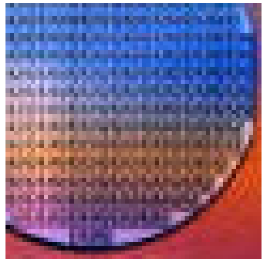
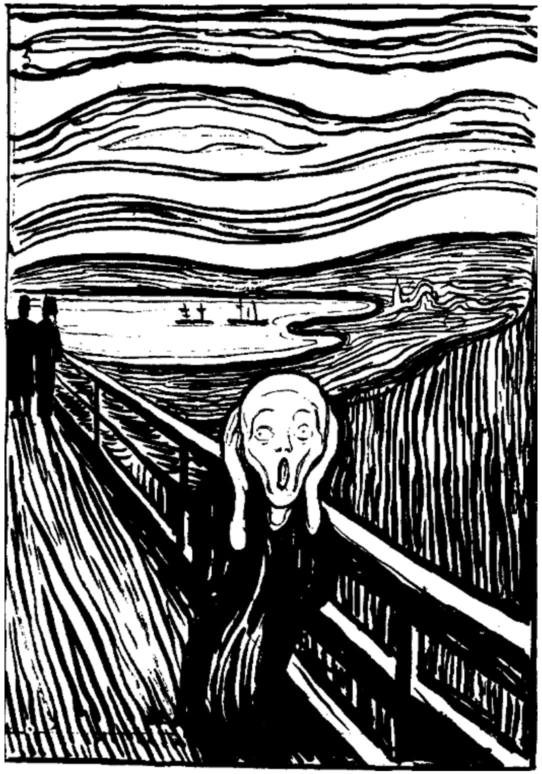
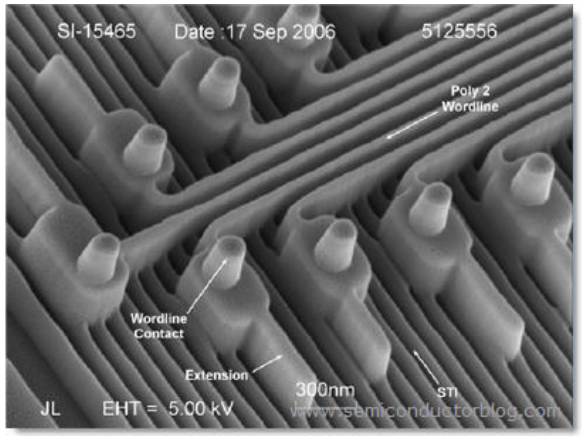
Lithography-
Pattern transfer

FYS 4310/9310

Λιτηογραπηψ







High magnification SEM image of IM Flash Technologies (IMFT) 4G 50nm NAND Flash (source: Semiconductor Insights)

Outline

Introduction (overview what is it, history, trends)

Photolithography - transfer processes classification

Contact -, Proximity-, Projection - print

Strength, weaknesses,

Diffraction

Optical systems

Photoresist positive negative

X-ray lithography

E-beam lithography

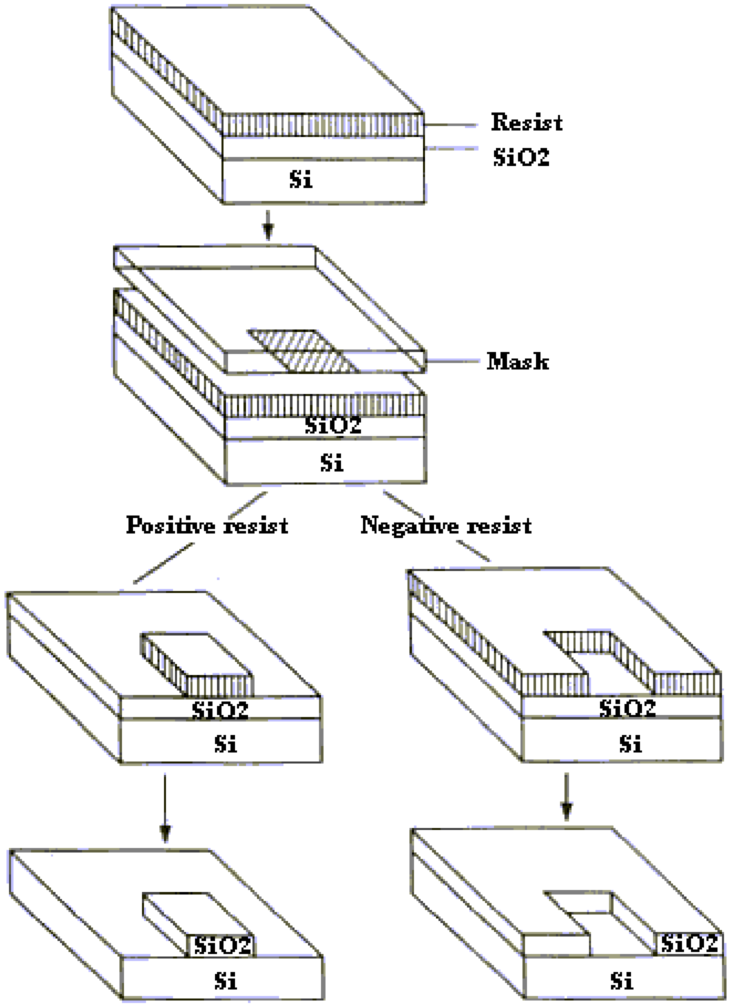
principles, comparison optical litho, limitations

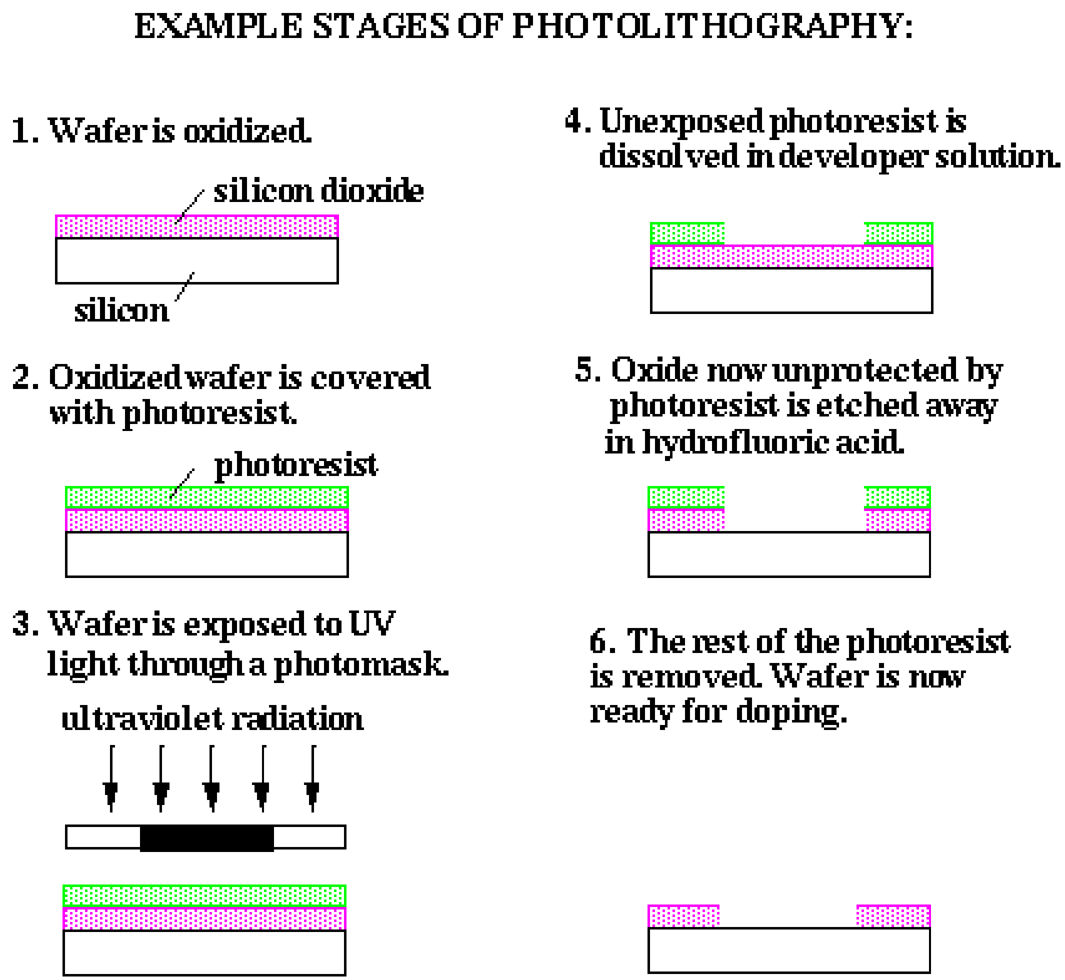
Ion beam litho, Stencil printing

Photoresists, Organic inorganic, optical resolution enhance

Introduction (overview what is it, history, trends)

Schematics of photo-litography process





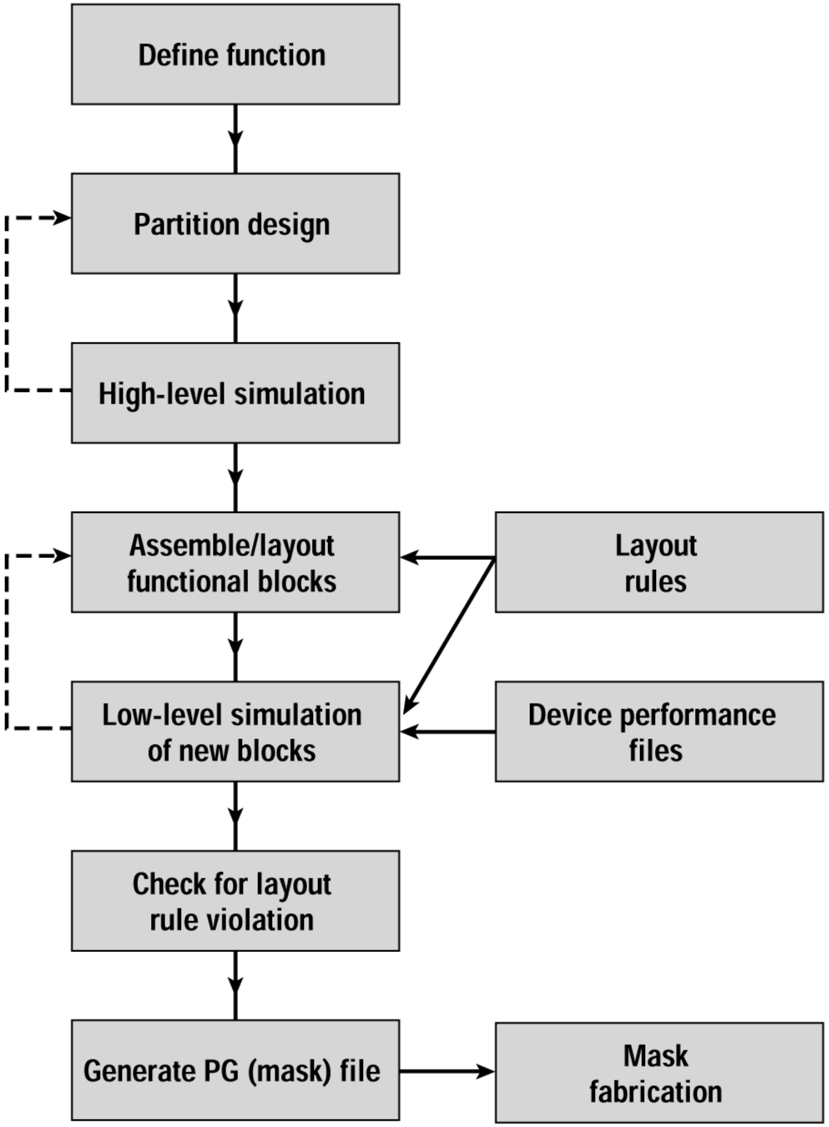
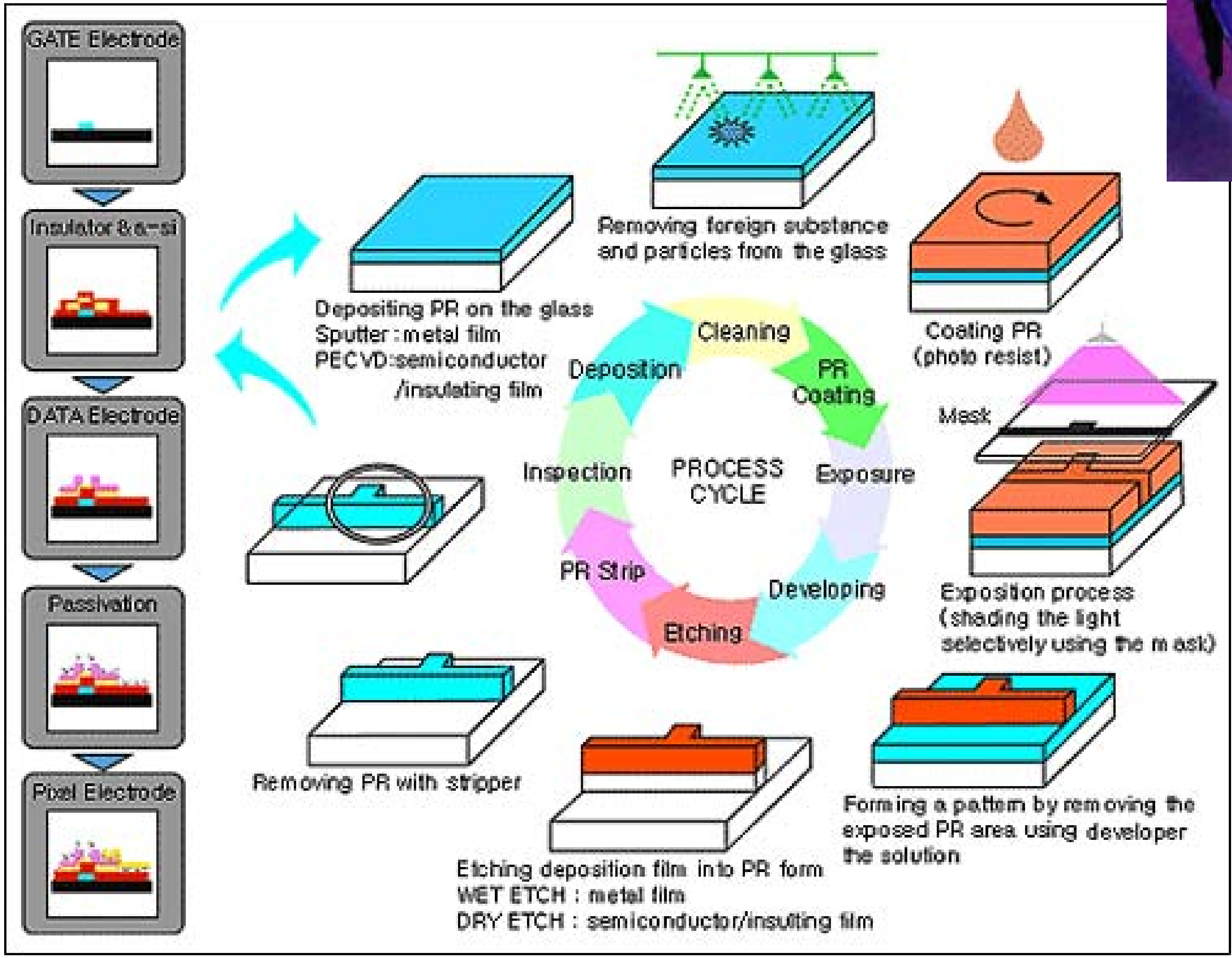
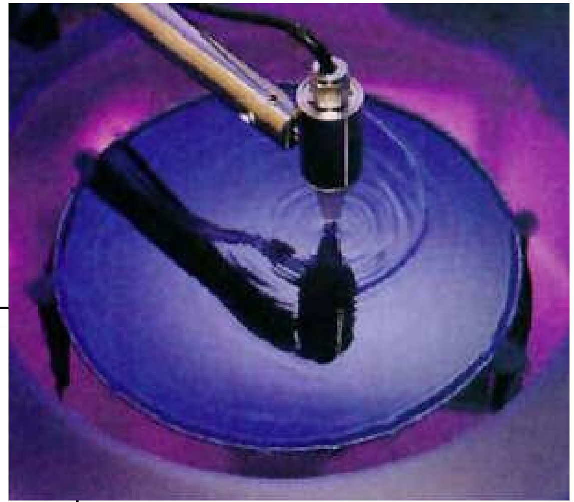


Figure 7.1 Simplified IC design process flow diagram.

Process flow lithography

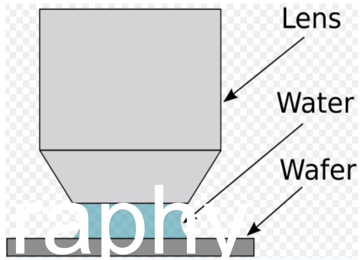




‘new’ emerging lithographic methods

Phase contrast masks, double patterning, inorganic resists

Immersion lithography



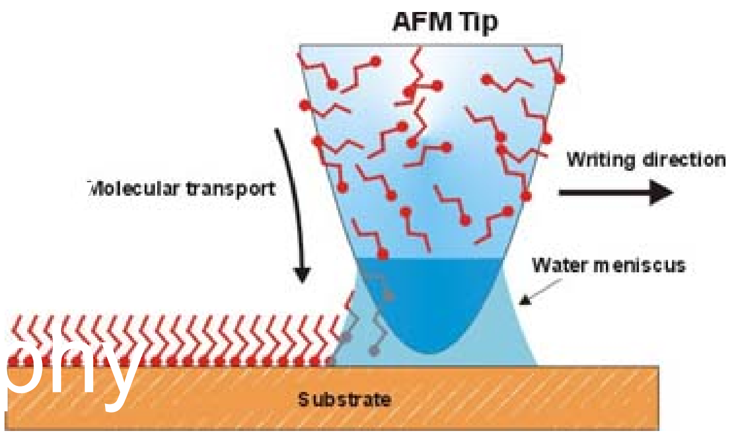
Nano imprint

Self organization,

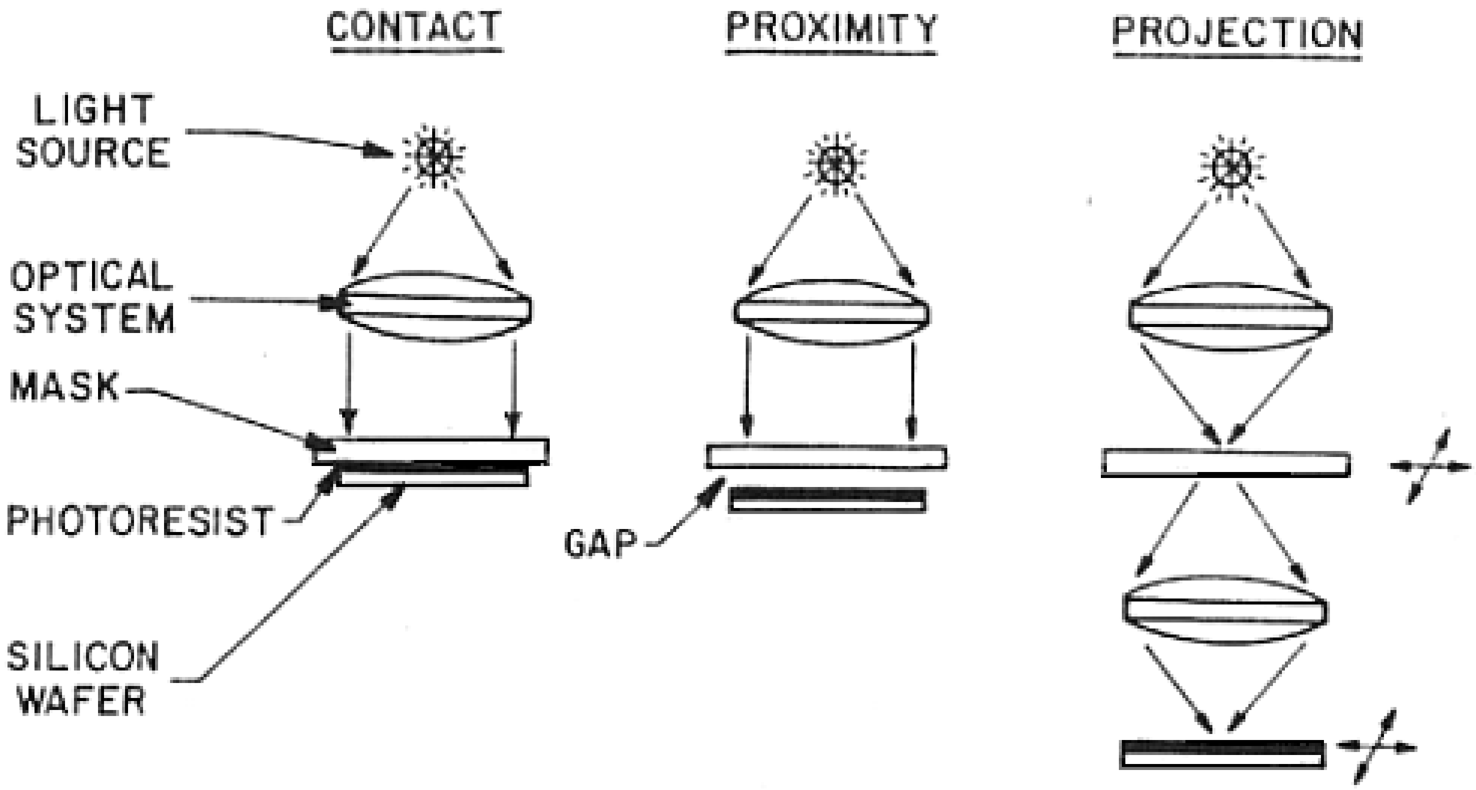
nano sphere lithography

Scanning probe lithography

Dip pen lithography



3 ‘print’ methods optical lithography



Trend. Benefit of decrease wavelgth

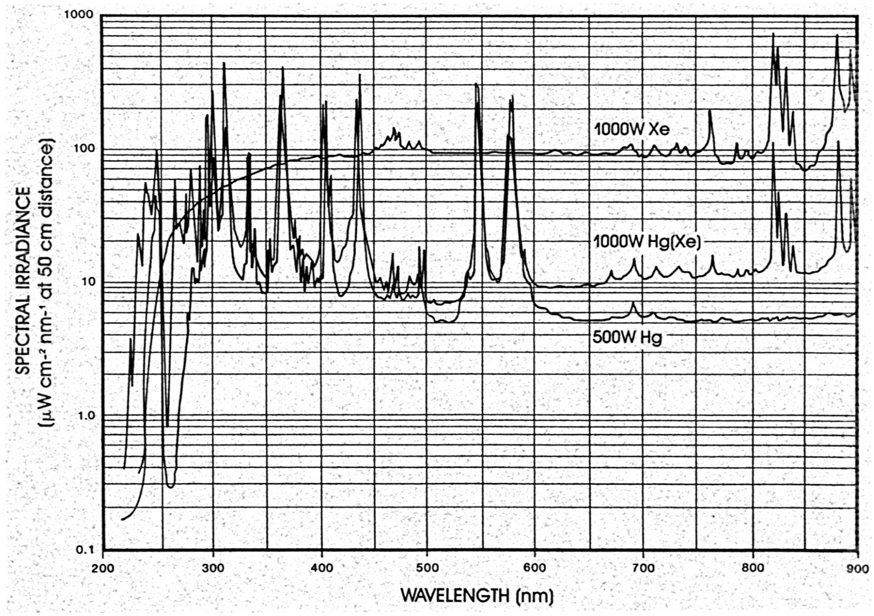


Figure 7.11 Line spectra for mercury and xenon arc lamps *(courtesy of Oriel Corporation).*

ions electrons X-ray Deep UV UV

λ

Min feature size

diffraction

diffraction

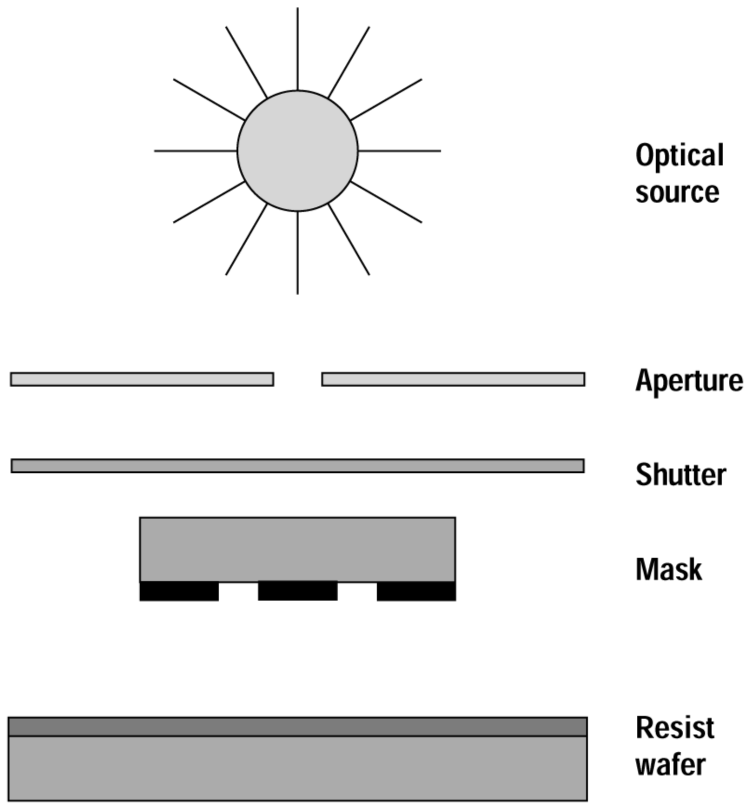


Figure 7.4 Schematic of a simple lithographic exposure system.

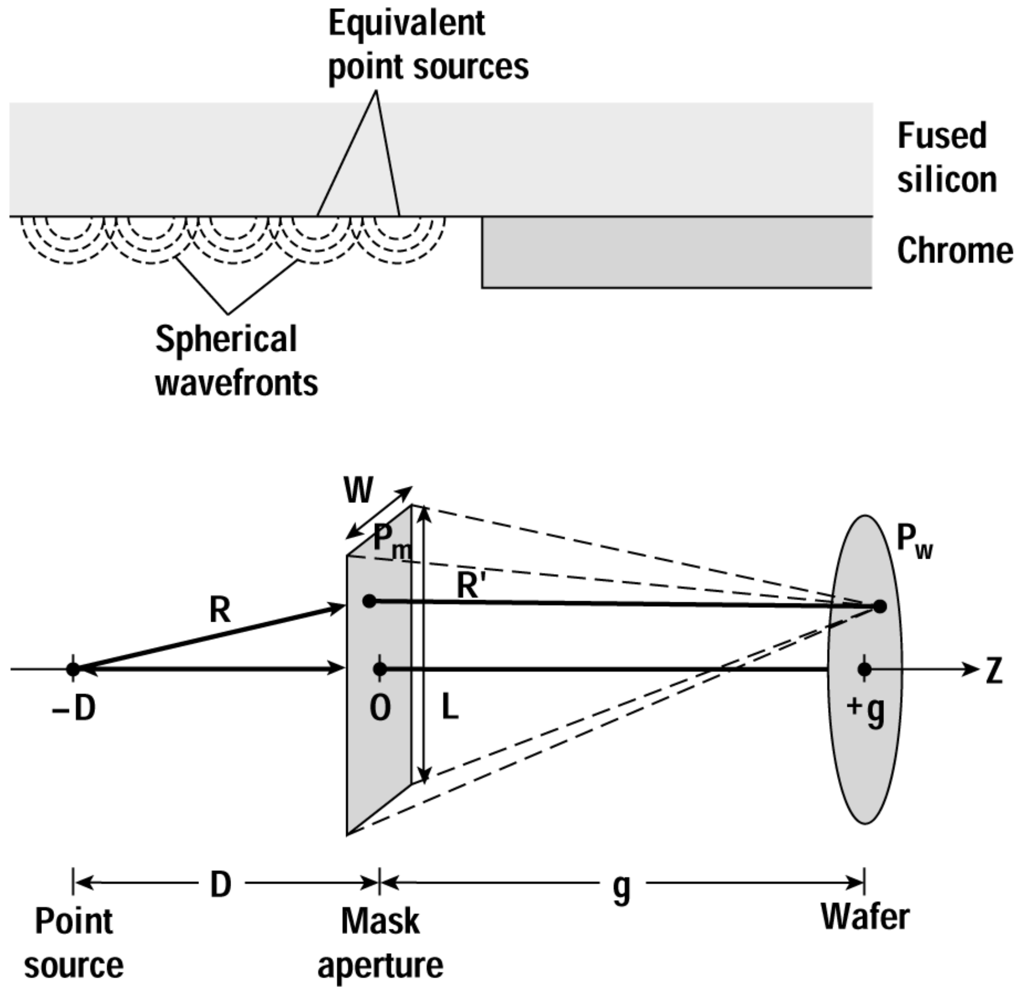


Figure 7.5 Huygen's principle applied to the optical system shown in Figure 7.4. A point source is used to expose an aperture in a dark field mask.

Diffraction limitations

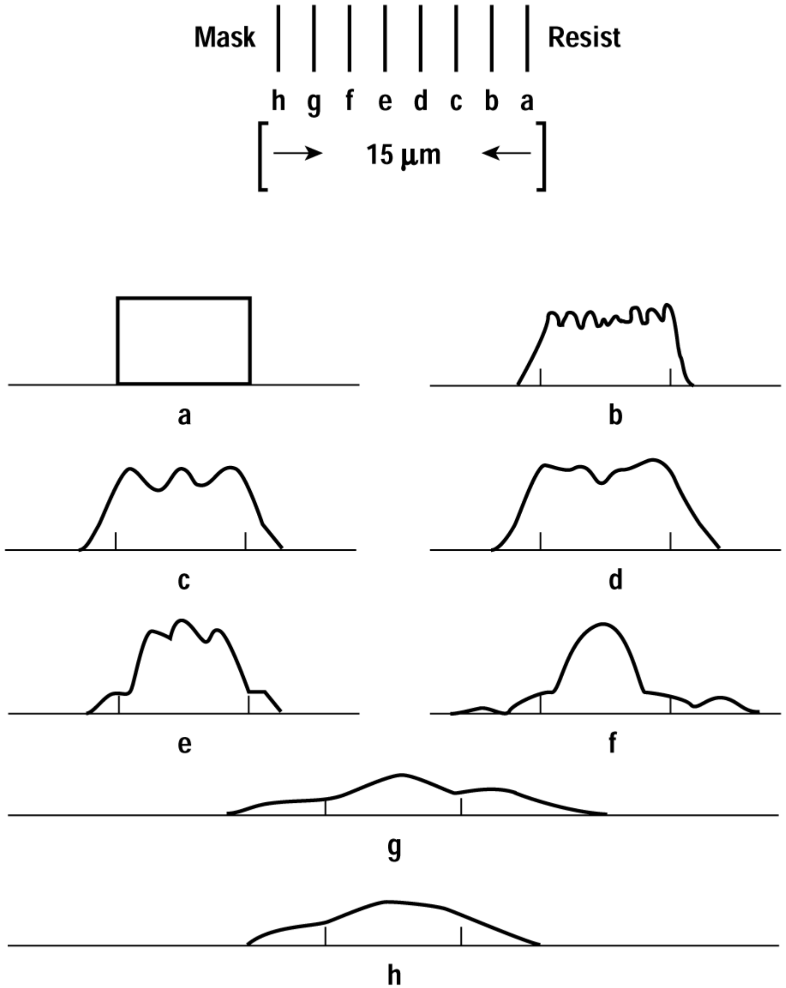


Figure 7.16 Intensity as a function of position on the wafer for a proximity printing system where the gap increases linearly from *g* 5 0 to *g* 5 15 mm *(after Geikas and Ables)*.

Fresnel diffraction

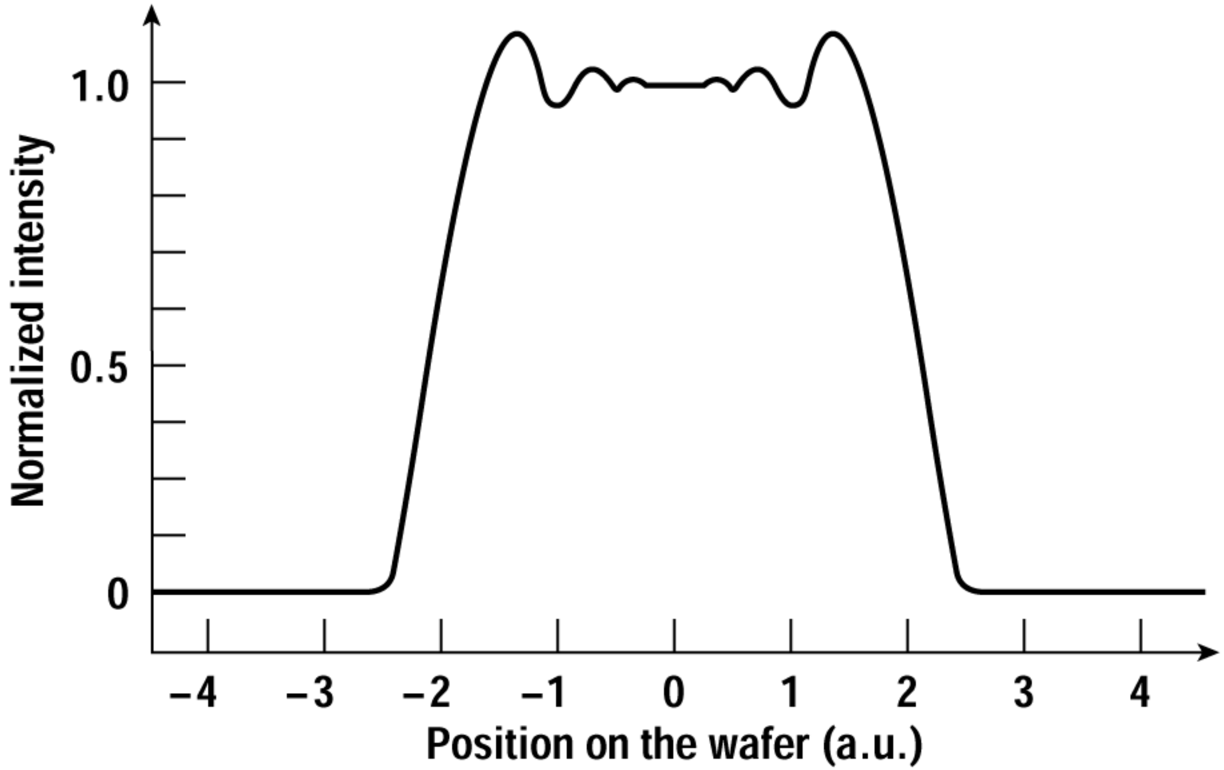


Figure 7.6 Typical near field (Fresnel) diffraction pattern.

Frauenhofer diffraction

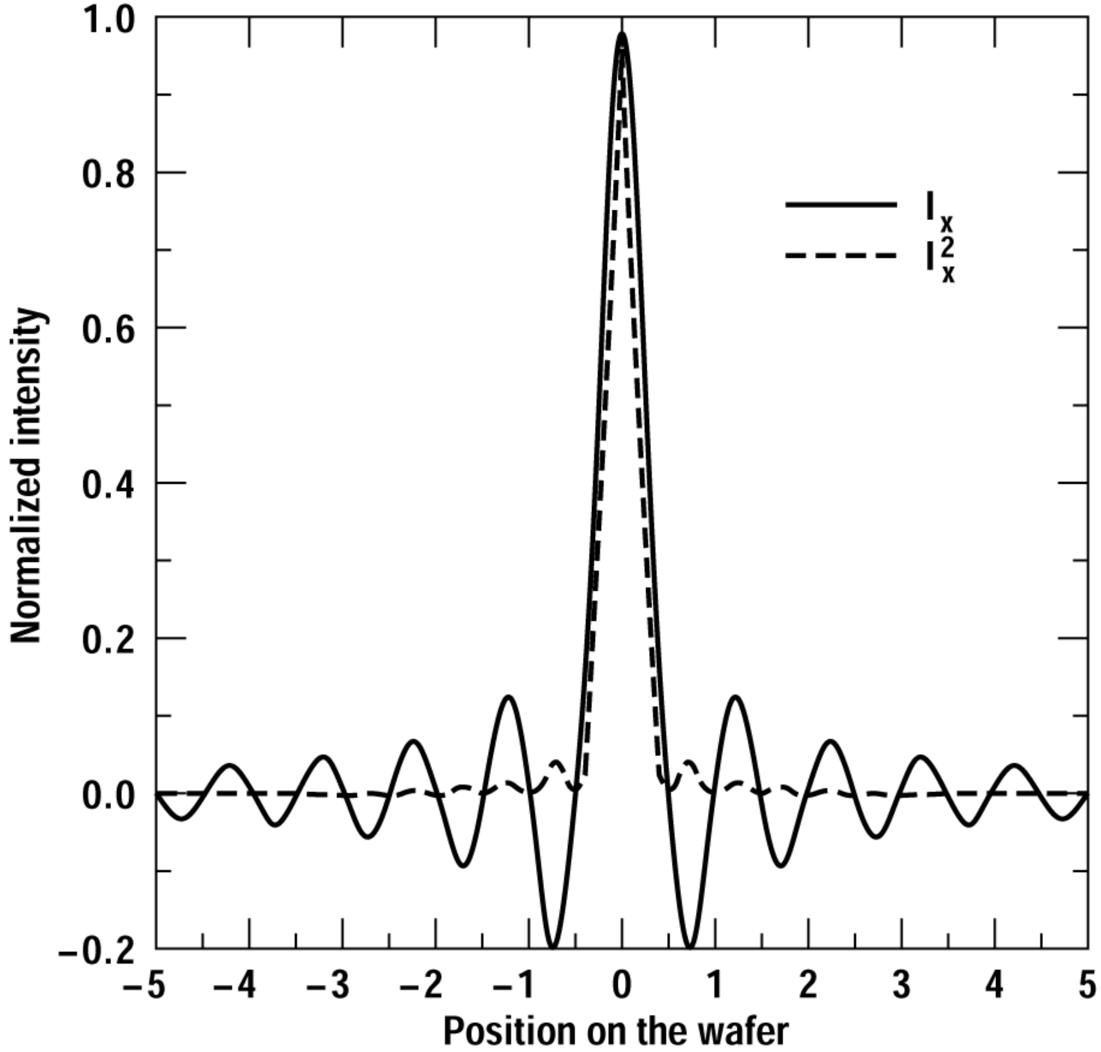


Figure 7.7 Typical far field (Fraunhofer) image.

Intensity vs distance round mask

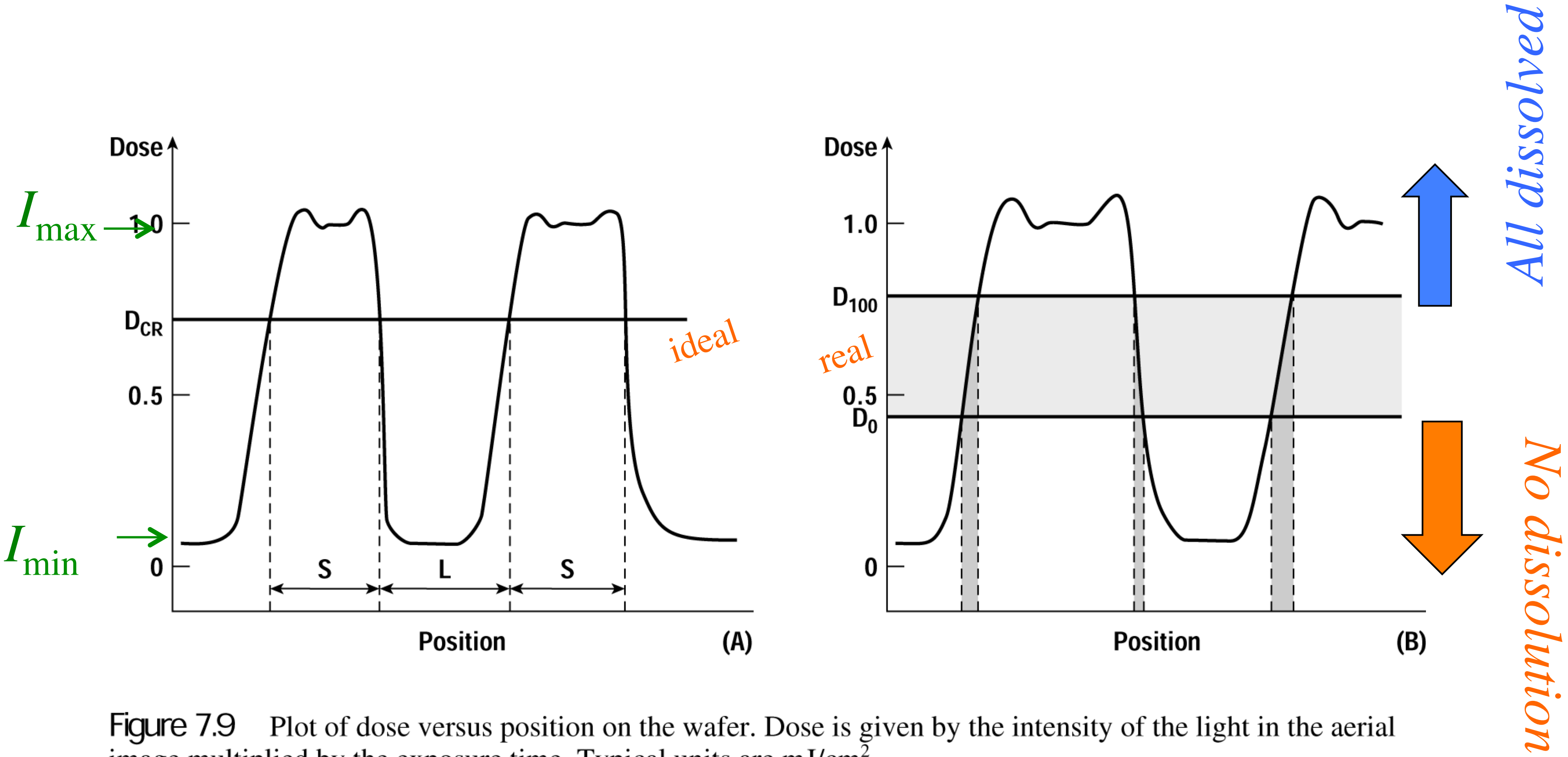


Figure 7.9 Plot of dose versus position on the wafer. Dose is given by the intensity of the light in the aerial image multiplied by the exposure time. Typical units are mJ/cm^2.

Modulation transfer function:

$$MTF = \left(\frac{I_{max} - I_{min}}{I_{max} + I_{min}} \right)$$

Resolution Enhancement Techniques (I)
Phase-shifting mask (PSM)

Optical Intensity and Exposure Energy

•Light is an Electromagnetic Wave

-Electrical field (ε)

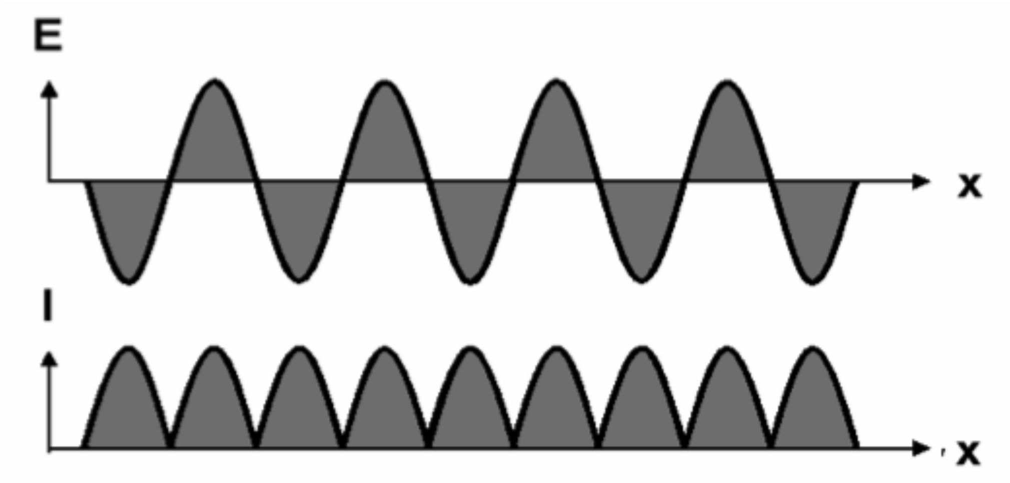
$$\varepsilon(\vec{r},\nu) = \varepsilon_0(\vec{r})e^{j\phi(\vec{r},\nu)}$$

-Intensity I

$$I = \varepsilon \cdot \varepsilon^* = \phi_0 e^{j\phi} \cdot \varepsilon_0 e^{-j\phi} = \varepsilon_0^2$$

-Energy E

$$E = \int I \cdot dt \approx I \cdot t$$



Resolution Enhancement Techniques (I)

Phase-shifting mask (PSM)

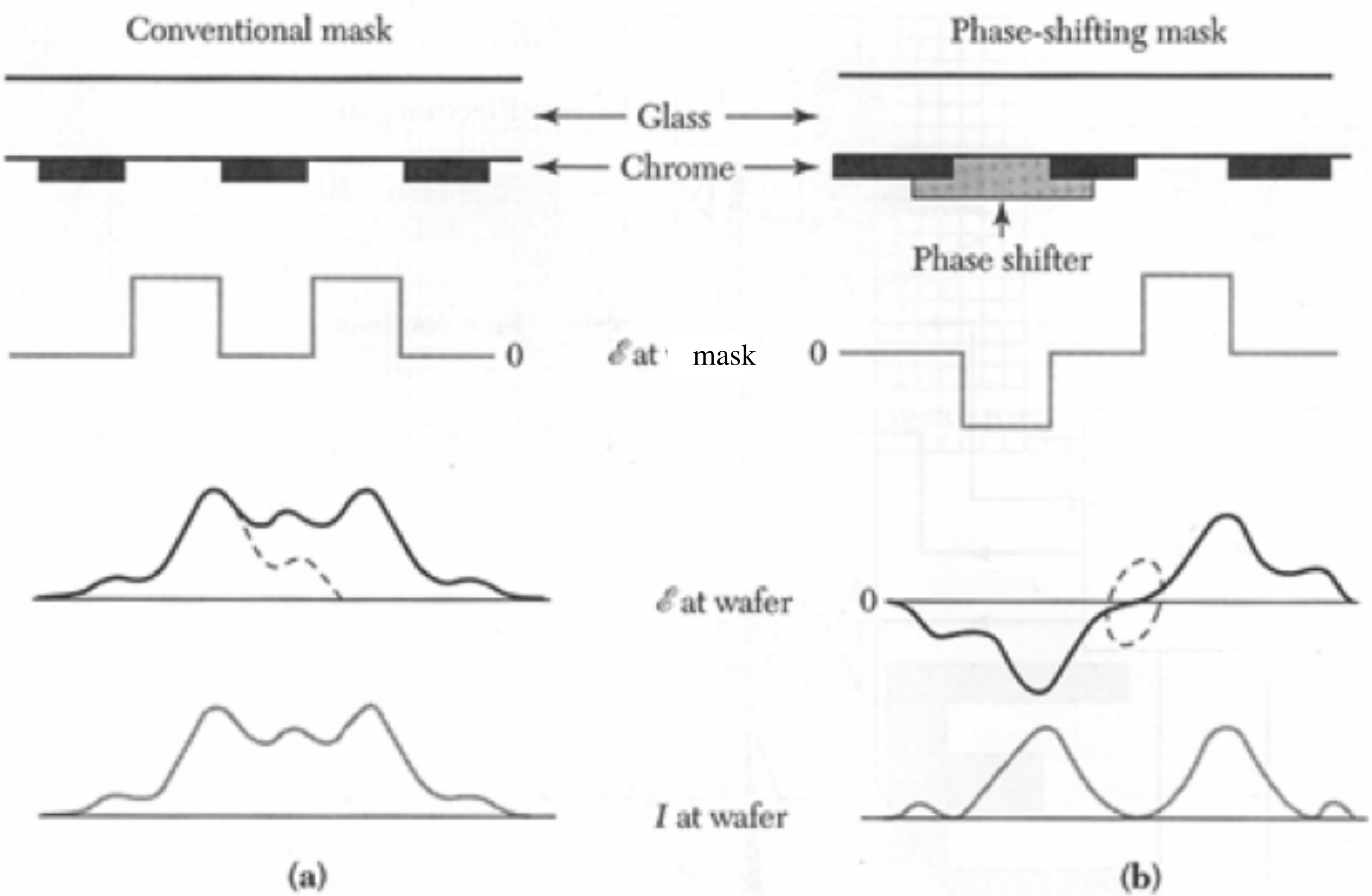
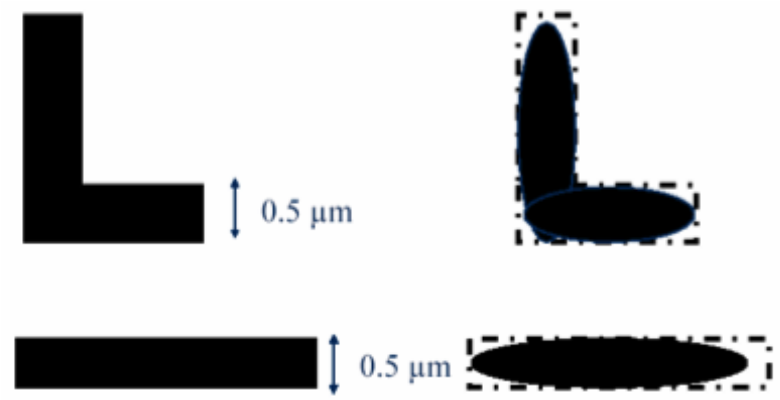


Figure 4.12 The principle of phase-shift technology. (*a*) Conventional technology. (*b*) Phase-shift technology.[9]

Resolution Enhancement Techniques (I)
Optical proximity correction (OPC)

OPC uses modified shapes of adjacent subresolution geometry to improve imaging capability

Figure on the mask **Pattern on the wafer**



When the feature size is smaller than the resolution, the pattern will be distorted in several ways:

- **Line width variation**
- **Corner rounding**
- **Line shortening**

Modify the Mask based on rules or model

Mercury lamp

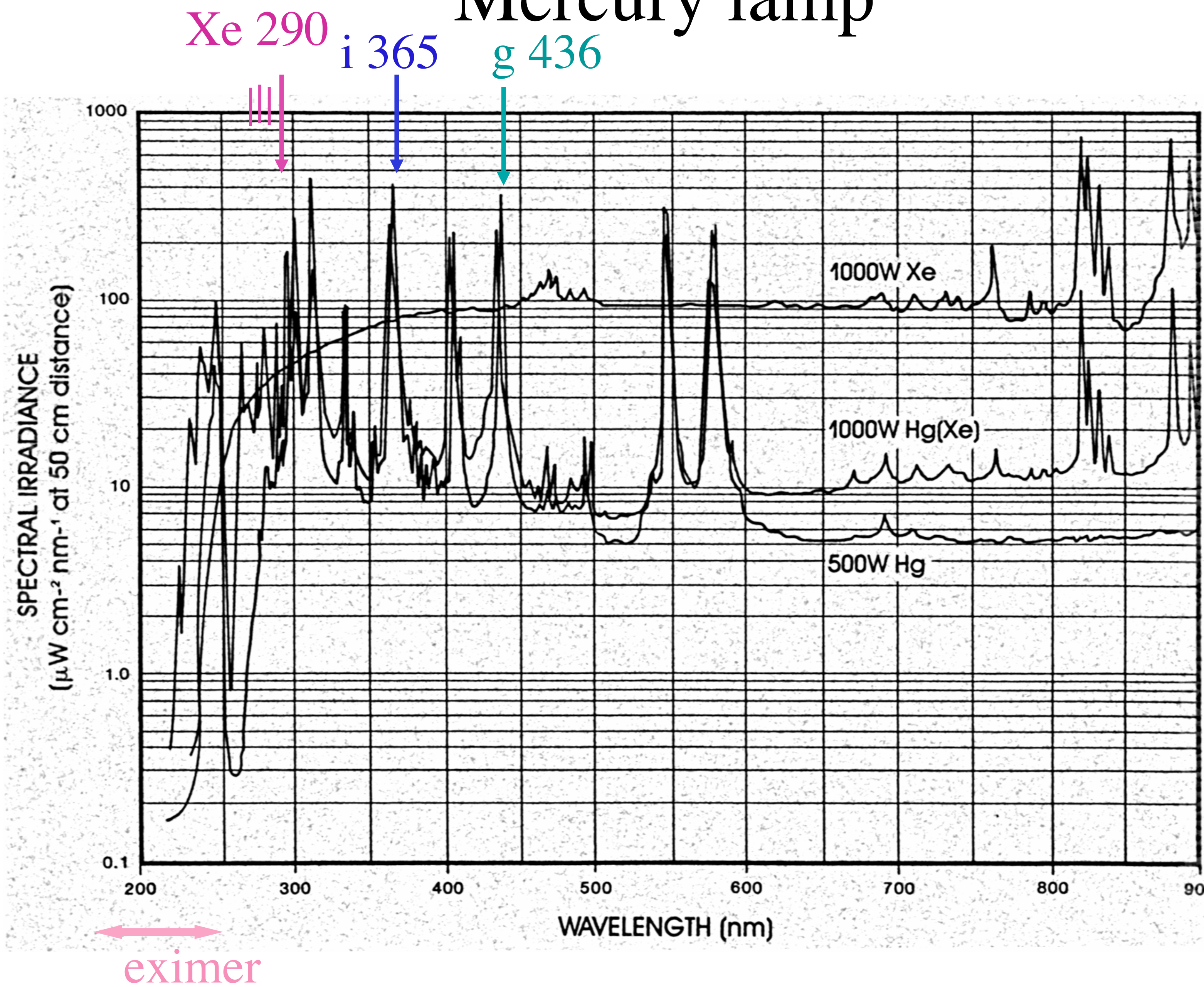
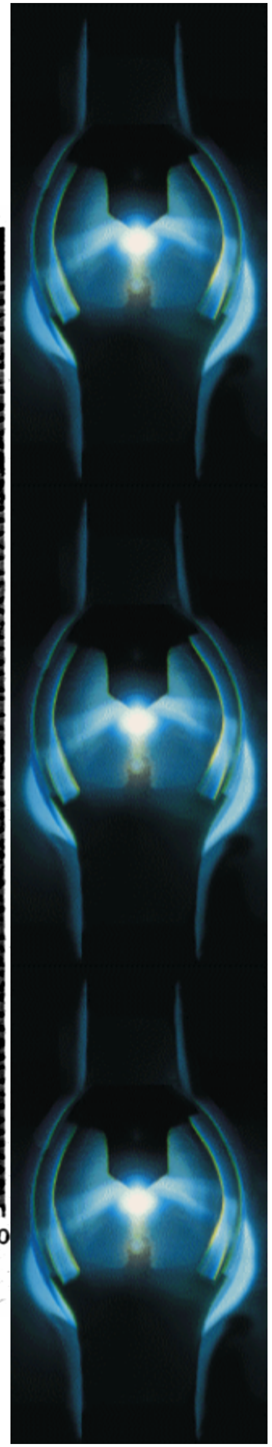
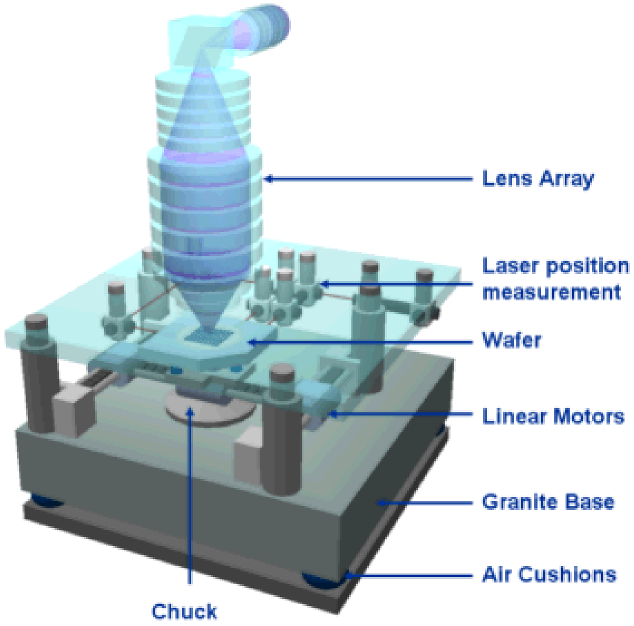


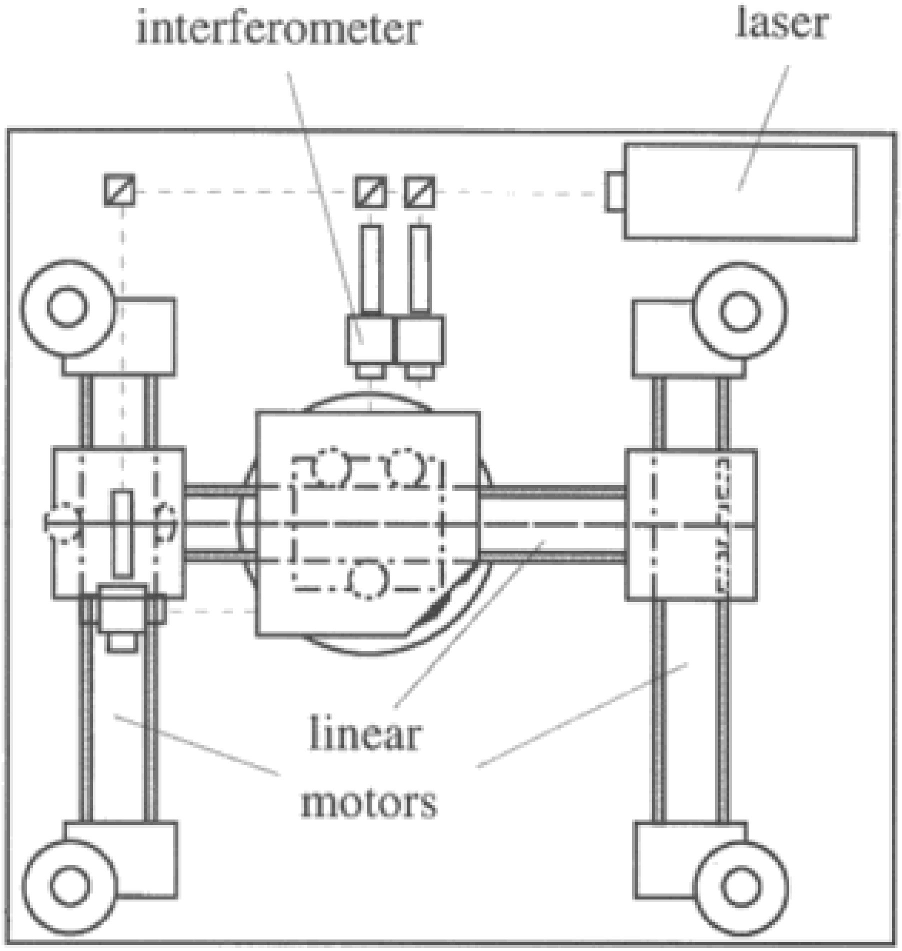
Figure 7.11 Line spectra for mercury and xenon arc lamps *(courtesy of Oriel Corporation).*



Optical systems: Litho machines



Optical systems: Litho machines stage manipulatiion



Optical systems: typical contact/proxi

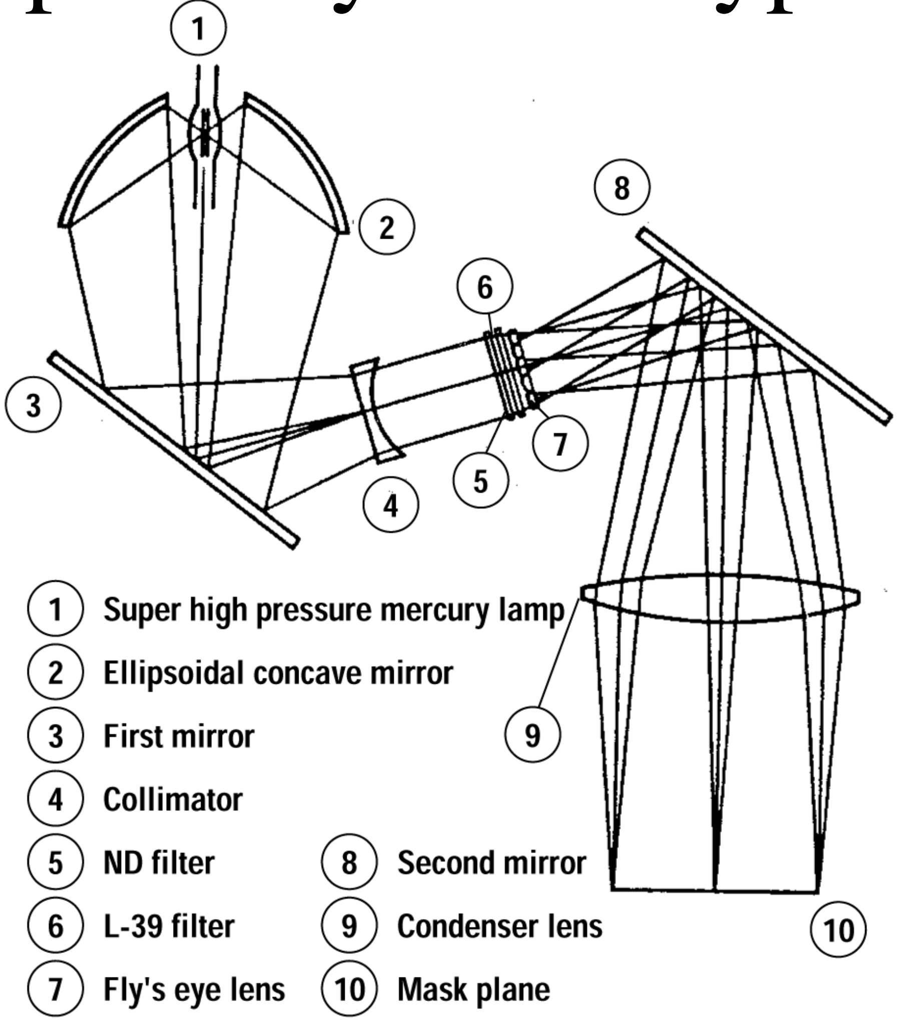


Figure 7.12 Schematic of a typical source assembly for a contact/proximity printer *(after Jain)*.

λ decrease.
.more mirrors less lenses

Optical systems: excimer laser stepper

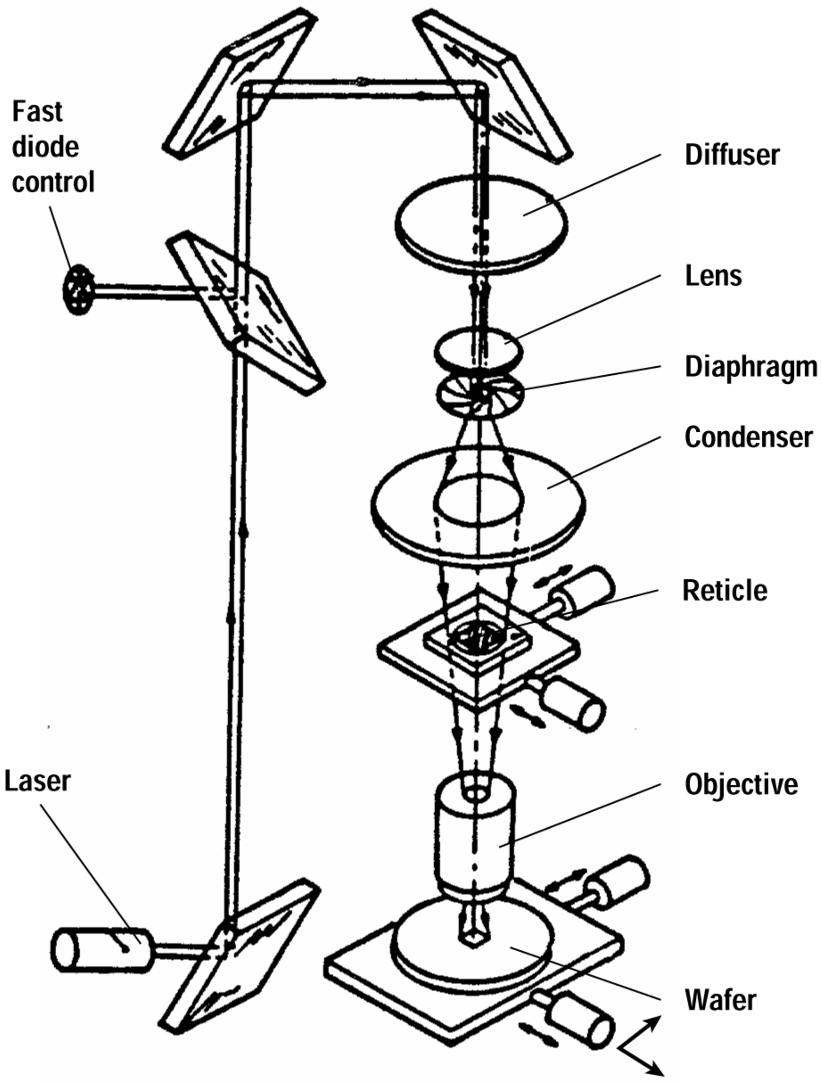
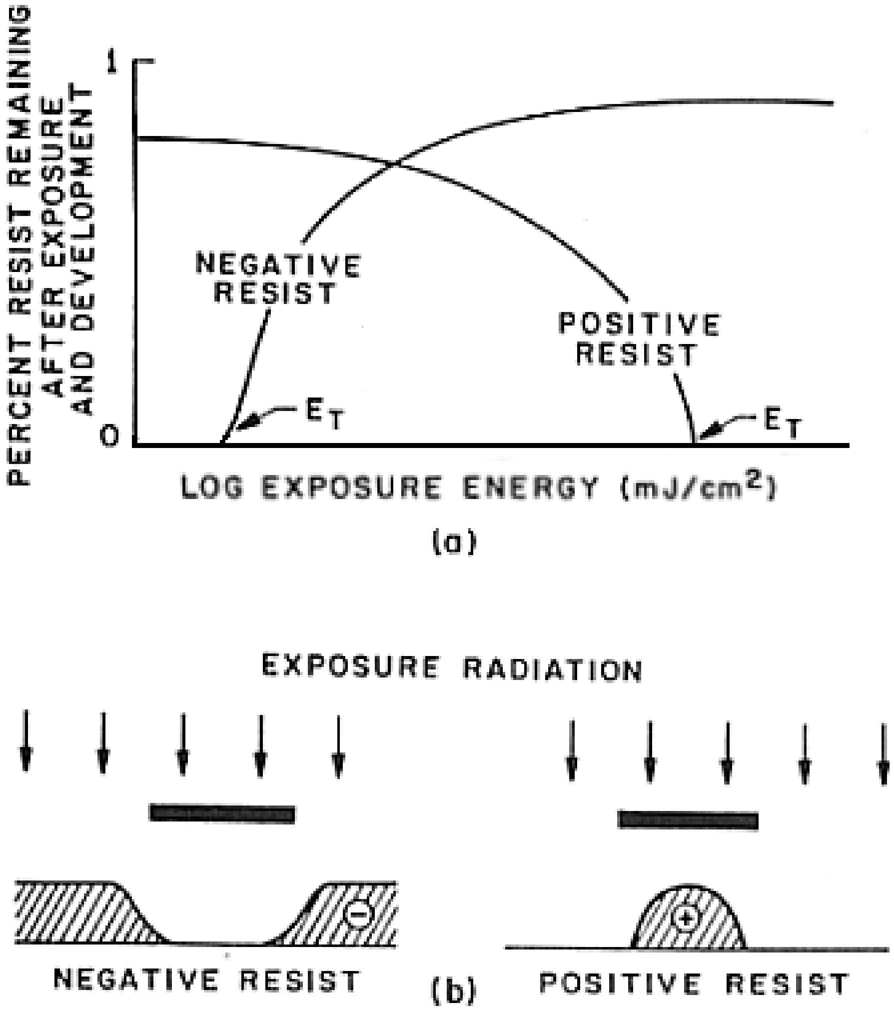


Figure 7.14 Optical train for an excimer laser stepper *(after Jain)*.

Negative and Positive resist



(a) Resist exposure characteristics. (b) Resist after development.

Conventional Photoresists

Typically consist of 3 components:

-resin or base material

- **a binder that provides mechanical properties (adhesion, chemical resistance, etc)**

-photoactive compound (PAC)

-solvent

- **control the mechanical properties, such as the viscosity of the base, keeping it in liquid state.**

Positive Photoresist (I)

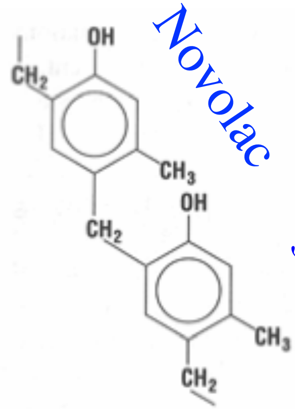
•Two-component DQN resists:

Currently the most popular positive resists are referred to as DQN, corresponding to the photo-active compound, diazoquinone (DQ) and resin, novolac (N), respectively.

•Dominant for G-line and I- line exposure, however, these resists cannot be used for very-short-wavelength exposures.

•Novolac (N):

- a polymer whose monomer is an aromatic ring with two methyl groups and an OH group.
- it dissolves in an aqueous solution easily.
- solvent added to adjust viscosity, however, most solvent is evaporated from the PR before exposure and so plays little part in photochemistry

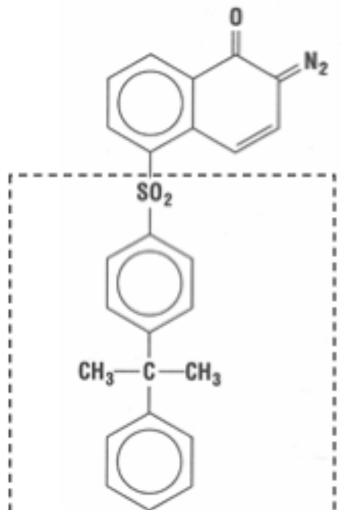


Novolac

5-200 repeats

•Diazoquinone(DQ)

- 20-50 % weight
- photosensitive
- DQ $\xrightarrow{UV}$ Carboxylic acid (dissolution enhancer)

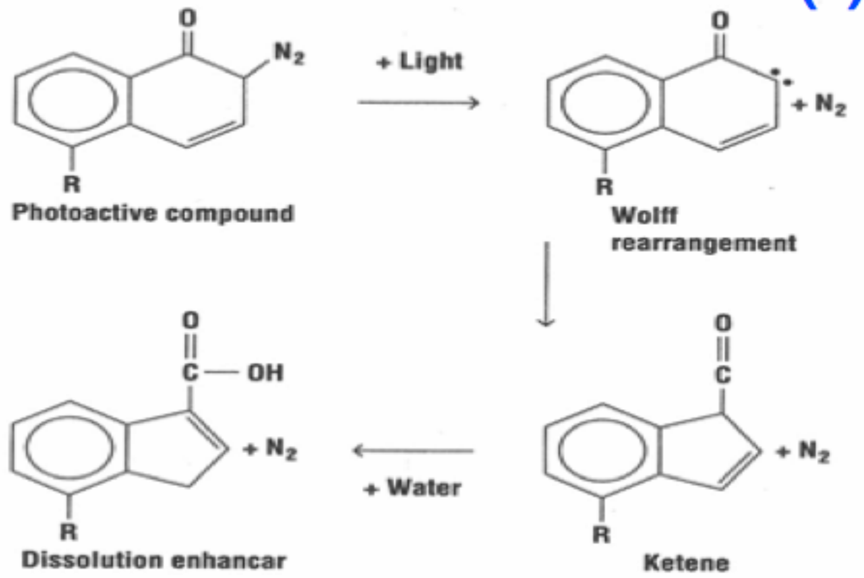


DQ

R

<u>*mechanism by which unexposed DNQ inhibits novolac dissolution is not well understood*</u>

Positive Photoresist (I)



-Photoactive compound (DQ) is insoluble in base solution.
-Carboxylic acid readily reacts with and dissolve in a base solution
  -resin/carboxylic acid mixture will rapidly takes up water
  (the nitrogen released in the reaction also foams the resist, further assisting the dissolution)
  -The chemical reaction during the dissolution is the breakdown of the carboxylic acid into water-soluble amines such aniline and slat of K (or Na depending on the developer).
  -Typical developer KOH or NaOH diluted with water

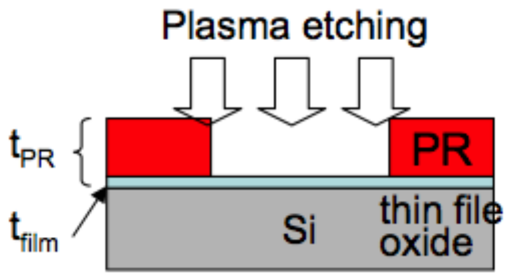
Advantages of DQN photoresists:

- the unexposed areas are essentially unchanged by the presence of the developer. Thus, line width and shape of a pattern is precisely retained.
- novolac is a long-chain aromatic ring polymer that is fairly resistant chemical attack. The PR therefore is a good mask for the subsequent plasma etching.

Positive Photoresist (II)

- PMMA (Ploymethyl methacrylate)

  - short-wavelength lithography: deep UV, extreme UV, electron-beam lithography
  - resin itself is photosensitive (Slow)
  - (pro's) high resolution
  - (con's)
    - Plasma etch tolerance of the resist is very low.
      it needs to have thick PMMA to protect the thin film,
      otherwise the PMMA will disappear before the thin film does



resist feature with aspect ratio higher than 4 is not considered to mechanical stable.

    - dissociation of PMMA changes the chemistry of the plasma etch and often leads to polymeric deposits on the surface of the substrate.

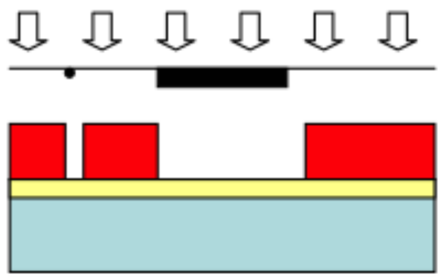
  - Low sensitivity
    it needs to add PACs or to elevate exposure temperature
    to increase the speed (the elevation of temperature can also increase the contrast).

Negative Photoresist (I)

- Based on azide-sensitized rubber such as cyclized polyisoprene

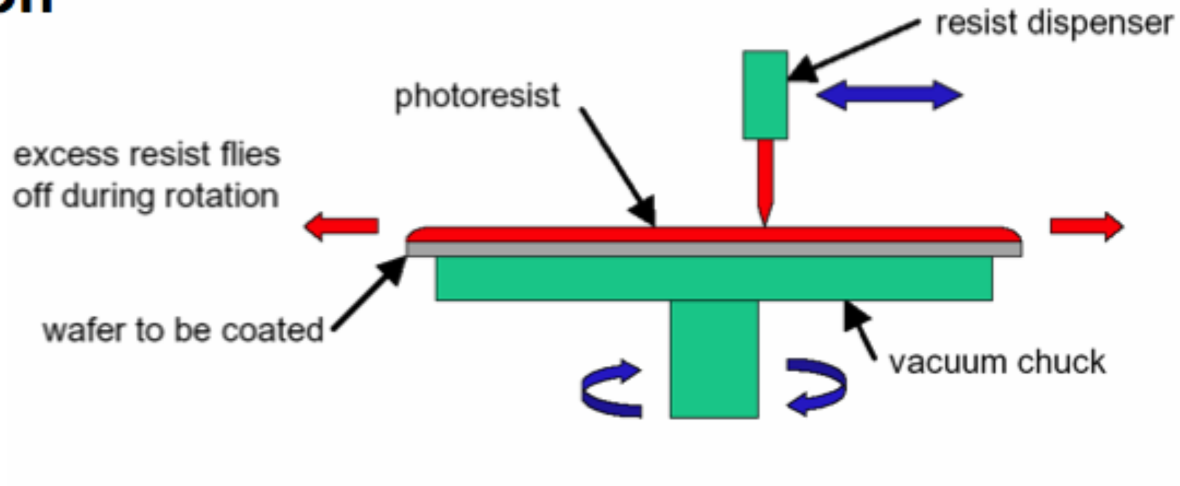
- **Advantages**
  - Negative photoresists have very high photospeeds
  - Adhere to substrate without pretreatment

- **Disadvantages**
  - Swelling of photoresists during the development.
    - an after develop bake will make the lies to return to their original dimension, but this swelling and shrinking process can cause the lines to be distorted. The minimum feature size of negative PR is limited to 2 μm
  - Dirt on mask causes pinhole
  - Developer is usually organic solvent
    - less ecological



Photoresist Deposition Methods

- **Spin on**



Thickness of PR $$t := K \cdot S \cdot \left(\frac{\nu}{\omega^2 \cdot R^2} \right)^{\frac{1}{3}}$$

t = thickness
K = constant
S= fraction of solids
υ= viscosity
ω= angular velocity
R = radius

- **Spray on**

- **Plate on**

Resists, Organic material, polymer, Benzene ring

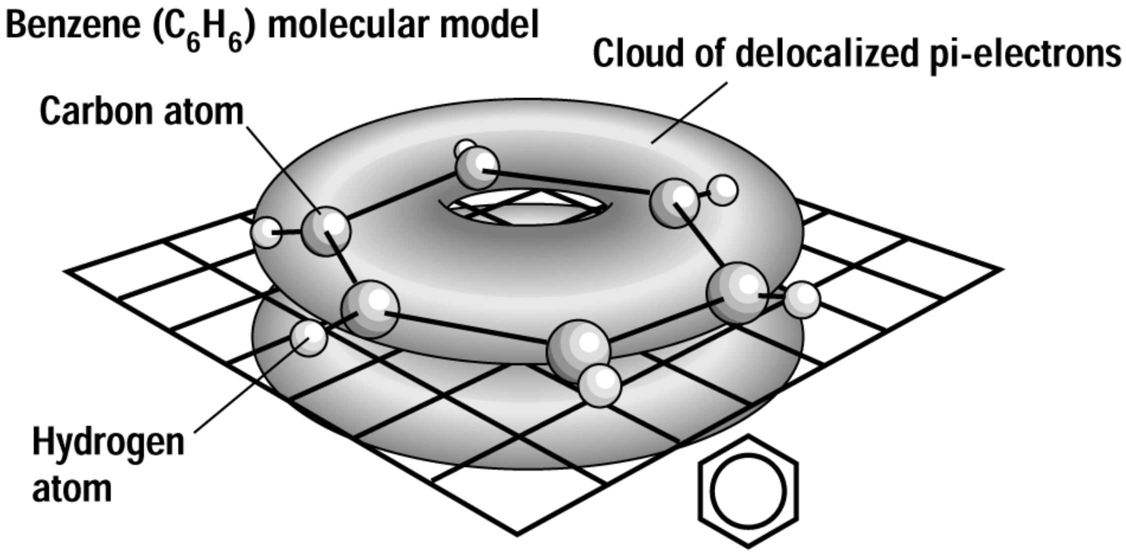


Figure 8.1 Diagram of simple benzene aromatic ring. The delocalized pi-bond electrons are in a ring that surrounds the nuclei. The symbol indicates the currently accepted ring notation.

Toulen, Clorobenzene, Naphtalene

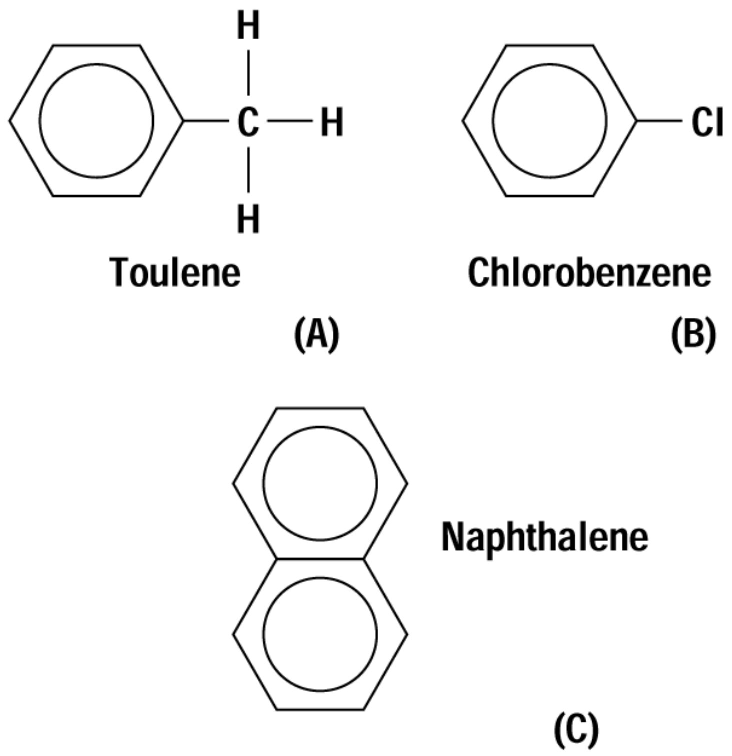


Figure 8.2 Some aromatic-based compounds based on (A) single site substitution, (B) double site substitution, and (C) aromatic condensation.

Novolac chem structure

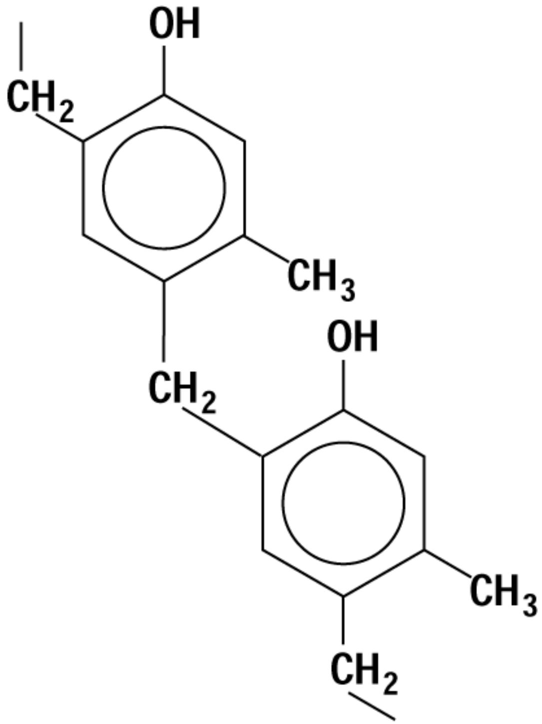


Figure 8.4 Meta-cresol novolac, a commonly used resin material in g- and i-line applications. The basic ring structure may be repeated from 5 to 200 times.

DQ chemical structure

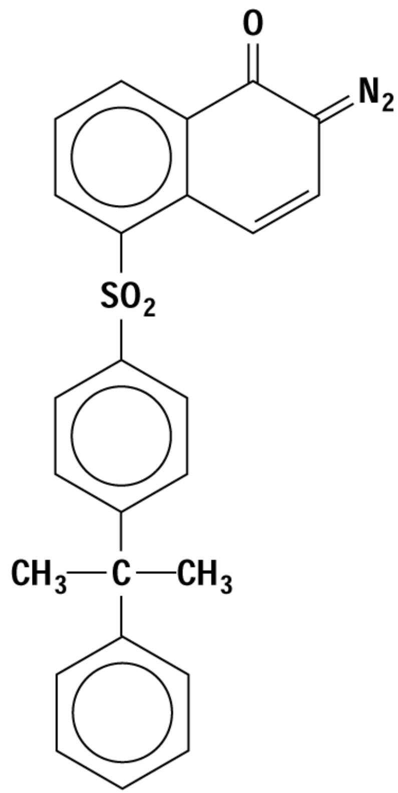


Figure 8.5 Diazoquinone (DQ), the most commonly used photoactive compound for g- and i-line applications. The right-hand ring is not an aromatic but has a double bond.

Inorganic resist

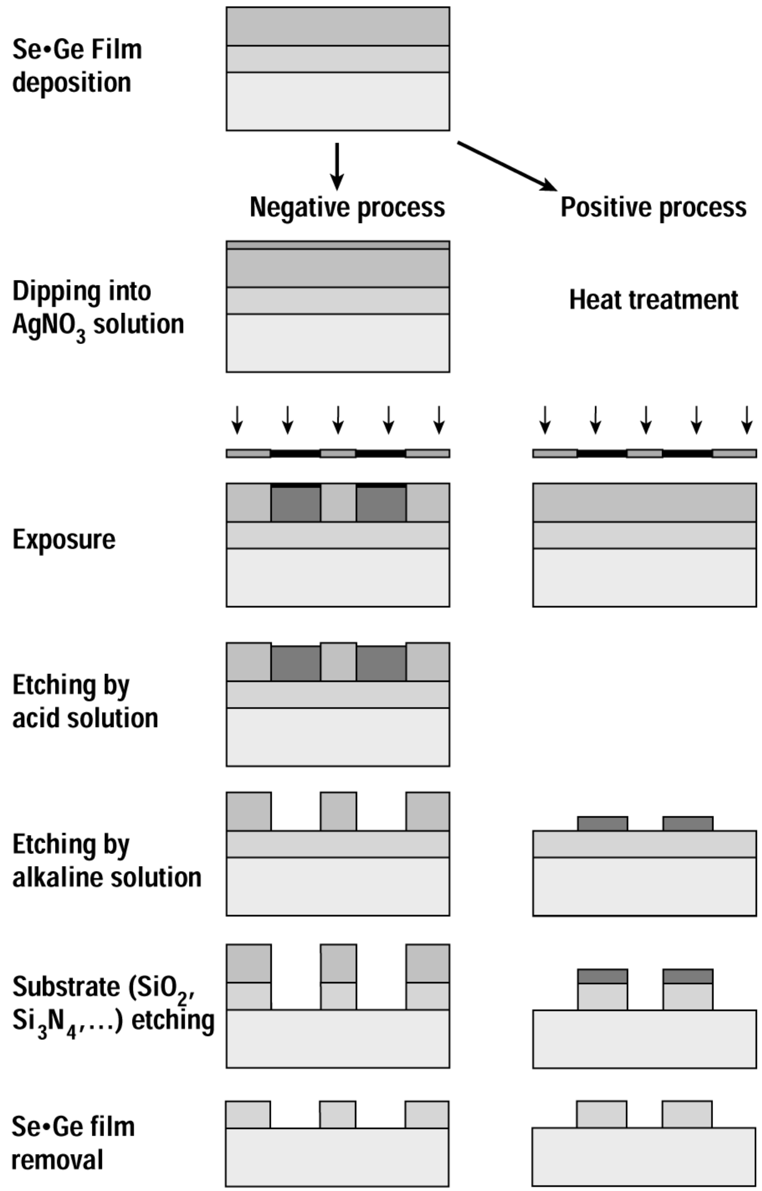


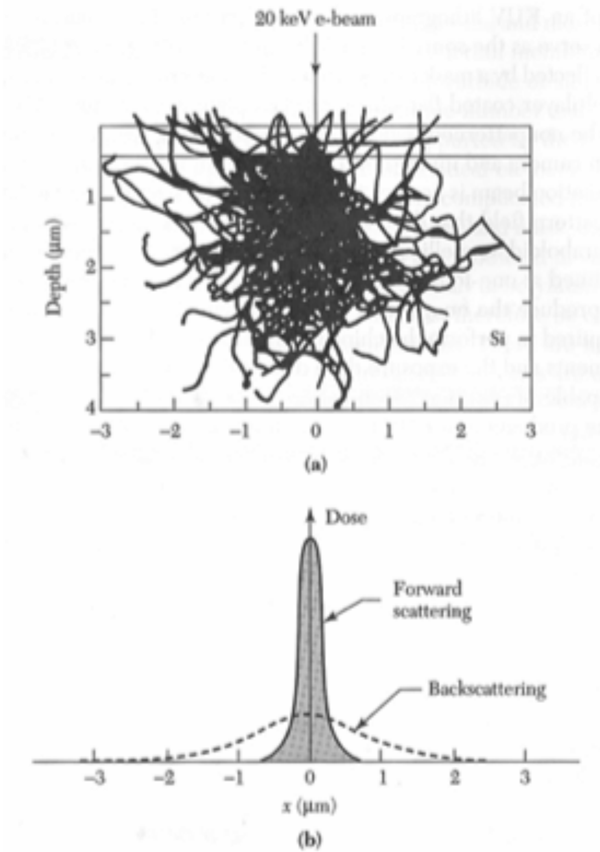
Figure 8.15 Processing sequence for Ag/Se–Ge resists *(after Yoshikawa et al., reprinted by permission, AIP).*

•Electron Beam (E-Beam) Lithography

- •Electron-beam is used for direct writing
- •E-beam lithography is primarily used to produce photomasks
- •Electron resist : PMMA

•**Advantages:**

- •Sub-micro resolution (even 20nm resolution can be achieved)
- •Direct patterning without a mask
- •Greater depth of focus
- •Highly automated and precise control



•**Disadvantages:**

- •Proximity effect due to electron scattering
- •Very low throughput (10 wafers per hour)
- •Very expensive

E-beam lithography,

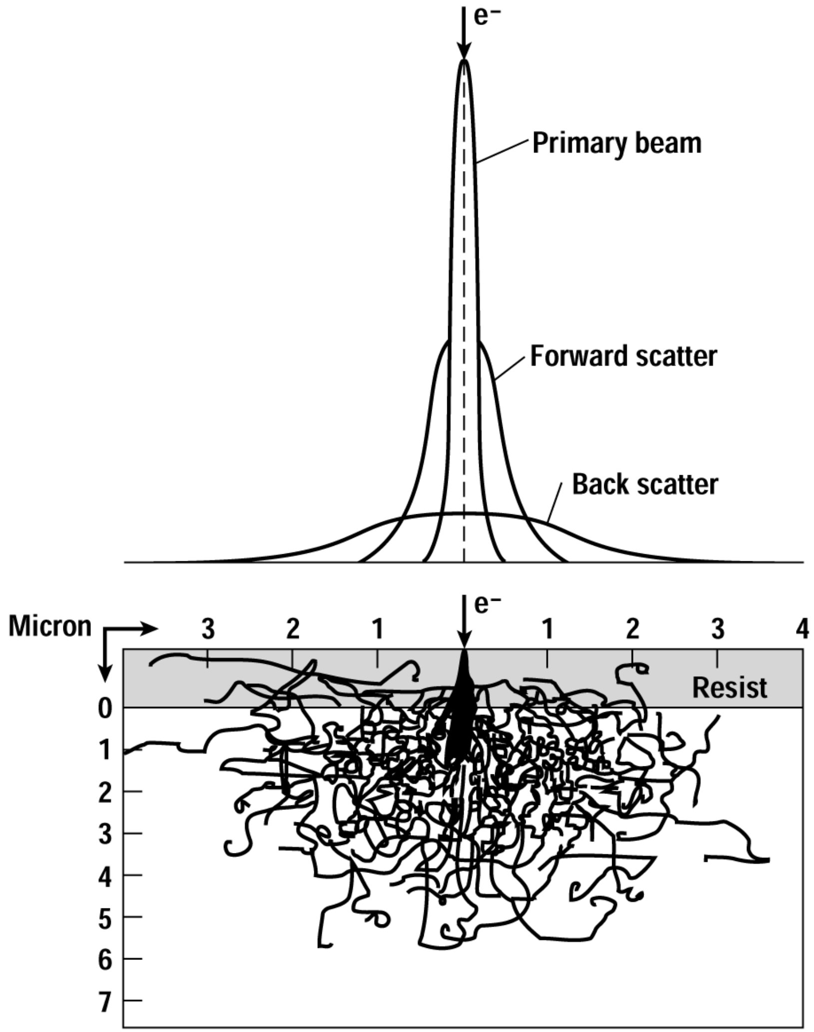


Figure 9.10 Monte Carlo simulation of electron trajectories during an EBL exposure. The upper curve indicates the forward and backscattered components of the beam (after Hohn, reprinted by permission, SPIE).

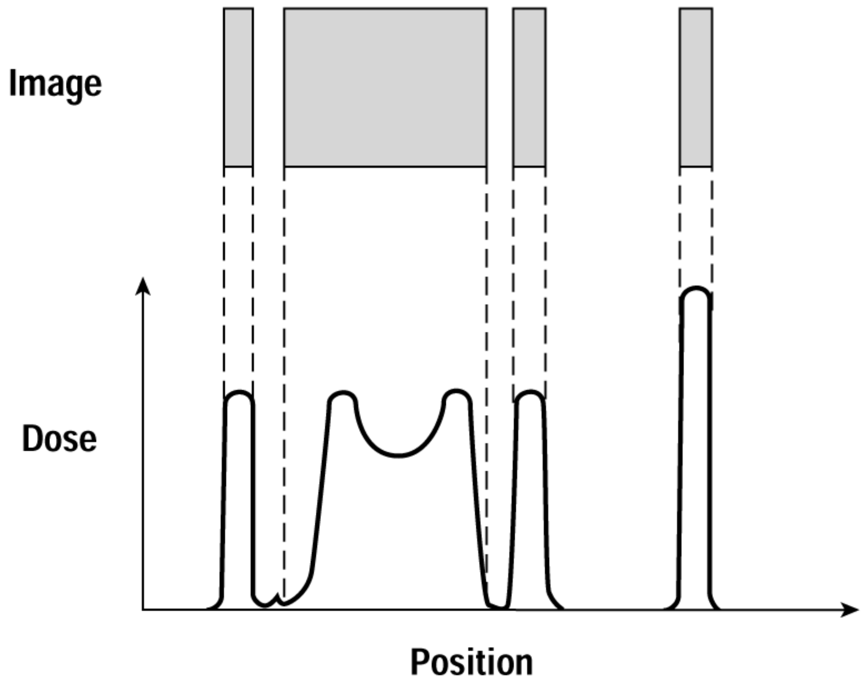


Figure 9.11 Small and large figures to be patterned with EBL requires position-dependent dosage to compensate for proximity effects.

E-beam lithography,

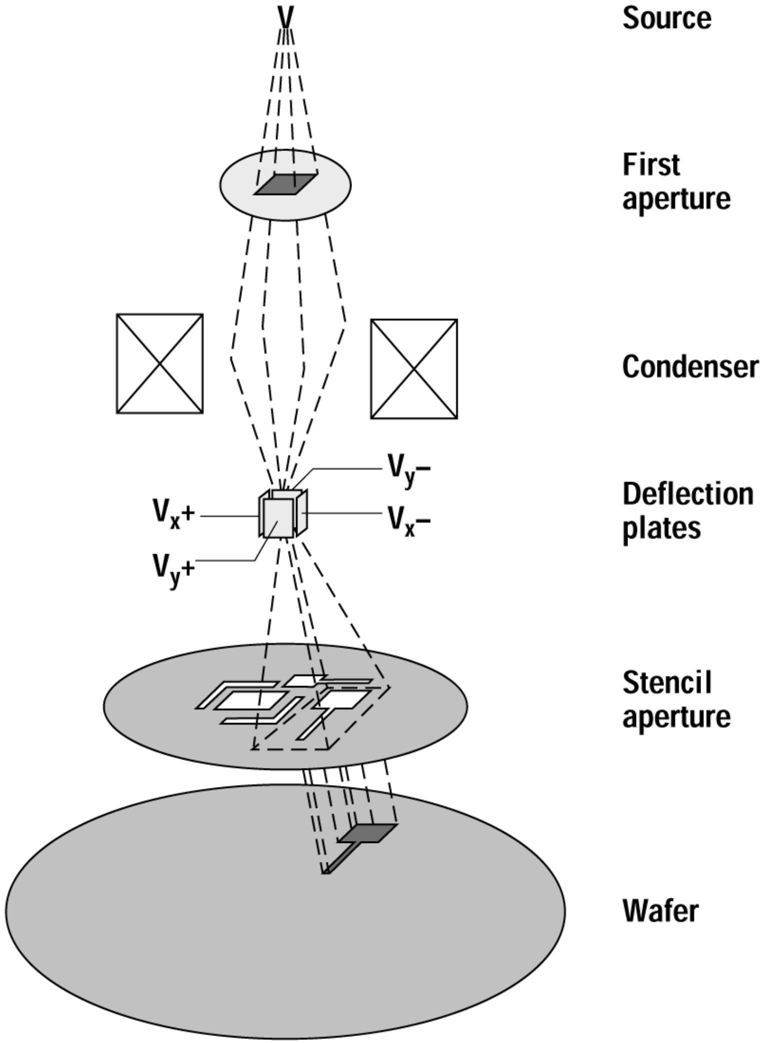


Figure 9.6 The use of stencil masks with EBL to improve system throughput. This type of exposure is

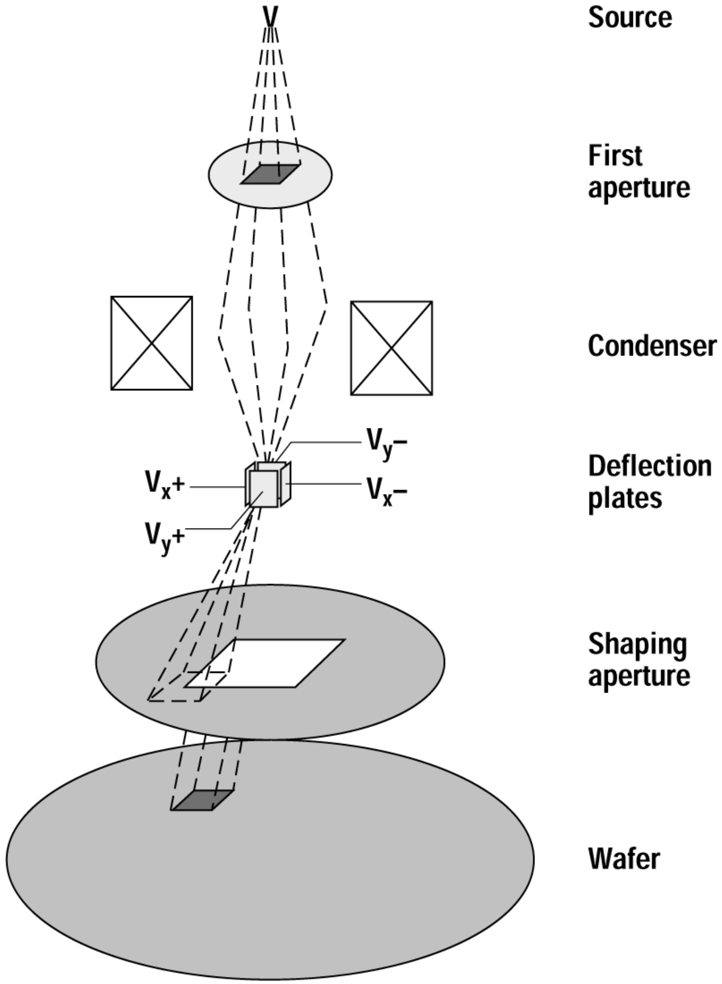


Figure 9.7 A variable shaped beam exposure system using mechanical beam stops for beam shaping. The broad beam exposes many pixels

E-beam lithography,

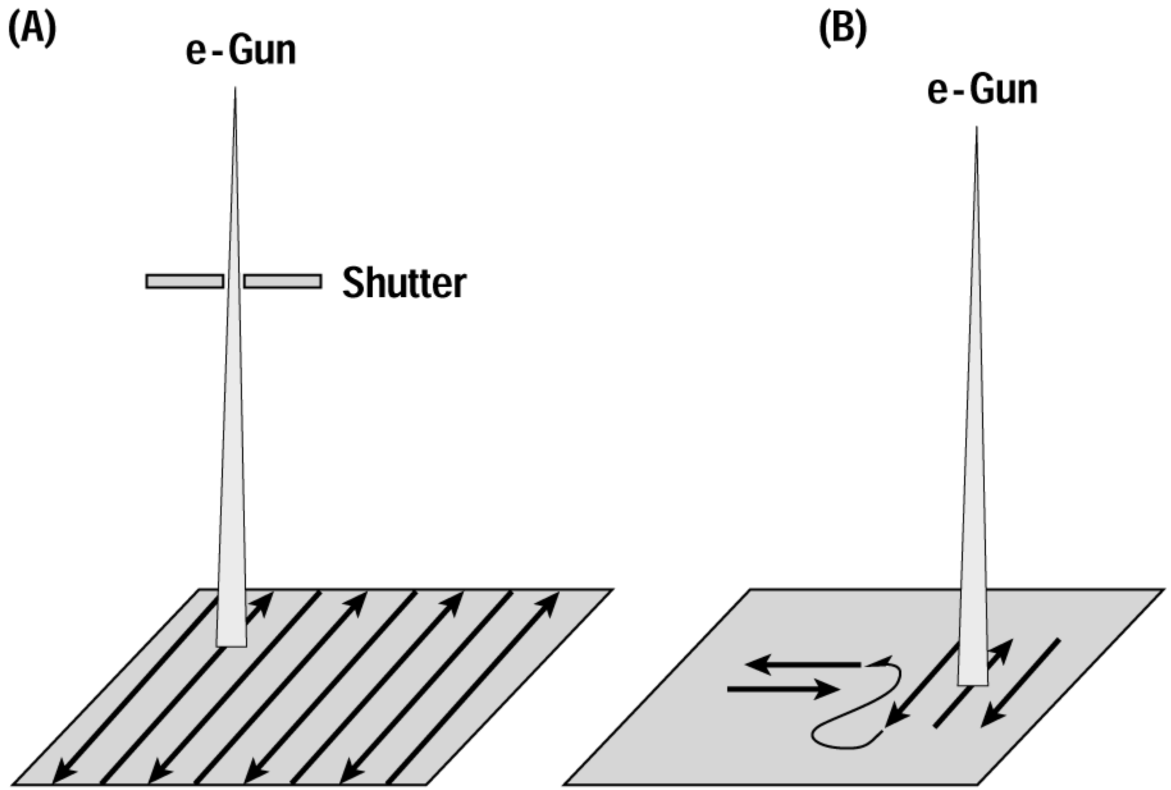


Figure 9.9 A comparison of scanning methodologies: raster scan (A) and vector scan (B).

E-beam lithography,

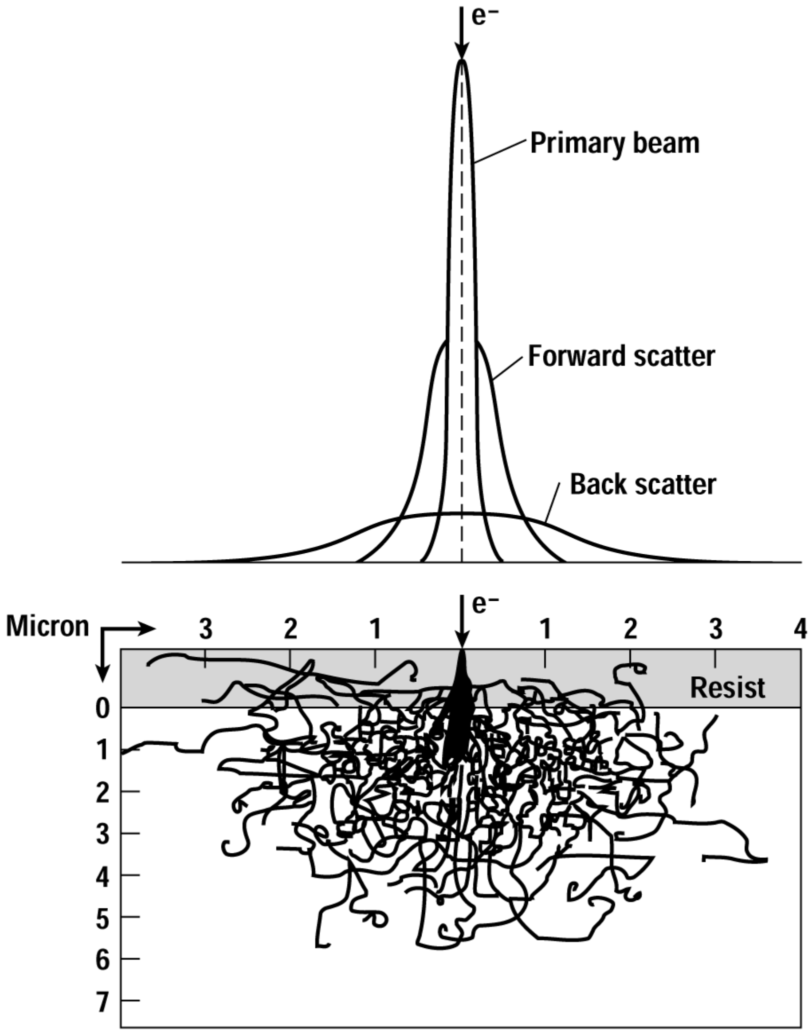


Figure 9.10 Monte Carlo simulation of electron trajectories during an EBL exposure. The upper curve indicates the forward and backscattered components of the beam *(after Hohn, reprinted by permission, SPIE)*.

X-ray litography, X-ray sources

3 sources: Electron impact, Plasma, Storage ring

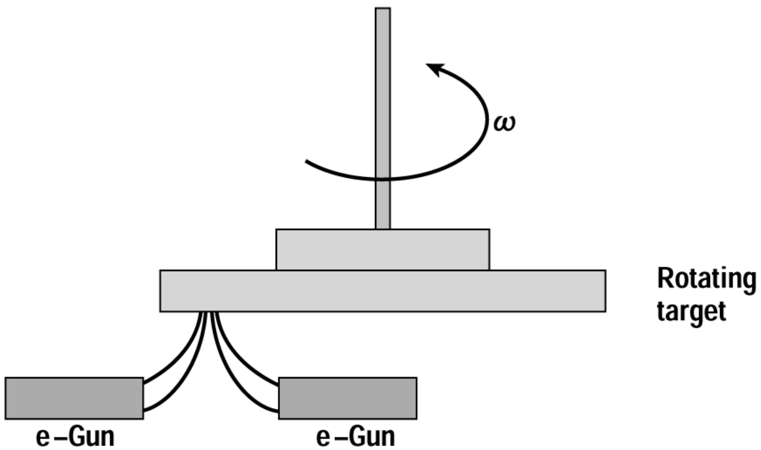


Figure 9.14 A simple rotating electron impact x-ray source uses electron beams focused on a rotating tungsten anode.

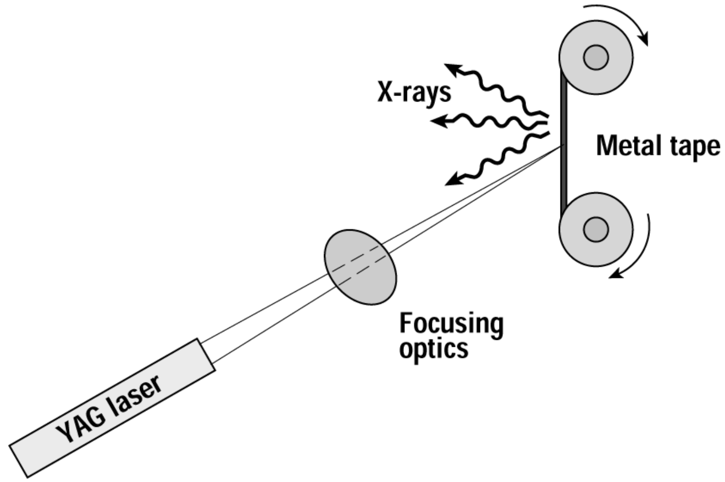


Figure 9.15 Laser plasma-heated x-ray source uses a focused high-intensity pulsed laser to ablate a metal film. The superheated metal atoms radiate x-rays.

X-ray lito

X-ray source

Storage ring

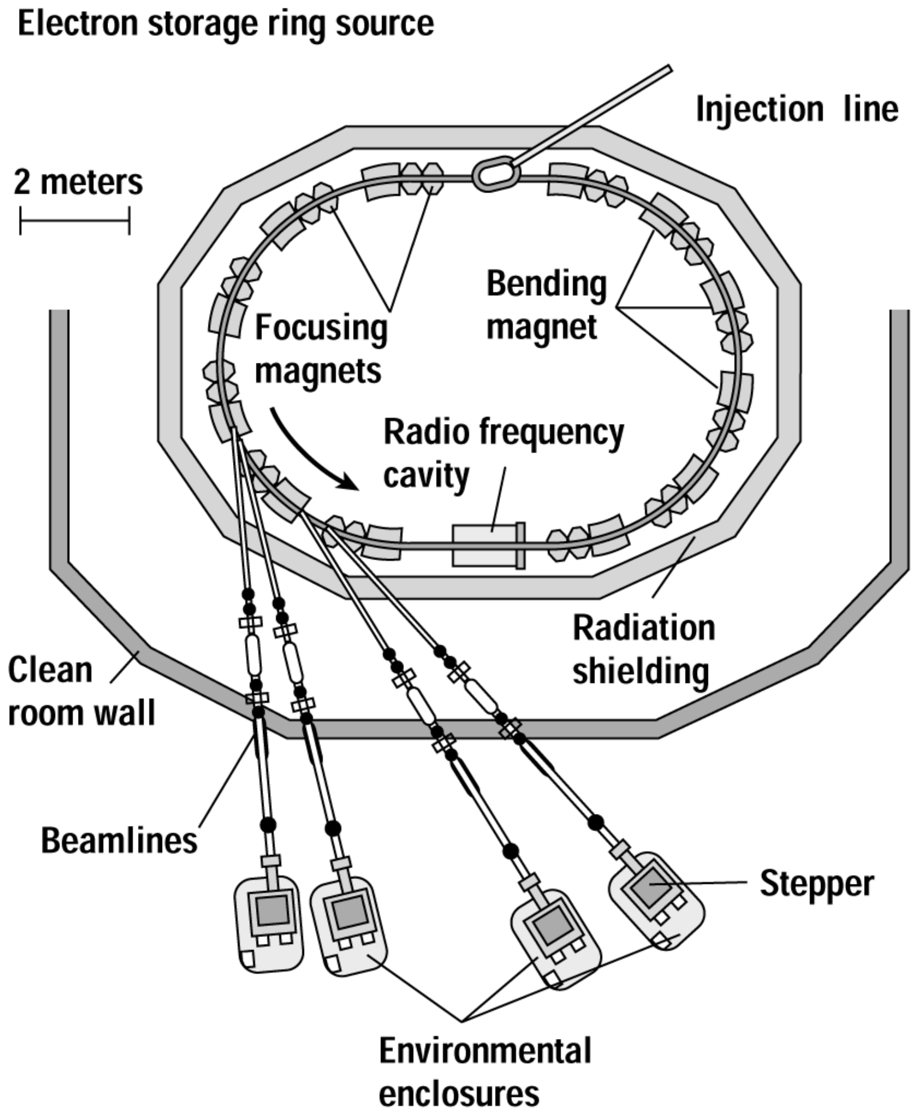
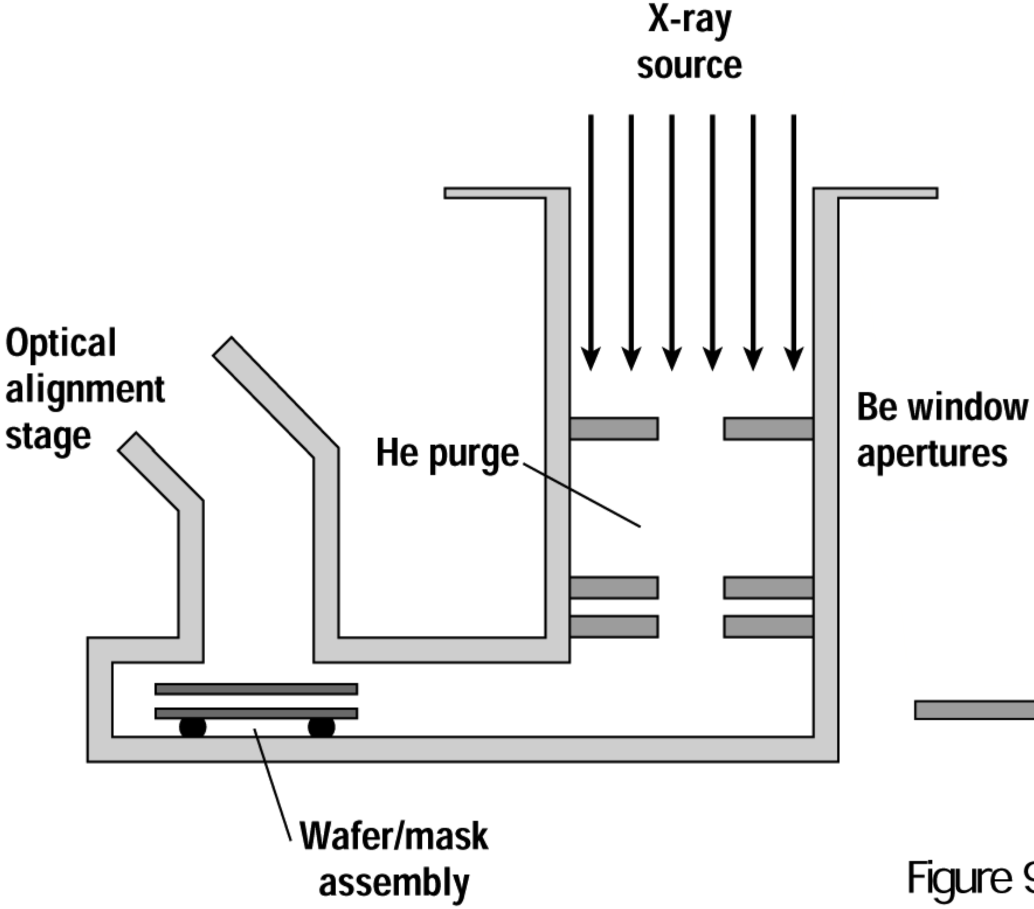


Figure 9.16 Basic schematic of an electron storage ring for XRL. Several exposure stations are indicated (*after Glendenning and Cerrina, reprinted by permission, Noyes Publications*).

X-ray lito



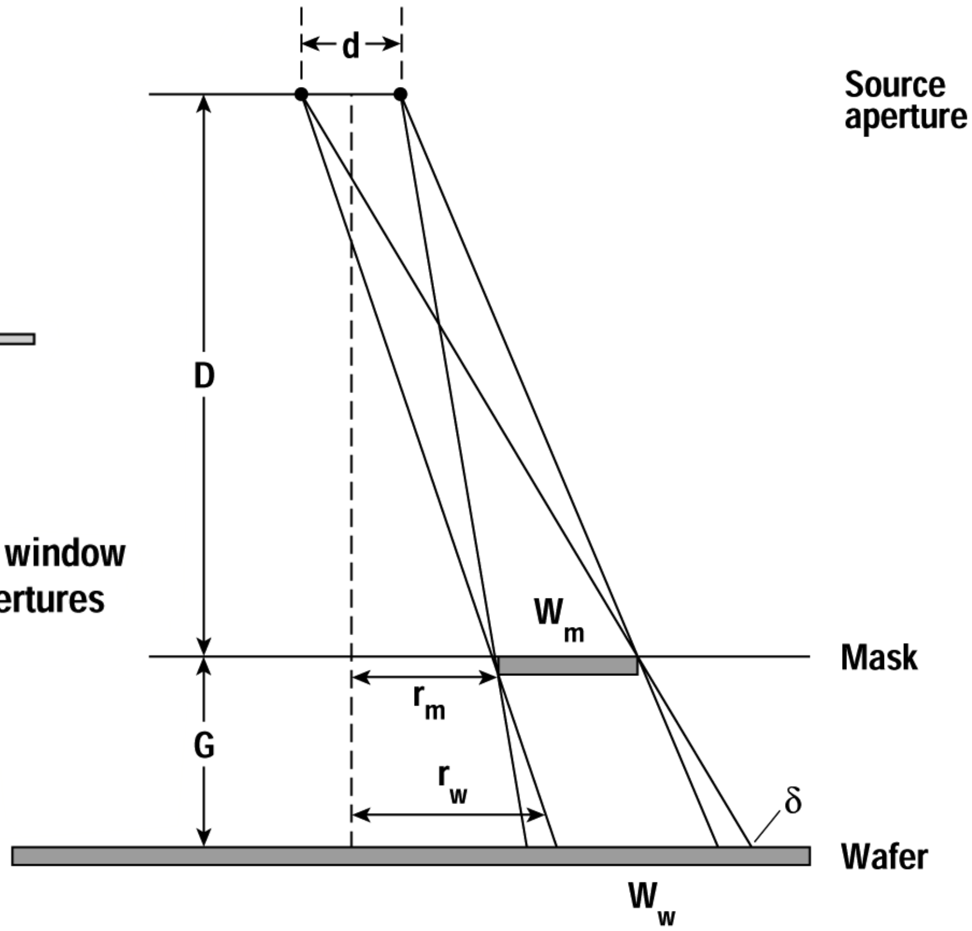
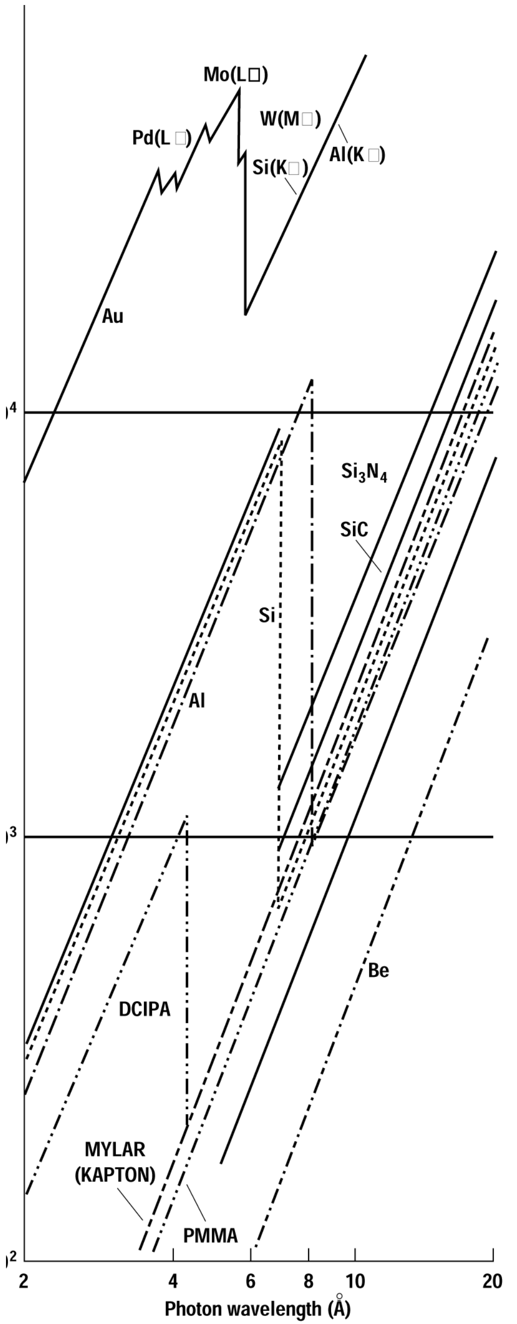


Figure 9.19 Geometry of the exposure system shown in Figure 9.18.

Figure 9.18 Simple proximity x-ray lithography aligner. The basic system is very similar to optical proximity systems.

X-ray lito

X-ray optics



e 9.2 Absorption coefficients for some common
rials as a funtion of photon energy *(after Glendenning
Cerrina, reprinted by permission, Noyes Publications).*

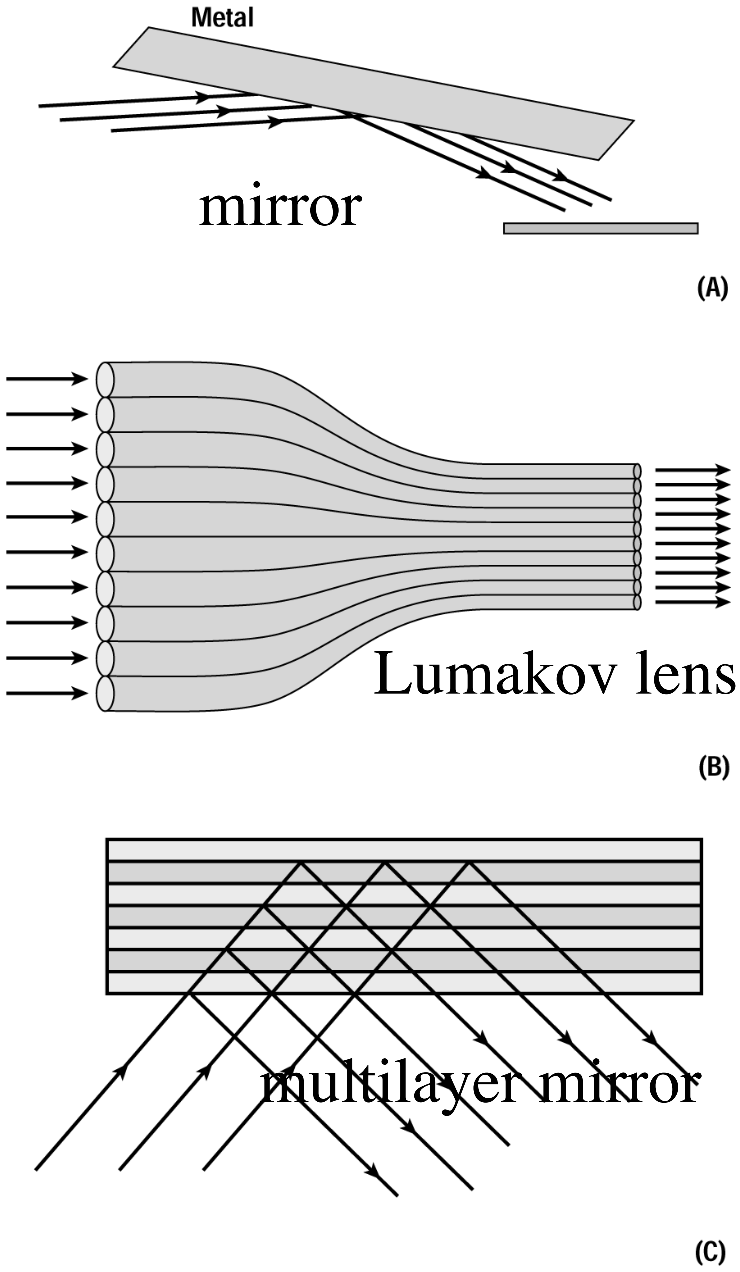


Figure 9.20 Possible choices for x-ray optics systems include glancing angle metal mirrors (A), Kumakhov lenses (B), and multilayer mirror (C).

X-ray lito

X-ray masks

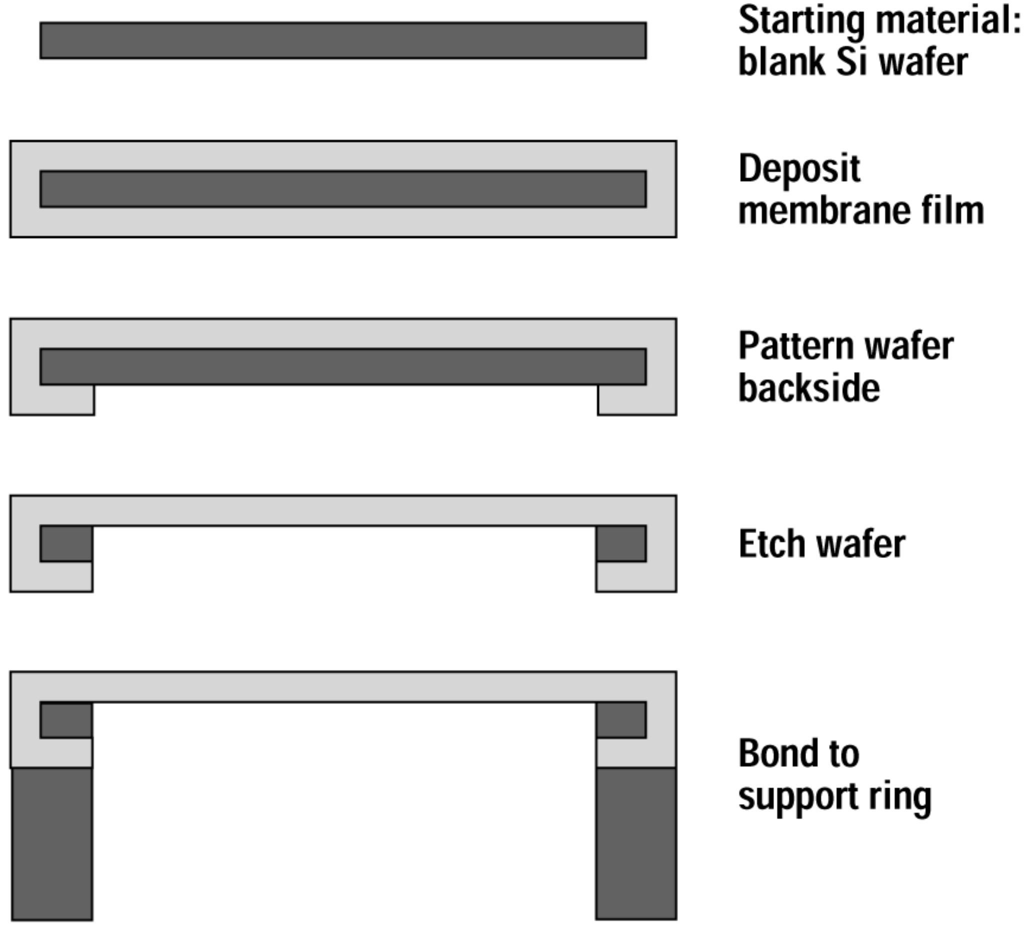


Figure 9.21 X-Ray mask blank fabrication process produces a membrane stretched across a mechanical support ring.

X-ray lito

X-ray masks

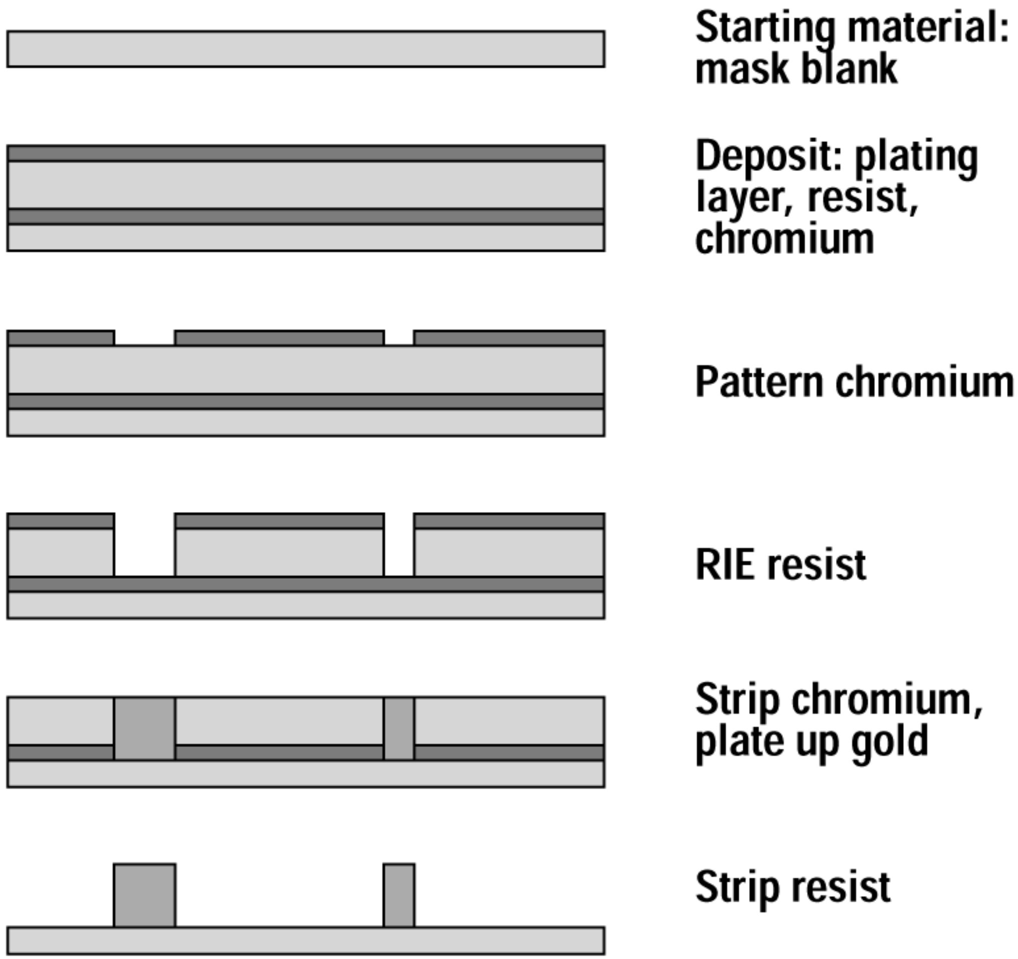


Figure 9.22 Additive process for x-ray mask fabrication.

X-ray lito

X-ray masks

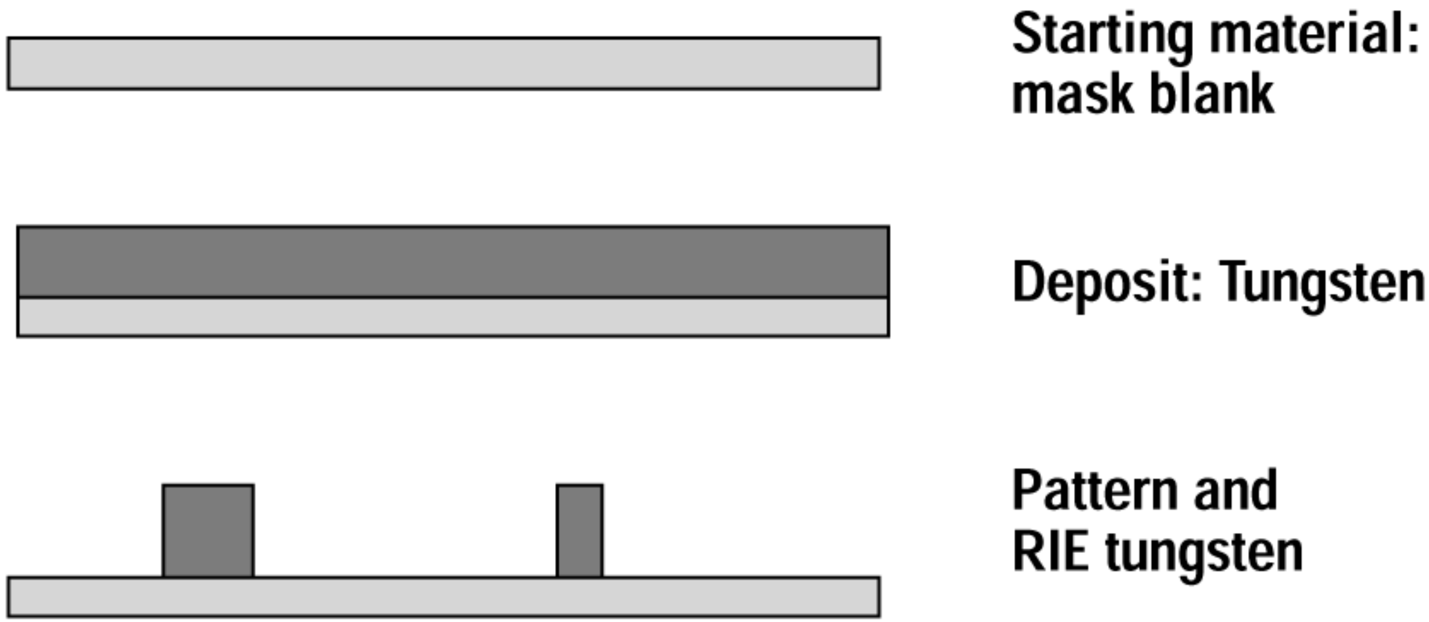


Figure 9.23 Subtractive process for x-ray mask fabrication.

X-ray lito

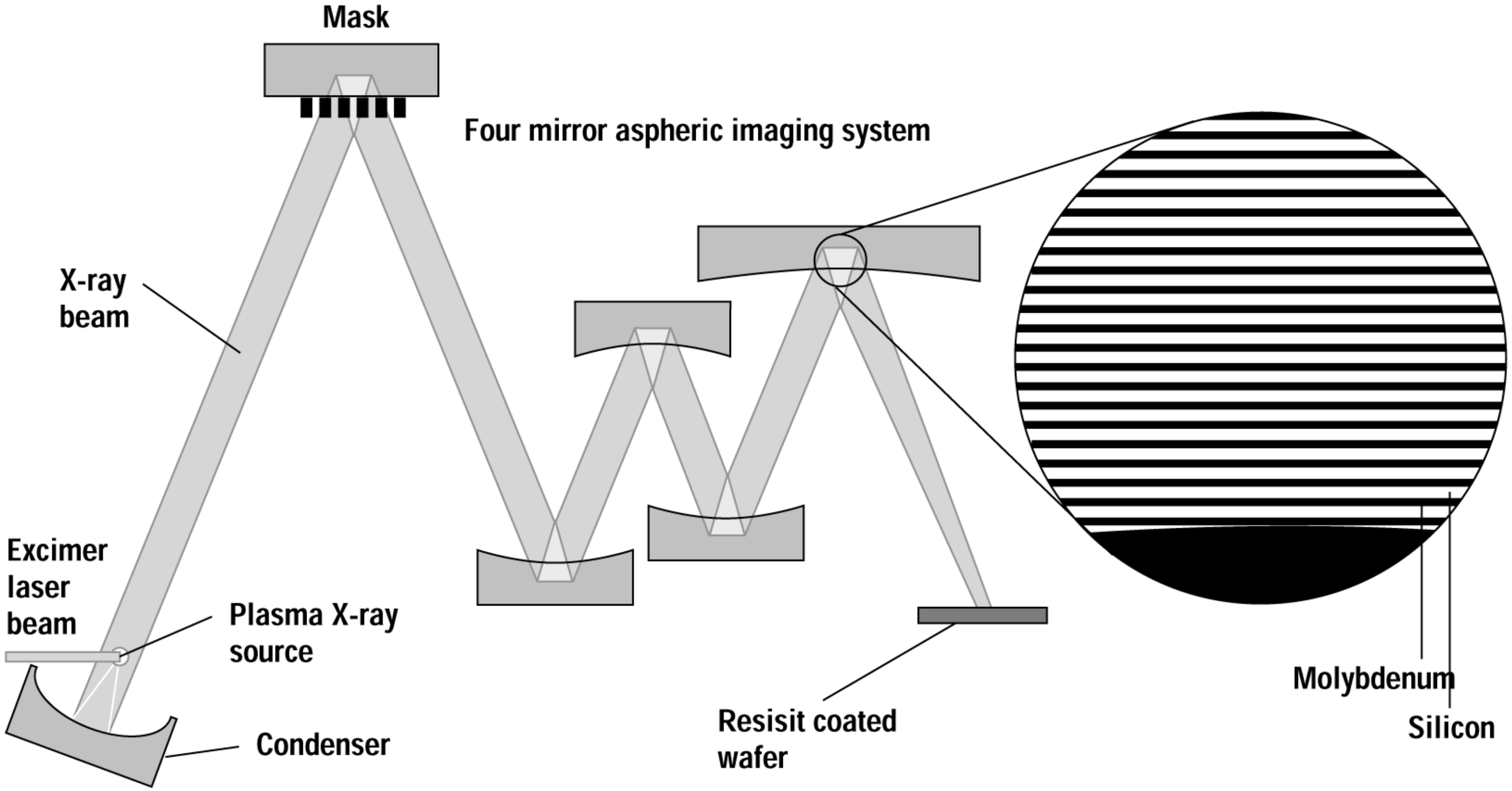


Figure 9.24 An x-ray projection lithography system using x-ray mirrors and a reflective mask *(after Zorpette, reprinted by permission, © 1992 IEEE).*

SCALPEL: projection electron beam lito

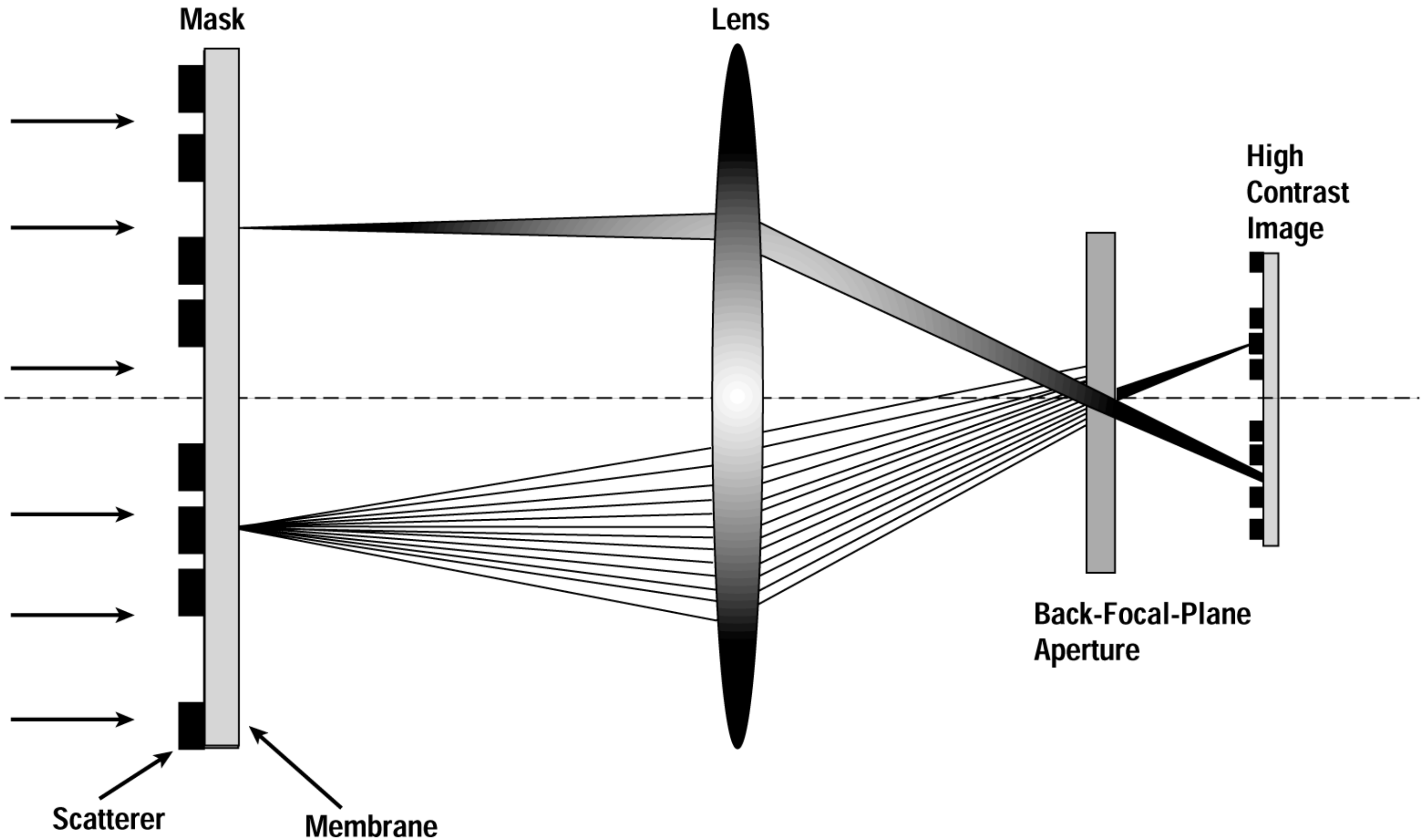


Figure 9.25 SCALPEL principle of operation.

•Ion Beam Lithography

•High energy ion beam is used for writing

•PR : PMMA

•**<u>Advantages:</u>**

•Higher resolution than optical, x-ray or e-beam lithography because Ions have a higher mass and therefore scatter less than electrons

•**<u>Disadvantages:</u>**

Ion beam lithography may suffer from random space-charge effects, causing broadening of ion beam

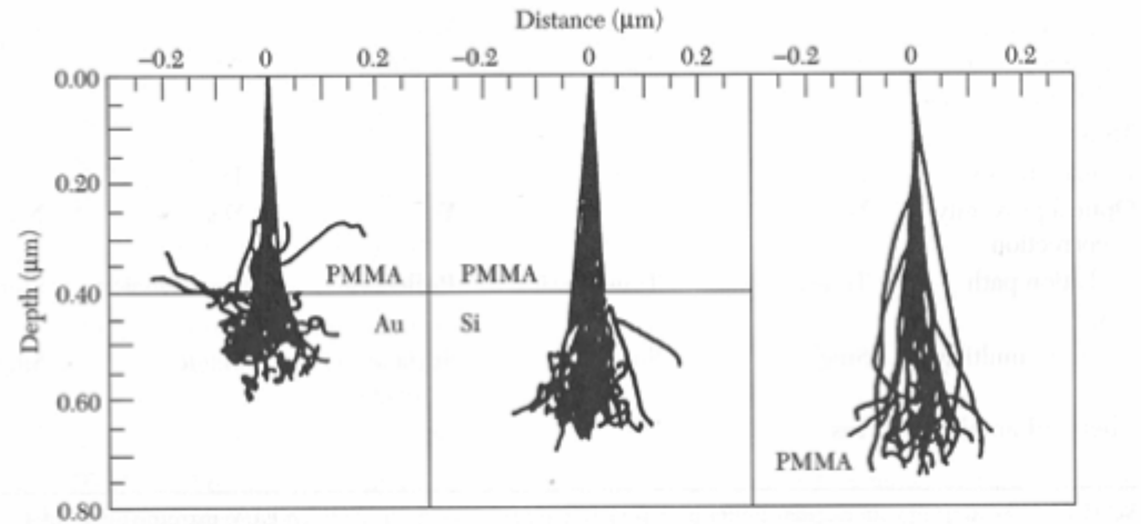


Figure 4.19 Trajectories of 60-keV H^+ ions traveling through PMMA into Au, Si, and PMMA.[17]

Nanoimprint lithography

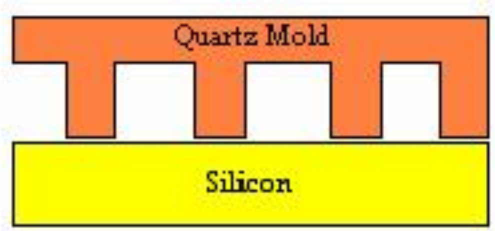


Figure 6: Quartz Mold on Silicon

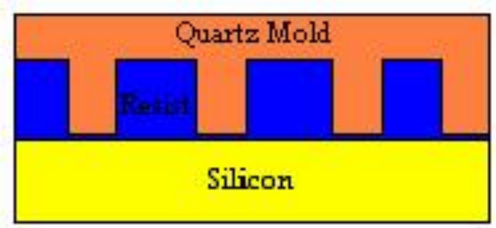


Figure 7: Liquid Resist between Mold and Silicon

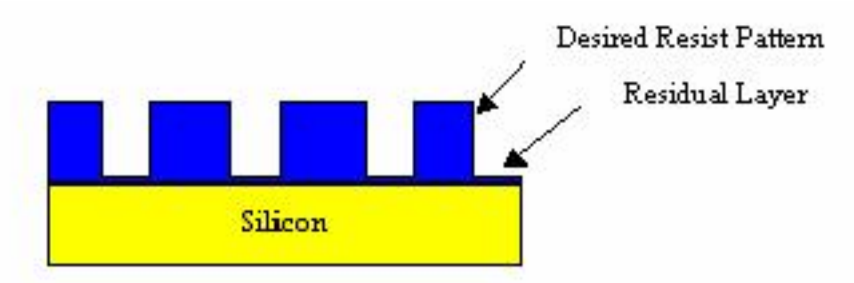


Figure 8: Quartz Mold Removed, with Desired Resist Pattern and Residual Layer

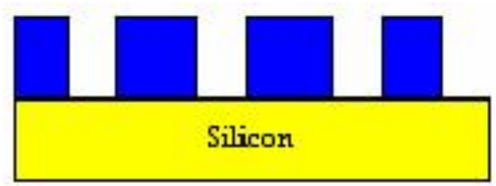


Figure 9: Desired Resist Pattern, after etching a few times

Laser Assisted Direct Imaging

Figure 10 : Quartz Mold Placed on Top of Silicon

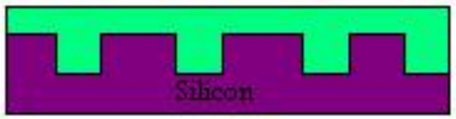


Figure 11: Silicon is Melted into Mold by Laser

Figure 12: Mold is Removed for Desired Silicon Pattern

Need for nanotechnology