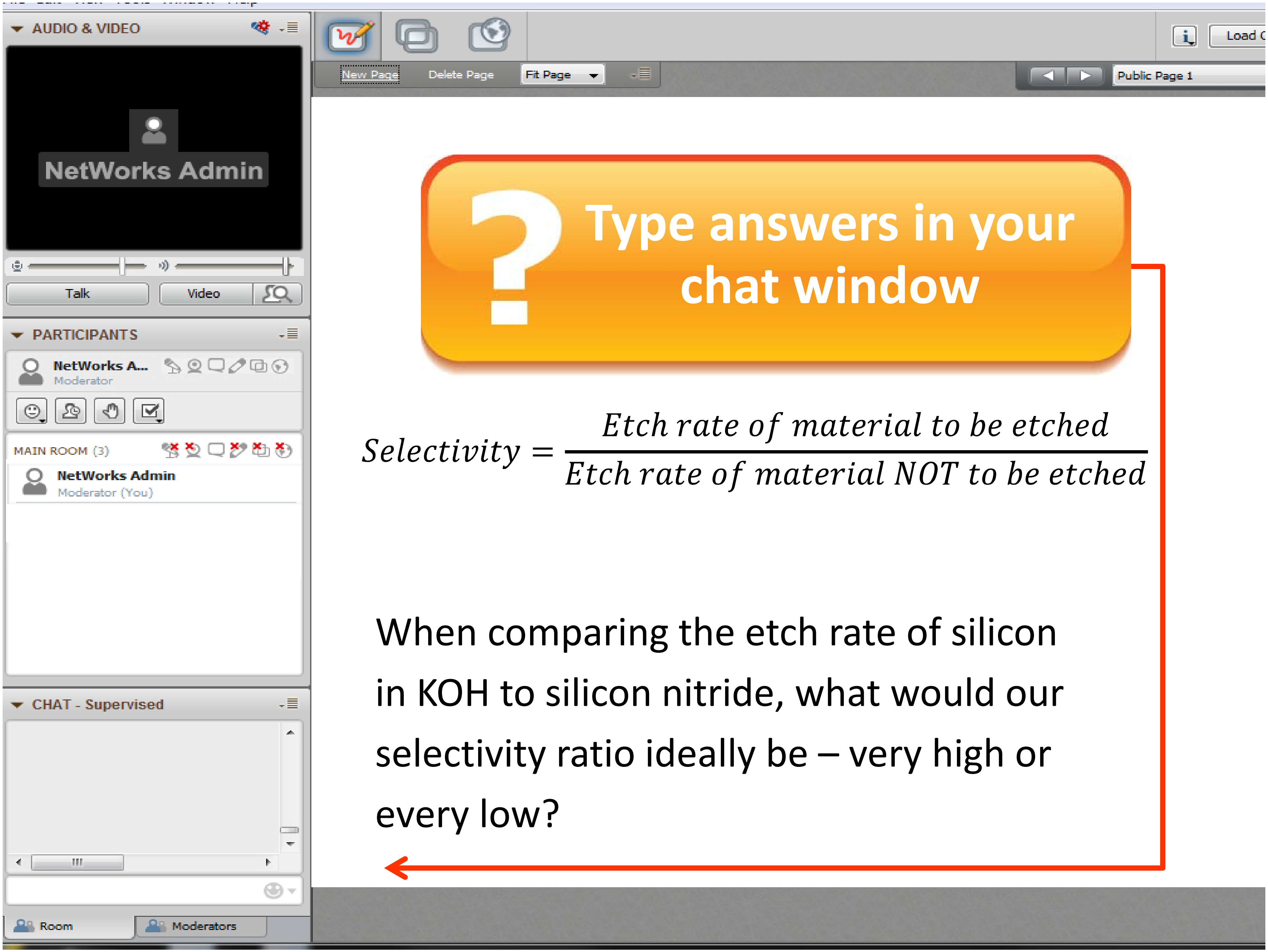
Etch rate – The rate at which the material is removed from the wafer.

Directional control – Since etch can occur in all directions or specific directions, it is important to be able to control the direction of the etch. Directional control results in achieving the desired "shape" or etch profile (isotropic, anisotropic or a combination of both)

Selectivity – The property of the etchant which permits it to selectively etch a specific material at a faster etch rate than other materials on the wafer.

$$Selectivity = \frac{Etch\ rate\ of\ material\ to\ be\ etched}{Etch\ rate\ of\ material\ NOT\ to\ be\ etched}$$





Type answers in your chat window

$$Selectivity = \frac{Etch\ rate\ of\ material\ to\ be\ etched}{Etch\ rate\ of\ material\ NOT\ to\ be\ etched}$$

When comparing the etch rate of silicon in KOH to silicon nitride, what would our selectivity ratio ideally be – very high or every low?

Question

What is the etch rate of this etch process?

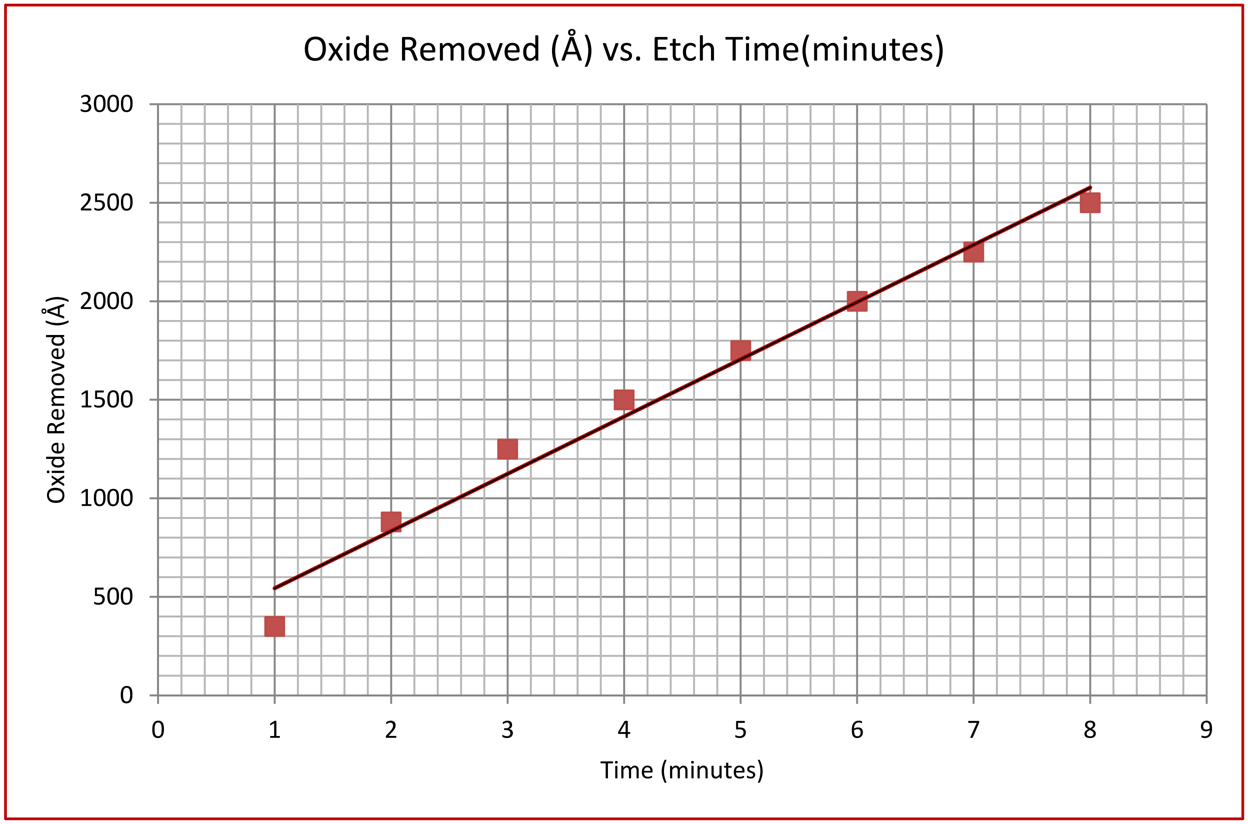
a. 600 Å / min

b. 500 Å / min

c. 400 Å / min

d. 300 Å / min

e. 200 Å / min



Poll Question

What is the etch rate of this etch process?

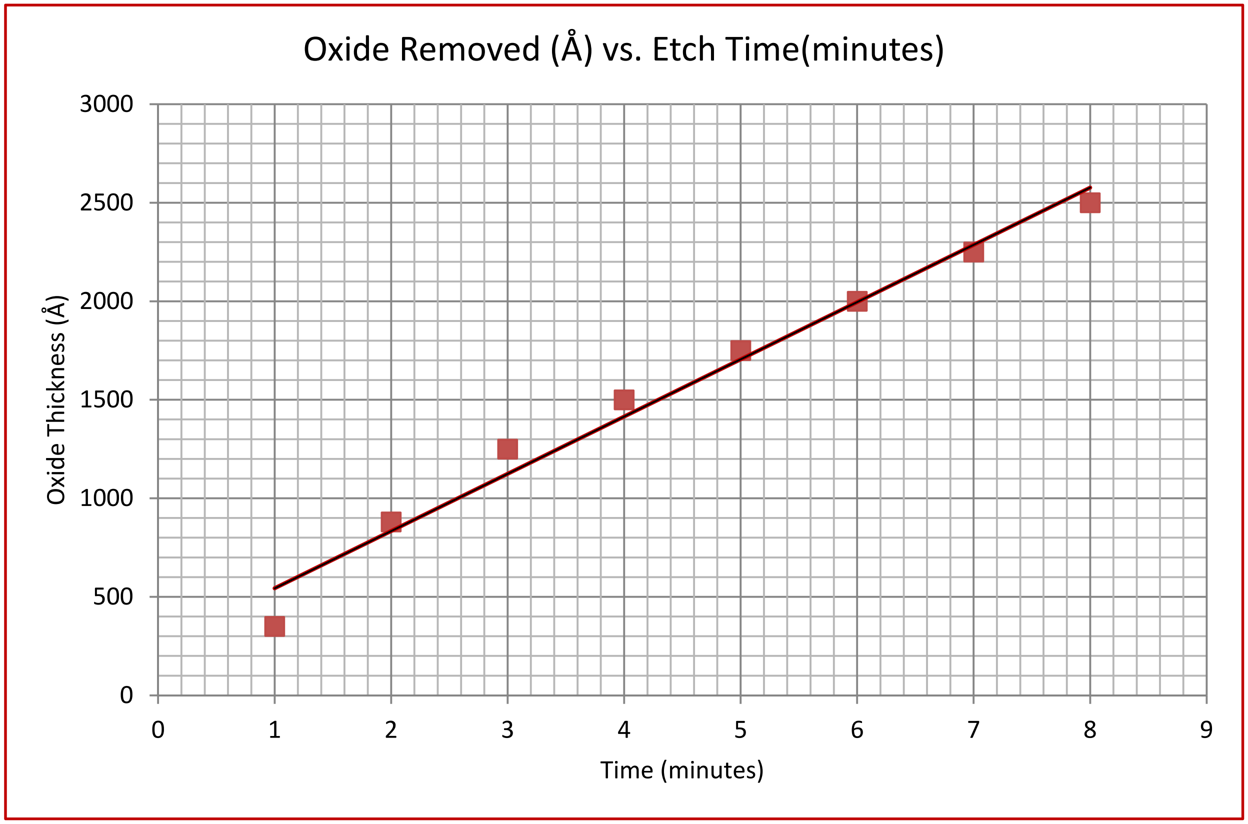
a. 600 Å / min

b. 500 Å / min

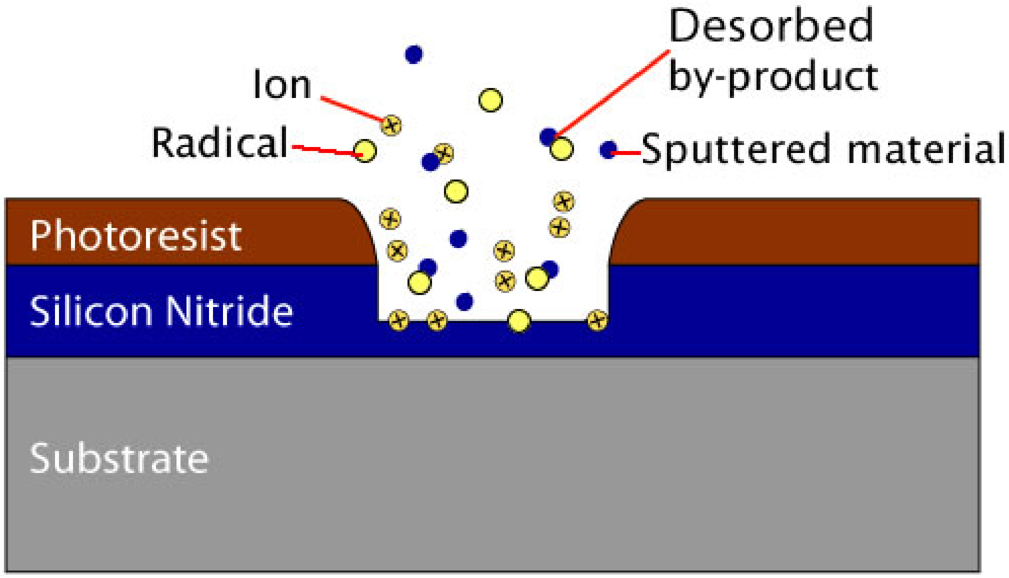
c. 400 Å / min

d. 300 Å / min

e. 200 Å / min



Reactive Ion Etch (RIE)

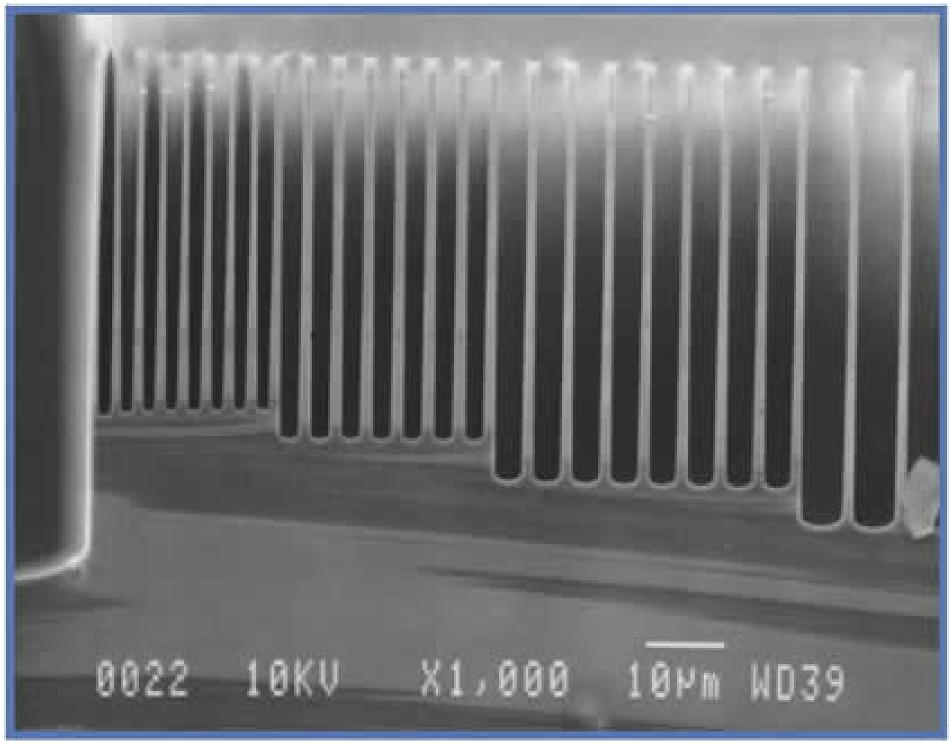


RIE process uses both ions and radicals

- Reactive ion etching (RIE) uses mid-level RF power and mid-range pressure to combine both physical and chemical etching in one process.
- The positive ions from the plasma bombard the wafer's surface at the same time that the radicals adsorb to the surface.

Deep RIE (DRIE)

- The SEM image to the right shows a series of cavities etched using a DRIE process.
- On the same wafer DRIE can achieve different depths.

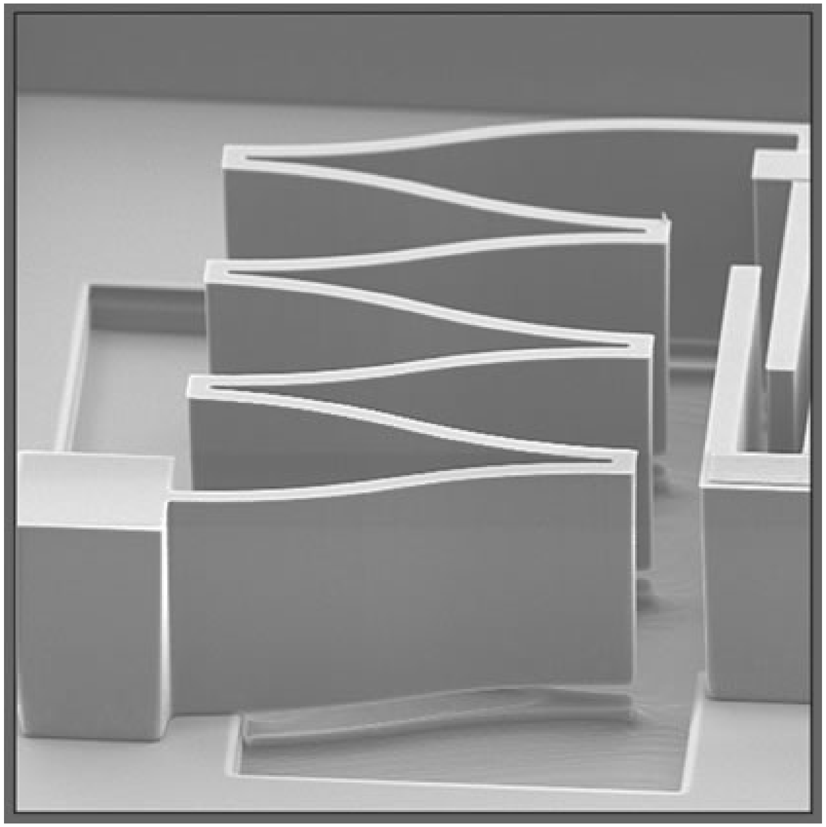


A SEM of cavities etched with DRIE.

[SEM courtesy of Khalil Najafi, University of Michigan]

DRIE Structures

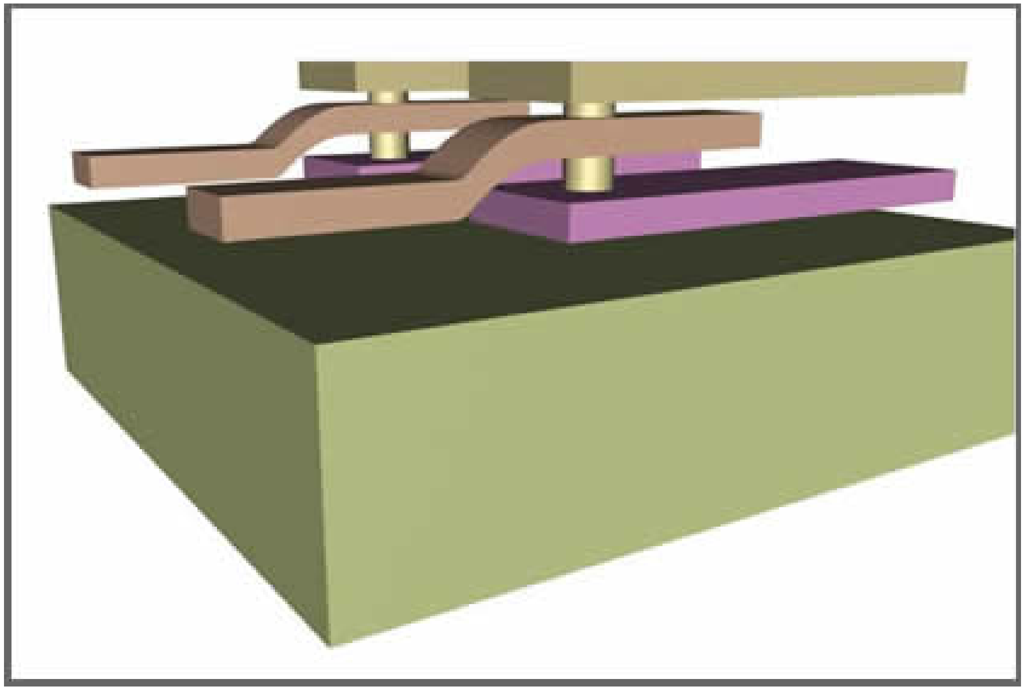
- DRIE can be used to create tall objects or components for microsystems devices which can later be "released" through other etch methods.
- SEM of a Leaf Spring fabricated using DRIE



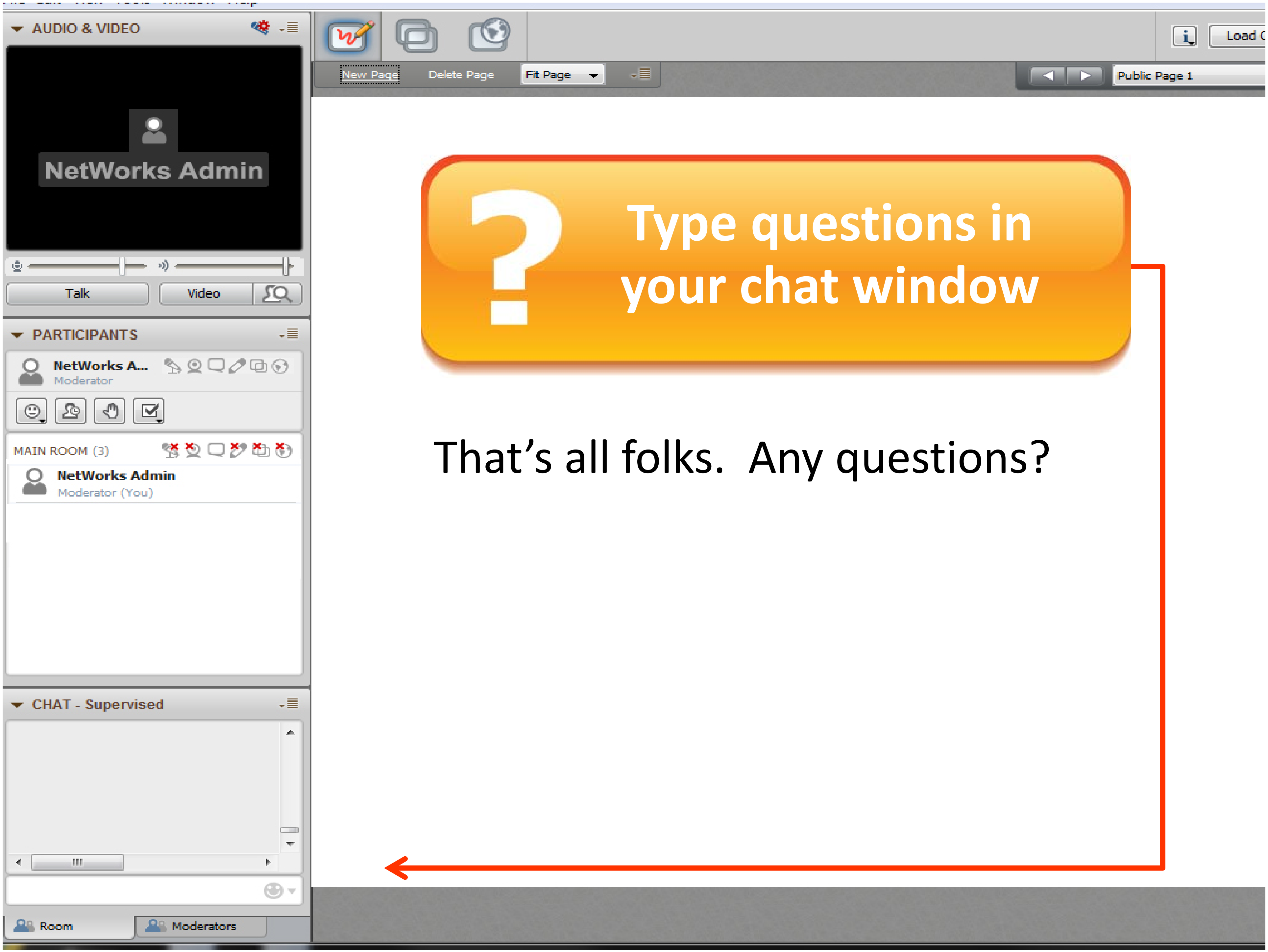
Leaf Spring

[SEM courtesy of Khalil Najafi, University of Michigan]

Let’s Review

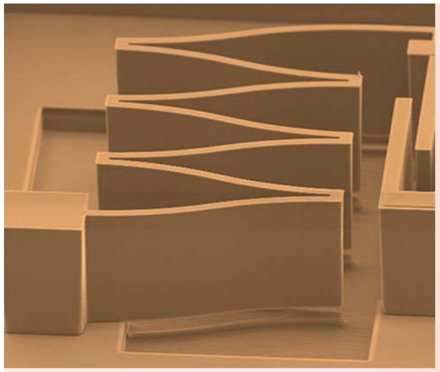


What types of etch processes were used to form the linkage system in the diagram?



Type questions in your chat window

That’s all folks. Any questions?



Thank You
For Joining Us

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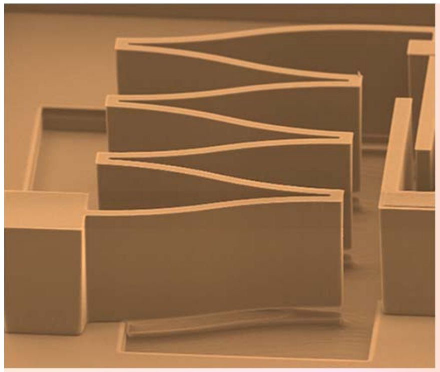
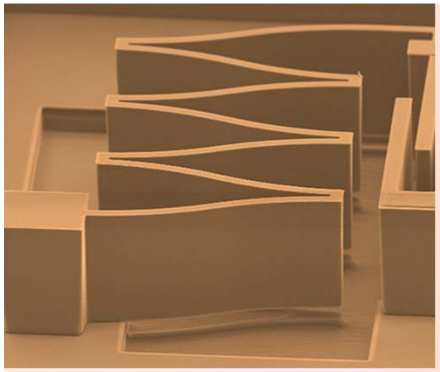


How Can We Serve You Better?

Please take 1 minute to provide your feedback and suggestions

https://www.research.net/s/7F3BT8F

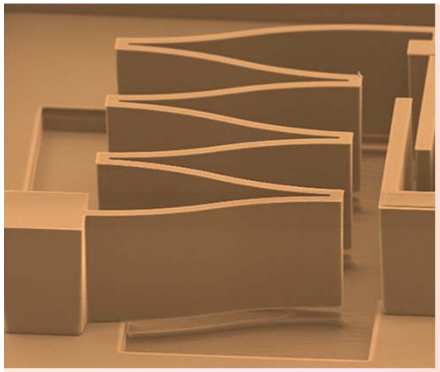


Webinar Resources

Southwest Center for Microsystems Education

To access this webinar recording, slides, and handout, please visit

www.scme-nm.org



SCME Upcoming Webinars

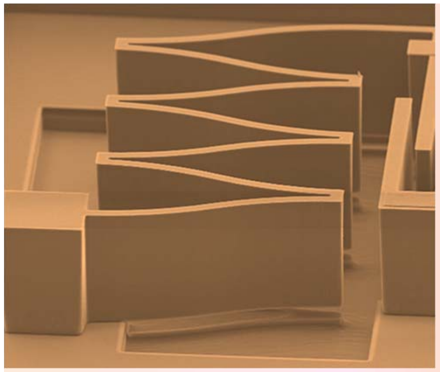
November 29, 2012: Problem Solving for Technicians

January 24, 2013: Statistical Process Control for Technicians

February 28, 2013: Design of Experiments for Technicians

TBA: Problem-solving Tools Applied to Microfabrication

All Webinars on Thursday @ 1 PM ET



It was Fun!

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Microsystems Education

Thank you for attending this SCME Webinar

Microsystems Processes Part II
Photolithography and Etch