B.Tech. (ECE), VI Sem
Unit-3
VLSI Technology

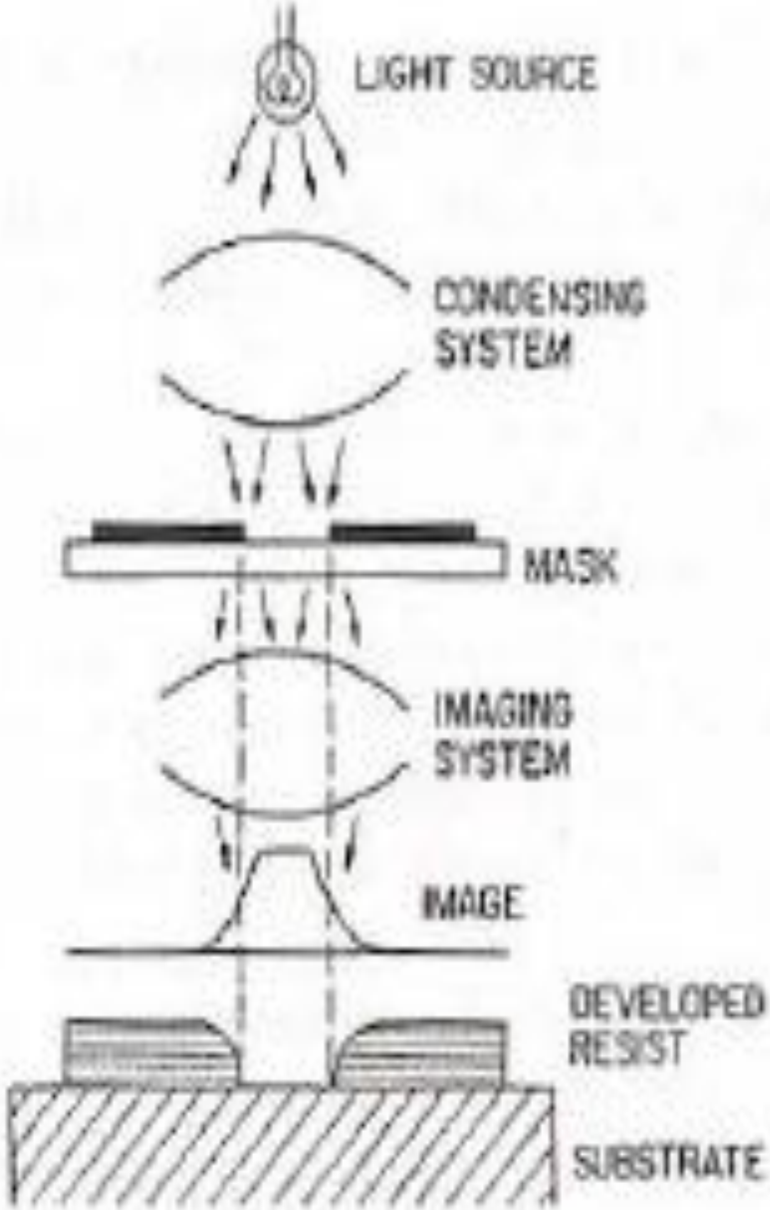
Lithography
Basic Fundamentals and Concepts

Part-I
March-April 2020

Photolithography Basic Concept

- ❖ Lithography consists of patterning substrate by employing the interaction of beams of photons or particles with materials.
- ❖ Photolithography is widely used in the integrated circuits (ICs) manufacturing.

- ❖ Process of IC manufacturing consists of a series of 10-20 steps or more, called mask layers where layers of materials coated with resists are patterned then transferred onto the material layer.


LIGHT SOURCE
CONDENSING SYSTEM
MASK
IMAGING SYSTEM
IMAGE
DEVELOPED RESIST
SUBSTRATE

Photolithography Basics

- A photo-lithography system consists of a light source, a mask, and a optical projection system.

- Photo-resists are radiation sensitive materials that usually consist of a photo-sensitive compound, a polymeric backbone, and a solvent.

- Resists can be classified upon their solubility after exposure into: positive resists (solubility of exposed area increases) and negative resists (solubility of exposed area decreases).

Types of Basic Lithography Processes

Different Processes of Photo-Lithography

❖Resist Coating (1)

- Surface preparation
- Spin coating
- Soft bake (pre-bake)

❖Exposure (2)

- Alignment
- Exposure
- Lift off/deposition

❖ Development (3)

- Development
- Hard bake (post-bake)
- Stripping

❖ Pattern Transfer (4)

- Etching

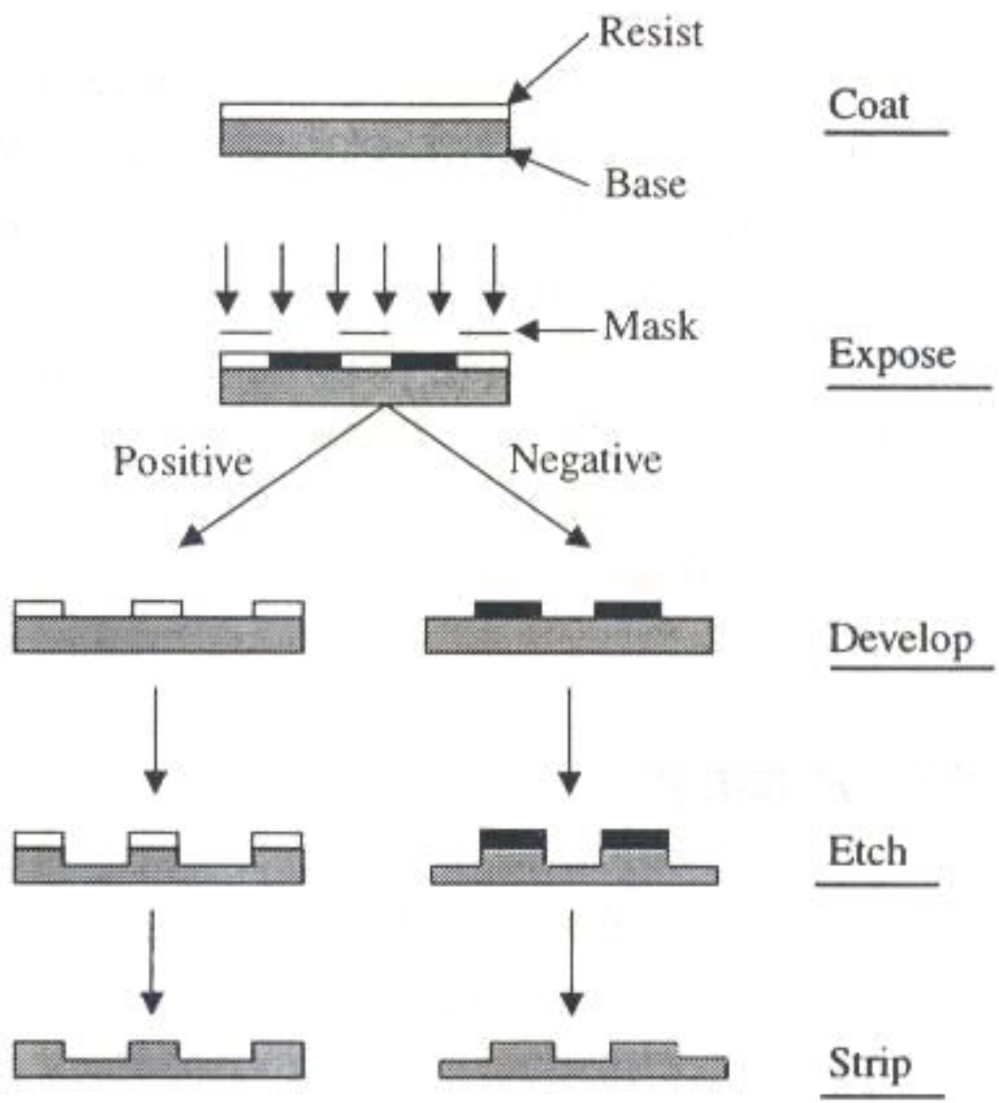
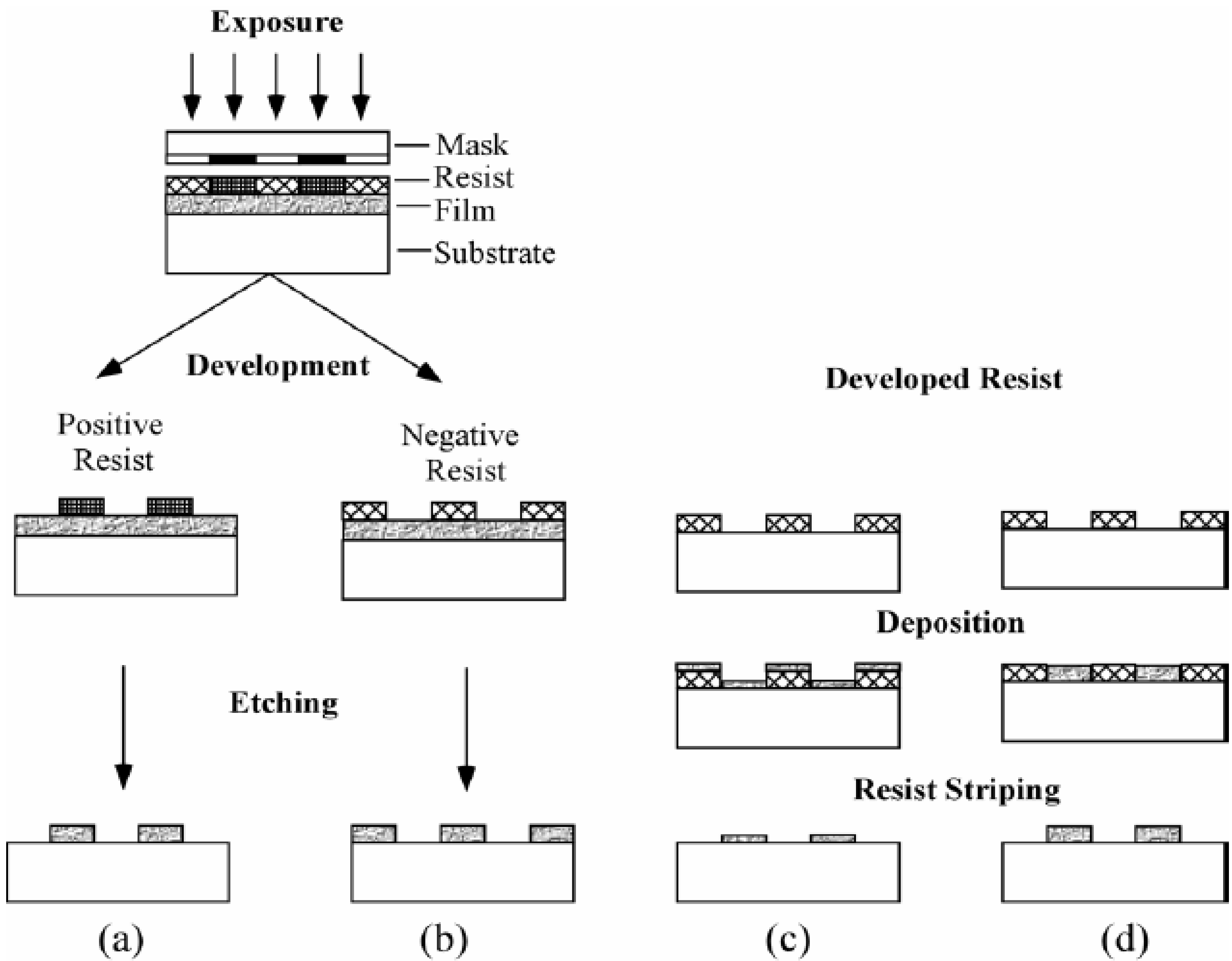


Fig. 7.1. Schematic representation of the photolithographic process sequences, in which images in the mask are transferred to the underlying substrate surface.



Exposure
Mask
Resist
Film
Substrate
Development
Positive Resist
Negative Resist
Etching
Developed Resist
Deposition
Resist Striping
(a)
(b)
(c)
(d)

Substrate Cleaning

❖ Particularly troublesome grease, oil or wax stains

- 2-5 min ultrasonic bath in trichloroethylene (TCE)
- or trichloroethane (TCA), 65-75ºC (carcinogenic)

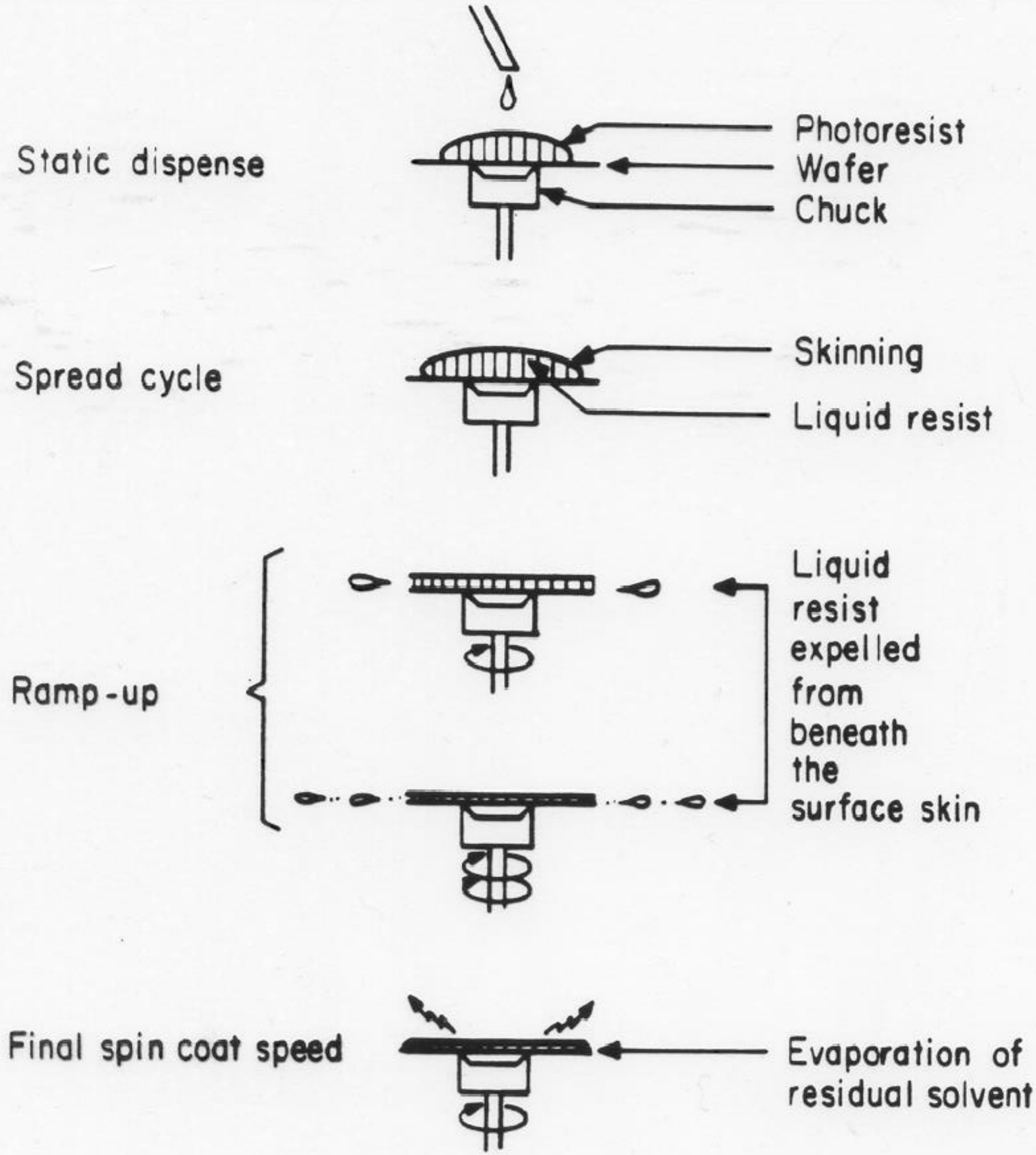
❖ Standard grease removal

- 2-5 min ultrasonic bath in acetone
- 2-5 min ultrasonic bath in methanol
- 2-5 min ultrasonic bath in D.I. H_2O
- Repeat the first three steps 3 times
- 30 sec rinse under free flowing D.I. H_2O

❖ Oxide and other material removal

- 5 min $H_2O:H_2O_2:NH_3OH$ 4:1:1 70-80ºC (cleaning Ge)
- 30 sec 50% HF (Glass or SiO2)
- D.I. H_2O 3 rinses
- 5 min $H_2O:H_2O_2:HCl$ 5:1:1 70-80ºC
- D.I. H_2O 3 rinses
- **Spin dry (wafer) / N_2 blow dry**

Spin Coating -A



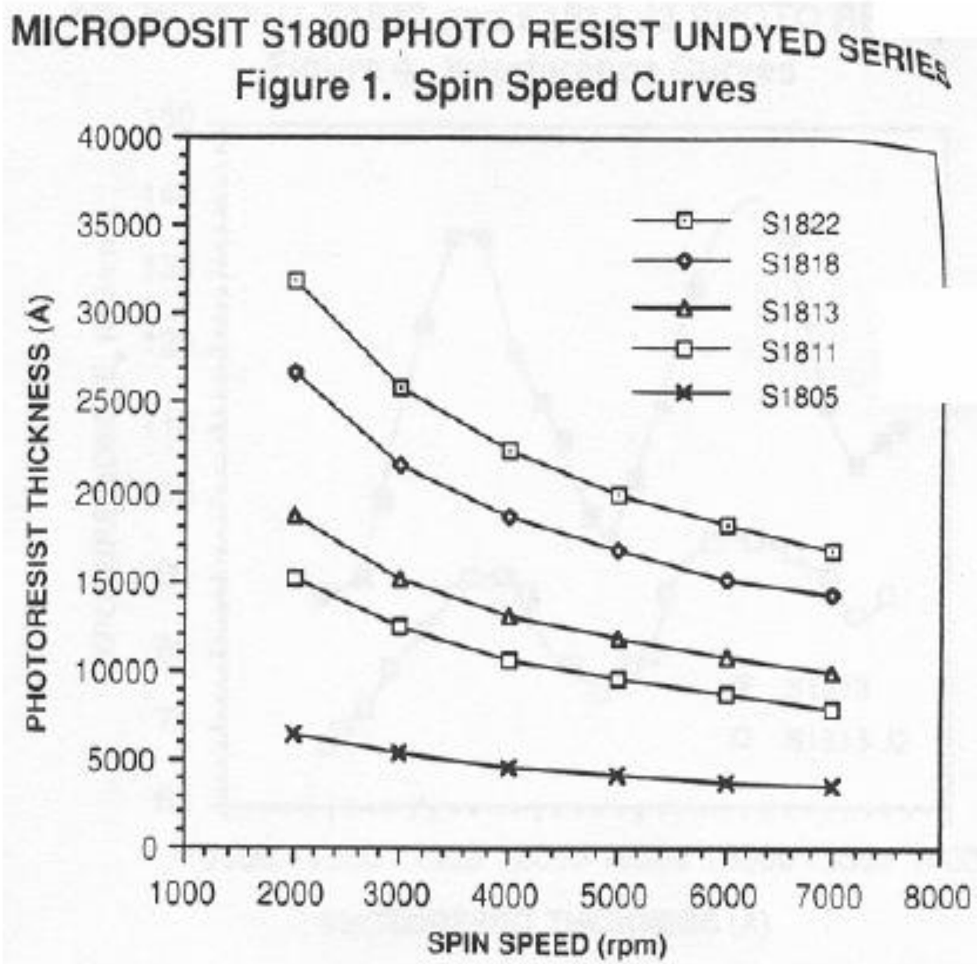
Spin Coating

Adhesion

- moisture (baking)
- wetting
- surface smoothness
- surface contamination

Spin coating

- 30-60s, 3000-6000rpm
- thickness:~µm
  - viscosity
  - spinning speed
- imperfections
  - striation
  - edge



Soft-bake

- **Remove the resist solvent**
- **Convection Oven**

  90-100 ºC, 15-20 min

  removal starts at surface

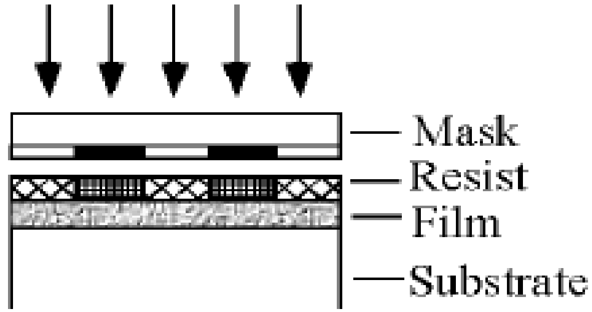
  solvent trapping
- **Conduction (hotplate)**

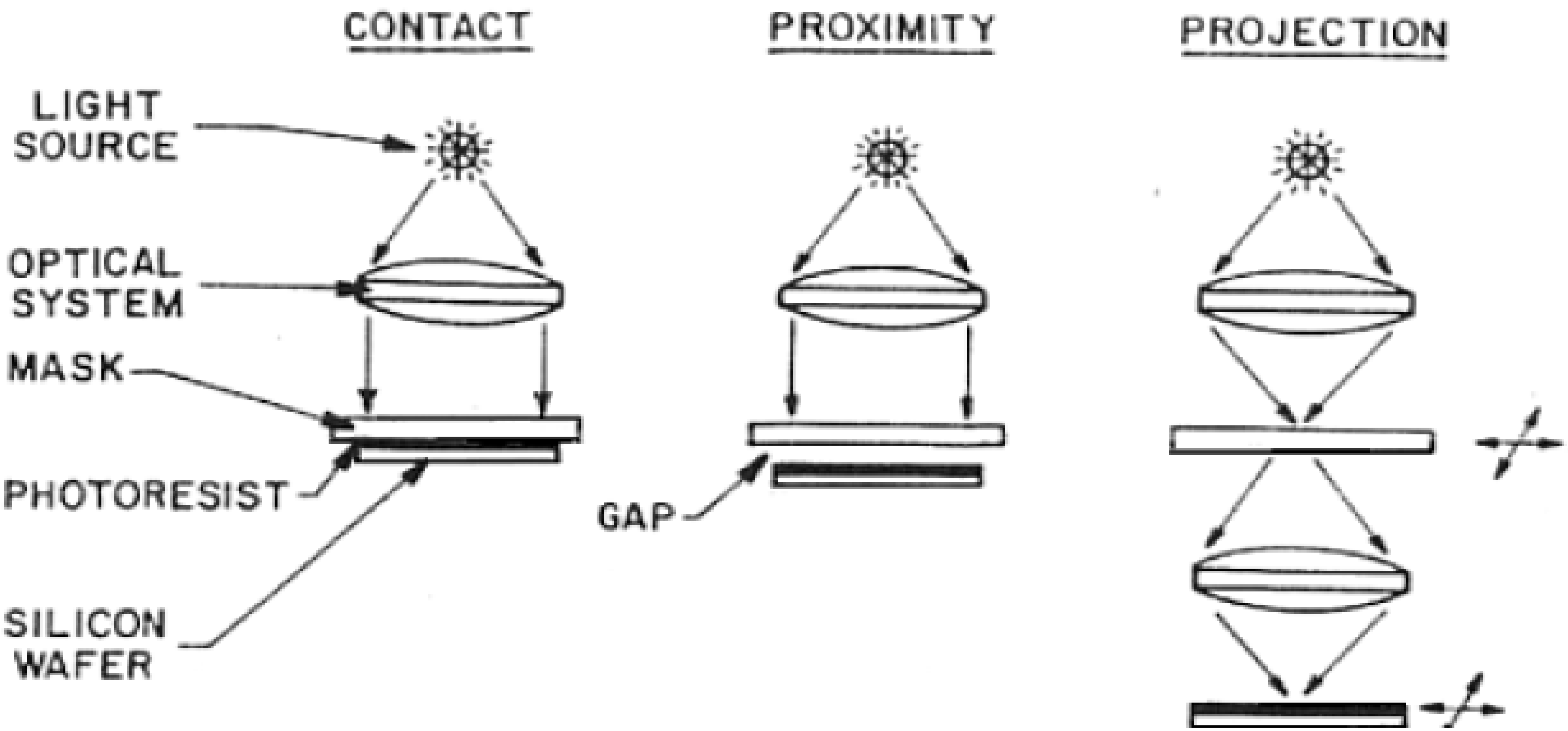
  75-85ºC, 40-60 sec

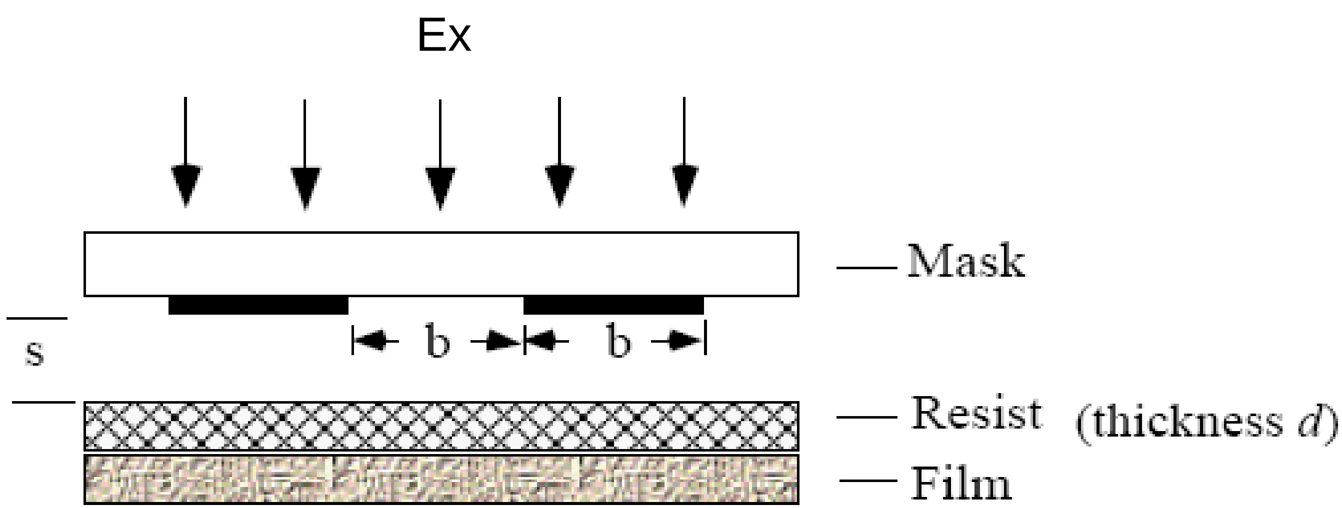
  removal starts at bottom

  uniform heating

Exposure


Mask
Resist
Film
Substrate


CONTACT
PROXIMITY
PROJECTION
LIGHT SOURCE
OPTICAL SYSTEM
MASK
PHOTORESIST
SILICON WAFER
GAP



Resolution limit:

Contact	Proximity	Projection
$2b_{min} = 3\sqrt{\lambda d / 2}$	$2b_{min} \approx 3\sqrt{\lambda s}$	$b_{min} = \frac{k\lambda}{NA}$

Beating the diffraction limit:

Near field optical lithography

see references 77-81 in the review paper [JMMM **256**, 449 (2003).]

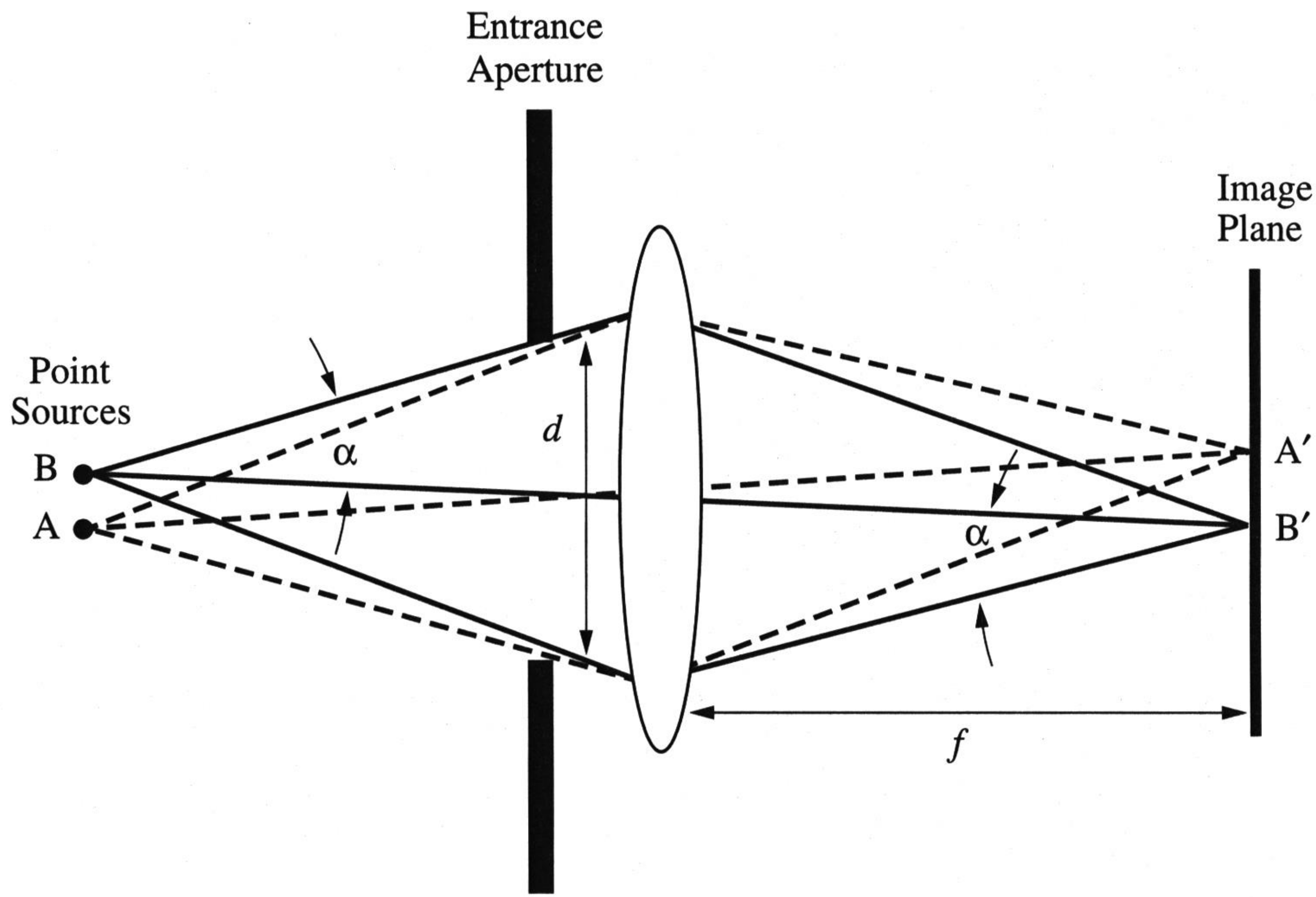


Figure 5–8 Illustration of the resolving power of a lens when two point sources are to be separated in the image.

- $R = k_1\lambda/NA$
- where λ is wavelength employed; NA is numerical aperture of lense and NA = sin α; k_1 is a constant, typically k = 0.6 - 0.8.

- $DOF = \pm k_2\, \lambda/(NA)^2$

Example Estimate the resolution and depth of focus of a state-of-the-art excimer laser stepper using a KrF light source ($\lambda = 248$ nm) with a $NA = 0.6$. Assume $k_1 = 0.75$ and $k_2 = 0.5$.

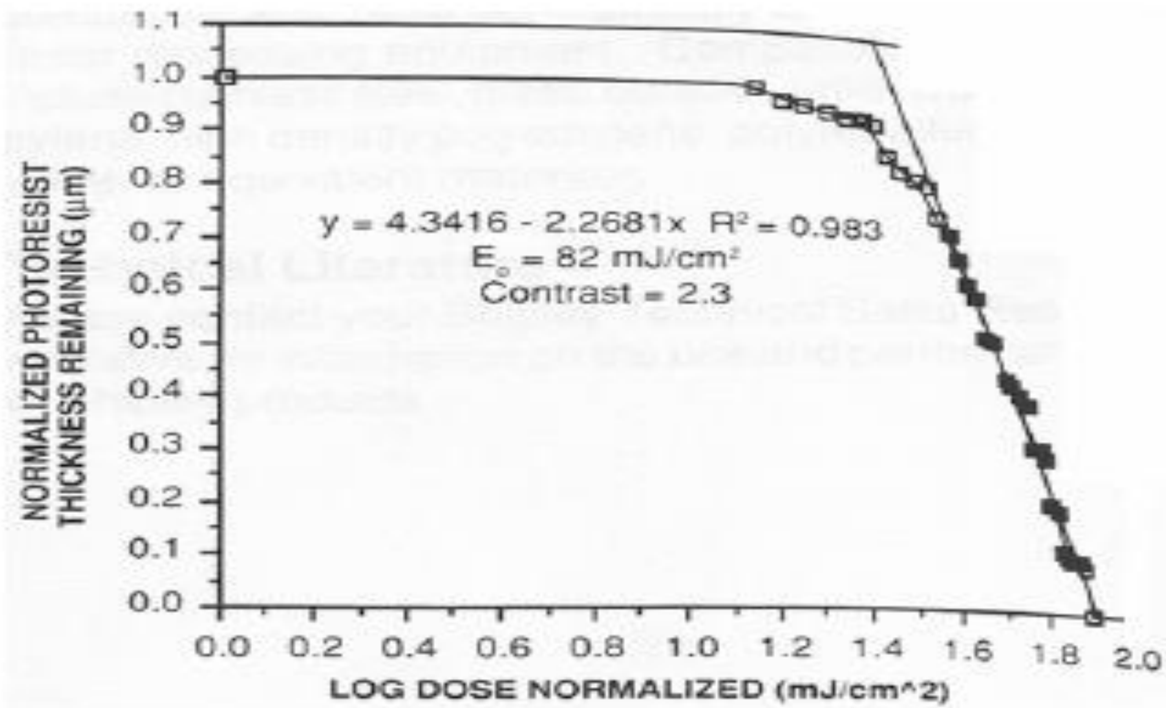
Answer

$$R = k_1 \frac{\lambda}{NA} = 0.75 \left(\frac{0.248\ \mu\text{m}}{0.6} \right) = 0.31\ \mu\text{m}$$

$$DOF = \pm k_2 \frac{\lambda}{(NA)^2} = \pm 0.5 \left[\frac{0.248\ \mu\text{m}}{(0.6)^2} \right] = \pm 0.34\ \mu\text{m}$$

Using additional technical "tricks" like off-axis illumination, the resolution can be pushed below 0.25 μm, suitable for the SIA NTRS 0.25-μm generation. Further improvements can be obtained through more sophisticated mask designs using concepts like optical proximity correction and phase shift masks, which we will describe later. The depth of focus is on the same order as the resist layer thickness itself and therefore requires very flat topography and careful attention in the stepper to keeping the image plane focused by adjusting the height of the wafer with respect to the lens.

Exposure-3

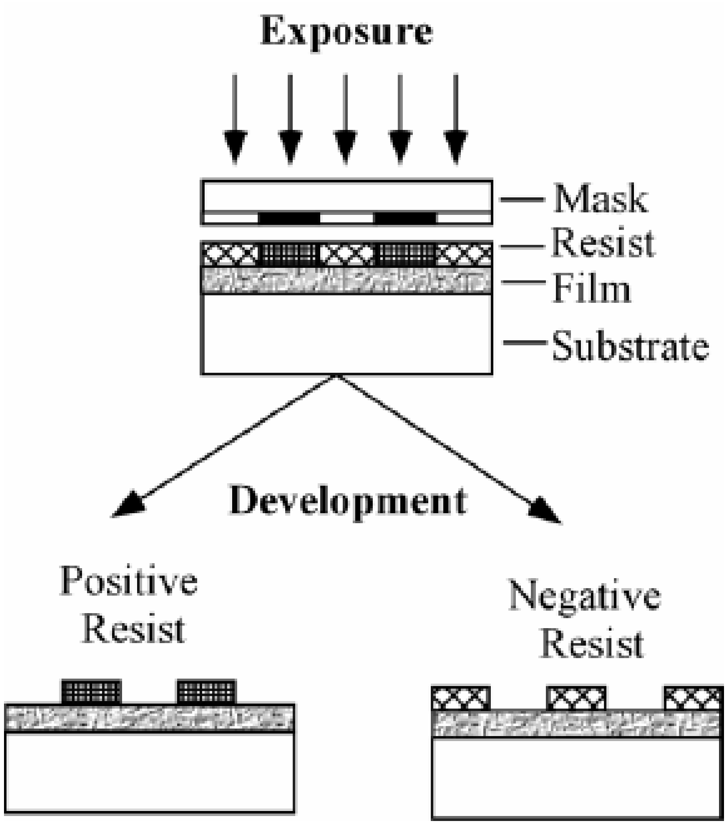


Monitor exposure power

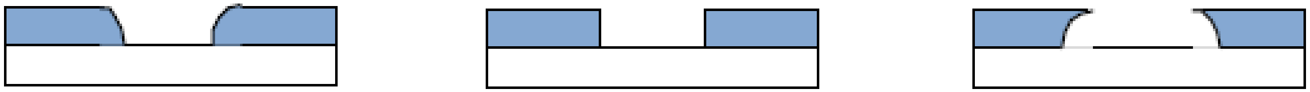
Sufficient exposure w/o over-exposure

Development

Remove the exposed (unexposed) areas in positive (negative) resists.



Vertical profile



(a) (b) (c)

Hard-bake

- Stabilize the developed resist for subsequent processes
- Can make removal very difficult
- Remove residual solvent
- Not necessary for lift-off
- Temperature/time can change the profile

Stripping

Resist Removal

Positive photoresist stripper

acetone

tricholoroethylene (TCE)

phenol-based strippers (indus-Ri-Chem J-100)

Shipley SVC150 & SVC175

Negative photoresist stripper

methyl ethyl ketone (MEK), $CH_3COC_2H_5$

methyl isobutyl ketone (MIBK), $CH_3COC_4H_9$

Shipley NRX422

Etching

O_2 plasma etching

Pattern Transfer

Wet chemical etching

isotropic

resolution limited by film thickness

Dry etching

Physical: sputtering, ion milling

Chemical: plasma

Combined: reactive ion etching

Wet chemical etching

isotropic

resolution limited by film thickness

Dry etching

Physical: sputtering, ion milling

Chemical: plasma

Combined: reactive ion etching

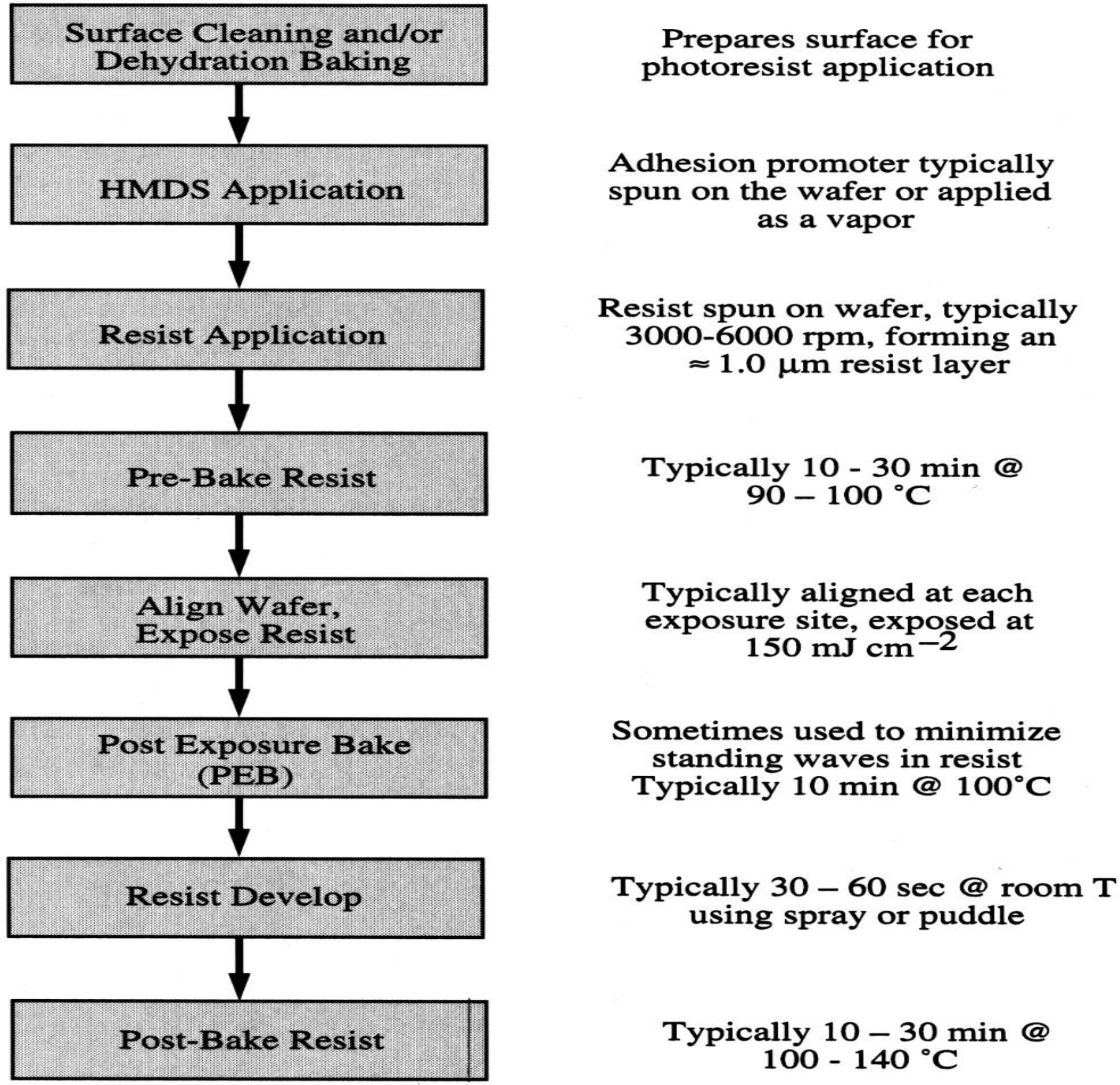
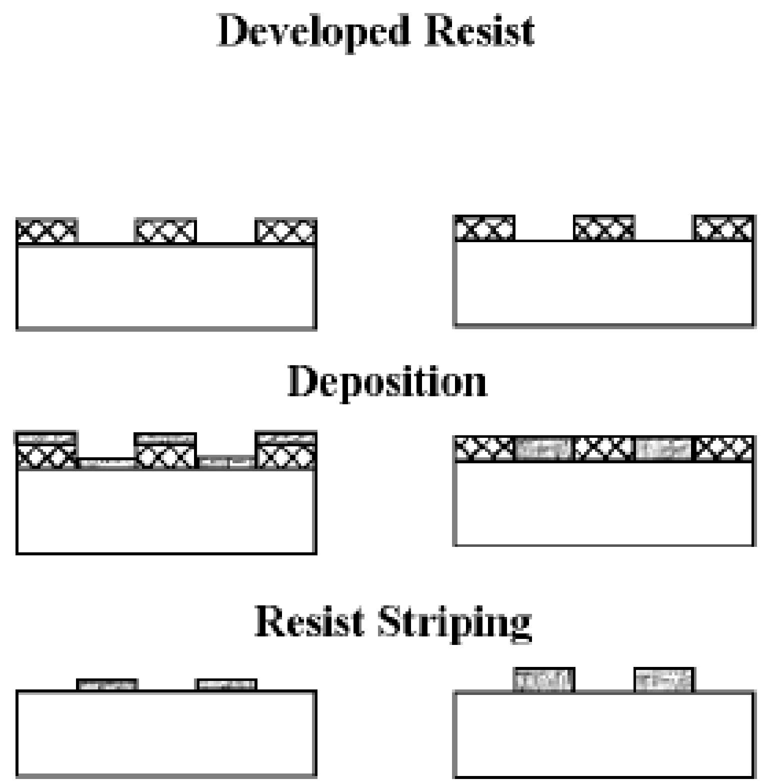


Figure 5–31 Typical photoresist process flow for DNQ g-line and i-line positive resists.

Liftoff



Liftoff

large resist/film thickness ratio

undercut preferable

multiple layer resist/mask

Electrodeposition

deposit thickness limited by resist

conducting surface