# LITHOGRAPHY

Somesh Kumar Malhotra
Assistant Professor
ECE Department,UIET

# Photolithography

- Photolithography is the process of transferring geometric shapes on a mask to the surface of Si wafer by using light.
- The selective removal of the oxide in the desired area is performed with Photo-lithography. Thus, the area over which diffusion are effective are defined by the oxide layer with window cut in it through which diffussion can take place. This windows are produced by the photolithographic process.
- For IC manufacturing following type of lithographic can be used
  - Photo lithography
  - X-Ray lithography
  - Electron Beam Lithography
  - Ion beam Lithography

# Photo resist

- Photoresist  is radiation sensitive compound. The principle constituent of photoresist solution are a polymer, a sensitizer and a suitable solvent solution.
- Polymer (Resin) which bond everything together and provide the film's mechanical properties.
- Senstizer (which reacts to UV light)- intiate chemical change.
- Solvent(e.g. ethylene glycol, ether, xylene etc)- keep the polymer in solution. As the combine resin and senstizer can be very viscous material that is different to spread, a solvent is added as a thinner, this will reduce the viscosity allowing for easier application.

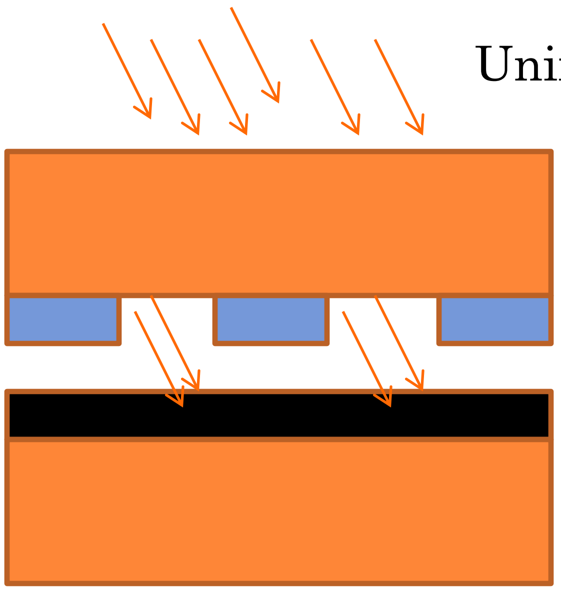
## Photo resist

- The photo resist is exposed with UV light whereever the underlying material is to be removed .In these resist , exposure to UV light changes the chemical structure of the resist so that it becomes more soluble in the developer.
- Exposed resist is then washed away by the developer solution, leaving window of the bare underlying.
- Photoresist are sensitive to wide range of wavelength of light, typically 200-500 nm

# PHOTO RESIST

- Characteristics of a good photoresist
  - Uniform film deposition
  - Good adhesion to the film substrate
  - Good resolution
  - Resistance to wet and dry etching.
- Types of Photo resist
  - **Positive Photoresist** 'softenend' by exposure to the UV light and the exposed area are subsequently removed in the development process, the resist image will be identical to opaque image on the mask.
  - **Negative Photoresist** is 'hardnened' by the exposure to the UV light and therefore it is the unexposed area that are removed by the development process, the resist image will be –ve image of the mask.

# Photo resist



Uniform UV exposure illumination

Chrome on glass photomask

photoresisit

Substrate wafer

- Negative resist

Positive resist

# Photo resist

| Lithography | Name | Type | Sensitivity |
|---|---|---|---|
| Optical | Kodak 747 | Negative | 9 $mJ/cm^2$ |
| | AZ-1350J | Positive | 90 $mJ/cm^2$ |
| | PR102 | Positive | 140 $mJ/cm^2$ |
| e-beam | COP | Negative | 0.3 $\mu C/cm^2$ |
| | GeSe | Negative | 80 $\mu C/cm^2$ |
| | PBS | Positive | 1 $\mu C/cm^2$ |
| | PMMA | Positive | 50 $\mu C/cm^2$ |
| X-ray | COP | Negative | 175 $mJ/cm^2$ |
| | DCOPA | Negative | 10 $mJ/cm^2$ |
| | PBS | Positive | 95 $mJ/cm^2$ |
| | PMMA | Positive | 1000 $mJ/cm^2$ |

# Photo-lithograph Process

The various step involves in a photolithographic process are as follows:

**1.Cleaning**

Before the resist is applied to the substrate, the surface is cleaned to remove an traces of contamination from the surface of the wafer, such as dust, organic or metallic compound.

**2.Bakeout**

The silicon wafer are heated at the temperature of 100 degree C to drive off moisture from the wafer so as to obtain better adhesion of the photoresist.

# Photo-lithograph Process

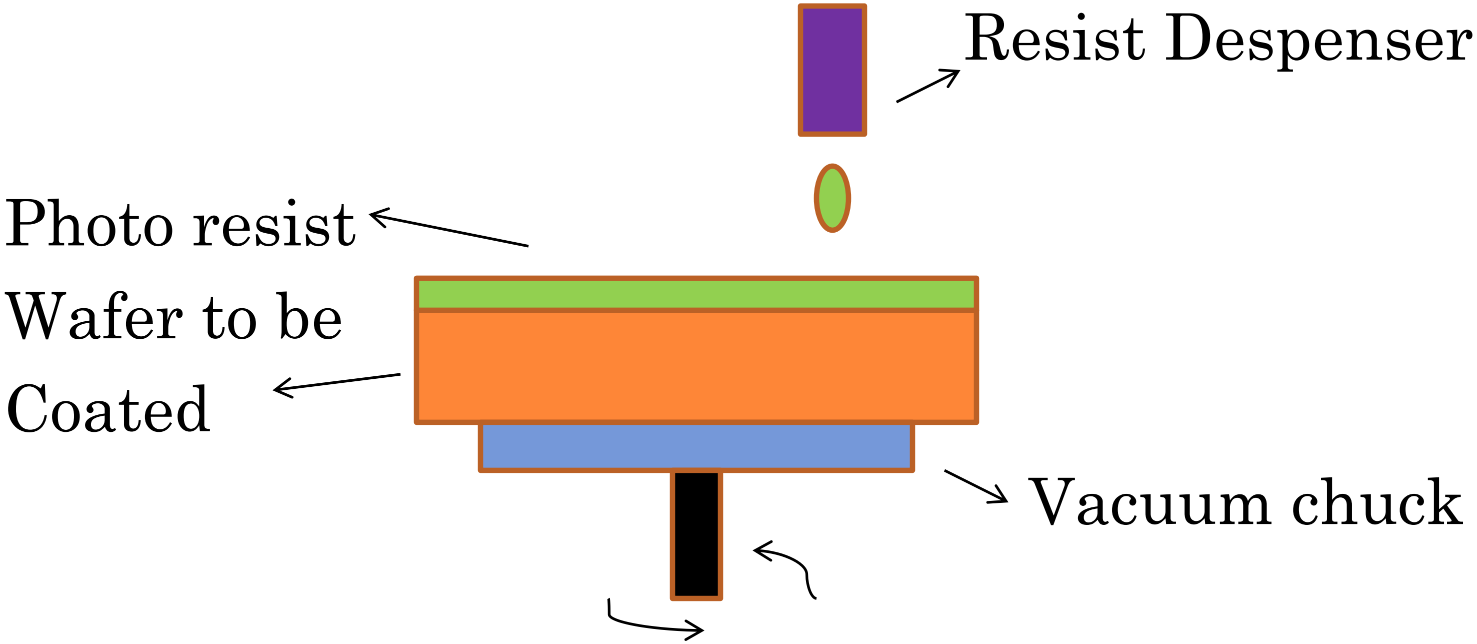
## 3.Spin coating

- A drop of light sensitive liquid called photoresist is applied to the center of the oxidized wafer that is held out by vacuum chuck. The wafer is rotated with a velocity of 3000-7000 rpm for 30-60 seconds.
- This action spread the solution in a thin nearly uniform coat and spin off the excess liquid.
- The thickness of the photo resist layer will be inversely proportional to the square-root of the rotational velocity

## 4. Soft baking and Pre baking

- The Si wafer coated with photoresist are now put into ovenat about 80 degree C for about 30-60 minutes to drive off solvent and to harden it.

# Photo-lithograph Process



# PHOTO-LITHOGRAPH PROCESS

**5.Mask Alignment and Exposure**

- The coated wafer is placed in an apparatus called a mask aligner in very close proximity to a photo-mask to transfer the pattern on the wafer surface.
- A photomask is a square glass plate with a pattern emulsion of metal film on one side.
- After aligning the mask on the wafer, the photoreist is exposed through the pattern on the mask with a high intensity of UV light.

**6.Development**

- A highly collimated UV light is then turned on and the areas of the Si wafer that are not covered by the opaque area of the photomask are exposed to the UV radiation.Time is generally between 3-10 seconds.

# Photo-lithograph Process

- Suppose negative resist is to be used, the area of the photoreist are exposed to UV light become polymerized or insoluble. This make the resist tougher and make in insoluble in developer solution.

**7.Post bake**

After development and rinsing, the wafer are usually given a post bake in an oven at a temperature of about 150 degree C for about 30 to 60 sec to toughen further the remaining resist on the wafer and also to make more resist to hydrofluoric acid (HF) solution used for etching of $SiO_2$.

**8.Oxide etching**

For etching of oxide , the wafer are immersed in or spread with HF solution which etch $SiO_2$ but will not attack the photoresist material.

# Optical lithography

- Optical lithography comprises the formation of images with visible or UV radiation in a photoresist using contact, proximity or projection printing.
- For IC production the line width limits of optical lithography lies near 0.4 micrometer, although 0.2 micrometer features may eventually be printed under carefully controlled conditions.

# Contact and proximity printing

- In **contact printing** a photomask is pressed against the resist covered wafer with pressure typically in the range of 0.05 atm to 0.3 atm and exposure by light of wavelength near 400 nm.
- The contact produces defects in both the mask and the wafer so that the mask , whether thick or thin may have to be discarded after short period of use.
- Defects includes
  - Pin hole in the chromium film
  - Scratches
  - Intrusions and star features.

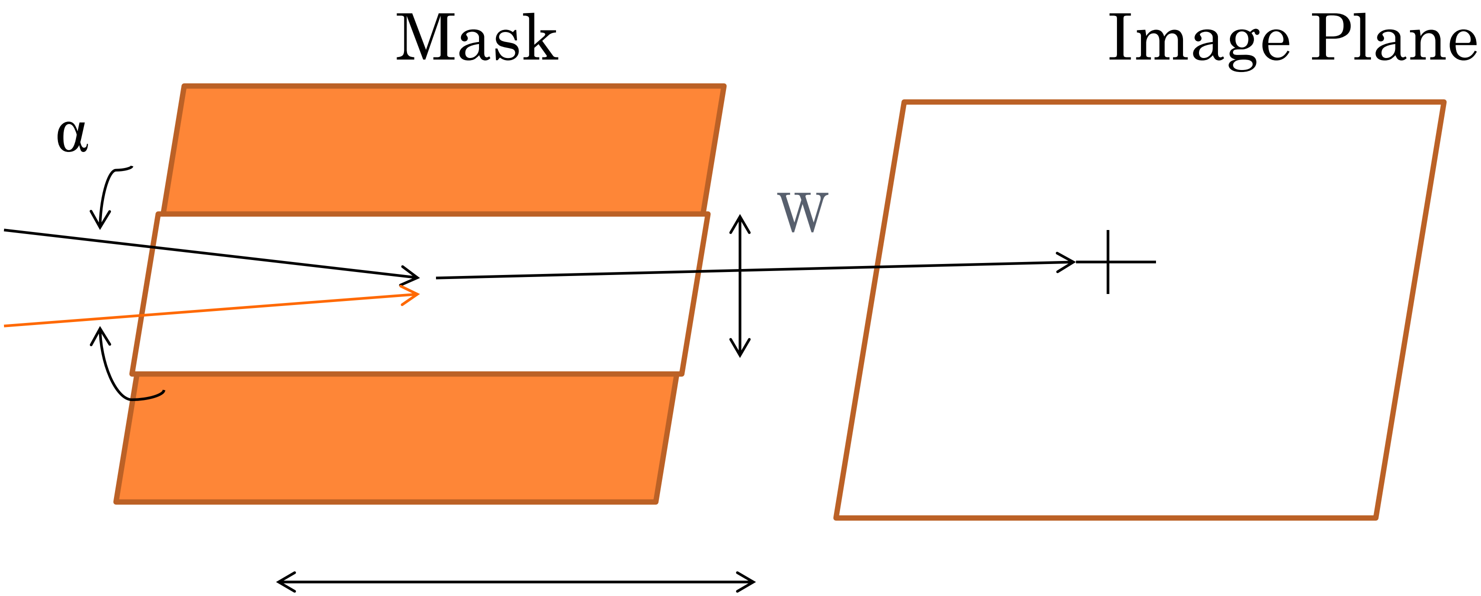
# CONTACT AND PROXIMITY PRINTING

- **Contact printing** nevertheless continue to be widely used. Feature are as small as 0.25 micrometer have been produced in 1.8 micrometer thick PMMA (Polymethyle methacrylate) resist using 200 to 600 nm resolution. Quartz and alumina mask substrate must be used to pass these shorter wavelength, since the usual borosilicate glass strongly absorbs wavelength less than 300 nm.

# Contact and proximity printing

- **Proximity printing** has the advantage of longer mask life because there is no contact between mask and wafer are in the range of 20 and 50 micrometer.
- Resolution is not good as in contact or projection printing.
- Fig shows **proximity printing** in the schematic form of mask with a long slit width W seperated from wafer by a gap g.
- g and W are larger than the wavelength of the imaging light.

# Contact and proximity printing




- g

# Contact and proximity printing

- The diffraction that forms the image of the slit is a function only of the particular combination of $\lambda$,W and g which we shall call parameter Q where

$$Q = W\sqrt{(2\lambda g)}$$

- The larger the value of Q, the more faithful the image.
- Thus the resolution become better at smaller gap and shorter wavlength.

# Contact and proximity printing

- The gap however result in optical diffraction of features edges on the photomask which degrades the resolution.In proximity printing the UV light beam has to be carefully alligned in a telecenteric manner (beam to be incidented normally on the mask)

# Projection printing

- Projection printing provides higher resolution than proximity printing together with large seperation between mask and wafer .
- Four important performance parameters of a printer are
  - Resolution
  - Level to level alignment accuracy
  - Throughput
  - Depth of Focus.

# Projection printing

In order to circumvent problems associated with shadow printing, projection printing exposure tools have been developed to project an image of the mask patterns onto a resist-coated wafer many centimeters away from the mask. The small image area is scanned or stepped over the wafer to cover the entire surface. ***Figure 5.5*** depicts the various ways to project and scan the image. The resolution of a projection system is given by:

$$l_m = \lambda / NA \qquad \textit{(Equation 5.2)}$$

where $\lambda$ is the wavelength of the exposure radiation and $NA$ is the numerical aperture given by:

$$NA = \bar{n} \sin\theta \qquad \textit{(Equation 5.3)}$$

# Projection printing

where $\bar{n}$ denotes the refraction index of the imaging medium ($\bar{n}$ = 1 in air) and $\theta$ is the half angle of the cone of light converging to a point image at the wafer as shown in ***Figure 5.6***. The depth of focus, $\Delta z$, can be expressed as:

$$\Delta z = \pm l_m/2\tan\theta \cong \pm l_m/2\sin\theta = \pm \bar{n}\lambda/[2(NA)^2] \quad \textit{(Equation 5.4)}$$

Resolution can be enhanced by reducing $\lambda$ and this explains the trend towards shorter wavelength in optical lithography. Typically, scanning projection systems are capable of about 1 μm resolution, while step-and-repeat projection systems can accomplish deep sub-micrometer spatial resolution demanded by modern integrated circuits, especially when coupled with deep UV radiation sources.

# Projection printing

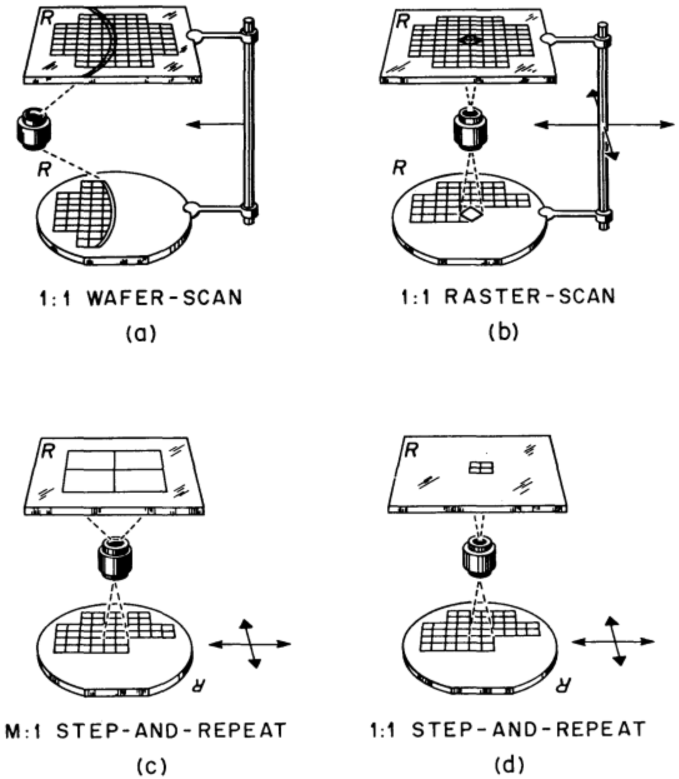



***Figure 5.5***: Image transfer techniques for projection printing. (**a**) Annular-field wafer scan. (**b**) Small-field raster scan. (**c**) Reduction step-and-repeat. (**d**) 1:1 step and repeat.

# PROJECTION PRINTING

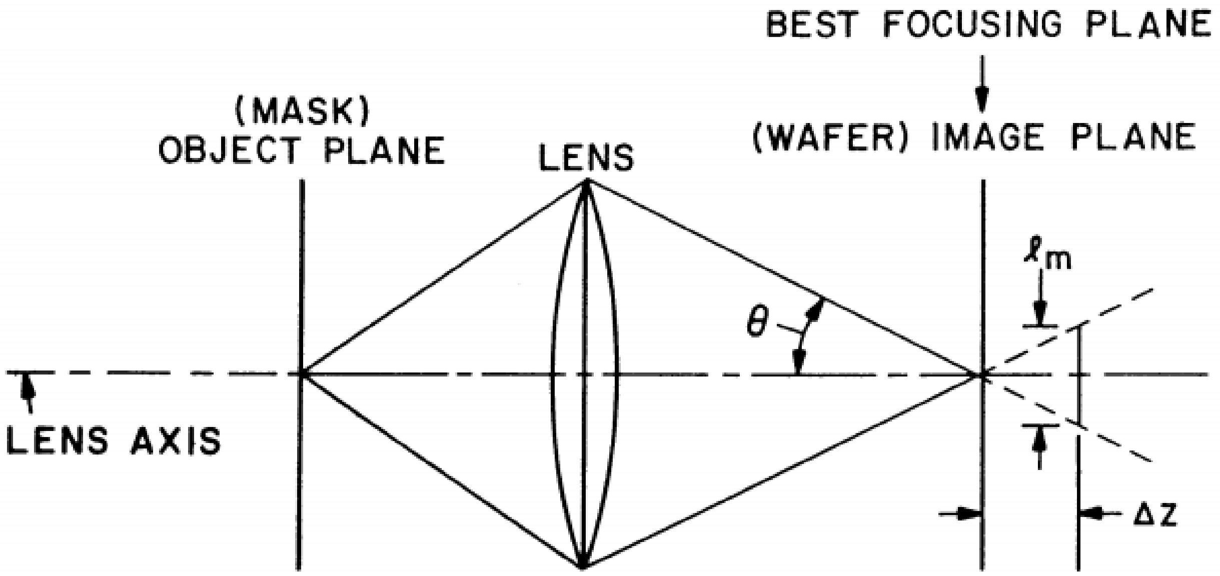
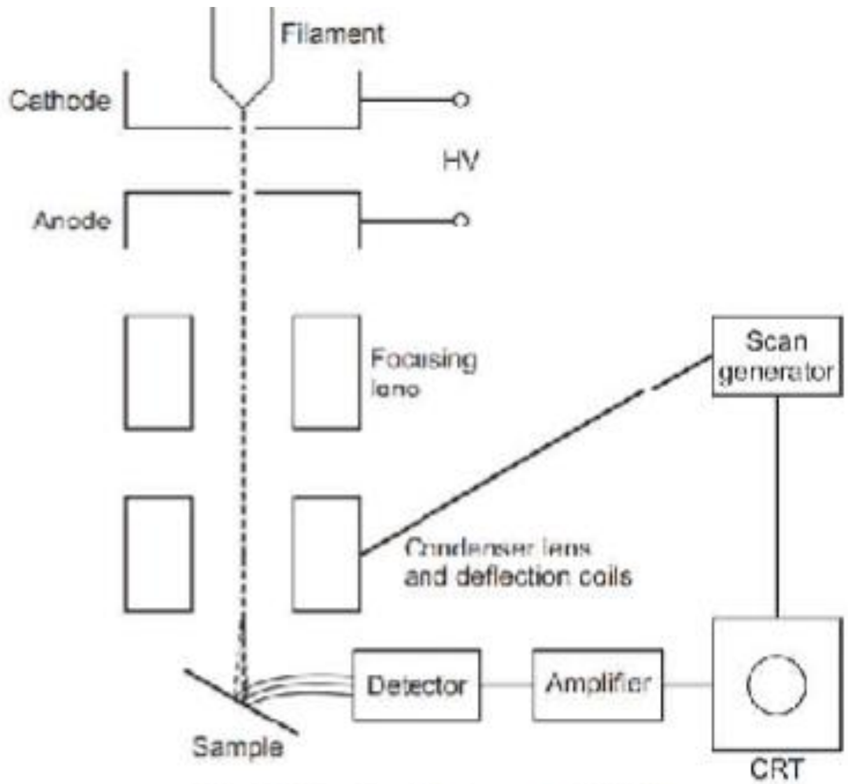



***Figure 5.6***: Simple image system.

## ELECTRON LITHOGRAPHY

- The direct write methode of electron beam lithography is capable of transferring a high resolution pattern directly to the reticle surface.
- In e-beam lithography, an electron source produces many electrons that are accelerated and focussed in the shape of a beam toward the reticle.
- The electron beam are focussed either magnetically or electrostatically and is scanned across entire recticle or scanned only over the printed area to eventually transfer the pattern to the reticle. Which is generally done by SEM (Scanning Electron Microscope)

# Electron lithography



# ELECTRON LITHOGRAPHY

- Electron lithography offers high resolution because of the small wavelength of electrons (< 0.1 nm for 10-50 keV electrons).
- The resolution of an electron lithographic system is not limited by diffraction, but rather by electron scattering in the resist and by the various aberrations of the electron optics.
- The advantages of electron lithography are:
  - Generation of micron and submicron resist geometries
  - Highly automated and precisely controlled operation
  - Greater depth of focus
  - Direct patterning without a mask

# ELECTRON LITHOGRAPHY

- When electrons are incident on a resist or other material , they enter the material and loose energy by scattering, thus producing secondary electron and X-rays.
- This fundamental process limits resolution of electron resist to an extent that depends on
  - Resist thickness
  - Beam energy and
  - Substrate composition

# Electron lithography

- The biggest disadvantage of electron lithography is its low throughput (approximately 5 wafers / hour at less than 0.1 µm resolution).
- There are two basic ways to scan an electron beam.
  - **Raster scanning** the patterns are written by an electron beam that moves through a regular pattern. The beam scans sequentially over the entire area and is blanked off where no exposure is required.
  - **Vector scanning**-the electron beam is directed only to the requested pattern features and hops from features to features.

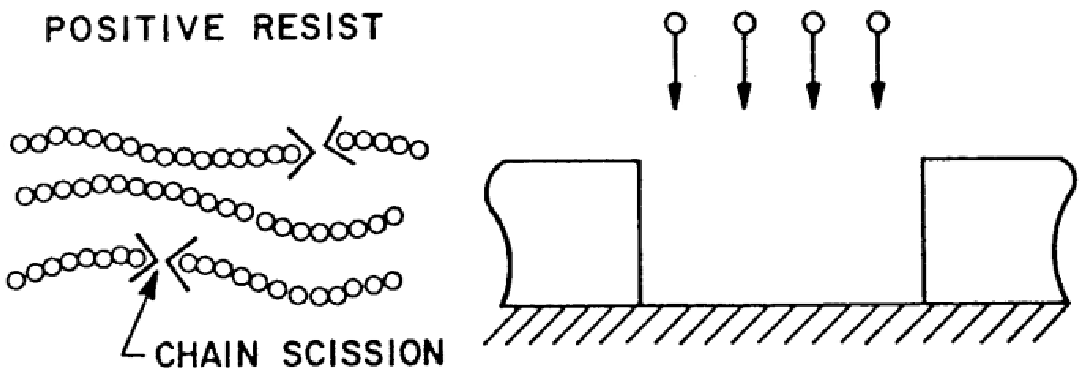
# Electron lithography

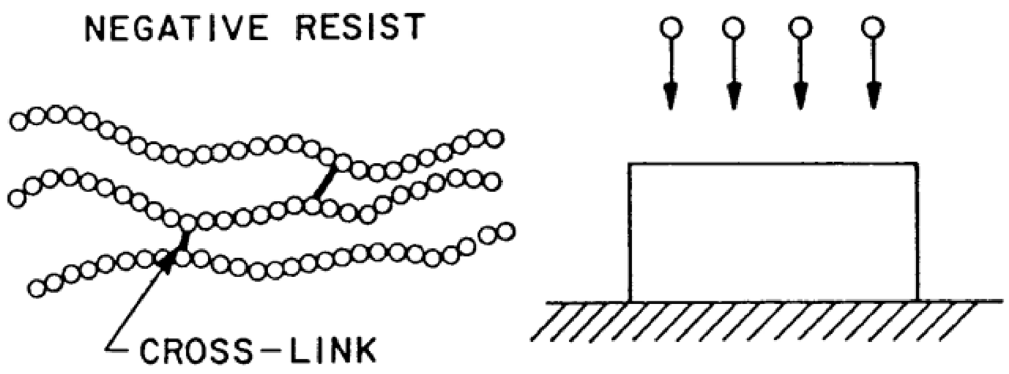
- Electron resists are polymers.
- For a positive electron resist, the polymer-electron interaction causes chain scission, that is, broken chemical bonds . The irradiated areas can be dissolved in a developer solution that attacks low-molecular-weight material.E.g.
  - PMMA, poly(methyl methacrylate), and
  - PBS poly(butene-1 sulfone),

  typically have resolution of 0.1 μm

- When electrons impact a negative electron resist, polymer linking is induced.e.g.
  - COP Poly(glycidyl methacrylate-co-ethyl-acrylate), resolution is limited to about 1μm

# ELECTRON LITHOGRAPHY

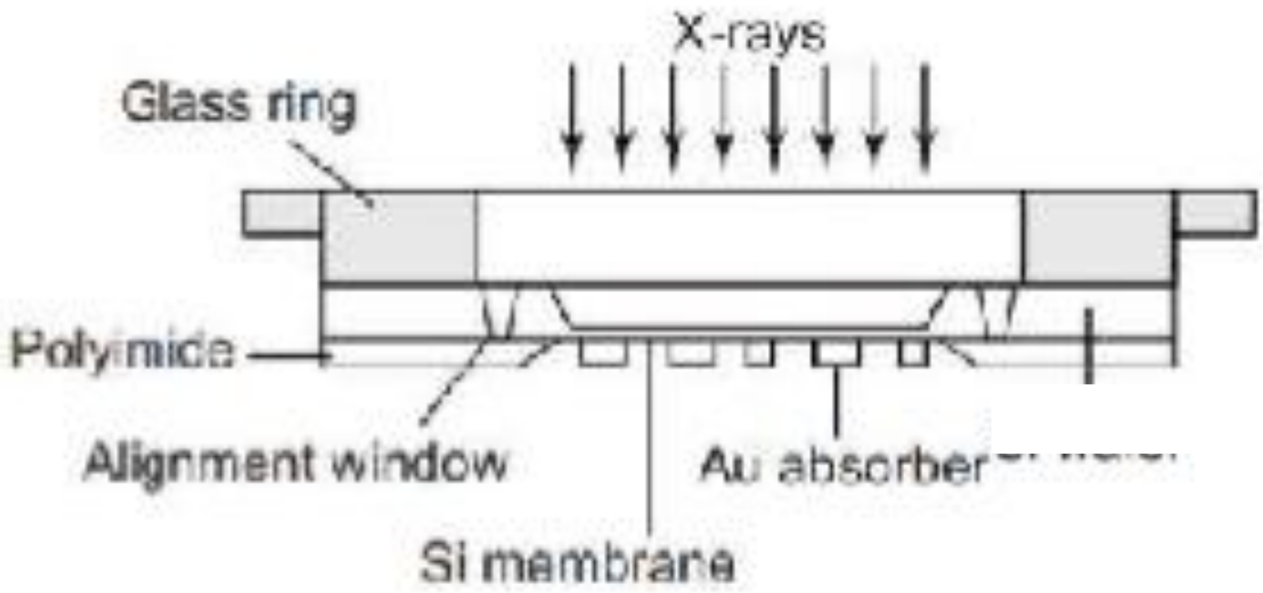


# X-Ray Lithography

- X-ray lithography is an established technology for imaging patterns of 100 nm on wafer. An X-ray source projects X-rays onto a special Mask that forms a pattern on a resist coated wafer.
- The system component of x-ray lithography are:
  - An X-ray Photo Mask
  - An X-ray source
  - An X-ray resist
- **X-ray Mask**:heavier metal layer compare to chromium are used ,e.g. gold,tungsten and tantalium for making patterns on photo mask. The thickness of metal layer are comparatively larger.

# X-Ray Lithography



# X-Ray Lithography

**X-ray source**

- The X-ray used in lithography are soft X-rays.

X-ray ⟶ 0.1nm to 10nm
(Soft X-ray) (Hard X-ray)

- Common X-ray source used in lithography is known as **synchrotron.** High energy electrons are forced into closed curved path by magnetic fields and made to accelerate which cause them to emit radiation. This action produces X-ray radiation that is very intense and reasonable collimated (parallel)

# X-Ray Lithography

- X-ray lithography employs a shadow printing method similar to optical proximity printing.
- The x-ray wavelength (0.4 to 5 nm) is much shorter than that of UV light (200 to 400 nm).
- Hence, diffraction effects are reduced and higher resolution can be attained.
- X-ray lithography has a higher throughput when compared to e-beam lithography because parallel exposure can be adopted.

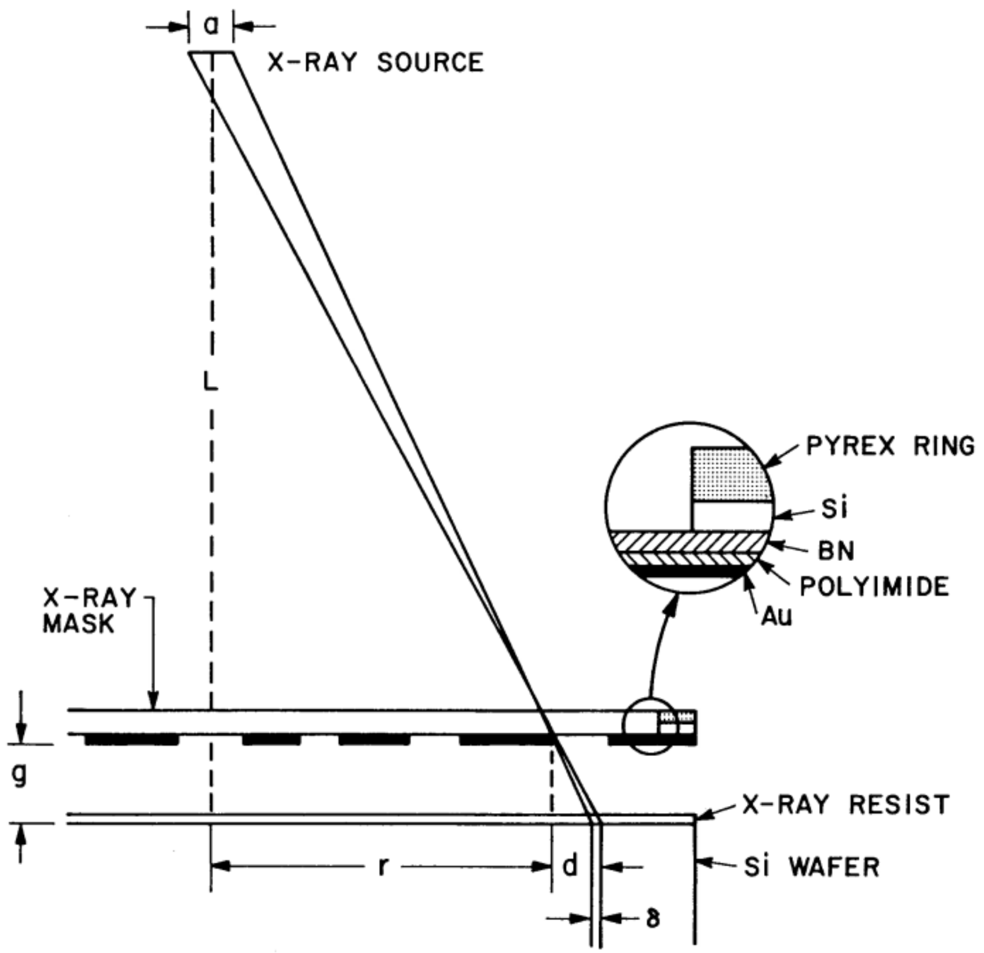
# X-Ray Lithography

- However, on account of the finite size of the x-ray source and the finite mask-to wafer gap, a penumbral effect results which degrades the resolution at the edge of a feature.
- As shown in ***Figure***, the penumbral blur, $\delta$, on the edge of the resist image is given by:

$$\delta = ag / L$$

- where $a$ is the diameter of the x-ray source, $g$ is the gap spacing, and $L$ is the distance from the source to the x-ray mask.

# X-Ray Lithography



# X-Ray Lithography

- An additional geometric effect is the lateral magnification error due to the finite mask-to-wafer gap and the non-vertical incidence of the x-ray beam. The projected images of the mask are shifted laterally by an amount *d*, called runout:

$$d = rg / L$$

where *r* denotes the radial distance from the center of the wafer.

# X-Ray Lithography

- Electron beam resists can be used in x-ray lithography because when an x-ray photon impinges on the specimen, electron emission results.
- One of the most attractive x-ray resist is DCOPA (dichloropropyl acrylate and glycidyl methacrylate-co-ethyl acrylate), as it has a relatively low threshold (~ 10 mJ/cm2).

# Ion Lithography

- Ion lithography uses multi electrode electrostatic optics to direct the hydrogen or helium ion to the wafer.
- Ion transfer their energy to the resist more efficiently than electron beam because ion has larger mass.
- There also fewer secondary electrons produced by the ion bombardment and these produced have very low energy,which make for less back scatter.
- Back scatter creats proximity effects that determines the limit to the minimum feature size for wafer patterning.

# Ion Lithography



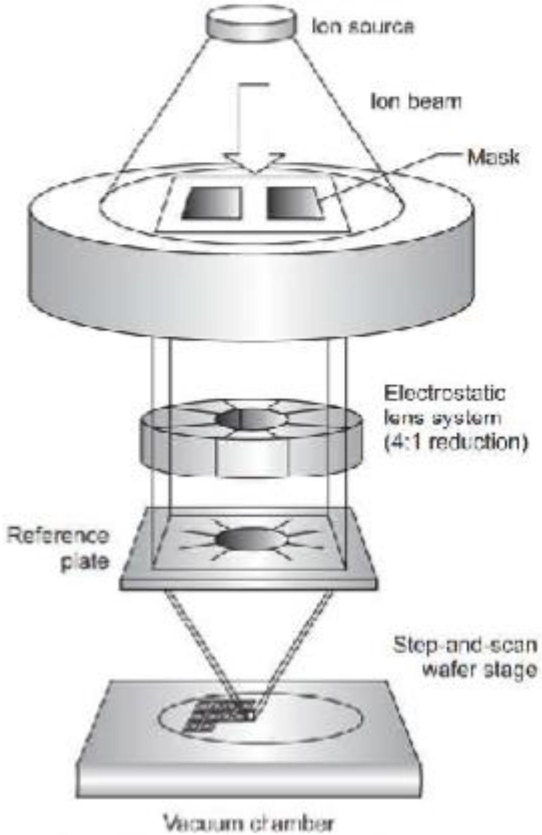



**Fig. 8.19** *Ion Projection Lithography*

# Ion Lithography

- Ion lithography can achieve higher resolution than optical, x-ray, or electron beam lithographic techniques because ions undergo no diffraction and scatter much less than electrons.
- In addition, resists are more sensitive to ions than to electrons.