Lecture 2 Lithography I

1. **Lithography**:

- Environment requirement:

  Clean room environment: Class 1-10,000, (0.5 μm particles/cubic foot), defects 10% each layer yield=> 50% functional devices after 7 mask process.

- Process:

Fig. 2.1 Steps of the photolithographic process.

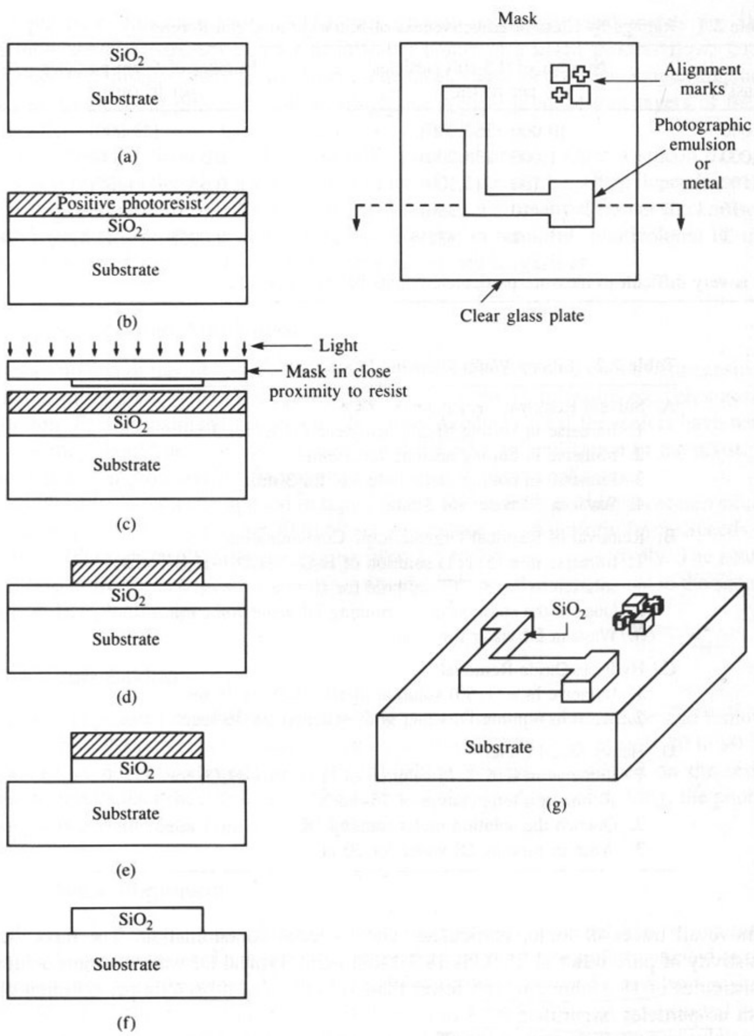


Fig. 2.2 Drawings of wafer through the various steps of the photolithographic process. (a) Substrate covered with silicon dioxide barrier layer; (b) positive photoresist applied to the surface of the wafer; (c) mask in close proximity to the surface of the resist-covered wafer; (d) substrate following resist exposure and development; (e) substrate following etching of the silicon dioxide layer; (f) oxide barrier on wafer surface after resist removal; (g) view of substrate with silicon dioxide pattern on the surface.

- **Wafer cleaning**:
  Standard wafer cleaning + Piranha cleaning (no metal on wafers)

- **Wafer Priming**
  1. Purpose: A pre-resist coating to promote the adhesion of the resist to the substrate and reduce the amount of lateral etching or undercutting.
  2. Nature: intermolecular bonding between the resist and the surface onto which it is applied.
  3. external factors which effect resist adhesion to wafer surface:

     a. Surface Moisture
     Hydrated surface reduces resist adhesion. Traped wafter molecule between prometer and resist allow etchant to cut through. Pre-bake can reduce this problem.

     b. Resist wetting properties
     Positive contact angle is required for increasing adhesion. Primed and baked surface can help wetting.

     c. Primer type, concentration, and method of application
     Usually silanes like HMDS and TCPS diluted in xylene.

     d. Imaging process delay
     The chemical and physical forces that impact resist adhesion vary as a function of time.

     e. Resist chemistry
     Depends on the resins, solvents and their physical and chemical reactions with wafer surfaces.

     f. Surface smoothness
     Smoother surface has less mechanical adhesion. Micro etching sometimes is desired to roughen wafer surface.

     g. Stress forces
     Introduced during spin coating, and soft-bake can release some.

     h. Surface defects and contamination
     Causing step coverage issues.

     i. Imaging factors affecting resist adhesion and etch resistance
     Increase soft and hard bake can promote adhesion of resist.

  4. Primer type:

a. Hexamethyldisilazane (HMDS, US patent 1970, most commonly used, can be diluted with xylene)
b. Trichlorophenylsilane (TCPS)
c. Bistrimethylsilylacetimide (BSA)
d. Monazoline C
e. Trichlorobenzene
f. Xylene (二甲苯)

HMDS:
a. No chlorine which is corrosive. Less toxic, good bonding effectiveness, no need for hard bake, left for several weeks, pinhole reduction.
b. HMDS ties up the molecular water on a hydroxylated silicon dioxide surface and with other side bonded with resist.
c. CH_3 group left outside which keep hydrophobic resisting wet etching.

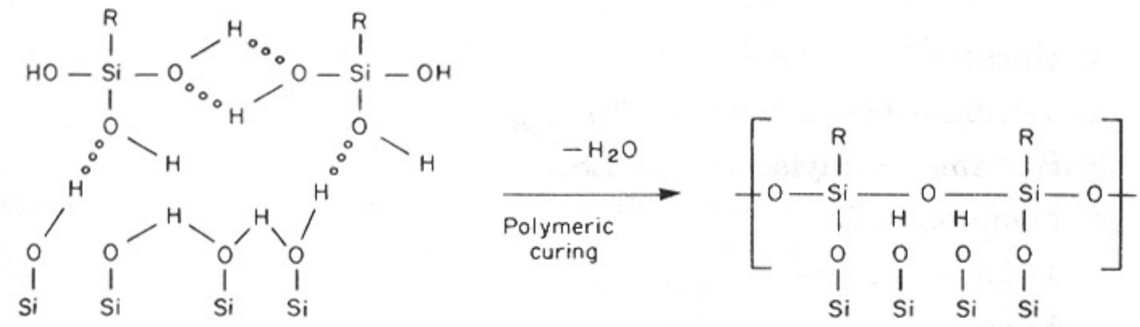


Figure 5.16 HMDS bonding mechanism with silicon dioxide.[3]

5. Primer application methods
   a. Puddle dispense on dip priming
   Build up thick PR, batch process, recommended for surface hard to bond resist (e.g., quartz, high doped glass)
   b. Spin priming
   Popular for spinner, 30 second spinning at 3000-6000 rpm.
   c. Vapor priming
   10 min in vapor, excellent for Al_2O_3, polysilicon, quartz, silicon nitride, and silicides. Very large number can be treated at the same time, priming uniformity is good.

- **Photoresist Coating**
  1. Spin coating
     Standard for IC process. Centrifugal force F, adhesion force A, solvent driven out force S, Surface tension force γ.

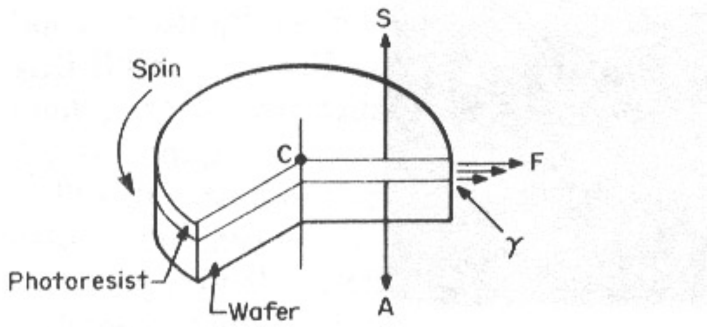


Figure 6.1 Dynamics of spin coating.[1]

PR coating procedure:

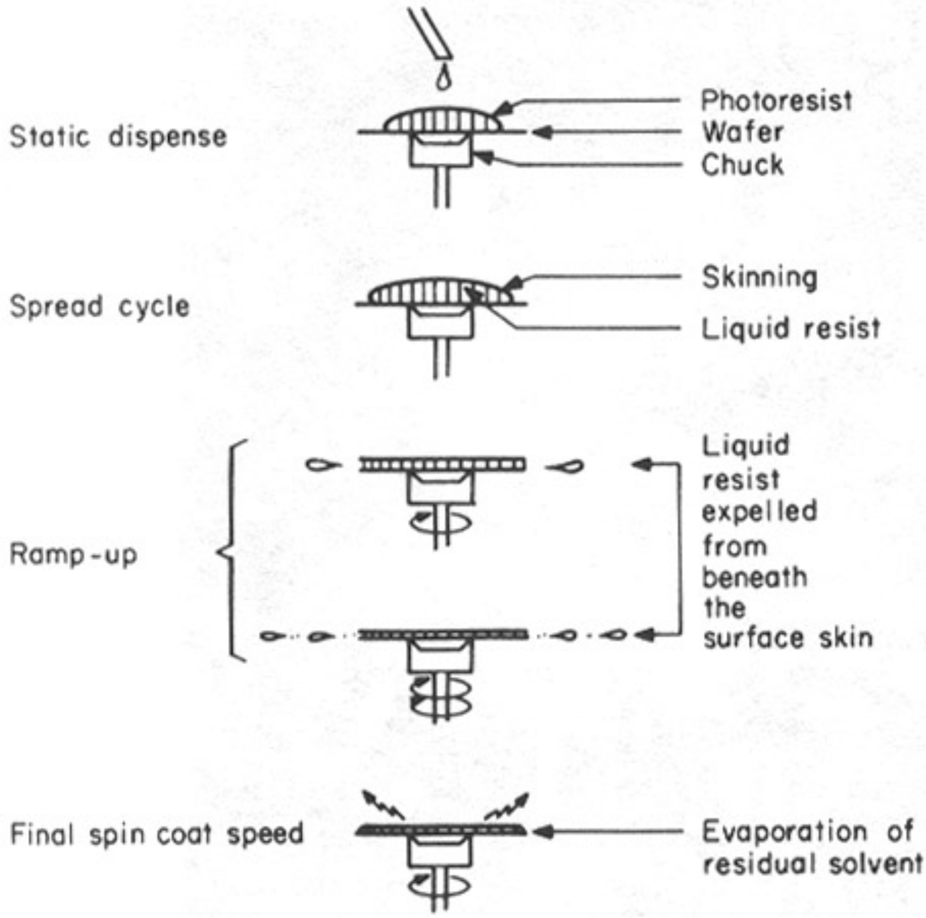


Figure 6.12 Physical factors in spin coating. (*Courtesy of R. Martin, Shipley Company.*)

a. coating fluid dynamic

Static dispense: equilibrium=>(0.01sec) wave stage=>(few rotations) corona stage=>(30 rotations) corona stage, crown like=>spiral stage (resist is scrubbed out of wafer to form drops)

Note: dust or wafer defect will form streak during spinning

Coating thickness:

$$T = \frac{KP^2}{\sqrt{W}}$$

T: thickness, K: spin coater constant, P: percentage of solids in the photoresist (relative to viscousity), W: spin coater rpm/1000.

b. Edge bead

Edge bead stabilized in 9 sec.

Can be minimized by negative wafer taper (1/8 in from the wafer edge)

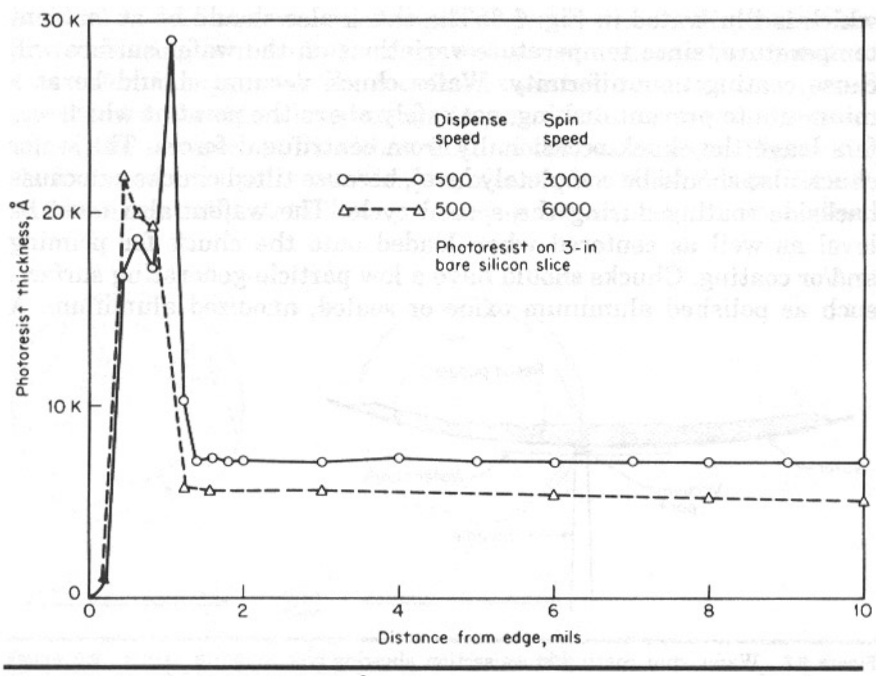


Figure 6.7 Resist edge bead profile.[8]

c. Wafer chuck
Should be similar to wafer size to prevent dishing effect.

d. Coating speed
Usually from 3000-6000 rpm for thin resist (less than 2 μm)

e. Dispense and spread cycle
Dispense volume: ~ml/in wafer diameter (for example: 4 ml for 4 in wafer)
Static dispensing before spinning commences gives better uniformity than dynamic dispensing.

f. Spin and ramp velocity
High spin ramping provides better coating uniformity, usually 8000-20000 rpm/sec

g. Spin time, bowl exhaust, and striations
At least 15-20 sec, usually 30 sec.

Spin time versus film thickness

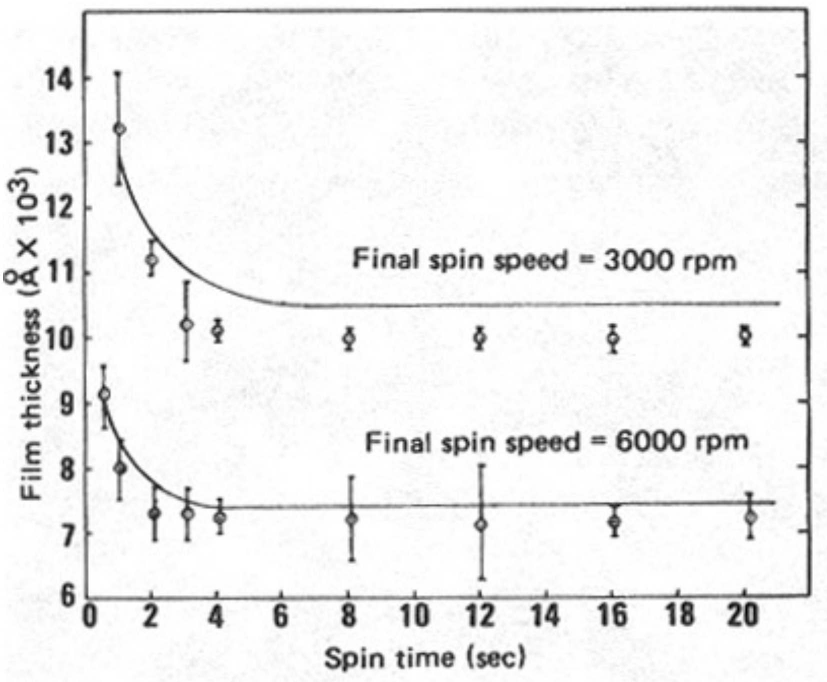


Figure 6.10 Spin speed time versus film thickness.

Striation: happens when film dry out too fast

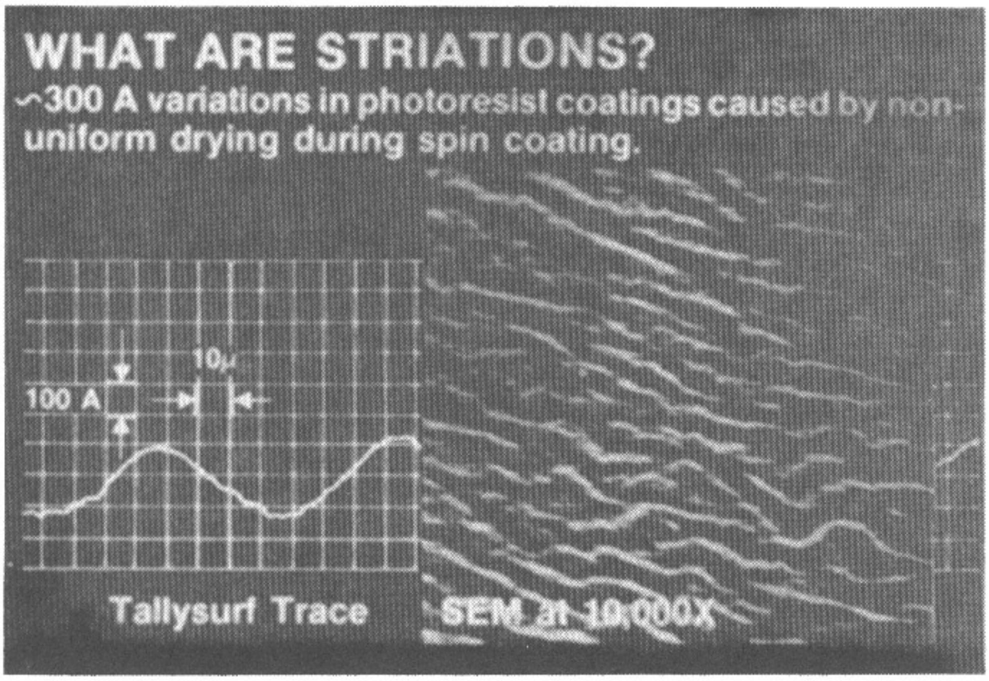


Figure 6.11 Radial striations.[3]

h. <u>Measurement:</u>
Stylus: destructive method

Optical measurement: ellipsometer, infrared laser scanning systems, optical microscope, Spectrophotometer.

SEM measurement

2. Spray coating
   Class 100 clean environment, dilution of the resist (4-20 cP) for 2-5 μm coating, traveling speed~5-20 in/min.

- **Soft bake**:
  1. To improve adhesion and remove solvent
  2. 1 min on 90-120°C hot plate or 10-30 min in an oven at 80-90°C in air or nitrogen environment for thin resist (less than 2 μm)
  3. Affect the following parameters: adhesion, exposure, development, geometry control, and solvent content.

Developing rate vs. softbake temp

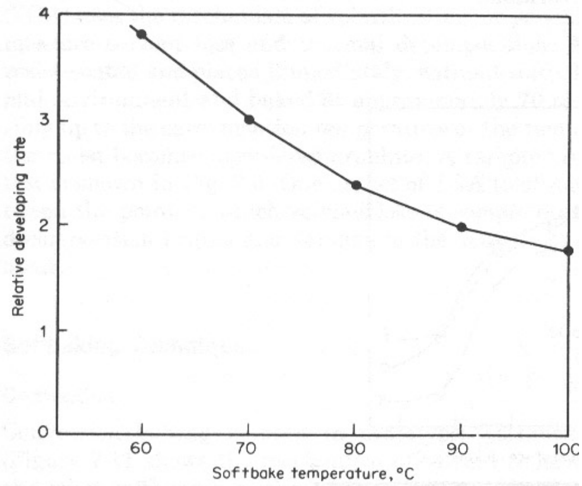


Figure 7.2 Development rate versus softbake temperature.

Weight loss vs. softbake temp

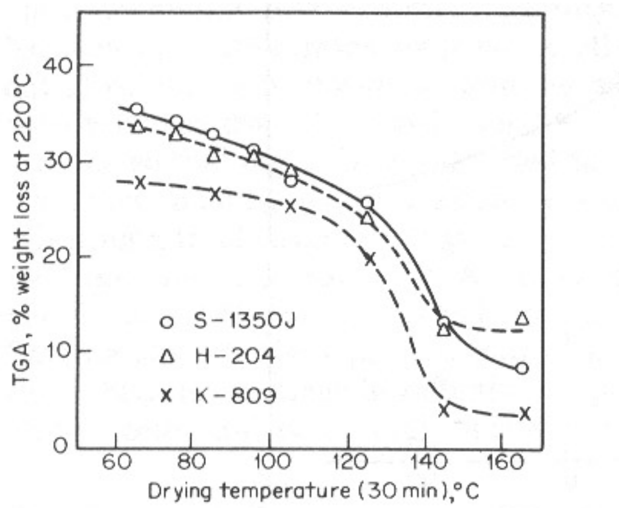


Figure 7.3 Solvent content versus softbake temperature.[2]

Resist thickness vs. soft bake temp

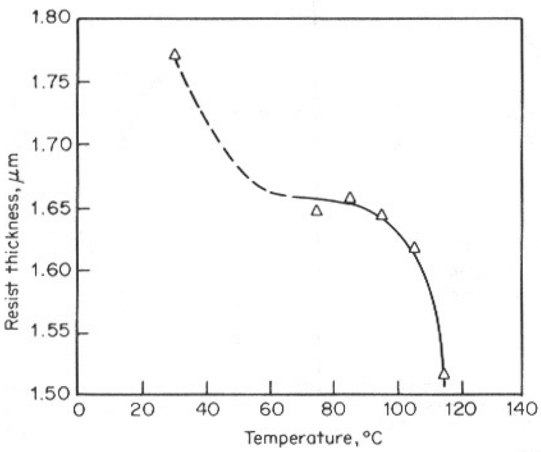


Figure 7.4 Resist thickness versus softbake temperature.[2]

Soft baking mechanisms

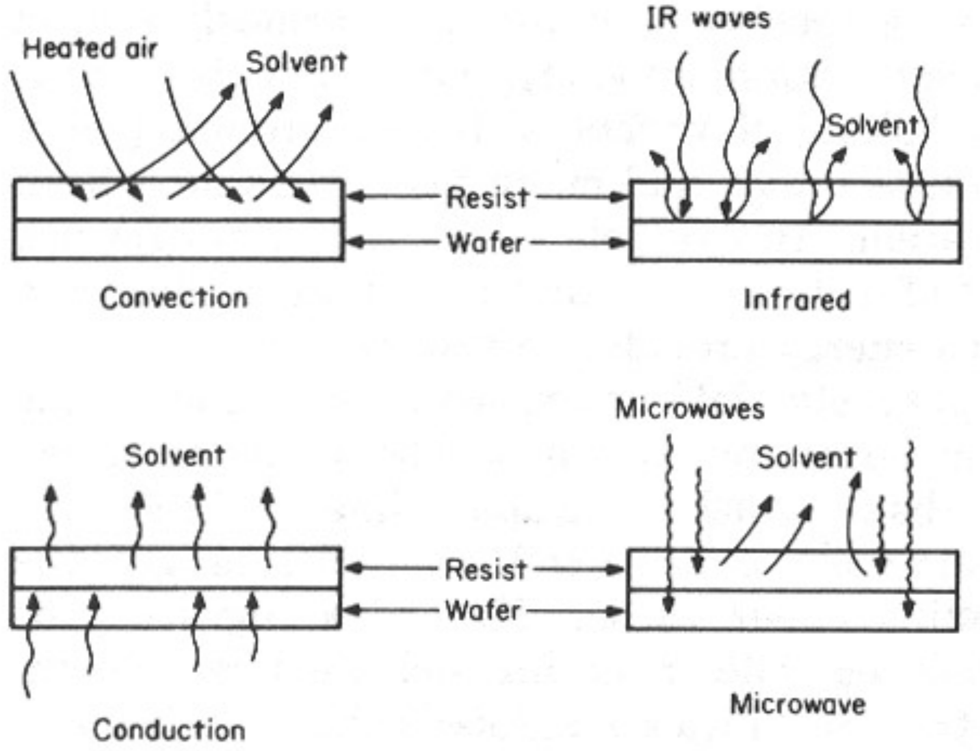
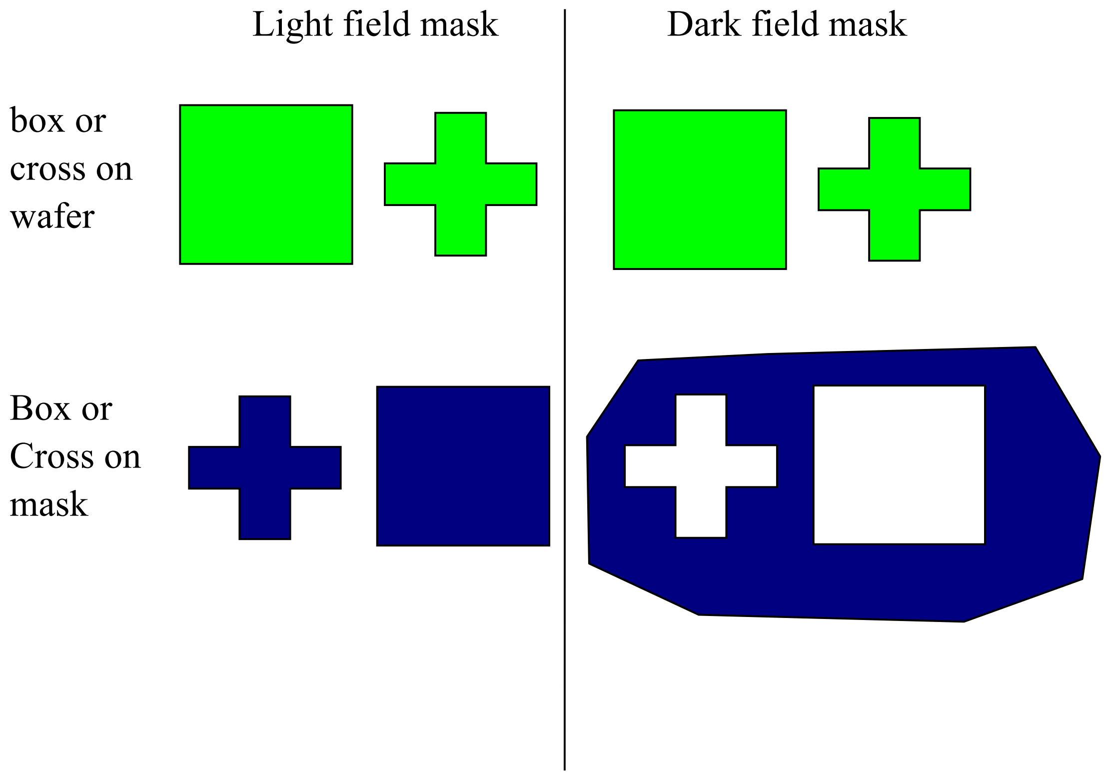
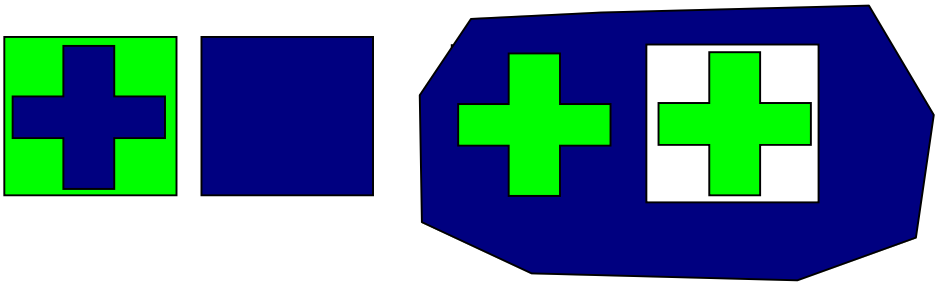


Figure 7.11 Convection, infrared, microwave, and conduction solvent removal mechanisms.

- **Mask alignment**:
  1. Alignment tolerance depends on feature size (typically 0.25-2 μm for 1.25-5 μm feature)
  2. Alignment marks:



Composite pattern After alignament



- **Photoresist Exposure**
  1. UV, x-ray, e-beam, ion beam resist
  2. High intensity UV light.(typically 350-450 nm, we use 365 and 405 nm in the lab.)

  Mercury arc lamp spectrum

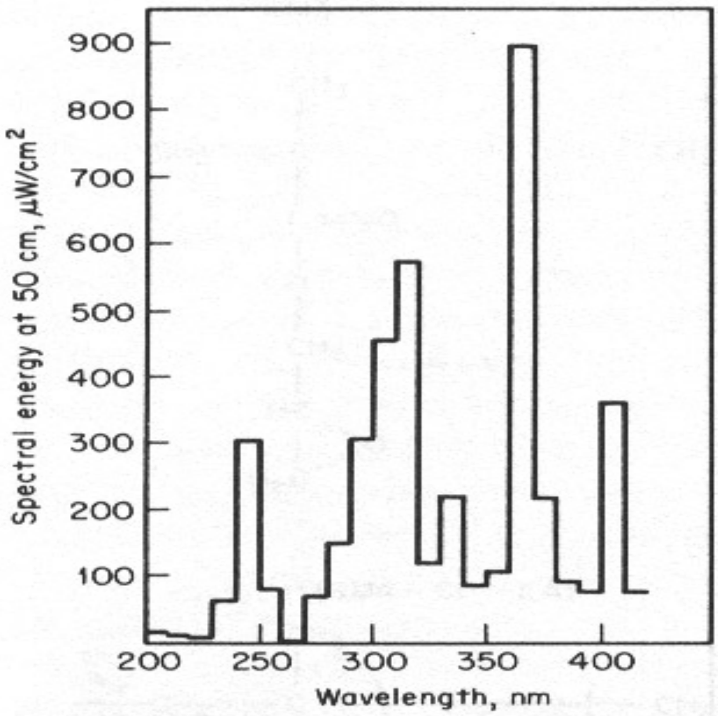


Figure 8.8 Mercury arc lamp spectrum. (*Courtesy of Canon.*)

g-line: 436 nm, h-line: 405 nm, i-line: 365 nm, mid-uv: 313 nm, deep-uv: 248 nm

2. Spectrum absorbance profiles for Resist

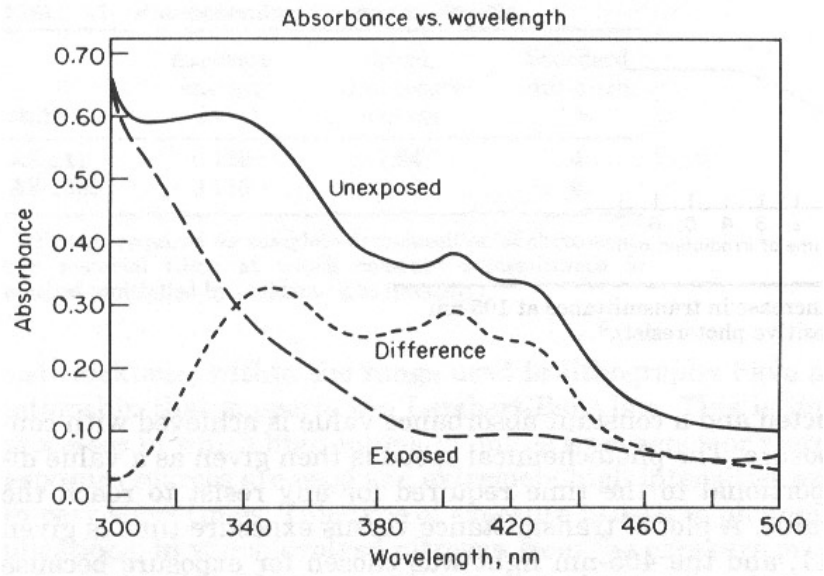


Figure 8.9 Spectral absorbance profiles for Shipley S-1400 positive photoresist.

3. Diffraction problem

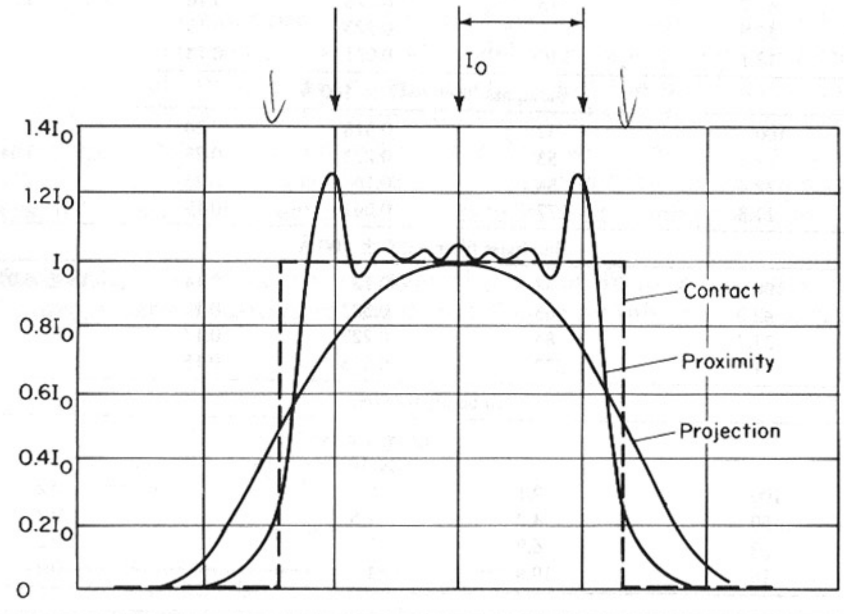


Figure 8.13 Optical diffraction patterns by various exposure methods.

4. Modulation transfer function and Contrast

Degree of contrast depends on optical system, including energy coherence, wave length, and f number of the lens.

Usually MTF need to be 0.4-0.6 to get good contrast.

MTF vs. non-coherent light

S: coherent value (vary from 0-∞)

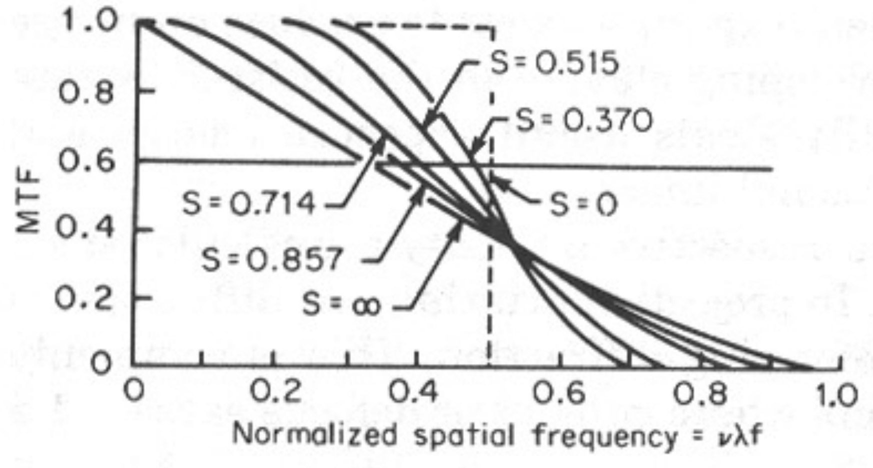


Figure 8.14 MTF of an ideal imaging system as a function of illumination coherence.

5. Contrast model

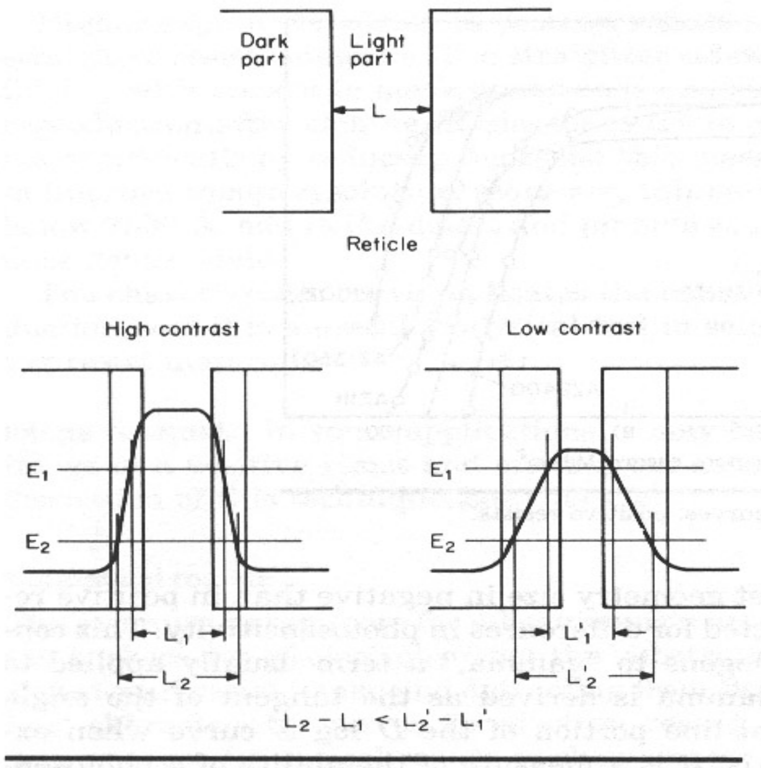


Figure 8.15 Contrast model.

6. Standing wave and reflections

Standing wave:

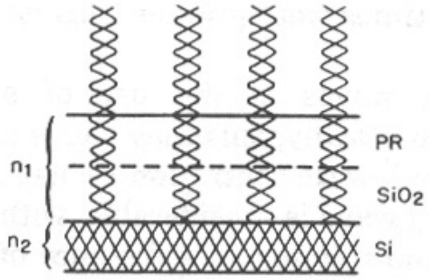


Figure 8.22 Standing-wave principle in photoresist.[8]

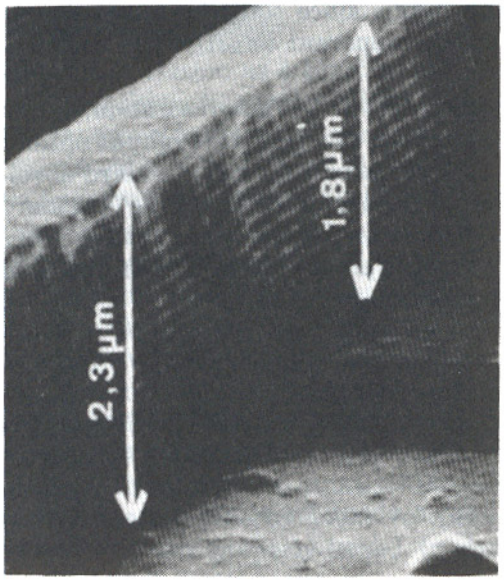


Figure 8.21 Micrograph of standing-wave patterns in photoresist. (*Courtesy of Paul Tigreat.*)

To eliminate standing wave:

a. varying optical thickness
b. reducing the reflectivity (antireflection coating)
c. using post exposure bake at 100°C
d. put dye in PR (eliminate long-range, geometry-dependent reflections)
e. short exposure time and concentrated developer

reflections:

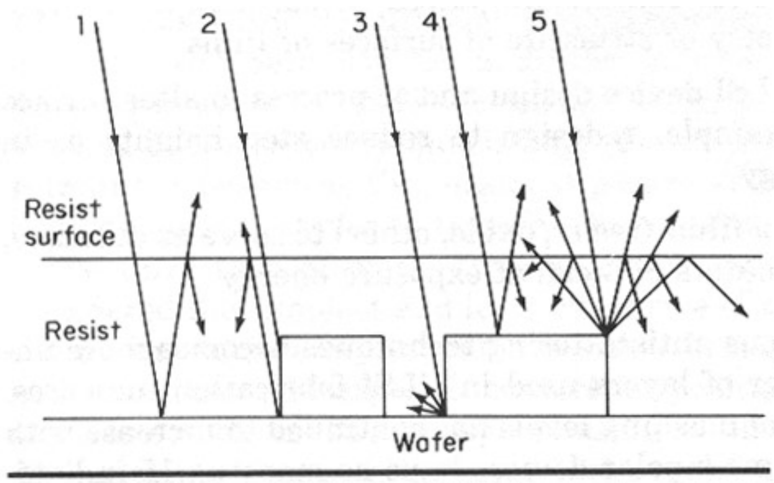


Figure 8.23 Surface reflections and light-scattering patterns encountered in microlithography.

To eliminate reflection:

a. antireflective coatings
b. black chrome on mask and reticles
c. dyes or absorbers added to resist
d. specific optical thickness (avoid quarter-wavelength multiples of exposing energy)
e. wavelength mixing
f. reduce step height
g. multiple layering of films (resist, oxide, others) to serve as diffusers.
h. put dye in PR (eliminate long-range, geometry-dependent reflections)
i. short exposure time and concentrated developer

7. Positive and negative PR.
   Positive resist: photoactive component (PAC), resins, and solvent
   Negative resist: photosensitive cross-linking material and nonphotosensitive synthetic rubber compound (etch resistance, adhesion, film-forming property)

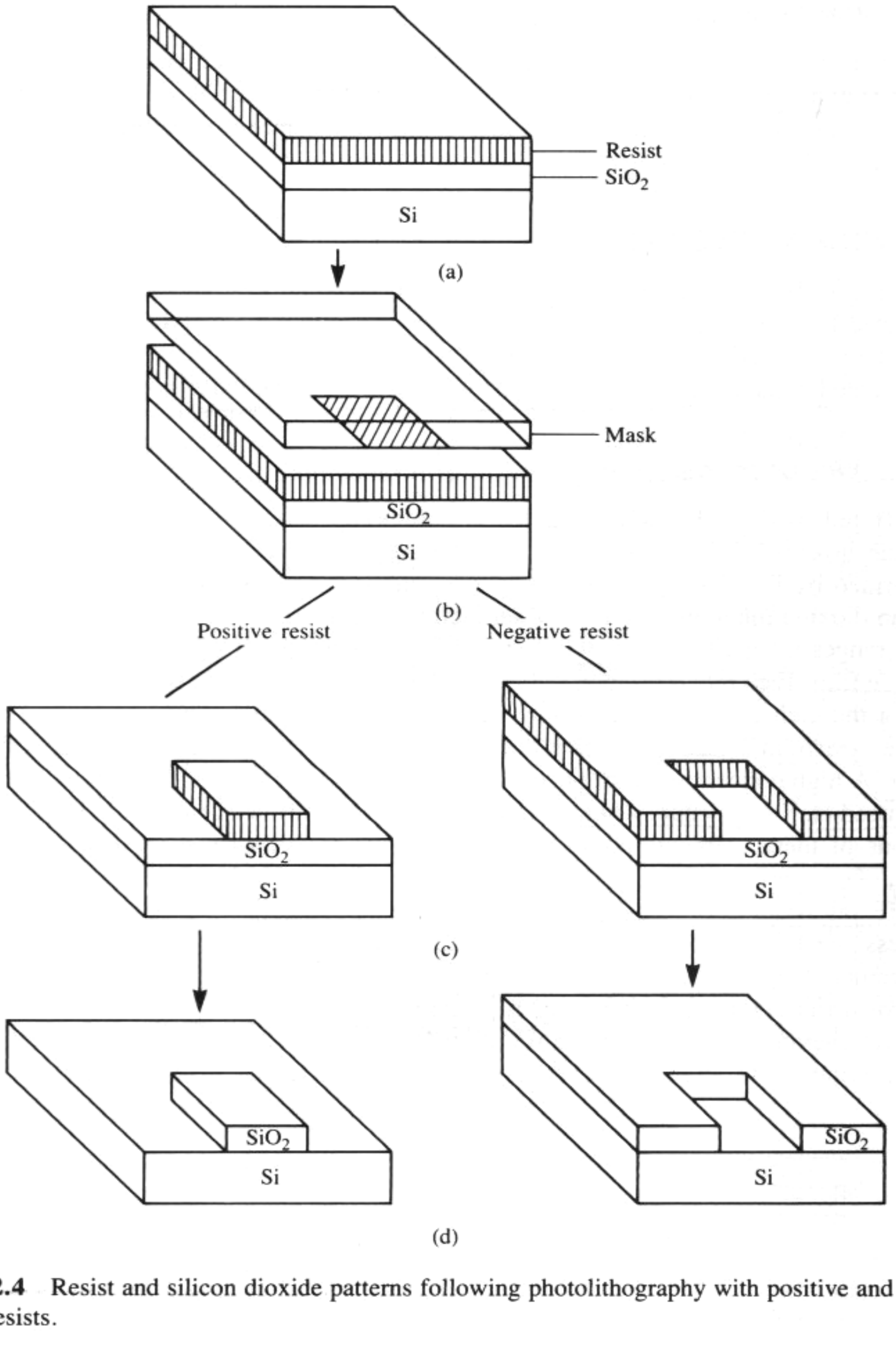


Fig. 2.4 Resist and silicon dioxide patterns following photolithography with positive and negative resists.

8. Photomask printing methods:

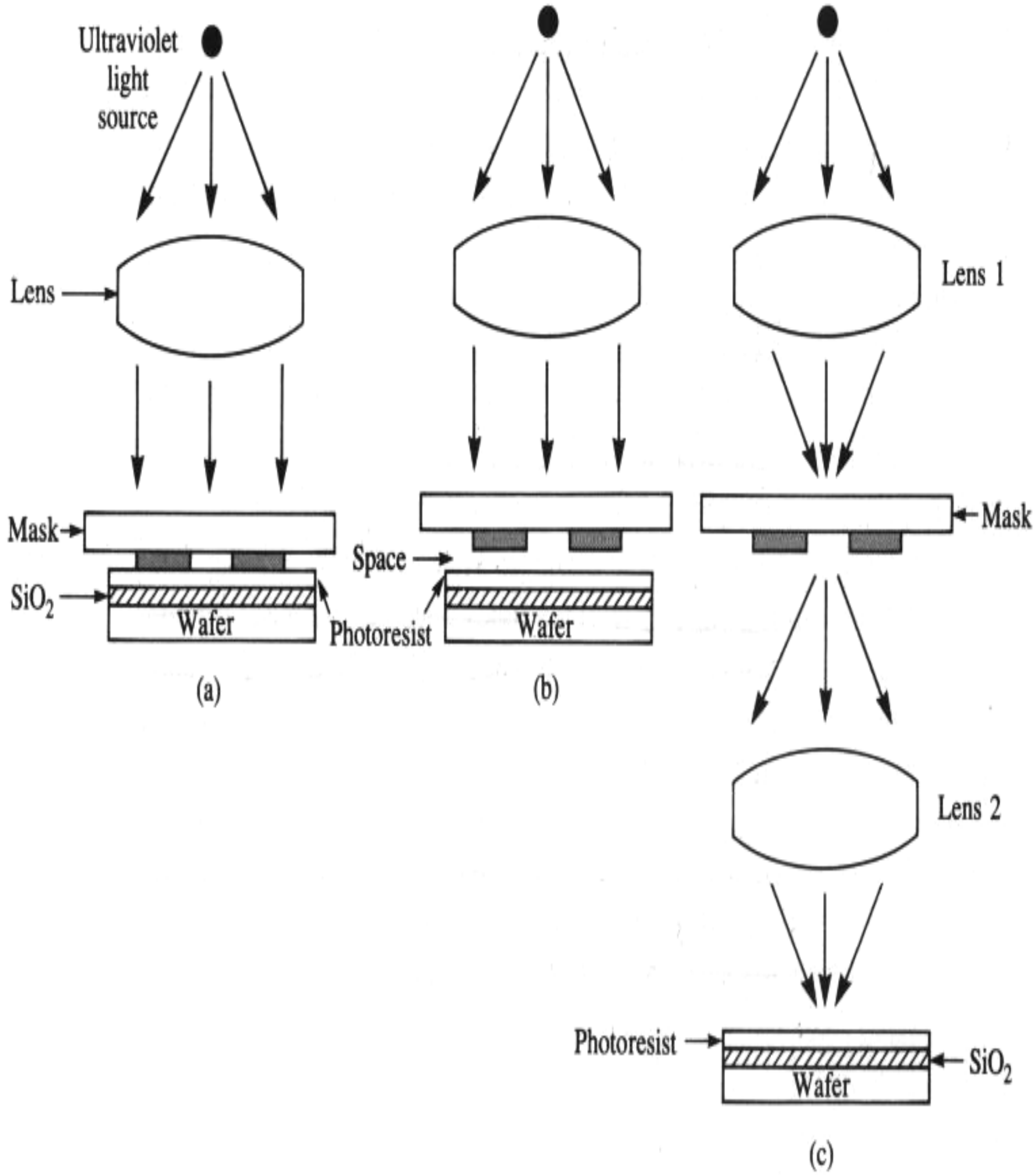


Fig. 2.8 Artist's conception of various printing techniques. (a) Contact printing, in which wafer is in intimate contact with mask; (b) proximity printing, in which wafer and mask are in close proximity; (c) projection printing, in which light source is scanned across the mask and focused on the wafer. Copyright, 1983, Bell Telephone Laboratories, Incorporated. Reprinted by permission from ref. [2].

- **Resist Development:**
  1. negative resist
  2. positive resist
  3. development approaches

a. immersion
b. puddle
c. spray-puddle
d. spray

4. Developer Parameters
a. time
b. temperature
c. concentration

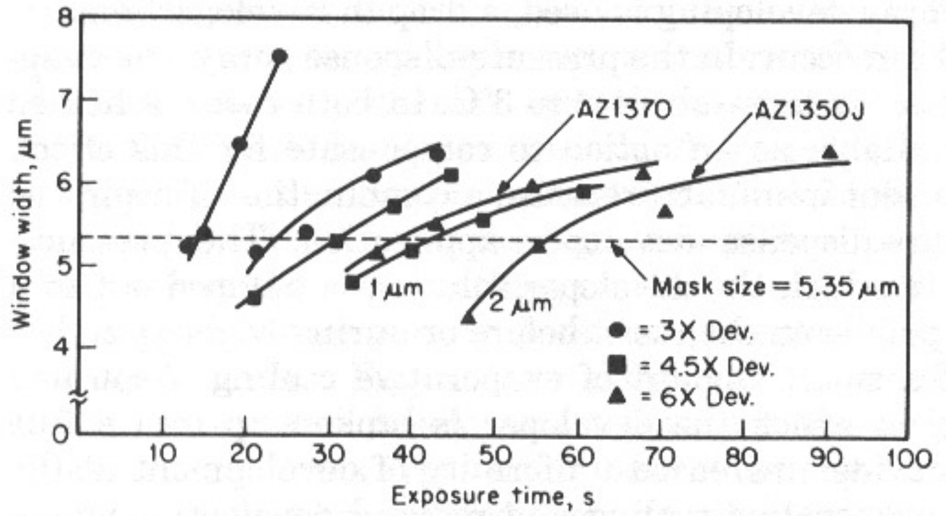


Figure 9.15 Exposure versus line width for three developer concentrations.[4]

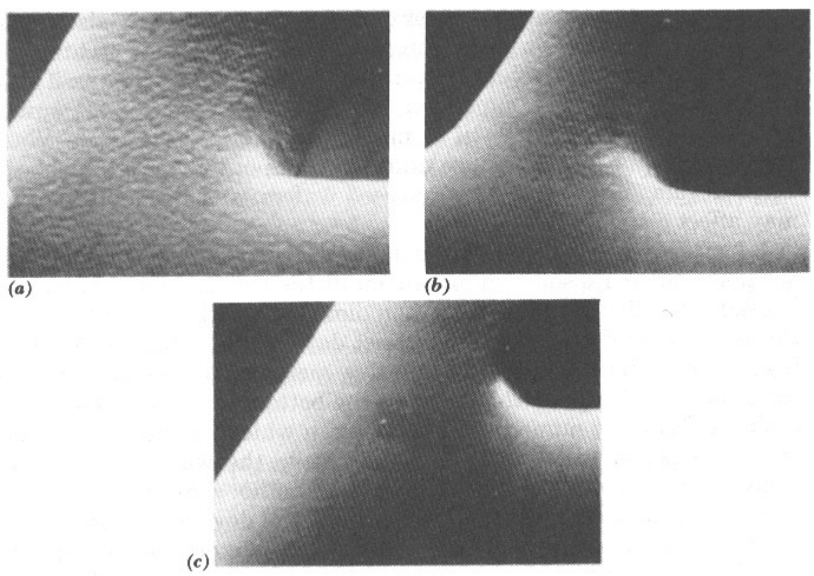


Figure 9.16 Developer concentration versus resist surface attack. (*a*) 3× developer. (*b*) 4.5× developer. (*c*) 6× developer.[4]

d. agitation: movement of the resist-coated wafers, bubbling gas through developer, spinning the wafer while dispensing a stream of deveoper, and spraying developing.

- **Hard Baking:**
  1. remove the final 3-4% solvent and harden the photoresist and improve adhesion to the substrate.
  2. typically 5 min on hot plate or 20-30 min in oven at 120-180 C.
  3. higher postbake temperatures mean more difficult removal.

Postbake vs. thermal flow

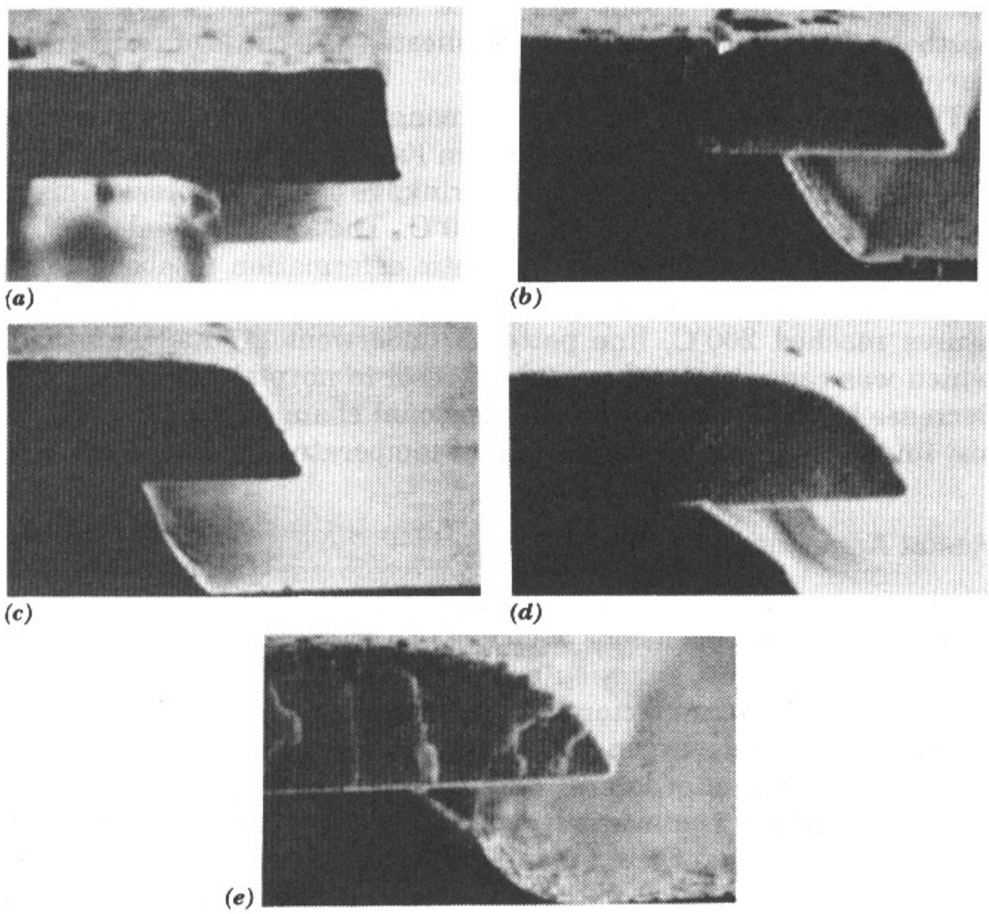


Figure 10.1 Postbake temperature versus thermal flow (1350J): (*a*) 100°C; (*b*) 110°C; (*c*) 120°C; (*d*) 130°C; (*e*) 140°C.

Ahsesion vs. temp.

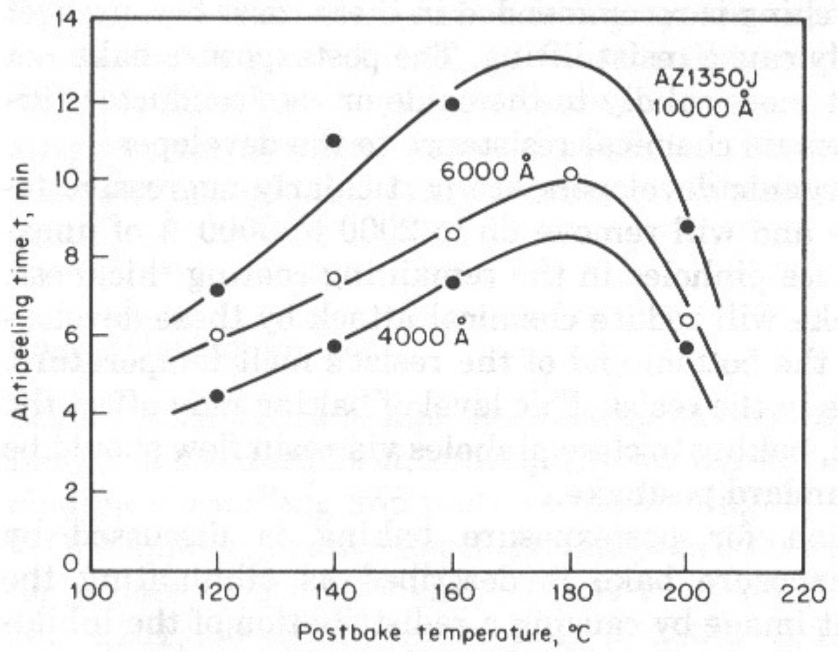


Figure 10.4 Antipeel time versus postbake temperature.[2]

Reference:

1. Integrated circuit fabrication technology, David J. Elliott, McGRAW-HILL international editions, 1989.
2. Introduction to Microelectronic Fabrication, Richard C. Jaeger, Addison-Wesley Publishing Company, Inc, 1998.