Engineering of Semiconductor

:Semiconductor Physics and Devices

Chapter 2. Silicon Technology

Objectives

Overview of Silicon Technology

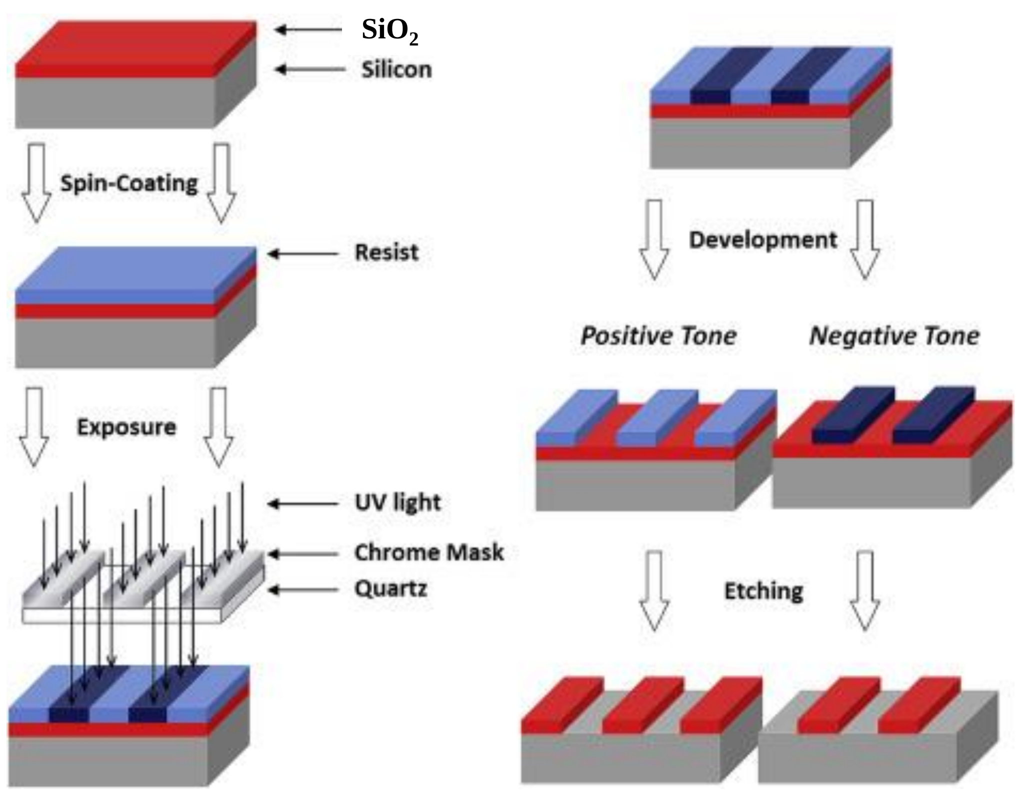
- Wafer preparation
- Oxidation
- Lithography (patterning)
- Etching
- Doping
- Deposition
- Packaging

Overview: Lithography

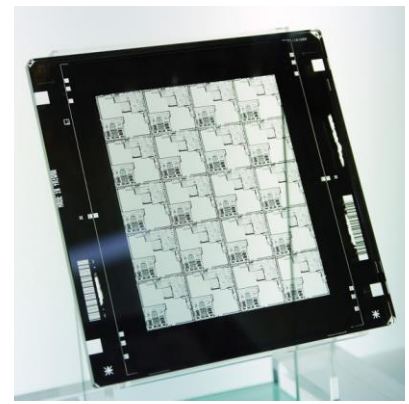
2. Patterning – Photolithography

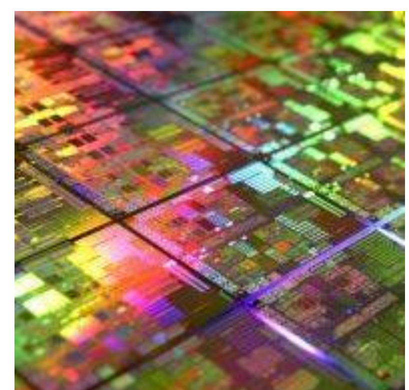
: Techniques that **use light to produce minutely patterned thin films** of suitable materials over a substrate, such as a silicon wafer, to protect selected areas of it during subsequent etching, deposition, or implantation operations.

: Pattern transfer to underlying layer

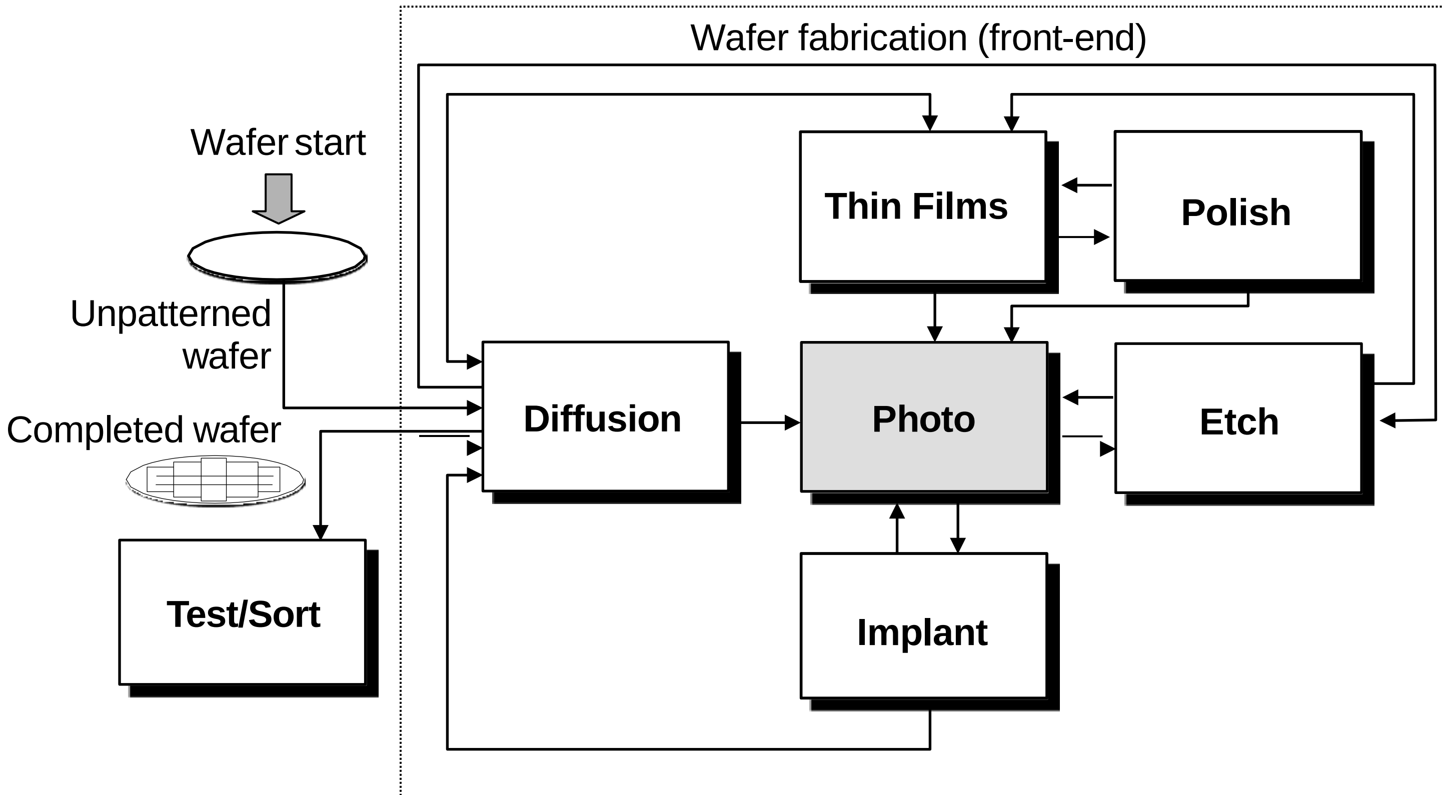


Cr mask





Wafer Fabrication Process Flow



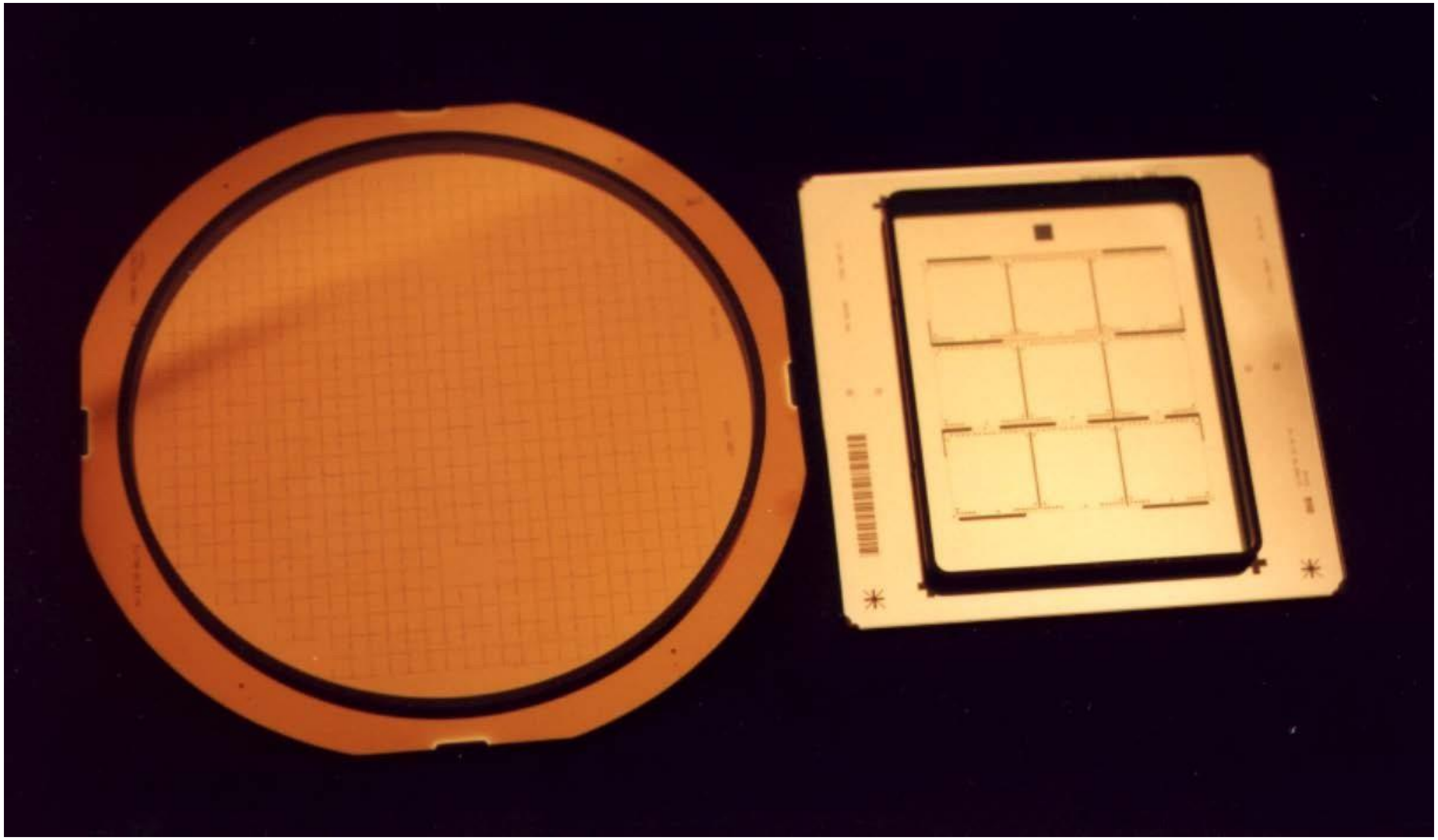
Photolithography Concepts

- Patterning Process
  - Photomask
  - Reticle
- Critical Dimension Generations
- Light Spectrum
- Resolution
- Overlay Accuracy
- Process Latitude

Photomask and Reticle for Microlithography

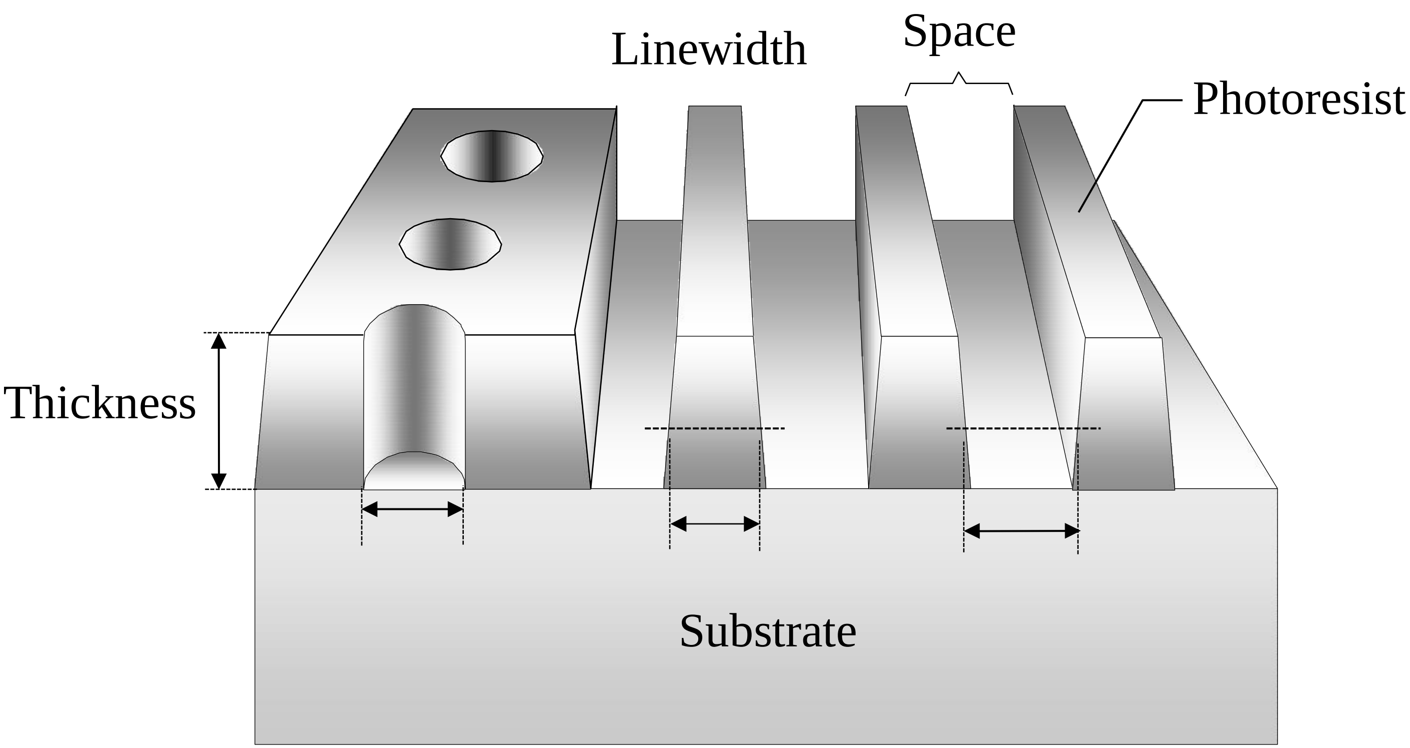
1:1 Mask

4:1 Reticle

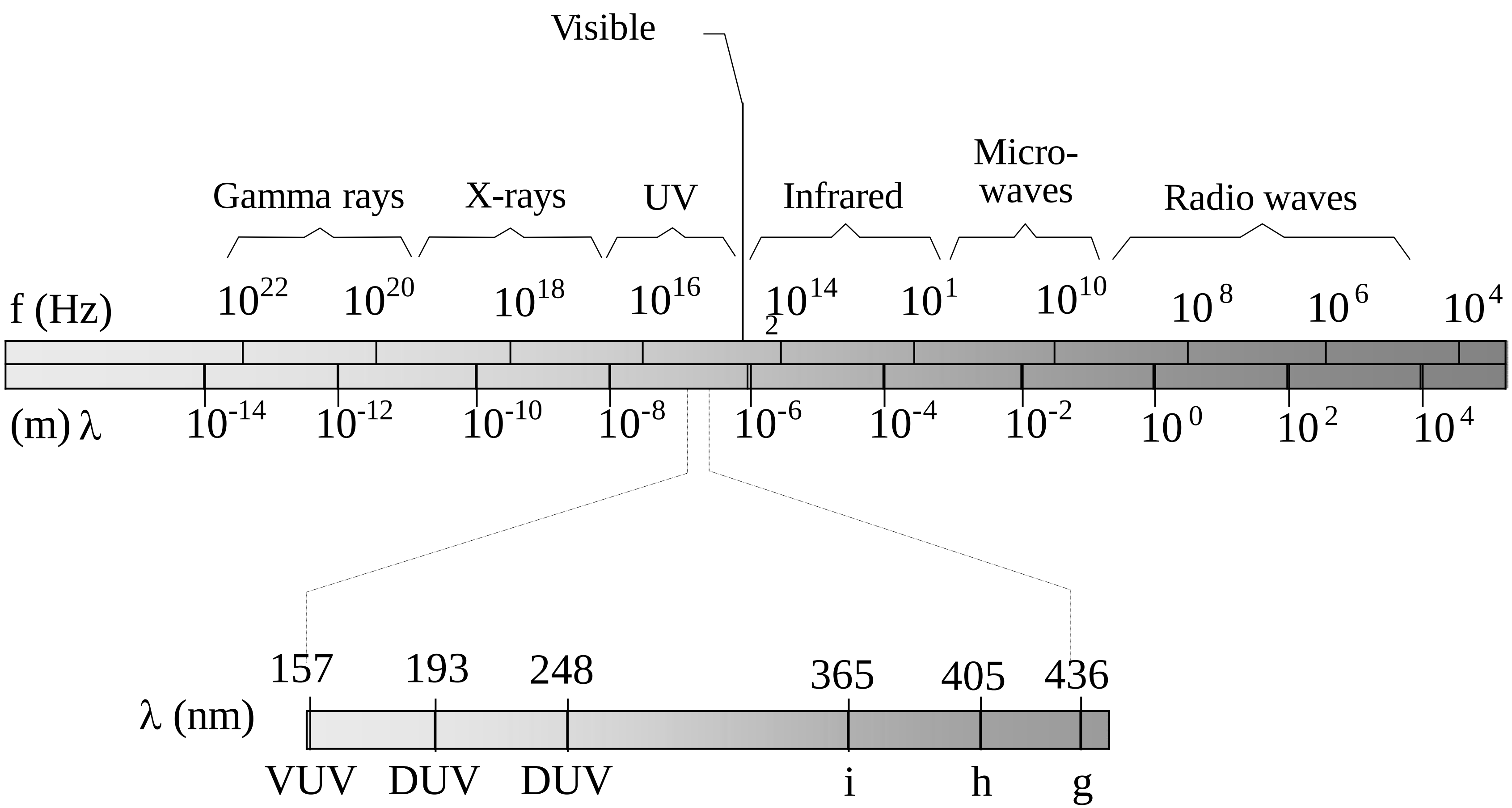


Photograph provided courtesy of Advanced Micro Devices

Three Dimensional Pattern in Photoresist



Section of the Electromagnetic Spectrum



Common UV wavelengths used in optical lithography.

Important Wavelengths for Photolithography Exposure

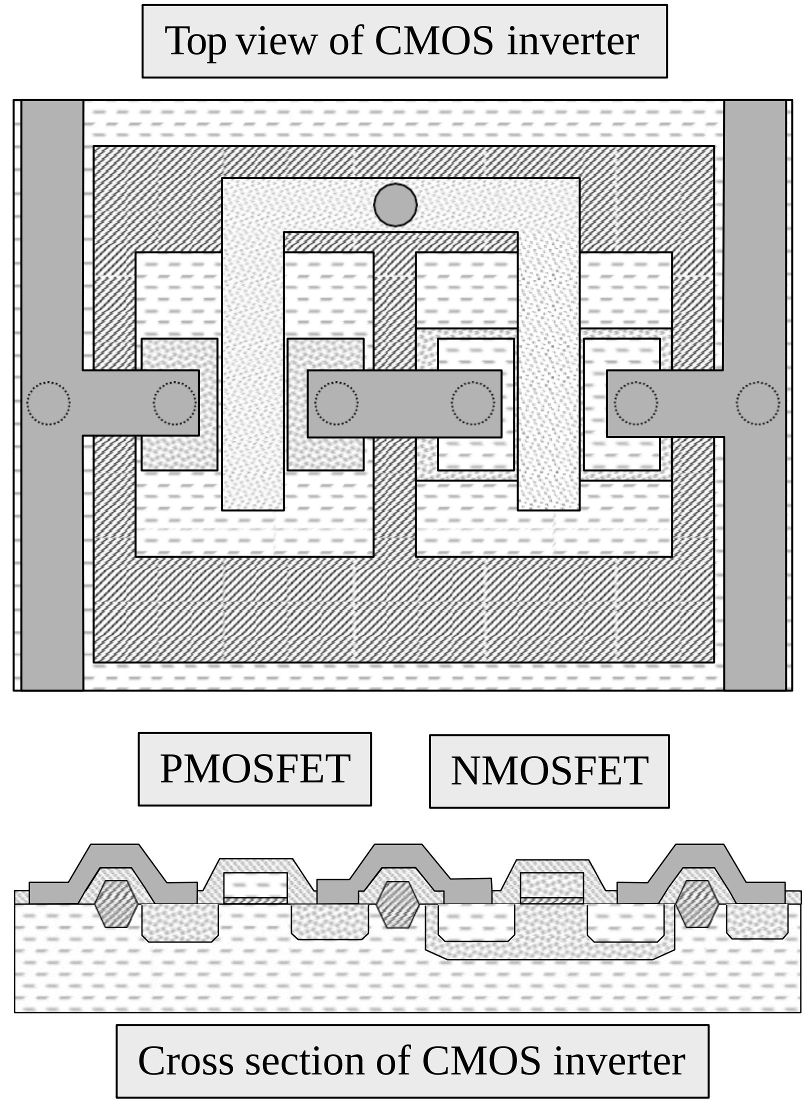
UV Wavelength (nm)	Wavelength Name	UV Emission Source
436	g-line	Mercury arc lamp
405	h-line	Mercury arc lamp
365	i-line	Mercury arc lamp
248	Deep UV (DUV)	Mercury arc lamp or Krypton Fluoride (KrF) excimer laser
193	Deep UV (DUV)	Argon Fluoride (ArF) excimer laser
157	Vacuum UV (VUV)	Fluorine (F_2)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

Importance of Mask Overlay Accuracy

- The masking layers determ ine the accuracy by which su bsequent processes can be pe rformed.

- The photoresist mask patte rn prepares individual layers for proper placement, orientat ion, and size of structures to be etched or implanted.

- Small sizes and low toleran ces do not provide much roo m for error.

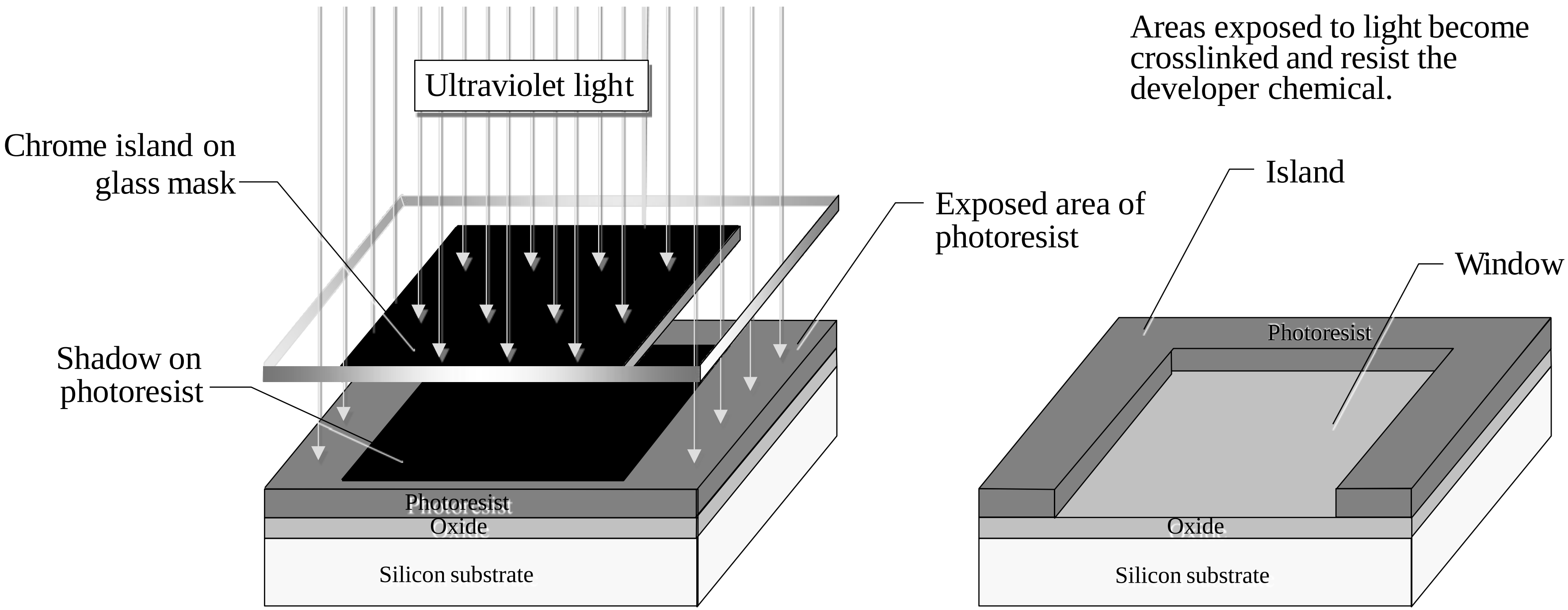


Photolithography Processes

- 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

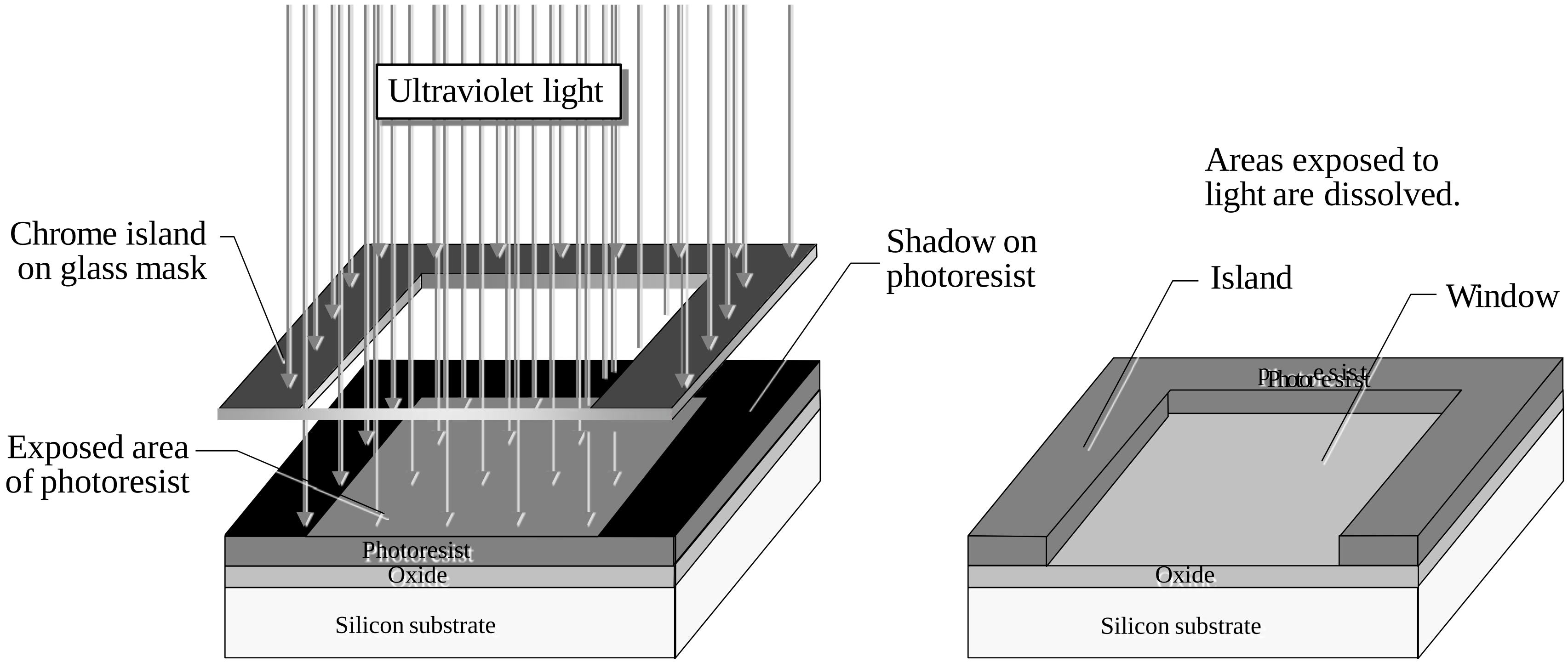
Negative Lithography

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



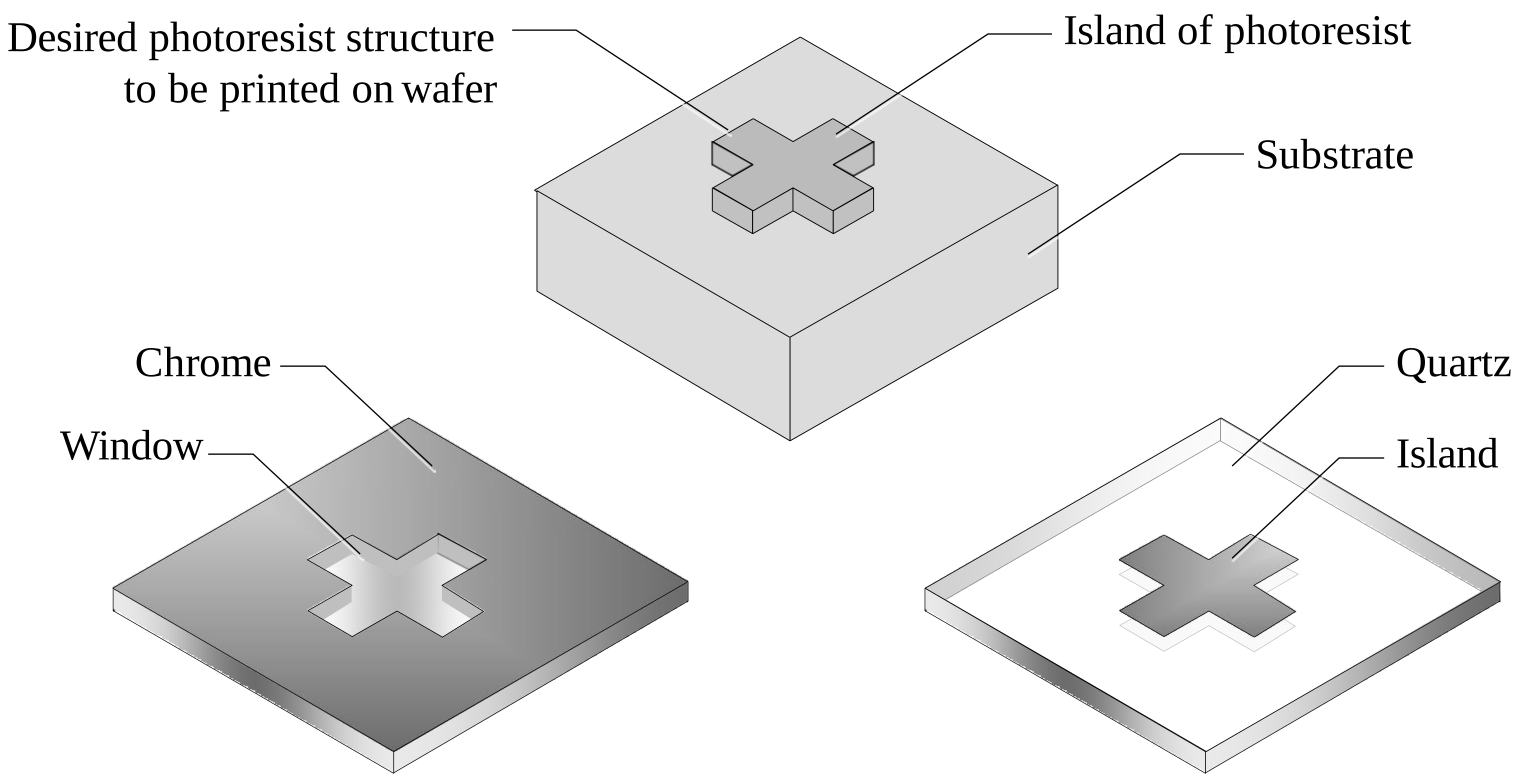
Resulting pattern after the resist is developed.

Positive Lithography



Resulting pattern after the resist is developed.

Relationship Between Mask and Resist

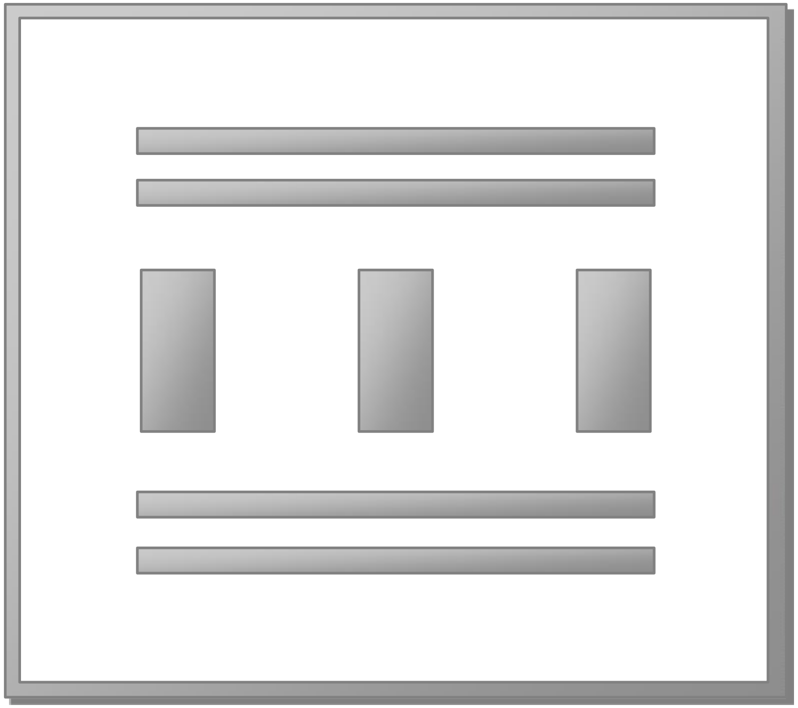


Mask pattern required when using negative photoresist (opposite of intended structure)

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

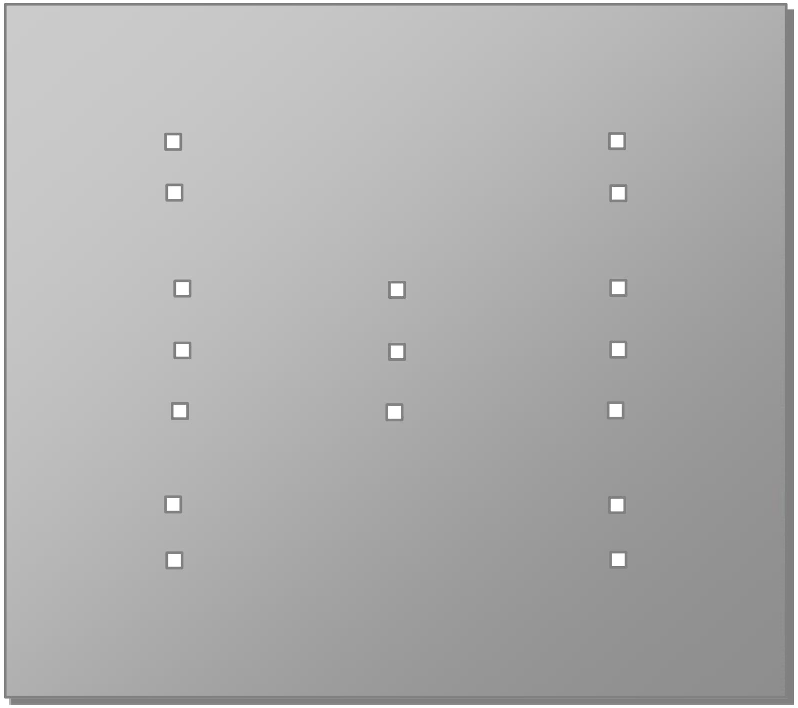
Clear Field and Dark Field Masks

Clear Field Mask



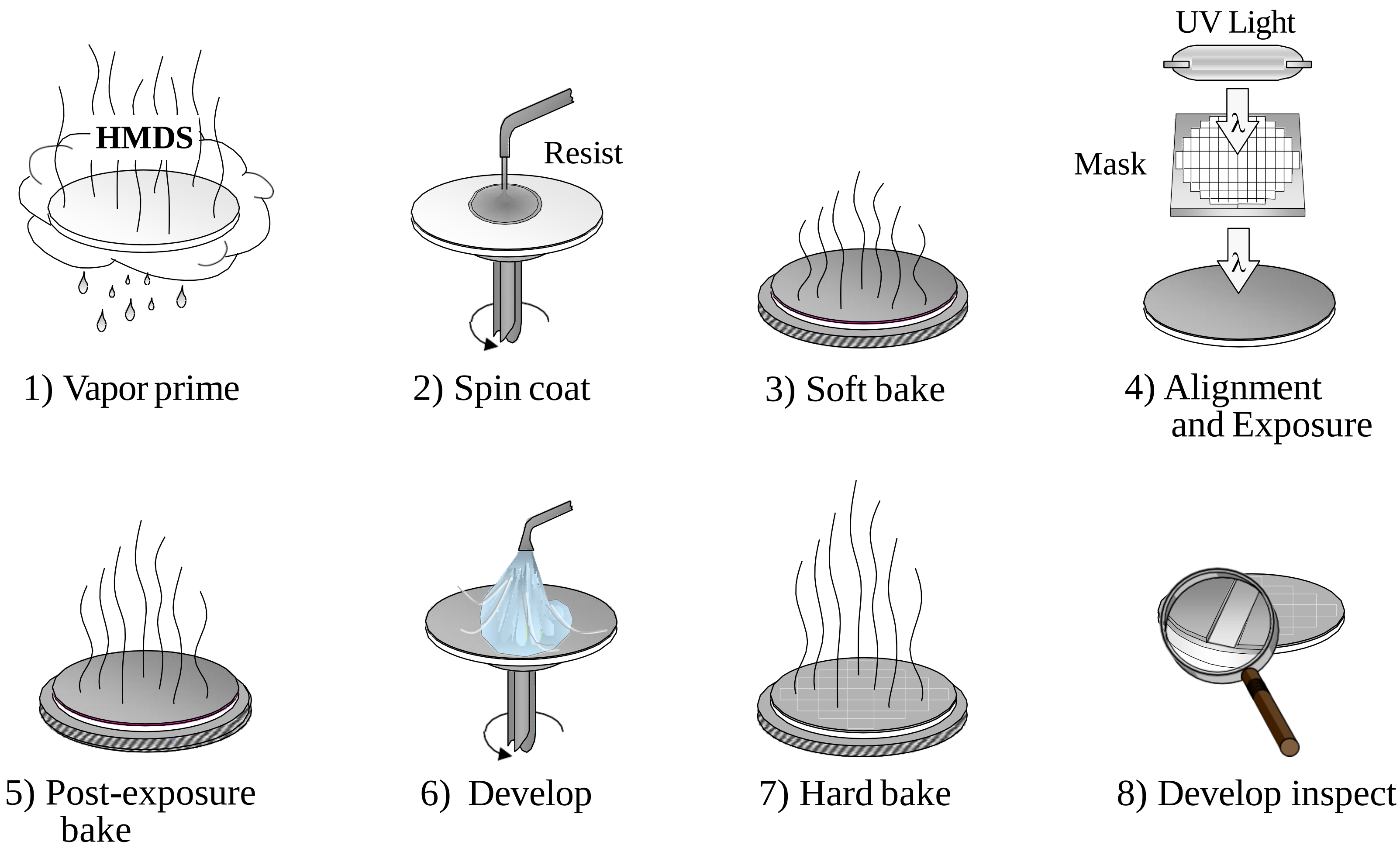
Simulation of metal interconnect lines
(positive resist lithography)

Dark Field Mask



Simulation of contact holes
(positive resist lithography)

Eight Steps of Photolithography



Photolithography Track System

Photo courtesy of Advanced Micro Devices, TEL Track Mark VIII

Vapor Prime

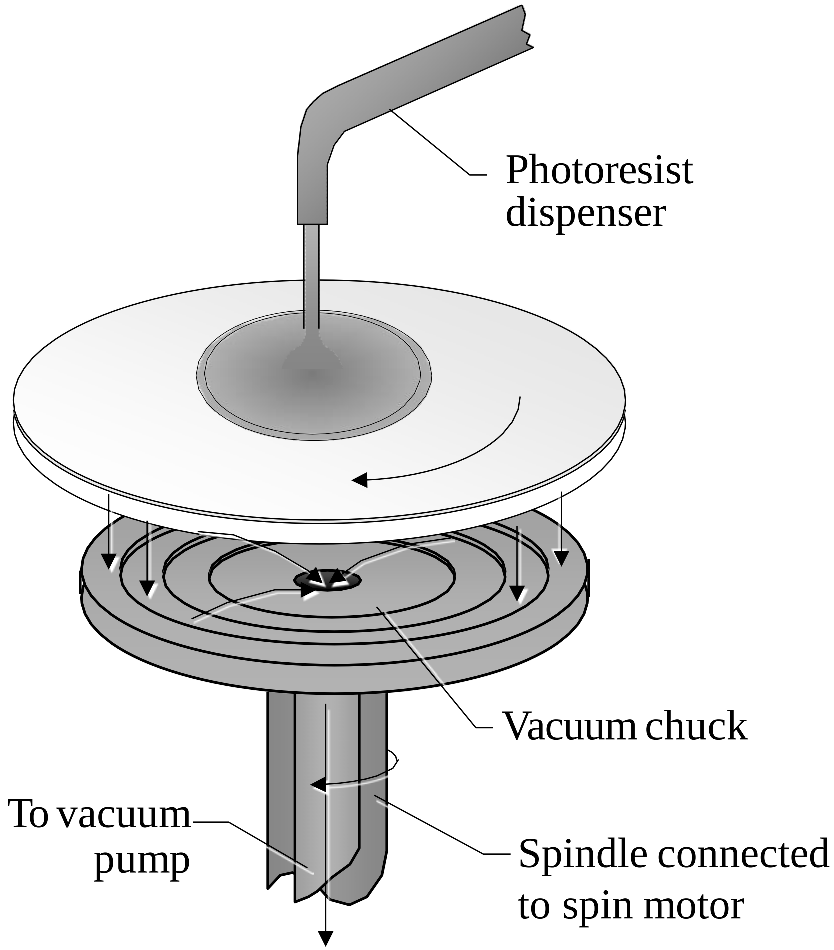
The First Step of Photolithography:

- Promotes Good Photoresist-to-Wafer Adhesion
- Primes Wafer with Hexamethyldisilazane, HMDS
- Followed by Dehydration Bake
- Ensures Wafer Surface is Clean and Dry

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



Soft bake

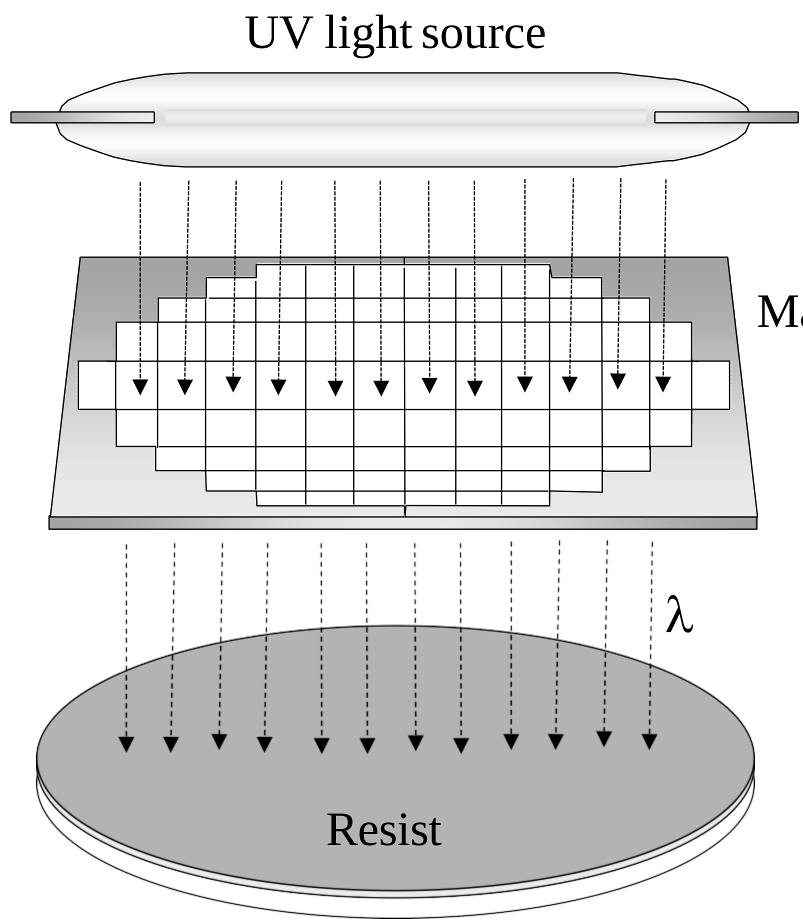
Characteristics of Soft Bake:

- 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

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



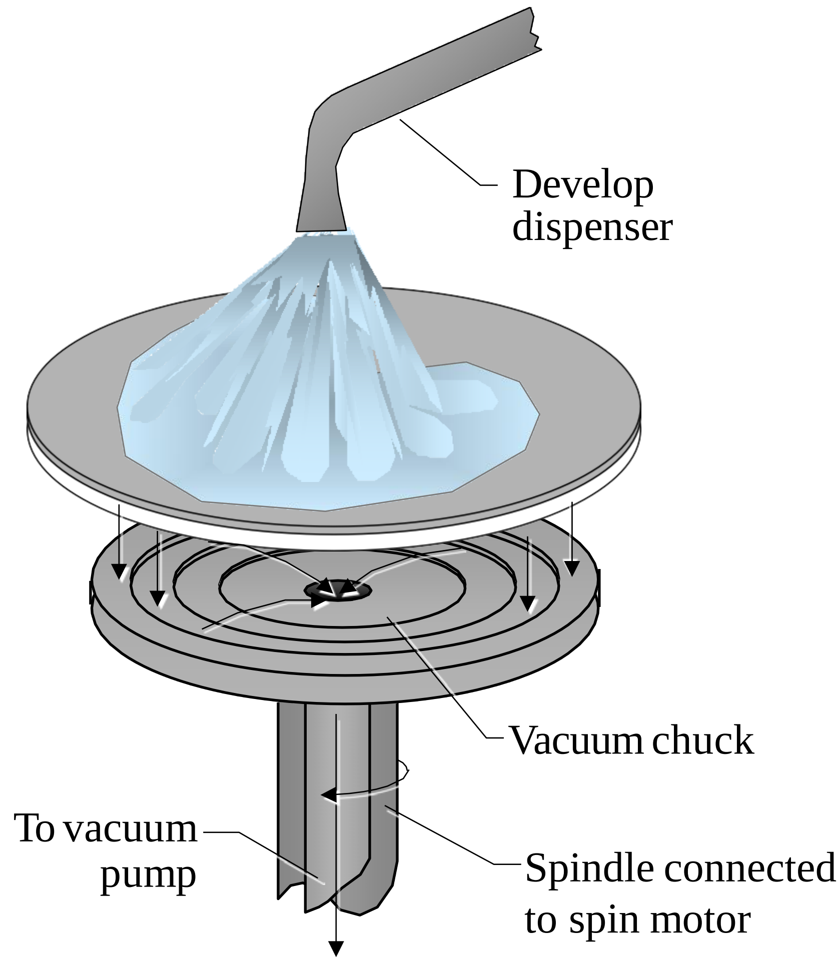
Post-Exposure Bake

- 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

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



Hard Bake

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

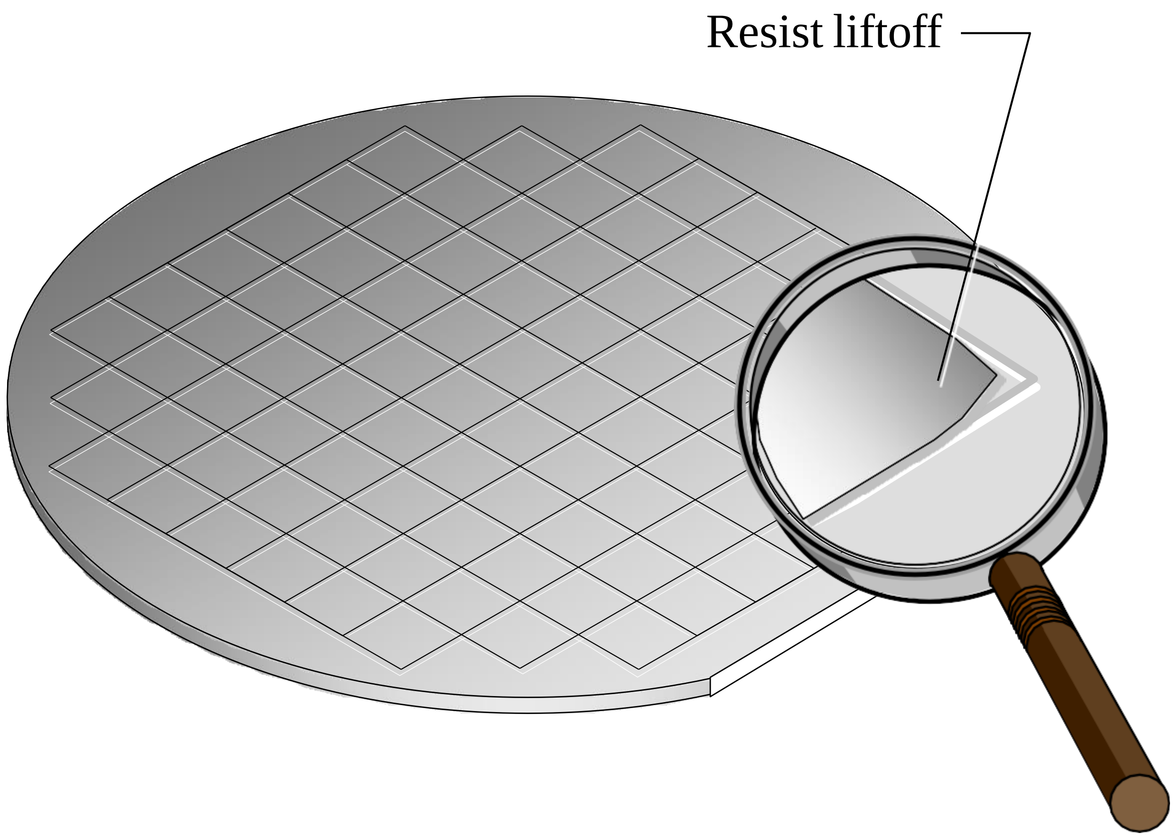
Develop Inspect

- 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

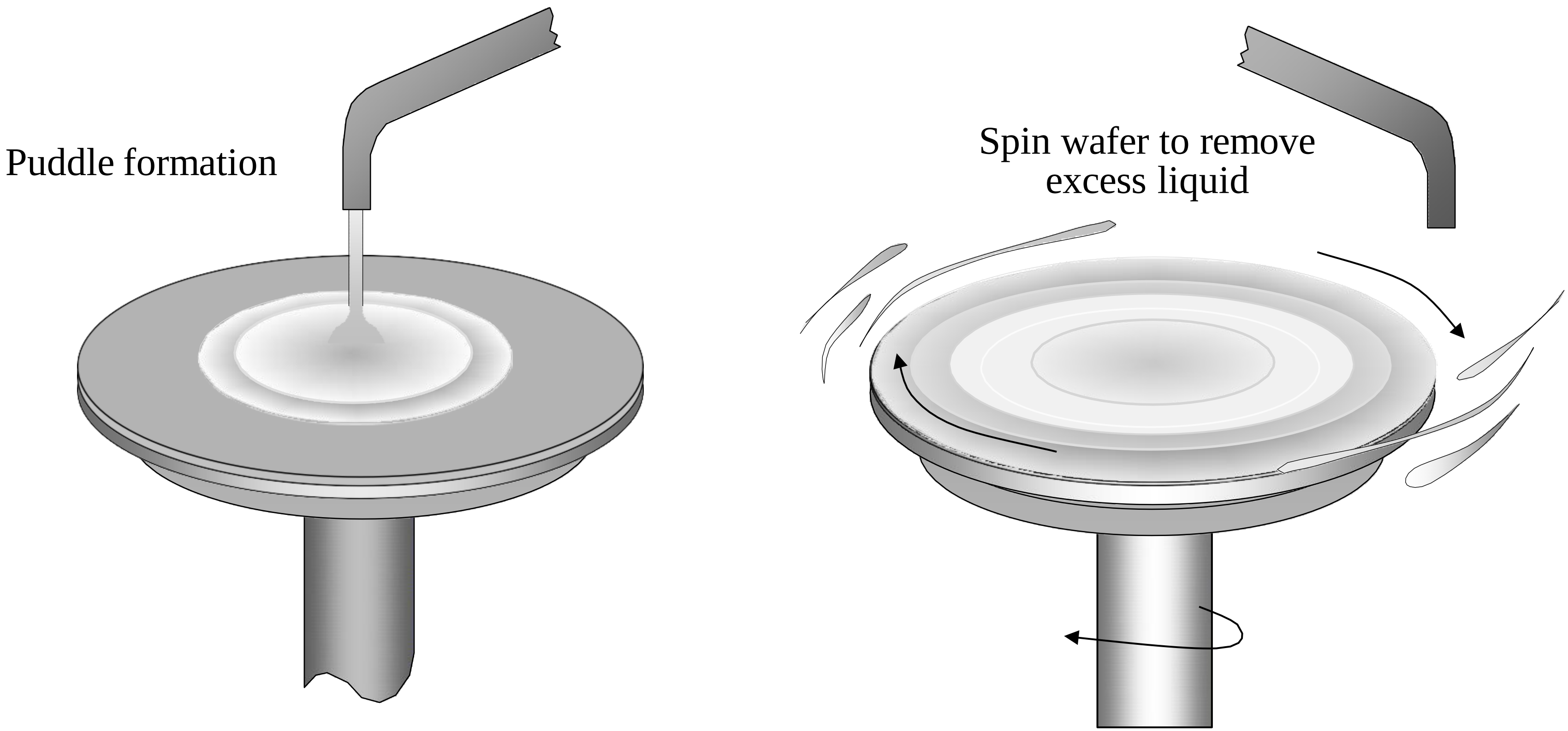
Vapor Prime

- Wafer Cleaning
- 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



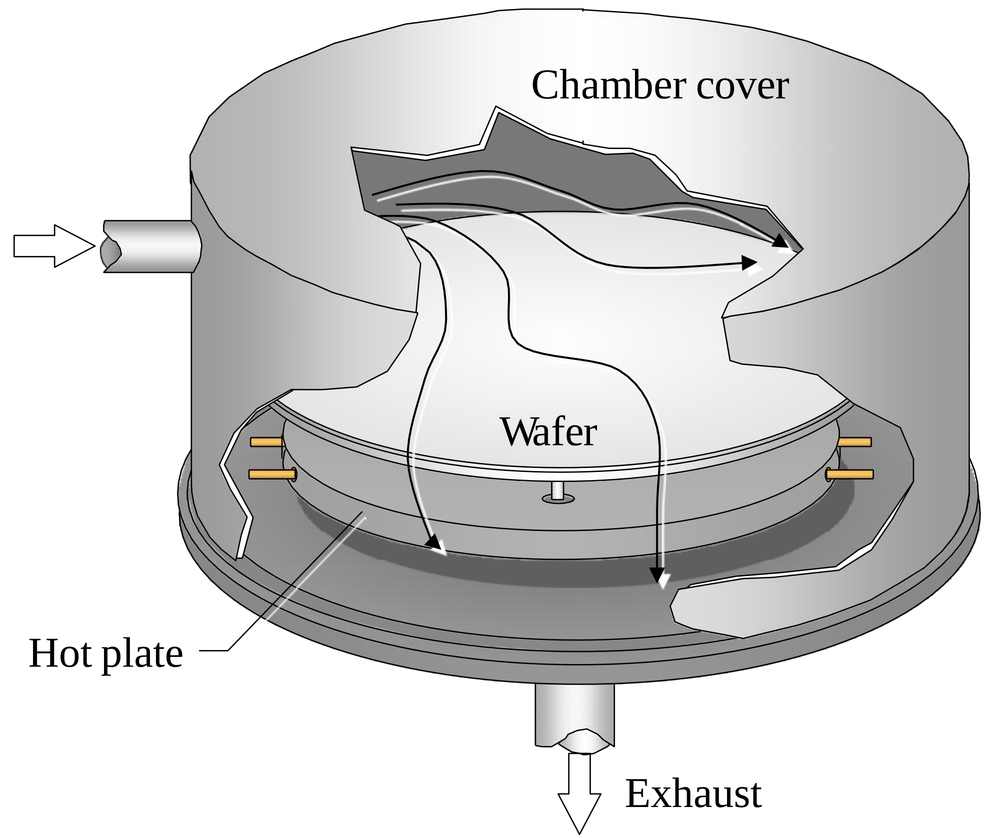
HMDS Puddle Dispense and Spin



HMDS Hot Plate Dehydration Bake and Vapor Prime

<u>Process Summary</u>:

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



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
  - Deep UV Resist
- 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
- Contrast
- Sensitivity
- Viscosity
- Adhesion
- Etch resistance
- Surface tension
- Storage and handling
- Contaminants and particles

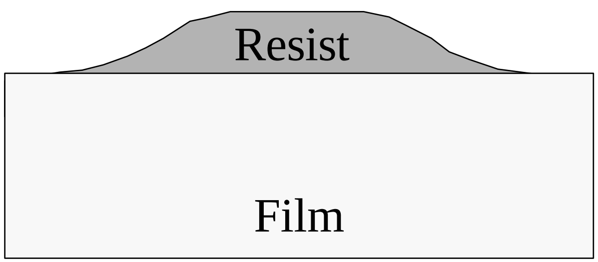
Resist Contrast

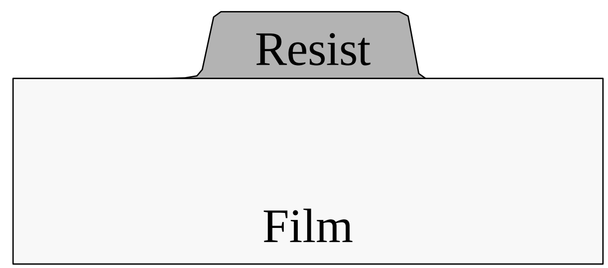
<u>Poor Resist Contrast</u>

- Sloped walls
- Swelling
- Poor contrast

<u>Good Resist Contrast</u>

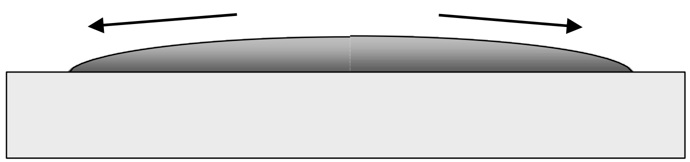
- Sharp walls
- No swelling
- Good contrast



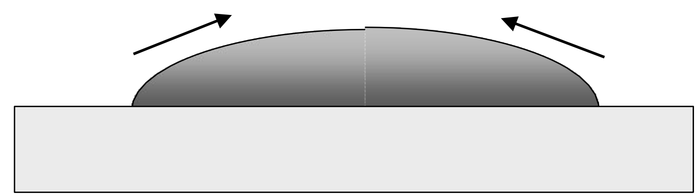


Surface Tension

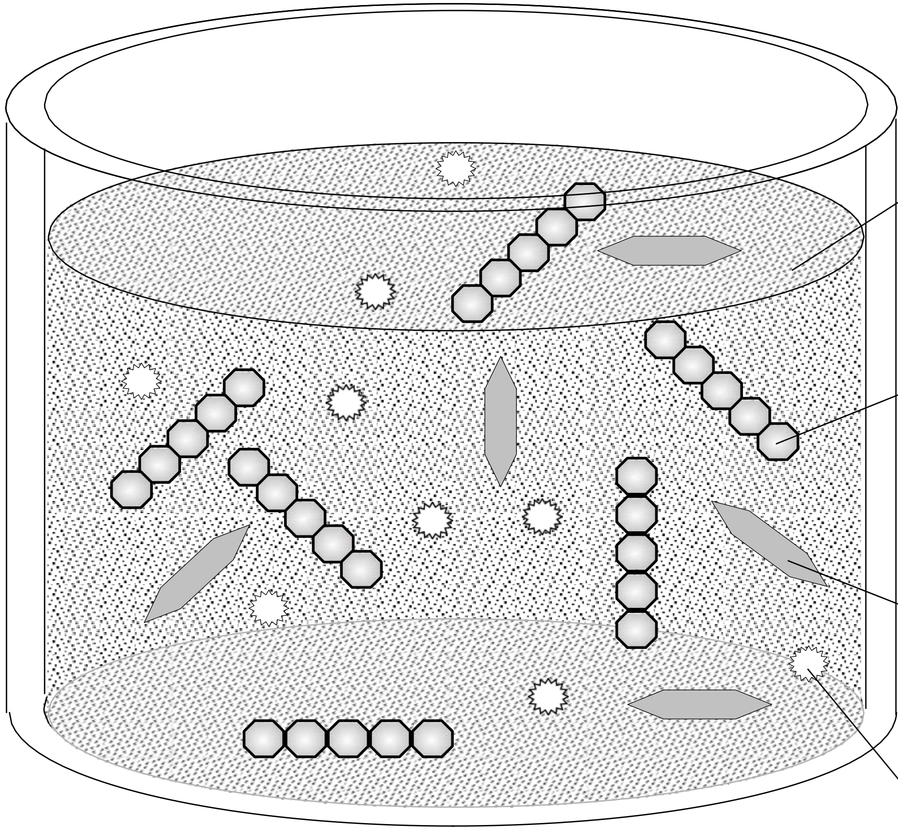
Low surface tension from low molecular forces



High surface tension from high molecular forces



Components of Conventional Photoresist



: Typically 3 component

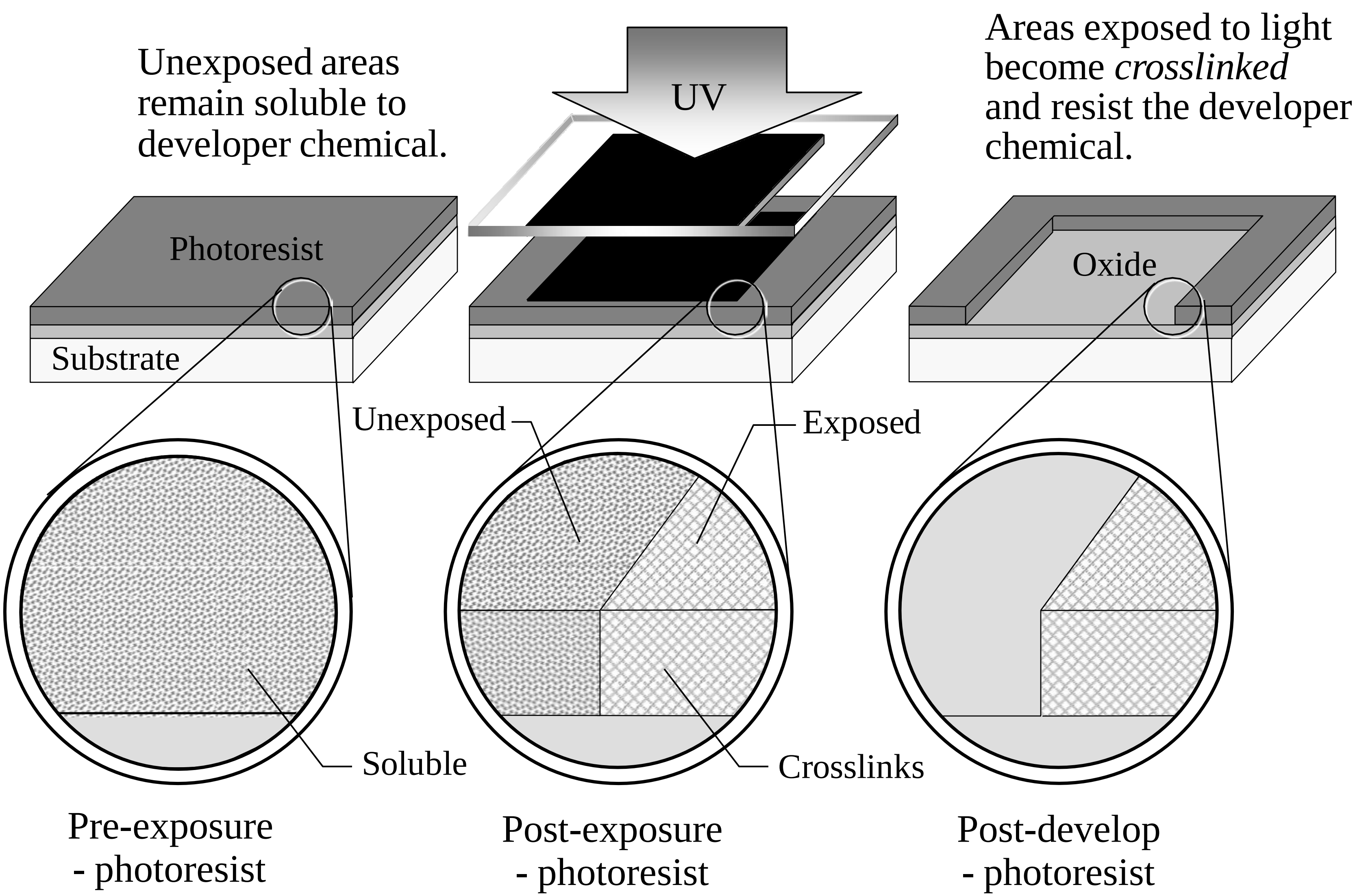
Solvent:
gives resist its flow characteristics

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

Sensitizers:
photosensitive component of the resist material

Additives:
chemicals that control specific aspects of resist material

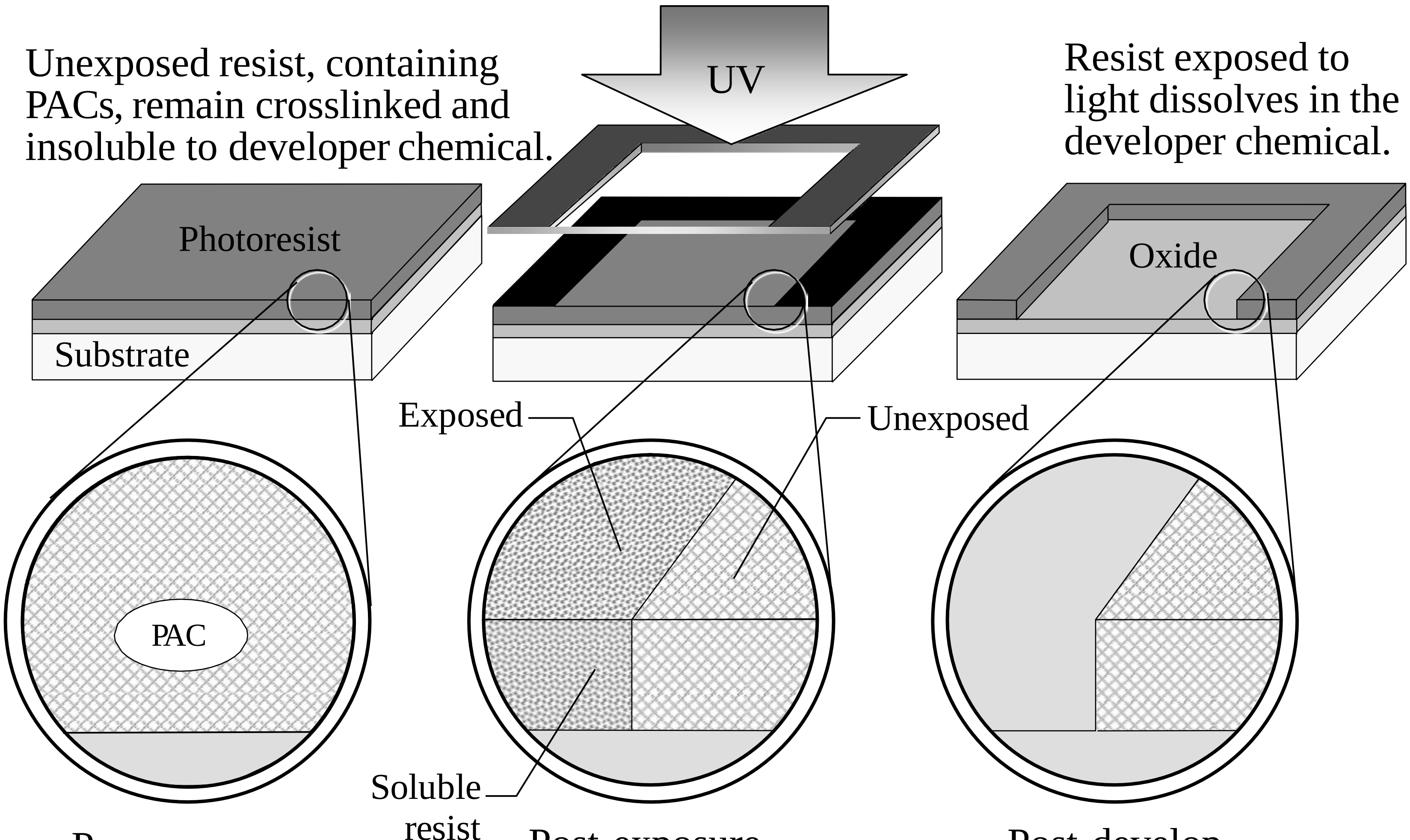
Negative Resist Cross-Linking



PAC as Dissolution Inhibitor in Positive I-Line Resist

Unexposed resist, containing PACs, remain crosslinked and insoluble to developer chemical.

Resist exposed to light dissolves in the developer chemical.



Pre-exposure + photoresist

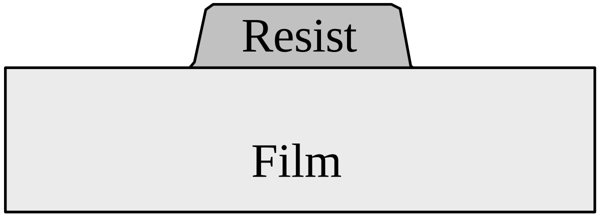
Post-exposure + photoresist

Post-develop + photoresist

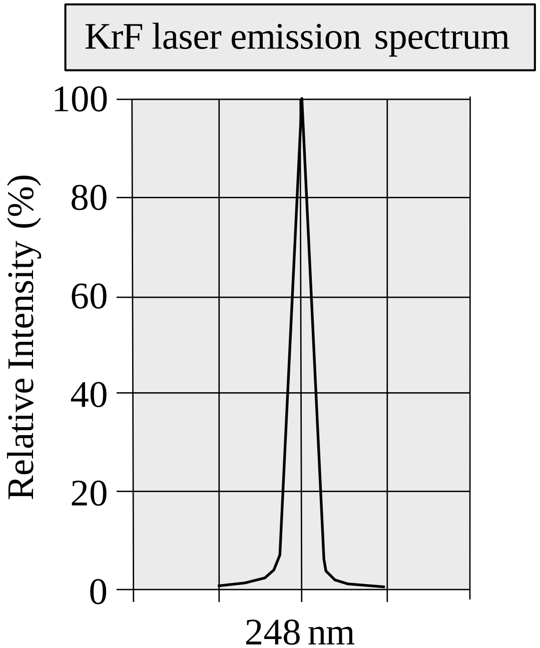
Good Contrast Characteristics of Positive I-line Photoresist

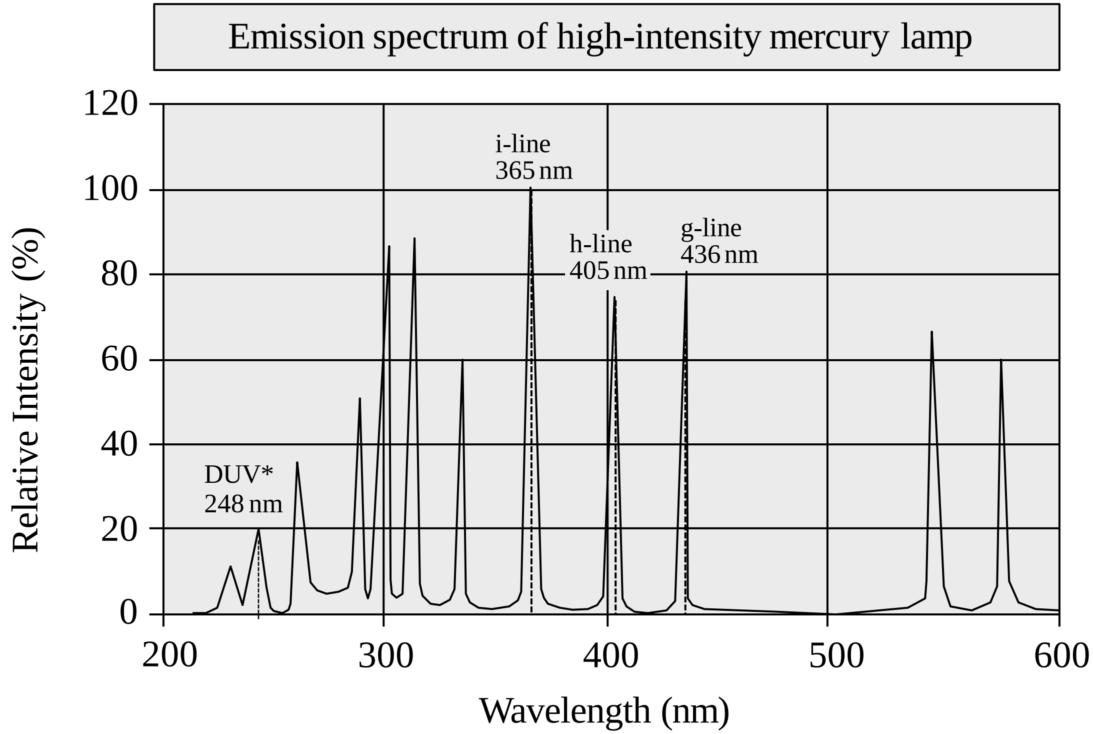
Positive Photoresist:

- Sharp walls
- No swelling
- Good contrast



DUV Emission Spectrum

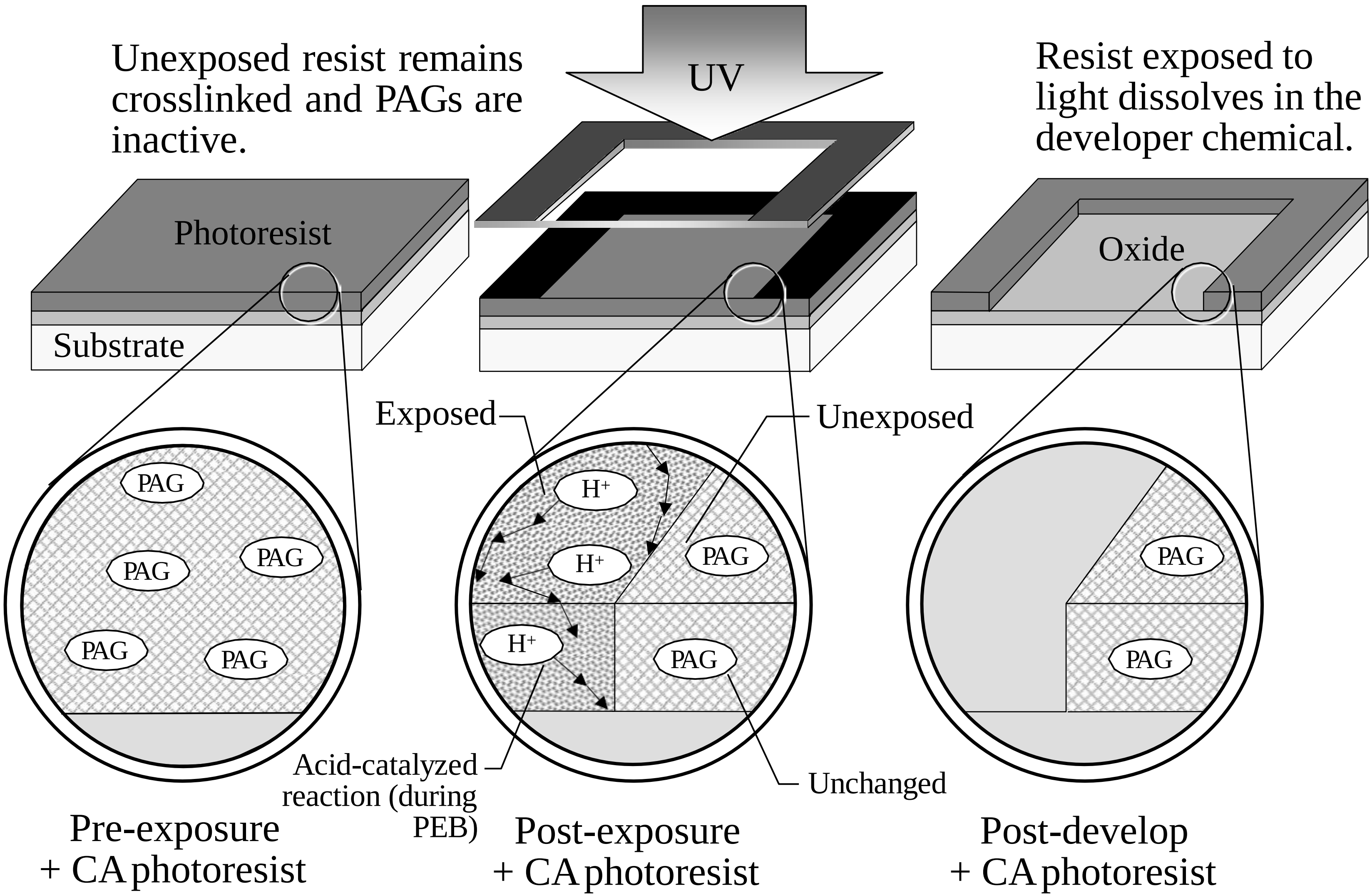




** Intensity of mercury lamp is too low at 248 nm to be usable in DUV photolithography applications. Excimer lasers, such as shown on the left provide more energy for a given DUV wavelength.*

Mercury lamp spectrum used with permission from USHIO Specialty Lighting Products

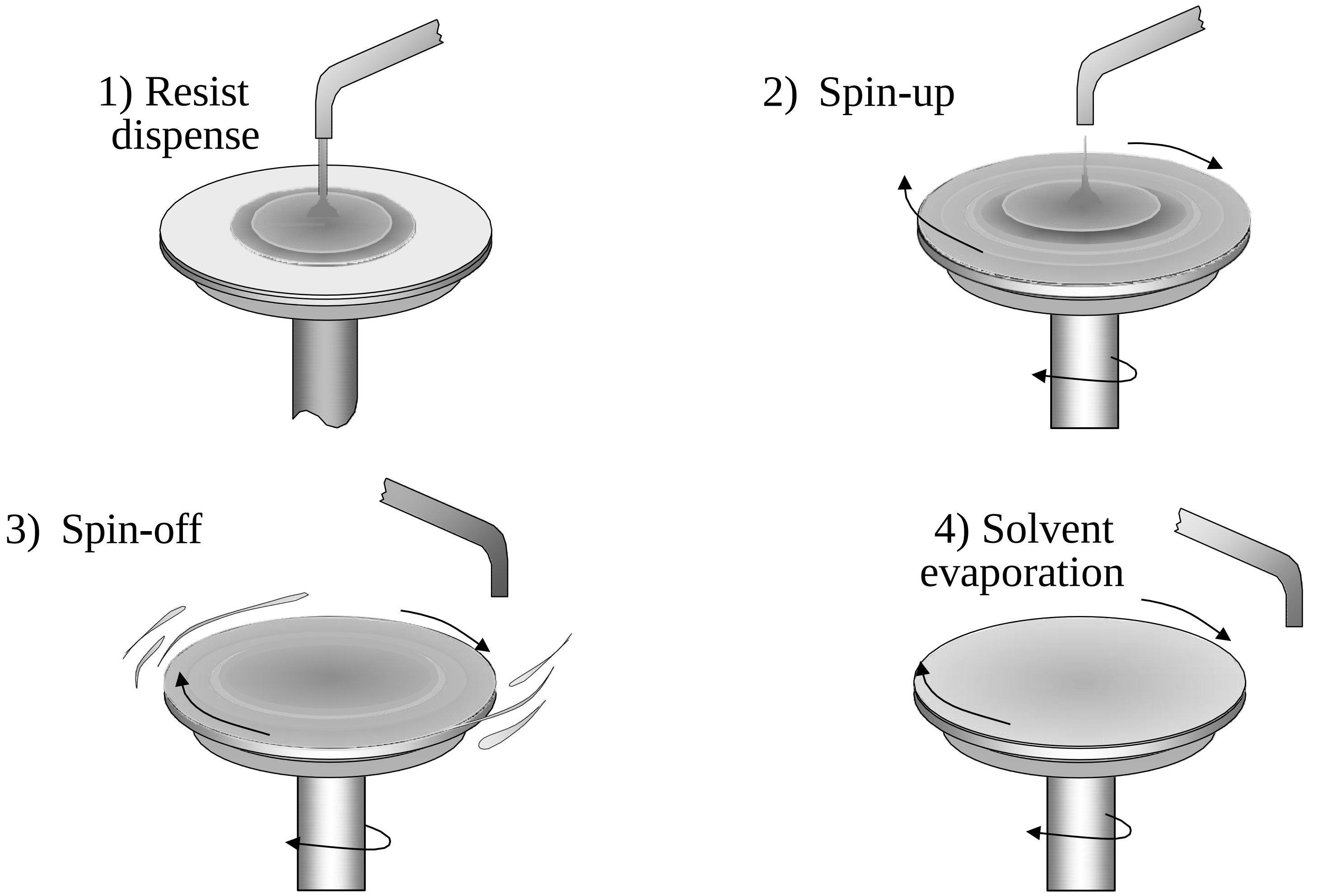
Chemically Amplified (CA) DUV Resist



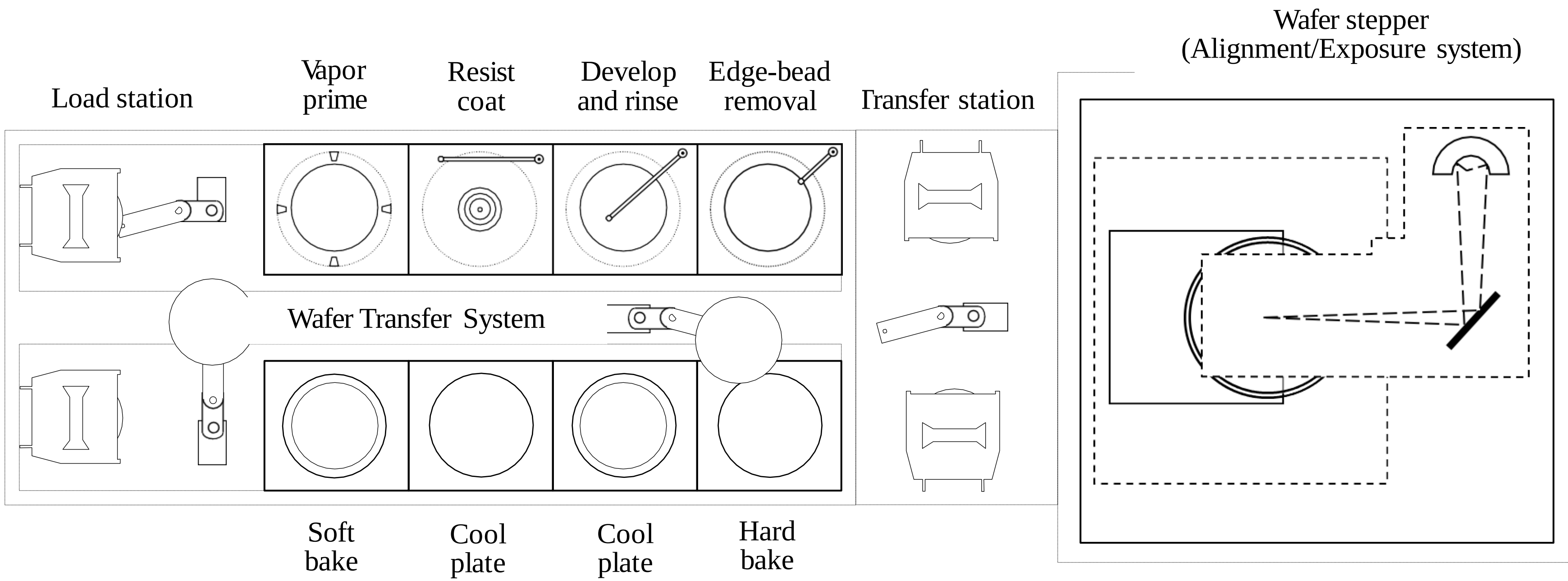
Exposure Steps for Chemically-Amplified DUV Resist

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.

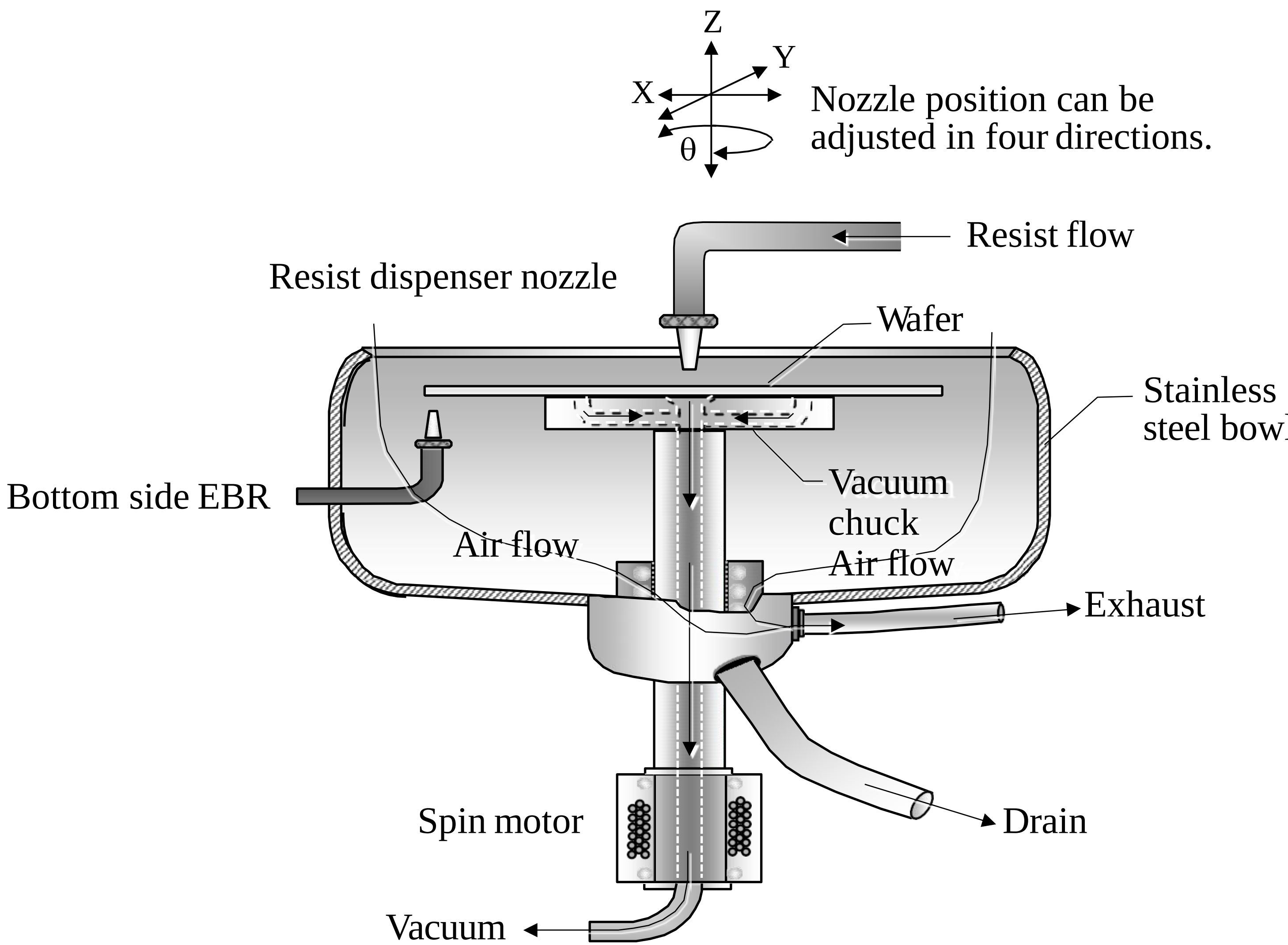
Steps of Photoresist Spin Coating



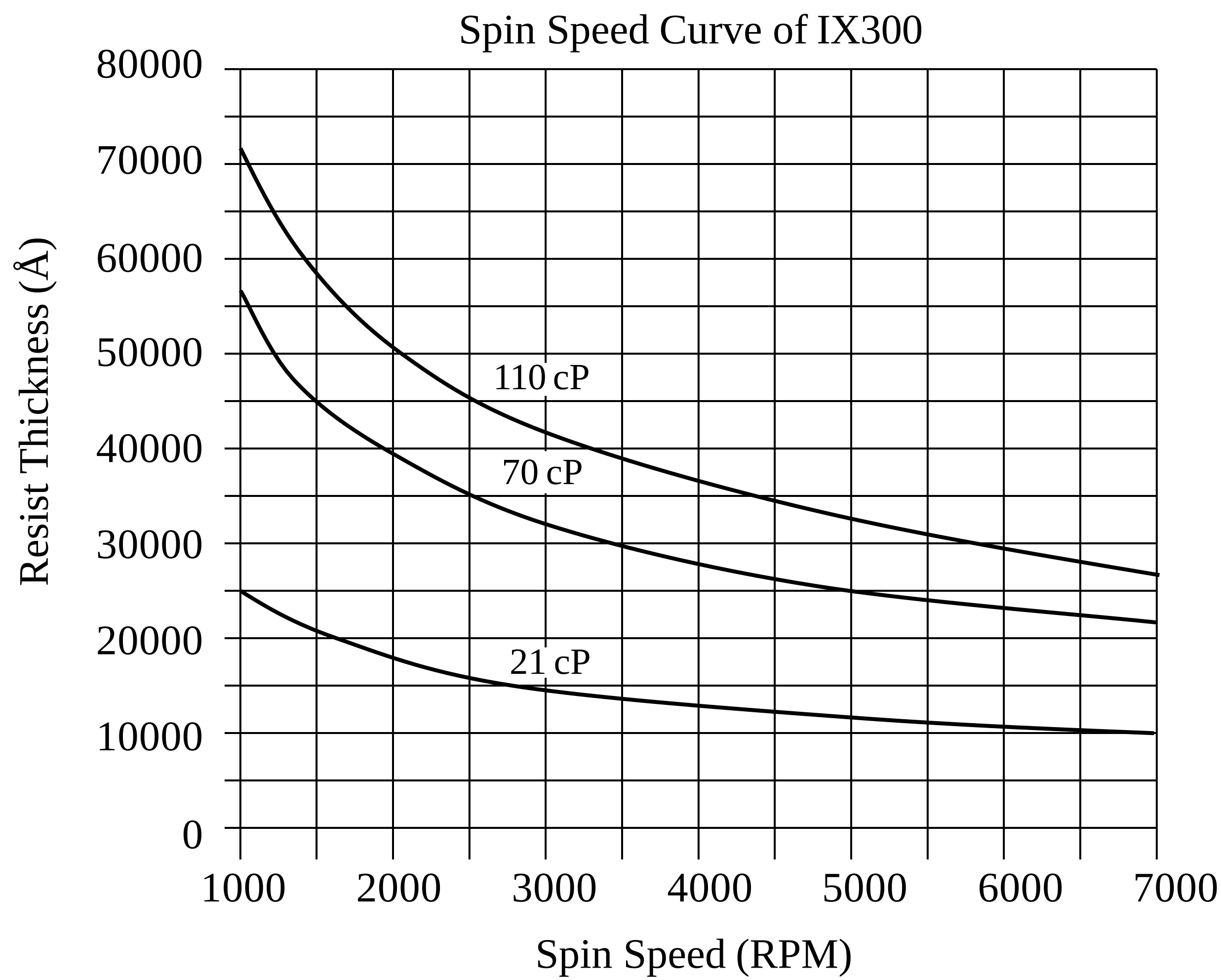
Automated Wafer Track for Photolithography



Photoresist Dispense Nozzle



Resist Spin Speed Curve

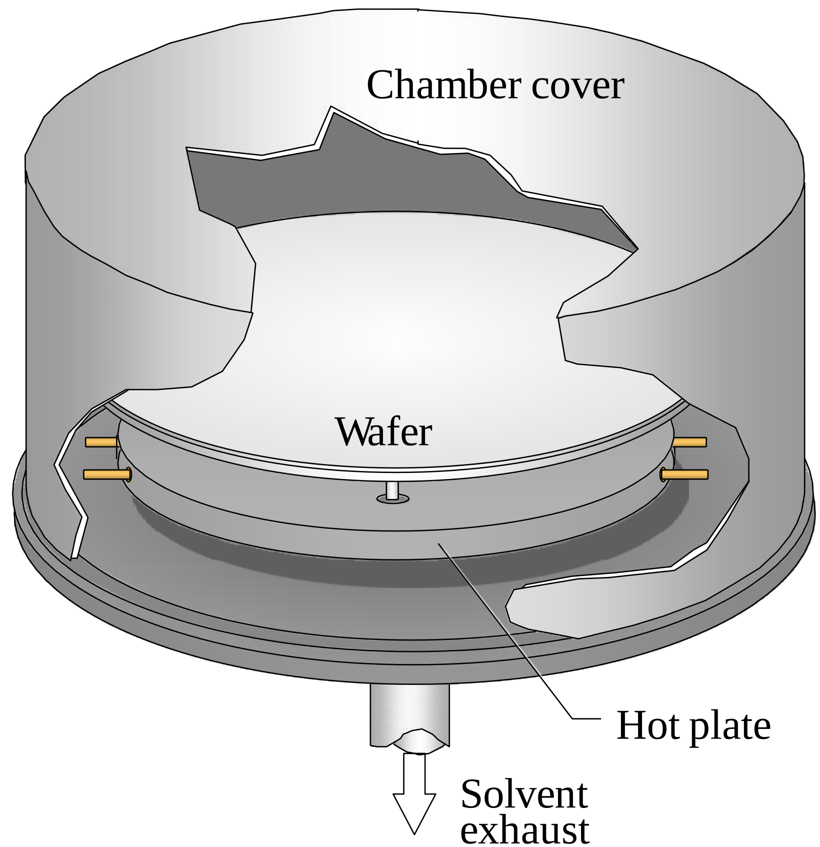


Used with permission from JSR Microelectronics, Inc.

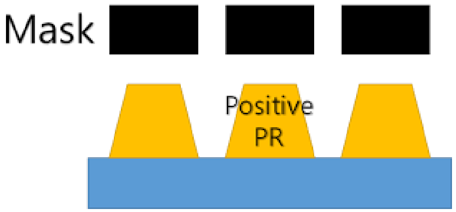
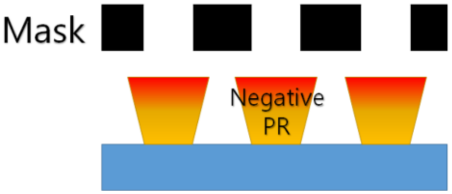
Soft Bake on Vacuum Hot Plate

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



Summary

Property	Positive PR	Negative PR
Resolution	High	Low (> 1 um)
Developer	Temp. sensitive	Temp. non-sensitive
Mask type	Dark-field mask : lower-defect	Clear-field mask : higher defect
Rinse	In Water	In solvent
Cost	More expensive	Cheaper
Adhesion	-	Better
Profile		

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