NANYANG TECHNOLOGICAL UNIVERSITY

Course: EE3013 Semiconductor Devices and Processing

School: School of Electrical and Electronic Engineering

Lithography 2 – Lithography Processing

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Lesson Objectives - Photolithography

By the end of this photolithography lesson, you should be able to:

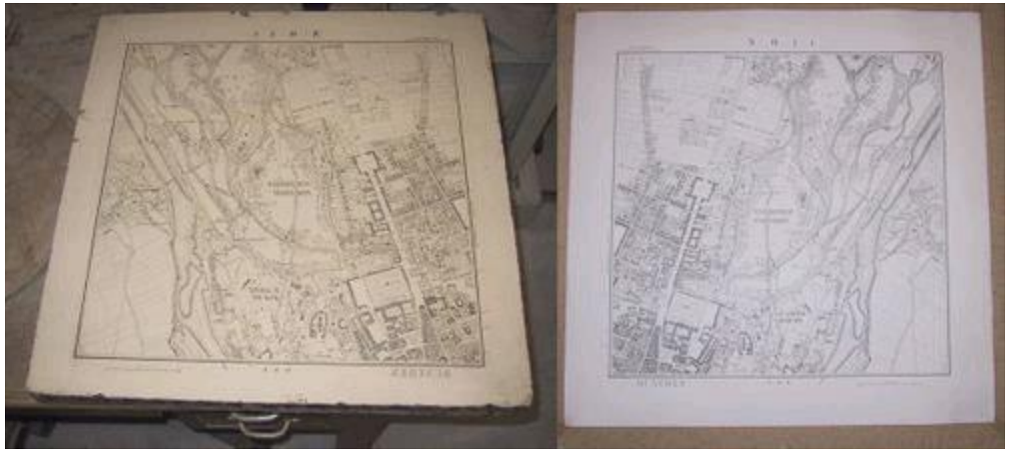
- Explain the basic concepts of photolithography, describe the eight main steps in photolithography, determine the resolution of printers, and the factors affecting resolution.
- Describe the types of printers and resists used in wafer manufacturing, and the chemistry behind the respective resists.
- Discuss the optical enhancement techniques in photolithography and describe the alternatives for advanced photolithography.

Lithography: Definition

- Creates a pattern on a silicon substrate
- Also known as **Photolithography**

In Greek origin,

Photo-litho-graphy: Light-stone-writing



Lithography stone and mirror-image print of a map of Munich

Lithography is a printing process that uses chemical processes (in response to light) to create an image.

Lithography History

- Historically, lithography is a type of printing technology based on the chemical repellence of oil and water.
- Photo-litho-graphy (Latin) can be translated as “light-stone-writing”.
- In 1826, Joseph Nicephore Niepce in Chalon France took the first photograph using bitumen of Judea on a pewter plate, developed using oil of lavender and mineral spirits.
- In 1935, Louis Minsk of Eastman Kodak developed the first negative photoresist.
- In 1940, Otto Suess developed the first positive photoresist.
- In 1954, Louis Plambeck Jr. of Du Pont developed the Dycryl polymeric letterpress plate.

Lithography press for printing maps in Munich

Lithography - Overview

Watch the video lecture to view this animation.

Fundamental Concept of Lithography

- **Lithography processing**
- **Lithography technology**
- **Resist technology**
- **Advanced lithography**

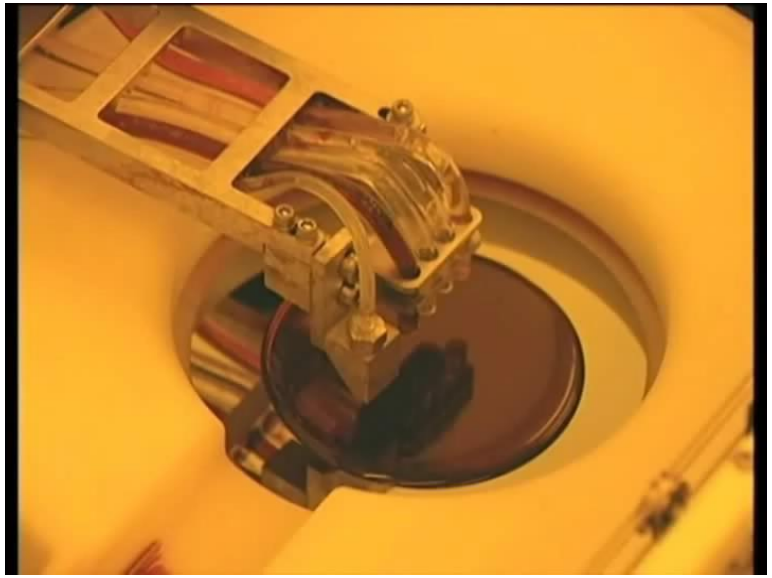
Lithography Processing – Lesson Overview

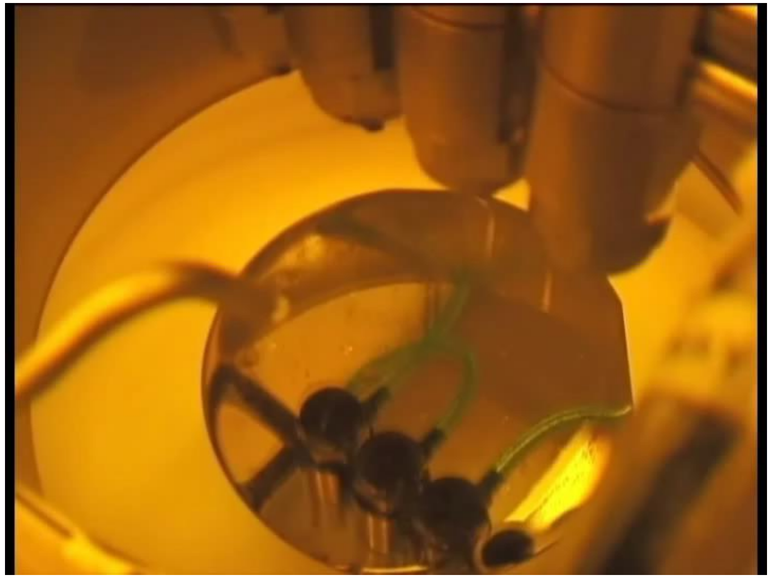
Lithography processing:

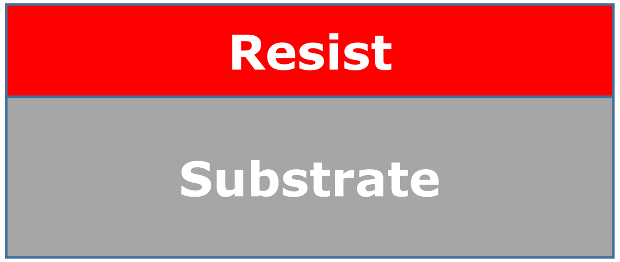
- Process overview
- UV light spectrum and resolution
- Negative and positive lithography (resist)
- Eight basic steps of the lithography process

Process Overview

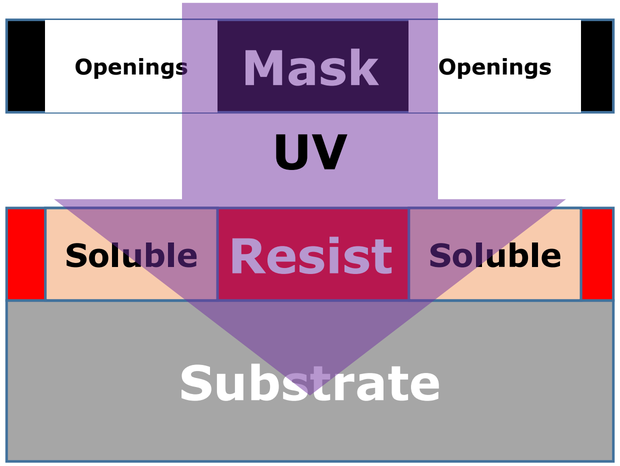
Process Overview – Coating, Exposure, and Developing





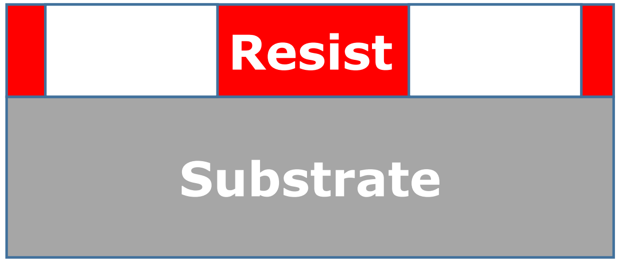


Coating



Expose

Soluble resist washed away by the developer (chemicals)

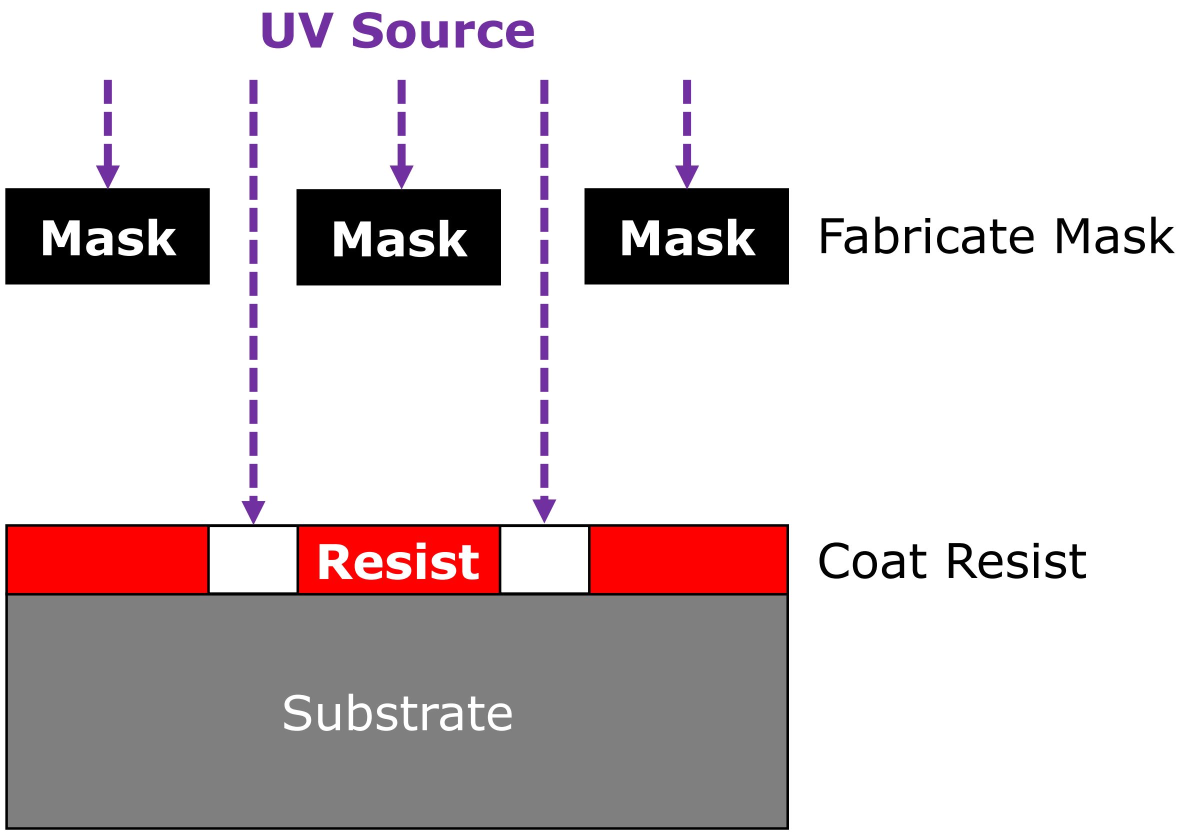


Developing

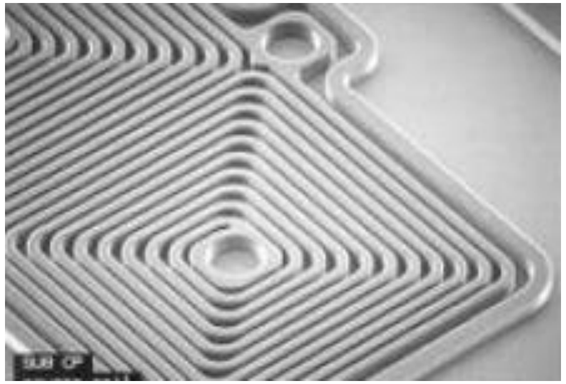
Lithography Concepts

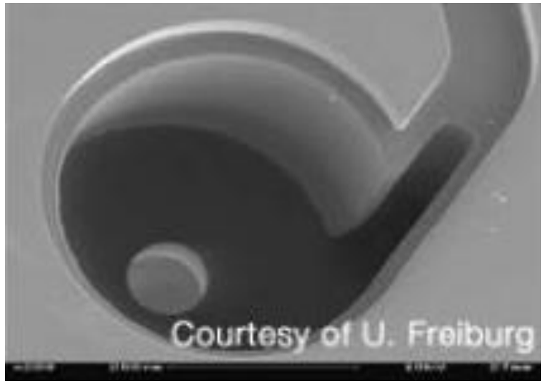
Overview – Lithography process:

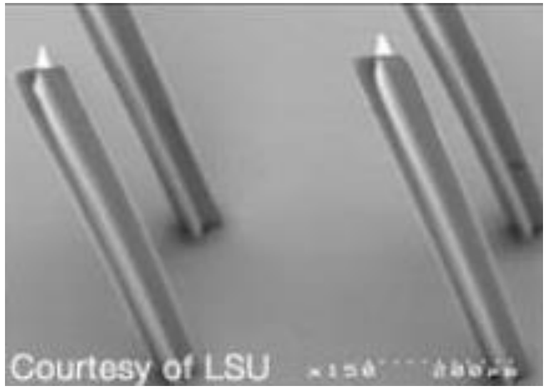
1. Coating
2. Expose
3. Developing

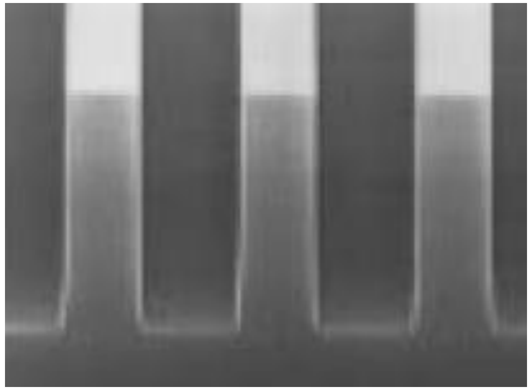


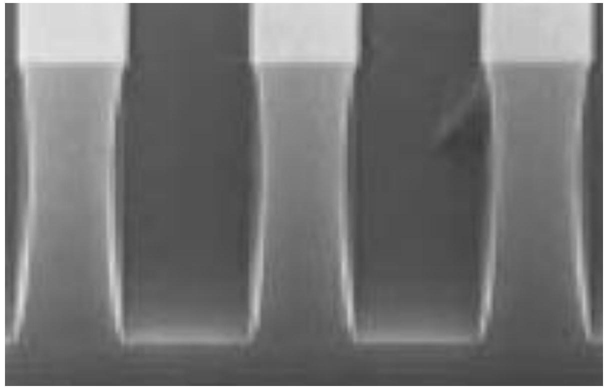
Lithographic Patterning











Shipley PR220 Resist Data Sheet (www.microhem.com)

Types of Lithography

Three basic components of lithography:

UV Source

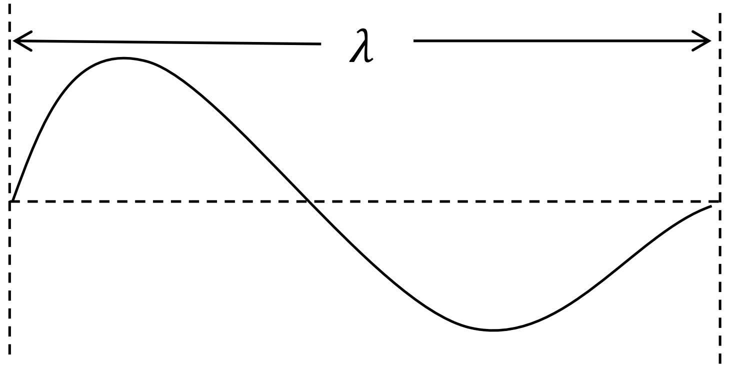
Resist

Mask

UV Light Spectrum and Resolution

Light Wavelength and Frequency

Light



Light as a wave in electromagnetic spectrum:

$$\lambda = \frac{v}{f}$$

v = velocity of light, $3 \times 10^8\ m/\mathrm{sec}$

f = frequency in Hertz (cycles per second)

λ = wavelength, the physical length of one cycle of a frequency, expressed in metres

Exposure Sources

Pause and read carefully

Optical Sources

Excimer Laser

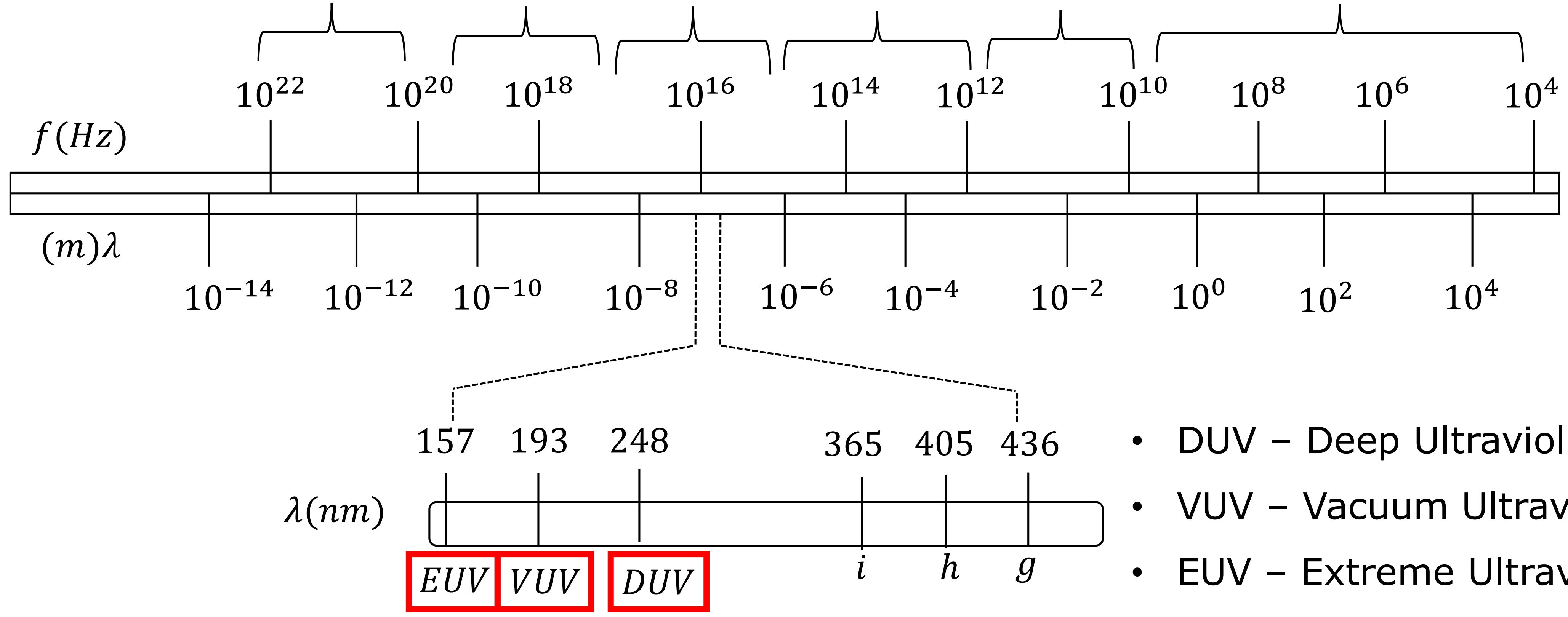
- **Deep UV by excimer lasers**
- **Kr + NF3 + (energy) → KrF + (photon emission)**
- **KrF: λ = 248 nm (used for 0.25 μm)**
- **ArF: λ = 193 nm (used for 0.12 μm)**

Mercury Arc Lamp

- **Hg vapour lamps: Hg plasma inside glass lamp**
- **Produces multiple wavelengths**
- **Limited in intensity**
- **“g” line: λ = 436 nm (used to mid 1980s)**
- **“i” line : λ = 365 nm (early 1990s, > 0.3 μm)**

Electromagnetic Spectrum of Light

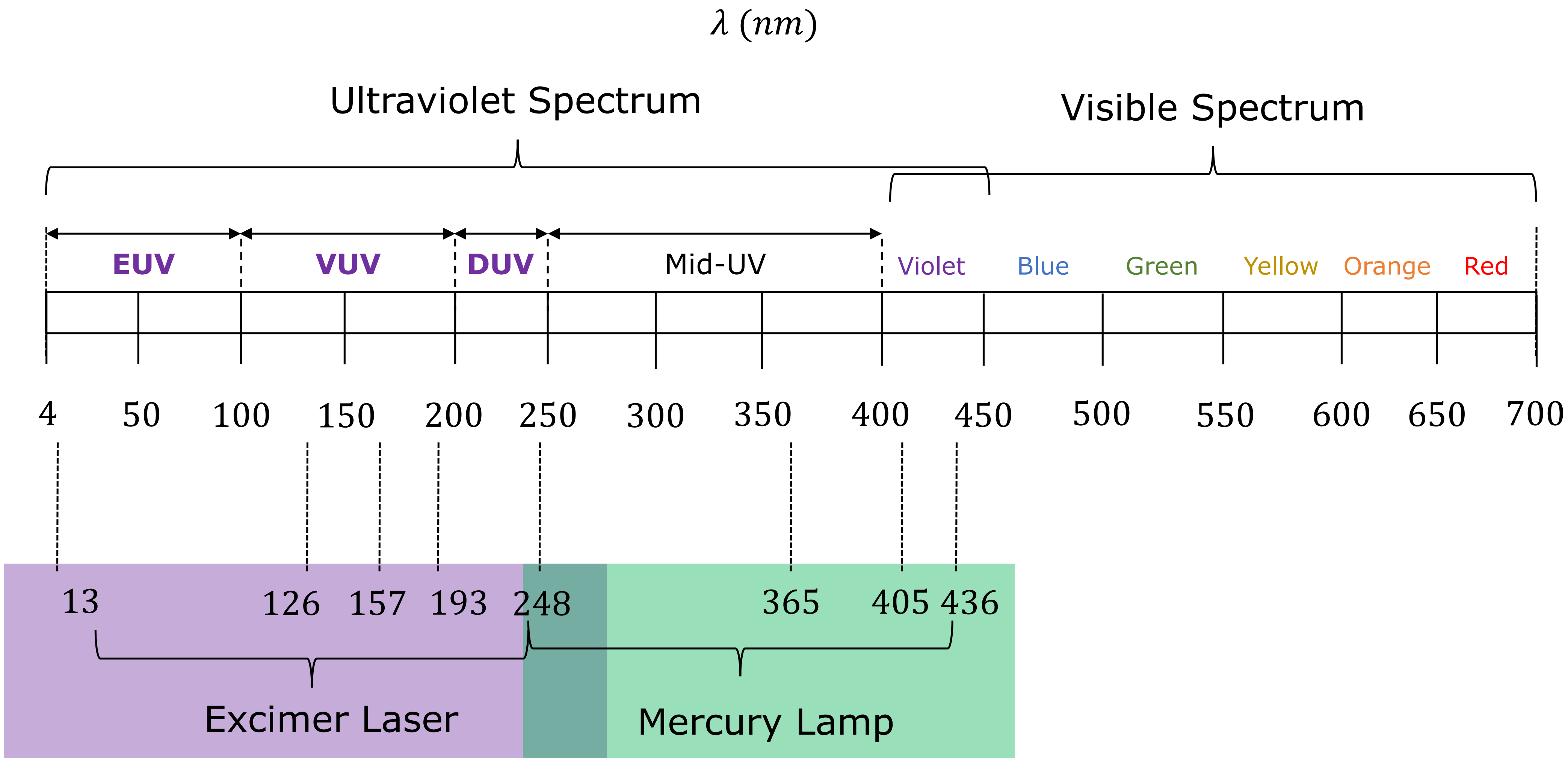
Most resists react with visible UV



- DUV – Deep Ultraviolet
- VUV – Vacuum Ultraviolet
- EUV – Extreme Ultraviolet

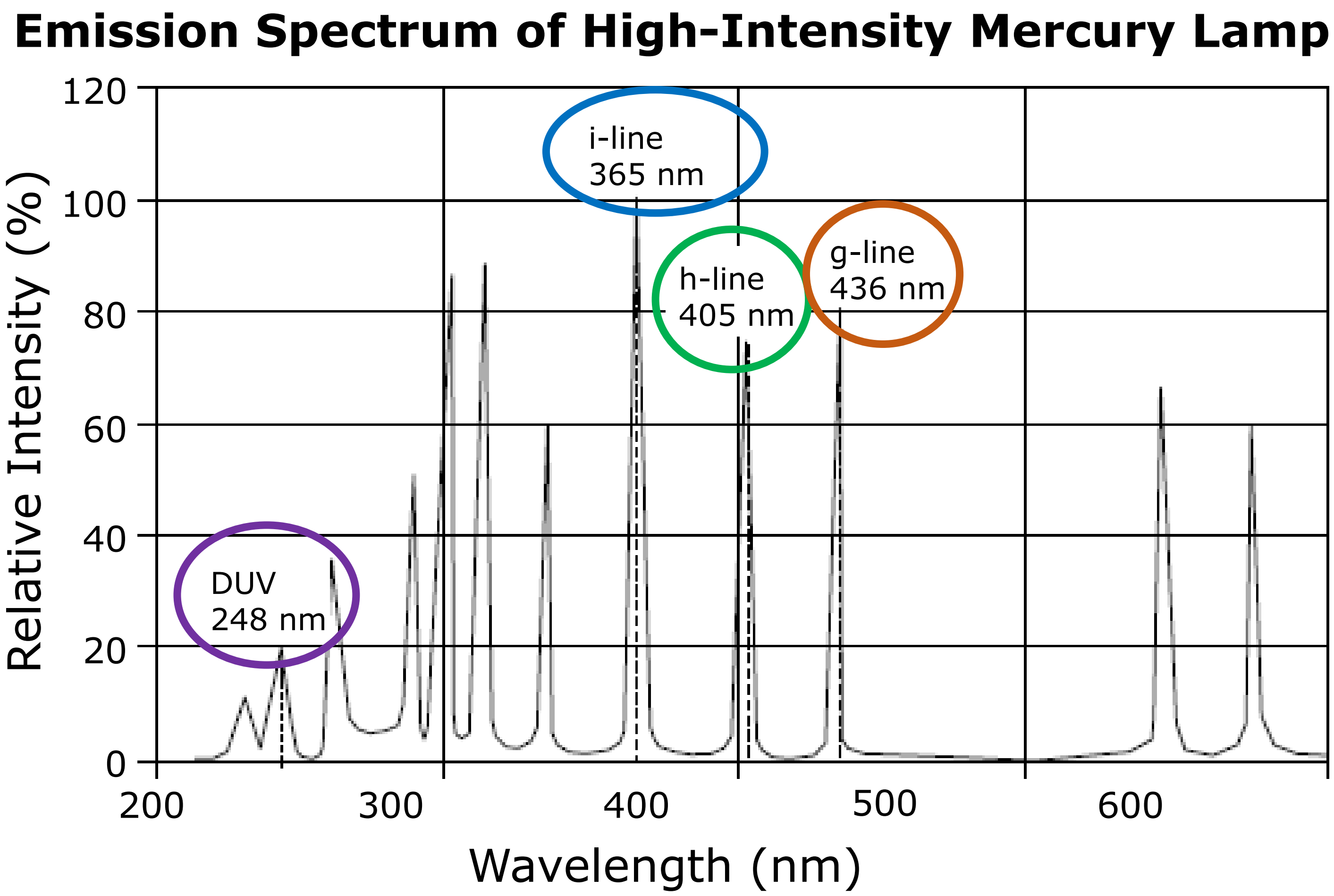
Common UV wavelengths used in optical lithography

Ultraviolet Spectrum



Photolithography Light Sources

Emission Spectrum of Typical Mercury Arc Lamp



Typical Mercury Arc Lamp

Mercury lamp spectrum used with permission from USHIO Specialty Lighting Products.

Mercury Arc Lamp Intensity Peaks

UV Light Wavelength (nm)	Descriptor	Critical Dimension Resolution (µm)
436	g-line	0.5
405	h-line	0.4
365	i-line	0.35
248	Deep UV (DUV)	0.25

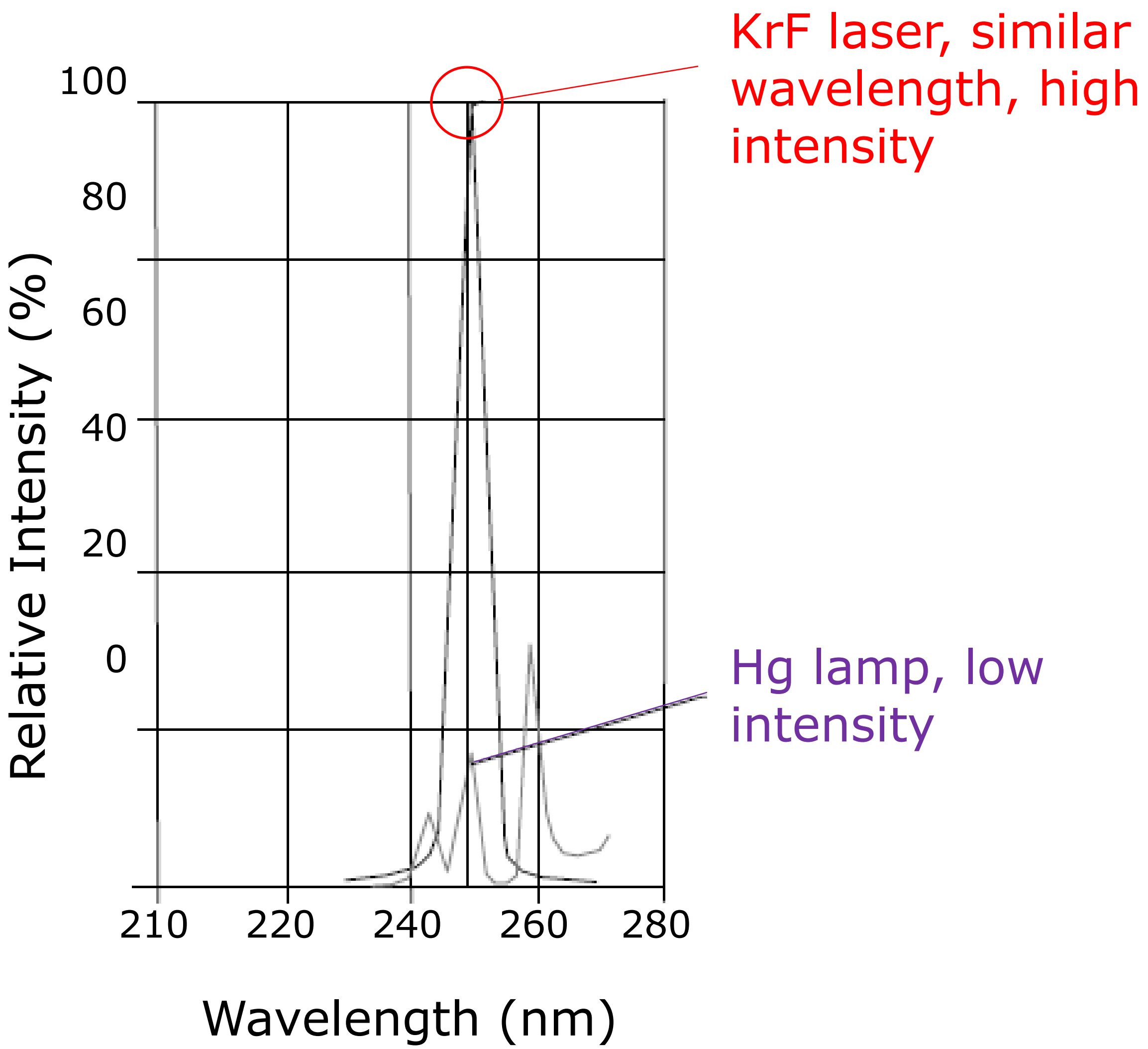
Pause and read carefully

For resolution, the higher the better – able to pattern smaller scale

1. **Resolution is the ability to differentiate between two closely spaced features on the wafer.**
2. **The actual dimensions of the patterned images are the feature sizes.**
3. **The minimum feature size is the Critical Dimension (CD).**
4. **Resolution is important for critical dimension.**

Light Intensity

- Higher intensity = Shorter exposure time
- Lower intensity = Longer exposure time
- KrF laser is preferred over Hg lamp DUV (248 nm)



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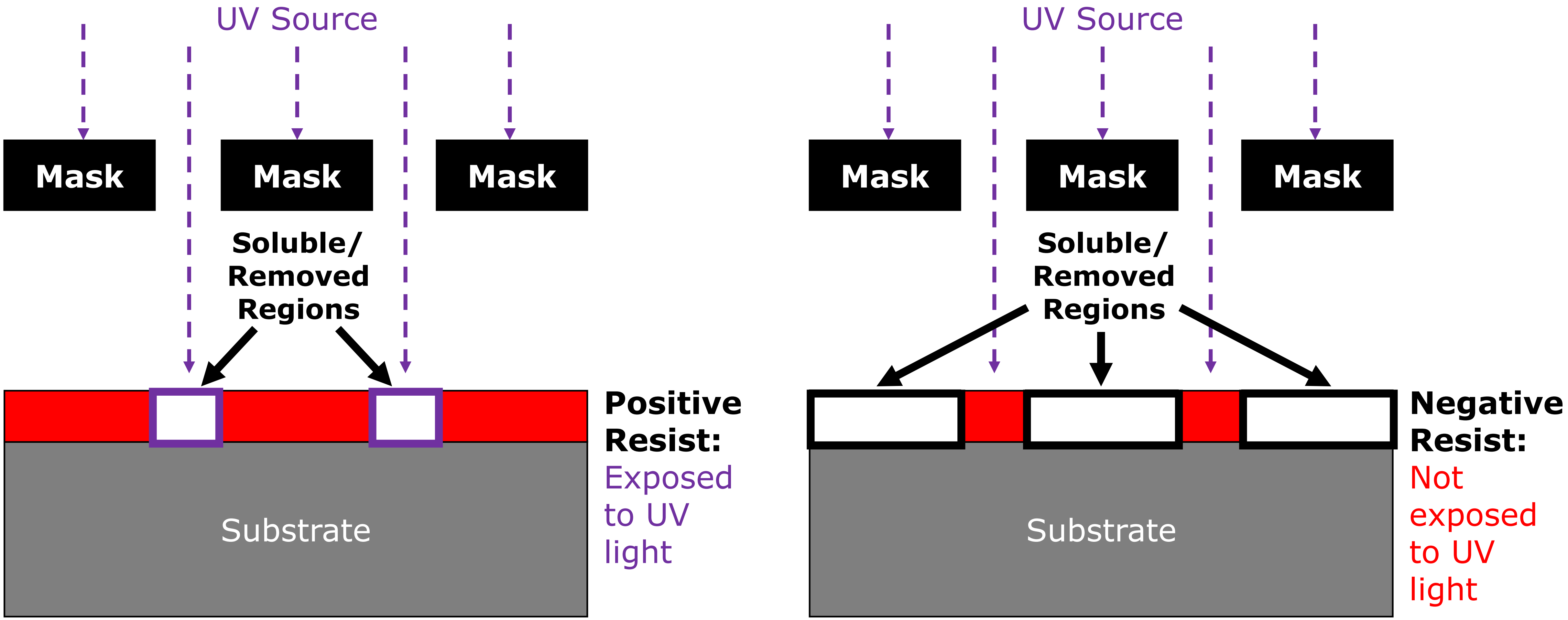
Different materials to achieve different wavelengths

Material	Wavelength (nm)	CD Resolution (µm)
KrF	248	≤ 0.25
ArF	193	≤ 0.18
F_2	157	≤ 0.15

Negative and Positive Lithography (Resist)

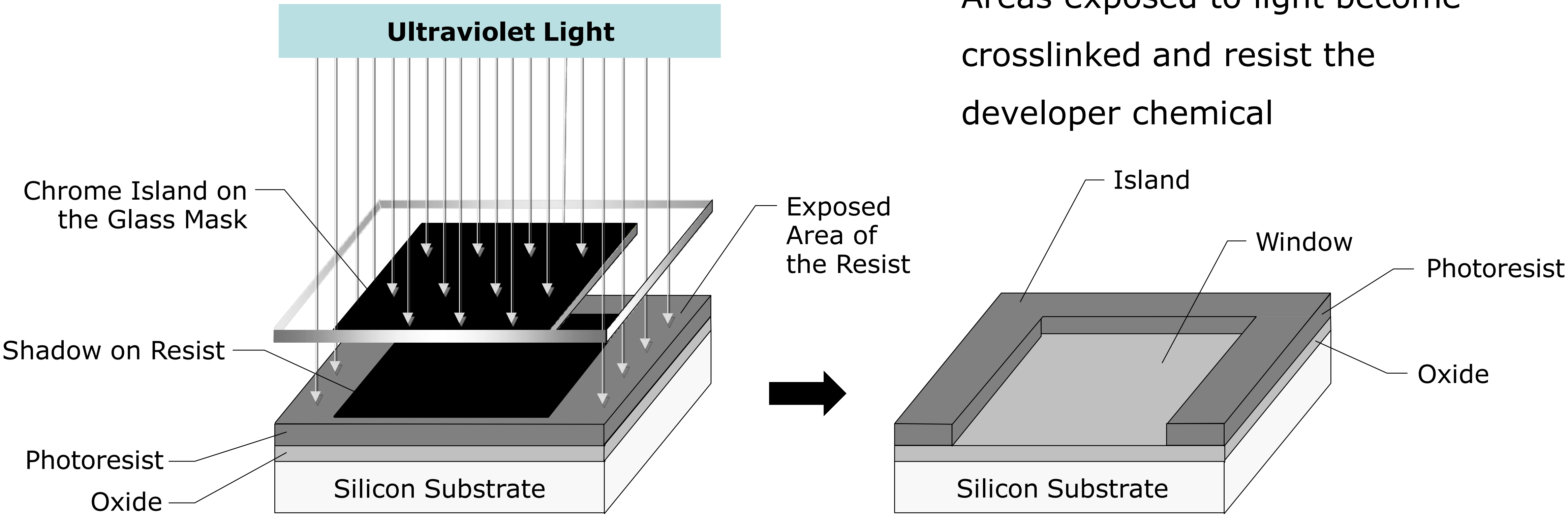
Types of Resists

- Resist is a polymer chemical that is sensitive to light.



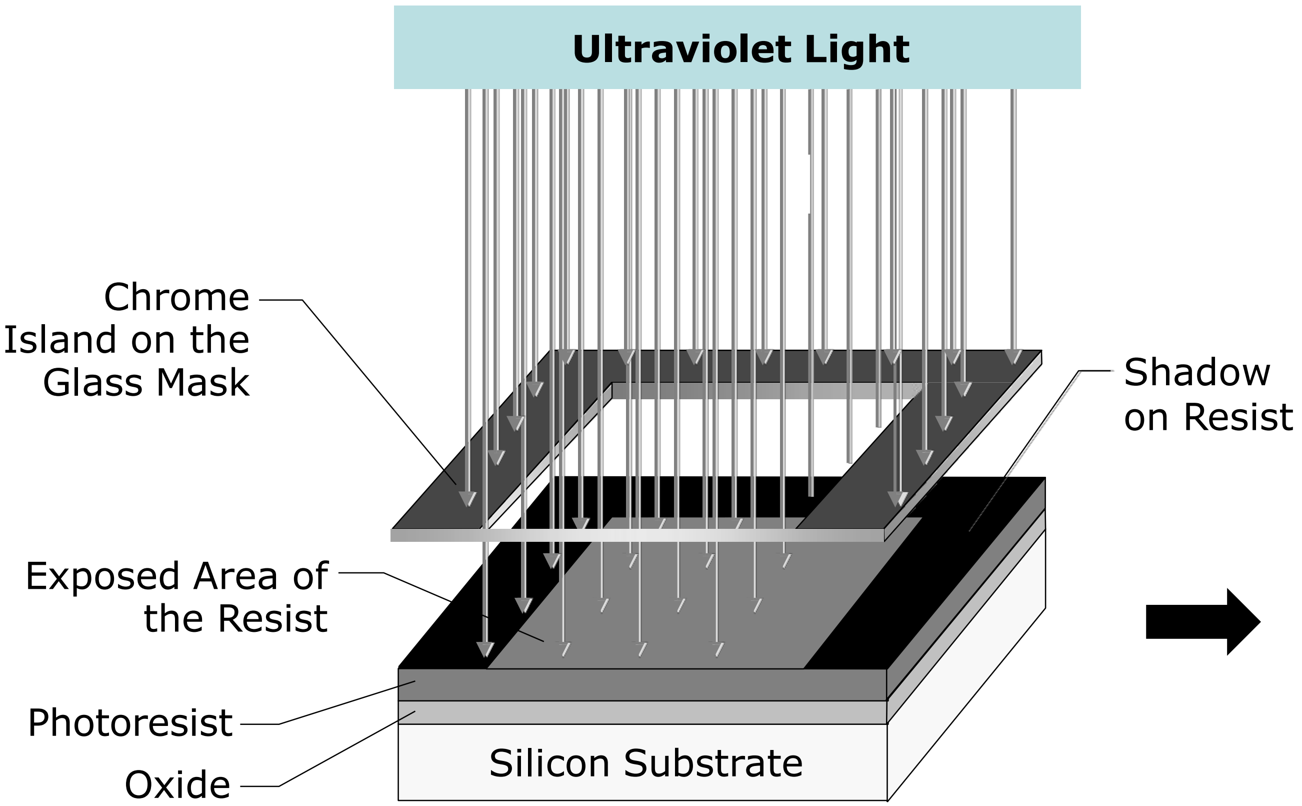
Negative Lithography

Areas exposed to light become crosslinked and resist the developer chemical

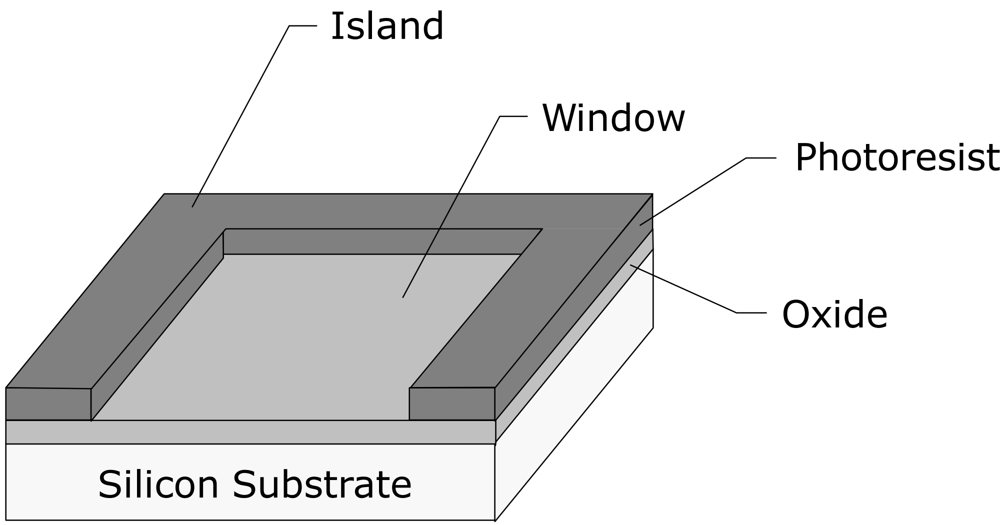


Resulting pattern after the resist is developed

Positive Lithography

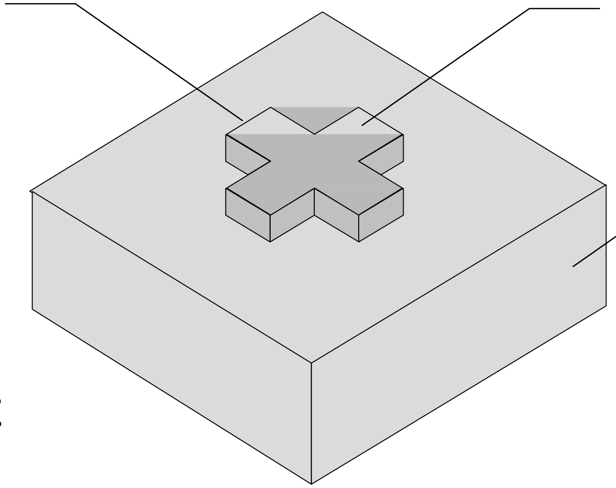


Areas exposed to light are dissolved

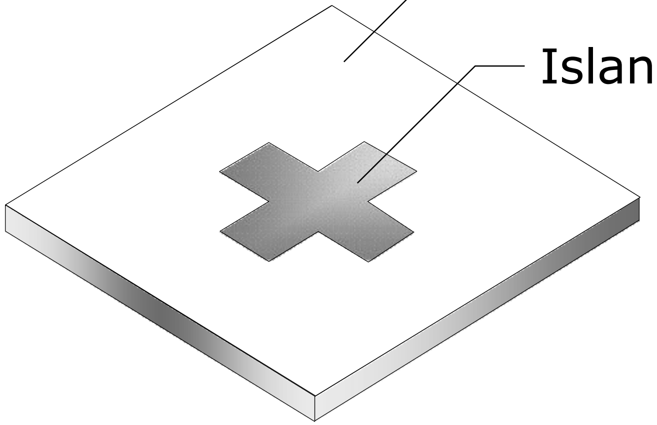


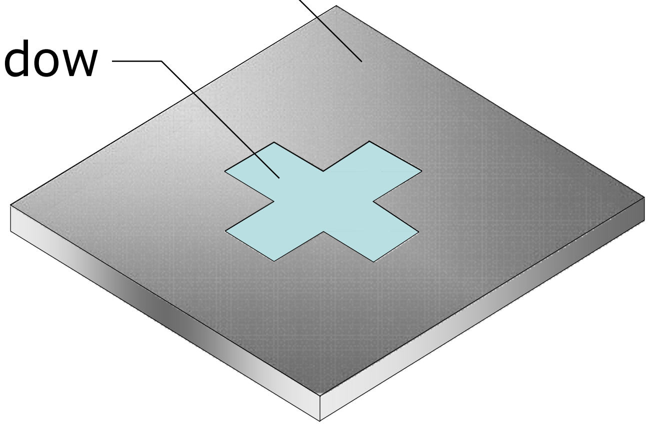
Resulting pattern after the resist is developed

Relationship Between Mask and Resist



Pause and observe carefully





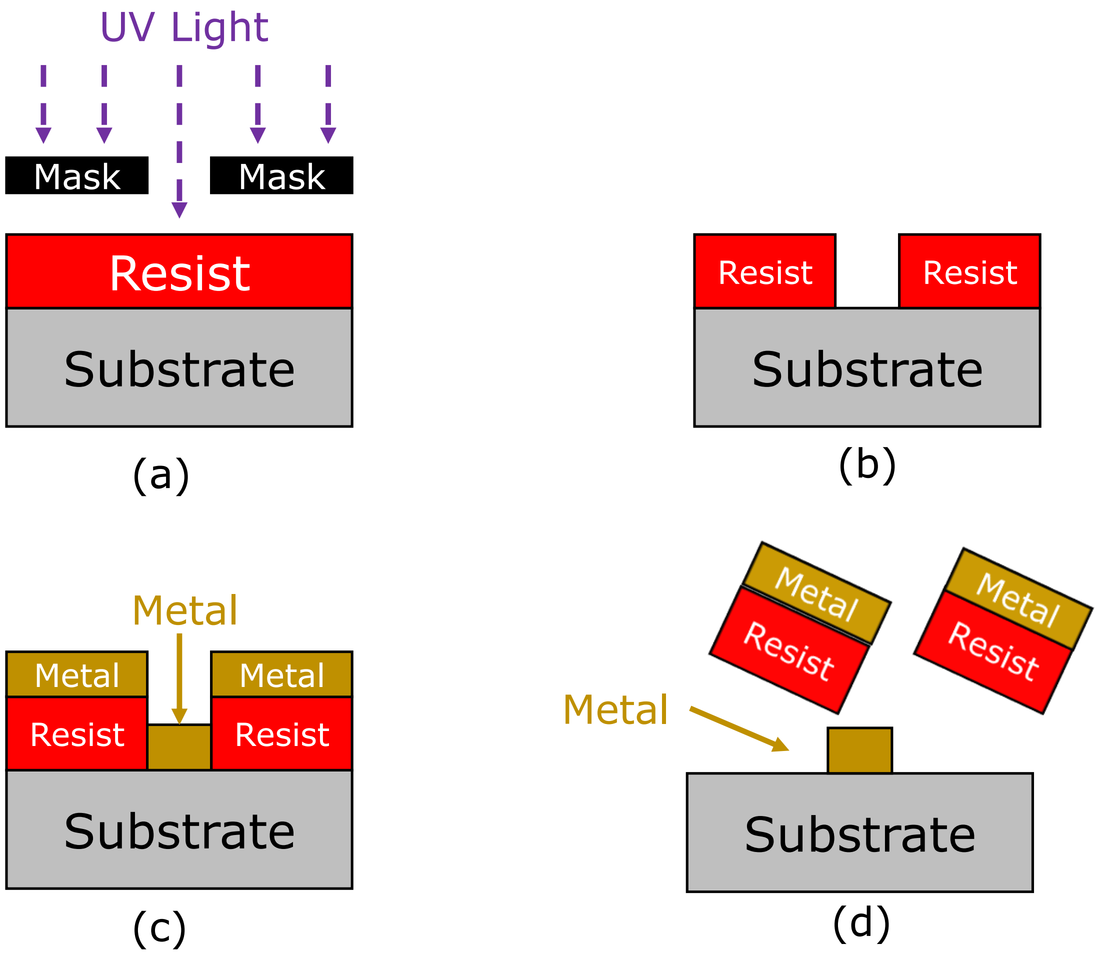
Mask pattern required when using positive resist (same as intended structure)

Mask pattern required when using negative resist (opposite of intended structure)

Main Functions of Resist

- Protect underlying films such as SiO_2, Al, polysilicon, Si_3N_4 etc. from etching
- Define windows for metal-contact and thin film deposition
- Prevent ions from penetrating the underlying Si during selective ion implantation
- Lift-off process used to create metal patterns on the substrate

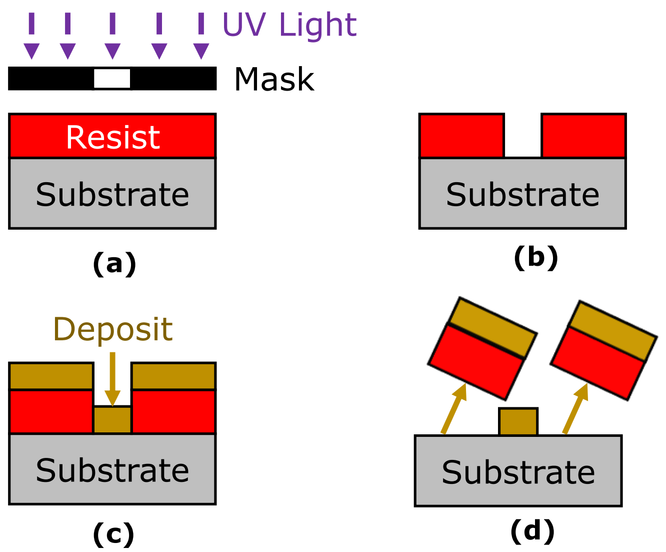
Lift-off Process



a) The substrate is coated with resist. Then the resist is exposed through a mask with the desired pattern.
b) The resist is developed to obtain the desired pattern on the substrate.
c) The metal film is deposited onto the resist-patterned substrate.
d) The metal-deposited resist is removed (acetone is usually used). The metal pattern will remain on the substrate.

Practice Question

A lift-off process is used mostly to create metallic interconnections. Starting with a positive photoresist pattern, formed on a wafer, provide sketches to illustrate a typical lift-off process.



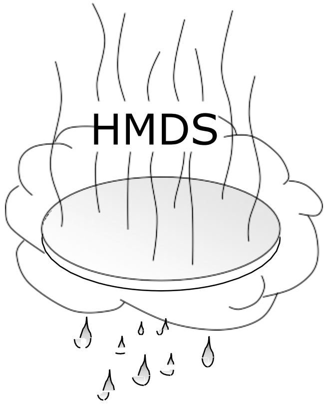
Pause and try out this question

a) Coat the wafer with photoresist and expose the photoresist.
b) Remove exposed resist.
c) Deposit metal film.
d) Remove metal on resist: Metal pattern remains on silicon.

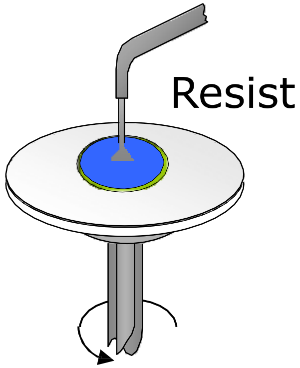
Lift-off process in microstructuring technology is a method of creating structures (patterning) of a target material on the surface of a substrate (eg. Wafer) using a sacrificial material.
It is an additive technique as opposed to more traditional subtracting technique like etching.

Eight Basic Steps of the Lithography Process

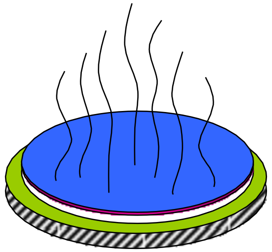
Eight Steps of Lithography



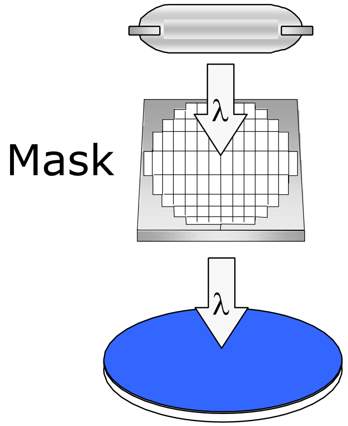
Step 1:
Vapour Prime



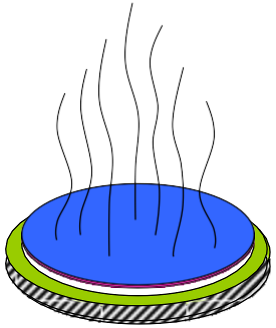
Step 2:
Spin Coat



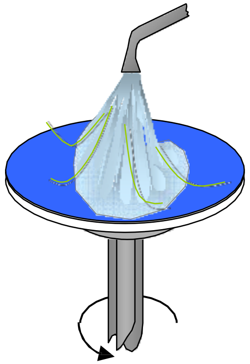
Step 3:
Soft Bake



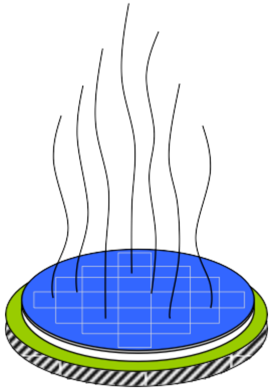
Step 4:
Alignment and Exposure



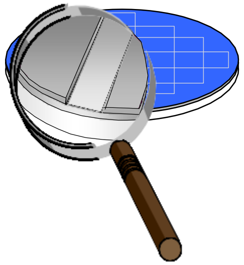
Step 5:
Post-Exposure Bake



Step 6:
Develop



Step 7:
Hard Bake



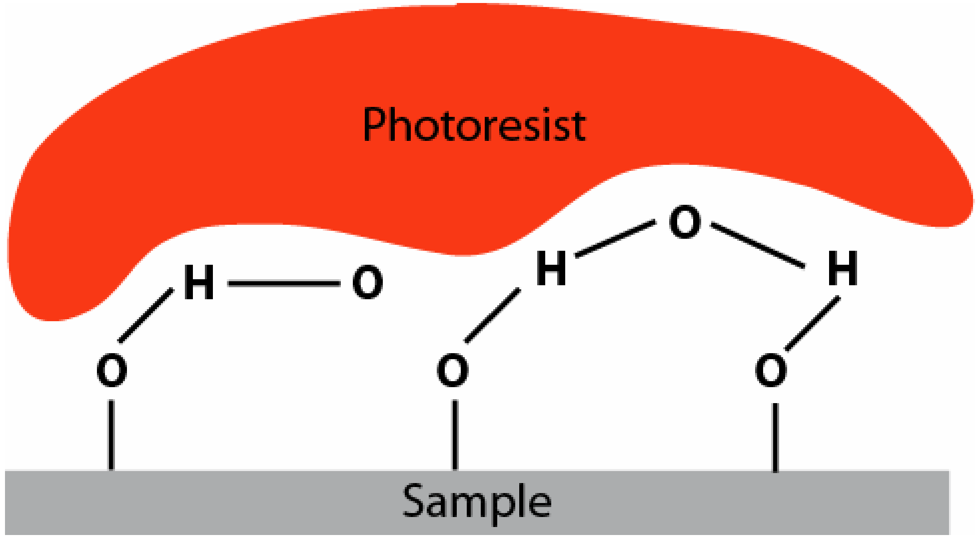
Step 8:
Develop Inspect

1. Vapour Prime Pre-Step – Dehydration Bake

The pre-step of photolithography:

- Wafer dehydration bake – removal of water molecules on the wafer surface
- Ensures wafer surface is clean and dry

Cleaning the sample is very important to make sure that it is free from dust, dirt, or residual resist. Dehydration baking will ensure that any H_2O on the sample evaporates out. This is especially important for samples that oxidise easily, for example like silicon. The oxides will then bond to water vapour available in the air. When the resist is then coated onto the sample, the resist will adhere to the H_2O and not to the wafer surface.



Water presented on the wafer surface causes poor photoresist adhesion and resist lift-off due to surface contamination and presence of moisture layer.

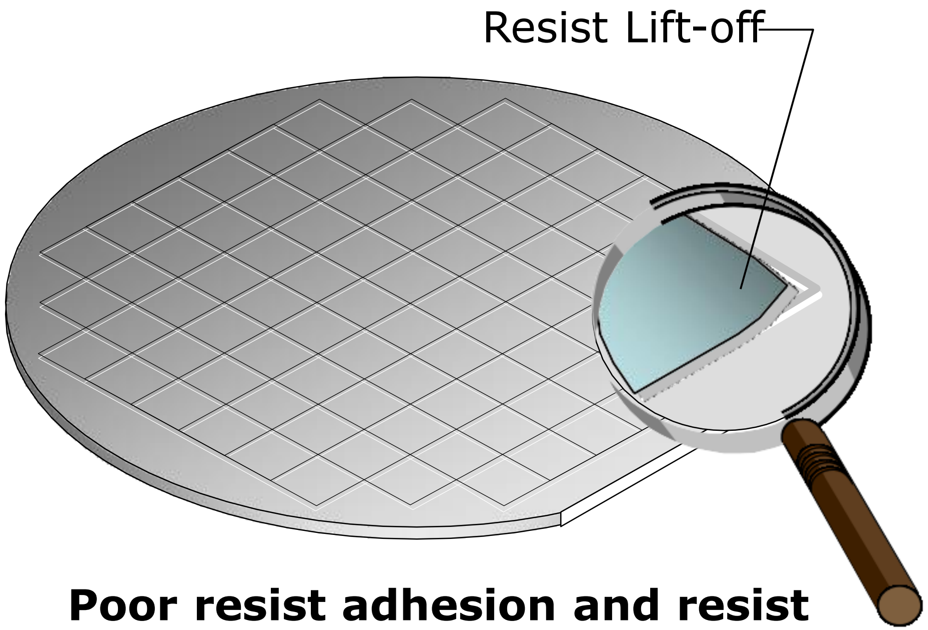
1. Vapour Prime – Cleaning and Dehydration Bake

The first step of photolithography:

- Usually integrated with the wafer dehydration bake on the same process
- Primes wafer with Hexamethyldisilazane (HMDS)
- Promotes good resist-to-wafer adhesion

Typical process sequence:

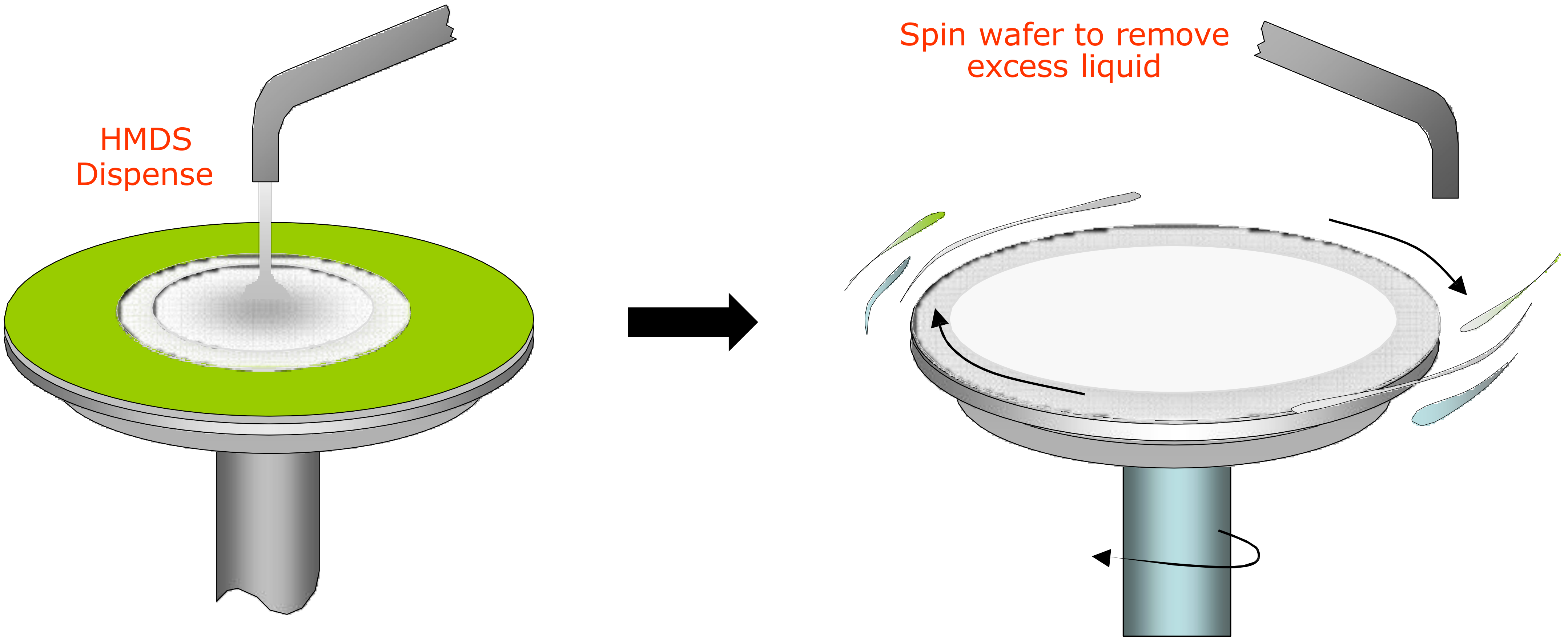
- Dehydration bake (200°C to 250°C)
- Vapour priming
- Priming techniques:
  - Puddle/ spray dispense and spin



Poor resist adhesion and resist lift off due to surface contamination and presence of moisture layer.

HMDS Priming Techniques

HMDS (liquid) dispense and spin:

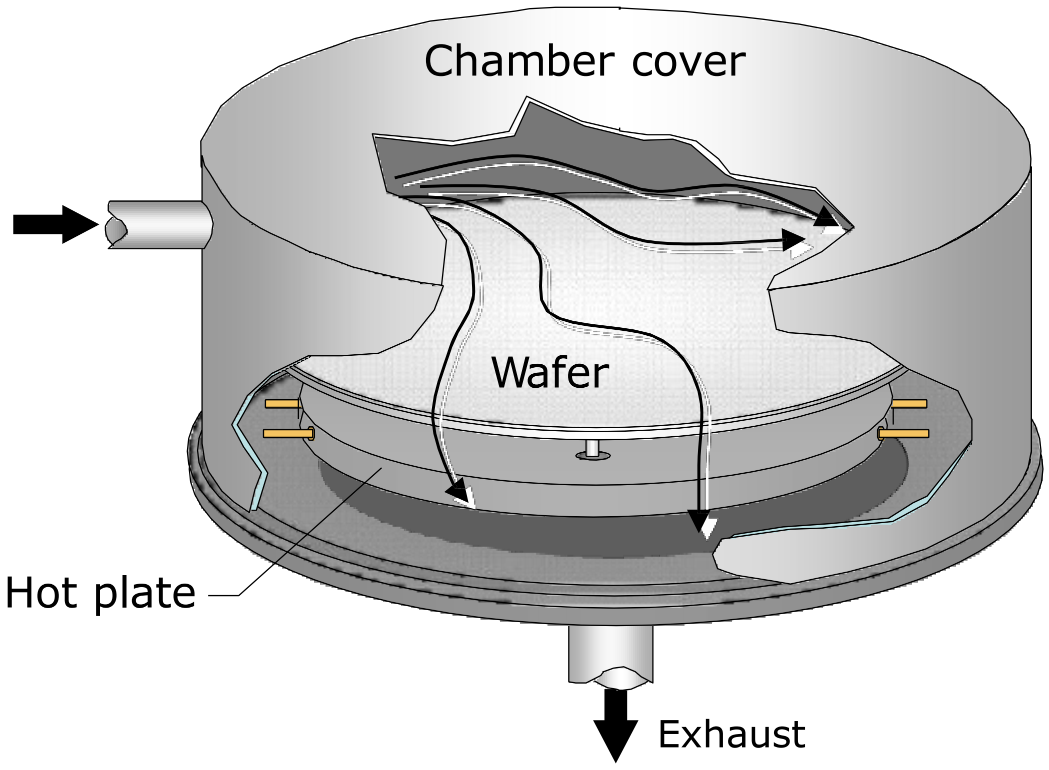


HMDS Priming Techniques

Dehydration bake and HMDS vapour prime:

Process Summary

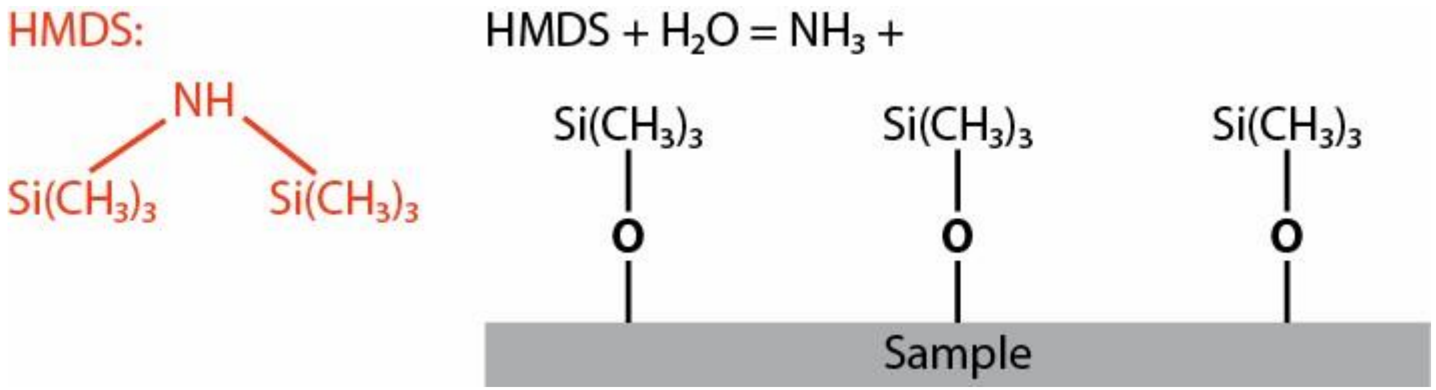
- Dehydration bake in an enclosed chamber with exhaust
- Hexamethyldisilazane (HMDS) prime
- Exhaust
- Clean and dry wafer surface (hydrophobic)
- Temperature ~ 200°C to 250°C
- Time ~ 60 seconds



Action of HMDS Priming on Silicon/ Oxide Surface

HMDS – Hexamethyldisilazane:

- HDMS turns wafer surface from hydrophilic to hydrophobic for better resist adhesion.
- Si-dioxide + H_2O + HMDS $\rightarrow$ Hexamethyldisiloxane + Ammonia

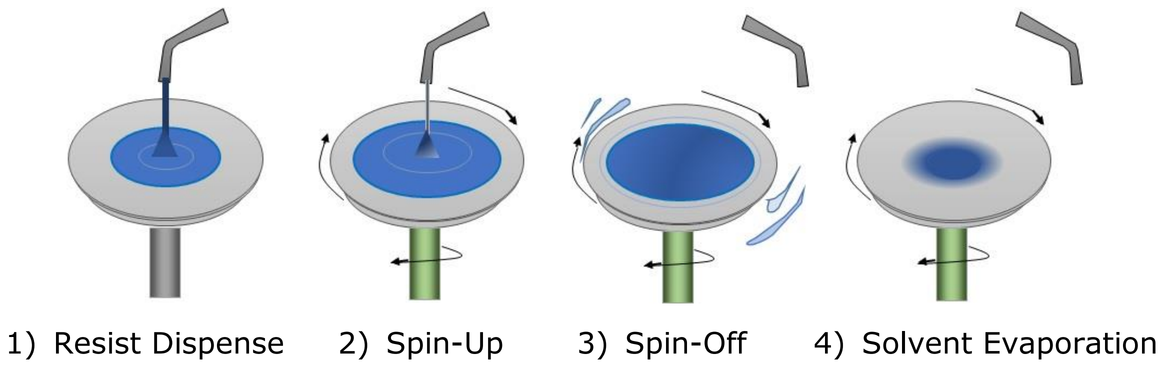


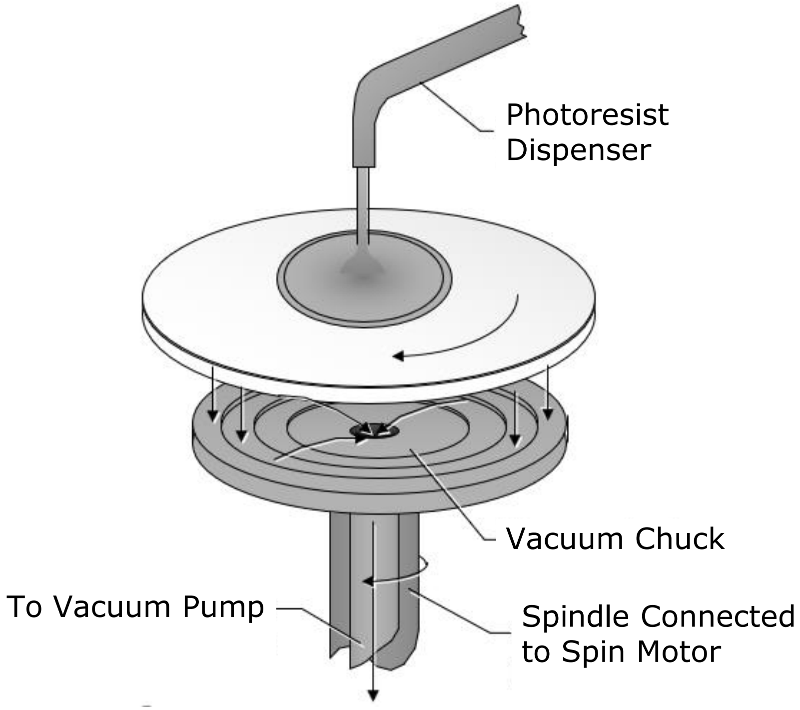
- After dehydration baking these oxidised samples, it is important to spin coat them first with HMDS primer. The HMDS primer will bond with the oxide groups to seal out the moisture.
- The $Si(CH_3)_3$ groups are compatible with the resist, creating adhesion between the sample and the resist.

2. Spin Coat

Process Summary:

- The wafer is held onto the vacuum chuck
- Dispense ~5 ml of the resist at static or slow spread speed of ω_1~500 rpm
- Ramp up to ω_2~3000 to 5000 rpm
- Quality measures:
  1. Time
  2. Speed
  3. Thickness
  4. Uniformity
  5. Particles and defects

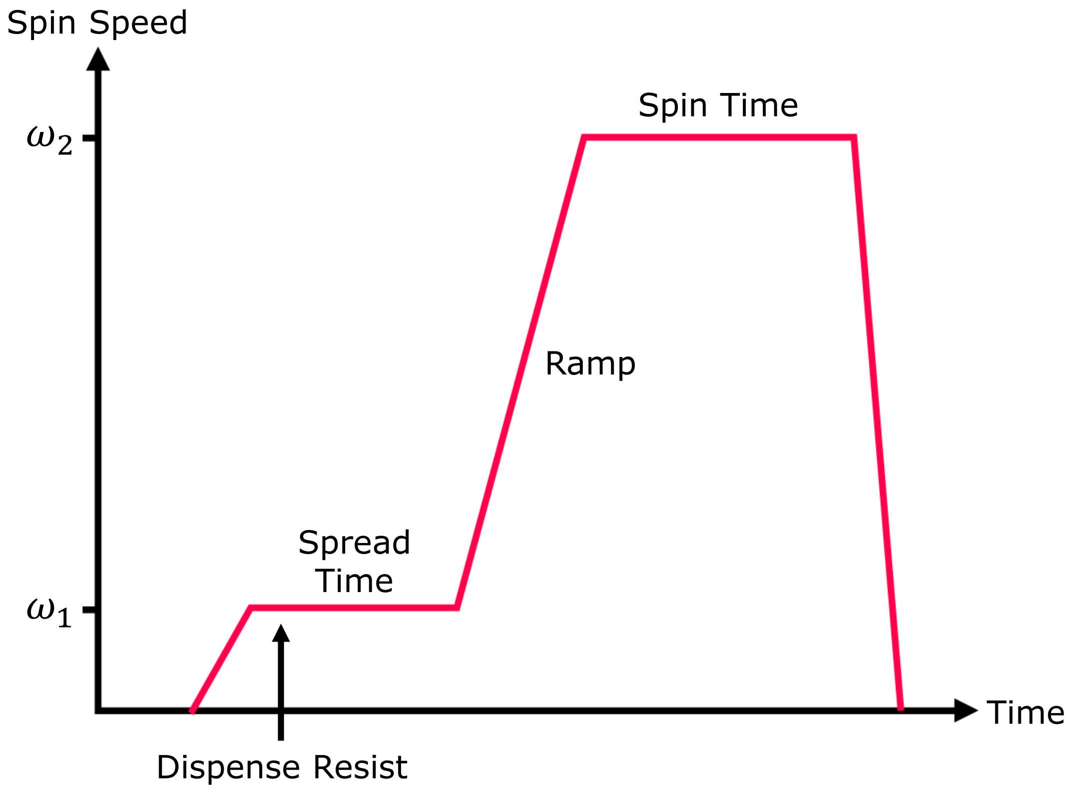


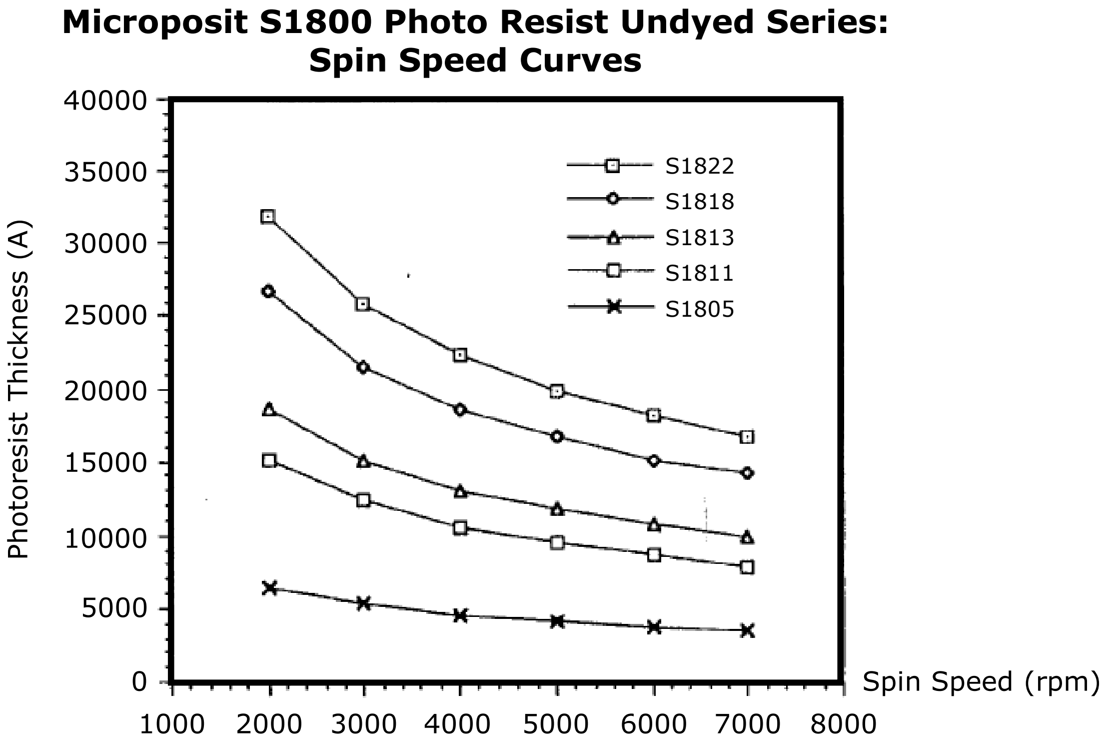


Resist Spin Coating

Watch the video lecture to view this video.

Resist Spin Coating

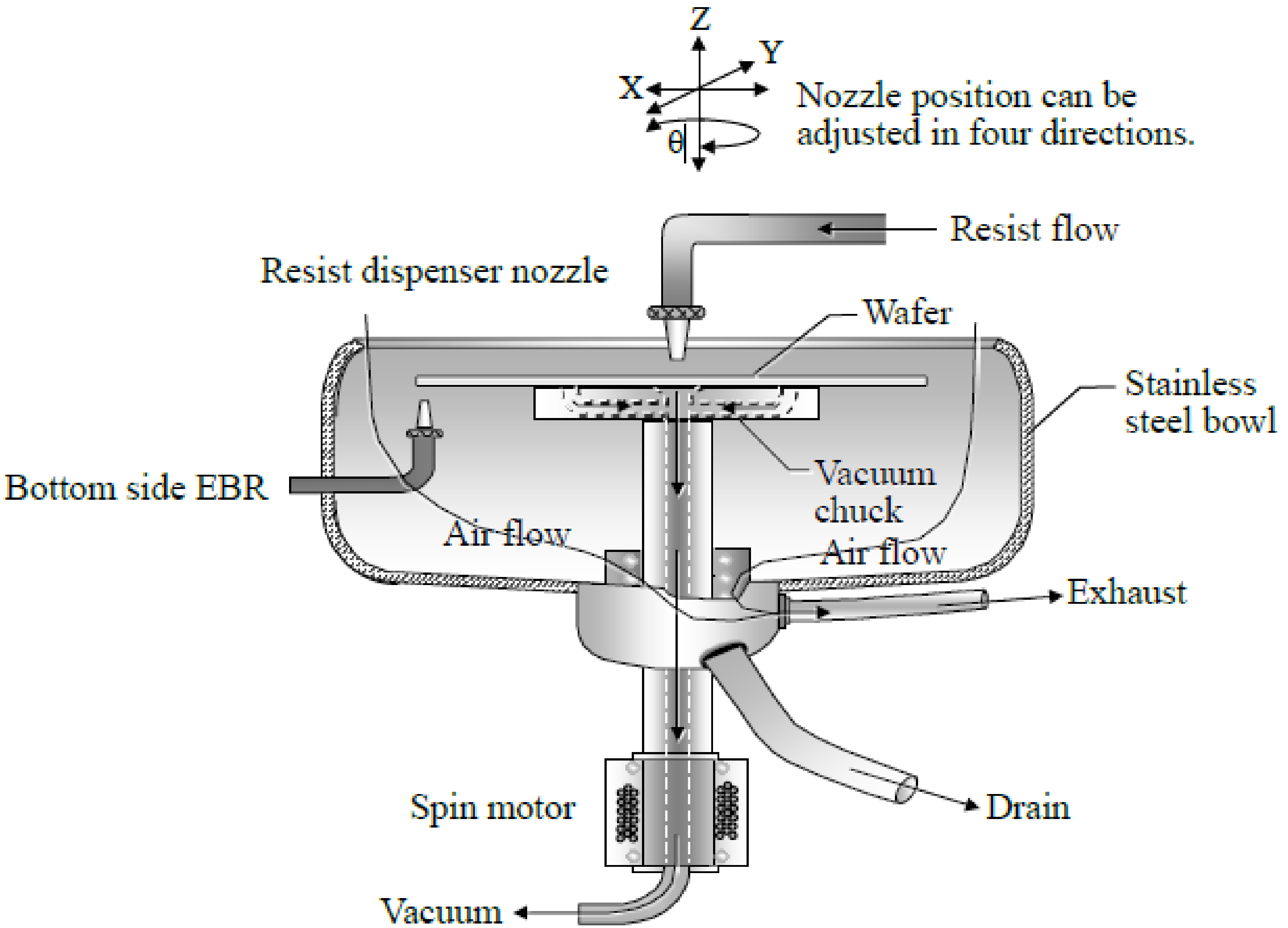




Pictorial representation of a simple resist spin coat cycle. If $\omega_1 > 0$, the dispense is said to be dynamic.

Resist layer thickness depends on the viscosity of resist and is inversely proportional to the square root of the spin speed, $t \, \alpha \, 1/\omega_2$.

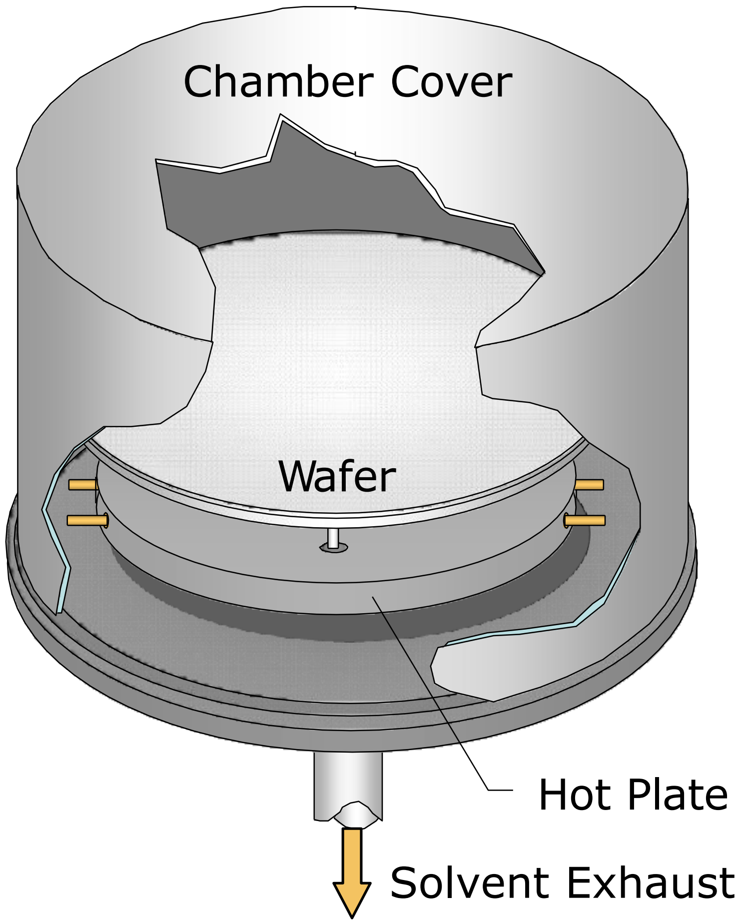
Resist Dispense Nozzle



3. Soft Bake

Characteristics of Soft Bake:

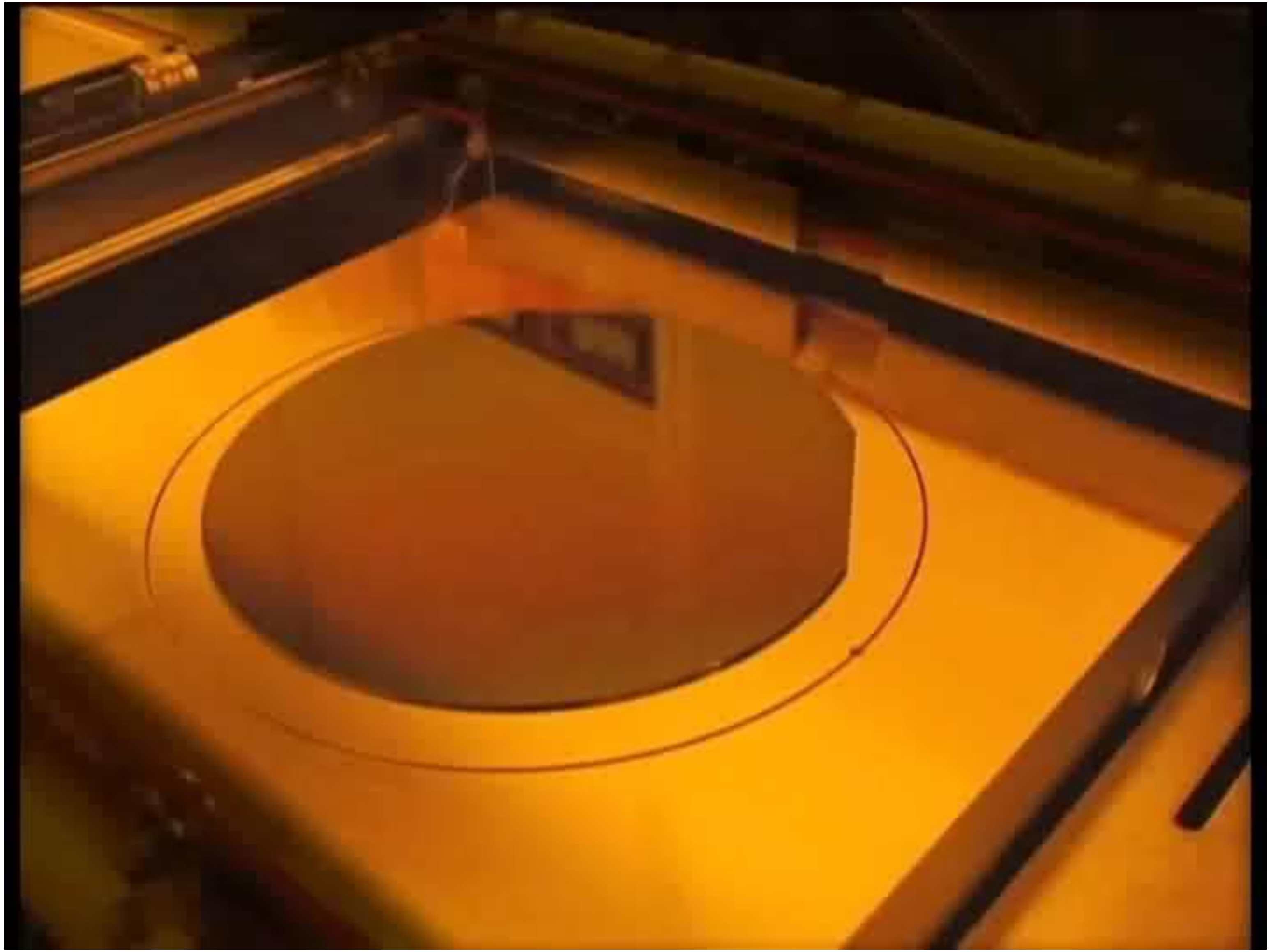
- Partial evaporation of resist solvents
- Improves resist-to-wafer adhesion
- Promotes resist uniformity on the wafer
- Optimises light absorbance characteristics of resist (optimises the photo-speed)
- Improves etch resistance and linewidth control during etching
- Drives off most of the solvent in the resist
- Typical bake temperatures are 90°C to 100°C:
  1. For about 30 seconds
  2. On a hot plate
  3. Followed by a cooling step on a cold plate



Soft Bake on Vacuum Hot Plate

3. Soft Bake

- Prebaking or Soft Bake makes the PR sensitive to UV light by removing the solvent component of the PR.
- A short prebake will prevent UV light from reaching the PAC (photoactive compound, will be further explained in Chapter Resist Technology) due to an excess of solvent remaining in the PR.
- Over-baking the sample will increase the sensitivity to UV light and, in severe cases, may destroy the PAC and reduce the solubility of the PR in the developer.

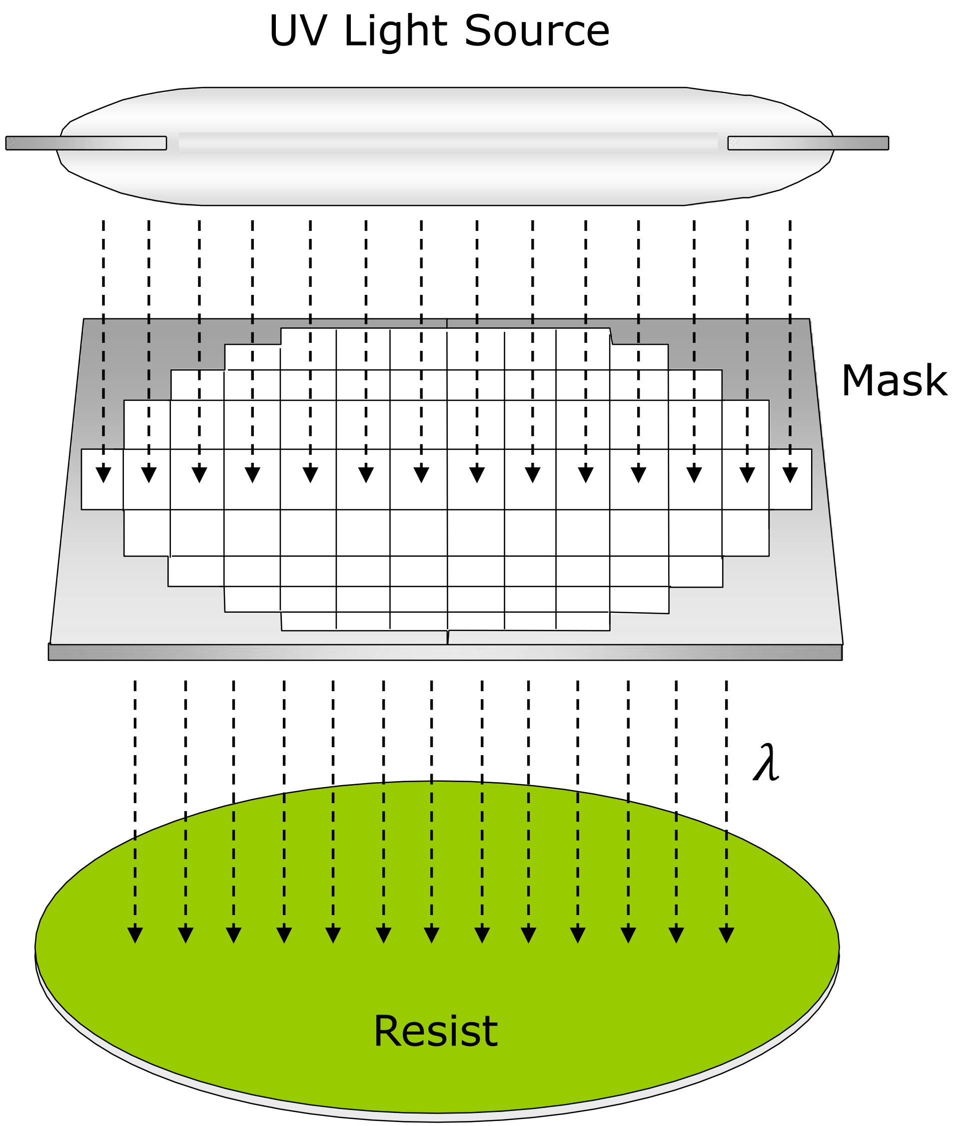


4. Alignment and Exposure

Process Summary:

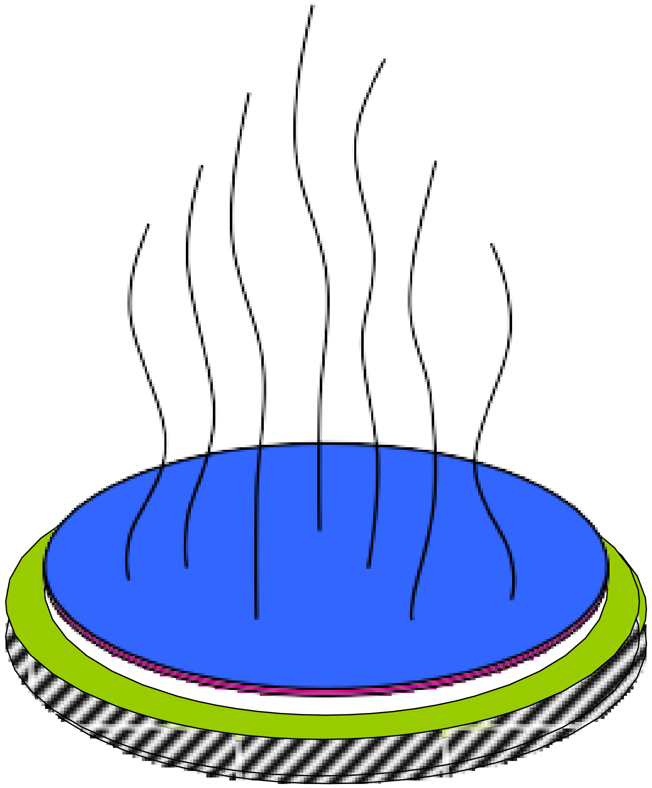
- Transfers the mask image to the resist-coated wafer
- Activates photo-sensitive components of the resist
- Quality measures:
  - Linewidth resolution
  - Overlay accuracy
  - Particles and defects

We will discuss further in "lithography technology" and "resist technology" sections.



5. Post-Exposure Bake

- Required for deep UV resists
- Typical temperatures 100°C to 110°C on a hot plate
- Immediately after exposure



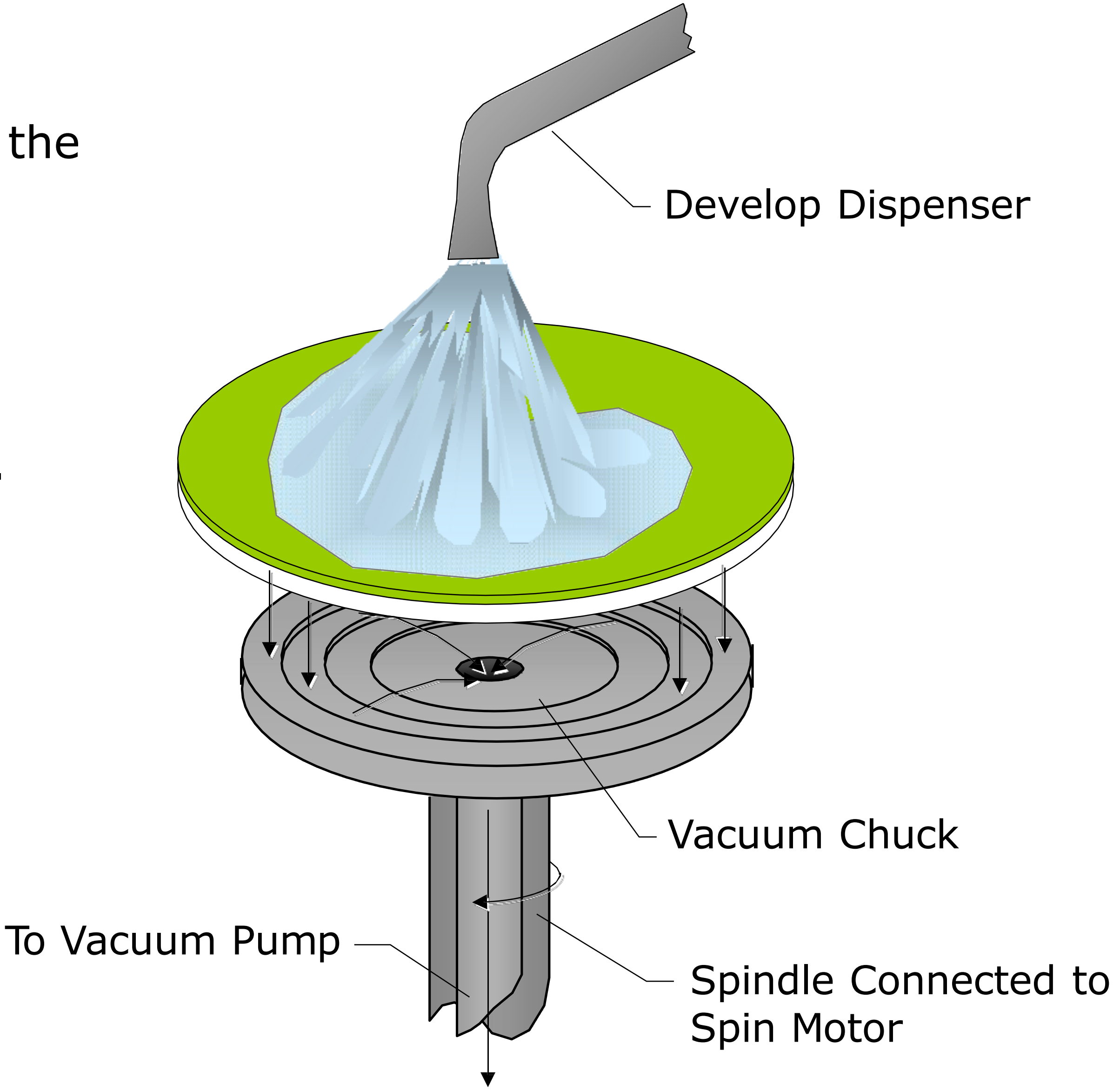
6. Developing

Purpose:

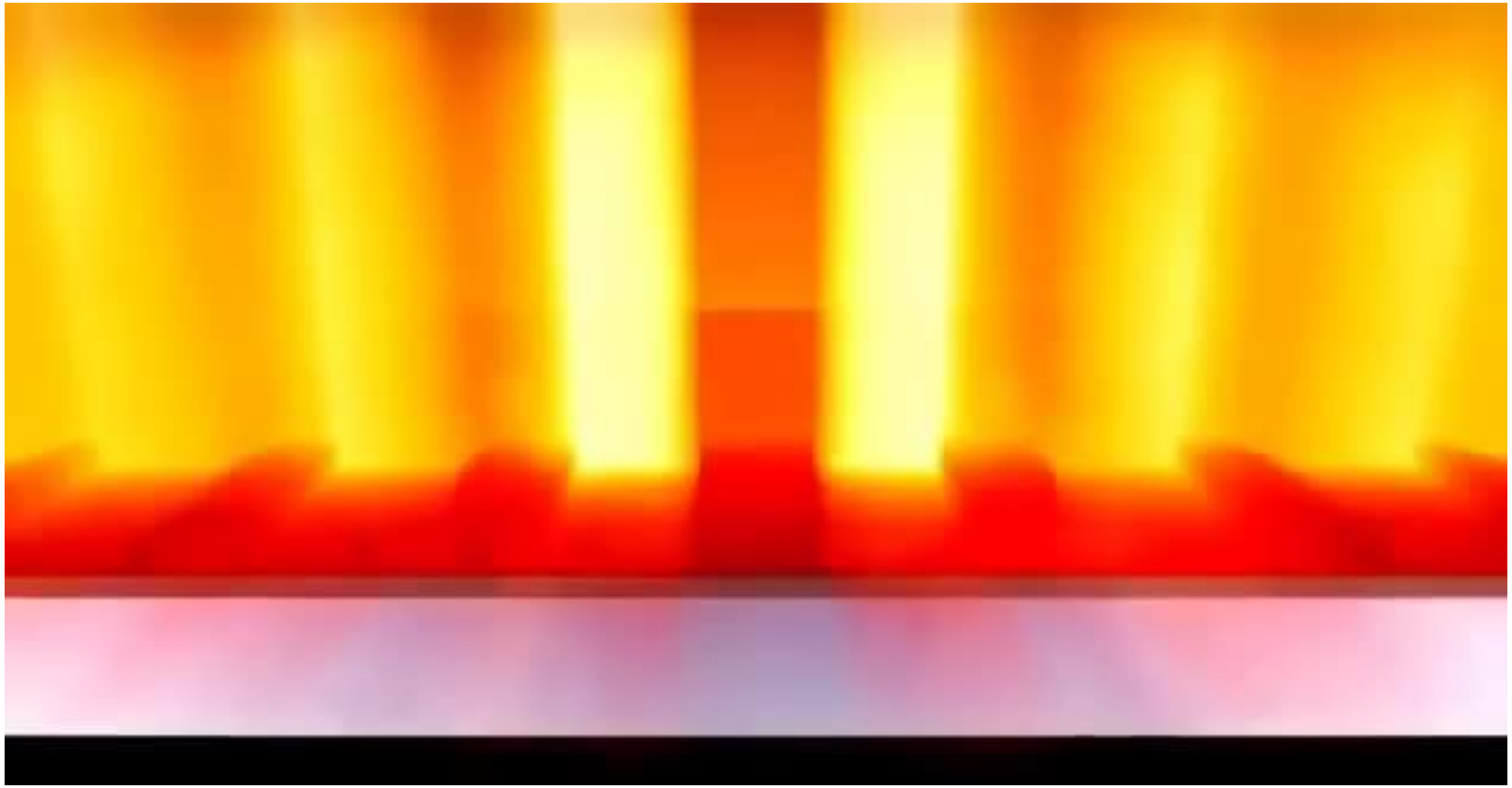
- Developing creates the pattern in the resist on the wafer surface.

Step Summary:

- The developer washes away the soluble region.
- The insoluble region remains on the wafer.



6. Develop – Animation



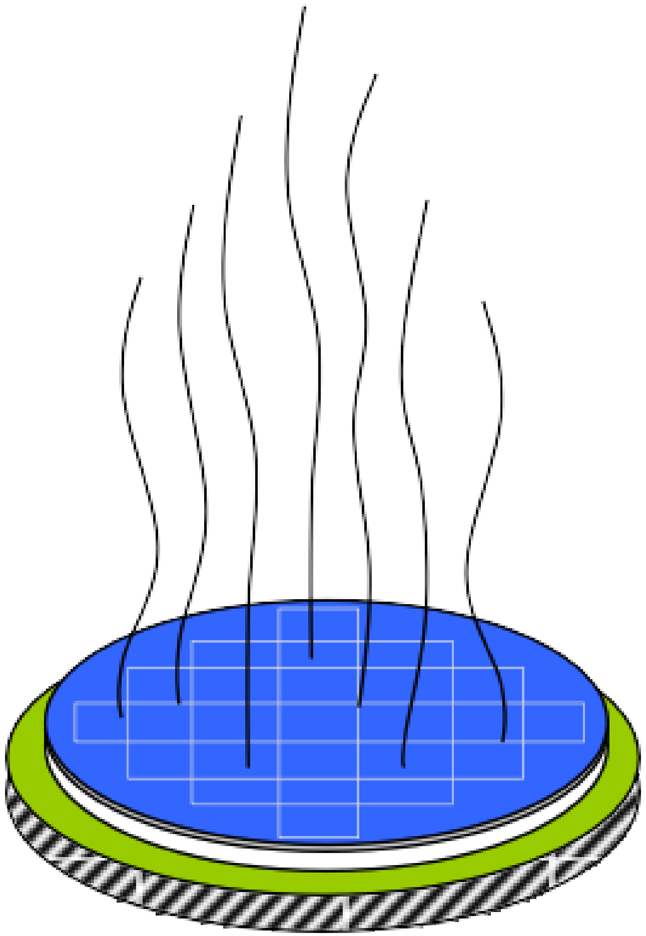
Watch the video lecture to view this animation.

6. Develop – Video

Watch the video lecture to view this video.

7. Hard Bake

- A post-development thermal bake at about 110°C
- Evaporate remaining solvent
- Improve resist-to-wafer-adhesion

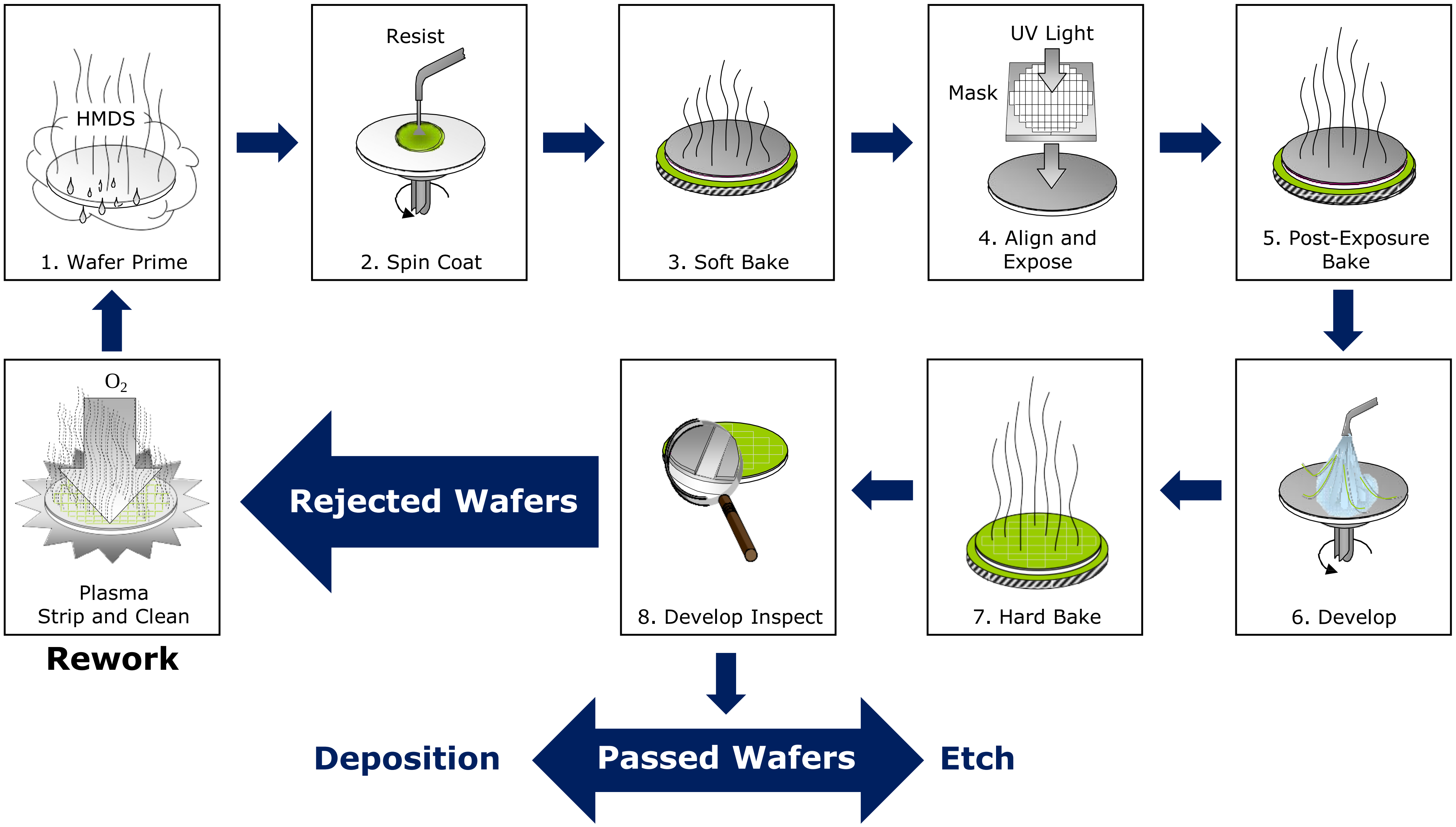


8. Develop Inspect

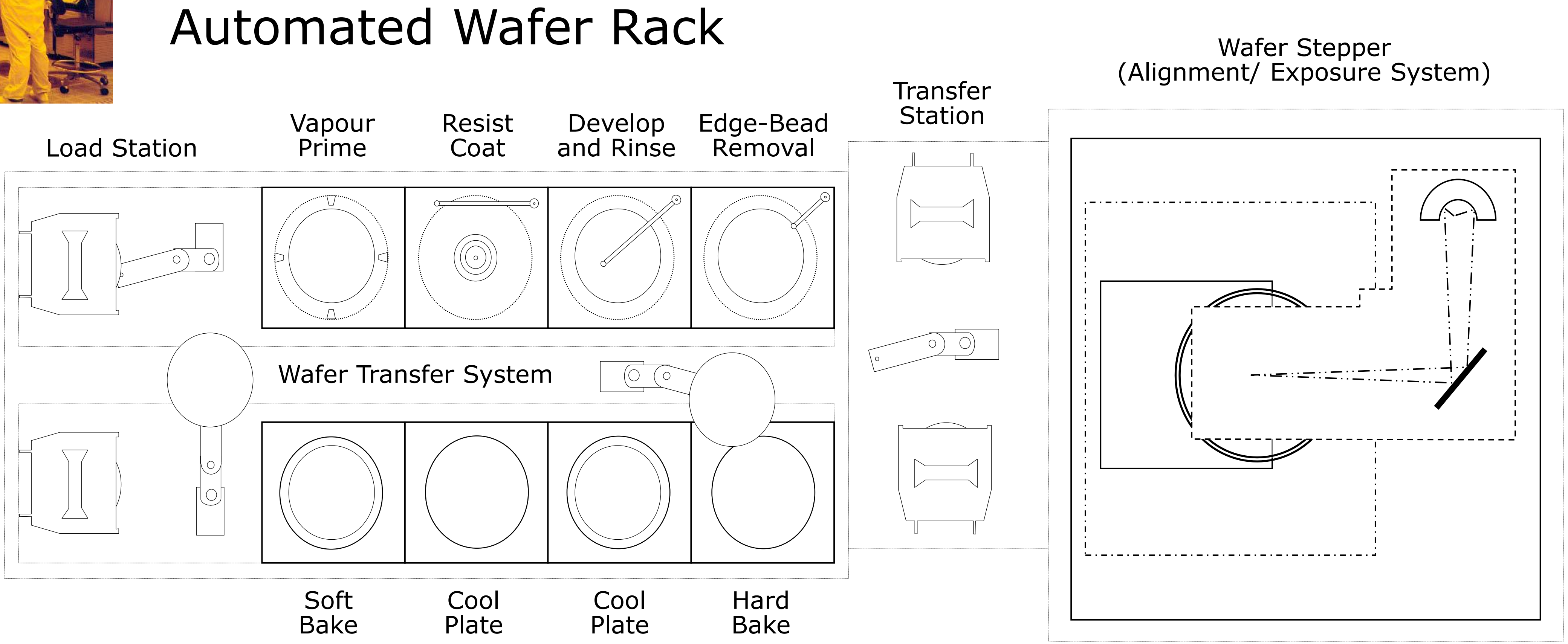
- Inspect to verify a quality pattern:
  1. Identify quality problems (defects)
  2. Characterise the performance of the photolithography process by providing feedback regarding the quality of the lithography process
  3. Prevents scrap
  4. Prevents passing defects to other areas such as etching or deposition
- Plasma Clean: Rework on defective resist-coated wafers
- Typically an automated operation
- Develop inspect rework flow

Inspection Tool for Develop Inspect

Develop Inspect and Rework Flow



Lithography Track System

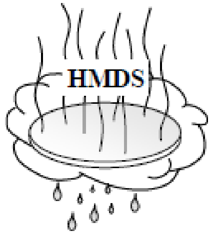
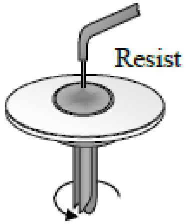
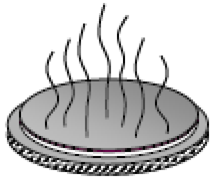
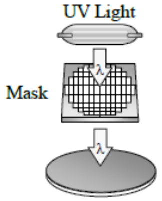
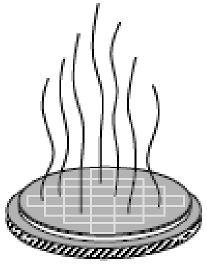


Summary

Step	Purpose
1. Vapour Prime	De-bakes and primes wafer surface with HMDS to improve photoresist to wafer adhesion
2. Spin Coat	Spin coat photoresist to the target thickness
3. Soft Bake	• Partial evaporation of photoresist solvents • Improves photoresist-to-wafer adhesion promotes resist uniformity on the wafer • Optimises light absorbance characteristics of photoresist (exposure speed) • Improves etch resistance and linewidth control during etching
4. Alignment and Exposure	Transfers the mask image to the resist-coated wafer activates photo-sensitive components of photoresist
5. Post-Exposure Bake (PEB)	Required for DUV resist preventing non-uniform exposure along the thickness of the photoresist film
6. Develop	Dissolves the exposed photoresist
7. Hard Bake	• Evaporates the residual solvent in the photoresist • Hardens the resist for subsequent ion implant or etch processing • Improves resist-to-wafer adhesion
8. Develop Inspect	Checks the quality of process to ensure the desired pattern is transferred to photoresist layer

Pause and read

Fill in the Missing Information

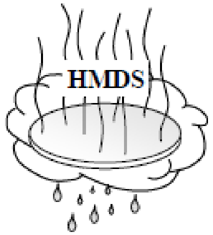
		Promotes Wafer-Resist Adhesion	
Step 1: Vapour Prime 	**Step 2:** 	**Step 3:** 	**Step 4: Alignment and Exposure** 
Step 5: Post Exposure Bake 	**Step 6:** 	**Step 7:** 	**Step 8: Develop Inspect** 
Smooth-Out Possible Interference Effect		Evaporates Remaining Solvent	

Pause and try out this question

Fill in the Missing Information

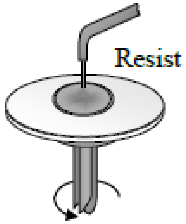
Step 1: Vapour Prime

Ensures Wafer is Clean and Dry



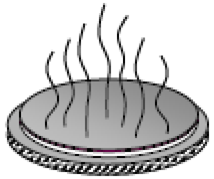
Step 2: Spin Coat

Coat Resist on Wafer



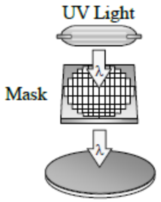
Step 3: Soft Bake

Promotes Wafer-Resist Adhesion



Step 4: Alignment and Exposure

Induces Photochemical Reaction in Resist



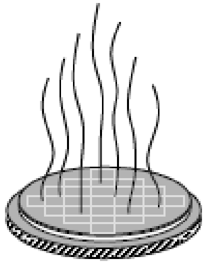
Step 5: Post Exposure Bake

Smooth-Out Possible Interference Effect

Step 6: Develop

Creates Pattern on Wafer

Step 7: Hard Bake



Evaporates Remaining Solvent

Step 8: Develop Inspect

Identifies Quality Problems

Pause and observe carefully

Lithography Processing – Summary

Lithography processing:

- UV light is used as the exposure source in optical lithography. Smaller UV wavelength enables printing of smaller features.
- For a positive resist, regions exposed to UV light will be washed away by the developer, whereas for a negative resist, regions shaded from UV light will be washed away by the developer.
- The eight basic steps of lithography include vapour prime, spin coat, soft bake, alignment and exposure, post-exposure bake, develop, hard bake, and develop inspect, sequentially.