Semiconductor Devises Physics & Fabrications

Photolithography

Lecture 16

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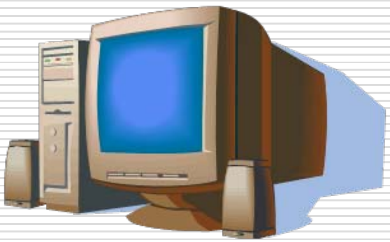
Photolithography

- Lithographic overview
- Resolution
- Depth of Focus
- Overlay Errors
- Photoresist Response
- E-beam and X-ray lithography

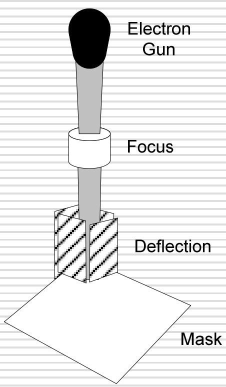
Photolithography

- Photolithography can be divided into three steps:

1. Design using CAD system
   - Layout
   - Simulation
   - Design Rule Verification

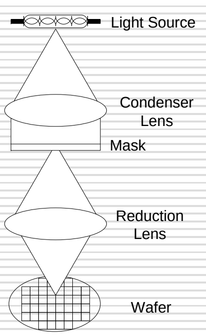


2. Mask making



Mask Making

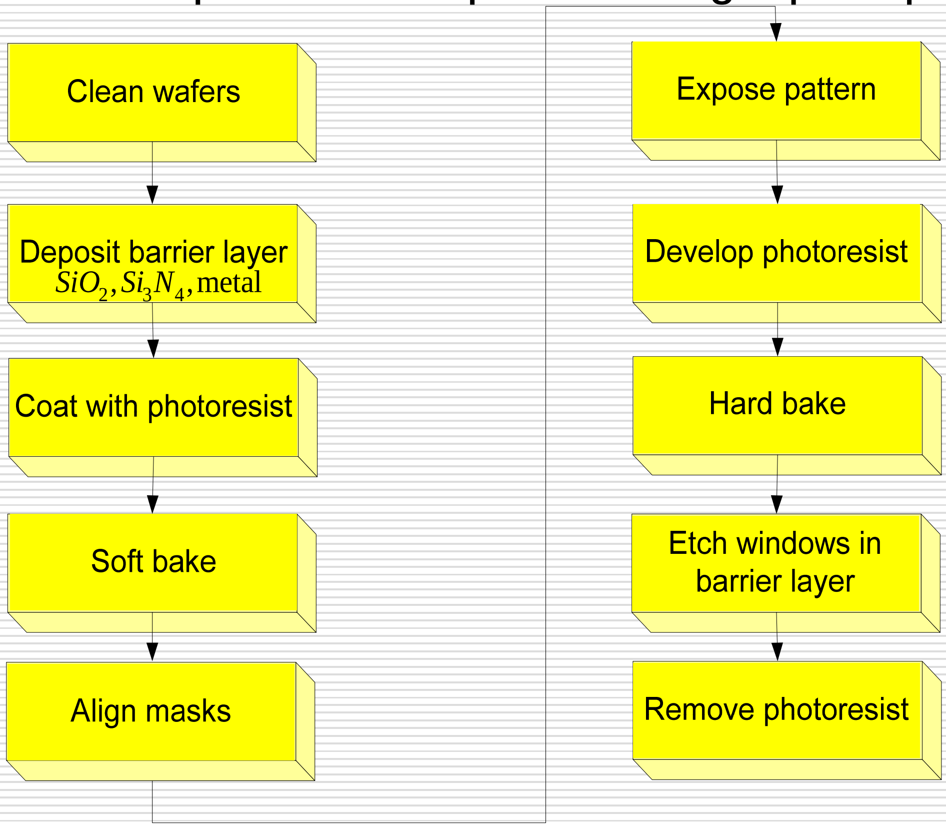
3. Wafer exposure
   - The patterns transfer form mask to photo resist
   - Chemical or plasma etching to transfer the pattern from the photo resist to burrier material on the surface of wafer.



Wafer Exposure

Steps of wafer exposure process

- The various steps of basic photolithographic process.

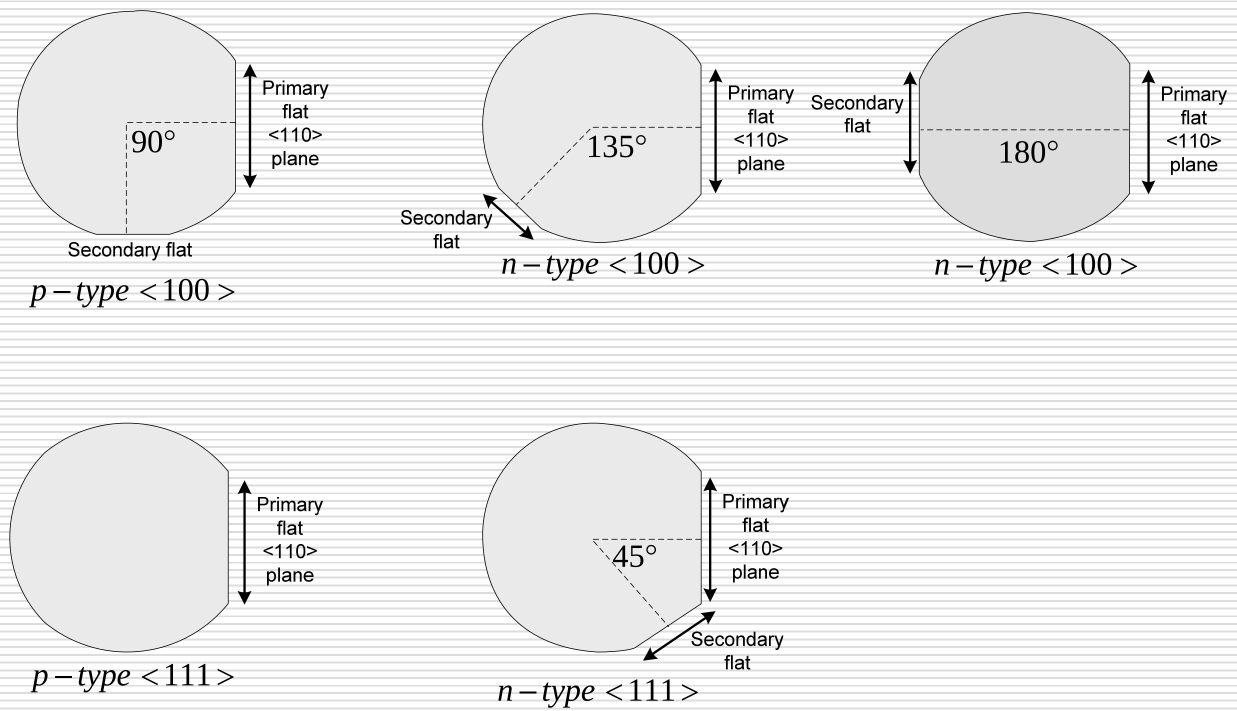


Silicon wafer

- n or p-type silicon wafer are available with a specified resistively
- Typically the growing crystal is doped with boron, phosphorous or arsenic. Arsenic and antimony is used for low resistively (high concentration) n-type crystal.
- The thickness $250\mu m \le t \le 500\mu m$
- The diameter $200mm\left(8 \text{ inch}\right) \le d \le 300mm\left(12 \text{ inch}\right)$ (wafers with diameter of 1,1.5,2,3,4,5 and 6 inches have been used at various stages in history of solid state devices).
- The diameter of wafer is chosen in order to withstand the mechanical and thermal strain during the process steps. (for example a 6 to 8 inch diameter semiconductor wafer needs to be about $500\mu m$ thick.

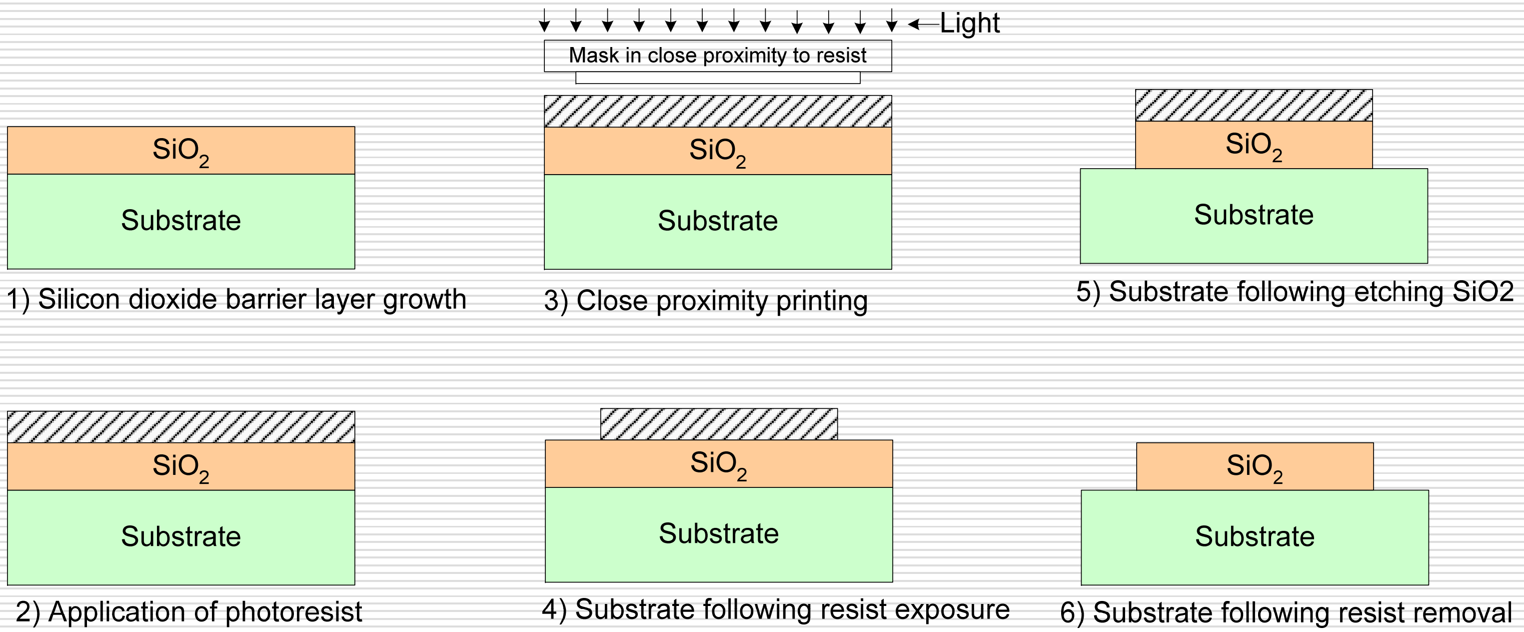
Silicon wafer orientation

- Silicon wafer orientation



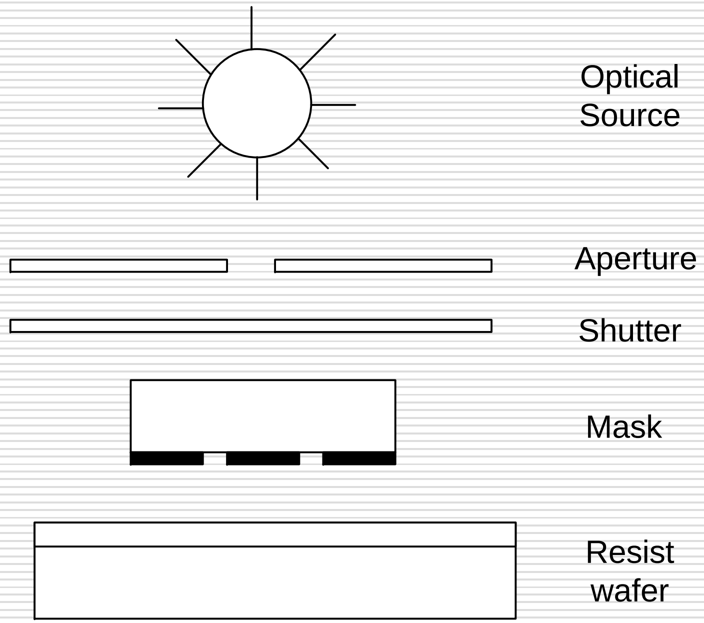
A wafer through the various steps of the photolithography process

- Various steps of the photolithography process



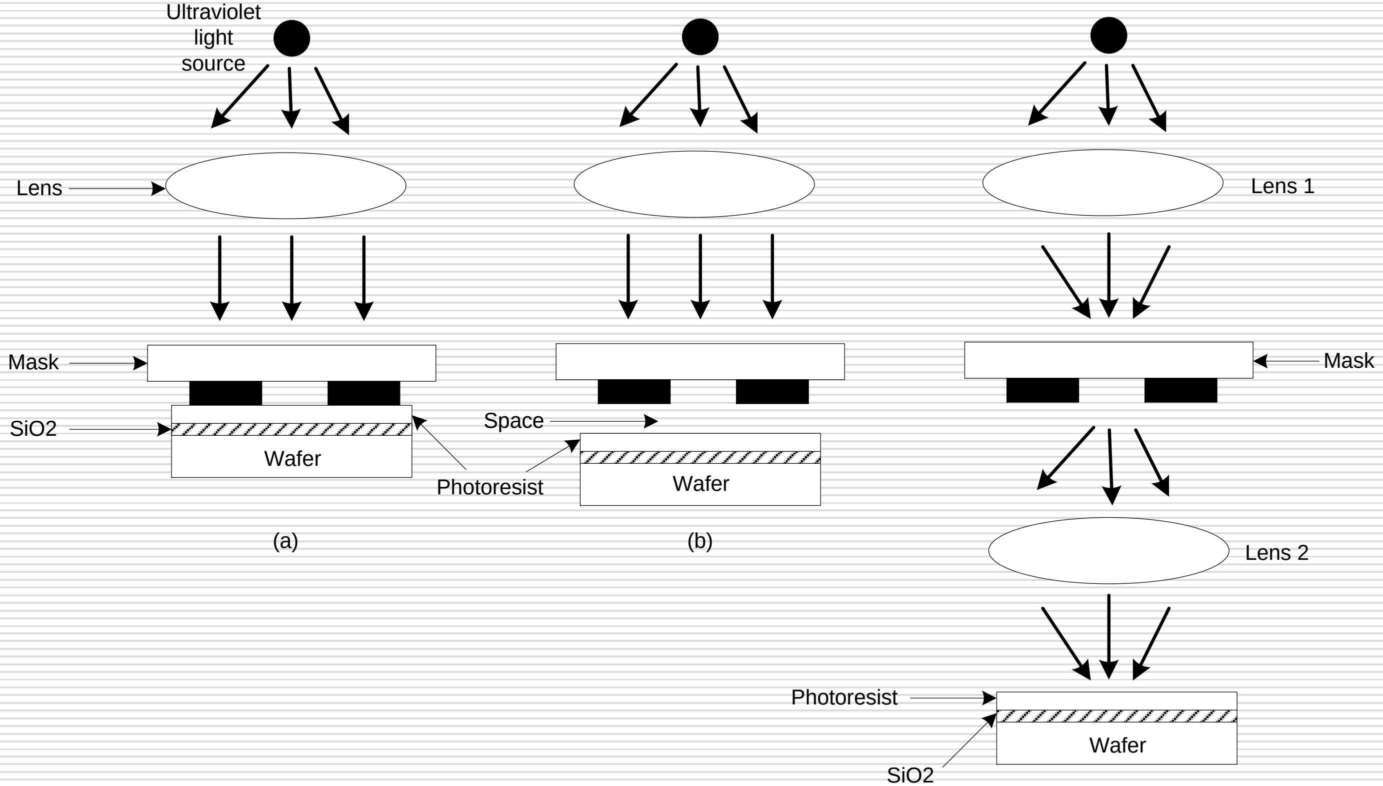
Lithographic exposure system

- Schematic of a simple lithographic exposure system



Lithographic exposure system

- (a) Contact printing, in which wafer is in intimate contact with mask, (b) proximity printing, in which wafer and mask are in close proximity (c) projection printing, in which light source is scanned across the mask and focused on the wafer.



(a) (b) (C)

Re-emission of scalar waves by points on a surface spanning the mask

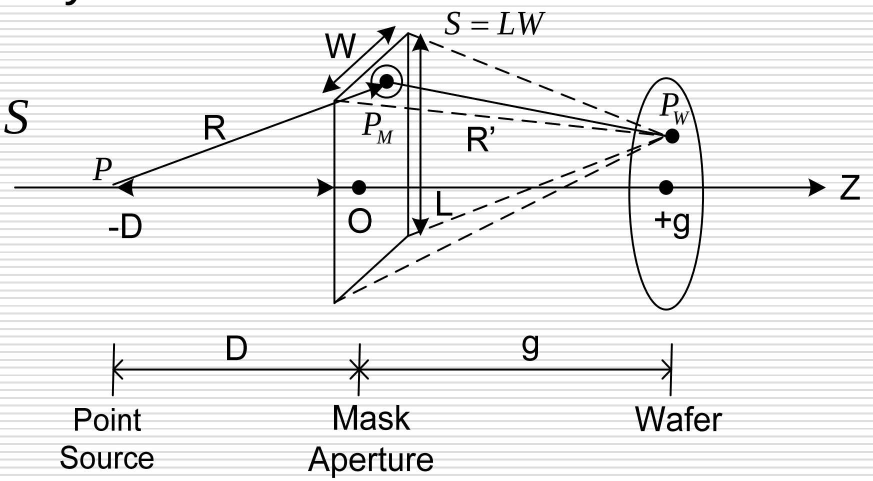
- The light propagates as an electromagnetic wave, where it can be represented by its electric field

$$E(\bar{r}, f) = E_0(\bar{r}) e^{j\phi(\bar{r}, f)}$$

- Where E_0 is the electric field amplitude, $\bar{r}$ is the position, ϕ is the phase and f is the frequency of the wave

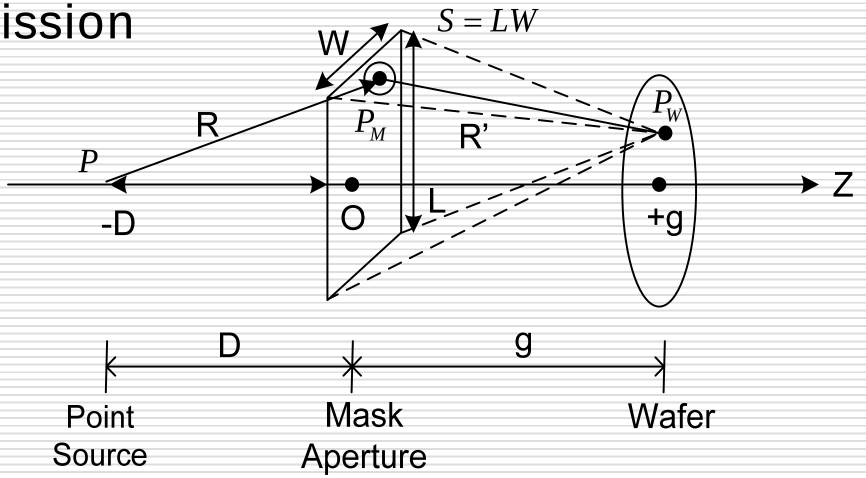
$$E(R') = j\frac{A}{\lambda}\iint_S \frac{e^{-jk(R+R')}}{RR'} dS$$

$$I = EE^* = E_0 e^{j\phi} E_0 e^{-j\phi} = E_0^{\ 2}$$



Re-emission of scalar waves by points on a surface spanning the mask

- Consider the amplitude E observed at a point P_W arising from light emitted from a point source P_M and scattered by a plane mask S.
- If an element of area dS at P_M on plane mask is distributed by a wave amplitude E_1 this same point acts as a coherent secondary emitter of strength $f_S E_1 ds$
- Where f_s is called the transmission function of S at point P_M
- In the simplest examples f_s is zero where the mask is opaque and unity where it is transparent.



Re-emission of scalar waves by points on a surface spanning the mask

- The scalar wave emitted from a point source P of strength E_p can be written as a spherical wave of wave number $k = 2\pi/\lambda$

$$E_1 = \frac{A}{R} e^{jkR}$$

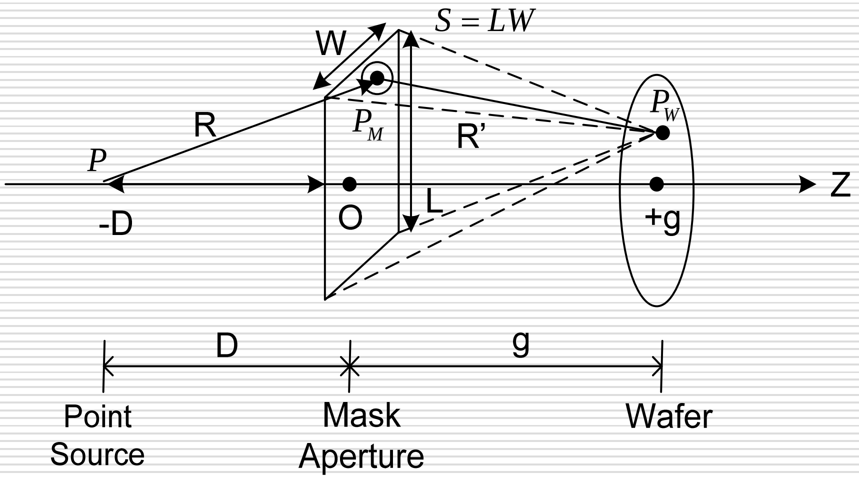
- And consequently S acts as a secondary emitter of strength E_s

$$A_s = f_s A_P \, dS$$

$$dE(R') = \frac{f_s A_1}{r} e^{ikR} dS$$

$$dE(R') = \frac{f_s A_P}{RR'} e^{ik(R+R')} dS$$

$$E(R') = A \iint_s \frac{f_s}{RR'} e^{ik(R+R')} dS$$



Nearfield or Fresnel diffraction

- The solution of equation

$$E(R') = j\frac{A}{\lambda}\iint_S \frac{e^{-jk(R+R')}}{RR'}\,dS$$

is photolithography is only considered in two limiting cases.

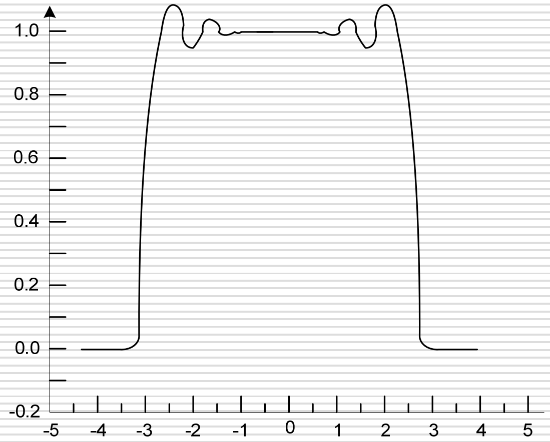
- 1- Nearfield or Fresnel diffraction, if the above equation is solved subject to the simplifying assumption that

$$W^2 \; \square \; \lambda\sqrt{g^2 + r^2}$$

where W is the width of aperture, λ is wavelength of incoming light, g is the distance form mask aperture to surface of wafer and finally r is the radial distance between the center of the diffraction pattern and the observation point.

Nearfield or Fresnel diffraction pattern

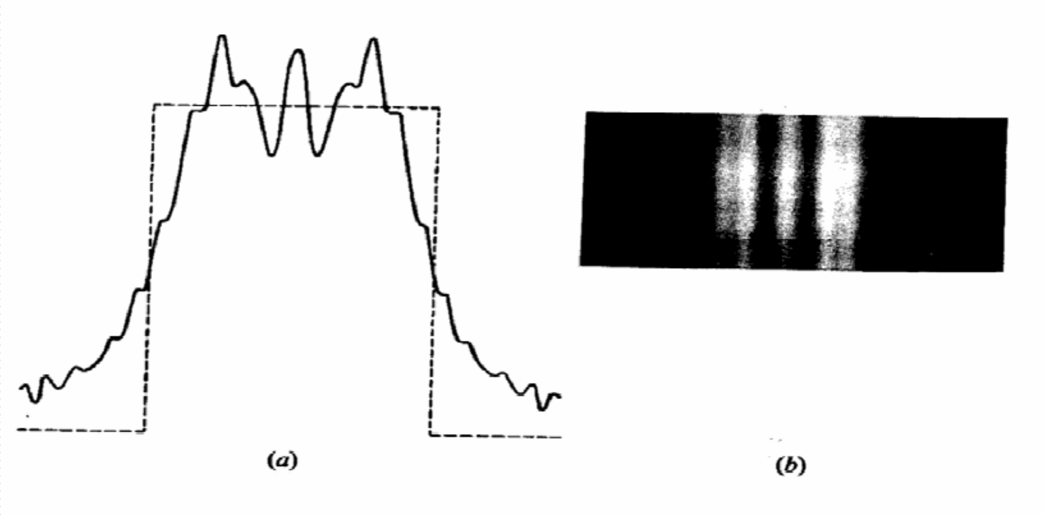
- The image of nearfield or Fresnal diffraction pattern is shown in below figure.



- The edge of the image rise gradually from zero and the intensity of the image oscillates about the expected density.
- The oscillation decay at the center of image. To constructive and destructive interference of Huygen's wavelets form apertures in the mask.

Nearfield or Fresnel diffraction pattern

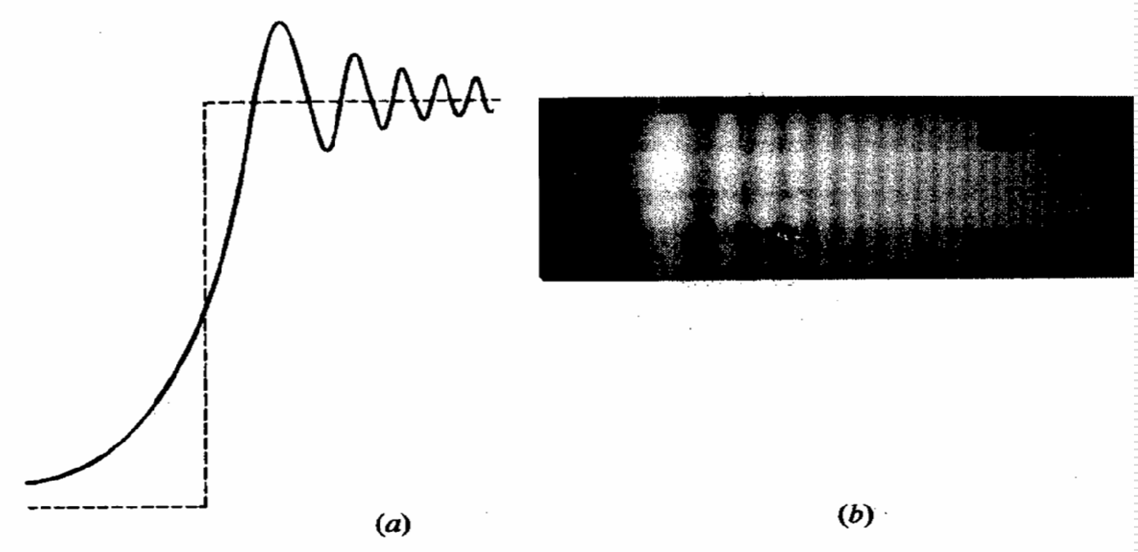
- a) Amplitude of the Fresnal diffraction pattern calculated for a slit of width 0.9mm observed with $L = 20cm,\ L_1 = 28cm$ and $\lambda = 0.6\mu m$
  The geometrical shadow is indicated by the broken lines.
  b) Photograph of the diffraction pattern observed under the same conditions.



Nearfield or Fresnel diffraction pattern

- a) Intensity of the Fresnal diffraction pattern of a single straight edge. The geometrical shadow is indicated by boken lines.

  b) Photograph of the observed pattern.



Farfield or Fraunhofer diffraction

- The solution of equation

$$E(R') = j\frac{A}{\lambda}\iint_S \frac{e^{-jk(R+R')}}{RR'}dS$$

is photolithography is only considered in two limiting cases.

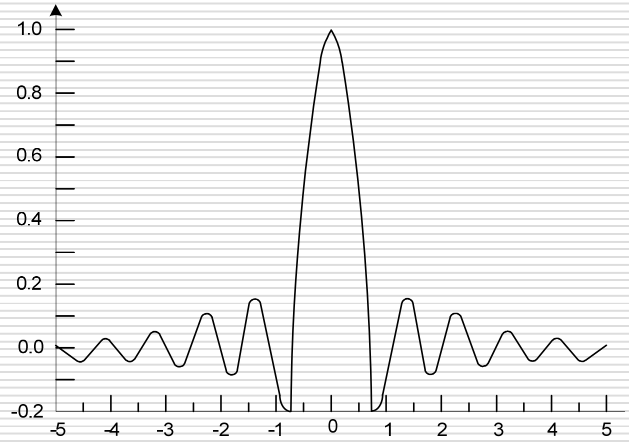
- 2 - Farfield or Fraunhofer diffraction, if the above equation is solved subject to the simplifying assumption that

$$W^2 << \lambda\sqrt{g^2 + r^2}$$

where W is the width of aperture, λ is wavelength of incoming light, g is the distance form mask aperture to surface of wafer and finally r is the radial distance between the center of the diffraction pattern and the observation point.

Farfield or Fraunhofer diffraction pattern

- The image of farfield or Fraunhofer diffraction pattern is shown in below figure.

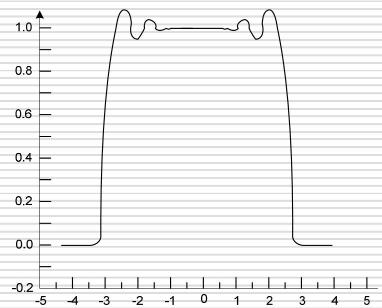


- The intensity as a function of position on surface of the wafer is given by

$$I(x,y) = I_{inc}(0)\left[\frac{(2W)(2L)}{\lambda g}\right]^2 I_x{}^2 I_y{}^2$$

Farfield or Fraunhofer diffraction pattern

- The image of farfield or Fraunhofer diffraction pattern is shown in below figure.



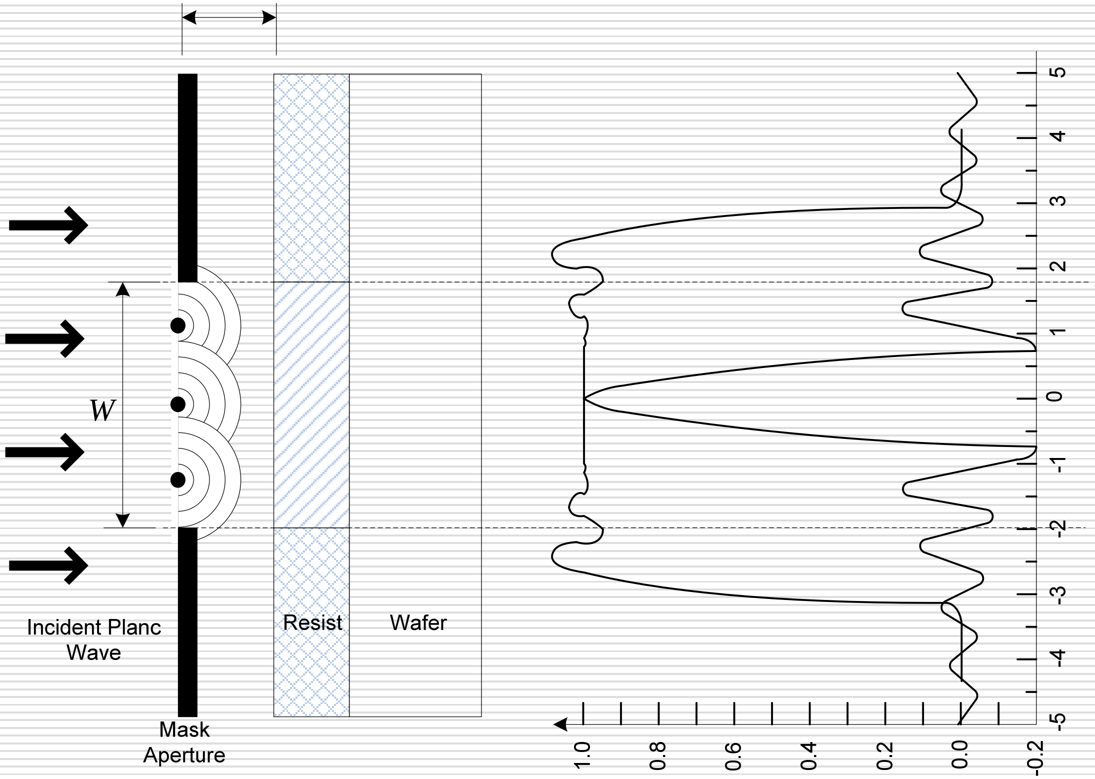
- The intensity as a function of position on surface of the wafer is given by

$$I(x,y) = I_{inc}(0)\left[\frac{(2W)(2L)}{\lambda g}\right]^2 I_x{}^2 I_y{}^2$$

- Where is the flux density (typically expressed in) beam and

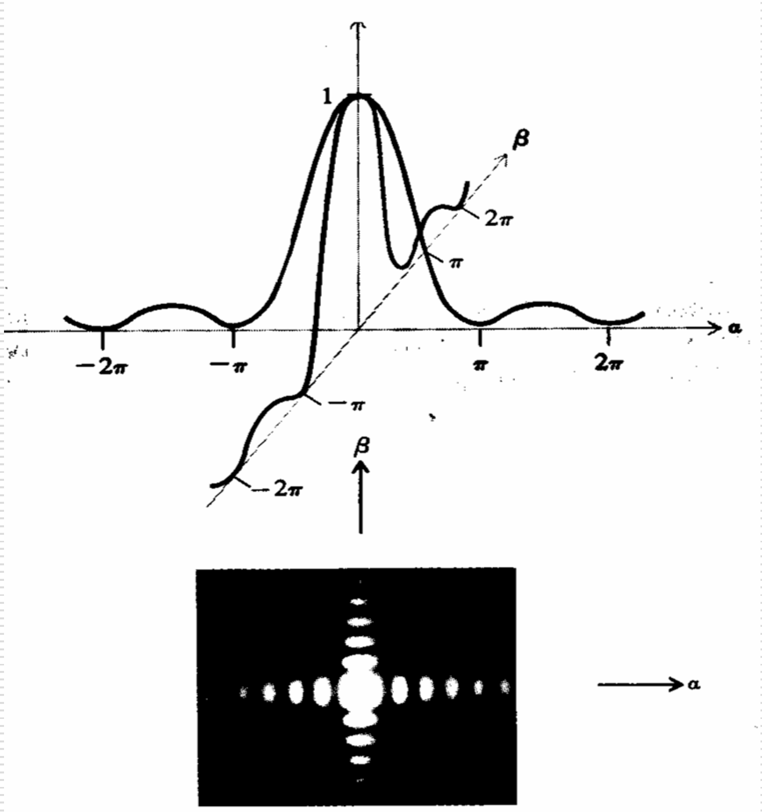
$$I_x = \frac{\sin\left[\frac{2\pi x W}{\lambda g}\right]}{\frac{2\pi x W}{\lambda g}} \qquad I_y = \frac{\sin\left[\frac{2\pi x L}{\lambda g}\right]}{\frac{2\pi x L}{\lambda g}}$$

Nearfield and Farfield diffraction pattern



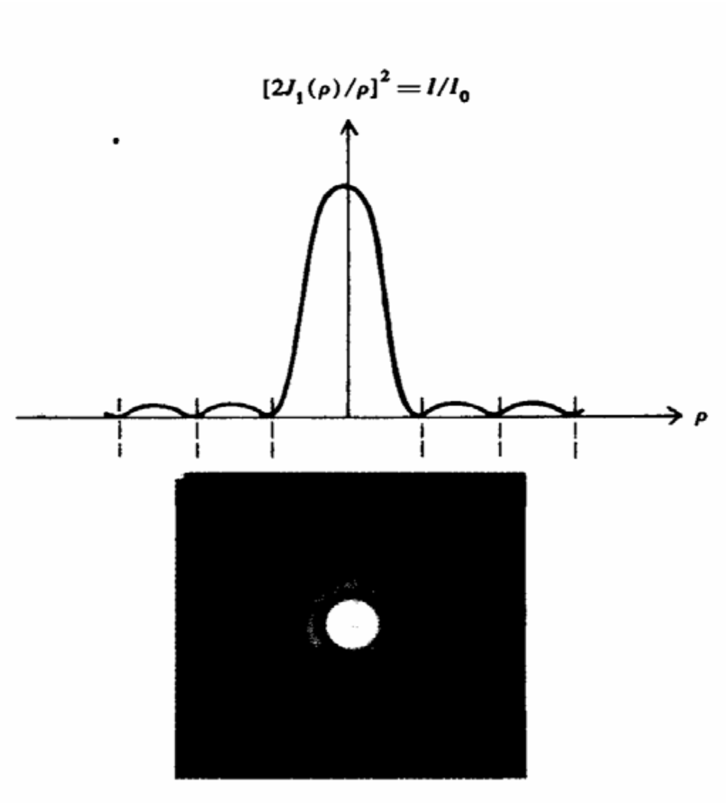
Farfield diffraction pattern

- Fraunhofer diffraction pattern of a rectangular aperture.



Farfield diffraction pattern

- Fraunhofer diffraction pattern of a circular aperture.



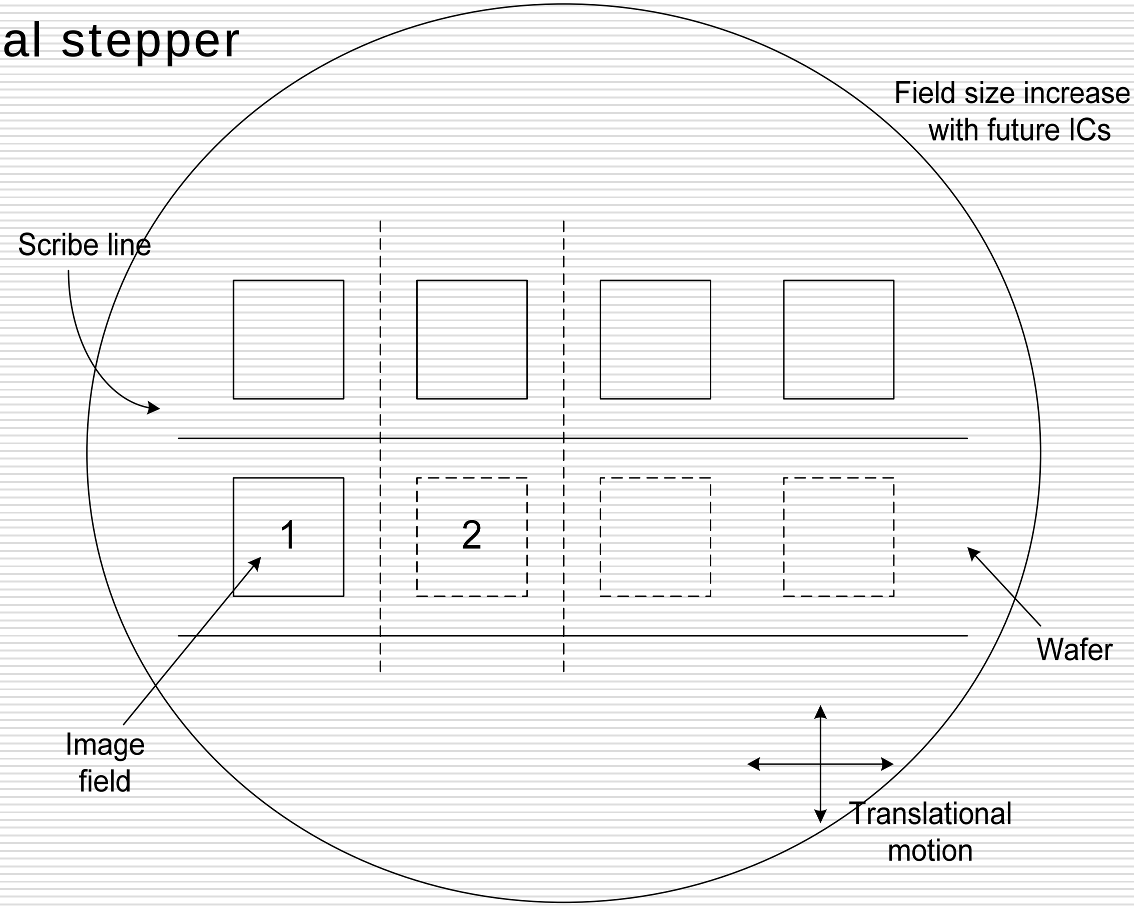
Clean Room for VSLI/ULSI

- Ultra clean condition must be maintained during the lithographic process

Ratings by Class of Effectiveness of Filtration in Clean Rooms			
Class	Number of $0.5\,\mu m$ particles per $ft^3\,(m^3)$		Number of $5\,\mu m$ particles per $ft^3\,(m^3)$
10000	10000	(350000)	65 (23000)
1000	1000	(35000)	6.5 (2300)*
100	100	(3500)	0.65 (230)*
10	10	(350)	0.065 (23)*
1	1	(35)	0.00065 (2.3)*
It is very difficult to measure particulate counts below 10 per ft^3			

Optical Stepper

- Optical stepper



Step control

- Step control