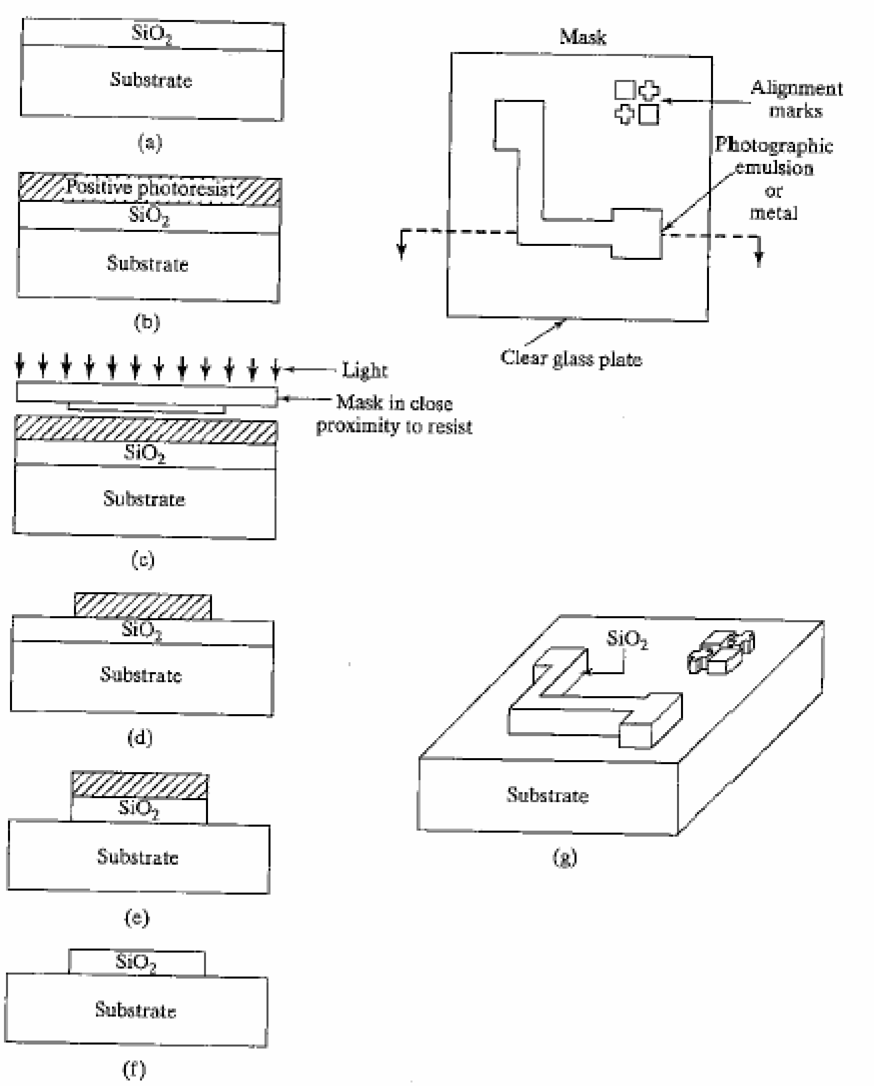
Photolithography-II

Outline

- A detailed photolithography step to transfer pattern from mask to wafer
- Exposure sources and systems
- Photomask fabrication

Steps of a typical photolithographic process

- Clean wafers
- Deposit barrier layer SiO_2, Si_3N_4, metal
- Coat with photoresist
- Softbake
- Align mask
- Expose pattern
- Develop photoresist
- Hard bake
- Etch windows in barrier layer
- Remove photoresist



Barrier layers

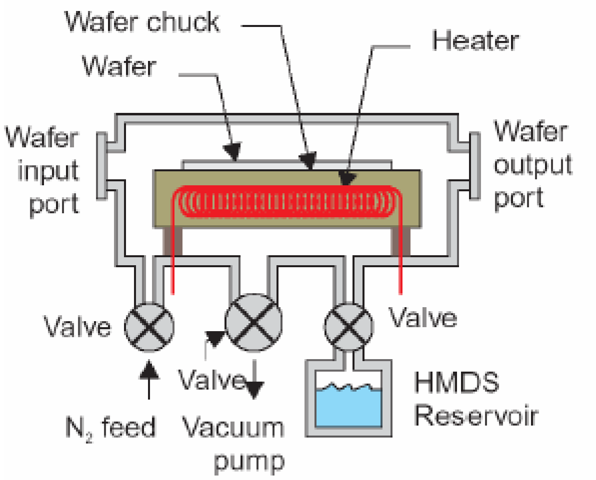
Barrier layers:
- SiO_2
- Si_3N_4
- Polysilicon
- Metal
- photoresist

Formation processes:
- Thermal oxidation
- Chemical vapor deposition
- Sputtering
- E-beam evaporation
- Simple spinning coating
- Etc.

Removing processes:
- Wet etching
- Dry etching

Photo-steps

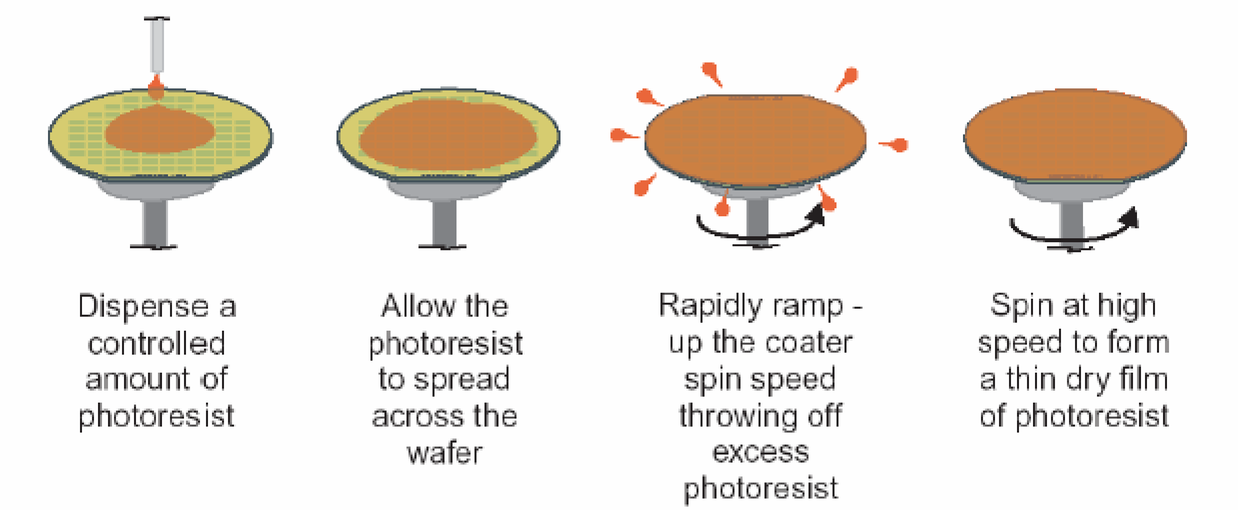
Dehydration and surface priming



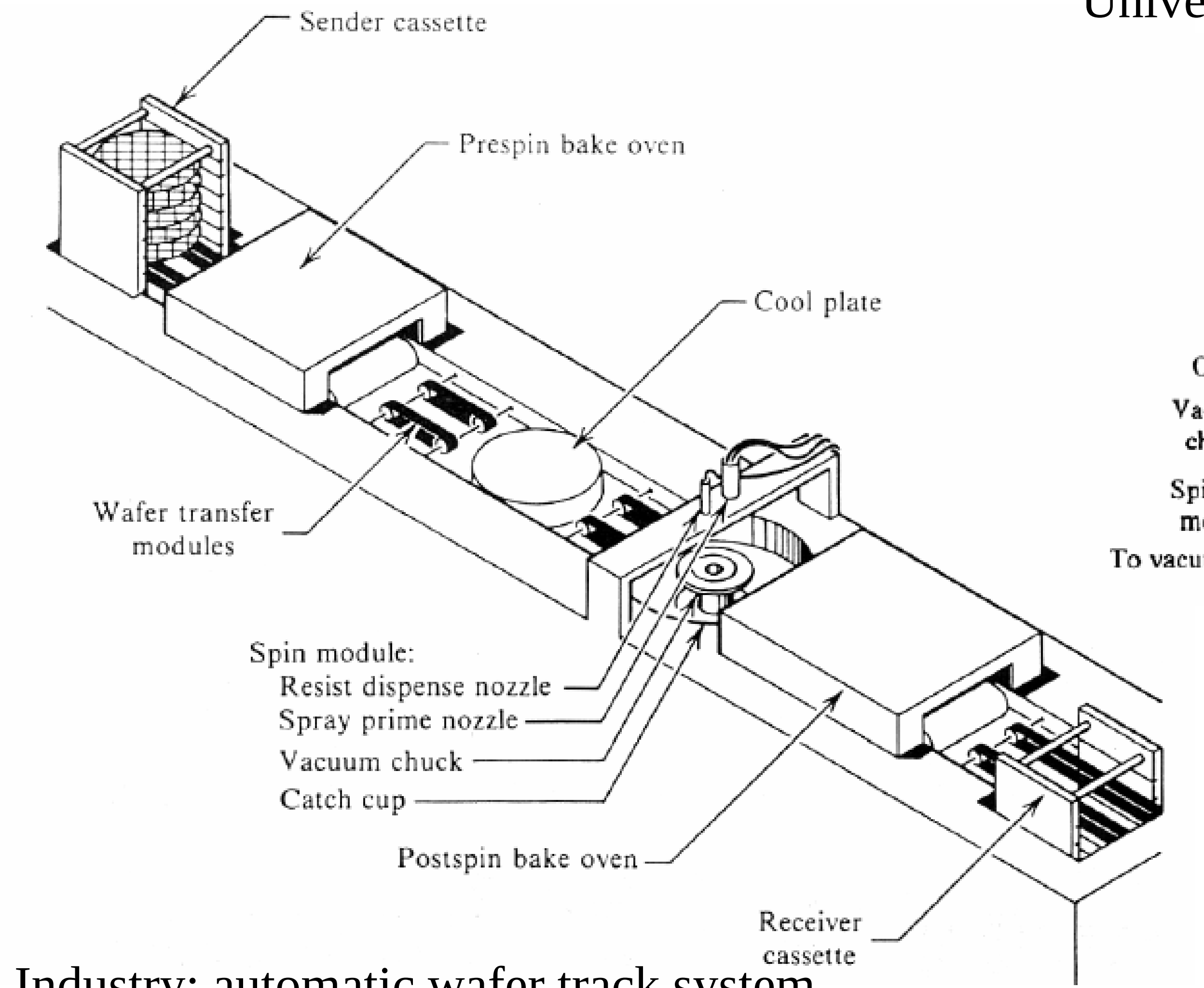
or

Hotplate (150°C 5 minutes)+ HMDS priming (10 minutes in a sealed beaker)

Spin coat

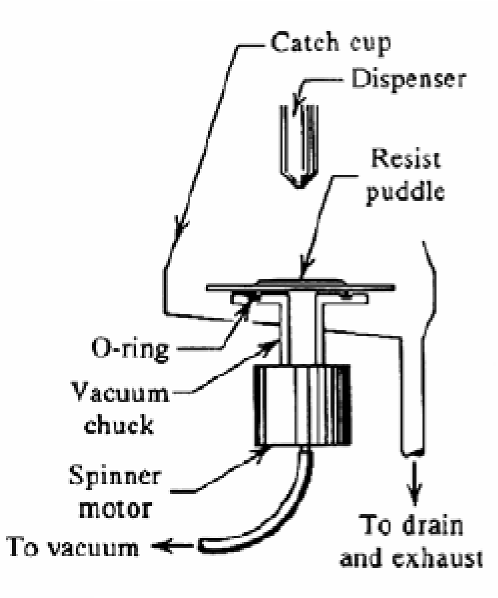


Spin coater



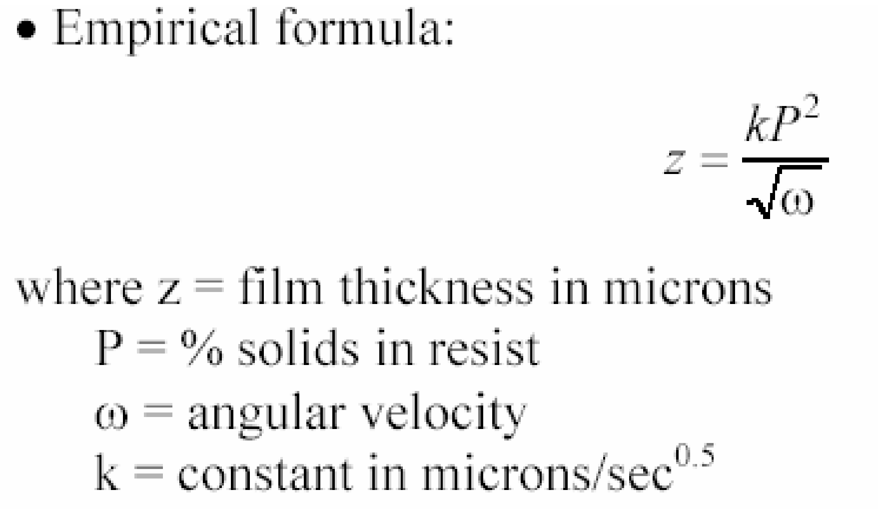
Industry: automatic wafer track system

University:



Resist thickness

- Depends on resist type, viscosity and spin speed
- Viscosity controlled by fraction of solid in solvent
- A higher-viscosity resist is harder to be thrown off
- A higher speed makes resist thinner

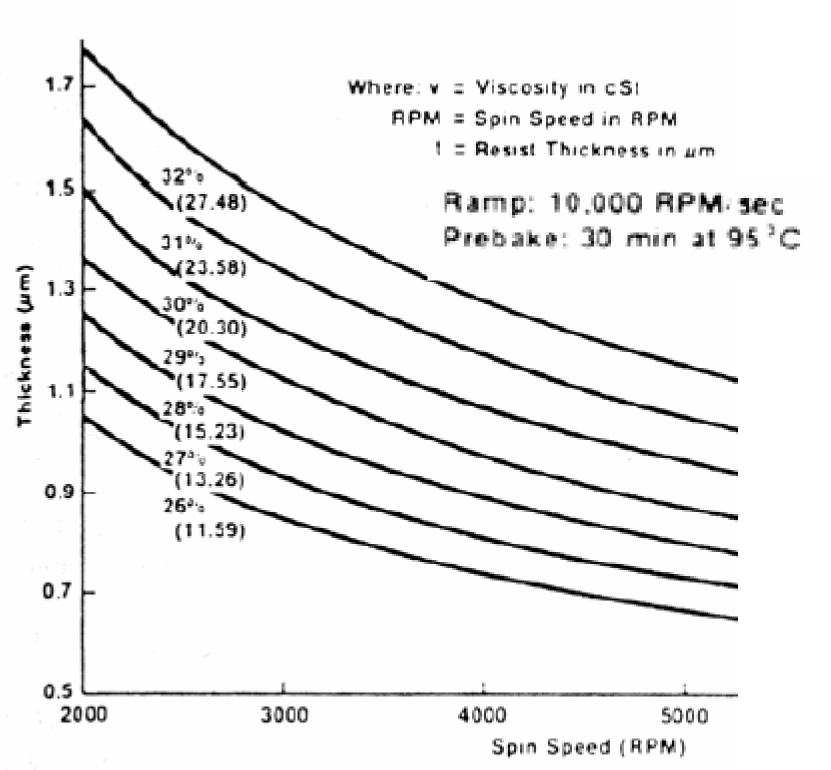


- Empirical formula:

$$z = \frac{kP^2}{\sqrt{\omega}}$$

where z = film thickness in microns
P = % solids in resist
ω = angular velocity
k = constant in microns/sec$^{0.5}$

Kodak 820:



Typical commercialized resist

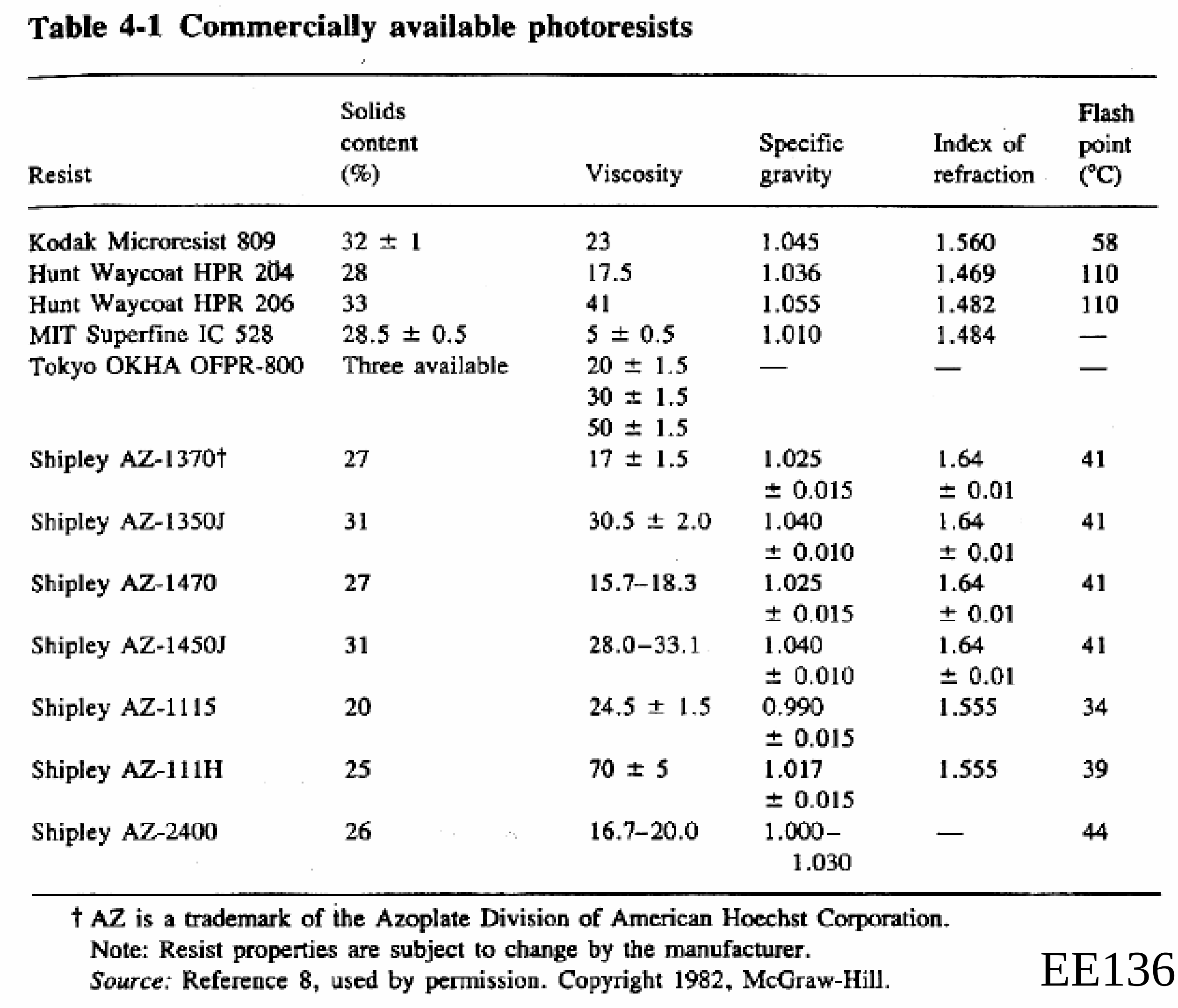


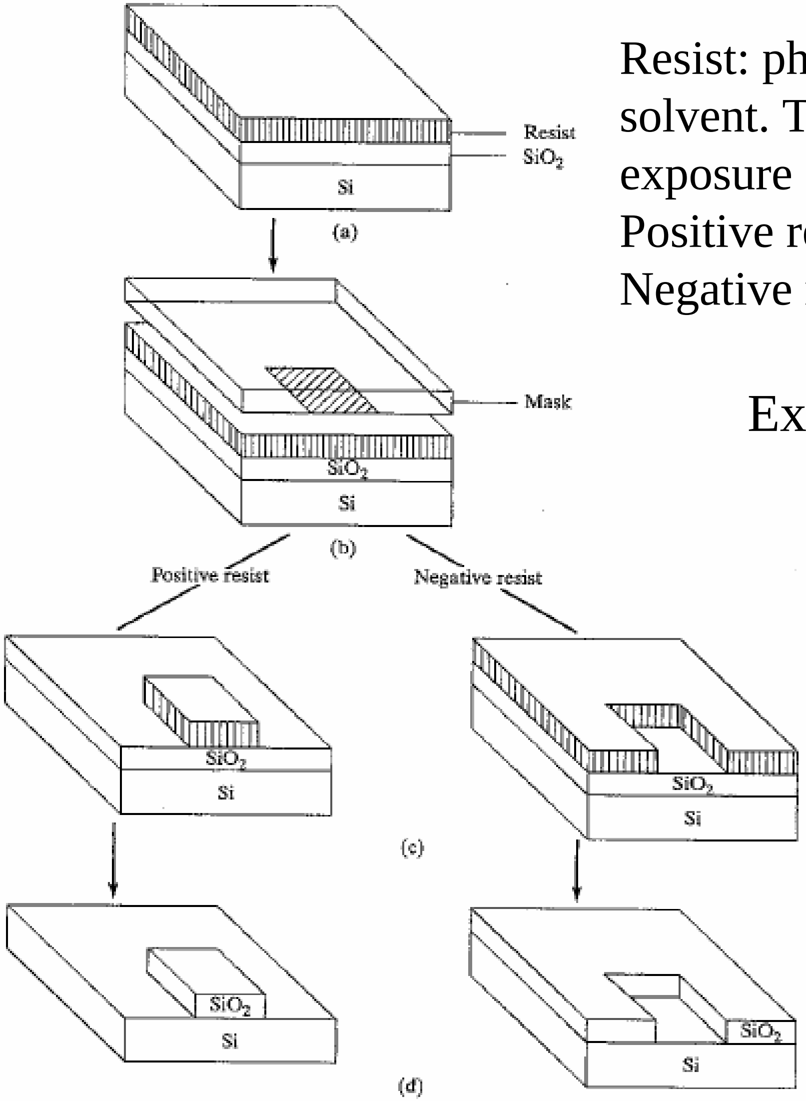
Table 4-1 Commercially available photoresists

Resist	Solids content (%)	Viscosity	Specific gravity	Index of refraction	Flash point (°C)
Kodak Microresist 809	32 ± 1	23	1.045	1.560	58
Hunt Waycoat HPR 204	28	17.5	1.036	1.469	110
Hunt Waycoat HPR 206	33	41	1.055	1.482	110
MIT Superfine IC 528	28.5 ± 0.5	5 ± 0.5	1.010	1.484	—
Tokyo OKHA OFPR-800	Three available	20 ± 1.5 30 ± 1.5 50 ± 1.5	—	—	—
Shipley AZ-1370†	27	17 ± 1.5	1.025 ± 0.015	1.64 ± 0.01	41
Shipley AZ-1350J	31	30.5 ± 2.0	1.040 ± 0.010	1.64 ± 0.01	41
Shipley AZ-1470	27	15.7–18.3	1.025 ± 0.015	1.64 ± 0.01	41
Shipley AZ-1450J	31	28.0–33.1	1.040 ± 0.010	1.64 ± 0.01	41
Shipley AZ-1115	20	24.5 ± 1.5	0.990 ± 0.015	1.555	34
Shipley AZ-111H	25	70 ± 5	1.017 ± 0.015	1.555	39
Shipley AZ-2400	26	16.7–20.0	1.000–1.030	—	44

† AZ is a trademark of the Azoplate Division of American Hoechst Corporation.
Note: Resist properties are subject to change by the manufacturer.
Source: Reference 8, used by permission. Copyright 1982, McGraw-Hill.

EE136 uses AZ-5214

Positive resist and negative resist



Resist: photosensitive polymer (solid) dissolved in solvent. The polymer changes structures upon light exposure (polymerization)

Positive resist: after exposure, gone during developing

Negative resist: after exposure, stay during developing

Example: positive resist Shipley AZ-1350J:

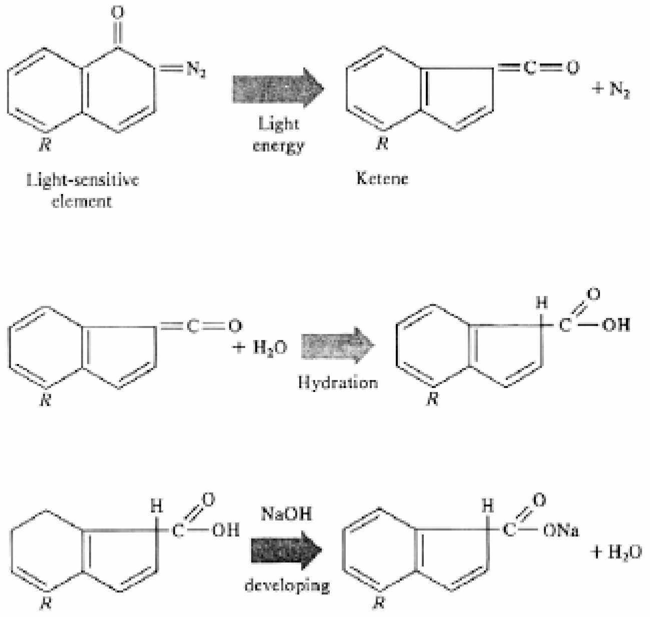
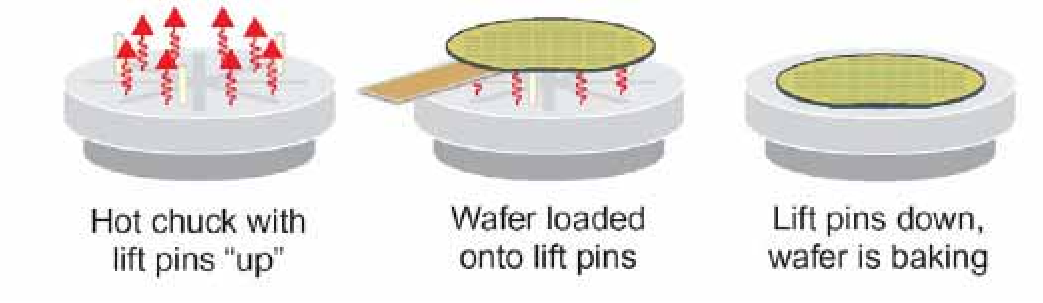


Photo-steps cont.

Soft bake: To evaporate a portion of solvent in the photoresist
For different photoresist, use different time and temperature

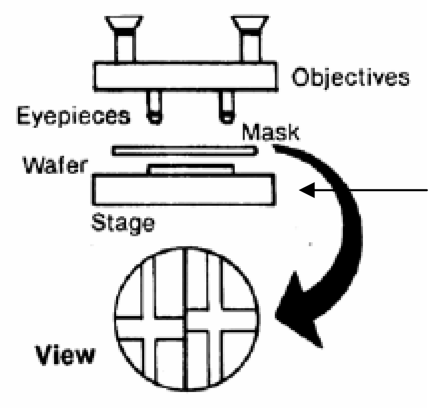


This step is needed as the solvent can absorb exposing radiation, thus interfering with proper chemical change in the photosensitive resist.

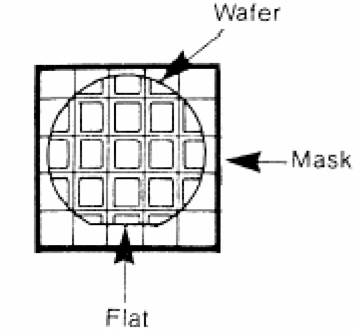
For AZ5214: put on the hotplate of 100ºC for about 1 minute

Besides hotplate: other methods include conventional ovens; microwave baking; vacuum baking etc.

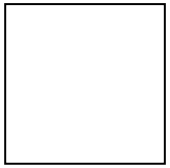
Align masks using alignment marks



Knobs to move
in x-y direction
and rotational

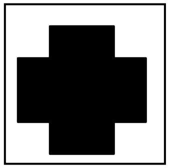


First mask alignment

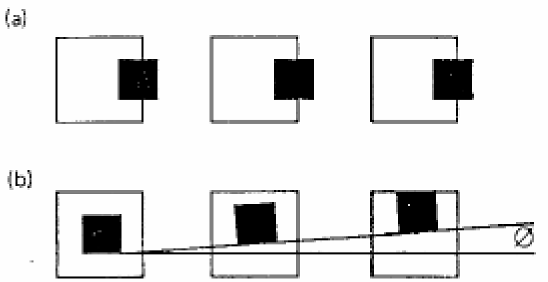


Alignment mark
on wafer

Alignment mark
on next photomask



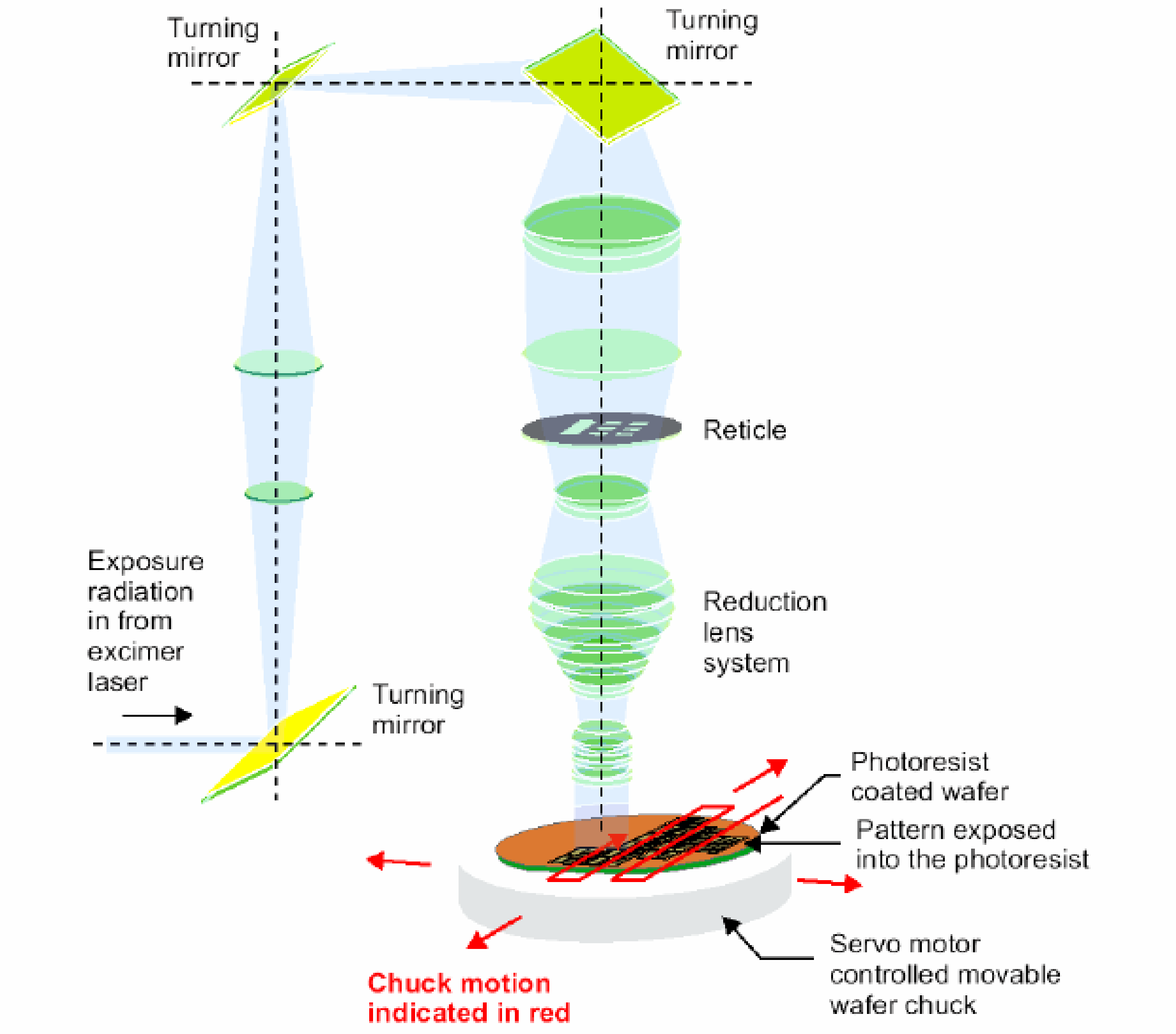
Composite pattern
after alignment



Avoid misalignment:
a)x-direction, b)rotational

Photo-steps cont.

Expose



Exposure sources

Optical:

- UV lamps—Hg lamps
  - 436 nm (1980s)
  - 365 nm (1990s)
- Excimer lasers
  - KrF laser at 248 nm (now)
  - ArF laser at 193 nm (now)
  - F_2 laser at 157nm (in Lab)
    - Lens material no longer glass but CaF
- Extreme UV
  - Uses Nd:Yag laser to focus on copper to create a plasma with EUV emission: 13.4 nm (in research)

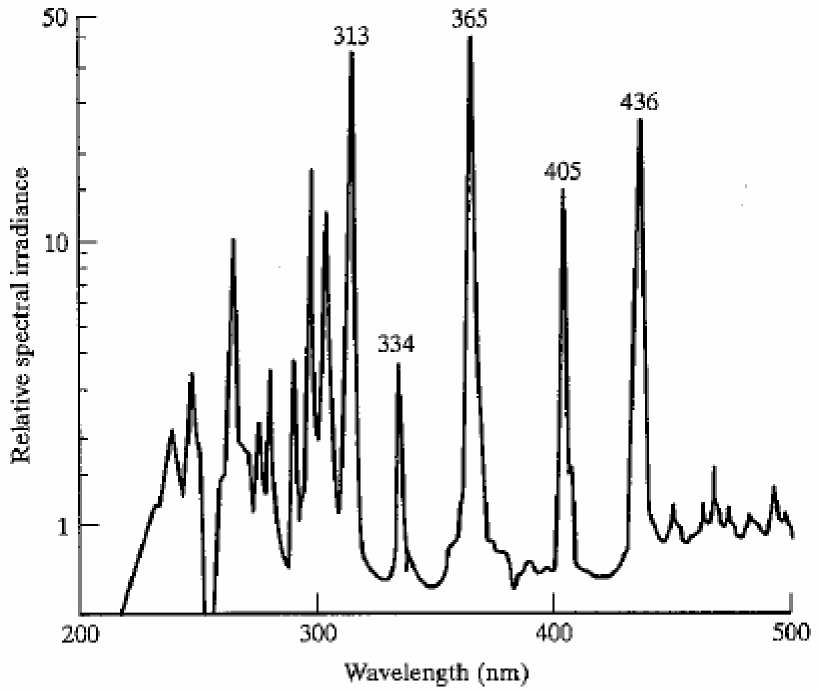


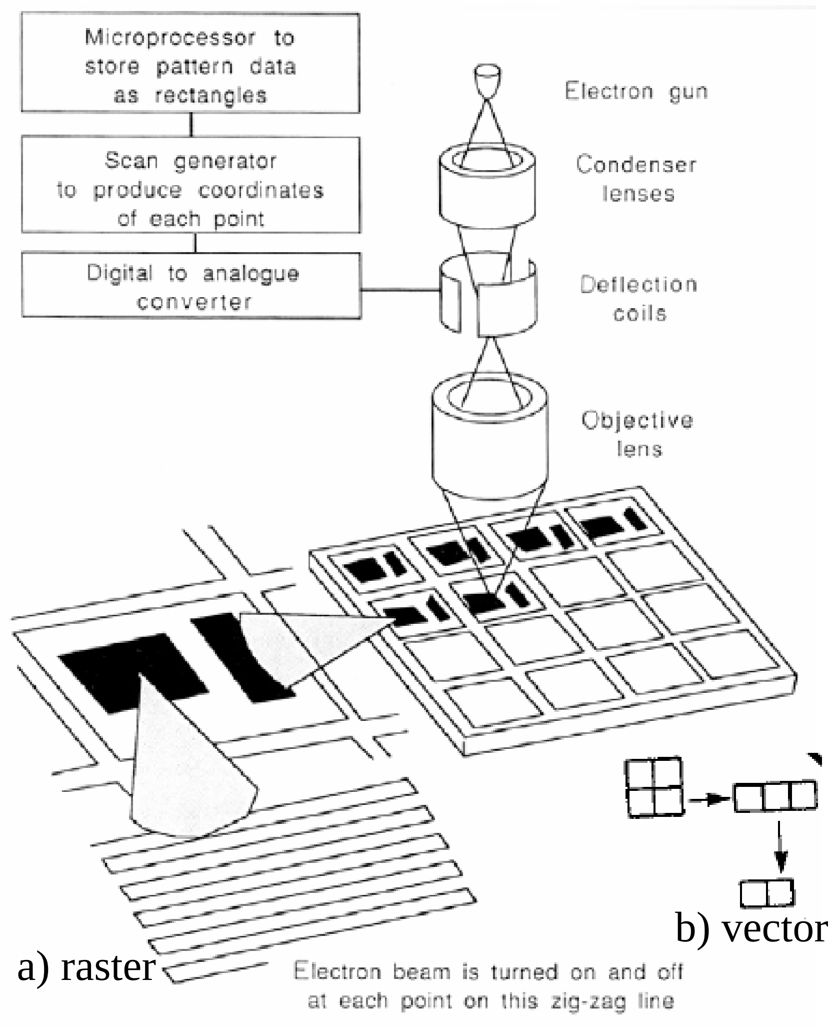
FIGURE 2.15

Spectal content of an Xe-Hg lamp (Courtesy of SVG)

Exposure sources—cont.

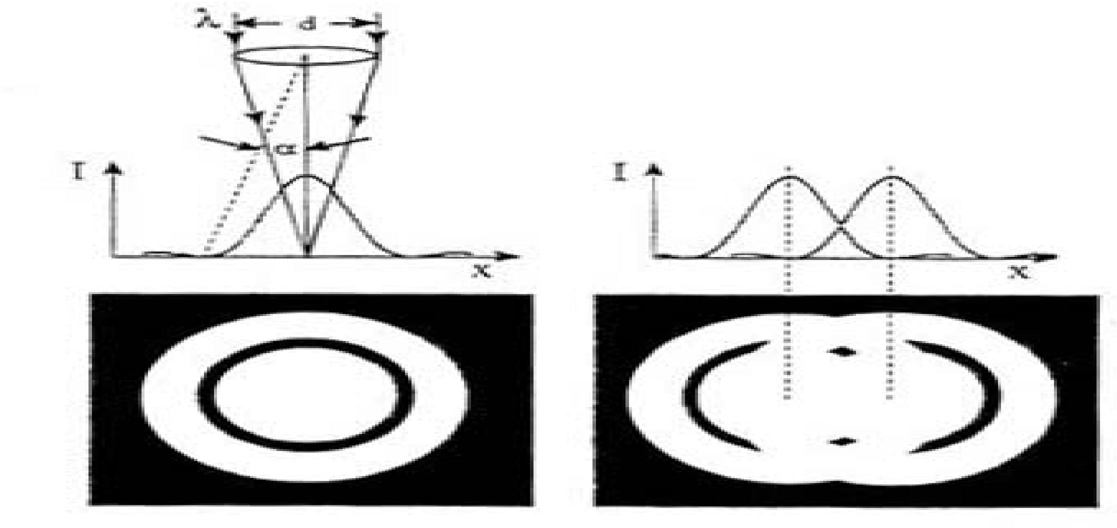
Non-optical:

- X-rays
  - <30 nm
  - Requires a new set of illumination, resist, and alignment technologies
- E-beam (no mask needed)
  - <3 nm
  - Already used for mask creation
  - Slow: beam raster scans each area on wafer (see figure) or vector scan (the beam is moved directly to the regions that have to be exposed and write small squares until building up the desired shape
  - Electron-sensitive resist
- Ion-beam?



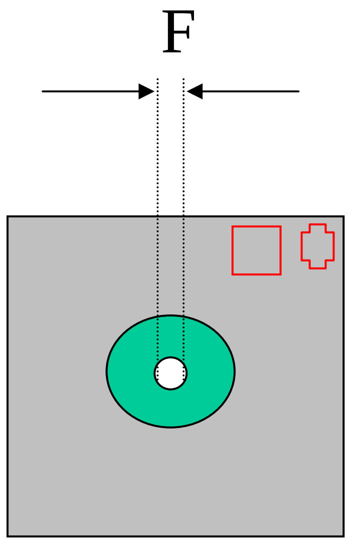
E-beam lithography

Minimum feature size



(a)

(b)



A photomask

- Limited by diffraction effect
    - Airy disk
- Raleign criterion: the central maximum of one coincides with the first minimum of the other

$$F = 0.6\frac{\lambda}{NA}$$

$$NA = n\sin\theta$$

Depth of focus

- Depth of field: the thickness of features in mask that is automatically in focus in image on wafer

- Depth of focus: the automatically focused image thickness

$$DF = 0.6\frac{\lambda}{(NA)^2}$$

Example: Assume NA=0.6
Minimum feature size F=100nm
Exposure source λ=100nm
DF=166nm

You achieve smaller feature size, but then DF is also smaller, effect: a thicker resist is not exposed completely.

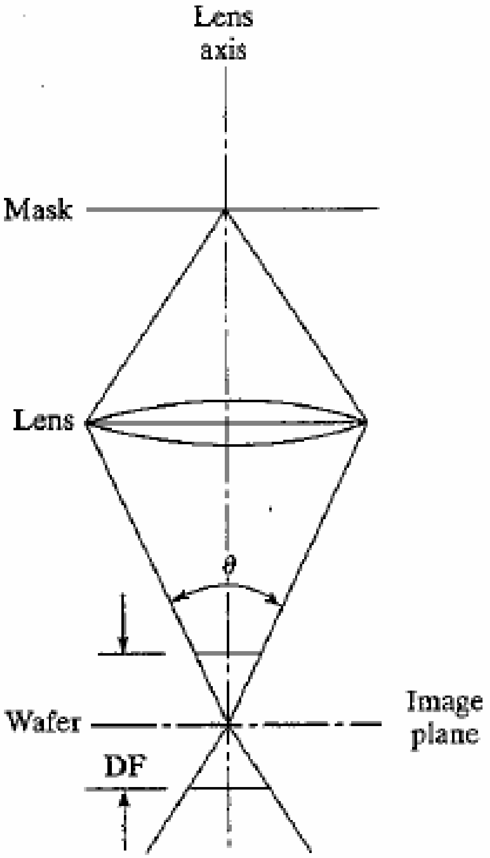


FIGURE 2.14

Optical focal plane and depth of focus

An example: Phase-shift mask

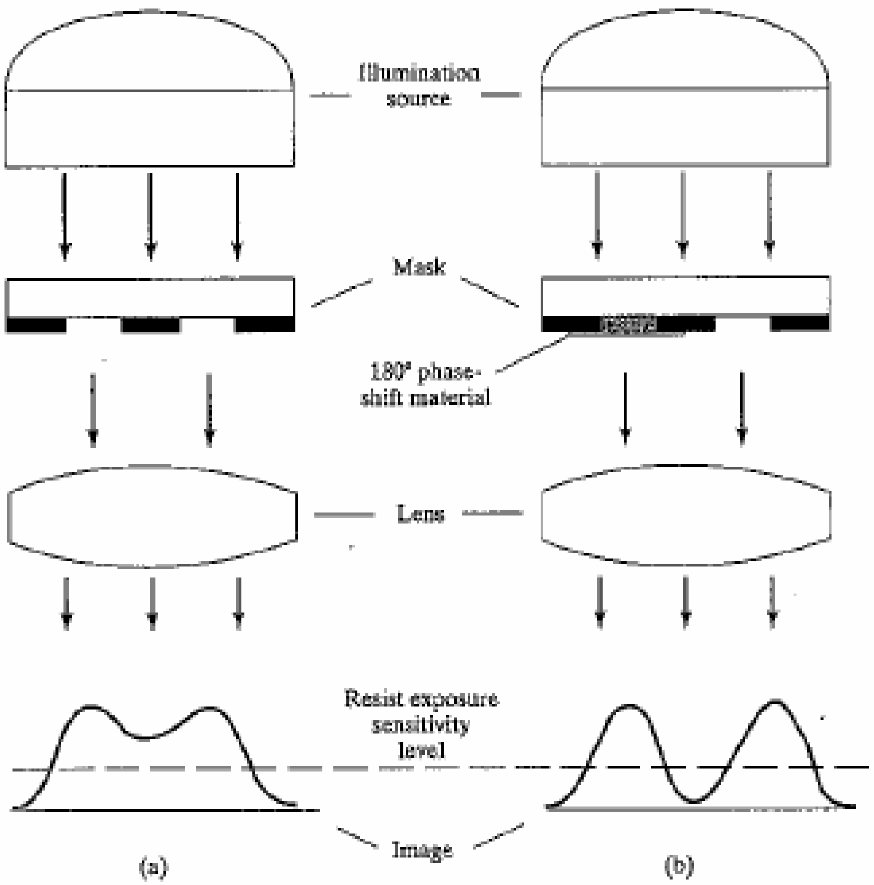


FIGURE 2.16

Pattern transfer of two closely spaced lines (a) using conventional mask technology (b) using a phase-shifting mask

← Electric field
What is the distribution?

← Light intensity

Another example: Immersion lithography

Immersion lithography means the immersion of lens (in stepper) and wafer in a high index fluid (for example water), i.e. expose wafer in water.

- Effectively reduces the wavelength of incident light by n (note: $n_{air}=1$):

$$\lambda_n = \frac{\lambda}{n}$$

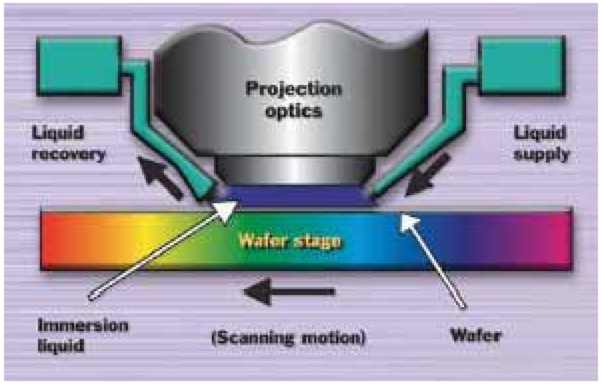
- For example: 193nm source, if the stepper is immersed in water, now gets effective 133nm source ($n_{water}=1.44$)

- Equivalent to effectively increase the numerical aperture:

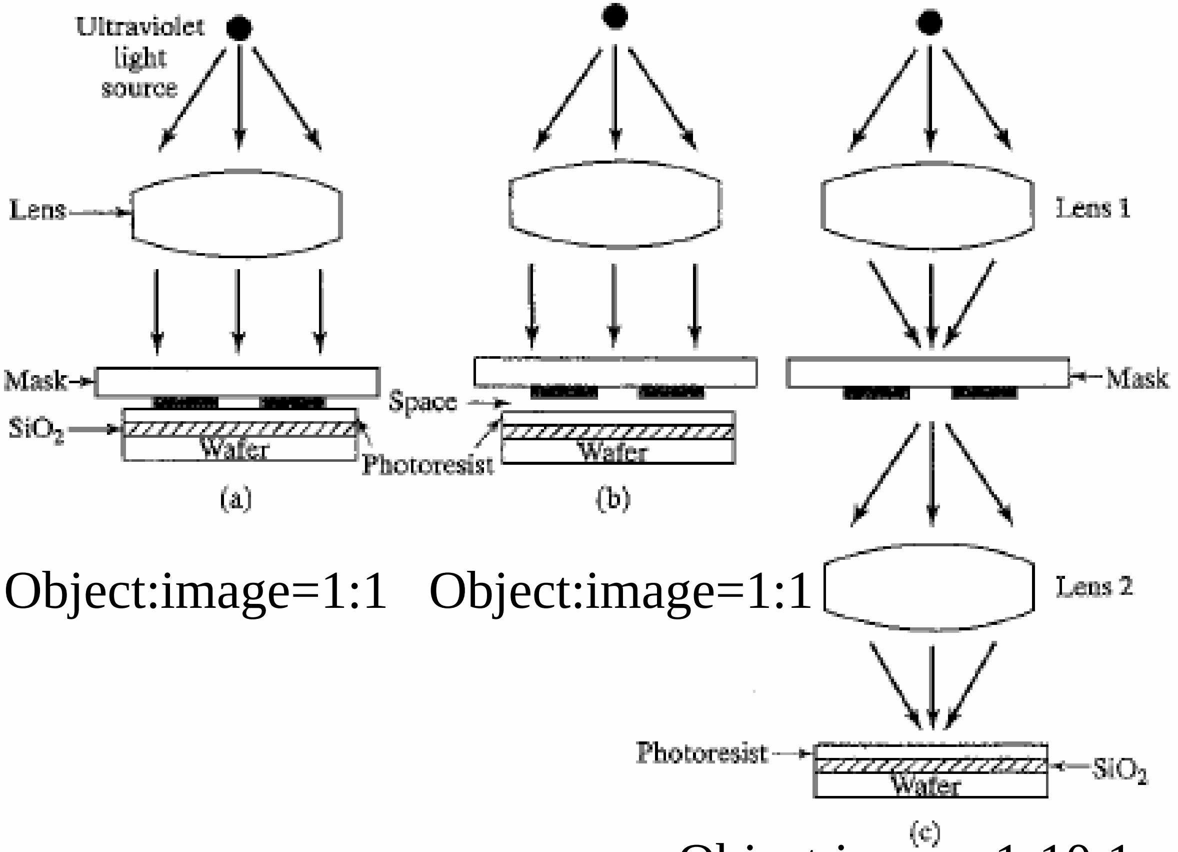
$$NA = n \sin\theta$$

- Therefore increases the resolution:

$$F = 0.6\frac{\lambda}{NA}$$



Exposure techniques



Object:image=1:1 Object:image=1:1

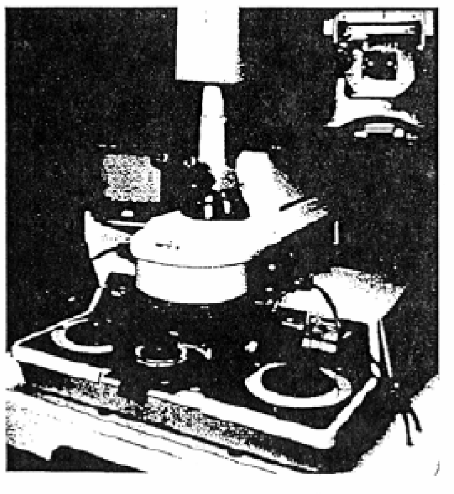
Object:image=1-10:1

FIGURE 2.11

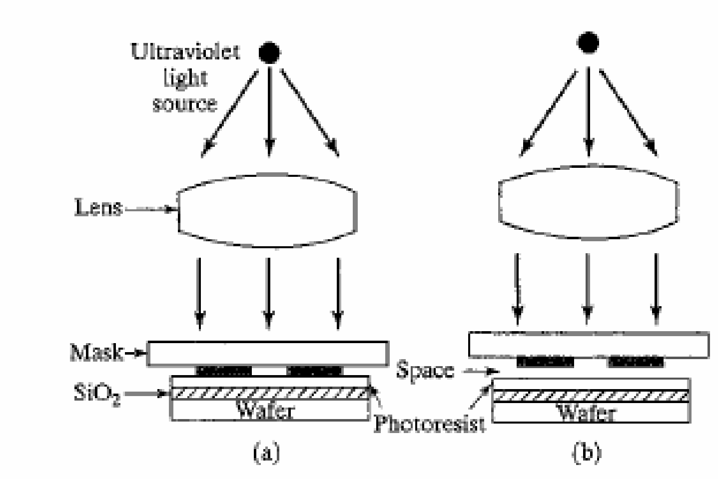
Artist's conception of various printing techniques. (a) Contact printing, in which wafer is in intimate contact with mask; (b) proximity printing, in which wafer and mask are in close proximity; (c) projection printing, in which light source is scanned across the mask and focused on the wafer. Copyright, 1983, Bell Telephone Laboratories, Incorporated. Reprinted by permission from Ref. [5].

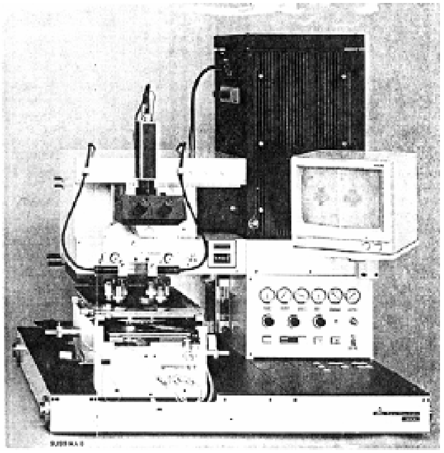
Mask aligner

Contact/proximity aligners:

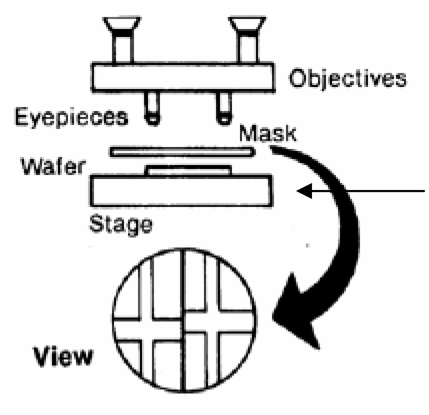


Quintell





Karl-Suss



Knobs to move in x-y direction and rotational

A Stepper

Projection-type aligner

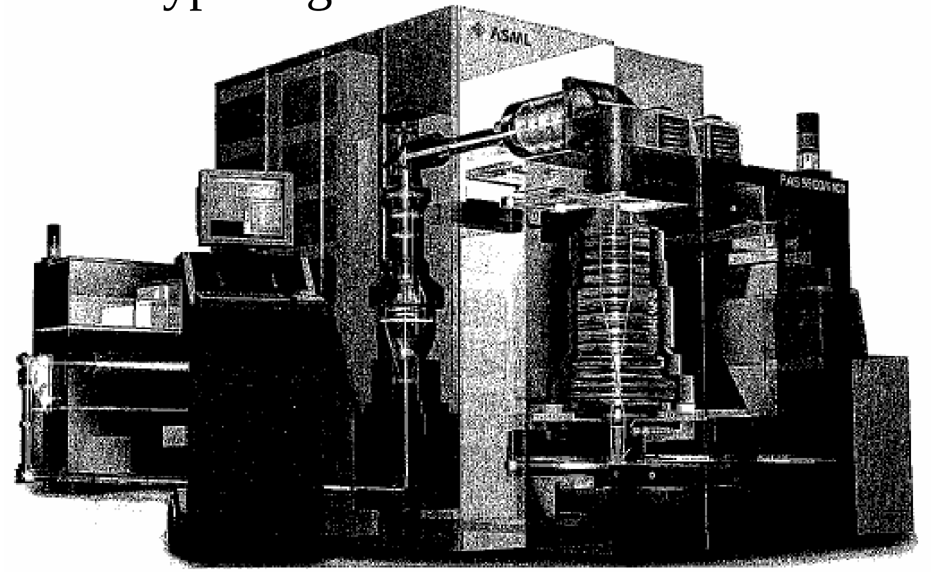
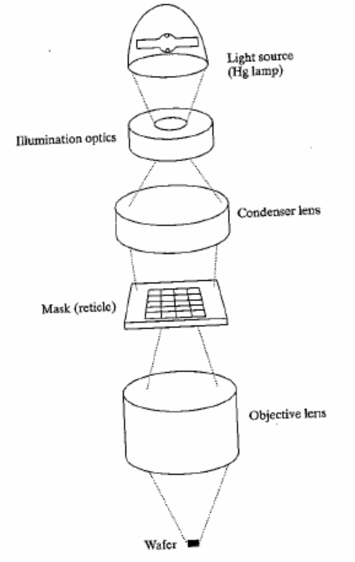


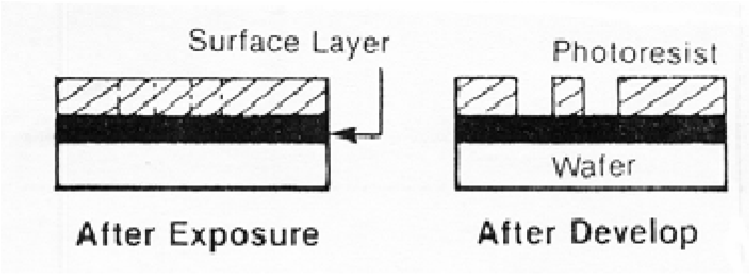
FIGURE 2.13

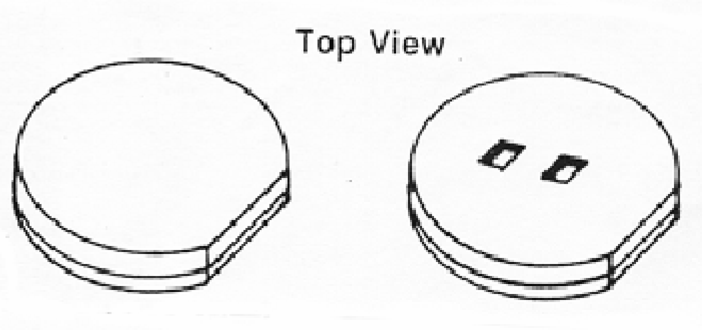


- The wafer is moved (stepped) from die site to die site on the wafer, and the pattern is aligned and exposed at each individual site (10 to 1 reduction step/repeat).
- Mask alignment:
  - Automatic alignment by passing low-energy laser beams through alignment marks on the reticle and reflecting them off corresponding alignment marks on the wafer surface. The signal is analyzed, and information is fed to the x-y-z wafer chunk controls by a computer, which moves the wafer around until the wafer and reticle is aligned. (for 1:1 step/repeat)
  - Vision system alignment: uses a camera to capture a vision of the die and compare it to a data base. The wafer is moved until it and the mask image match the data base.

Photo-steps cont.

Develop





Positive resist

Developer: Sodium hydroxide (NaOH)
Tetramethyl ammonium hydroxide (TMAH)

Rinse: DI water

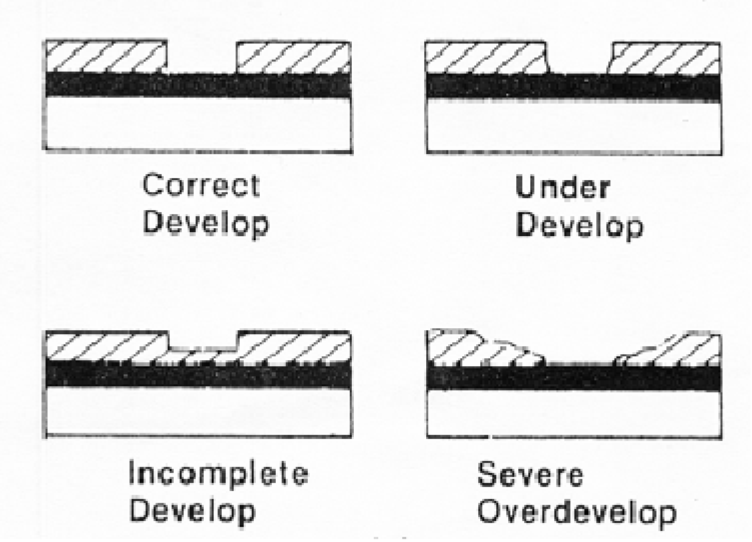
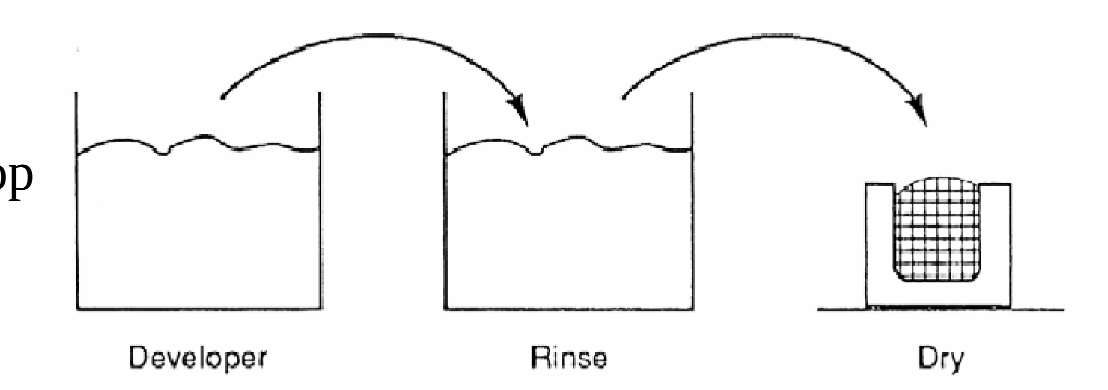


Photo-steps cont.

Develop method

Immersion develop

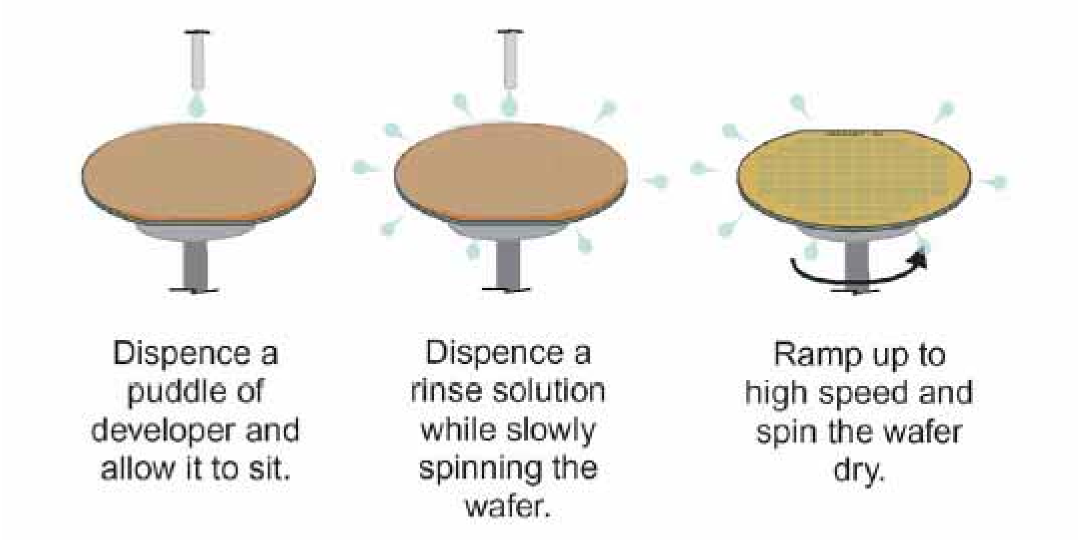


develop in developer (normally mixed with DI water) for 30-60 seconds

rinse in DI water

spin dry

Automatic puddle-spray develop



Dispence a puddle of developer and allow it to sit.

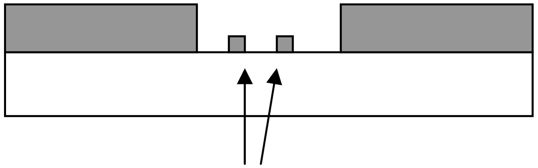
Dispence a rinse solution while slowly spinning the wafer.

Ramp up to high speed and spin the wafer dry.

Photo-steps cont.

Plasma descum

in an oxygen plasma system called asher



Resist

A piece of resist or dried developer

Hard bake: to drive off more solvent to make the resist tougher against subsequent etching

Typically 120°C hotplate for 20 minutes
For AZ5214: 150°C hotplate for 2 minutes
Note: soft bake was at a lower temperature for less time

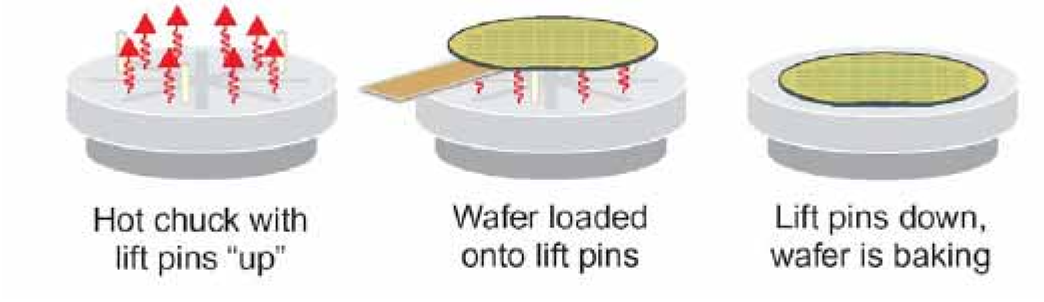
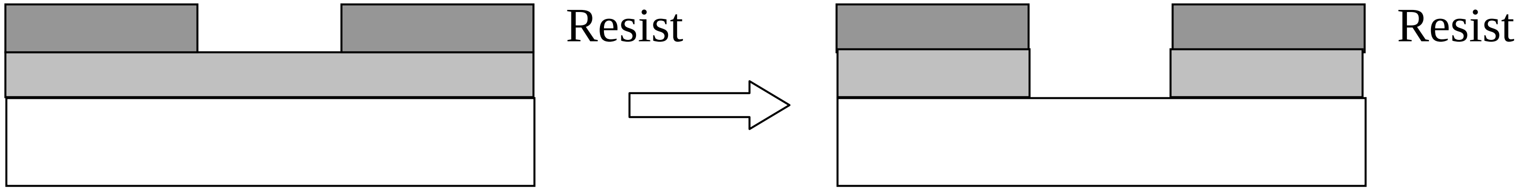


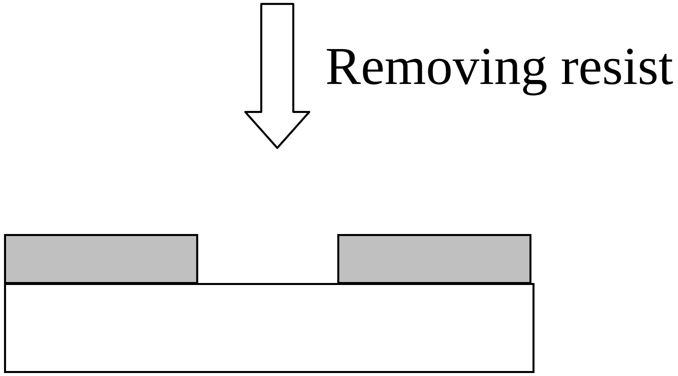
Photo-steps cont.

Etching



Photoresist stripping

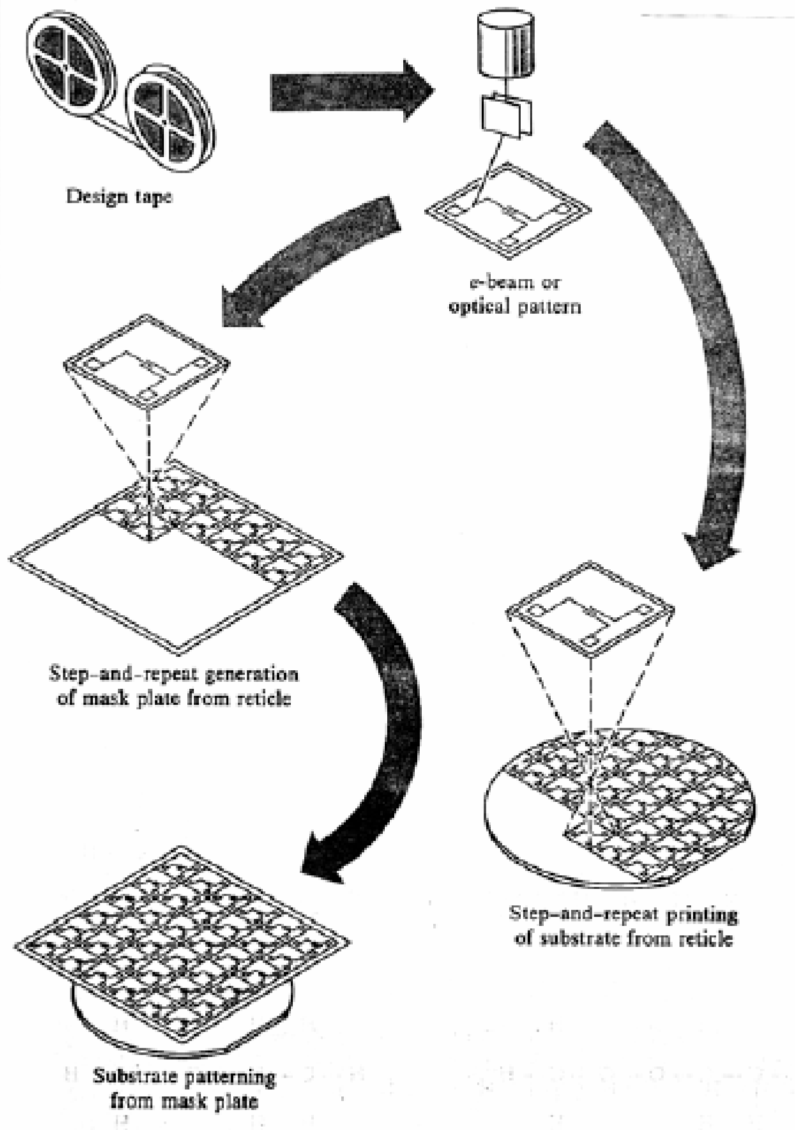
- •Solvent stripper: Acetone
- •Phenol-based organic strippers
- •Inorganic strippers (Nitric/Sulfuric acids)
- •Plasma strippers



The wafer is now ready for inspection and subsequent photo-steps, what are these steps?

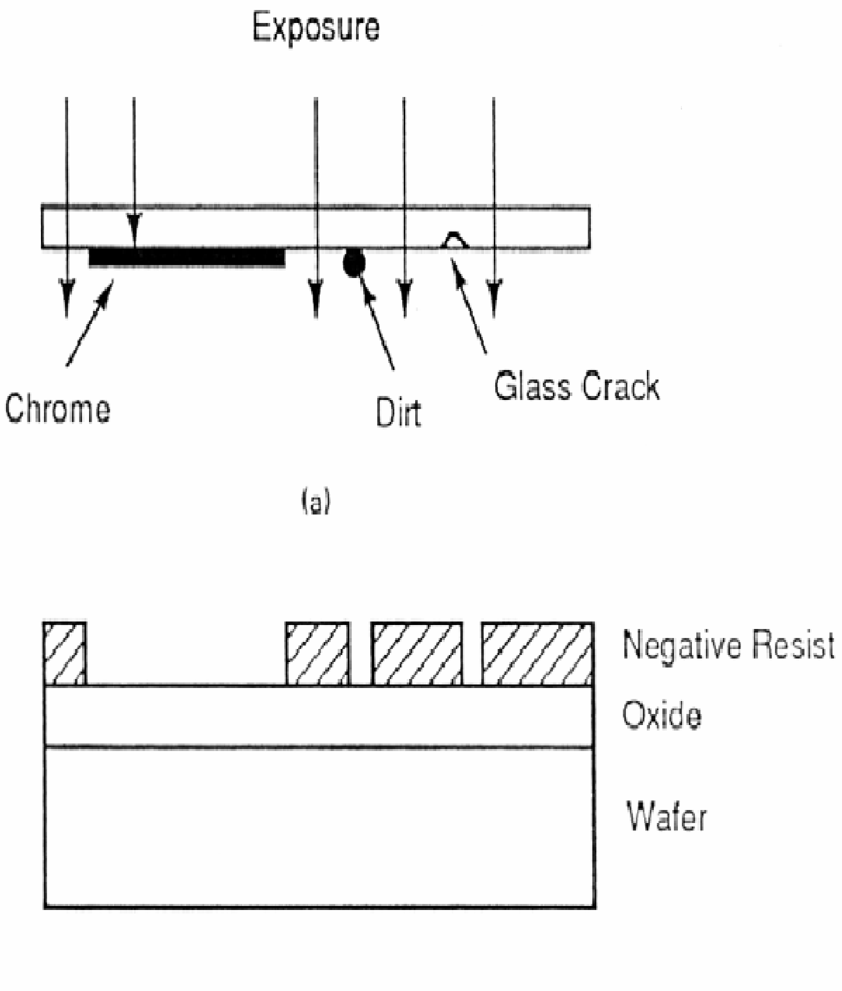
Photomask fabrication

- Create pattern of one die by CAD (computer aided design)
- Laser or e-beam pattern generator to transfer this die pattern to a photographic plate called reticle, a process similar to photolithography
    - Chrome thin film on glass or quartz plate, then cover with electron-sensitive resist, use e-beam to direct write the die pattern on the plate, then develop and etch to form reticle
- The final reticle size is typically 1-10 times of real die size you want
- Step-and-repeat (reduction) to transfer to final photomask or direct on wafer.



Example: Mask defect

- Mask defects the most deadly problem
- Repeat same defect on every wafer
- Typical problems
- Dirt on mask (may come from resist)
  solution: clean mask (easier with Chrome mask)
- Crack in glass, or scratched mask
  solution: replacement mask
- Photoemulsion masks last about 100 wafers
- Chrome almost indefinite: but more expensive
- Typical Mask cost \$500-\$1000



(a)

(b)