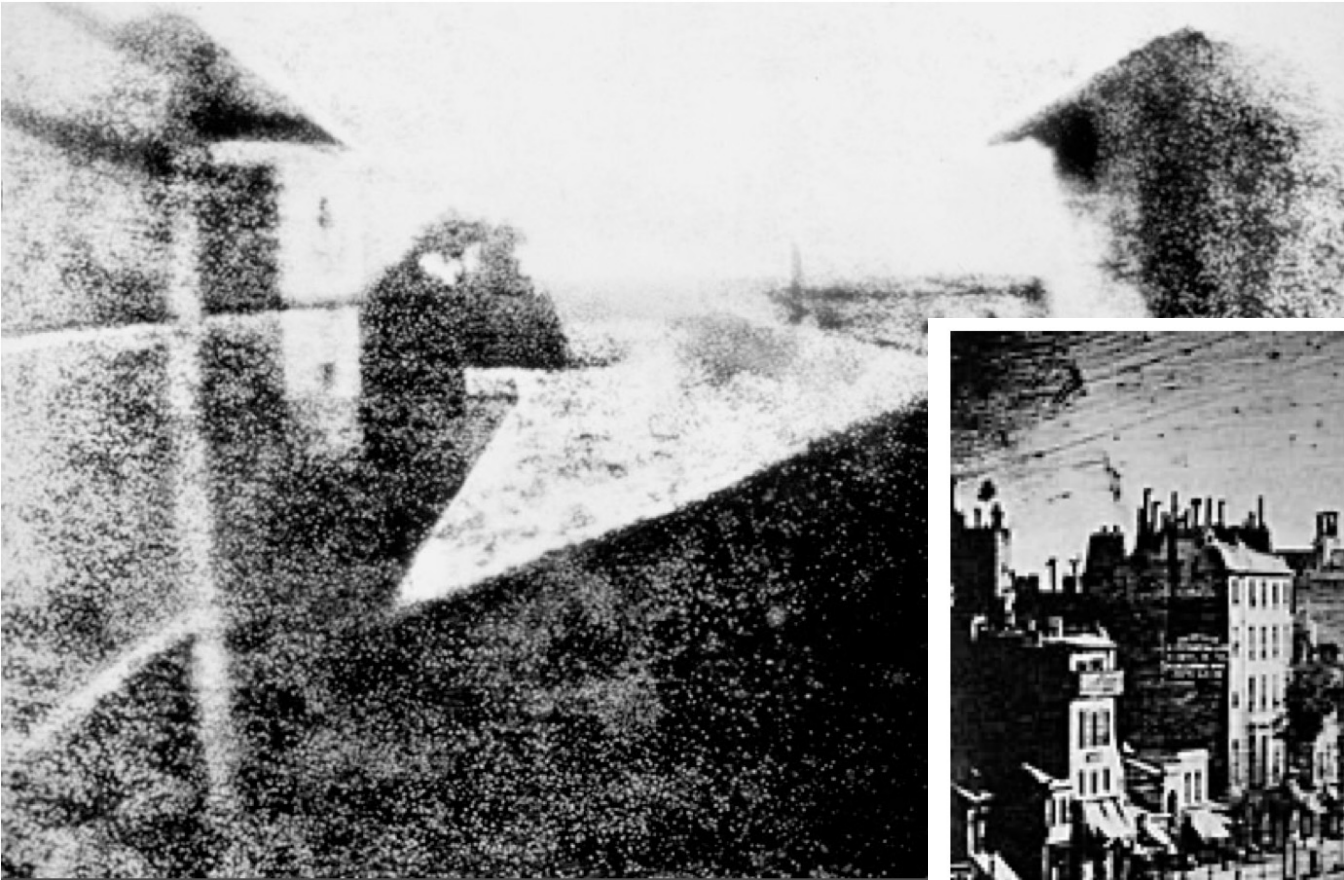


Lithography

Science of micromachining.



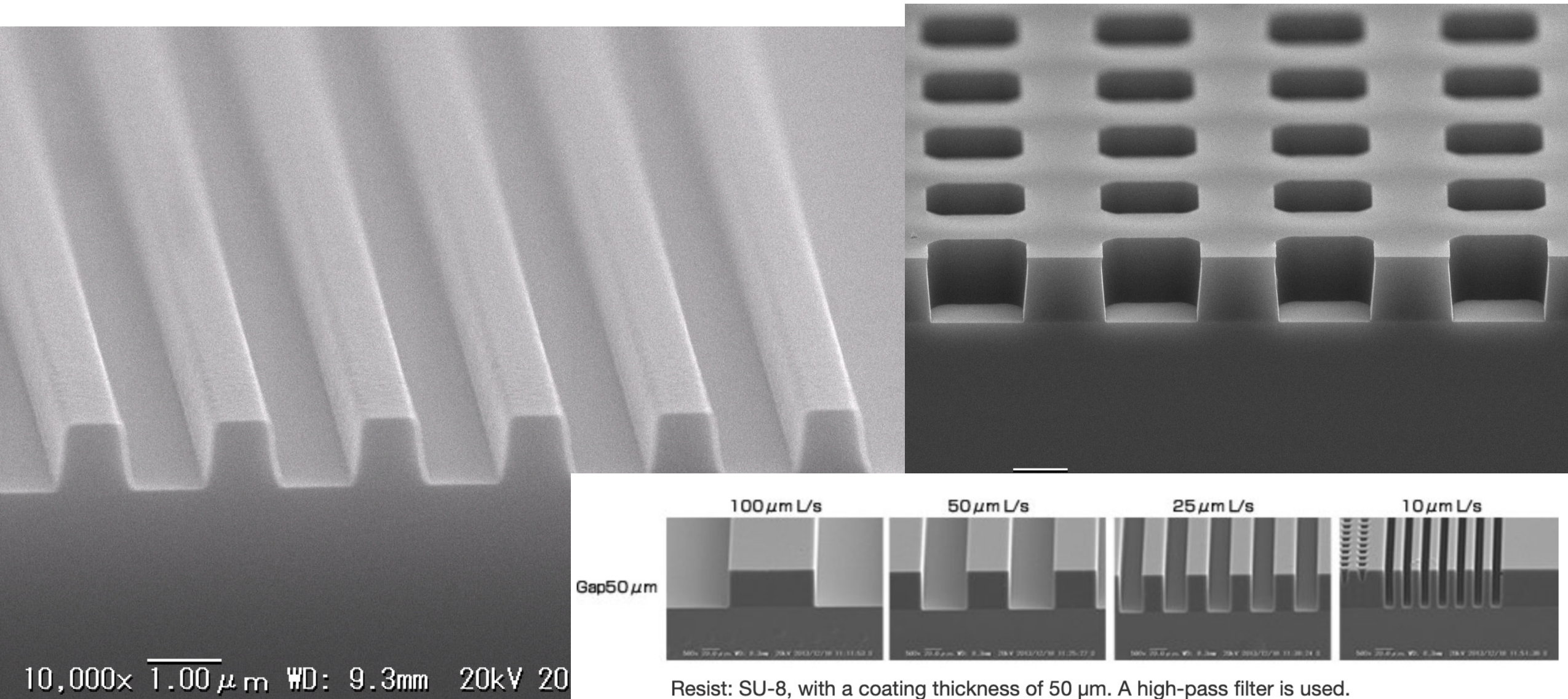
Mercury sits where light has fallen.
Protecting the region!

Sodium thio sulphate then dissolves
the remaining Silver iodide.

- daguerreotype process
Silver thin film is treated with iodine to
form silver iodide – photo sensitive.
Treated with mercury.

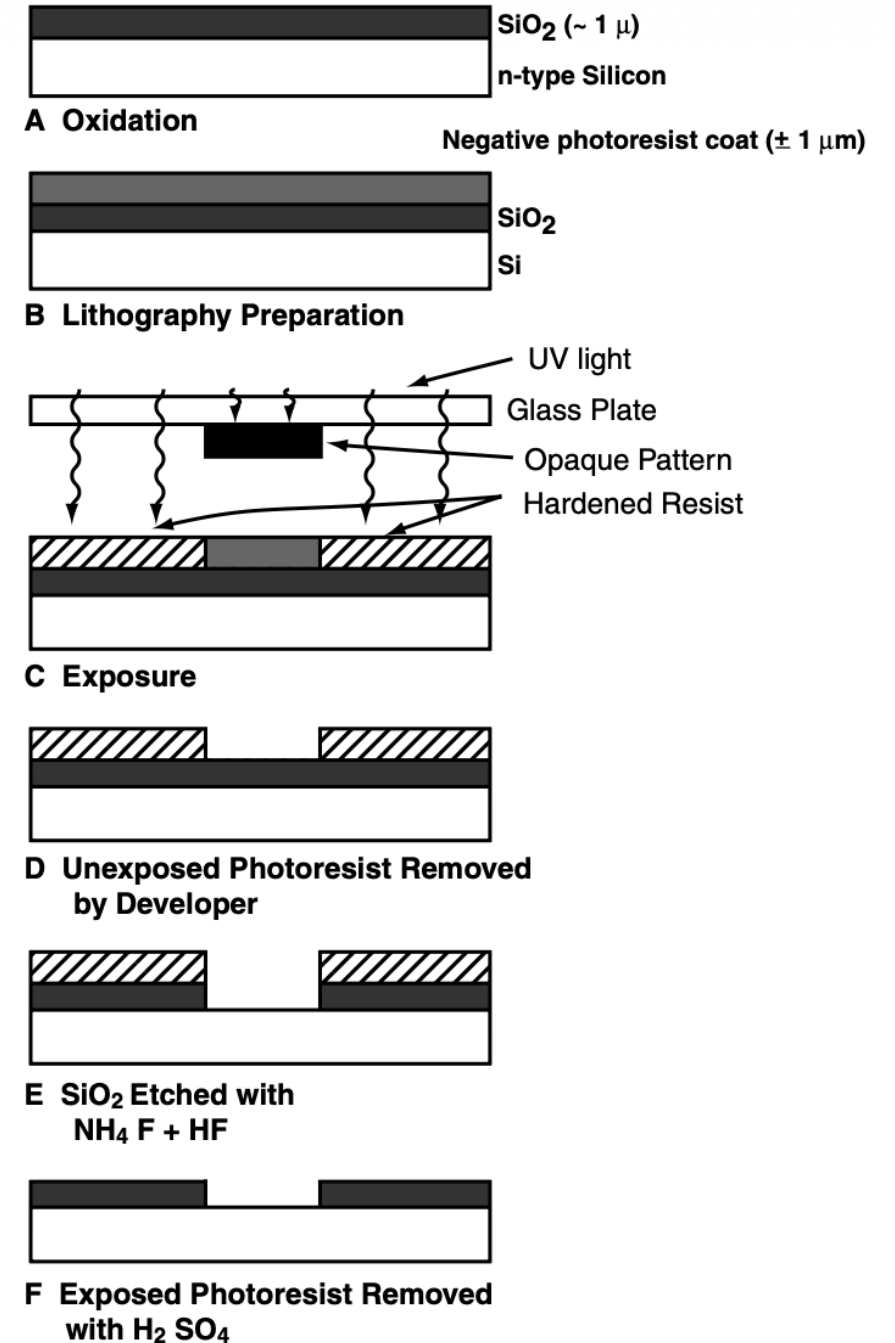
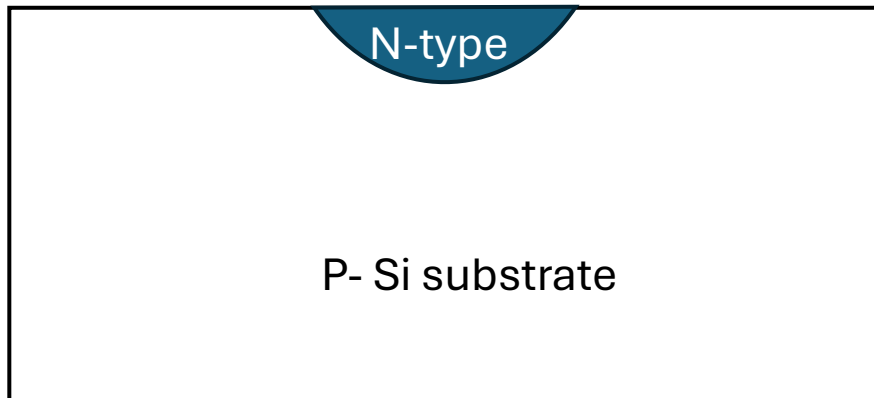


Photo-lithography in Micro/nano fabrication



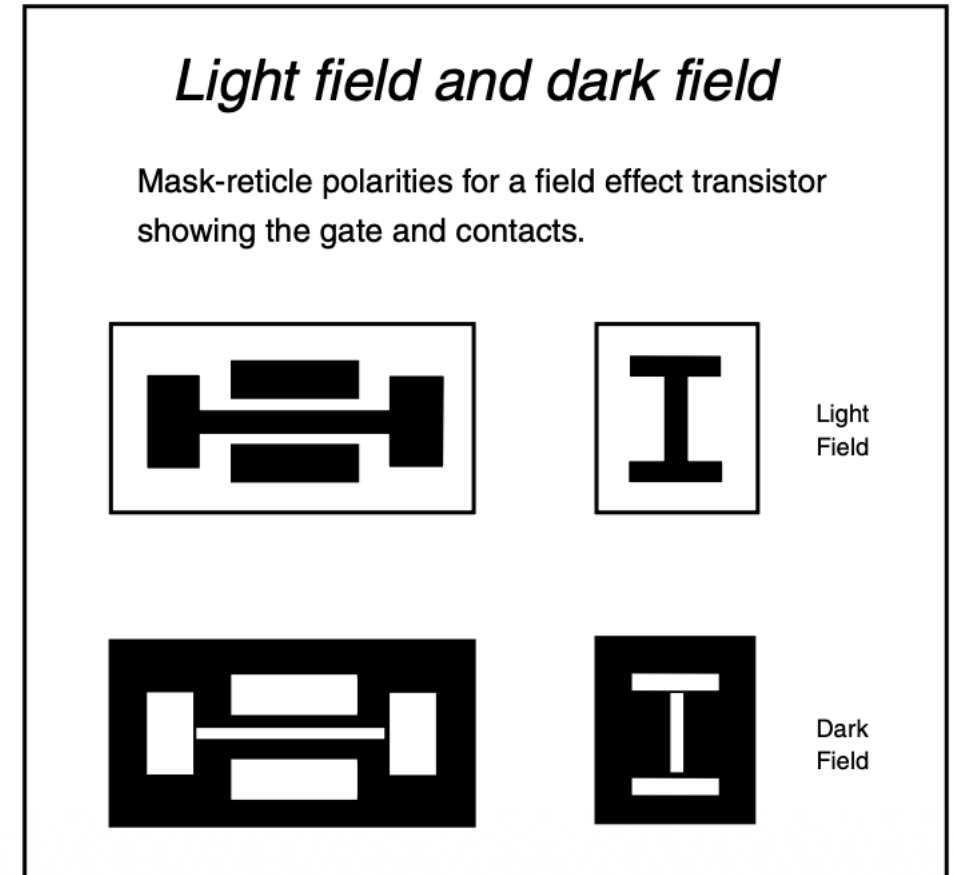
Typical lithographic process

How do you achieve this ?



Mask of a lithographic step

- Stencil used to repeatedly generate pattern
- Near –flat transparent medium (glass)
 - A pattern defined by opaque layer (Cr)
- Two kinds of transfer can happen:
 - 1. Light field
 - 2. dark field.
- Two kinds of mask plates
 - In-contact (typically 1:1)
 - Projection masks (
 - A high-resolution lens system
 - A pattern scaling of 1:5 or 1:10 is permissible.



Resists – Photosensitive layer

- Typically substrate (Si with oxide layer) is spin coated with a photo-sensitive layer called as photo resist.
- Resists are typically organic polymers sensitive to UV radiations.
- Spin coating:
 - A large lump of viscous solution (resist + solvent) is placed on sub
 - Substrate spun - 1500 to 8000 rpm
 - Centrifugal forces lead to equal distribution of resist on substrate
 - Any extra material is expelled.

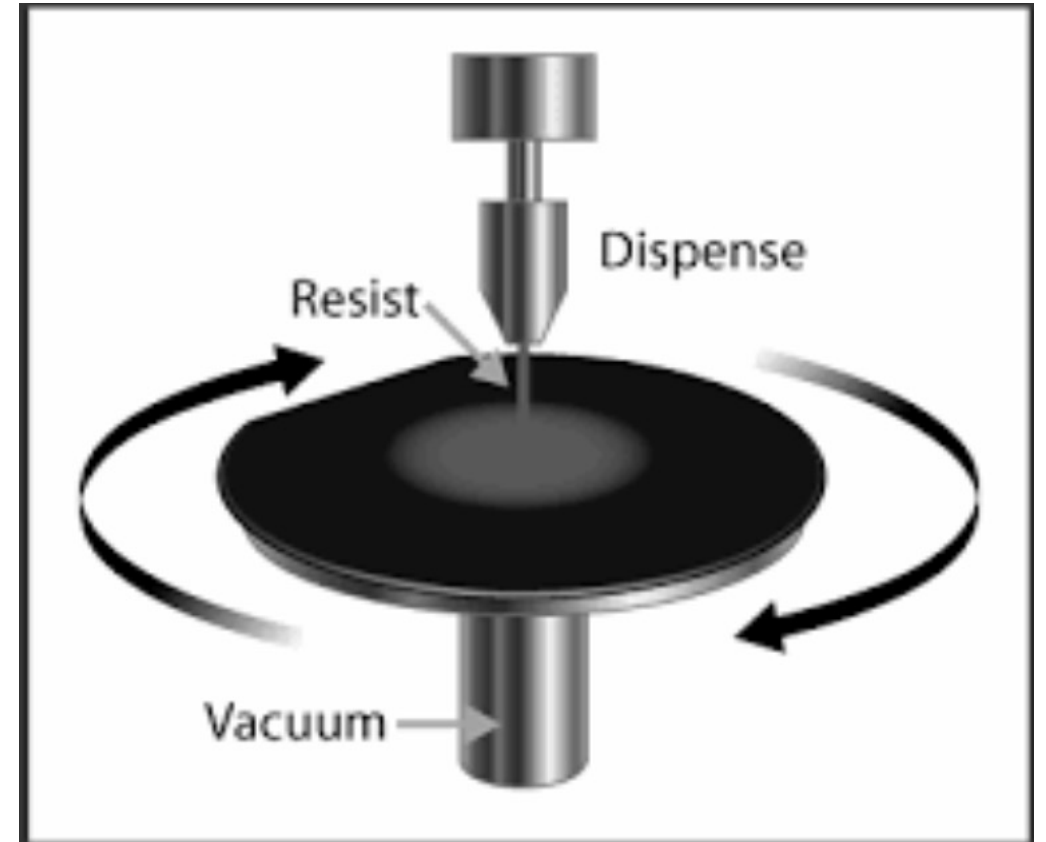
$$\text{Resist thickness } T = K \frac{C^\beta \eta^\gamma}{\omega^\alpha}$$

C – resist concentration
 η - intrinsic viscosity
 ω – rotations per minute

Spin coating of the resist is among the most important process step.

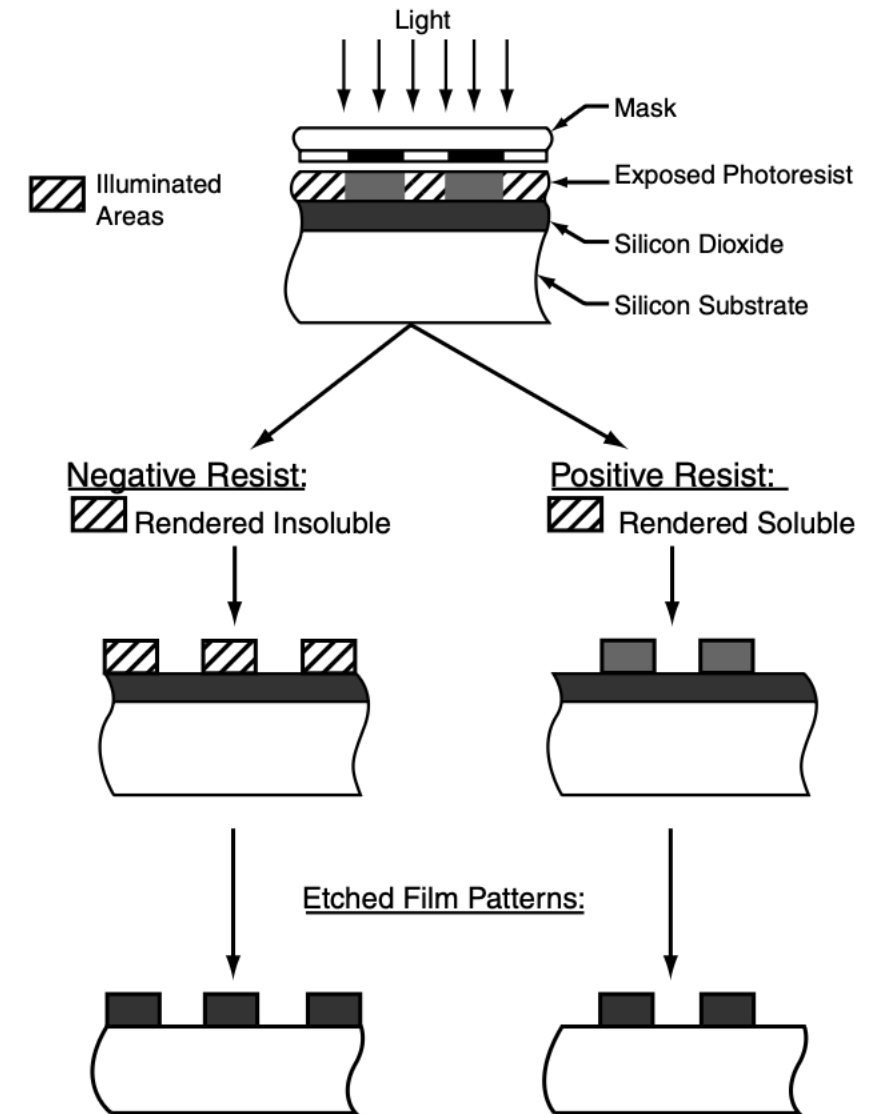
Resist spin coating

- Typical uniformity required is about $\pm 1\text{nm}$ over 12 inches.
- Typical resist thickness vary from $1\text{ }\mu\text{m}$ – 100 nm .
- Every factor influences the uniformity
 - Dispension rate and volume
 - Spin speed
 - Ambient temperature and humidity

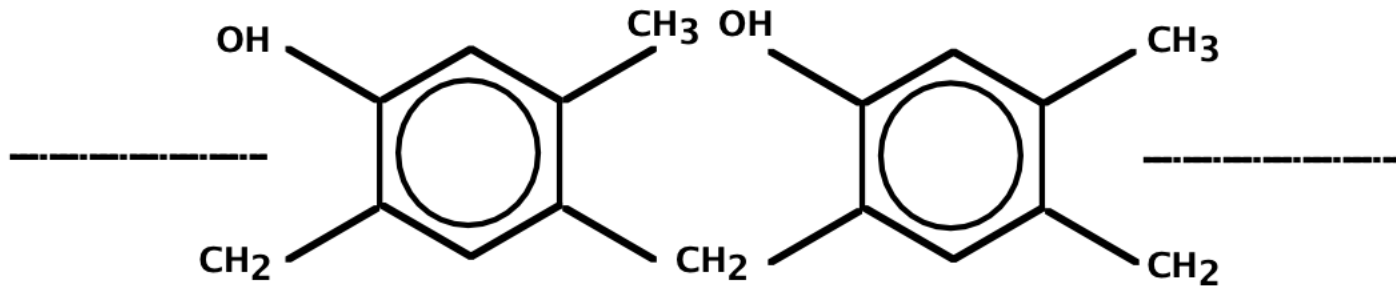


Tones of the resist

- Positive resist: Light exposed region is made soluble in a selected chemical
- Negative resist: Light exposed region is made in-soluble in a selected chemical.

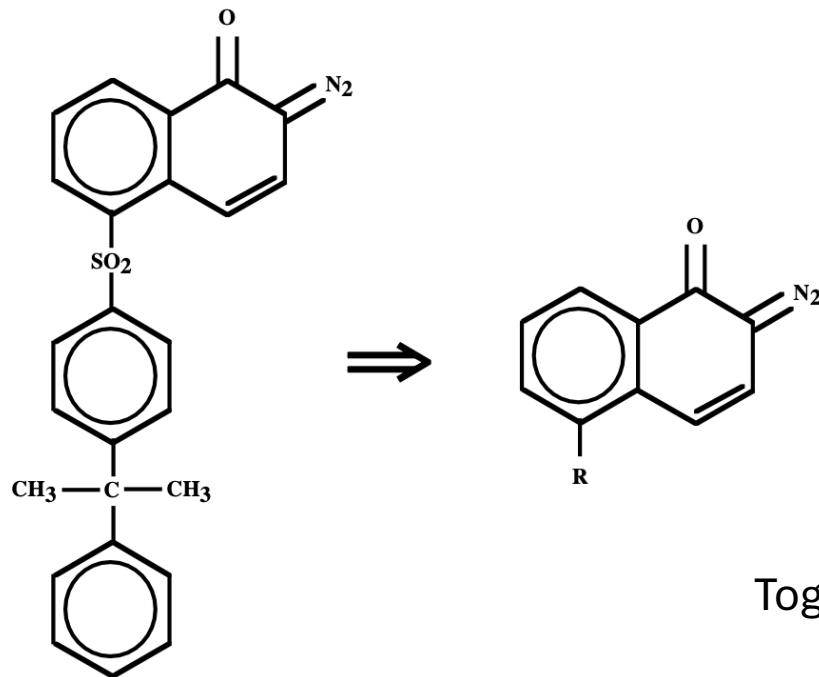


Chemistry of the resist



Novolac:
Base resin

Soluble in alkali solutions.

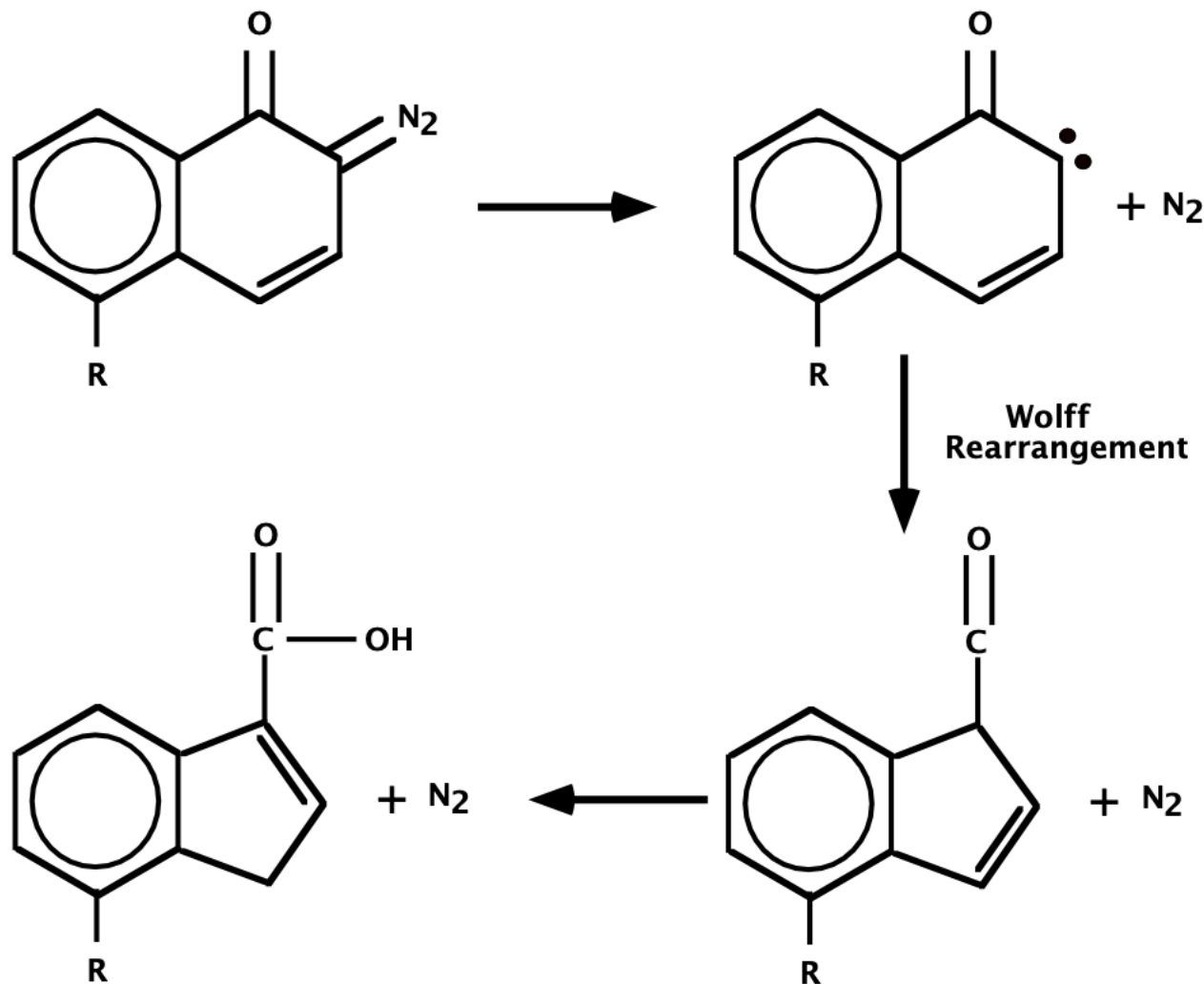


The photo-active material:

DiazoQuinone

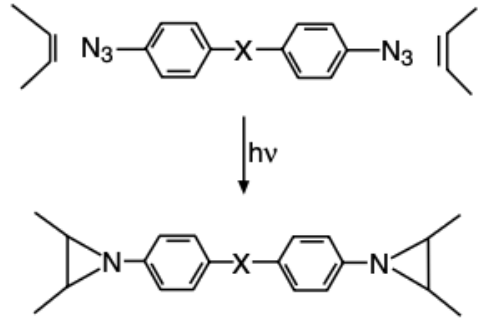
Together called – DQN is made insoluble in alkali solutions.

Impact of UV radiations

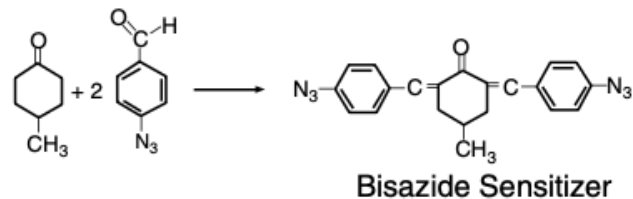
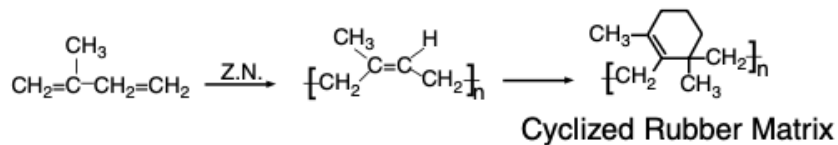
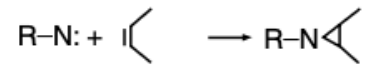
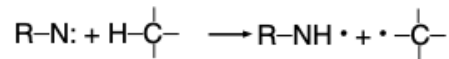
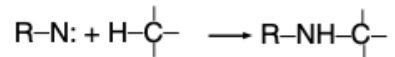
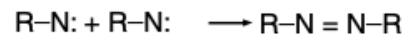


- Light breaks the loosely bound N_2
- The resultant structure undergoes Wolff rearrangement
- Finally to give carboxylic acid.
- This compound dissolves in a basic compound like KOH , NaOH with water.

Bis(aryl)azide-sensitized rubber resists with cyclized poly(cis-isoprene) as matrix resin



The primary photoevent in bisarylazide-rubber resists is the production of nitrene which then undergoes a variety of reactions that result in covalent, polymer-polymer linkages. A typical structure of one commonly employed sensitizer is shown. The reaction involved in the synthesis of the cyclized rubber matrix and the bisazide sensitizer is also shown.



Negative Resists

- Light initiates a series of covalent chemical reactions
- Cross-linking polymers
- Leading to regions becoming insoluble

Pre and post-exposure treatments

- Before exposure to light, resist layers have about 15% solvent.
- Layers are heated above glass transition temperature
 - To remove solvents
 - Layers flow well for uniform coating.
- Post-UV exposure, the resist layers are again heated,
 - To promote resist adhesion
 - Completion of any chemical reactions/processes.

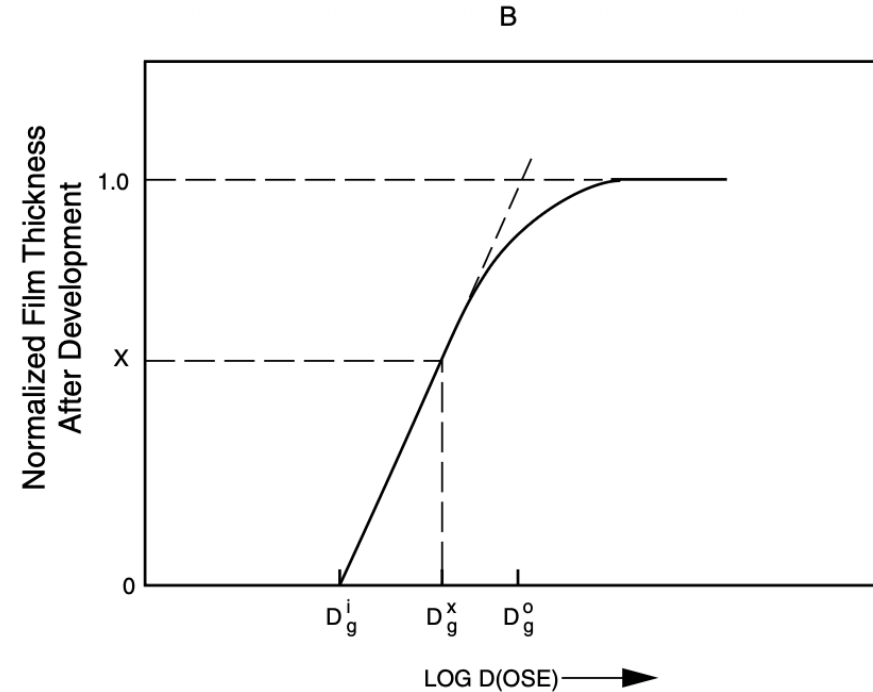
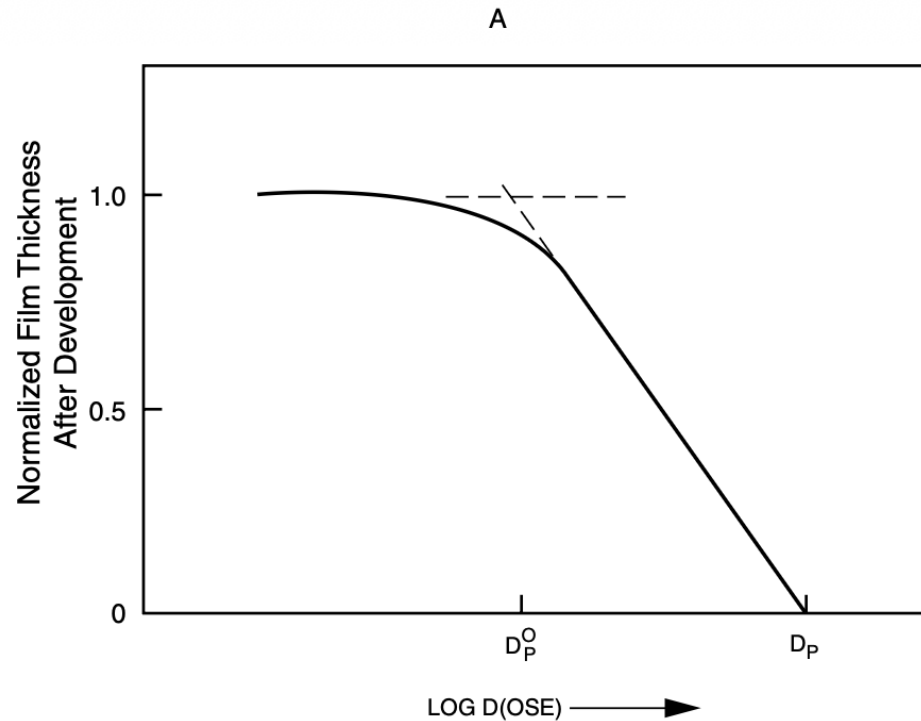
Development

- Wet development
 - Timed exposure to the alkaline medium removes designated regions.
 - Batch processing of wafers are typically carried out
 - Agitation of the developer with controlled temperature is a requirement.
- Spray development
 - Spray development from fan-type sprayers are common
 - Positive resists are aqueous based and negative resists have organic solvents
 - The developer pH, temperature can be accurately controlled.
- Dry development
 - Oxygen plasma is used as a selective remover.
 - The photo-exposed region has differential removal rate with the oxygen plasma.

Critical Dimensions, Overall Resolution and line width

- Line width: Horizontal distance between two resist-air boundaries
- Critical dimension: absolute size of a minimum feature in the device (line width, spacing, lateral dimensions, etc.)
- Tolerance: Is the variation of a specific parameter over several measurements. (Eg: linewidth tolerances should be smaller than $1/5^{\text{th}}$ of the line width value).
- Overall resolution: Describes the ability to consistently print the critical dimension with reasonable manufacturing tolerances. .

Contrasts with resists

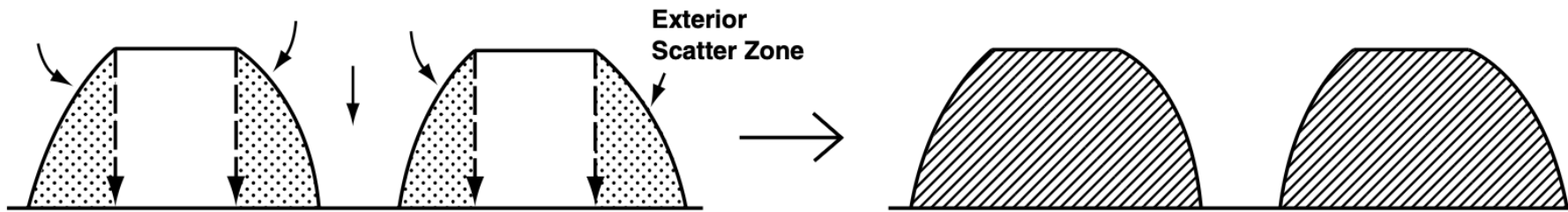


- For positive photoresist: at least D_p is required for proper development
- Contrast is defined as $\gamma_p = \left[\log \frac{D_p}{D_p^0} \right]^{-1}$

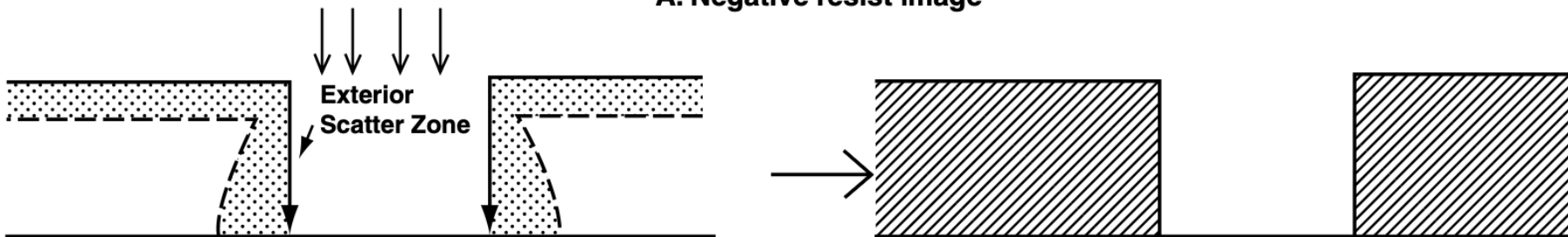
Photo-Resist Profiles

- The light-resist interface is a complicated physics
 - Depending on the substrate and resist dielectric constants
- Some examples of over-exposure

DEVELOPMENT STEP



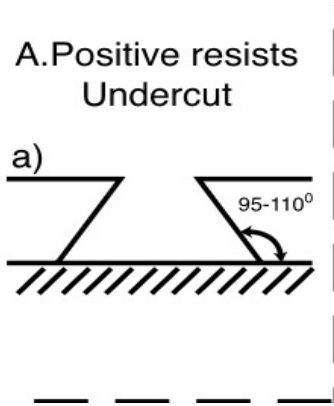
A. Negative resist image



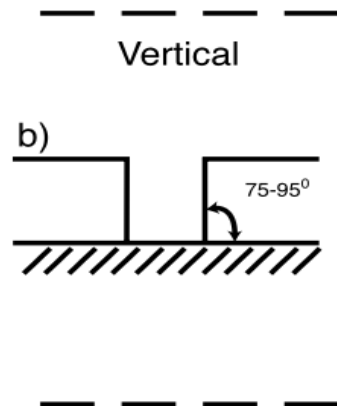
B. Positive resist image

Influence of the UV-light is seen in areas where it was not desired.

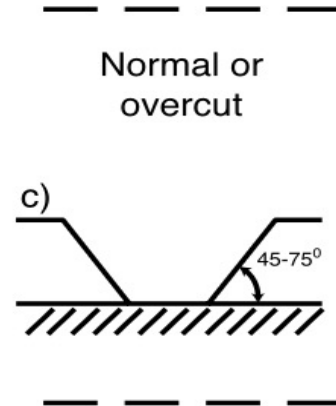
Side-wall of the resist



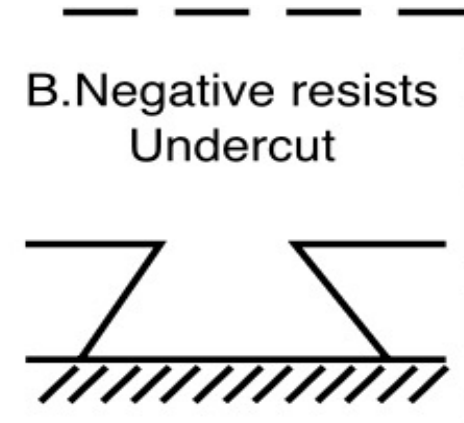
Under cut happens when there is significant reflection from the bottom leading to excess exposure near the substrate-resist interface



Normal optimized exposure

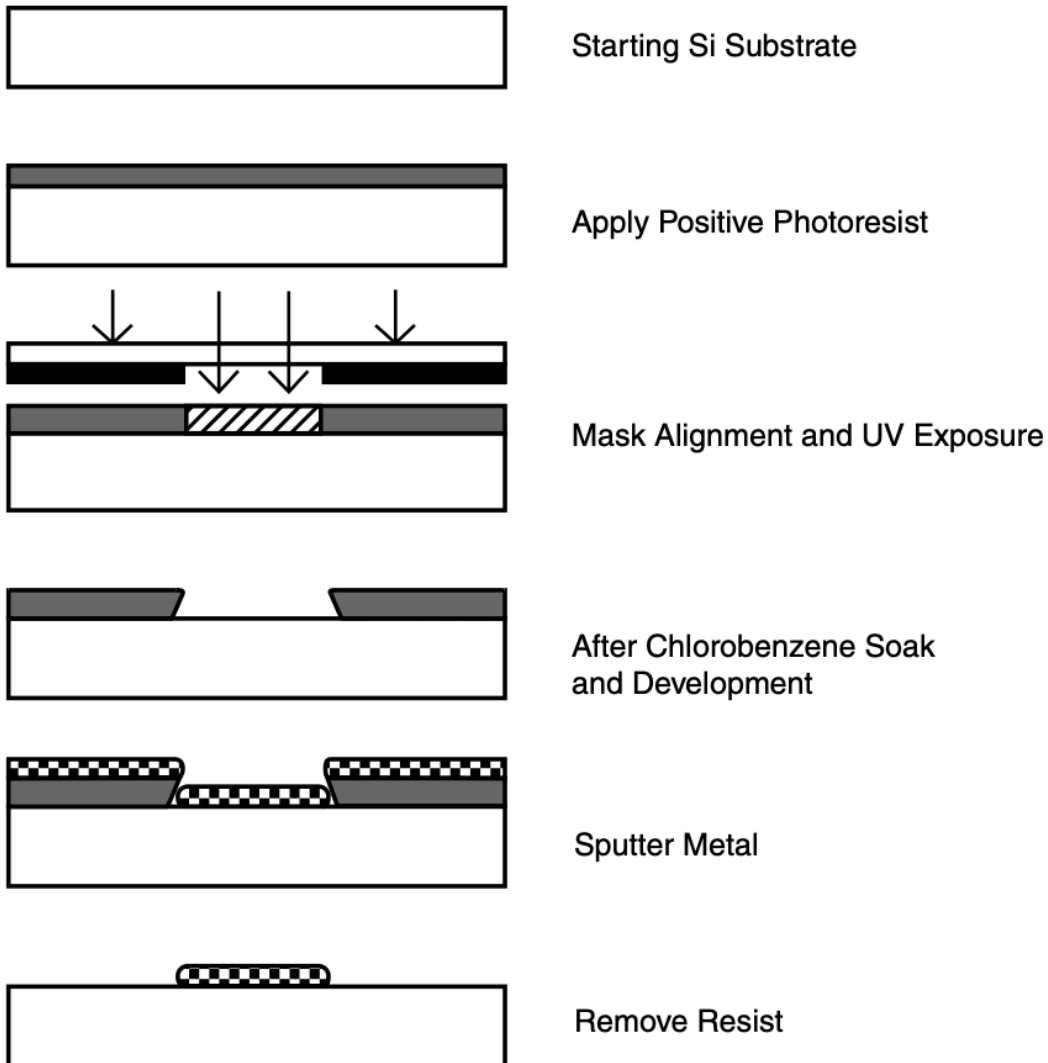


At low doses, when the light absorption leads to reduced intensity as it propagates through the medium



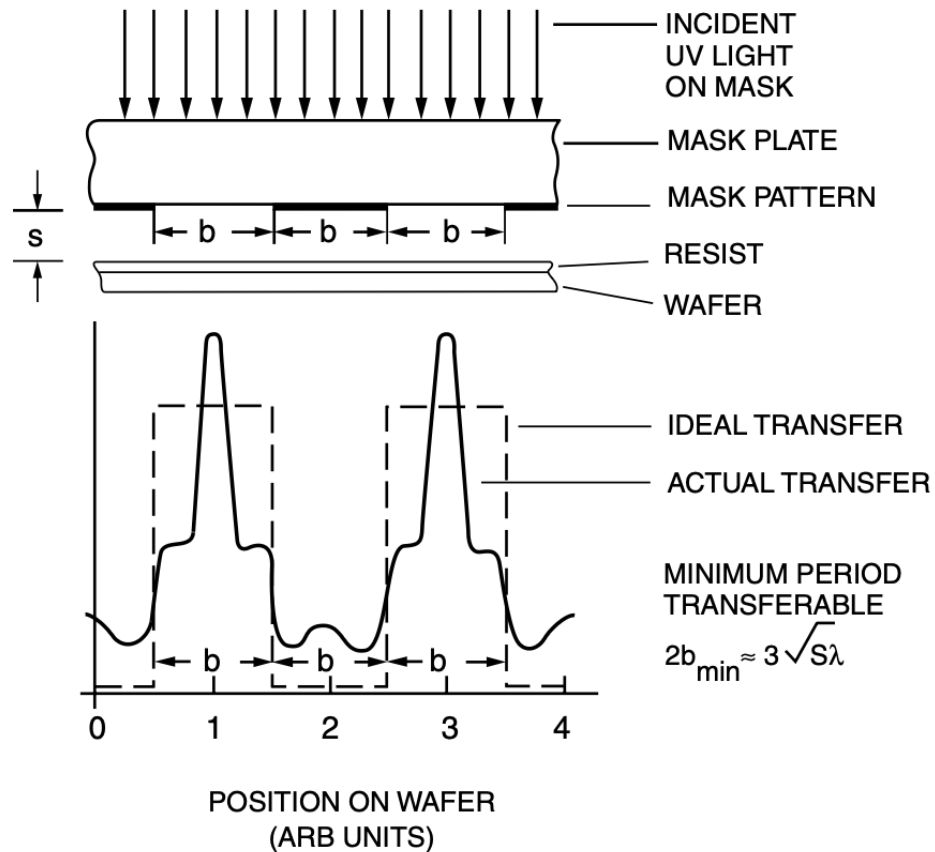
The under-cut is easy for negative resists. Why ?

The holy under-cut for lift-off processes.



- Mainly used for metallization,
- Lift-off is a very common technique
- All kinds of metals are deposited using this method.

Theoretical limits of different photo-lithography methods



Light behaves in complicated pattern when 'b' becomes comparable to λ

Theoretical resolution R is then

$$R = \frac{3}{2} \sqrt{\lambda \left(s + \frac{z}{2} \right)}$$

s – distance between mask plate and resist surface

z – Resist thickness

λ - wavelength of light.

Improving the Resolution

- Optical projection printing.
- Achievable $R = k_1 \frac{\lambda}{NA}$
- k_1 - determined by resist properties and is 0.3 – 1.1
- Have objective lens with better NA for higher resolution.
- If air is replaced by water, NA can reach 1.51

