Semiconductor Manufacturing Technology

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Chapter 13

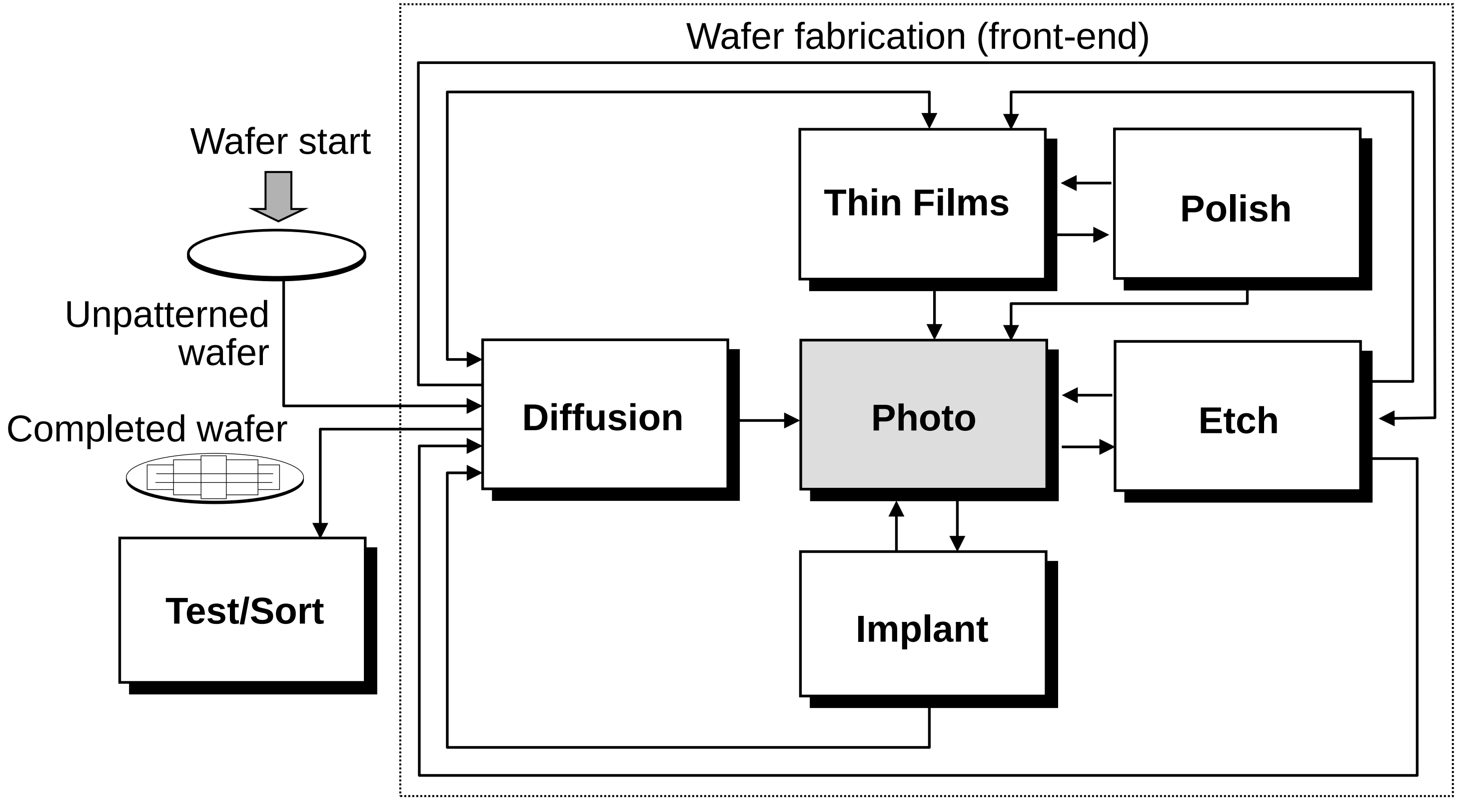
Photolithography: Surface Preparation to Soft Bake

Objectives

After studying the material in this chapter, you will be able to:

1. Explain the basic concepts for photolithography, including process overview, critical dimension generations, light spectrum, resolution and process latitude.
2. Discuss the difference between negative and positive lithography.
3. State and describe the **eight** basic steps to photolithography.
4. Explain how the wafer surface is prepared for photolithography.
5. Describe photoresist and discuss photoresist physical properties.
6. Discuss the chemistry and applications of conventional i-line photoresist.
7. Describe the chemistry and benefits of deep UV (DUV) resists, including chemically amplified resists.
8. Explain how photoresist is applied in wafer manufacturing.
9. Discuss the purpose of soft bake and how it is accomplished in production.

Wafer Fabrication Process Flow



Used with permission from Advanced Micro Devices

Figure 13.1

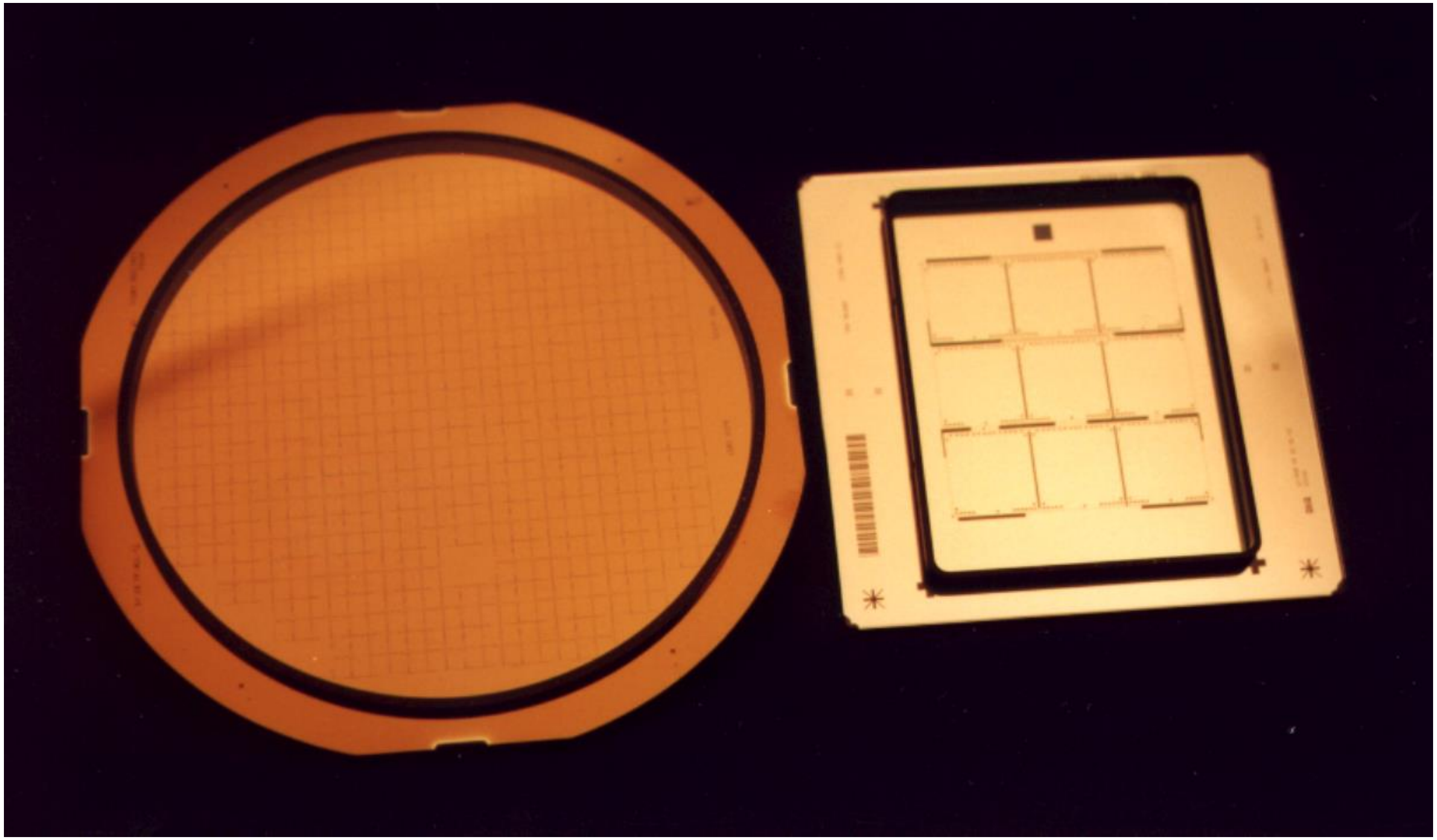
Photolithography Concepts

- Patterning Process (~ 30-step)
  - Photomask
  - Reticle
- Critical Dimension Generations
- Light Spectrum
- Resolution
- Overlay Accuracy
- Process Latitude

Photomask and Reticle for Microlithography

1:1 Mask

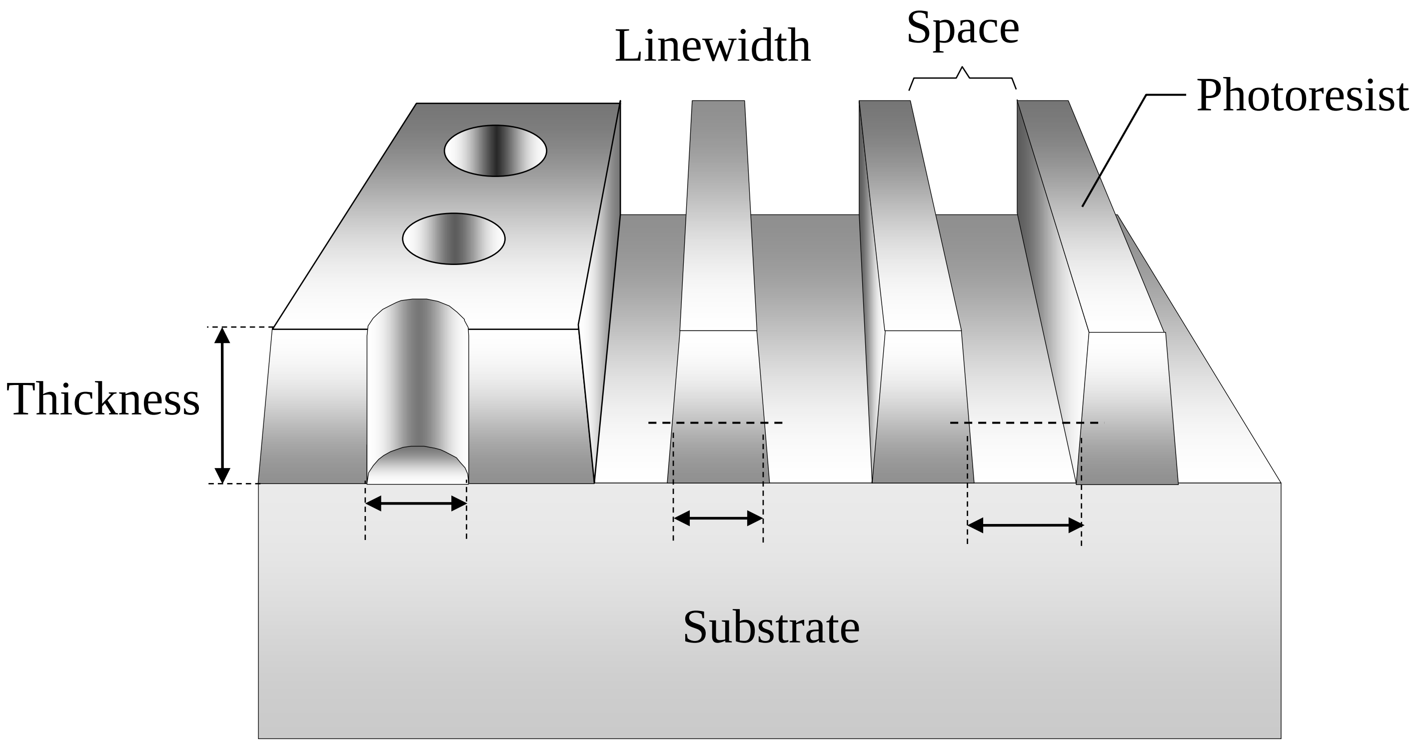
4:1 Reticle



Photograph provided courtesy of Advanced Micro Devices

Photo 13.1

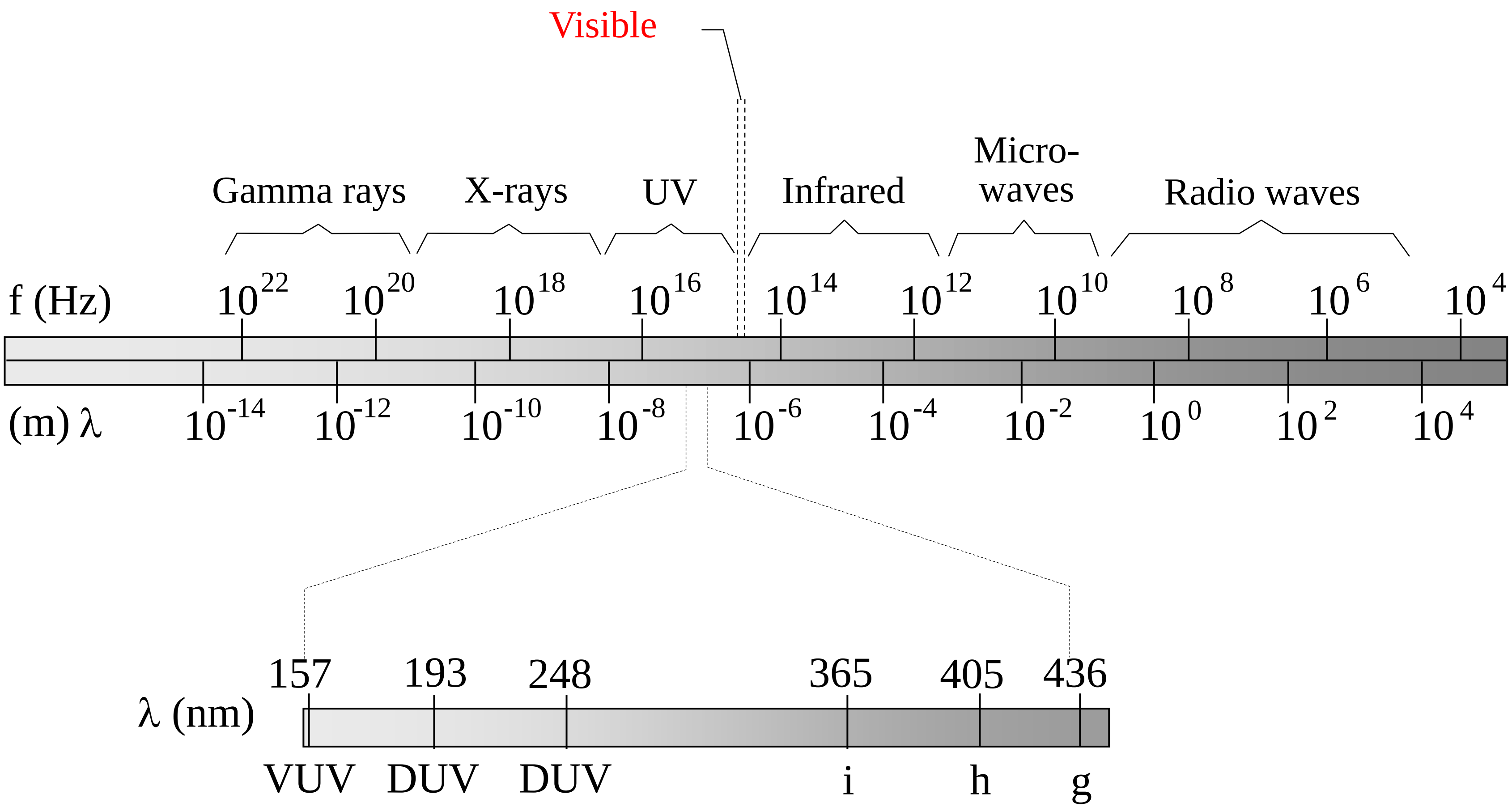
Three Dimensional Pattern in Photoresist



- **Photoresist is light-sensitive film**
- **It is temporary and is removed after ion implantation or etching**

Figure 13.2

Section of the Electromagnetic Spectrum



Common UV wavelengths used in optical lithography.

Figure 13.3

Important Wavelengths for Photolithography Exposure

UV Wavelength (nm)	Wavelength Name	UV Emission Source
436	g-line	Mercury arc lamp
405	h-line	Mercury arc lamp
365	i-line	Mercury arc lamp
248	Deep UV (DUV)	Mercury arc lamp or Krypton Fluoride (KrF) excimer laser
193	Deep UV (DUV)	Argon Fluoride (ArF) excimer laser
157	Vacuum UV (VUV)	Fluorine (F_2) excimer laser

- Resolution: ability to differentiate between two closely spaced features on the wafer
- The actual dimensions of the patterned images are the feature sizes
- The minimum feature size is the critical dimension (CD)
- Resolution is important for critical dimension

Table 13.1

Importance of Mask Overlay Accuracy

- Overlay accuracy: how precise alignment between pattern on the mask and the existing feature on the wafer surface (CMOS needs 30 masks)

- The masking layers determine the accuracy by which subsequent processes can be performed.

- The photoresist mask pattern prepares individual layers for proper placement, orientation, and size of structures to be etched or implanted.

- Small sizes and low tolerances do not provide much room for error.

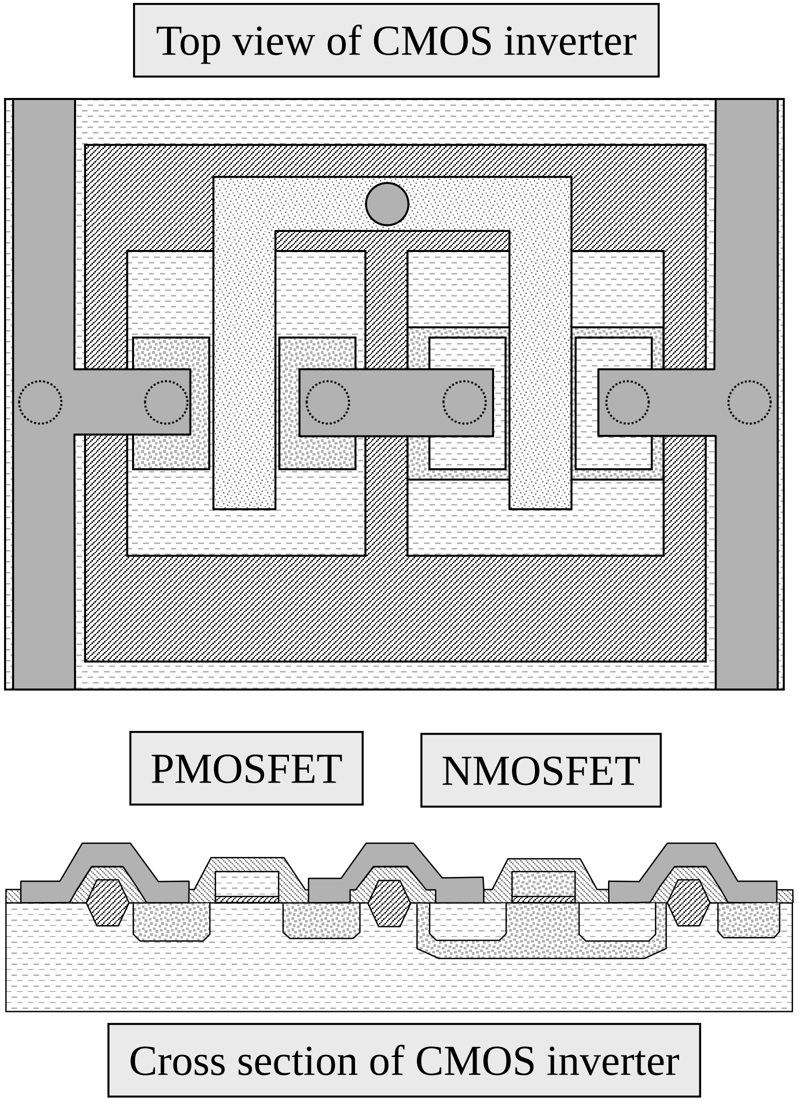


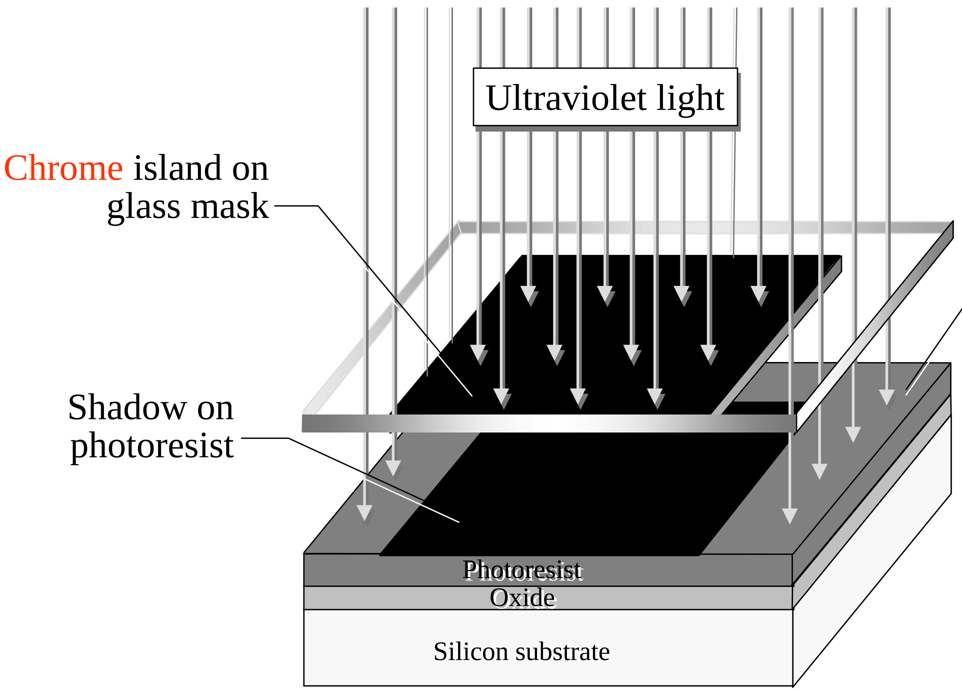
Figure 13.4

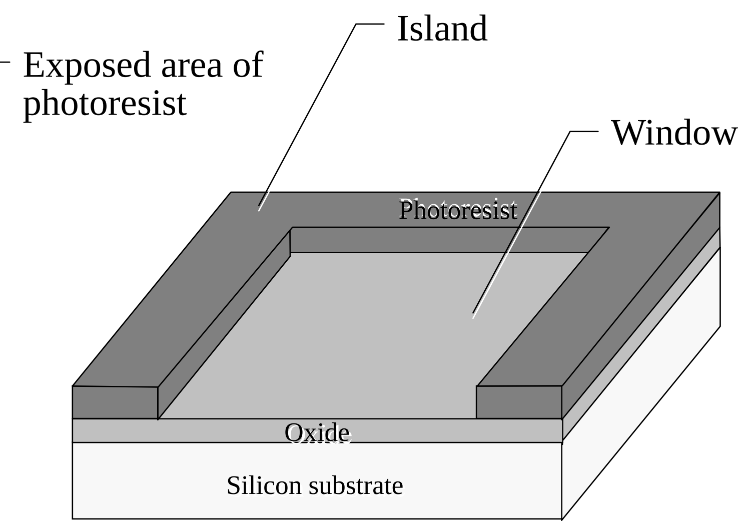
Photolithography Processes

- Negative Resist
  - Wafer image is opposite of mask image
  - Exposed resist hardens and is insoluble
  - Developer removes unexposed resist
- Positive Resist
  - Mask image is same as wafer image
  - Exposed resist softens and is soluble
  - Developer removes exposed resist

Negative Lithography

- Areas exposed to light become crosslinked and resist the developer chemical.

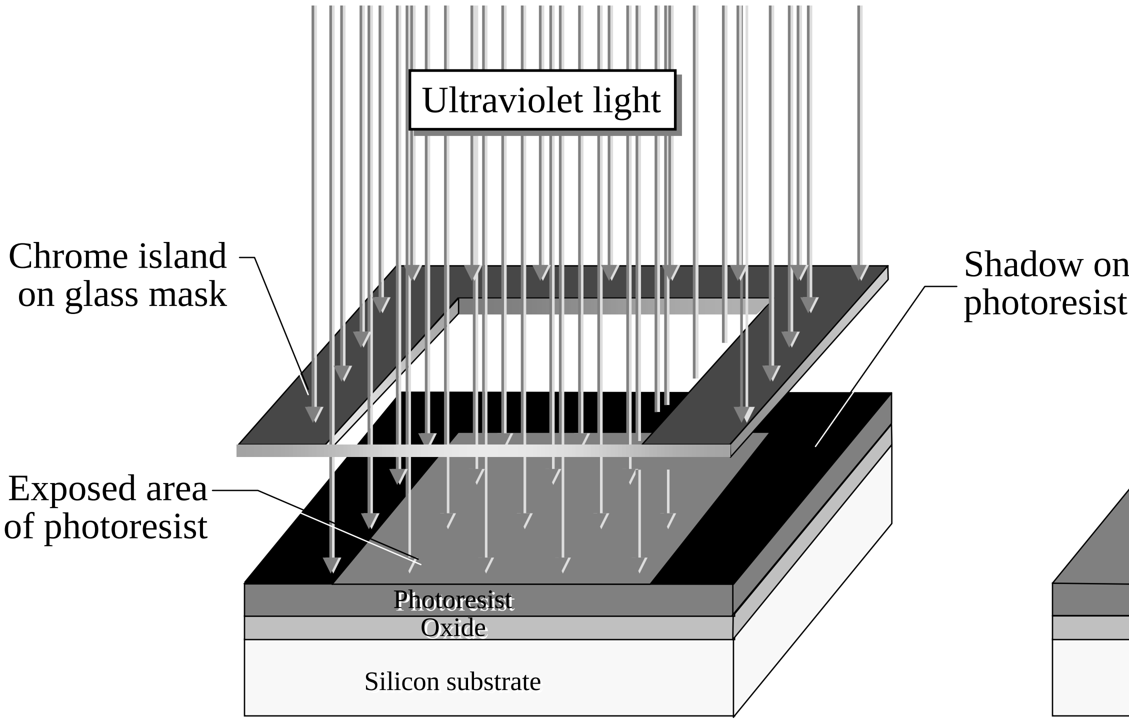




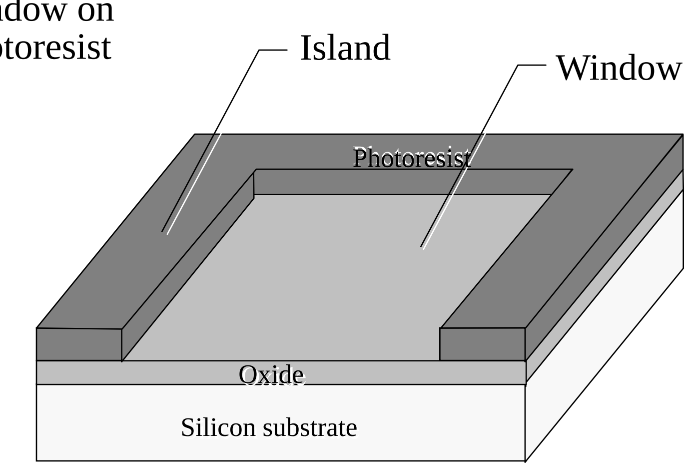
Resulting pattern after the resist is developed.

Figure 13.5

Positive Lithography



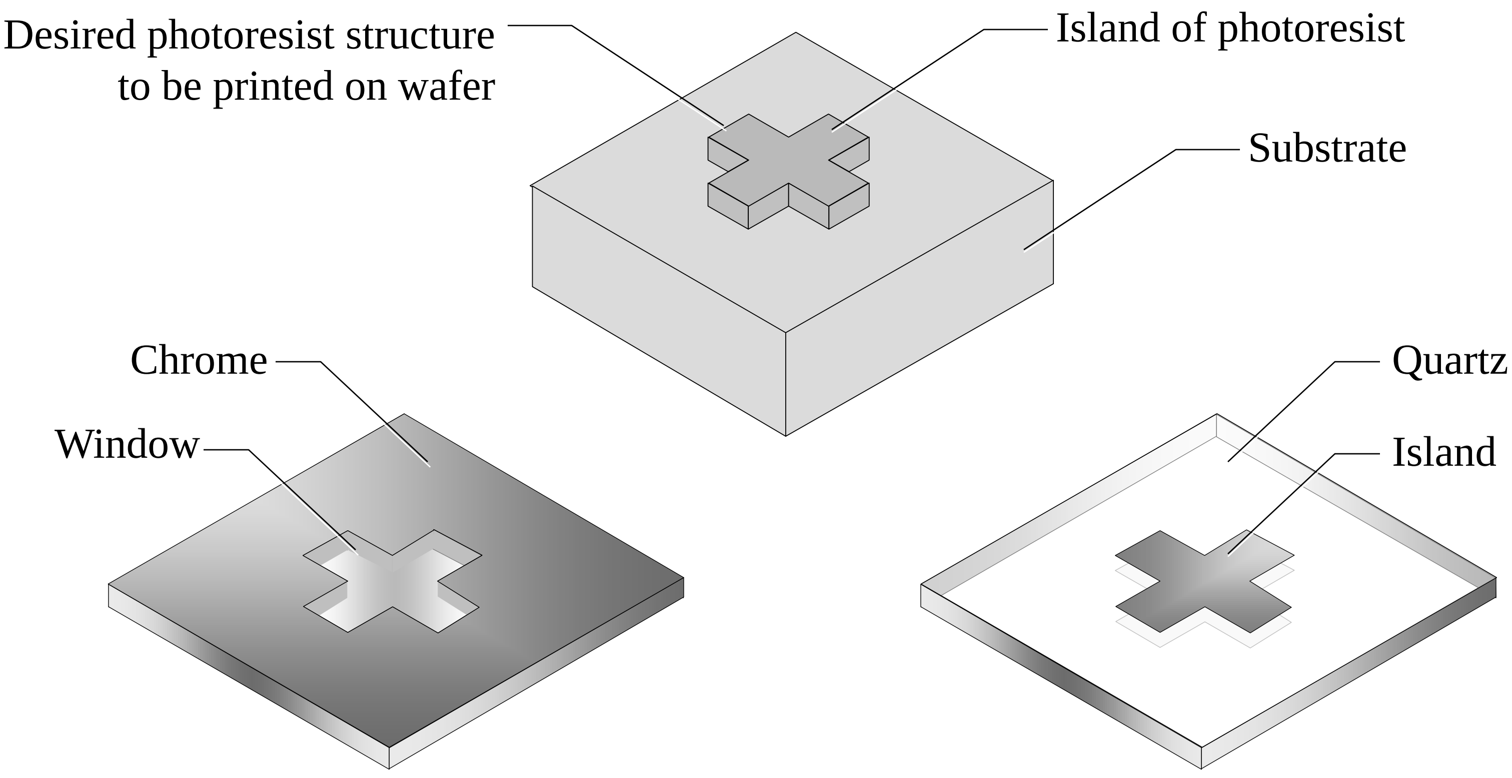
Areas exposed to light are dissolved.



Resulting pattern after the resist is developed.

Figure 13.6

Relationship Between Mask and Resist



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

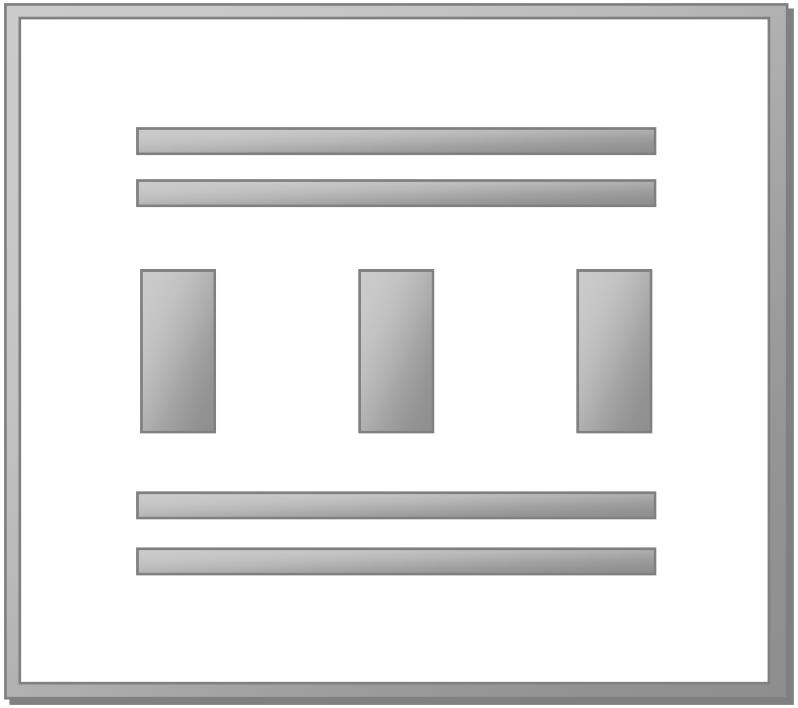
Mask pattern required when using positive photoresist (same as intended structure)

Figure 13.7

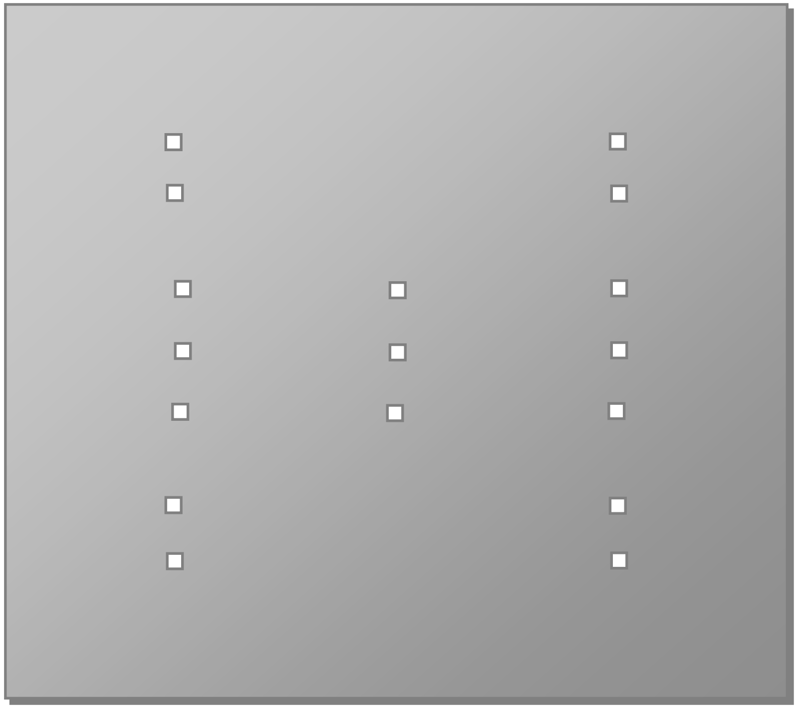
Clear Field and Dark Field Masks

Clear Field Mask: has very thin patterns of chrome with large areas of clear quartz

Dark Field Mask: much of the quartz plate is coated with chrome



Simulation of metal interconnect lines (positive resist lithography)



Simulation of contact holes (positive resist lithography)

Figure 13.8

Eight Steps of Photolithography

Step	Chapter
1. Vapor prime	**13**
2. Spin coat	**13**
3. Soft bake	**13**
4. Alignment and exposure	14
5. Post-exposure bake (PEB)	15
6. Develop	15
7. Hard bake	15
8. Develop inspect	15

Table 13.2

Eight Steps of Photolithography

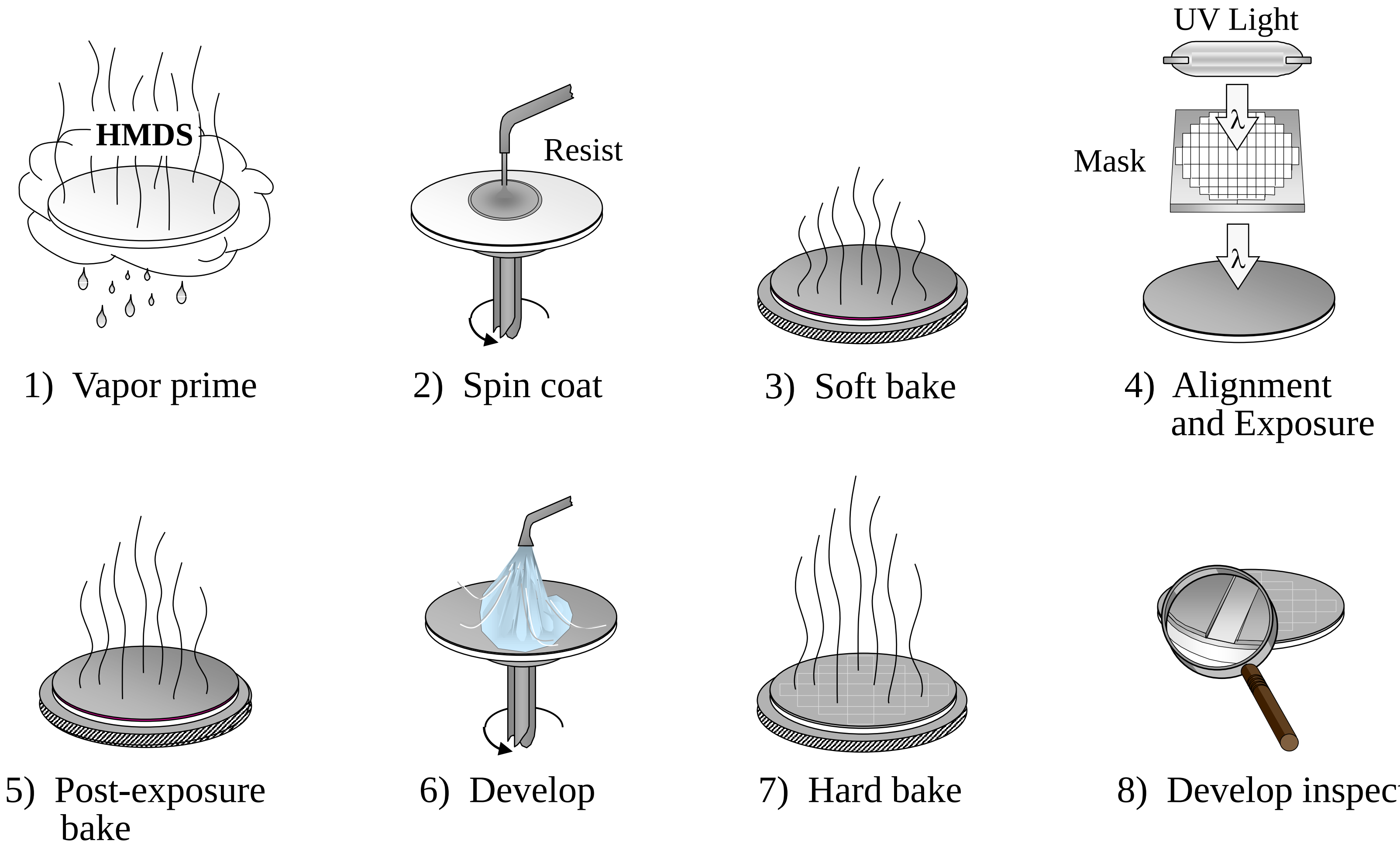


Figure 13.9

Photolithography Track System

- Tracks: employs robots, automated material handling, and computers to perform all eight steps without human intervention
- Improve: control delay between process steps, efficient, flexibility, reduced contamination, increasing safety due to reduced operator exposure to chemicals

1. Vapor Prime

The First Step of Photolithography:

- Promotes Good Photoresist-to-Wafer Adhesion
- Primes Wafer with Hexamethyldisilazane, HMDS [六甲基二矽氮]
- Followed by Dehydration Bake
- Ensures Wafer Surface is Clean and Dry

2. Spin Coat

Process Summary:

- Wafer is held onto vacuum chuck
- Dispense ~5ml of photoresist
- Slow spin ~ 500 rpm
- Ramp up to ~ 3000 to 5000 rpm
- Quality measures:
  - time
  - speed
  - thickness
  - uniformity
  - particles and defects

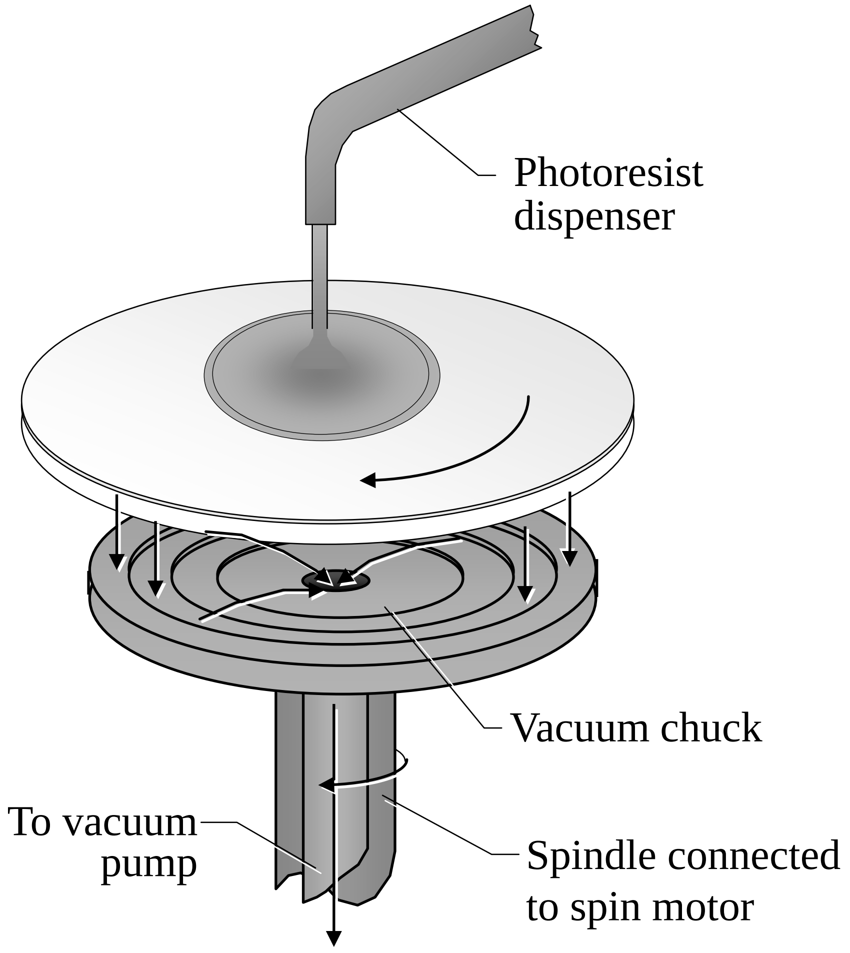


Figure 13.10

3. Soft bake

Characteristics of Soft Bake:

- Improves Photoresist-to-Wafer Adhesion
- Promotes Resist Uniformity on Wafer
- Improves Linewidth Control During Etch
- Drives Off Most of Solvent in Photoresist
- Typical Bake Temperatures are 90 to 100°C
  - For About 30 Seconds
  - On a Hot Plate
  - Followed by Cooling Step on Cold Plate

4. Alignment and Exposure

Process Summary:

- Transfers the mask image to the resist-coated wafer
- Activates photo-sensitive components of photoresist
- Quality measures:
  - linewidth resolution
  - overlay accuracy
  - particles and defects

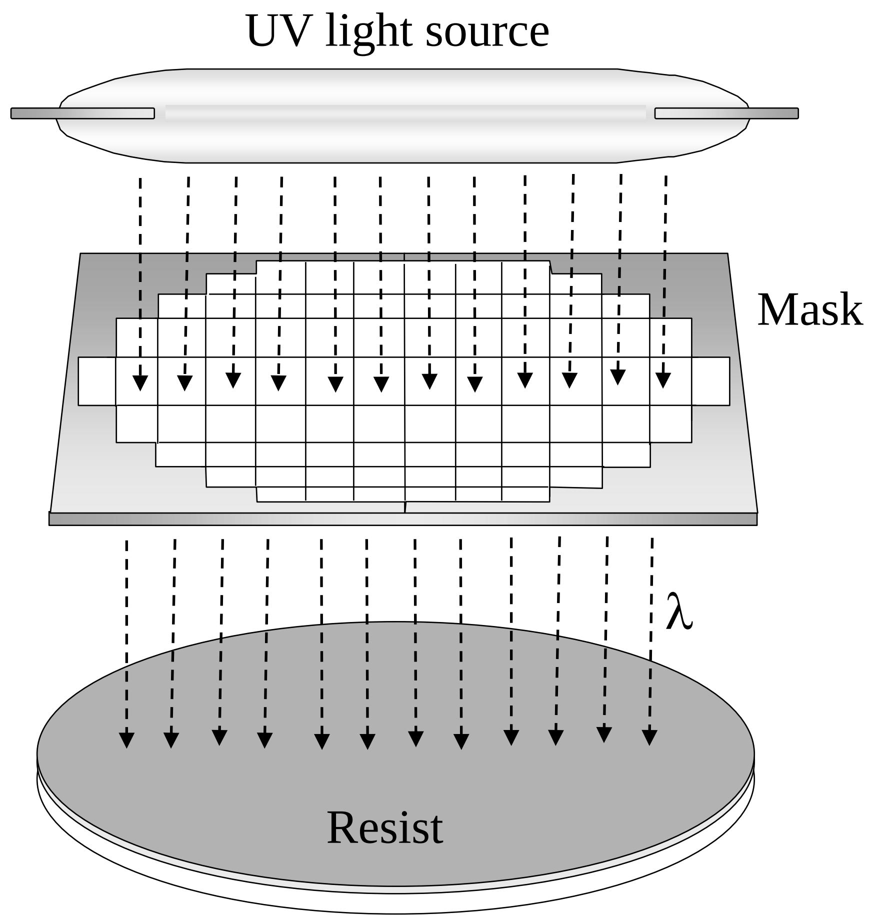


Figure 13.11

5. Post-Exposure Bake

- Required for Deep UV Resists
- Typical Temperatures 100 to 110°C on a hot plate
- Immediately after Exposure
- Has Become a Virtual Standard for DUV and Standard Resists

6. Photoresist Development

Process Summary:

- Soluble areas of photoresist are dissolved by developer chemical
- Visible patterns appear on wafer
  - windows
  - islands
- Quality measures:
  - line resolution
  - uniformity
  - particles and defects

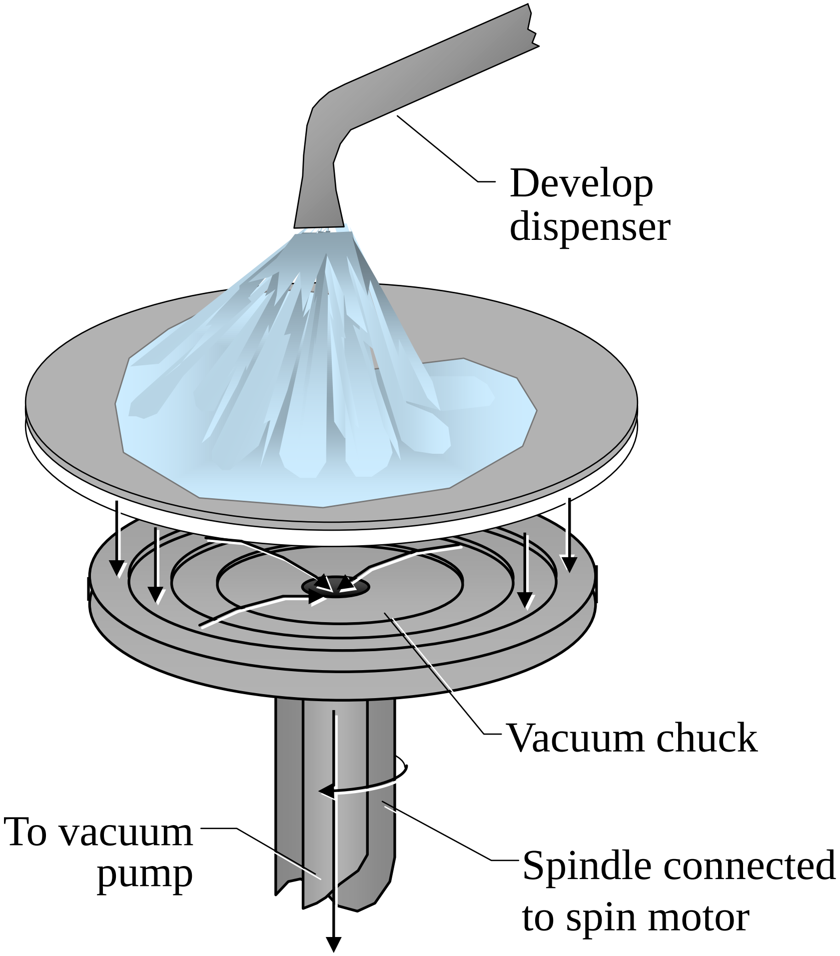


Figure 13.12

7. Hard Bake

- A Post-Development Thermal Bake
- Evaporate Remaining Solvent
- Improve Resist-to-Wafer Adhesion
- Higher Temperature (120 to 140°C) than Soft Bake

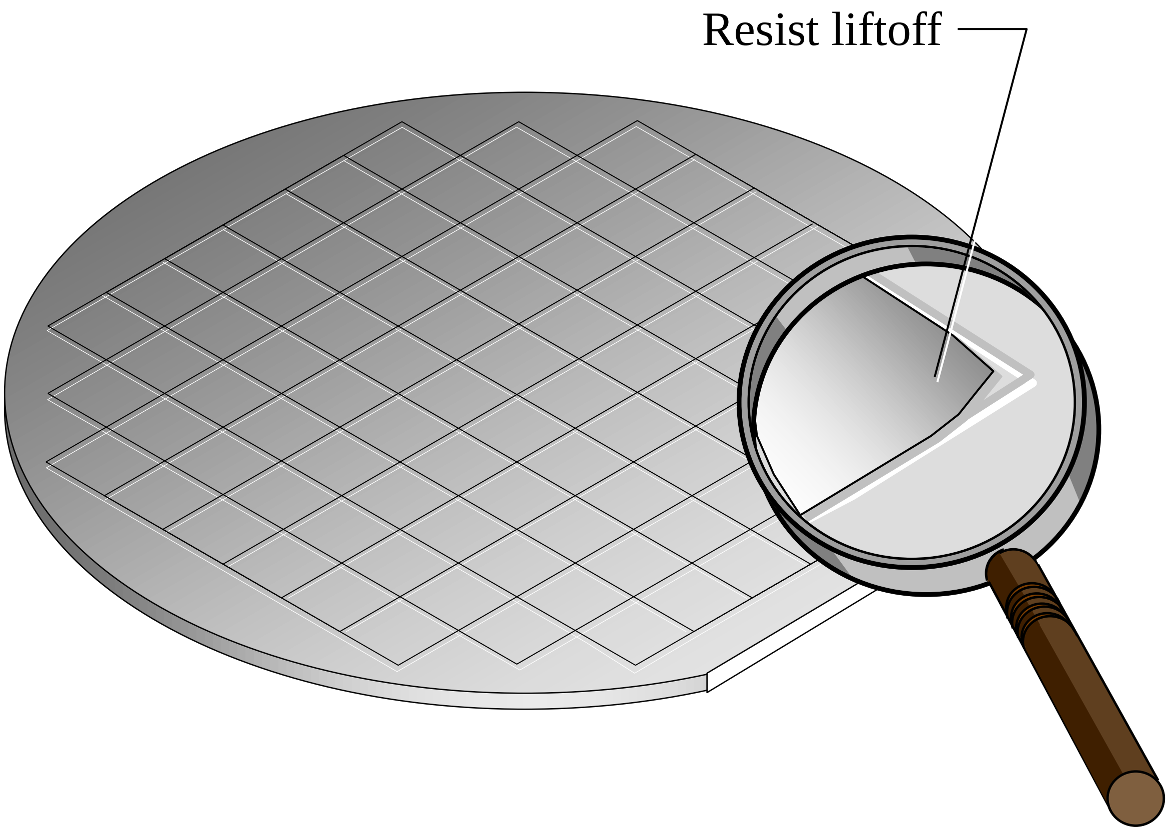
8. Develop Inspect

- Inspect to Verify a Quality Pattern
  - Identify Quality Problems (Defects)
  - Characterize the Performance of the Photolithography Process
  - Prevents Passing Defects to Other Areas
    - Etch
    - Implant
  - Rework Misprocessed or Defective Resist-coated Wafers
- Typically an Automated Operation

1. Vapor Prime

- Wafer Cleaning: good adhesion
- Dehydration Bake
- Wafer Priming
  - Priming Techniques
    - Puddle Dispense and Spin
    - Spray Dispense and Spin
    - Vapor Prime and Dehydration Bake

Effect of Poor Resist Adhesion Due to Surface Contamination



- **After oxidation and deposition, to coat PR on clean wafer as soon as possible (need no cleaning)**

Figure 13.13

HMDS Puddle Dispense and Spin

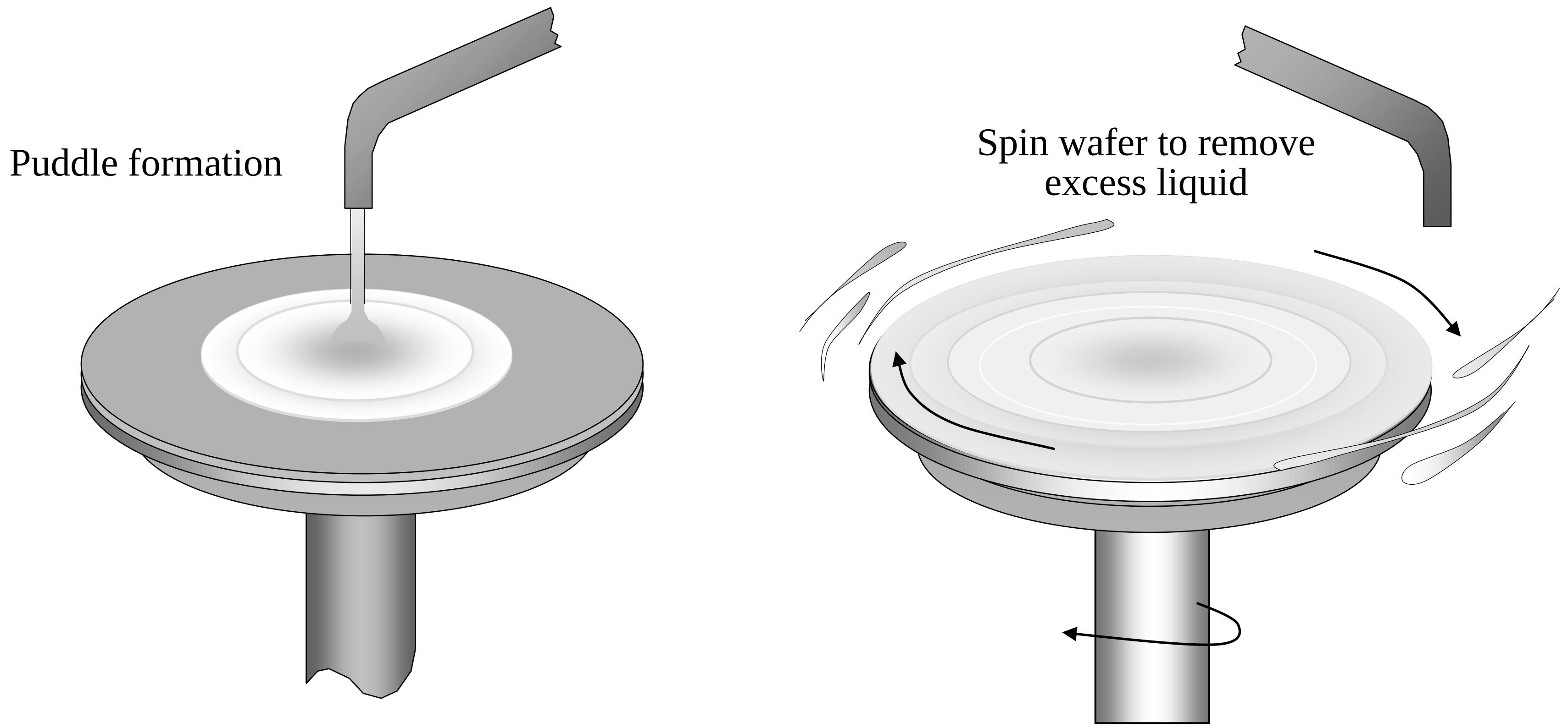


Figure 13.14

HMDS Hot Plate Dehydration Bake and Vapor Prime

Process Summary:

- Dehydration bake in enclosed chamber with exhaust
- Hexamethyldisilazane (HMDS)
- Clean and dry wafer surface (hydrophobic) vs. hydrophilic
- Temp ~ 200 to 250°C
- Time ~ 60 sec.

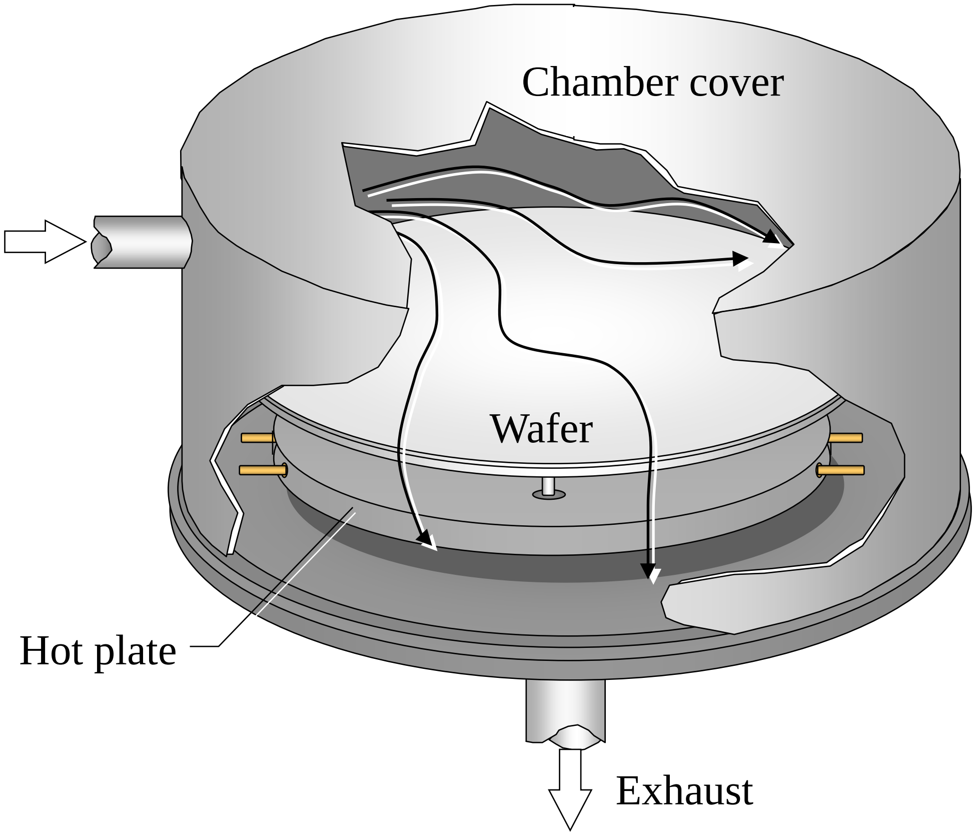


Figure 13.15

2. The Purpose of Photoresist in Wafer Fab

- To transfer the mask pattern to the photoresist on the top layer of the wafer surface
- To protect the underlying material during subsequent processing e.g. etch or ion implantation.

Successive Reductions in CDs Lead to Progressive Improvements in Photoresist

- Better image definition (resolution).
- Better adhesion to semiconductor wafer surfaces.
- Better uniformity characteristics.
- Increased process latitude (less sensitivity to process variations).

Spin Coat

- Photoresist
  - Types of Photoresist
  - Negative Versus Positive Photoresists
- Photoresist Physical Properties
- Conventional I-Line Photoresists
  - Negative I-Line Photoresists
  - Positive I-Line Photoresists
- Deep UV (DUV) Photoresists
- Photoresist Dispensing Methods

Types of Photoresists

- Two Types of Photoresist
  - Positive Resist
  - Negative Resist
- CD Capability
  - Conventional Resist (0.35 μm)
  - Deep UV Resist (0.25 μm, CA)
- Process Applications
  - Non-critical Layers
  - Critical Layers

Negative Versus Positive Resists

- Negative Resist
  - Wafer image is opposite of mask image
  - Exposed resist hardens and is insoluble
  - Developer removes unexposed resist
- Positive Resist
  - Mask image is same as wafer image
  - Exposed resist softens and is soluble
  - Developer removes exposed resist
- Resolution Issues
- Clear Field Versus Dark Field Masks

Photoresist Physical Characteristics

Resolution

The ability to differentiate between two spaced feature on the wafer

Contrast

The sharpness of the transition from exposure to non-exposure in PR

Sensitivity

The minimum light energy to produce a good pattern in the PR

Viscosity

Adhesion

Etch resistance: to dry etching

Surface tension: low enough

Storage and handling

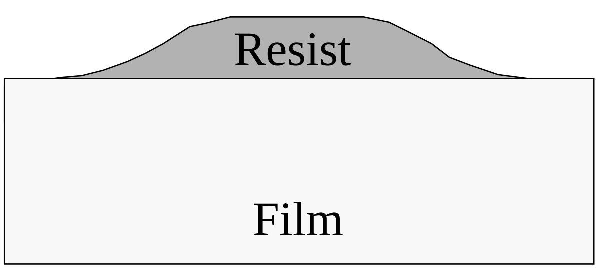
Contaminants and particles

Resist Contrast

Contrast :

Poor Resist Contrast

- Sloped walls
- Swelling
- Poor contrast



Good Resist Contrast

- Sharp walls
- No swelling
- Good contrast

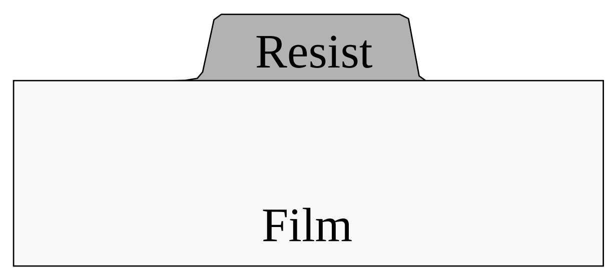


Figure 13.16

Surface Tension

Low surface tension from low molecular forces

High surface tension from high molecular forces

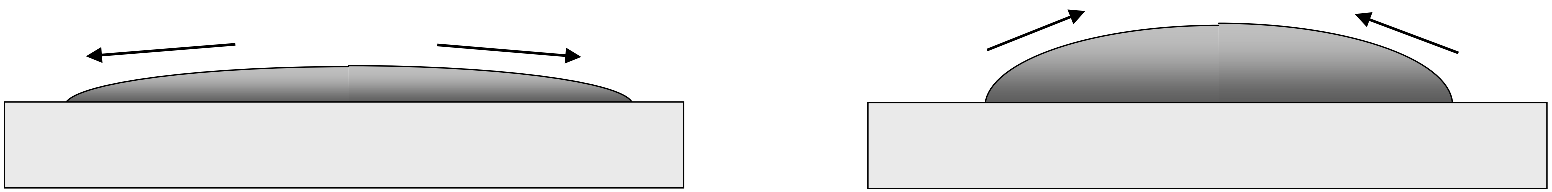
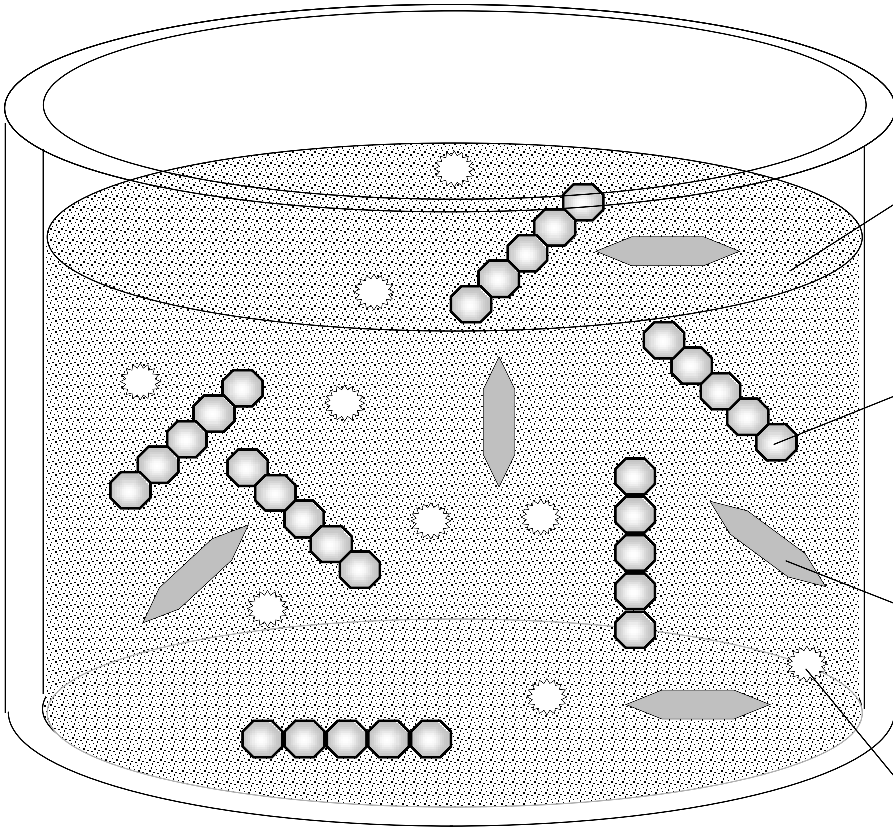


Figure 13.17

Components of Conventional Photoresist



Solvent:
gives resist its flow characteristics (xylene 二甲苯)

Resin: mix of polymers used as binder; gives resist mechanical and chemical properties (rubber)

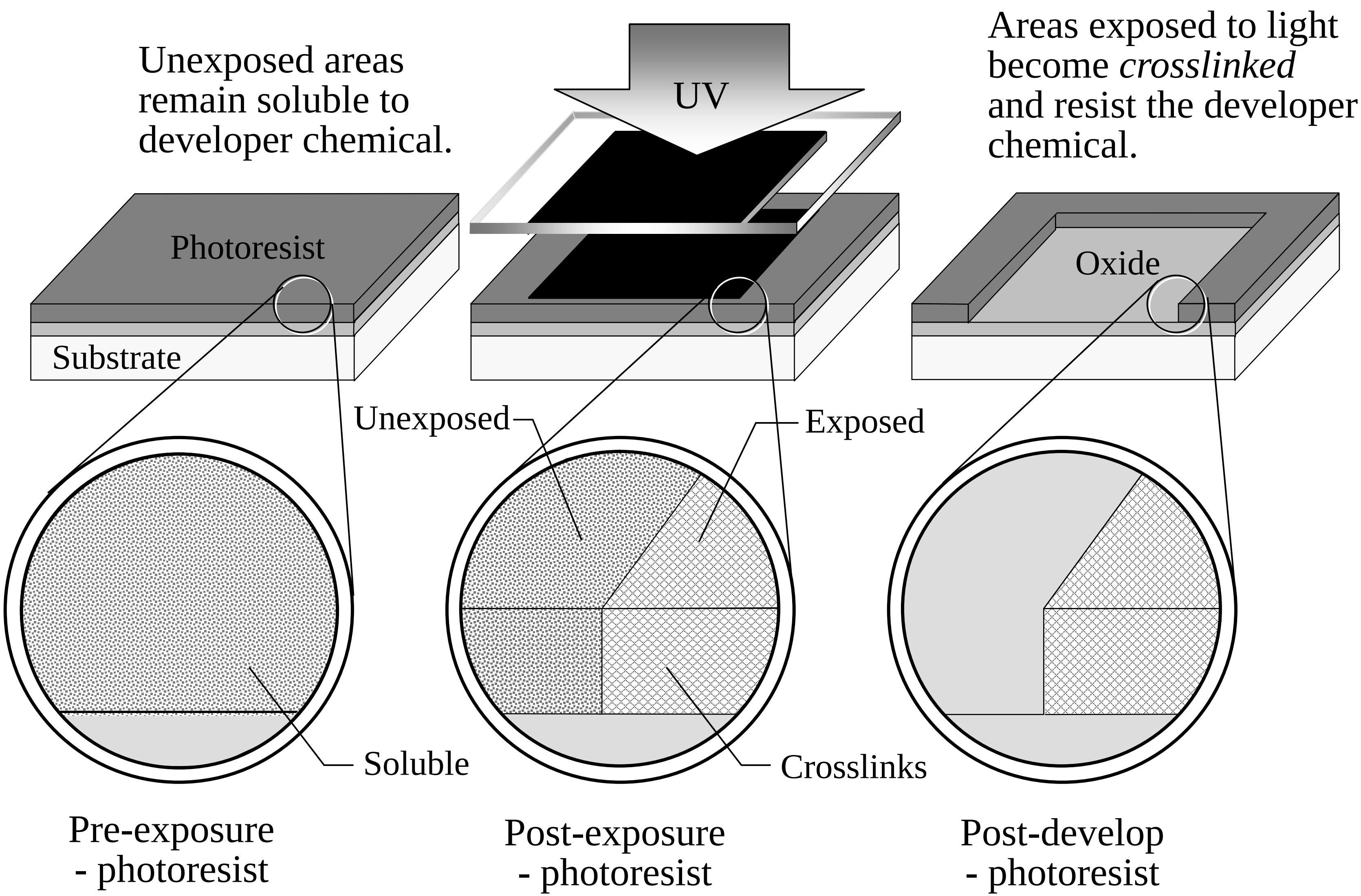
Sensitizers:
photosensitive component of the resist material

Additives:
chemicals that control specific aspects of resist material

- Resists are specified with a shelf life and storage temperature environment
- Crosslinking of negative resist and sensitizer-delay of positive resist can occur with extended storage time or elevated temperature

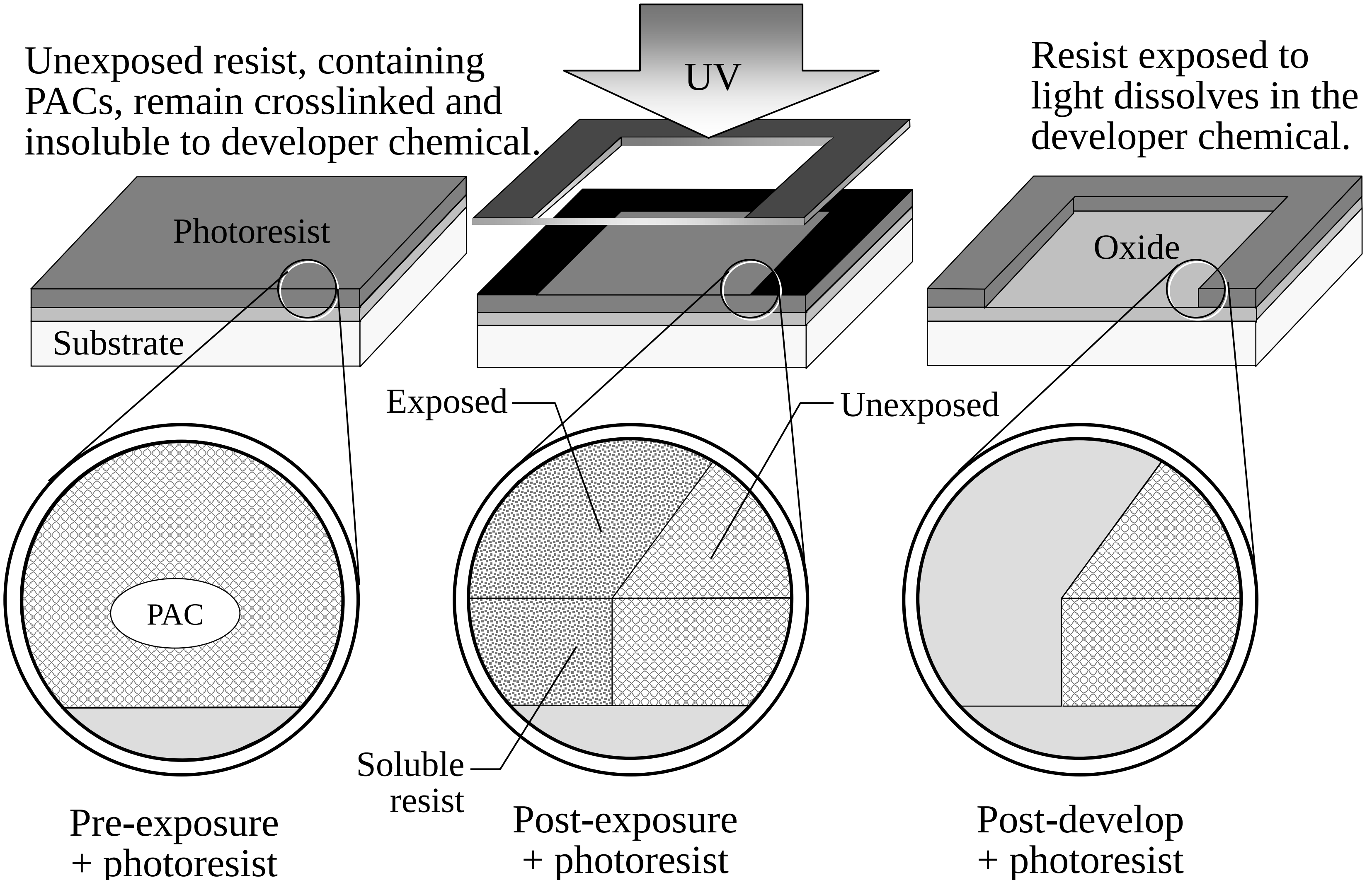
Negative Resist Cross-Linking

- The resist sensitizer is a photoactive agent that release nitrogen gas on exposure to UV light, generating free radical that form crosslinks between rubber



PAC as Dissolution Inhibitor in Positive I-Line Resist

- Resin is called novolak (glue to binds different layer), which is dissolves in developer solution when there is no dissolution inhibitor
- Sensitizer: photoactive compound (PAC) called DNQ is a dissolution inhibitor, after exposure to UV, DNQ promotes dissolution 100 time



Good Contrast Characteristics of Positive I-line Photoresist

Positive Photoresist:

- Sharp walls
- No swelling
- Good contrast
- Used for >0.35 μm, for 248nm never penetrate

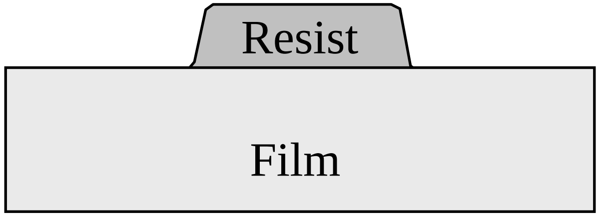
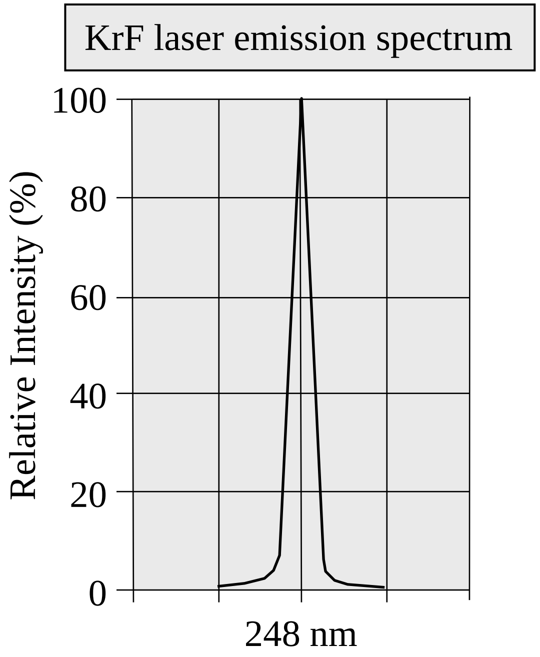
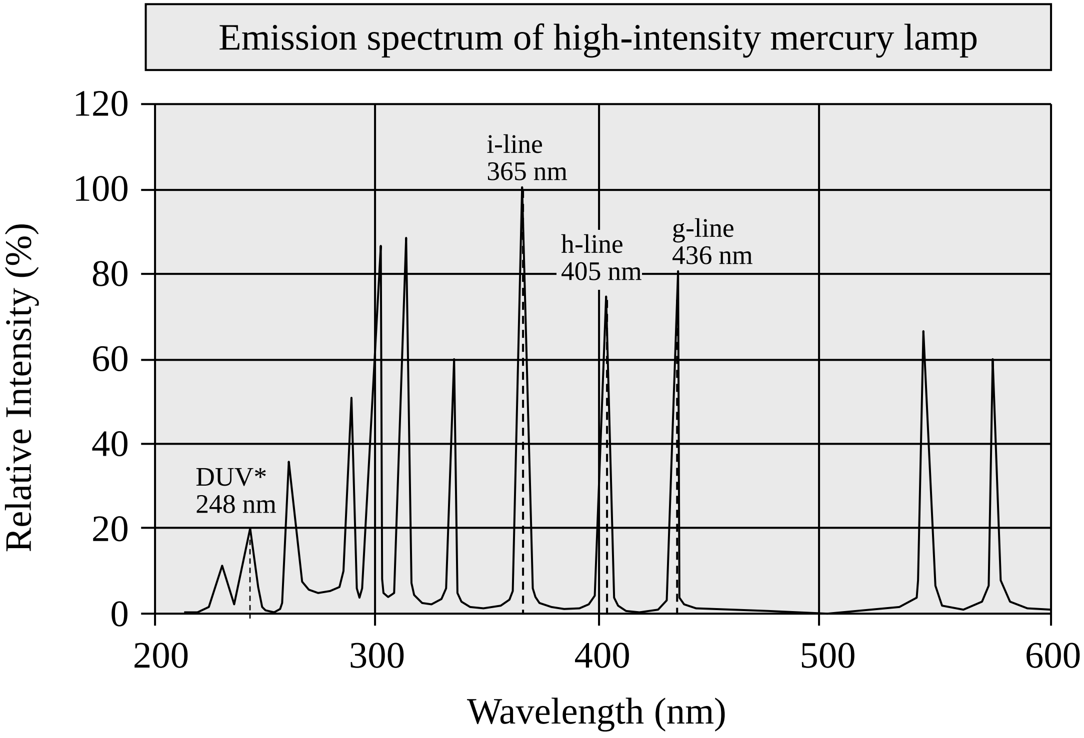


Figure 13.21

DUV Emission Spectrum





- Intensity of mercury lamp is too low at 248 nm to be usable in DUV photolithography applications. Excimer lasers, such as shown on the left provide more energy for a given DUV wavelength.

Figure 13.22

Chemically Amplified (CA) DUV Resist: [1980 IBM]

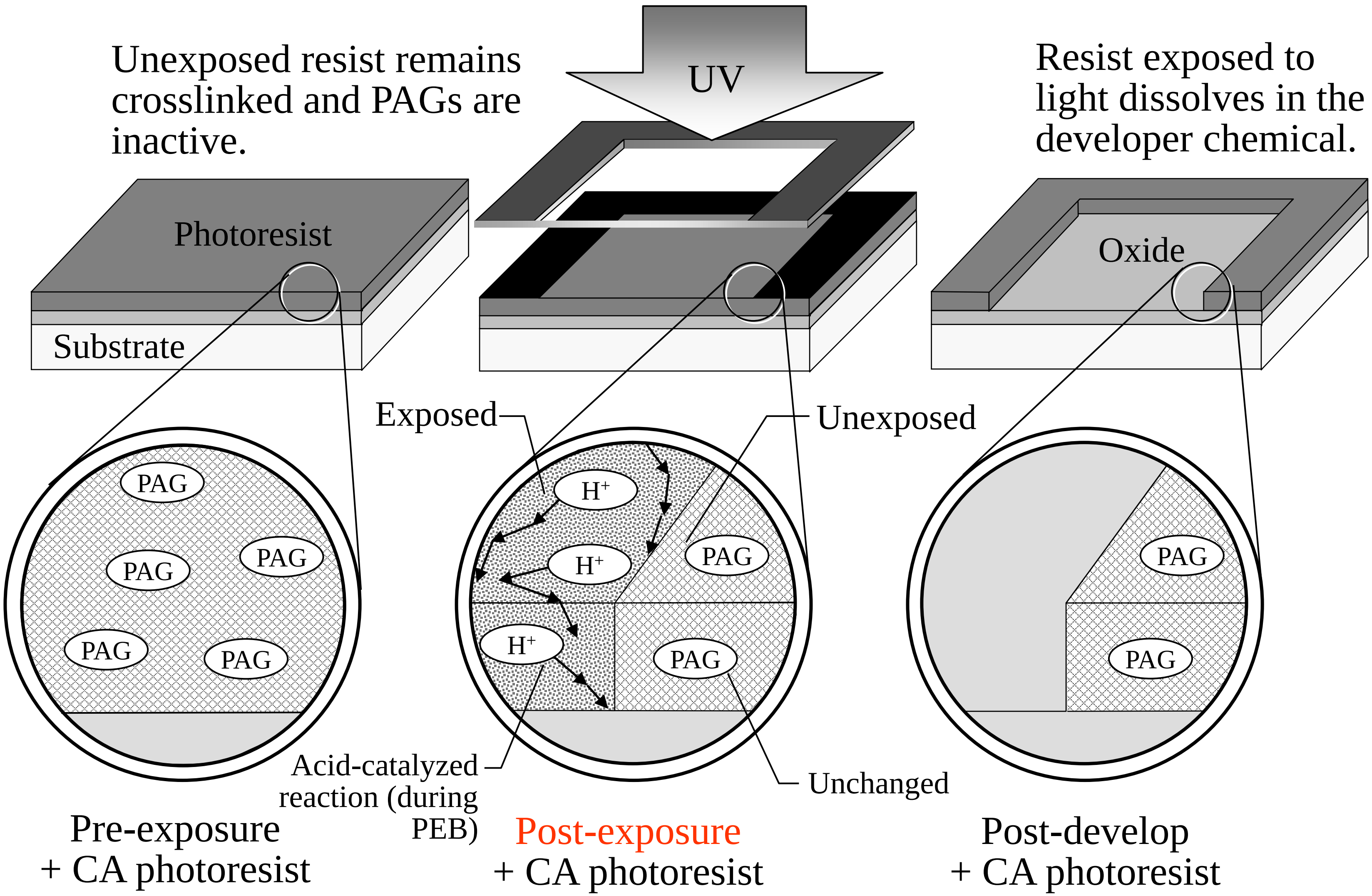


Figure 13.23

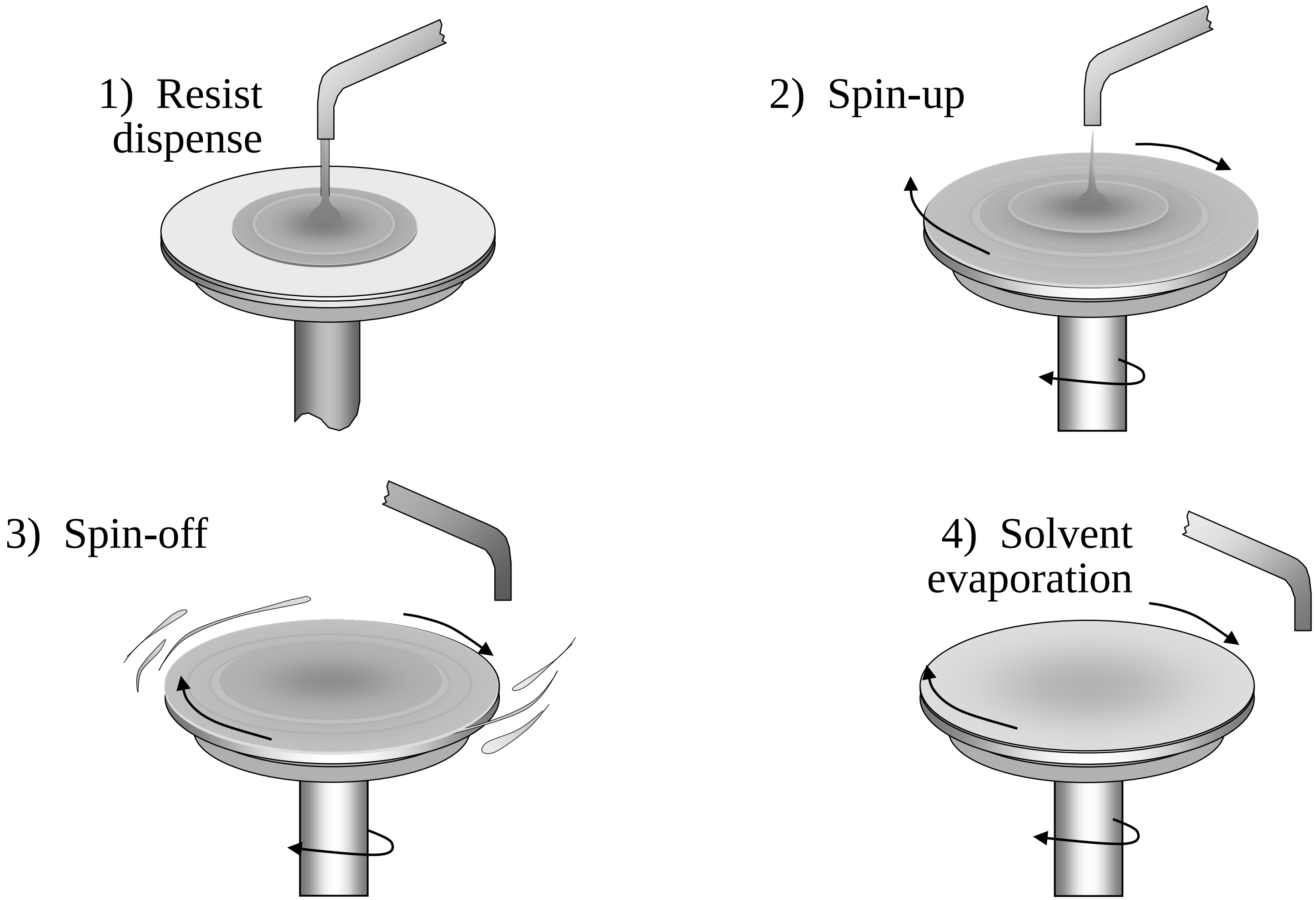
Exposure Steps for Chemically-Amplified DUV Resist

1.	Resin is phenolic copolymer with protecting group that makes it insoluble in developer.
2.	Photoacid generator (PAG) generates acid during exposure.
3.	Acid generated in exposed resist areas serves as catalyst to remove resin-protecting group during post exposure thermal bake.
4.	Exposed areas of resist without protecting group are soluble in aqueous developer.

- CA PR provides 10-fold improvement of sensitive over DNQ (i-line)
- DUV offers high-contrast imaging with vertical sidewall profiles and high resolution < 0.25 μm
- Sensitive to amines

Table 13.5

Steps of Photoresist Spin Coating



Thickness of PR < 1μm

Figure 13.24

Automated Wafer Track for Photolithography

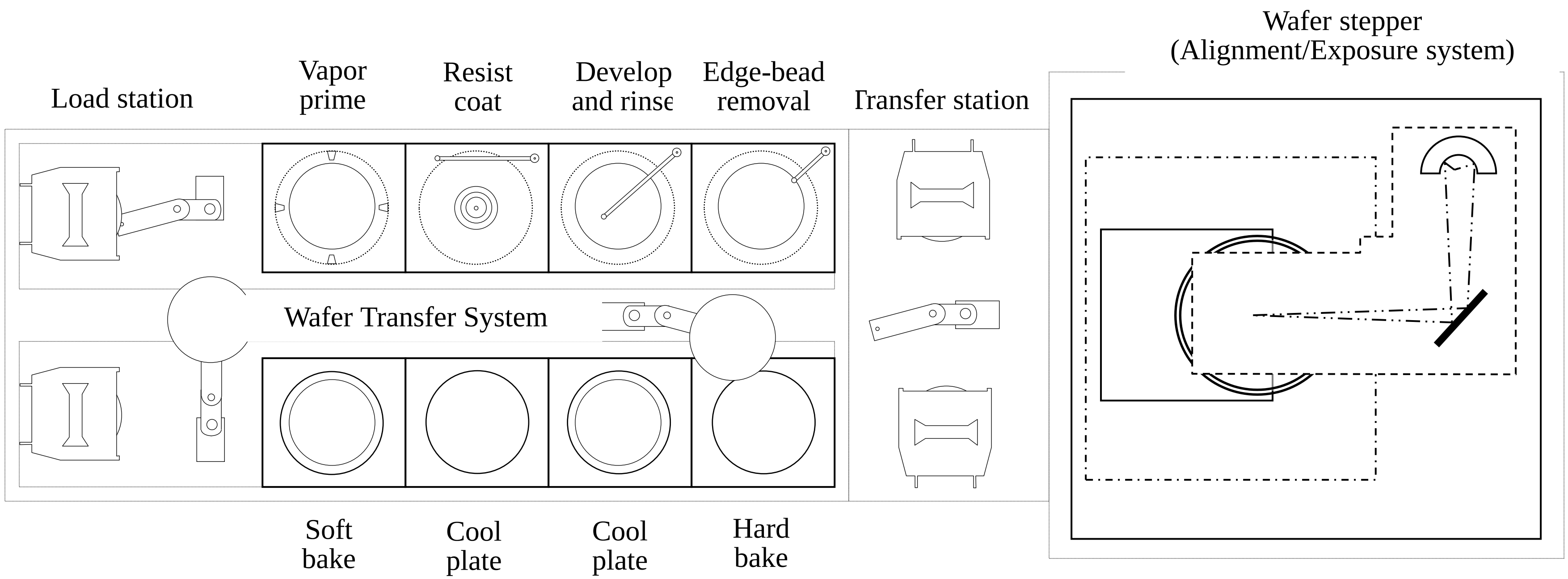
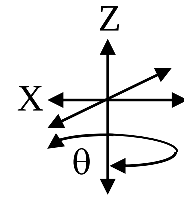


Figure 13.25

Photoresist Dispense Nozzle

- Less than 1% PR remains on the wafer
- Edge-bead removal (EBR) using spray nozzle



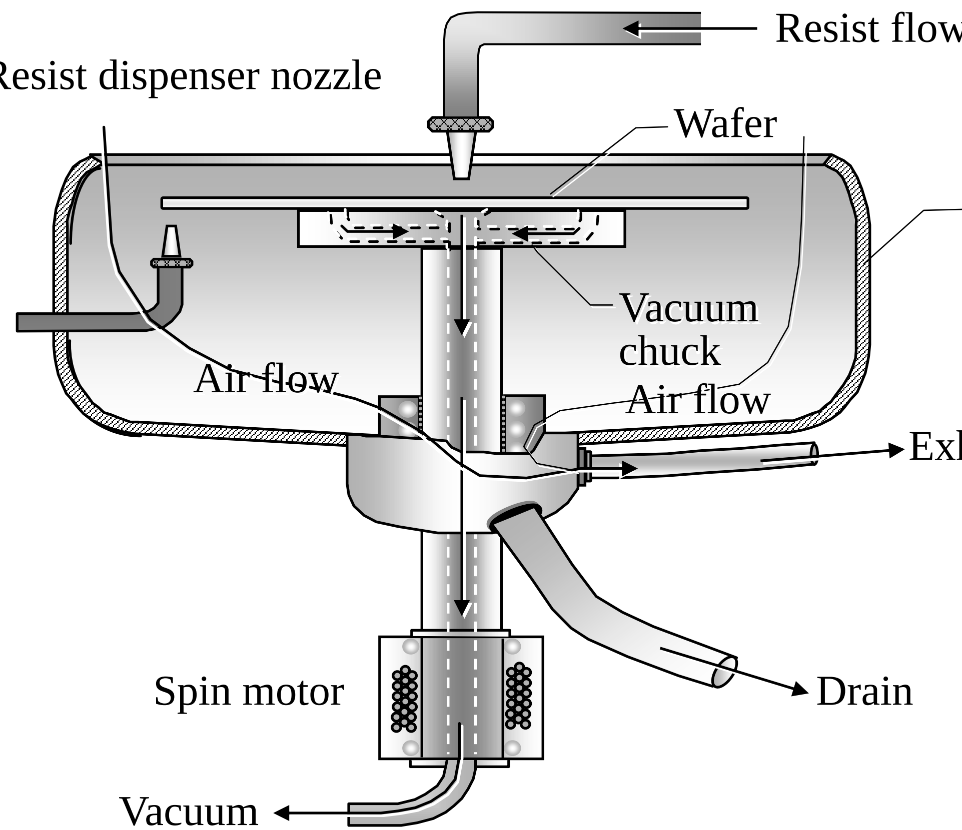
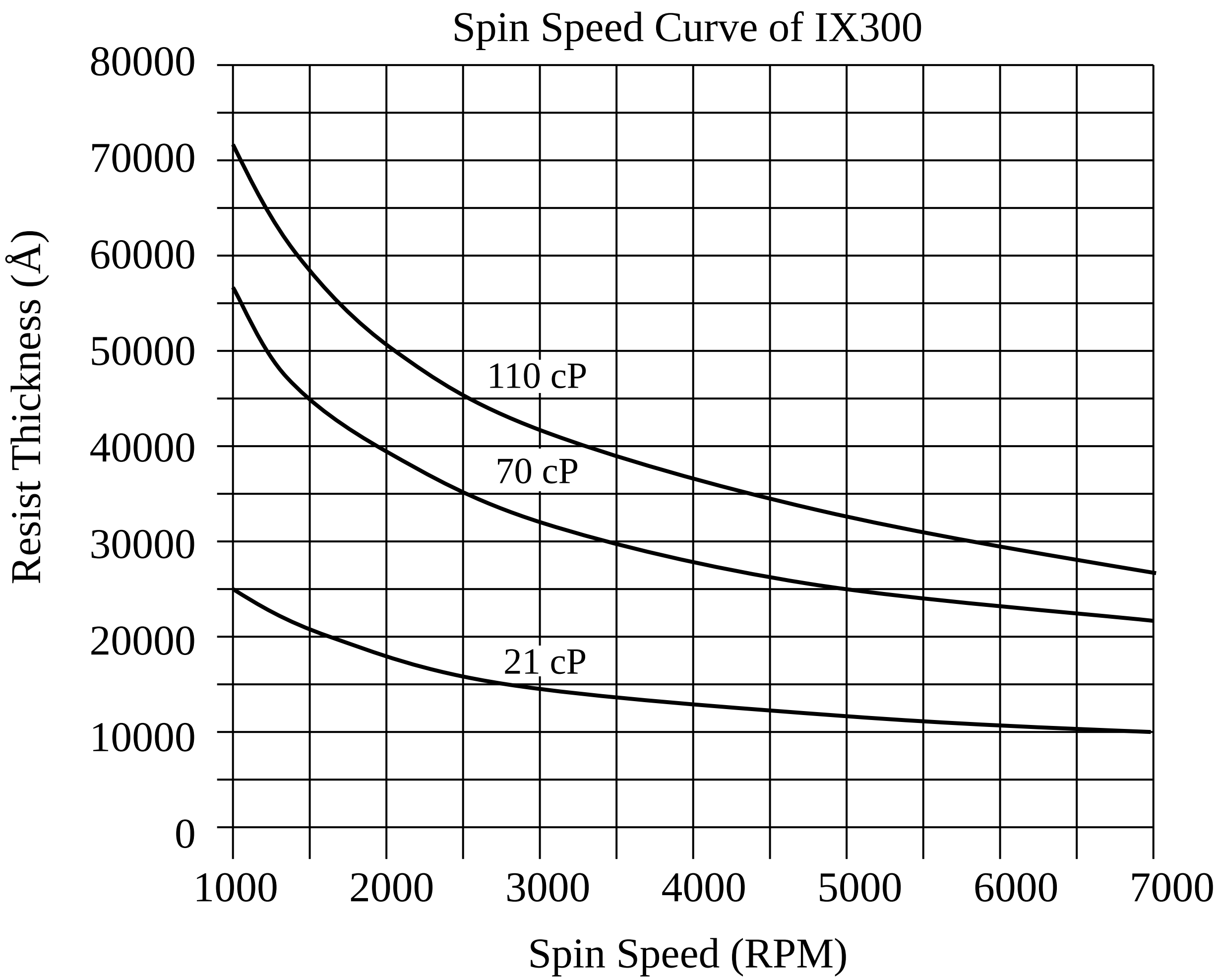


Figure 13.26

Resist Spin Speed Curve



Resist thickness α 1/ [RPM]$^{1/2}$

Figure 13.27

3. Soft Bake on Vacuum Hot Plate

Purpose of Soft Bake:

- Partial evaporation of photoresist solvents
- Improves adhesion
- Improves uniformity
- Improves etch resistance
- Improves linewidth control
- Optimizes light absorbance characteristics of photoresist

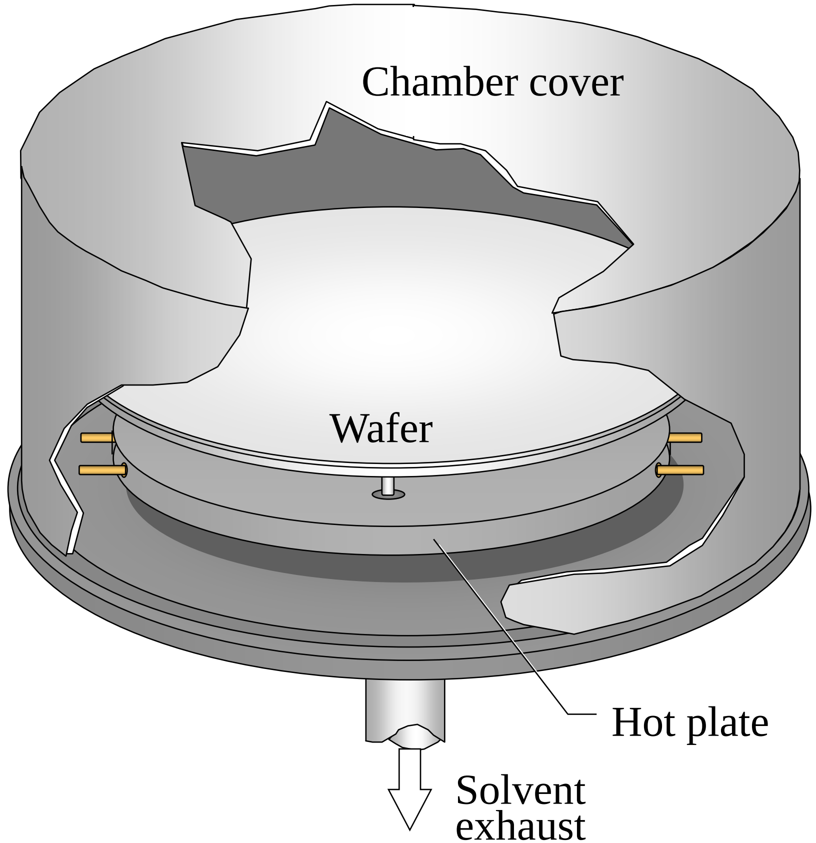


Figure 13.28

Solvent Content of Resist Versus Temperature During Soft Bake

- Before spin coating, photoresist typically contains between 65-85% solvents.
- After spinning, reduced to 10-20%
- The ideal amount of solvent after soft bake is ~ 4-7%

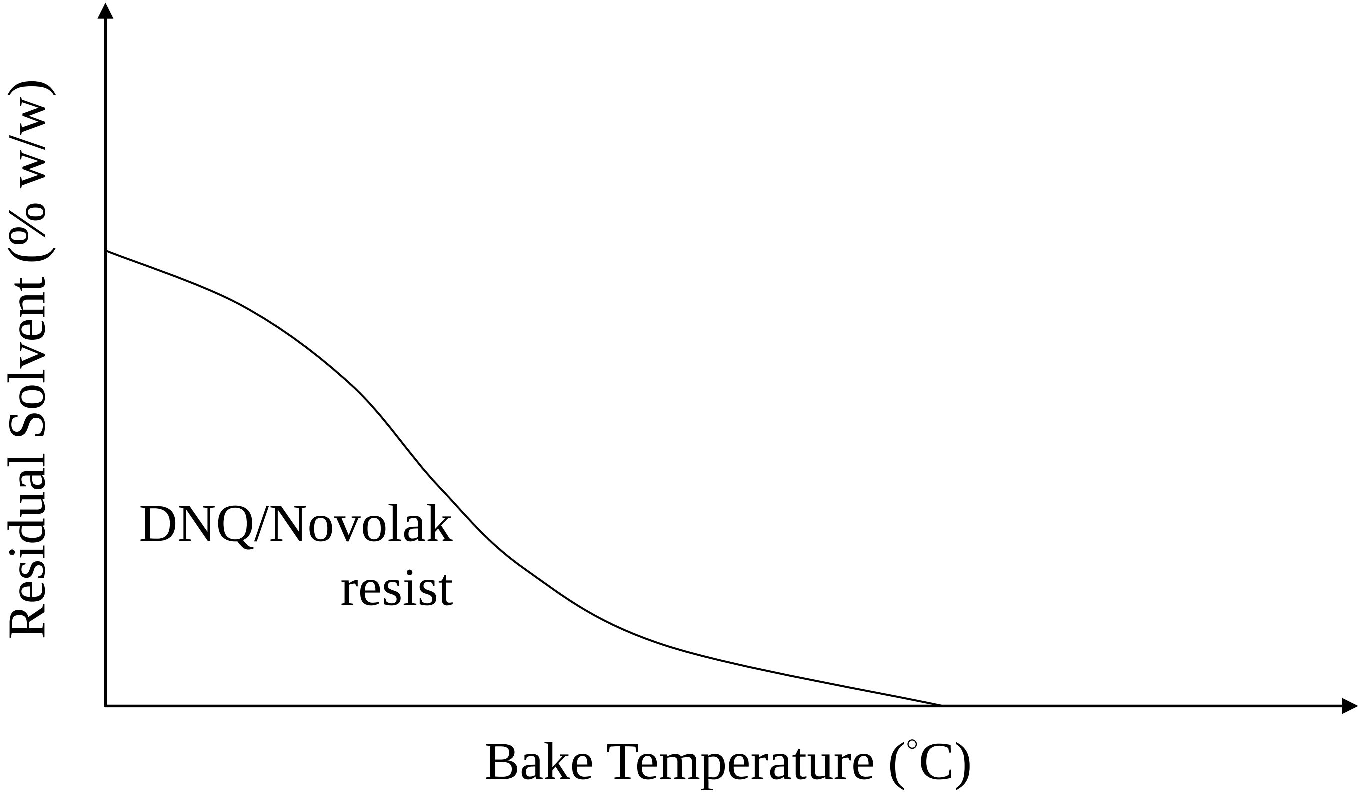


Figure 13.29