Lecture#3:

Photolithography (1)
: *Microlithography*

Photolithography (1): Microlithography

Photolithography

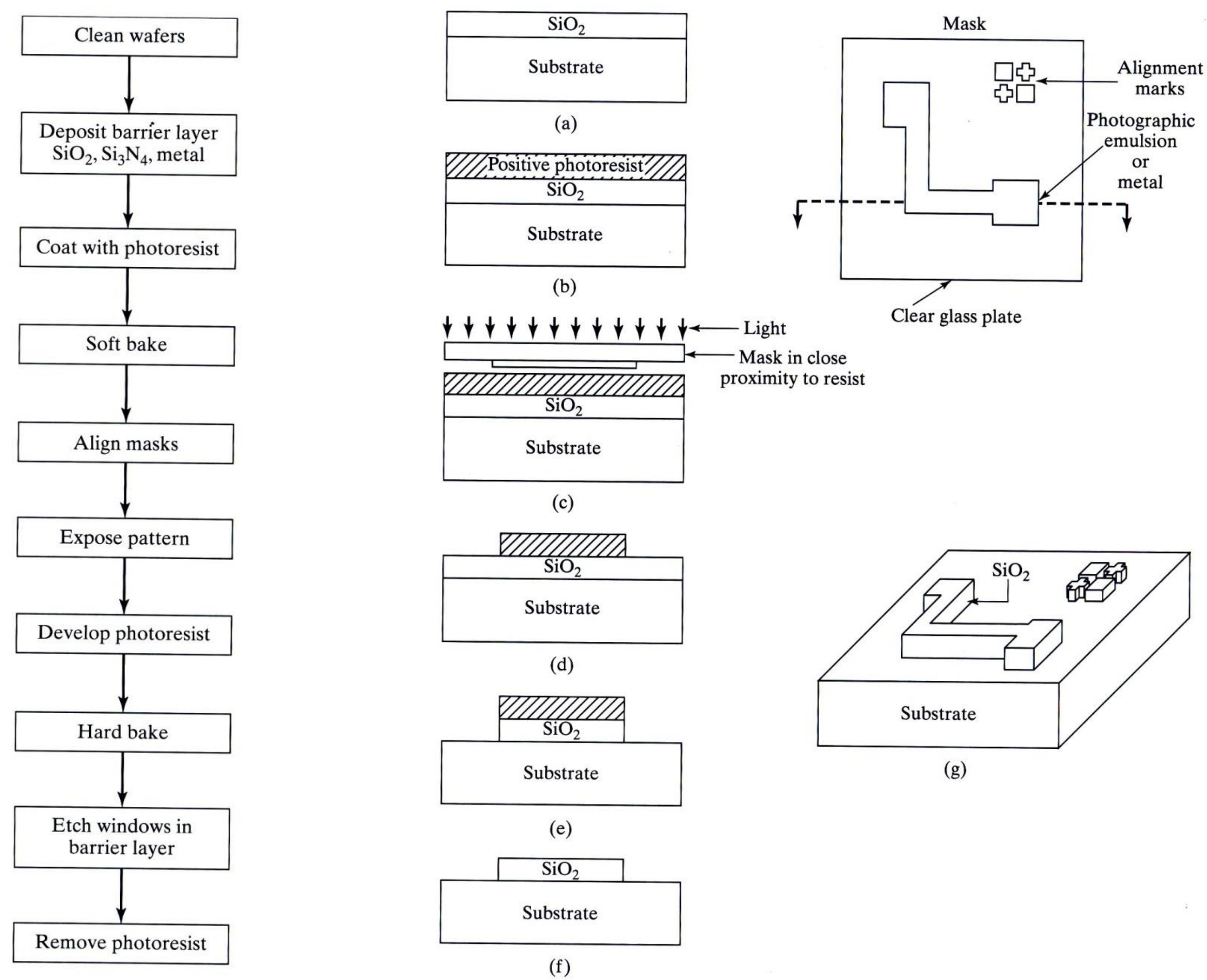
- Photolithography encompasses all the steps involved in transferring a pattern for a mask to the surface of the silicon wafer.

- Ultra-clean conditions must be maintained during the lithography process; clean-rooms have evolved from the Class 10,000 to Class 1 for VLSI (ULSI) processing.
  * Class: number of particle exceeding a size of 0.5 μm per ft^3

Class	# 0.5 µm particles per ft^3	# 5.0 µm particles per ft^3	air changes per hour	ceiling filter coverage (%)	air velocity (fpm)	max. vibration (µin/s)	temp. tolerance	RH tolerance	approx. capital cost per ft^2
office			12-18						$10
100,000	100,000	650	18-30	10					$50
10,000	10,000	65	40-60	30	10		±3.0°F	±5%	$200-250
1,000	1,000	6.5	150-300	50	30-50		±2.0°F	±5%	$350-400
100	100	0.65	400-540	80-100	75-90	500	±1.0°F	±5%	~$1200
10	10	0.065	400-540	100	75-90	250	±0.5°F	±3%	~$3500
1	1	0.0065	540-600	100	90-100	250	±0.3°F	±2%	~$10,000+
.5	.5	0.0033	540-600	100	100-110	125	±0.1°F	±1%	~$25,000+

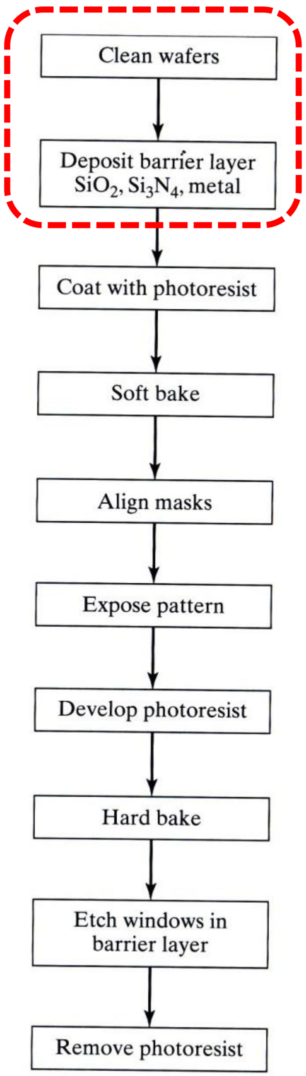
General Step

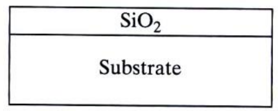
Photolithography (1): Microlithography



Wafer Cleaning & Barrier layer

Photolithography (1): Microlithography





(a)

- **Wafer Cleaning**

  - Prior to use, wafers are chemically cleaned to remove particulate matter on the surface as well as any traces of organic, ionic, and metallic impurities.

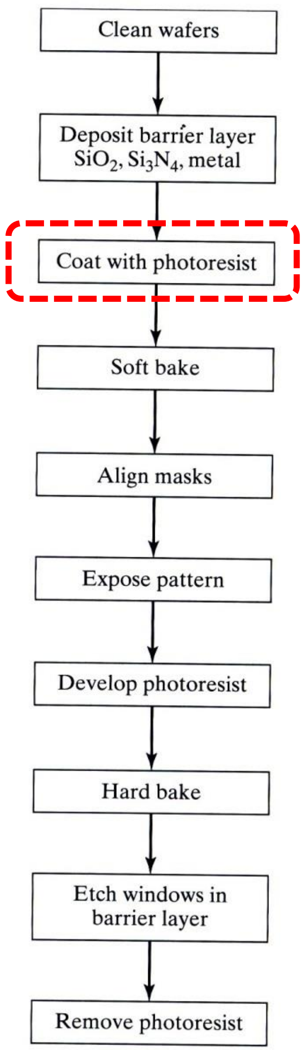
  * Deionized (DI) water :
    - highly purified and filtered
    - resistivity: 18 M-ohm-cm@25 C,
    - no particles larger than 0.25 µm

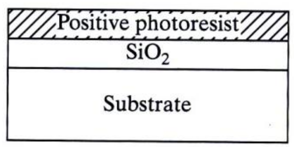
- **Barrier Layer**

  - SiO_2, Si_3N_4, Polysilicon, Metal, etc.

PR Coating (1)

Photolithography (1): Microlithography





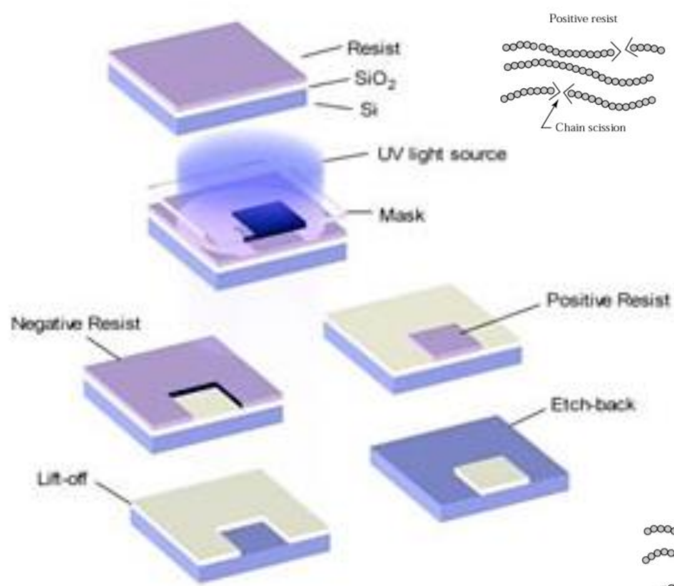
Photoresist

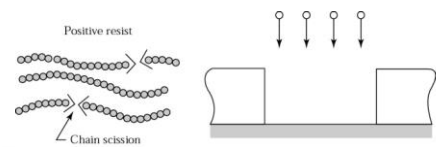
(conditions)

- light-sensitive material
- good adhesion to substrate

(Features)

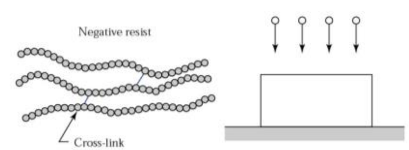
- Type: positive and negative





Positive(+):
exposure to the UV light changes the chemical structure of the resist so that it becomes more soluble in the developer.

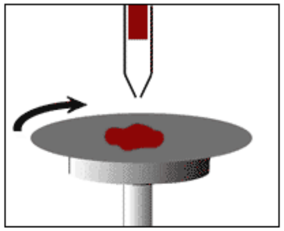
Negative(+):
When exposed to the UV light, the negative resist becomes crosslinked/polymerized, and more difficult to dissolve in developer.

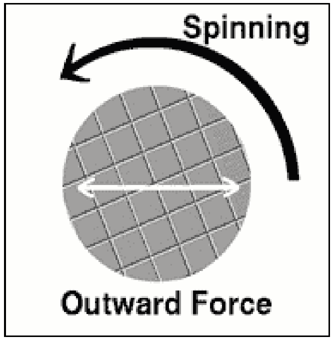


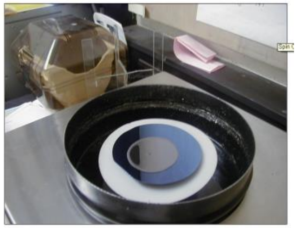
PR Coating (2)

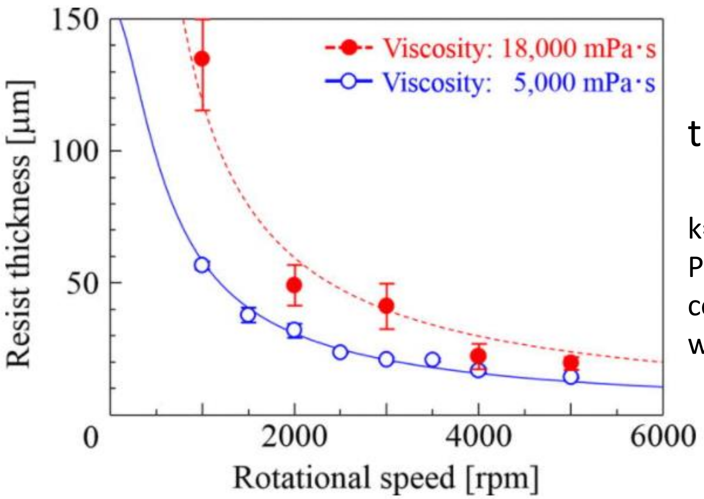
Photolithography (1): Microlithography

Spin Coating







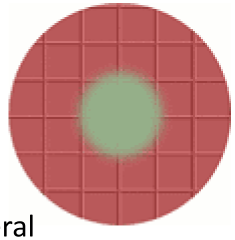


$t = kp^2/w^{1/2}$

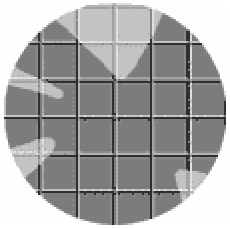
k=spinner constant
P=resist solid contents in percent
w=spinner speed

- Thickness depends on its viscosity and is inversely proportional to the square root of the spinning speed, typically 0.5 - 2.5 μm thickness.

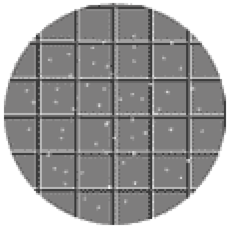
- Various cases



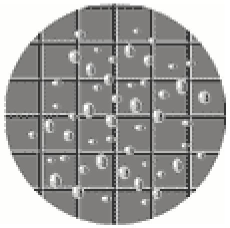
General
Center is thicker than edge position



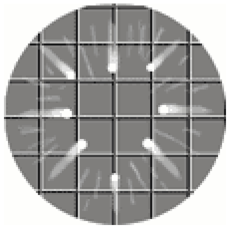
PR is not enough



Pinholes



Air bubble



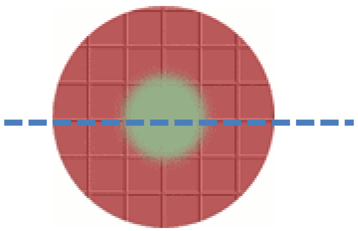
Particles

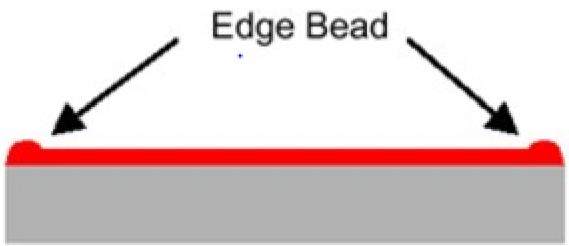
Swirl pattern

PR Coating (3)

Photolithography (1): Microlithography

* Edge bead

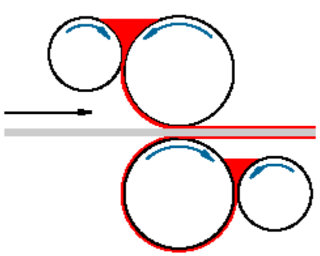


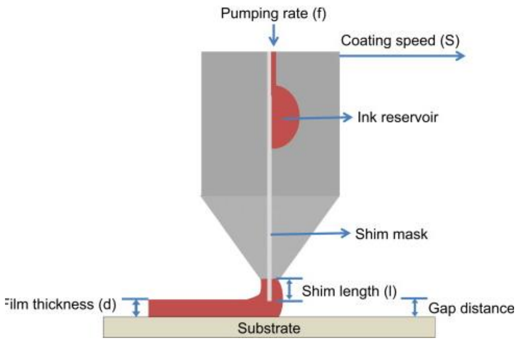


- Residual ridge in resist at edge of wafer
- Can be up to 20~30 times thinker than the nominal thickness of the resist

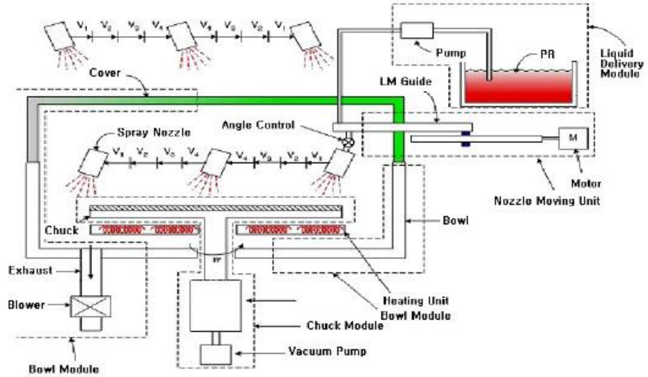
Roll/Die Coating

: large size substrate (LCD,PDP)

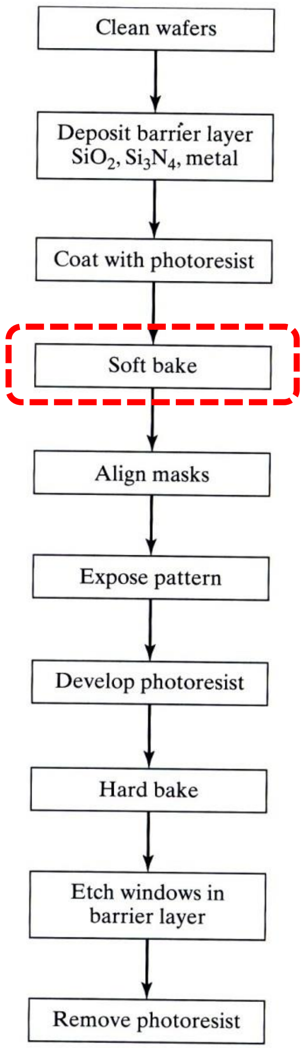


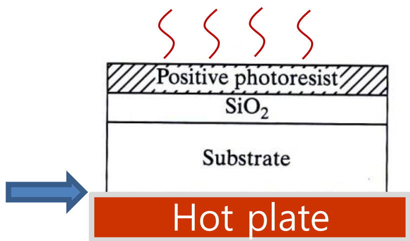


Spray Coating



Soft Bake





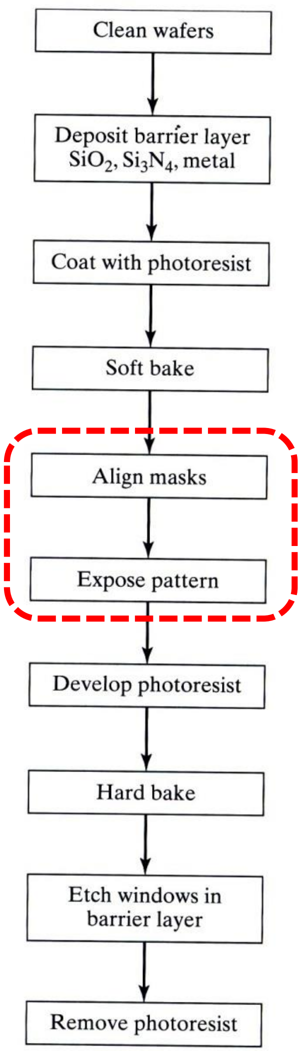
Soft Bake

- Improve adhesion
- Remove solvent
- 80 ~95°C: about 2min using hot plate or 10 ~30 min using oven
  → Thermal conductivity
  → Heat direction
- Commercially, microwave heating or IR lamps are also used in production line.

- The thickness of the resist is usually decreased by 25% during soft bake for both positive and negative resists.
- Less soft bake increases the development rate.

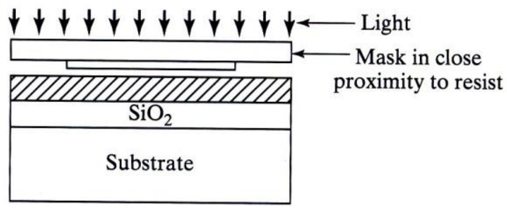
Align & Exposure (1)

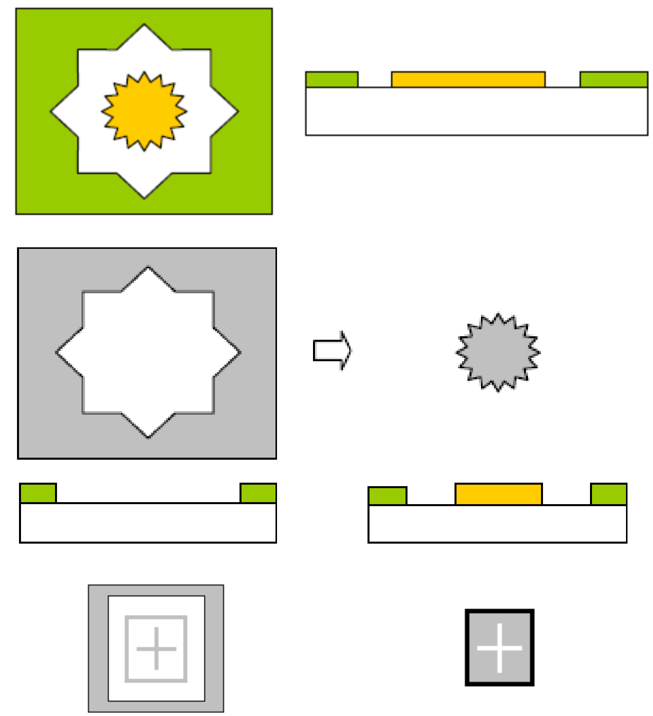
Photolithography (1): Microlithography



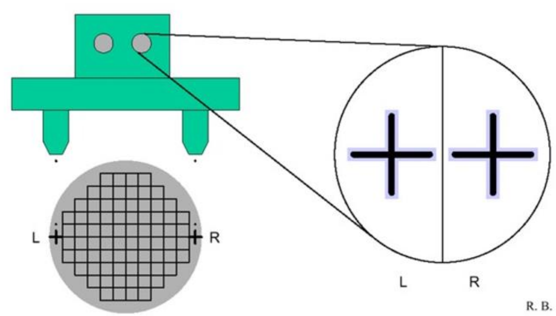
- **Mask Alignment**
  - Alignment marks are introduced on each mask and transferred to the wafer as part of the IC pattern. The marks are used to align each new mask level to one of the previous levels.

(Example)





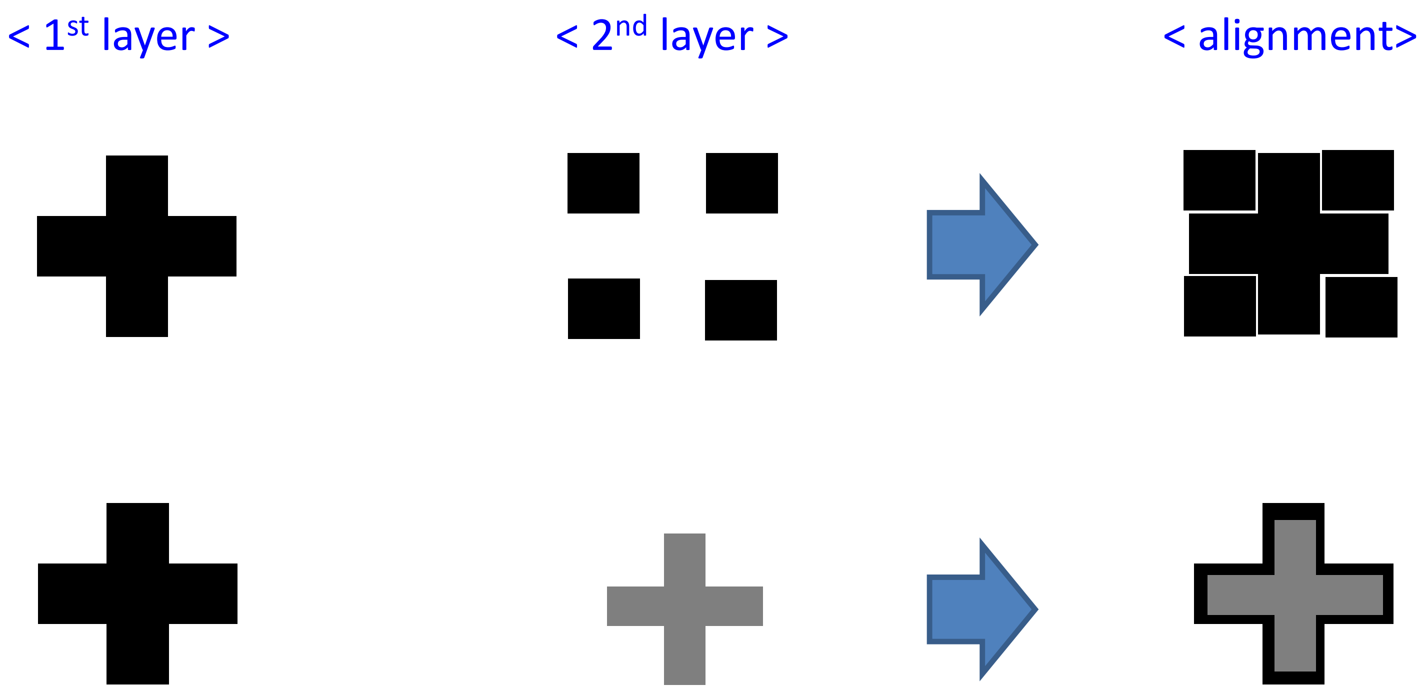
  - Normally requires at least two alignment mask sets



Example: Alignment

Photolithography (1): Microlithography

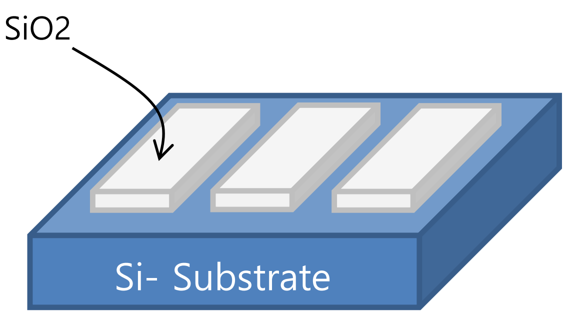
- **Mask Alignment**

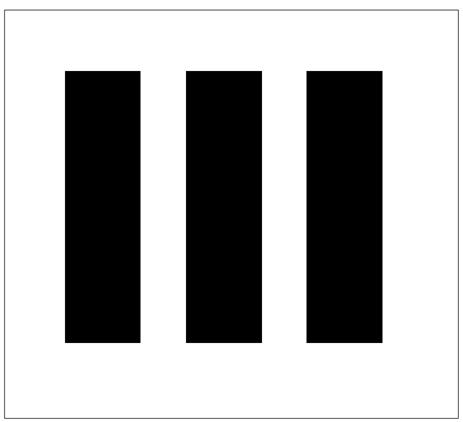


Align & Exposure (2)

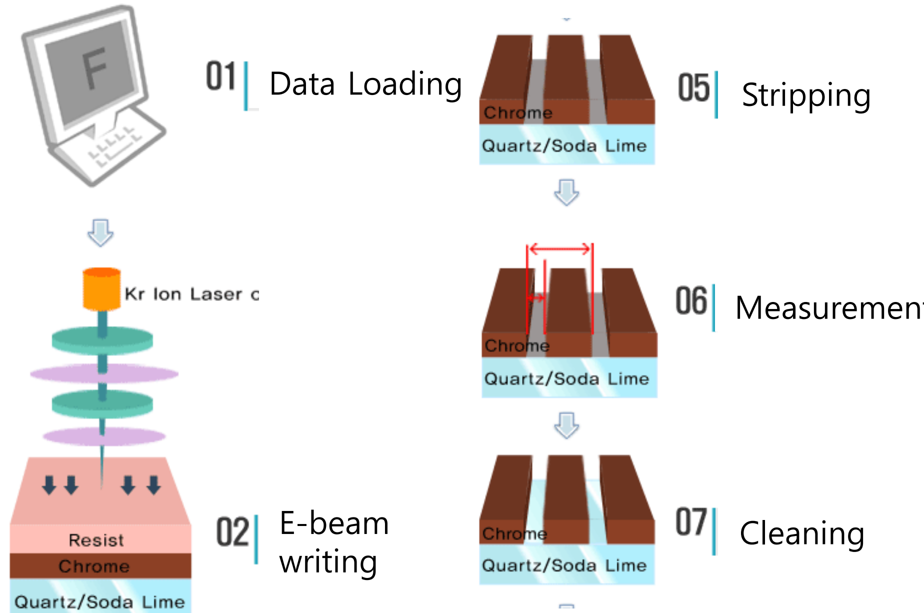
Photolithography (1): Microlithography

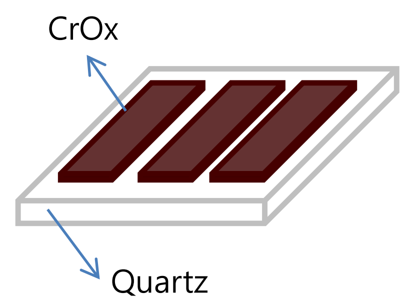
Photo Mask





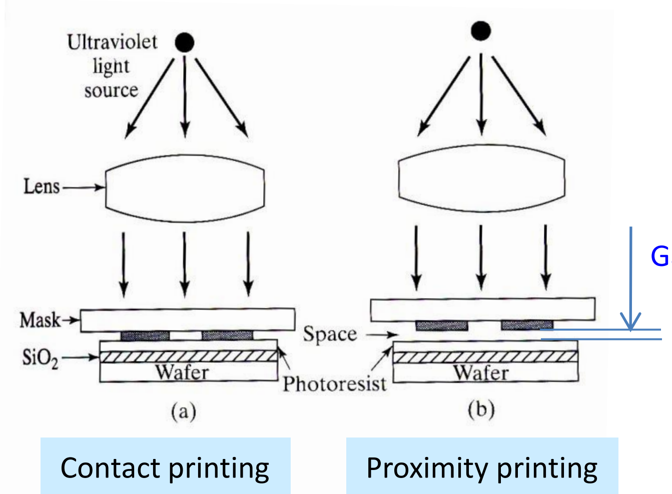
Drawing mask using CAD
(Bright field mask)





Final Photomask image
(Shadow mask)

Shadow Printing



Contact printing

- Minimum pattern size : ~1um
- Simple & Easy
- Mask contamination
- Mask damage

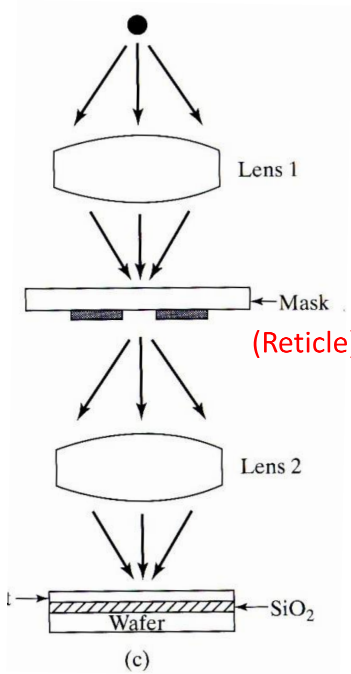
Proximity printing

- Minimum pattern size : 2~5um
- Precise gap control
- No contamination
- No damage

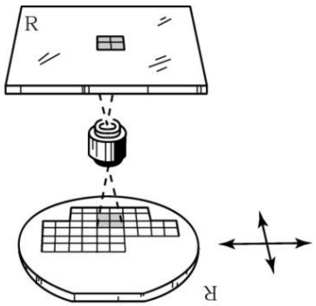
$$\text{CD(critical demension)} \cong \sqrt{\lambda g}$$

λ=0.4 , g=50um → CD 4.5um
λ=0.25 g=15um → CD 2um
λ=0.25 g=0.01 → CD 0.05um ?

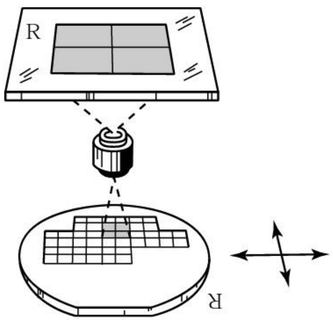
Projection Printing: Stepper



- Minimum pattern size ; ~70nm
- No contamination
- No damage
- Small exposure area
- Time loss



1X stepper

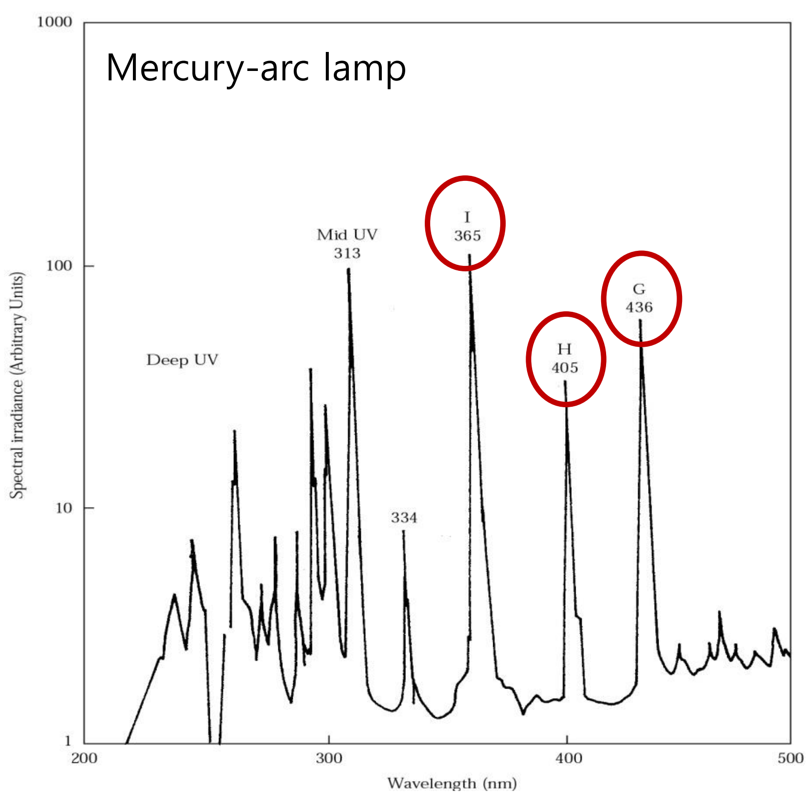


4X stepper

Align & Exposure (4)

Photolithography (1): Microlithography

Exposure Source



G-line stepper: 436nm

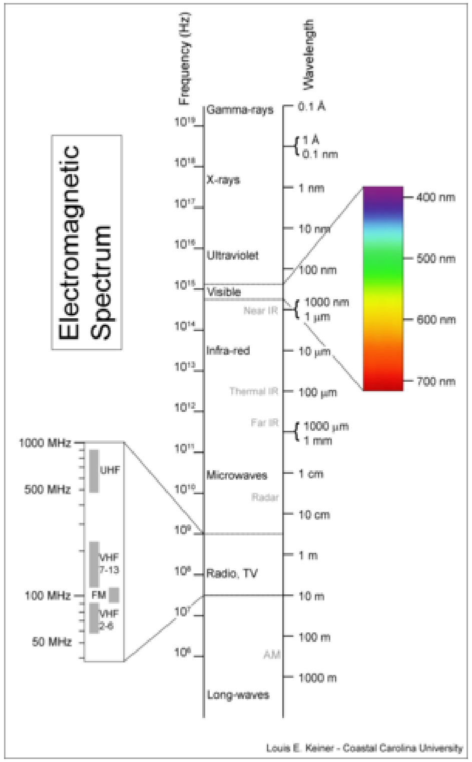
H-line stepper: 405nm

I-line stepper: 365nm
; 5x → 300nm

KrF eximer laser : 248nm
; 180nm

ArF eximer laser : 193nm
; 100nm

F_2 eximer laser : 157nm
; 70nm



We need new exposure technique

Align & Exposure (5)

Photolithography (1): Microlithography

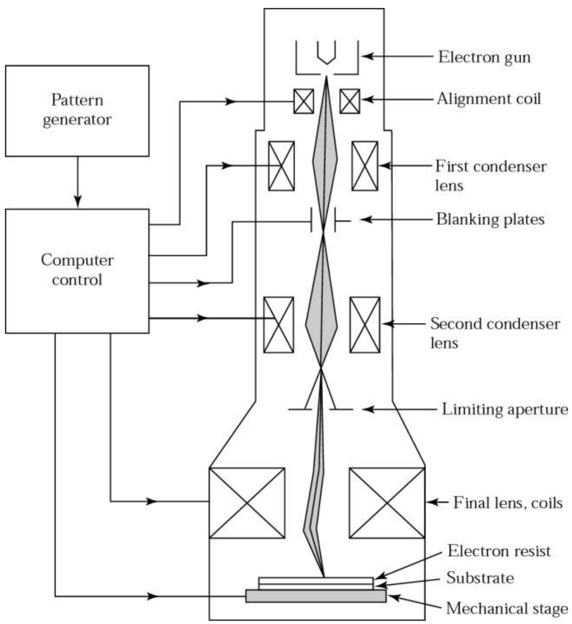
- **General Photolitho-Process**

Align & Exposure (6)

Photolithography (1): Microlithography

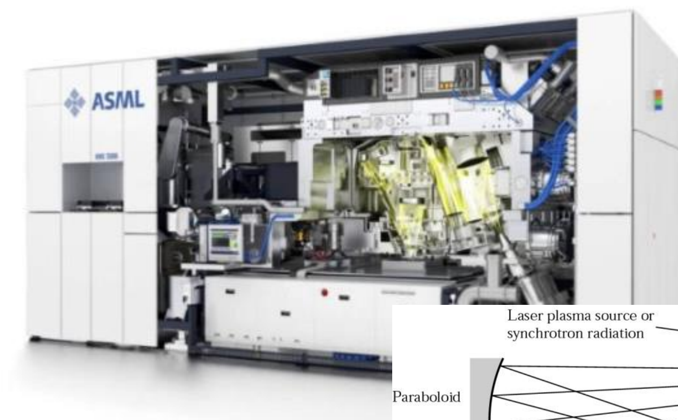
New Exposure Technique

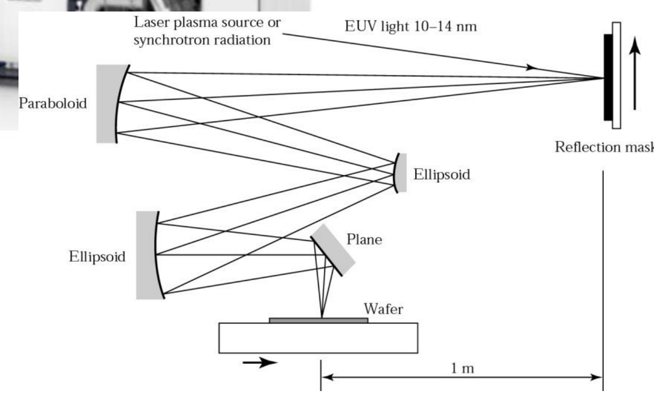
Electron beam lithography (Text 4.2.1)



- Condenser lenses are used to focus the electron beam
- Blanking plate: beam On & Off control
- Beam size: 5nm ~500nm
- Beam position is fixed: stage is moved (precision control)
- Disadvantage : Low throughput

Extreme ultraviolet lithography (Text 4.2.2)





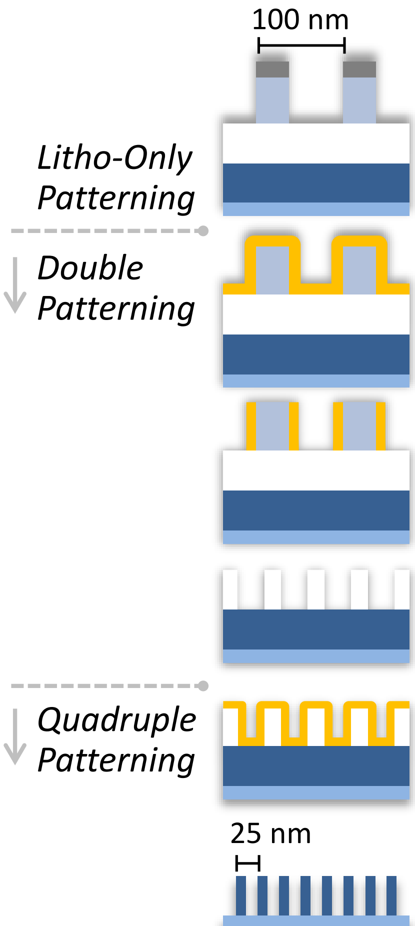
¼ speed of mask movement (4X case)

Target resolution ~30nm
Wave length (EUV) :10~14nm
Problem : Vacuum state

Align & Exposure (7)

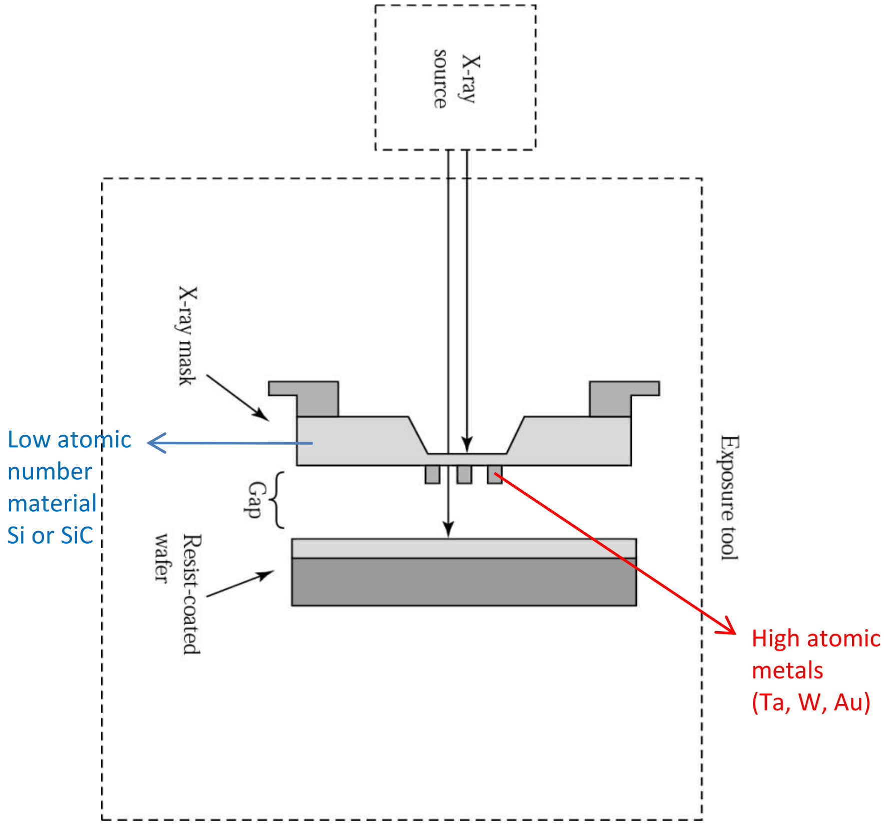
Photolithography (1): Microlithography

Double patterning



Photolithography (1): Microlithography

X-ray (or synchrotron) lithography (Text 4.2.3)

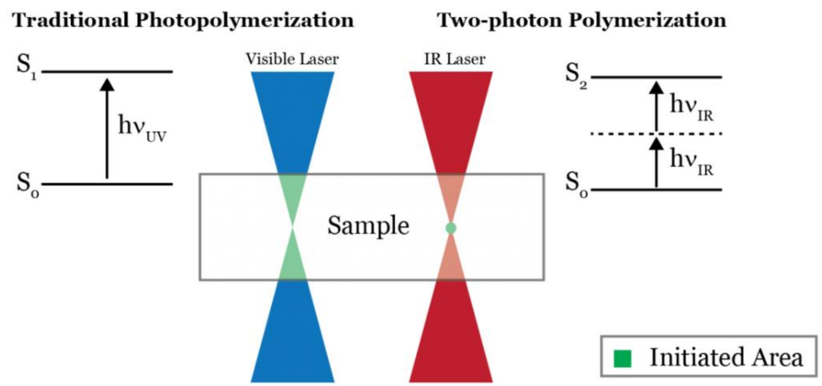


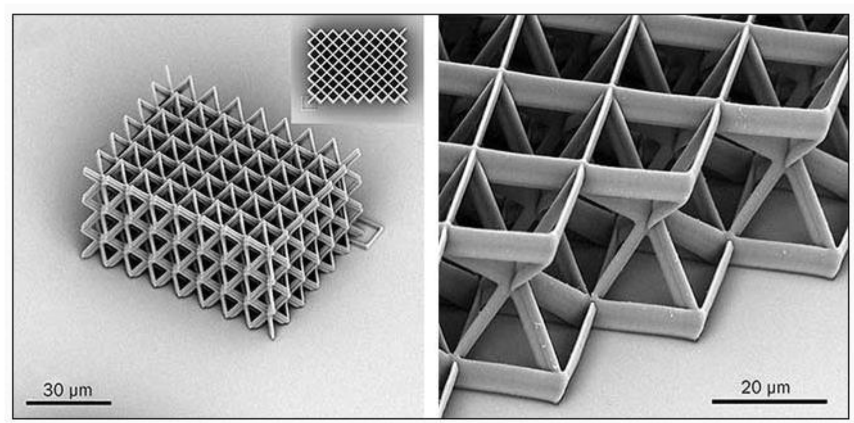
Target resolution 0.4 ~ 5 nm

Problem : Fabrication of Mask

Two photon lithography system

- 2PA is only observed in intense laser beams, particularly focused pulsed lasers, which generate a very high instantaneous photon density.

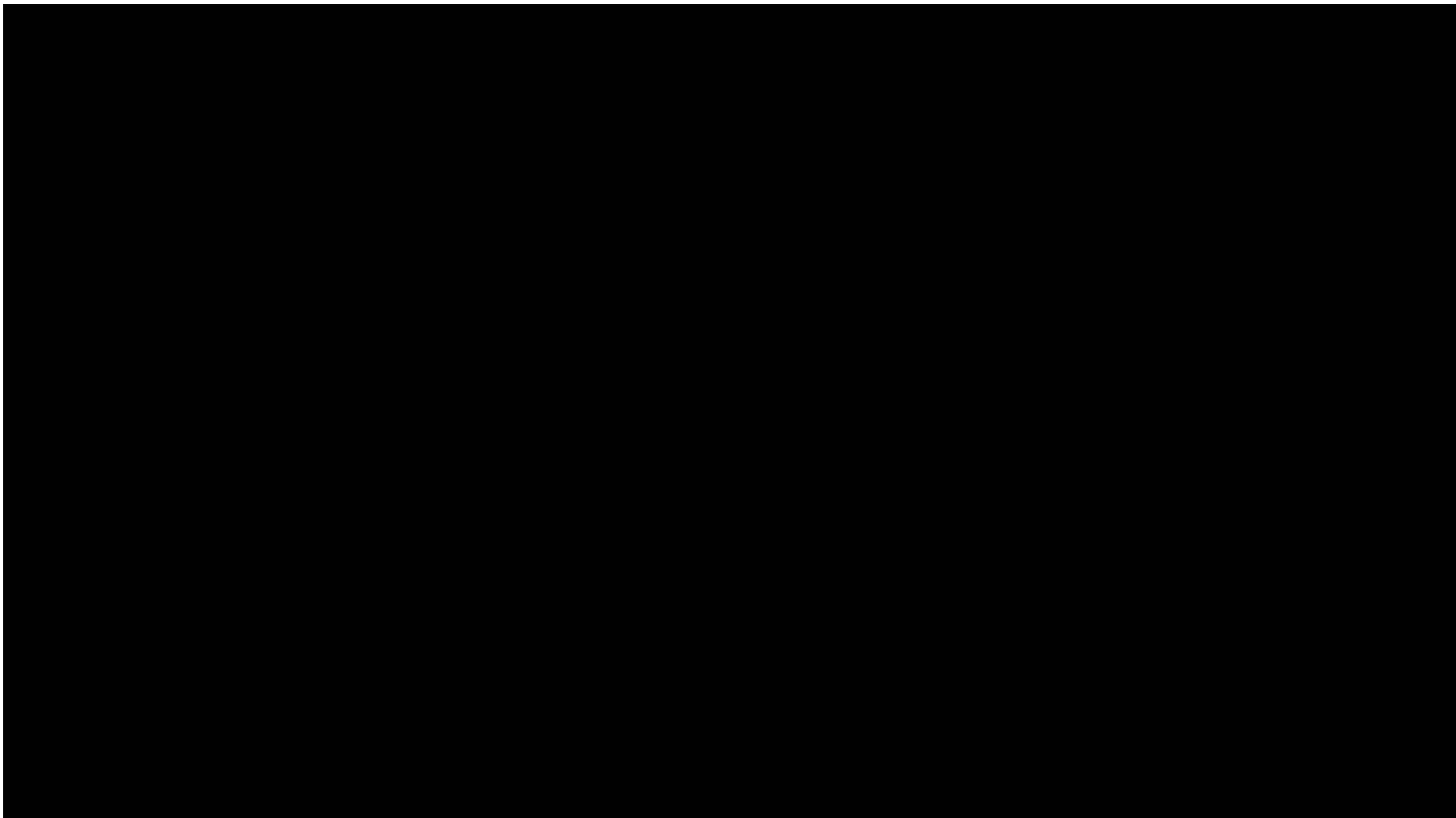




Align & Exposure (9)

Photolithography (1): Microlithography

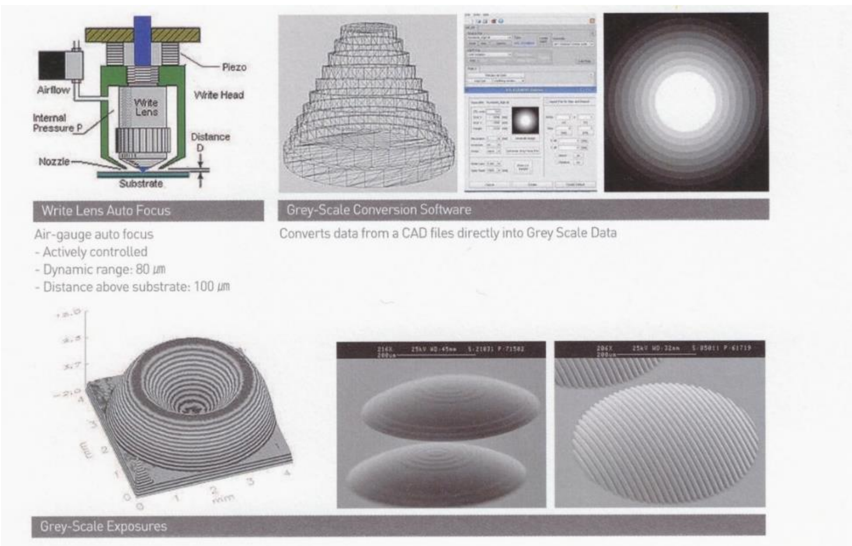
Two photon lithography system (Movie)

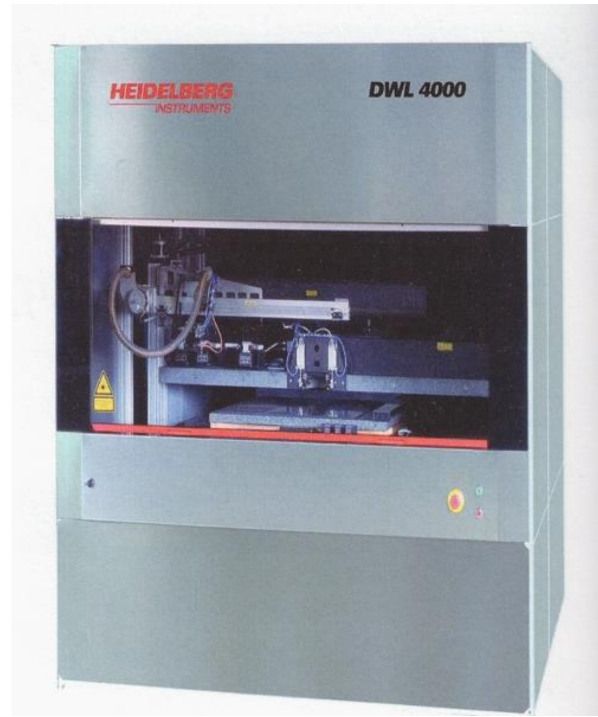


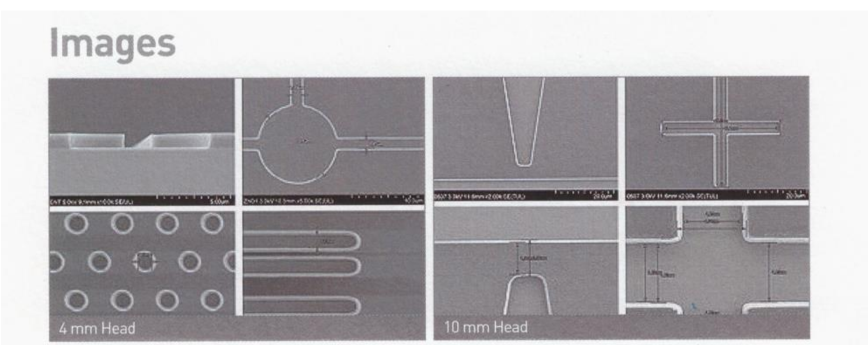
Align & Exposure (10)

Photolithography (1): Microlithography

Laser writer



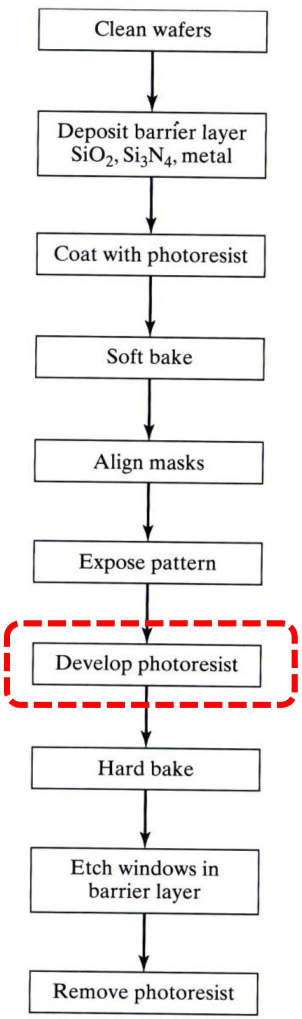




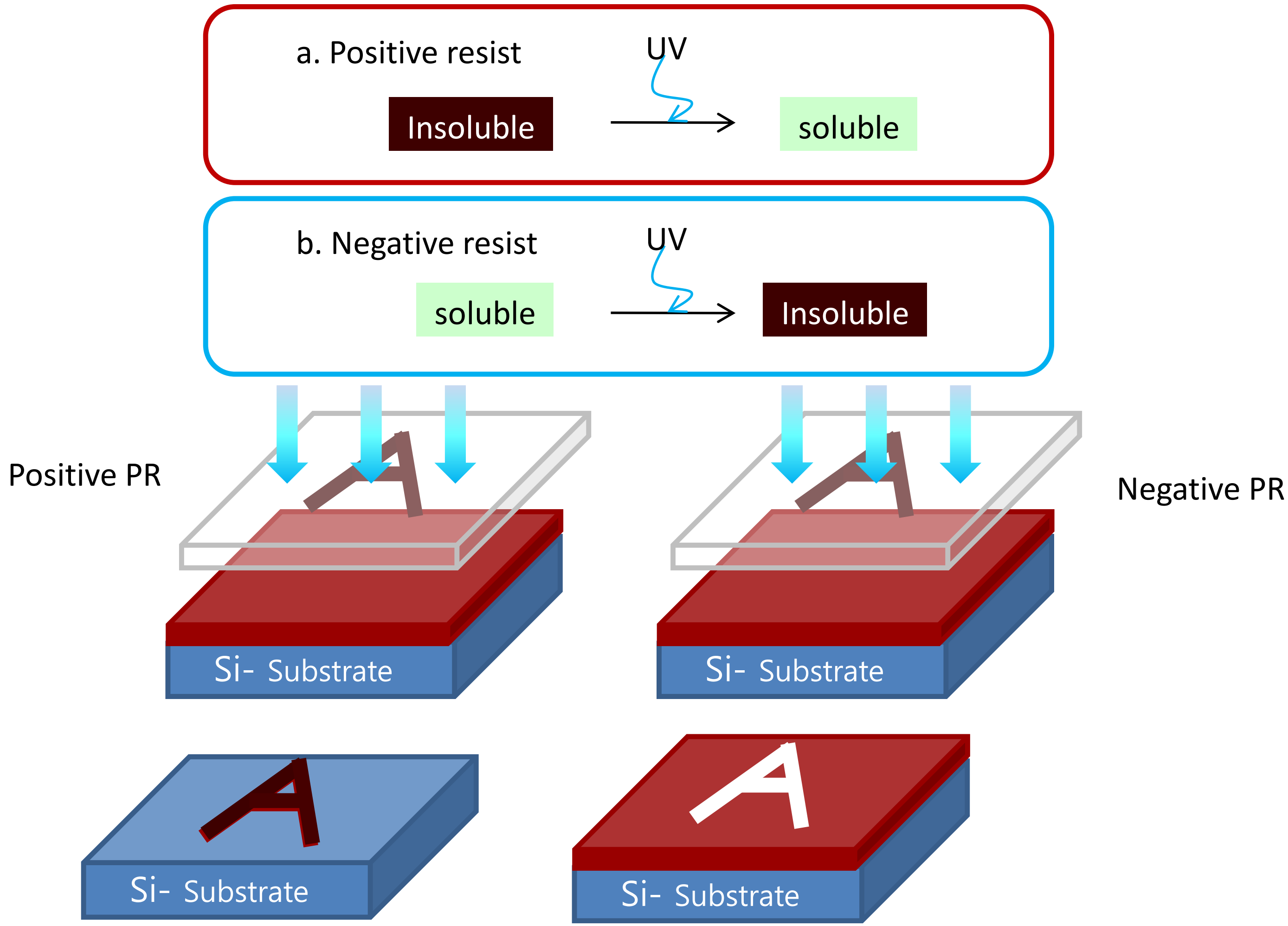
Development (1)

Photolithography (1): Microlithography

Photoresist & Development



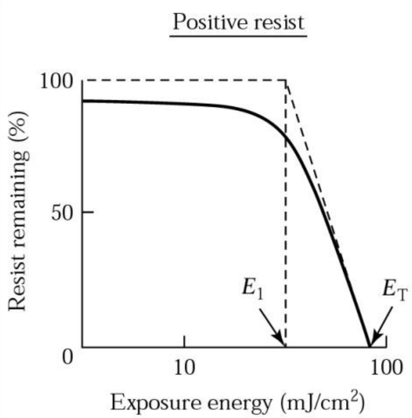
- Photoresist : Radiation sensitive compound (material)

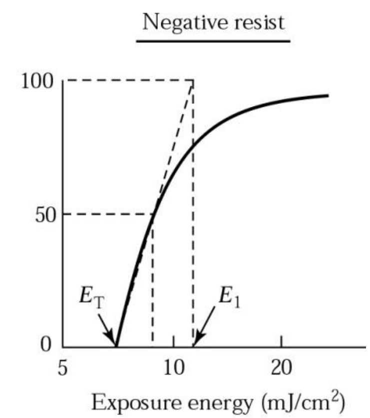


Development (2)

Photolithography (1): Microlithography

Contrast Ratio; it decides a shape of a pattern



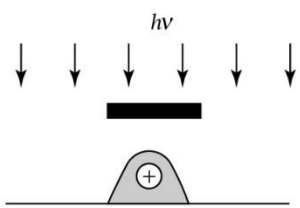


- Positive PR Contrast ratio

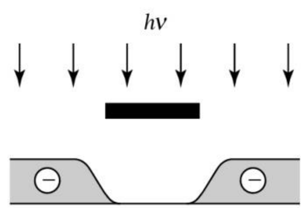
$$\gamma \equiv \left[\ln\left(\frac{E_T}{E_1}\right)\right]^{-1}$$

- Negative PR Contrast ratio

$$\gamma \equiv \left[\ln\left(\frac{E_1}{E_T}\right)\right]^{-1}$$



(a)



(b)

Contrast ratio↑ → Sharpness↑
: Positive PR shows better sharpness generally

E_T =Threshold energy to resolve the resist completely

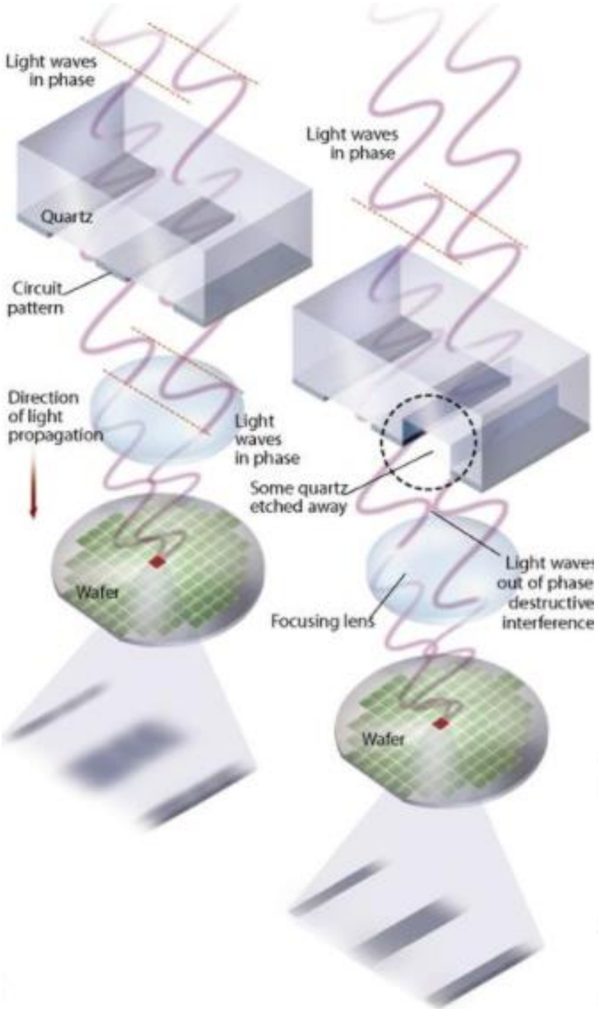
E_1 =Tangent value at E_T to reach 100% resist thickness

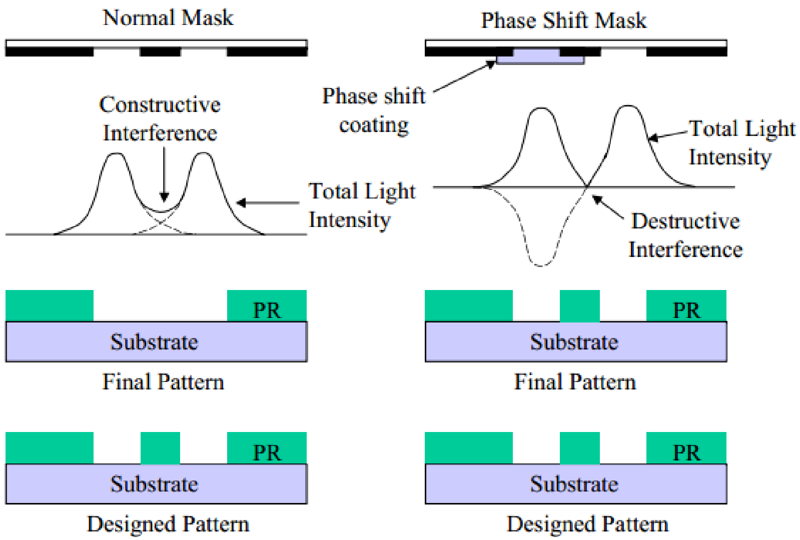
E_T =Threshold energy to remain the resist from this point

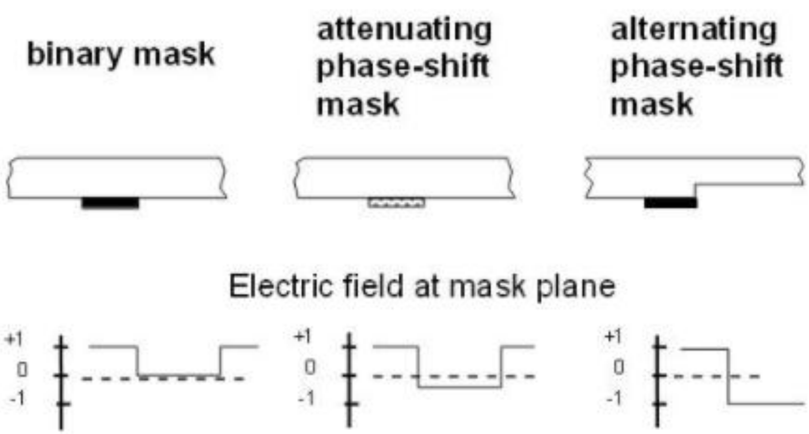
E_1 =Tangent value at 50% resist to reach 100% resist thickness

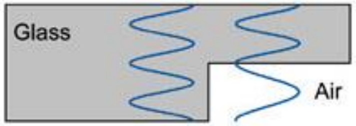
Photolithography (1): Microlithography

Phase Shift Mask (PSM)









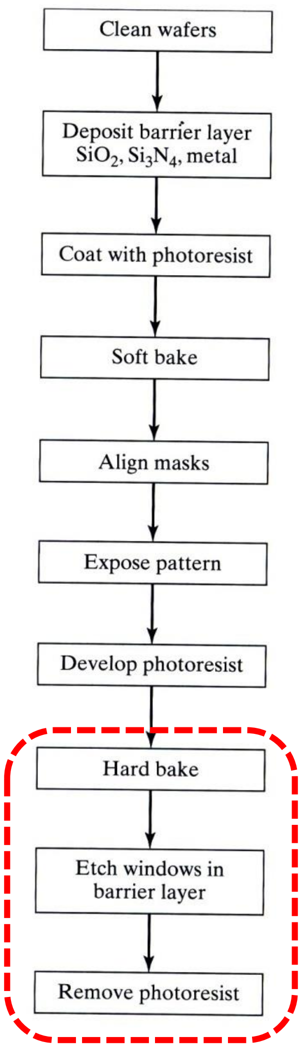
$\Delta\phi = 2\pi(n-1)d/\lambda$

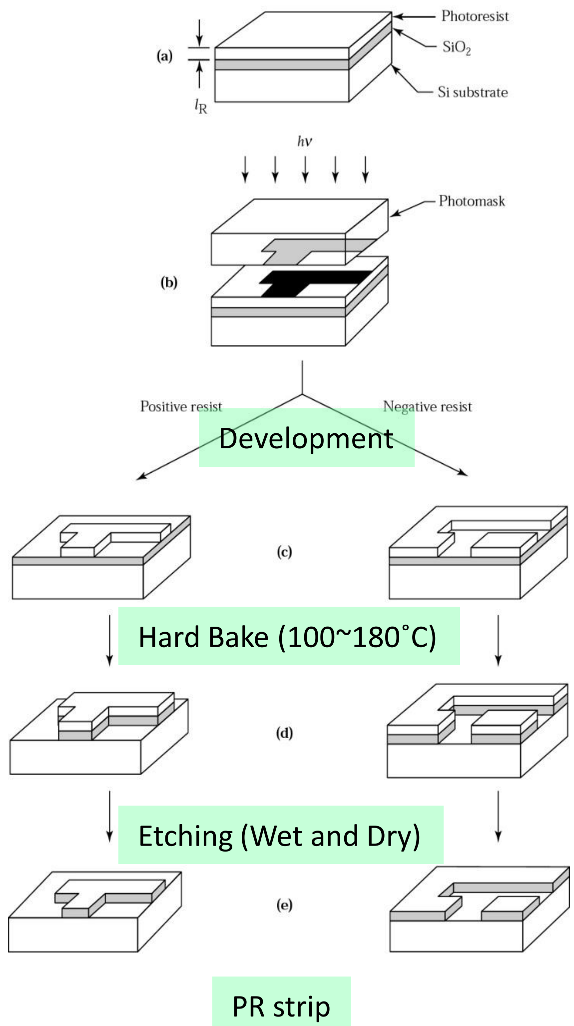
n = glass index of refraction

d = shifter thickness

Hard bake & Removal (1)

Photolithography (1): Microlithography



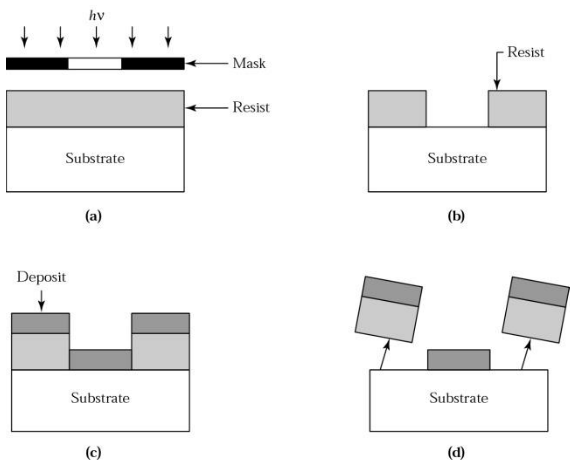


- **Hard Bake**

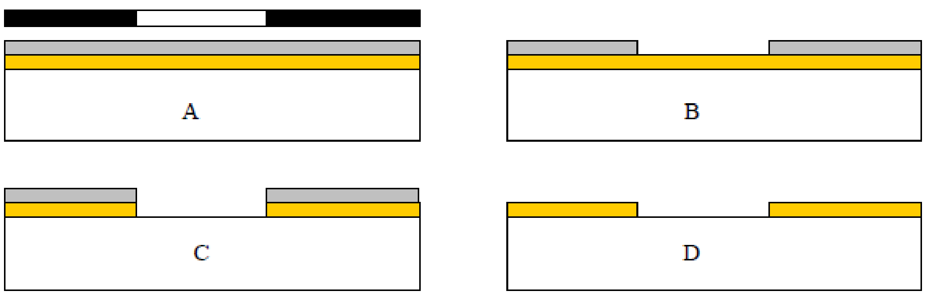
- Used to stabilize and harden the developed photoresist; the resist will mask
- Removing any remaining traces of the coating solvent or developer
- Some shrinkage of the photoresist may occur
- Longer or hotter bake makes resist removal much more difficult

Hard bake & Removal (2)

Lift-Off Technique



(General process)



- Easy and Simple process
- When it is hard to etch a material, it is useful.
- Film thickness has to be smaller than PR
- Bad step coverage is good for lift-off process
- Positive pattern -> negative pattern (shift)

PR Removal

- Chemical (PR stripper)
- Plasma (PR asher)

Photolithography (1): Microlithography