B.Tech (ECE) VI Sem
Unit-3
VLSI Technology (BEC-35)

Classification of Lithography and Its Properties

Photo-Masks and Photo-resists (PR)

Part-III

March-April 2020

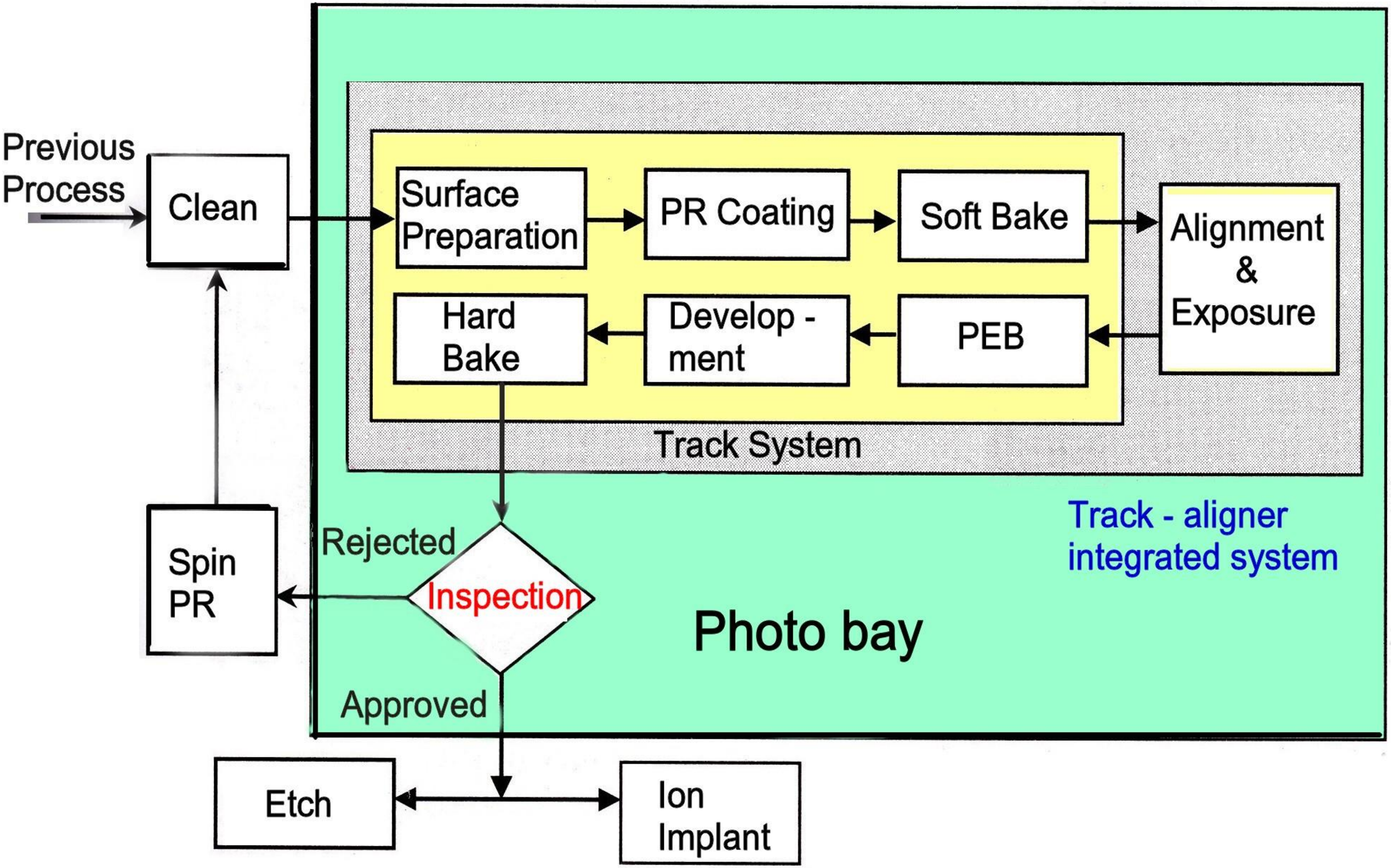


Fig 5: Flowchart of the photolithographic processes

Step No. 6: Pattern Development

- Purpose: to develop the desired pattern in the Photo-resist
- Equipment: Baths for developing and cleaning chemicals and spin dryer
- Method: Dip the wafer in the developing and rinsing chemicals for desired times and then spin dry.

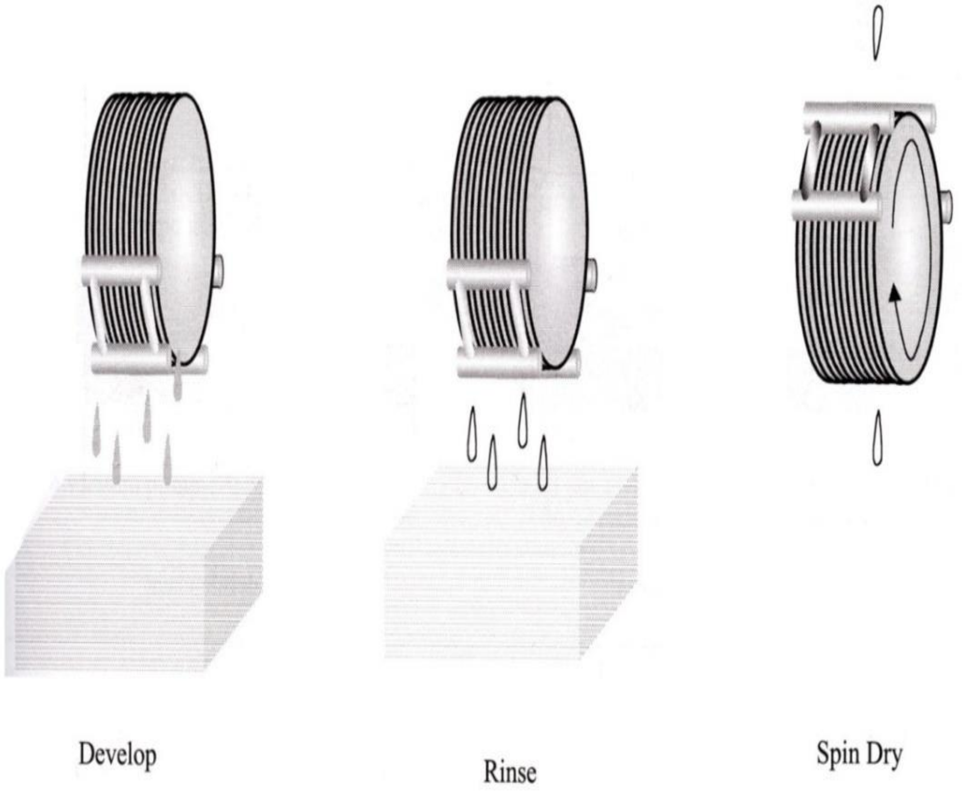


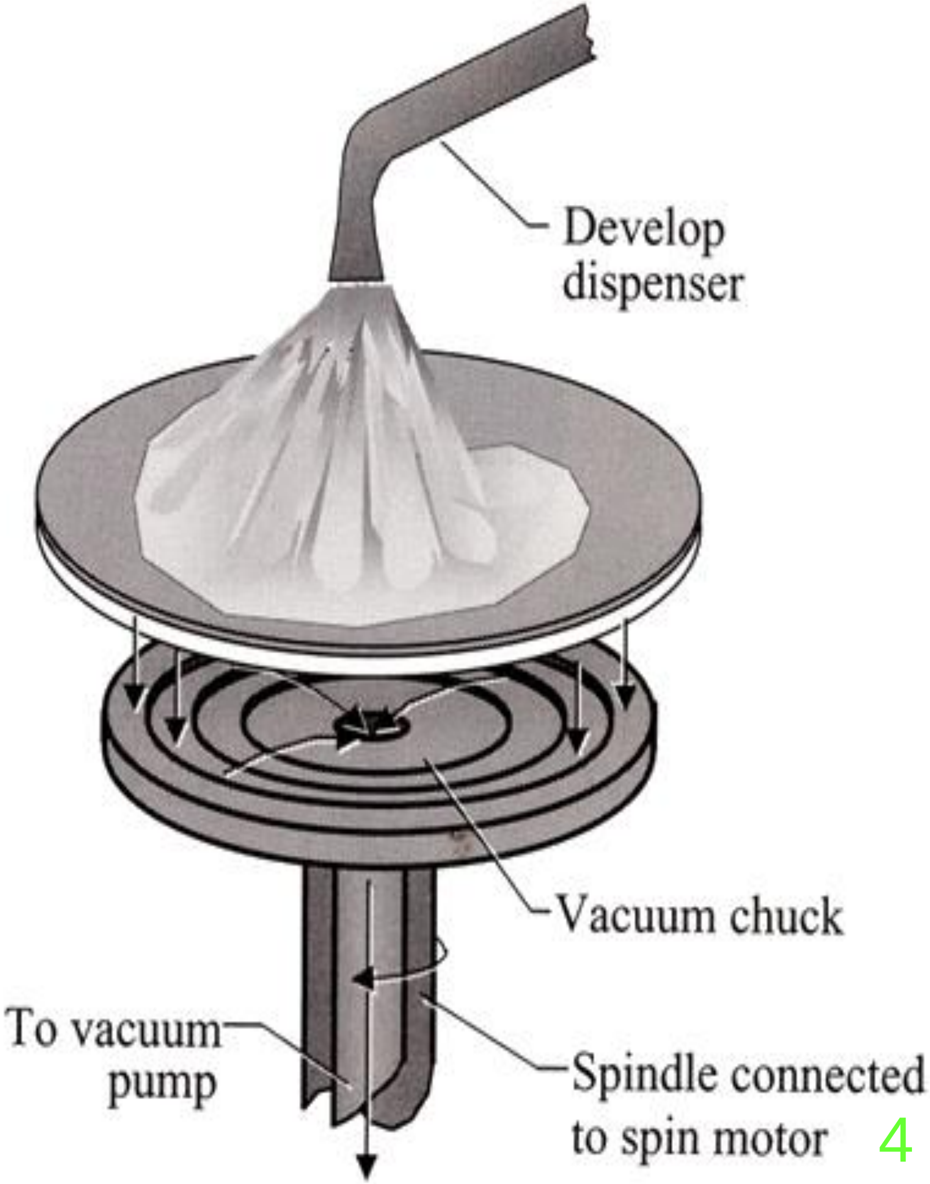
Fig 25: The three steps of the development process

Process Step

Photoresist Development

Process Summary:

- Soluble areas of photoresist are dissolved by developer chemical
- Visible patterns appear on wafer
  - windows
  - islands
- Quality measures:
  - line resolution
  - uniformity
  - particles and defects



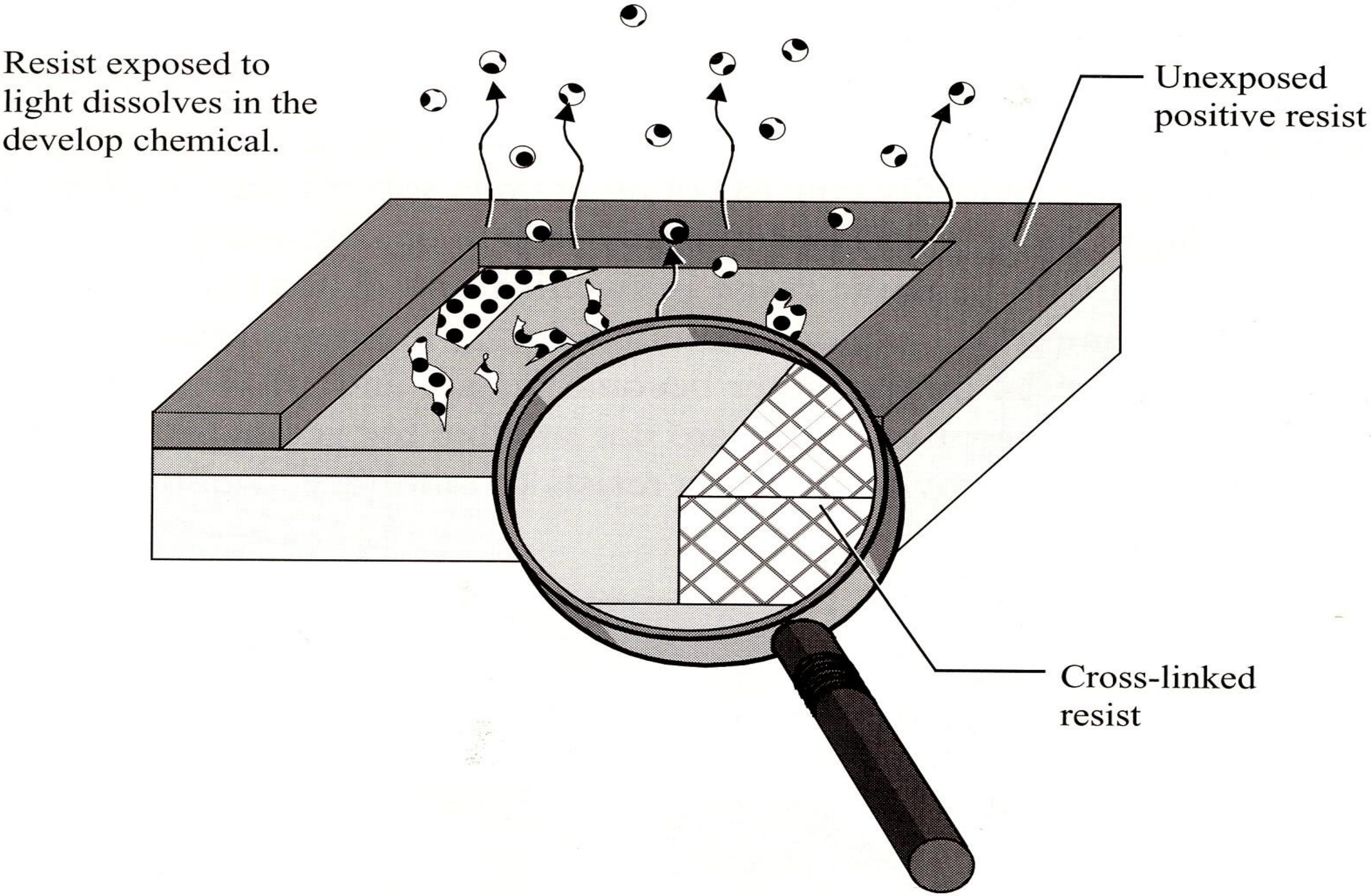


FIGURE 15.5 Development of Positive Resist

Step No. : Hard Bake

Purpose:

To remove water and any other liquid and to harden the photoresist present on the wafer.

Equipment:

Oven

Method:

Heat at ~ 200 C for about 20 minutes

Step No. : Develop Inspect

Optical Inspection under microscope (100X) is done to check for

- Line Resolution
- Line Width
- Resolution
- Particles and Defects

What is Photoresist?

- The photosensitive compound used in microelectronics is called Photoresist.

- Certain properties of these compounds change when they are exposed to light of a particular wave length.

- Photoresists are used to transfer the pattern on the substrate.

What is a pattern?

- The arrangement of black and white areas on the mask (glass plate) is called pattern.

- The pattern indicates the areas through which light will expose the photoresist

Requirements of a Photoresist

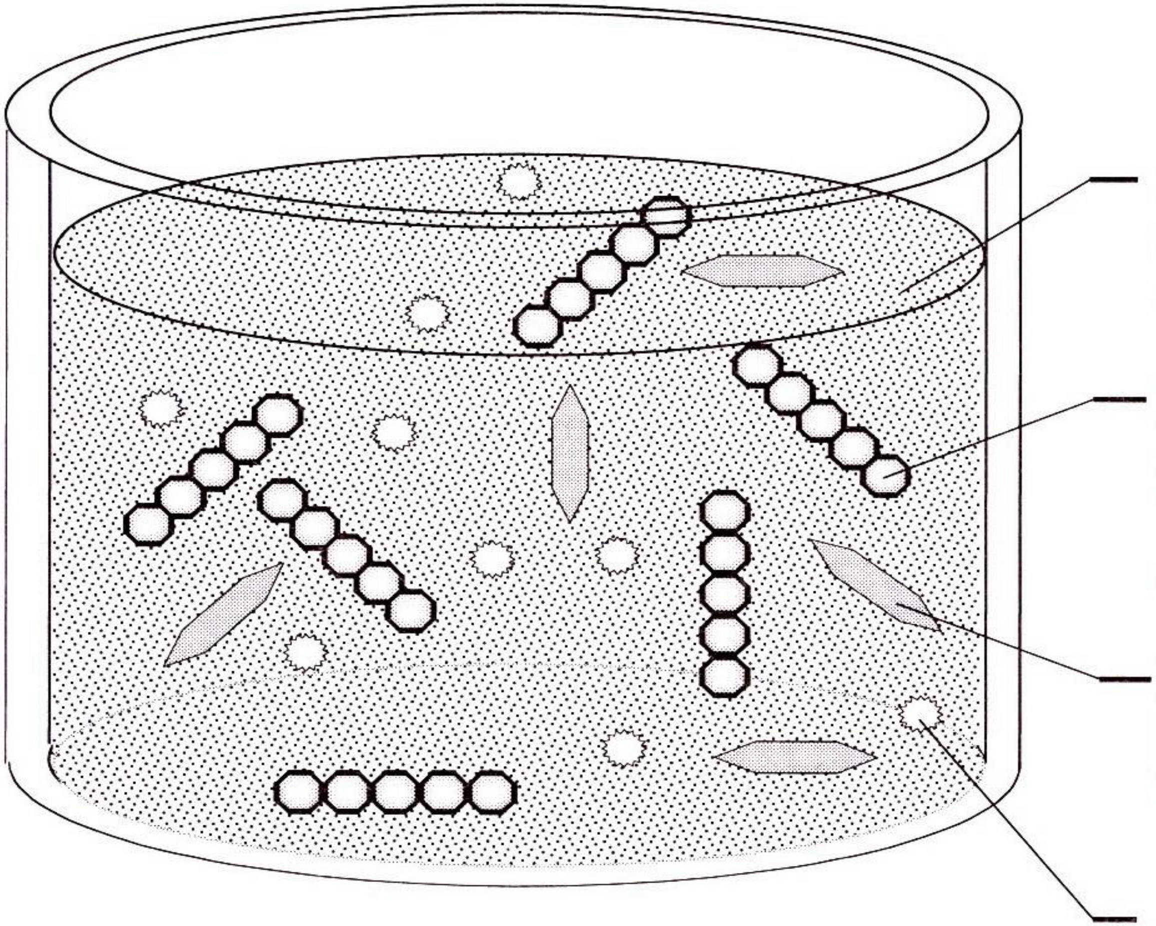
1. PR should be sensitive to the desired frequency and insensitive to yellow or red light.
2. It should have fine line definition that should be retained during subsequent processing while it is still present on the wafer.
3. The exposed resist should undergo chemical changes

Requirements of a Photoresist (contd.)

4. The ‘HARD RESIST’ (chemically inert part of the resist) should bind strongly to the substrate or the layer below PR.
5. The ‘SOFT RESIST’ (chemically active part of PR) should be easily removable from the wafer surface.
6. The Hard PR should be able to sustain further processing (Etching) without losing fine line definition.
7. The PR must not contribute impurities, introduce defects or in any other way degrade the performance of the device being fabricated.

Requirements of a photoresist (contd.)

8. The Hard PR should be easily removable when it is no longer required, without adversely affecting the other layers present.
    - This process of Hard PR removal is called STRIPPING
    - Chemical used for stripping the hard PR is called ‘STRIPPER’
    - ‘Plasma Aching’ is the technique used for removing hard PR by plasma technique



Solvent:
gives resist its flow characteristics

Resin:
mix of polymers used as binder; gives resist mechanical and chemical properties

Sensitizers:
photosensitive component of the resist material

Additives:
chemicals that control specific aspects of resist material

Fig q18: Components of Photo Resist

Types of photoresist (PR)

Photoresists are of 2 types

1. Positive – it creates a + ve image of the pattern on the mask.

2. Negative – it creates a – ve image of the pattern on the mask.

Two Types of Photoresists

Negative PR and Positive PR

Negative PR

- The exposed parts become cross linked and polymerized due to the photochemical reaction, which hardens and remains on the wafer surface after development, whereas the unexposed parts are dissolved by the developer.

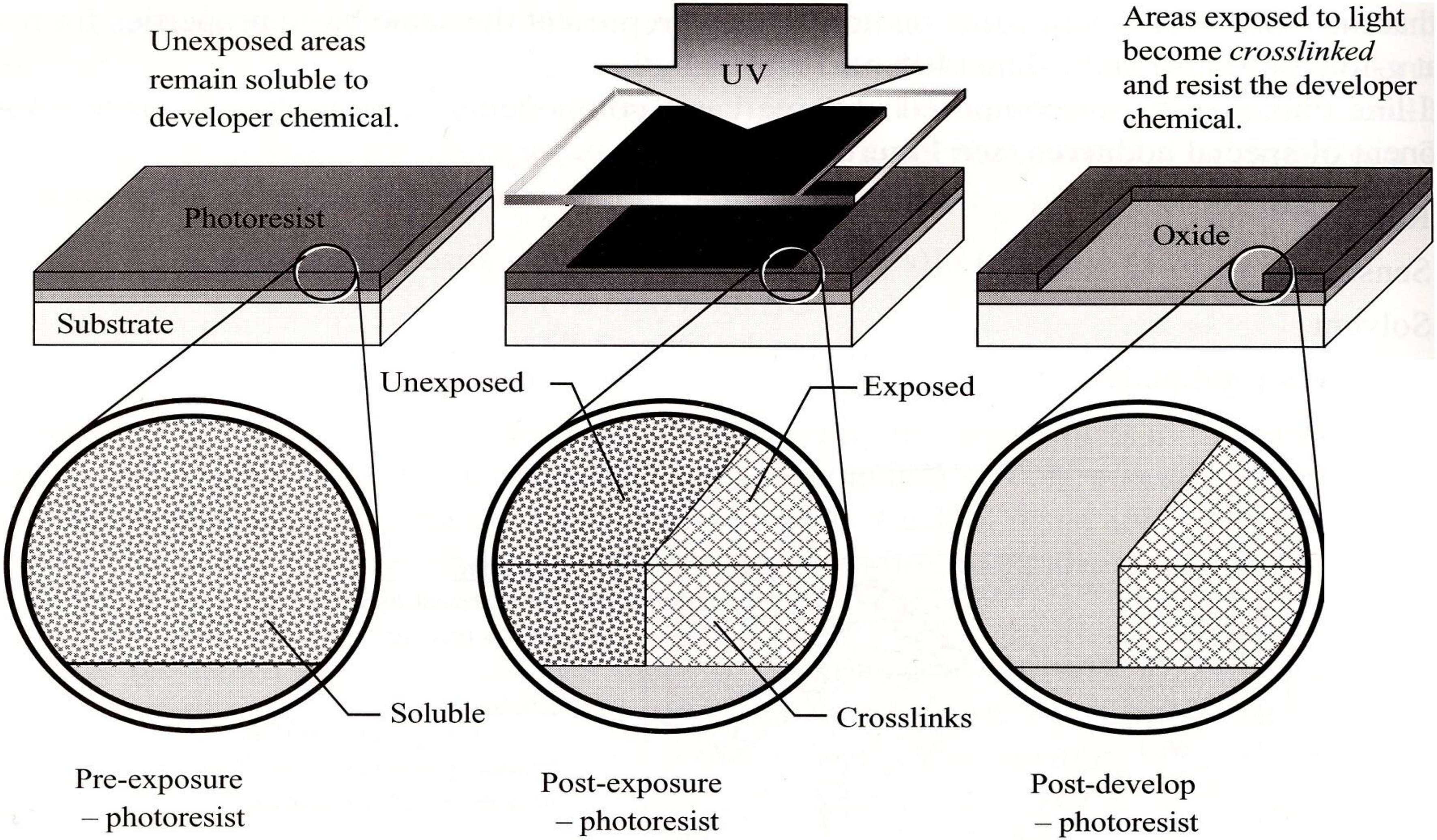


Fig q19: Negative Resist Crosslinkinking

Positive Photoresist

- The main component is novolac resin, which is a crosslinked polymer before the exposure.
- After the exposure process, the exposed part's cross-links break down and become "softened" due to the photochemical reaction called ***photosolubilization,***
- *It* will be dissolved by the developer, while the unexposed parts remain on the wafer surface.

Use of Photo Active Compound

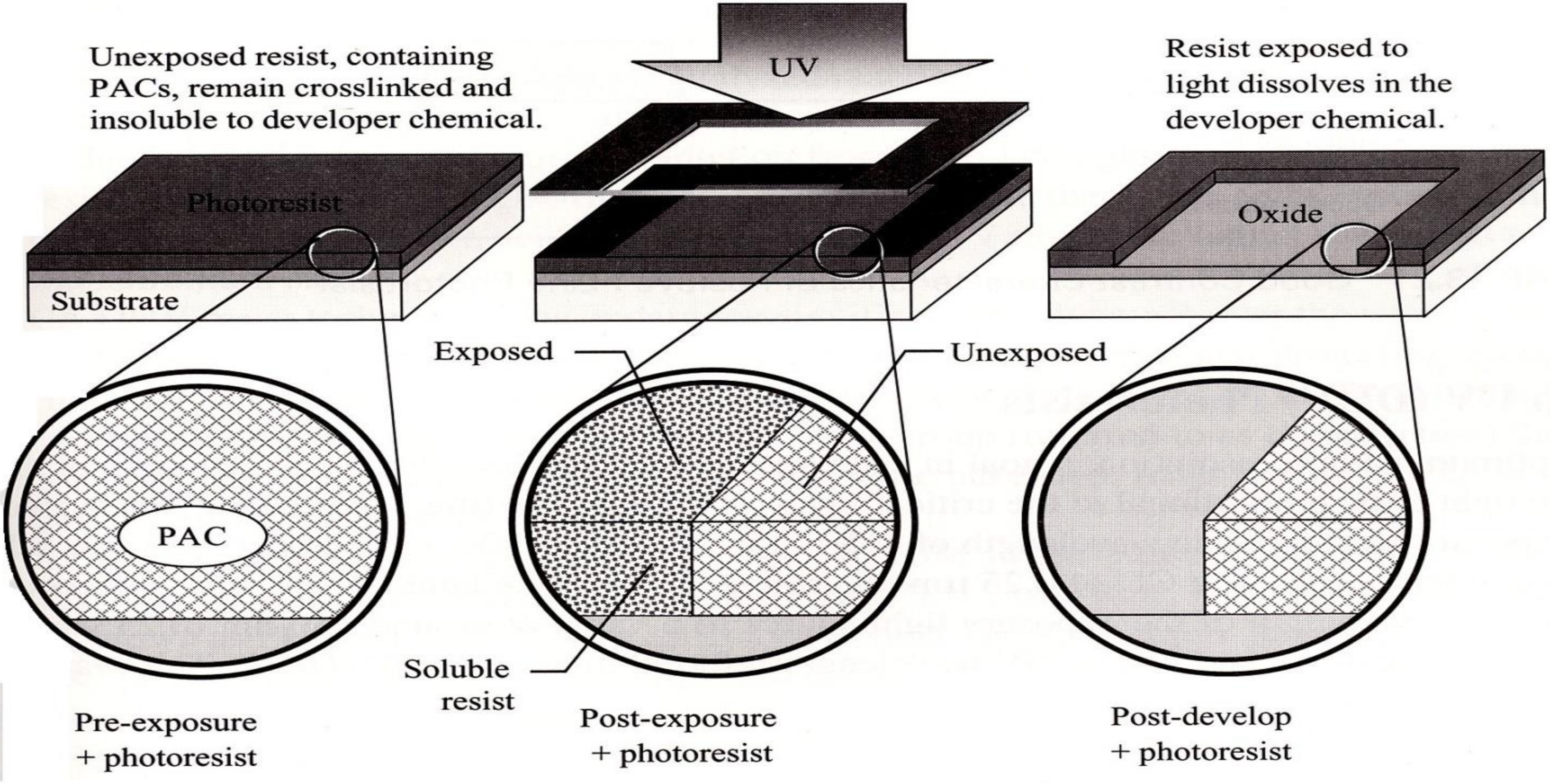


Fig q20: PAC as Dissoution Inhibitor in Positive I-Line Resist

DQN Positive Photoresist

- Diazo-Quinone Novalac is a +ve PR
- Its Photo-active Compound is Diazo-quinone
- Its matrix material is novalac

Photoresist Parameters (Useful Properties)

- **Dose** – it is the total quantity per unit area of photons falling on PR.

  Dose θ = Photon intensity x Exposure time

  Units: Energy (calories or joules) per unit area

- **Sensitivity** – amount of light energy necessary to create the chemical change

- **Resolution** – Smallest feature size that can be reproduced in a photoresist.

- **Contrast** – is the difference in appearance of two or more parts of a field seen simultaneously or successively.

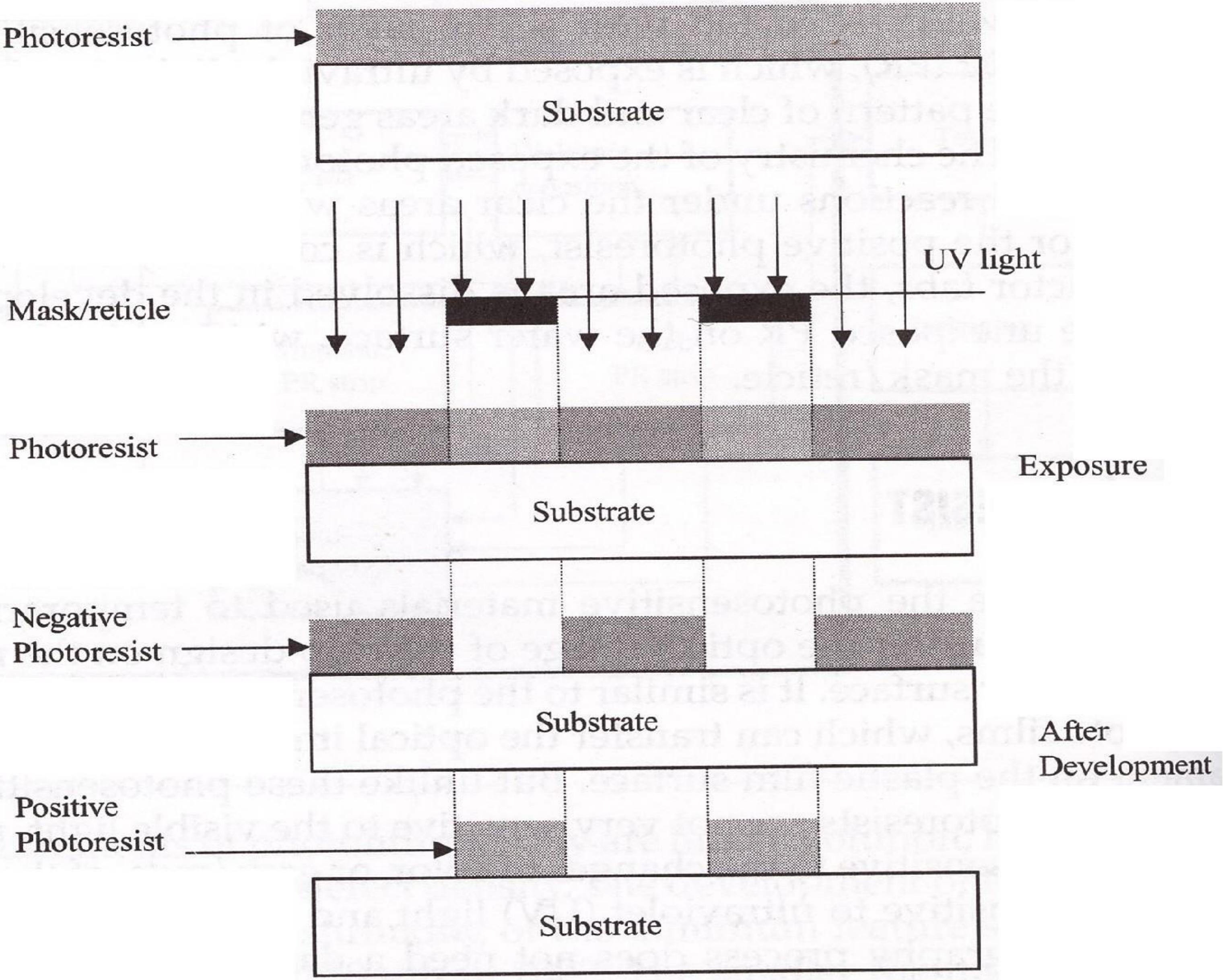
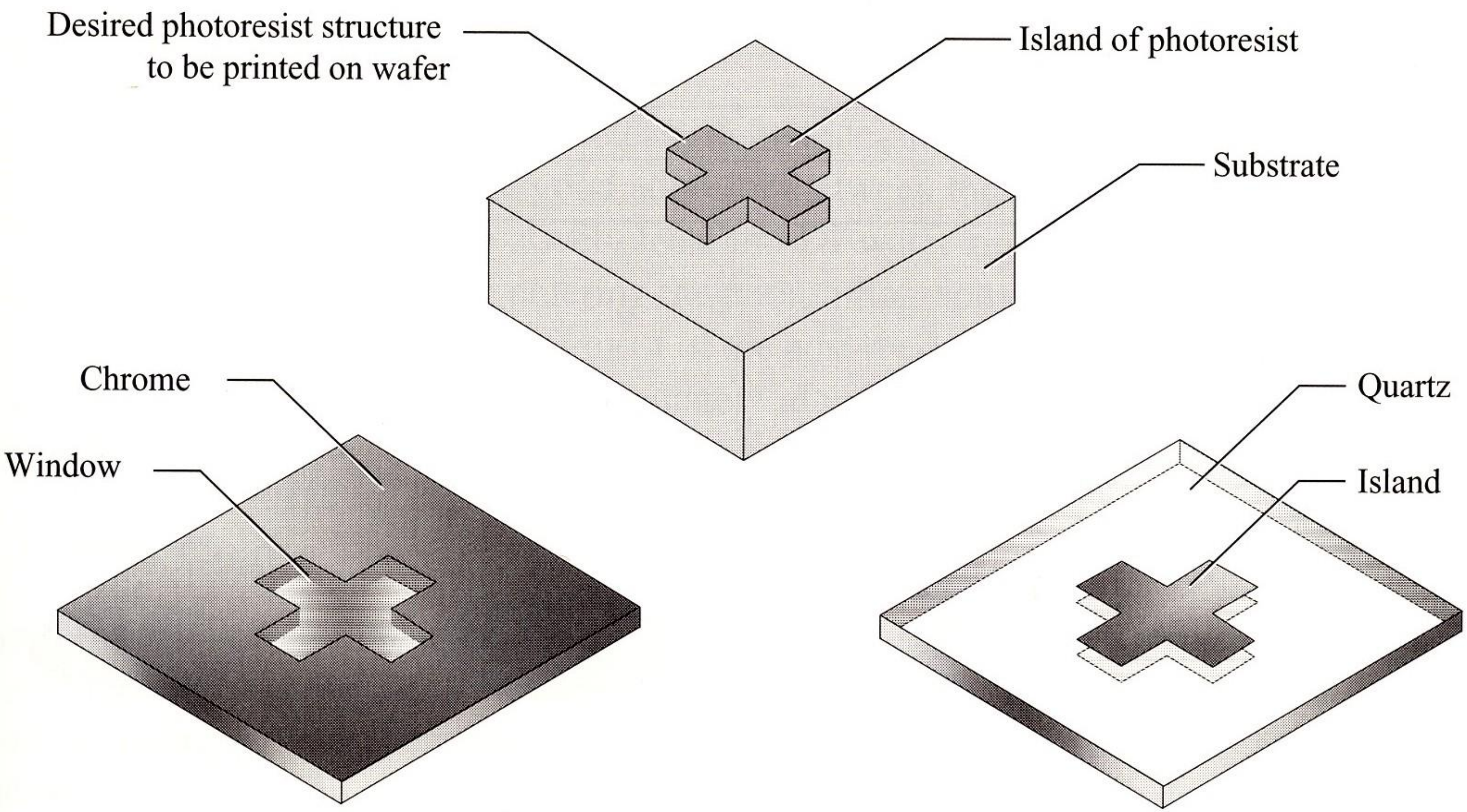


Fig 2: Patterning process with negative and positive photoresists



Mask pattern required when using negative photoresist (opposite of intended structure)

Mask pattern required when using positive photoresist (same as intended structure)

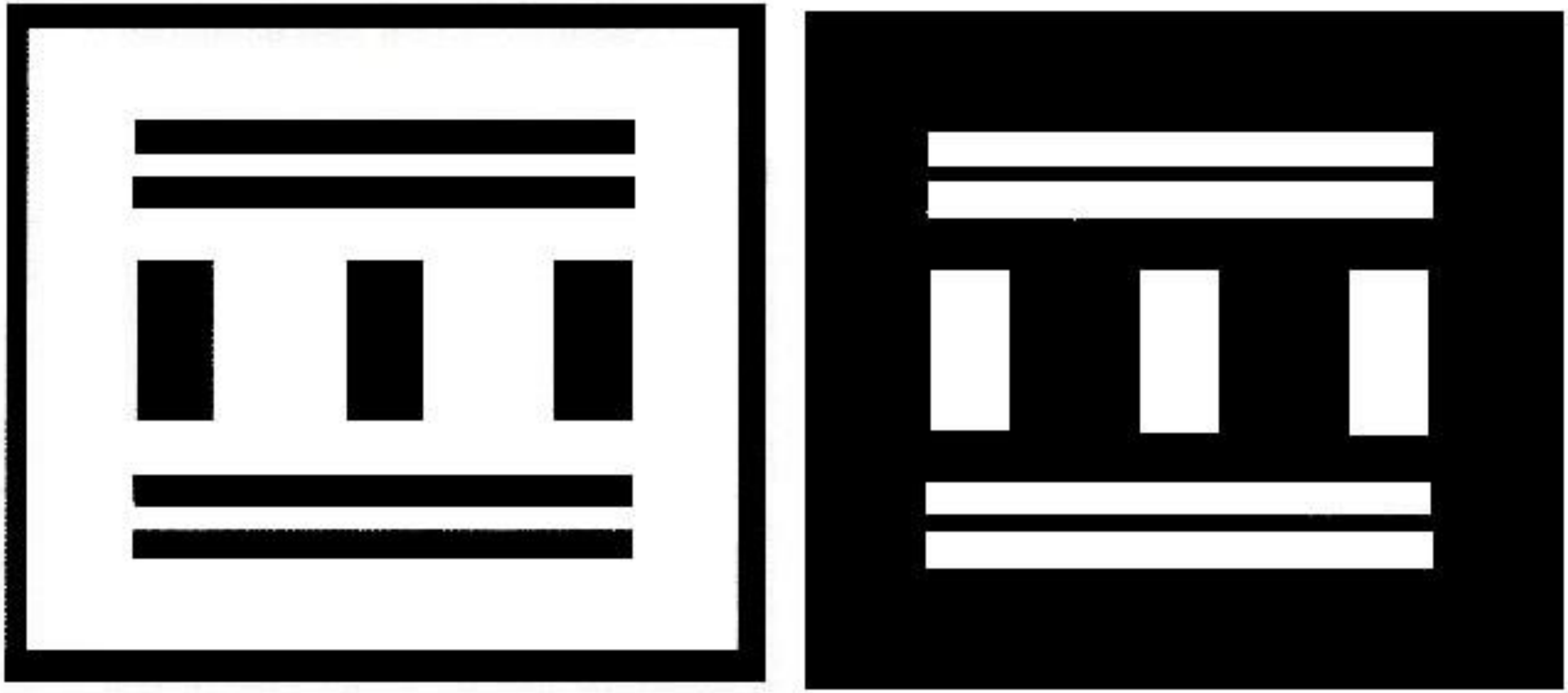
Relationship Between Mask and Resist

What is a Mask?

A **photomask** is an opaque plate with holes or transparencies that allow light to shine through in a defined pattern. They are commonly used in photolithography.

Dark Field Mask and Clear Field Mask

- Active Region - region of interest
- Field Region – rest of the glass plate region
- If the field region is dark it is a dark field mask
- If the field region is clear , it is a clear field mask



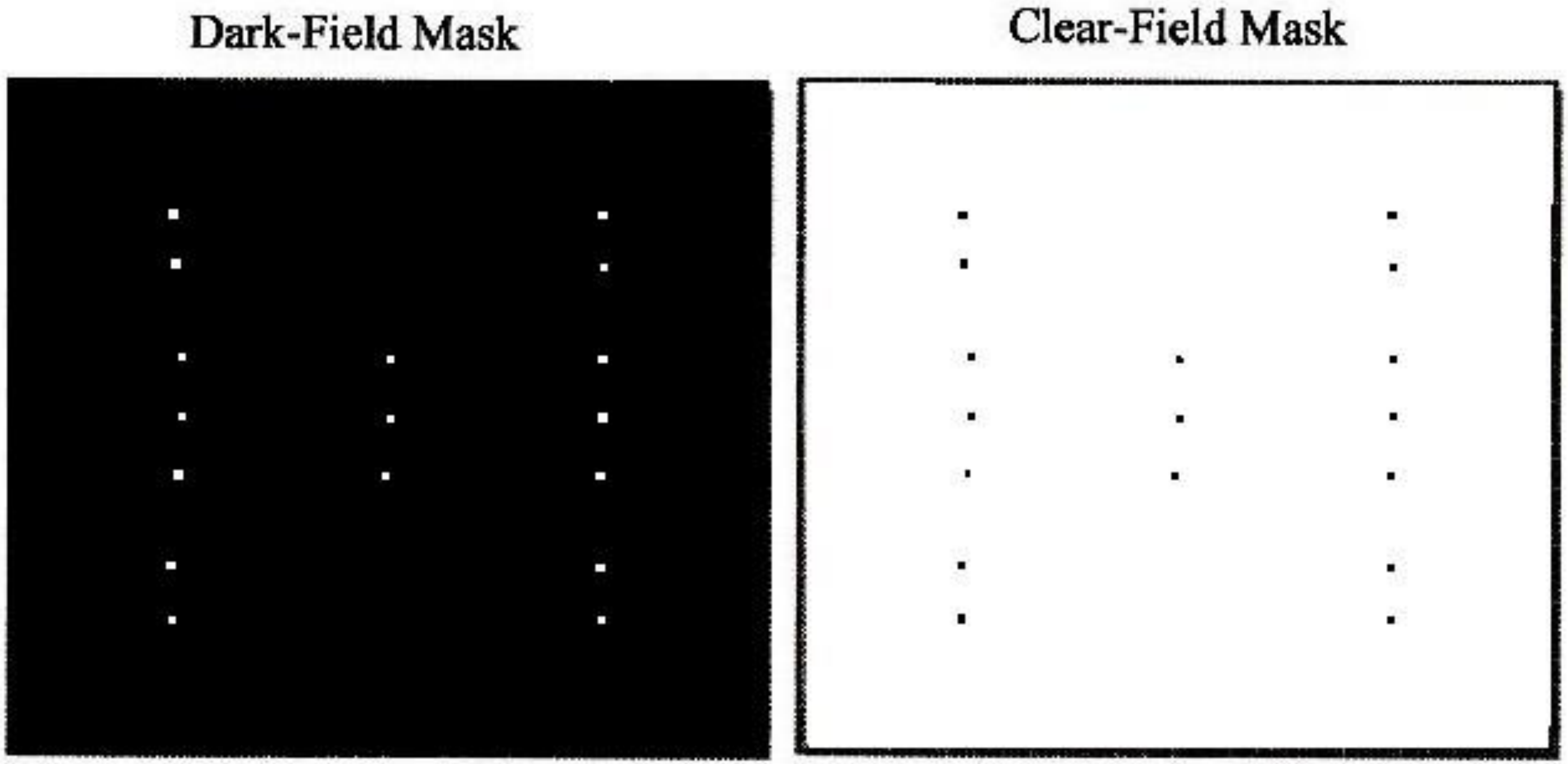
Clear-Field Mask

Dark-Field Mask

positive resist lithography

Negative resist lithography

Simulation of metal interconnect lines



Dark-Field Mask

Clear-Field Mask

positive resist lithography

Negative resist lithography

Simulation of contact holes

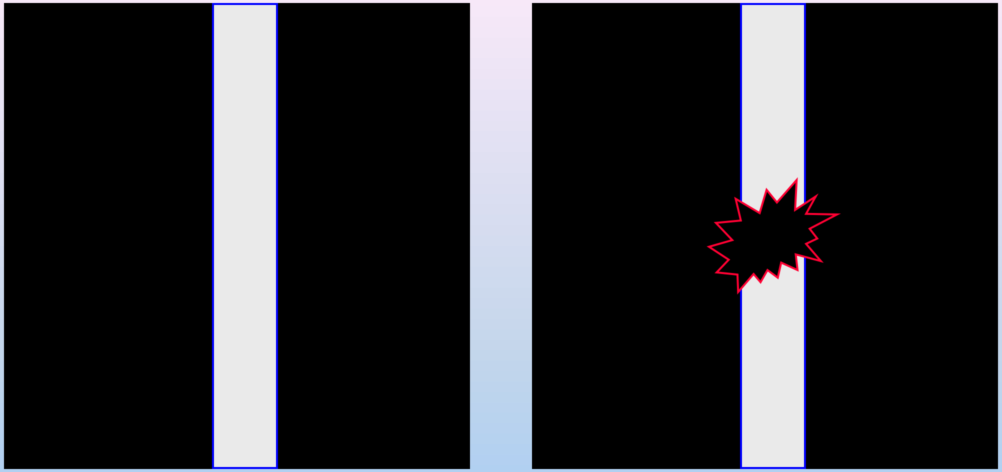
Preference between Dark Field Mask and Clear Field Mask

For aligning mask with the pattern on the wafer we must see the wafer pattern through the mask. Therefore a clear field mask is preferred.

Imaging errors due to dust particles:

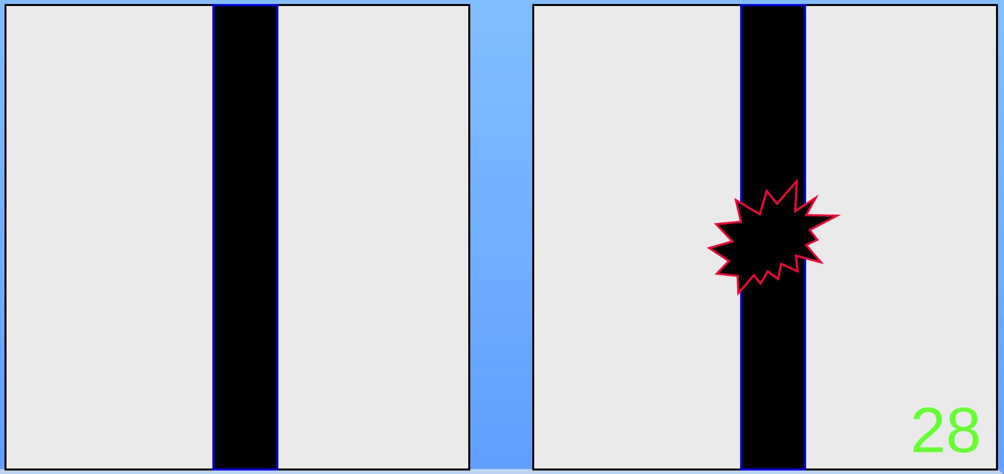
error is critical

- if the particle is in active region
- if the mask is dark field



Masks without dust particles

Masks with dust particles



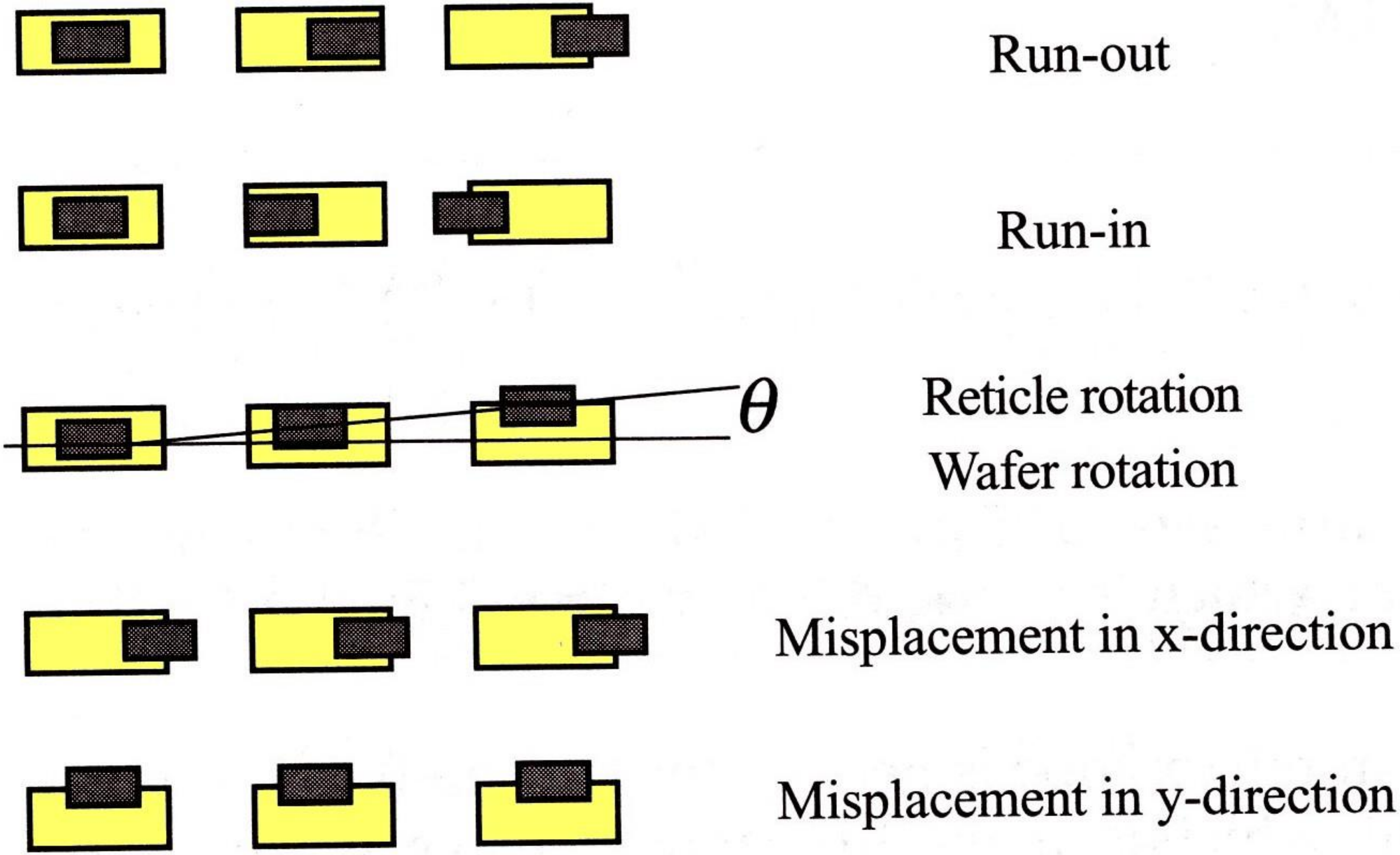
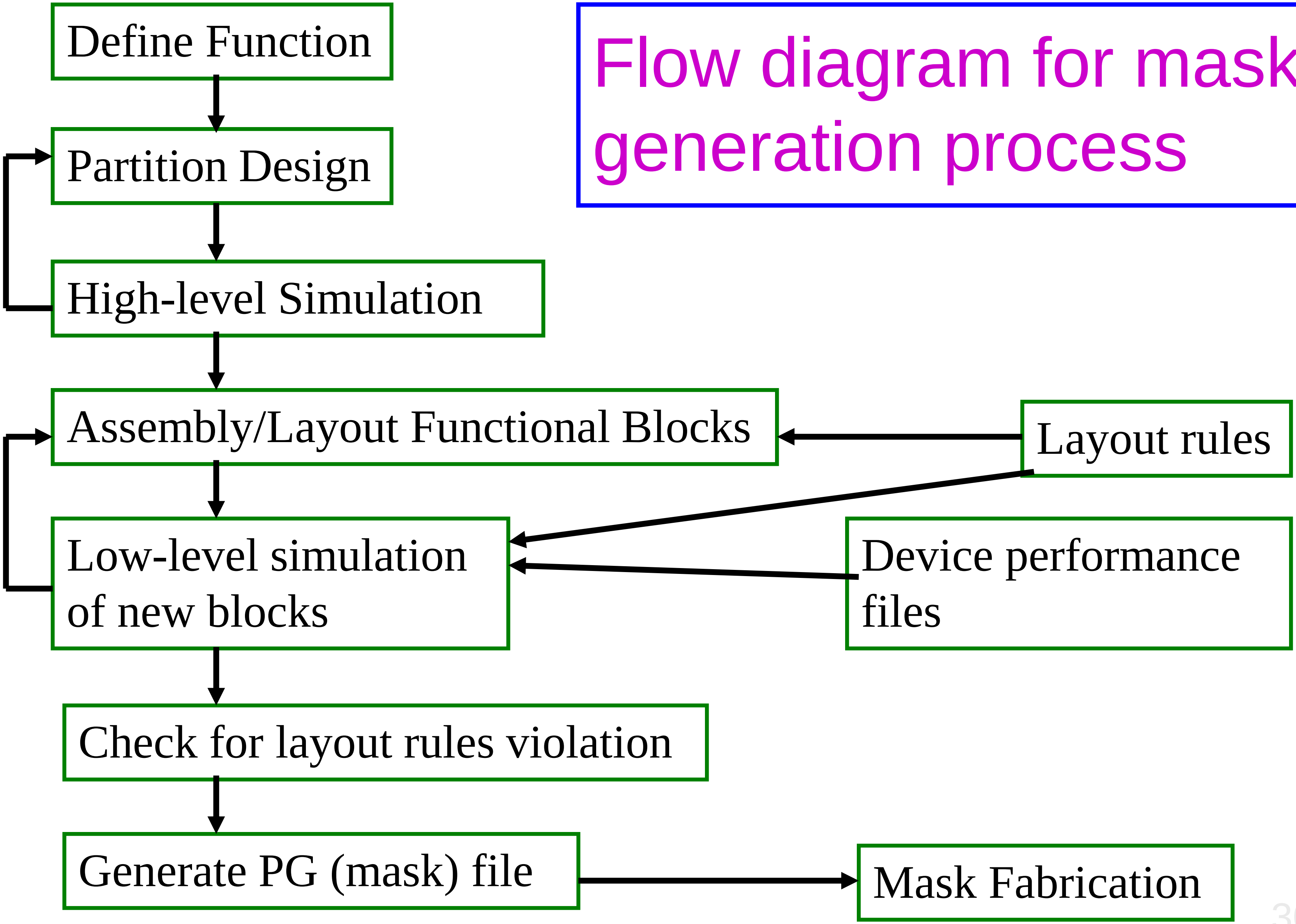


Fig 32: Examples of misalignment cases

Flow diagram for mask generation process


Define Function

Partition Design

High-level Simulation

Assembly/Layout Functional Blocks

Layout rules

Low-level simulation of new blocks

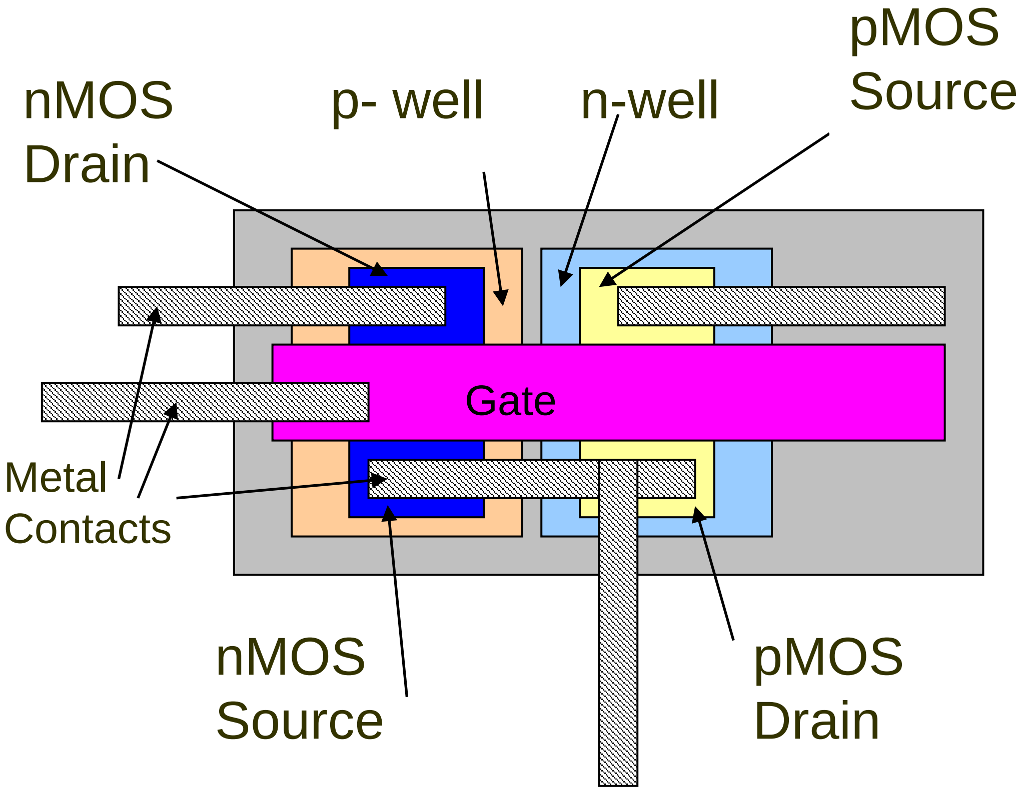
Device performance files

Check for layout rules violation

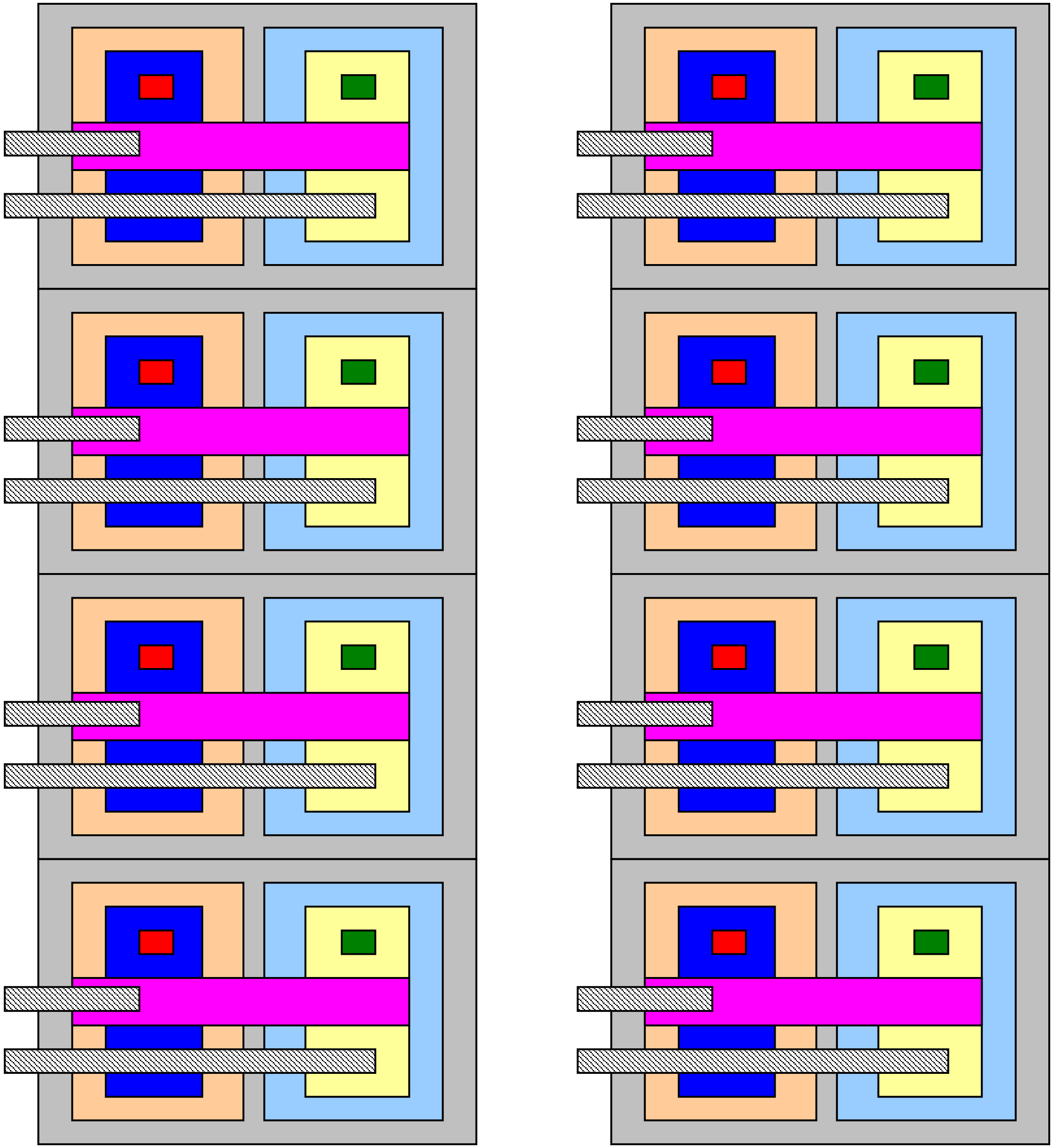
Generate PG (mask) file

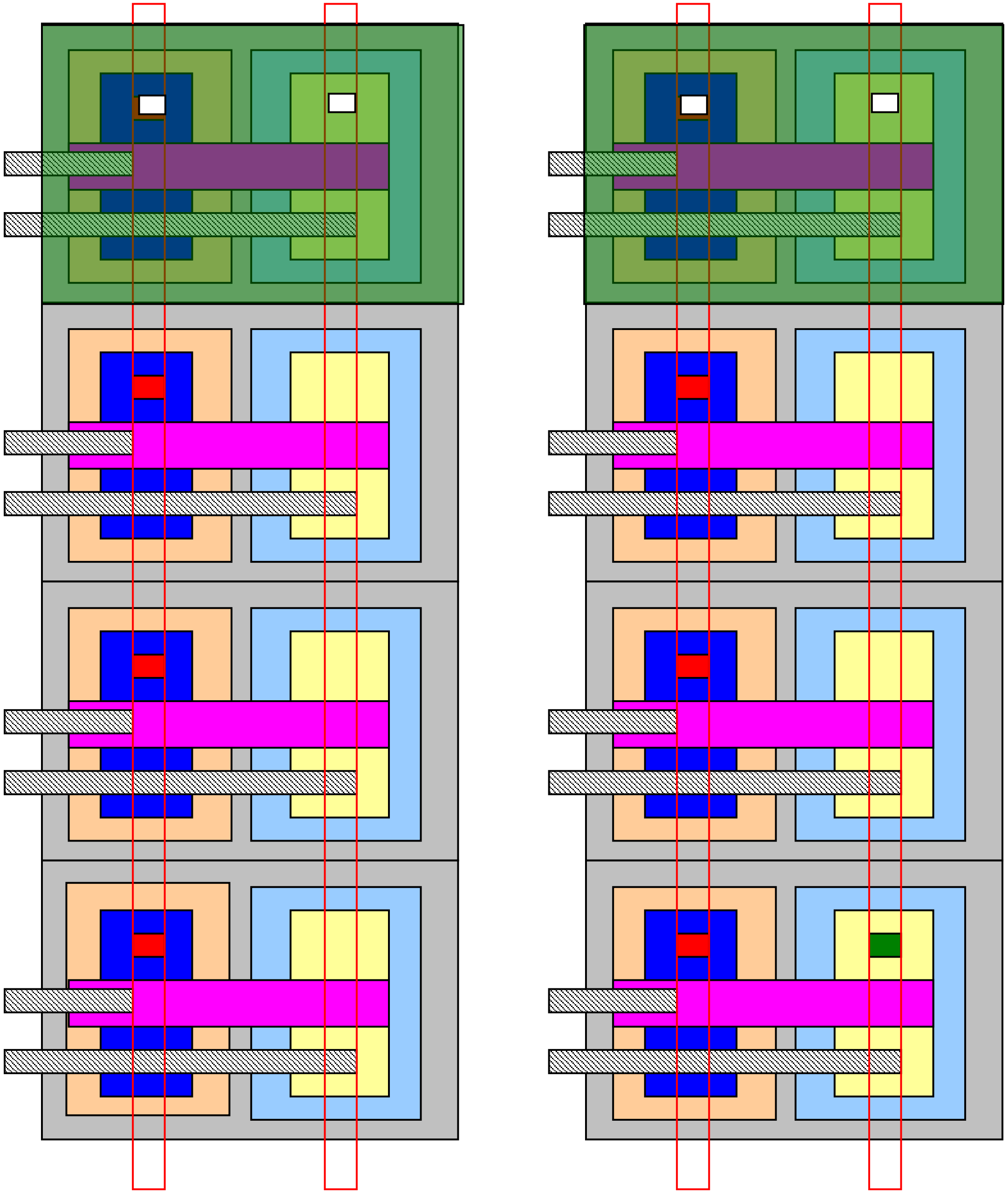
Mask Fabrication

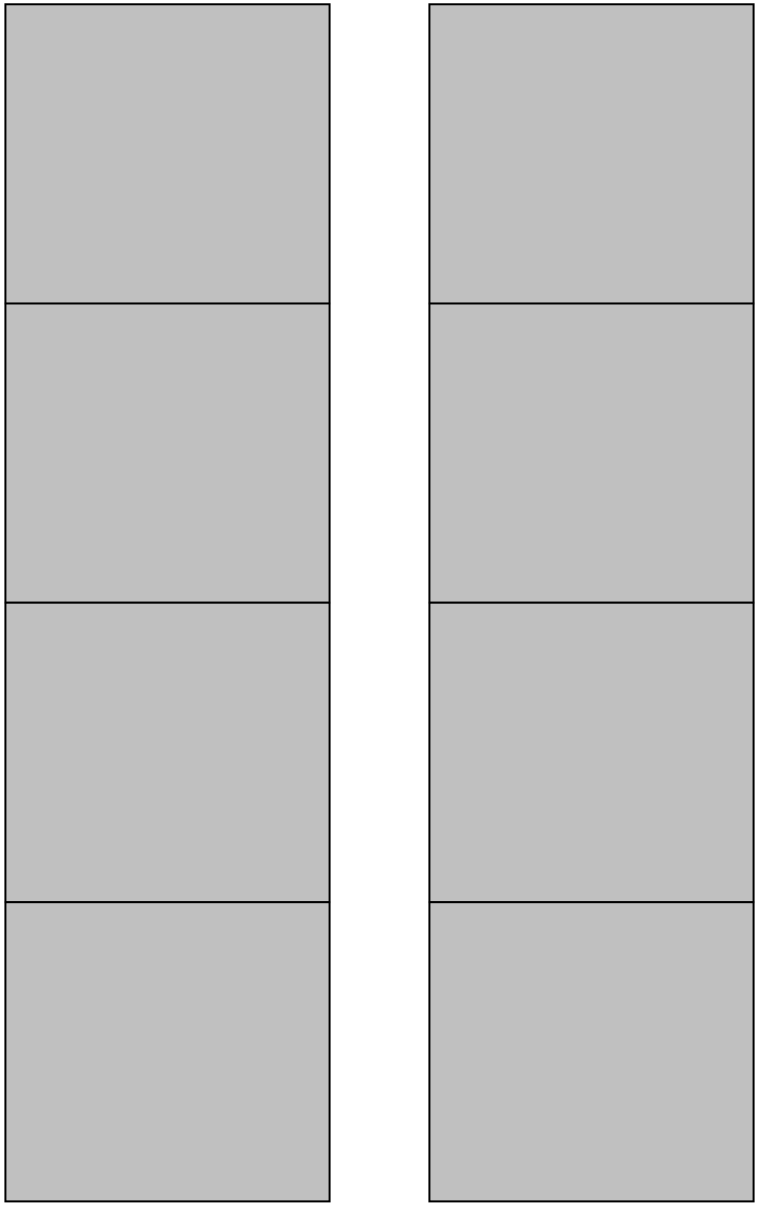
Layout of the Inverter (CMOS)



Layout Showing 8 Invertors

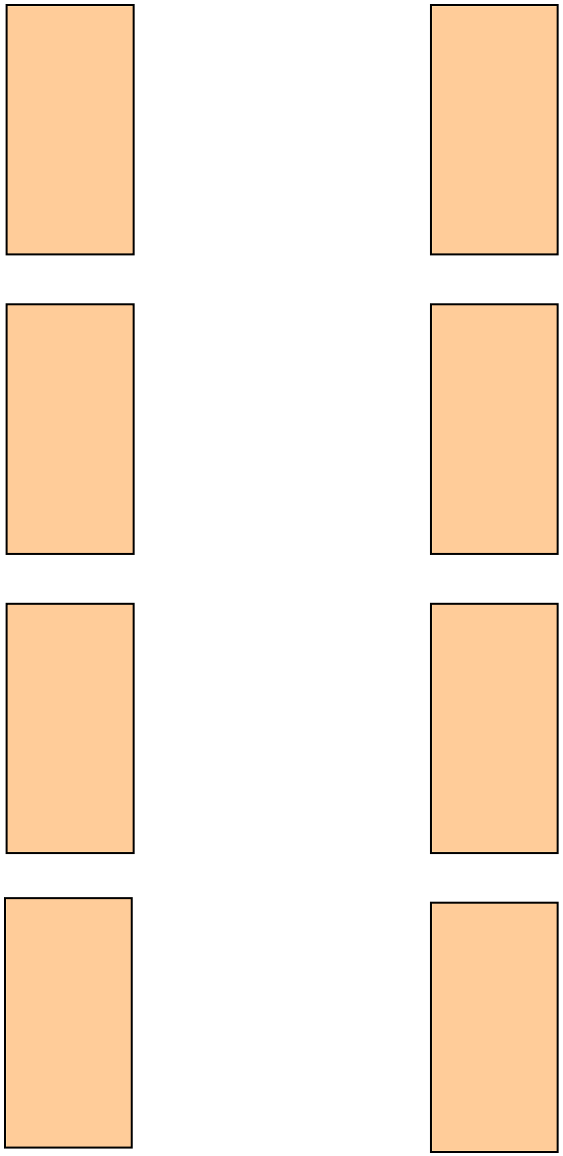




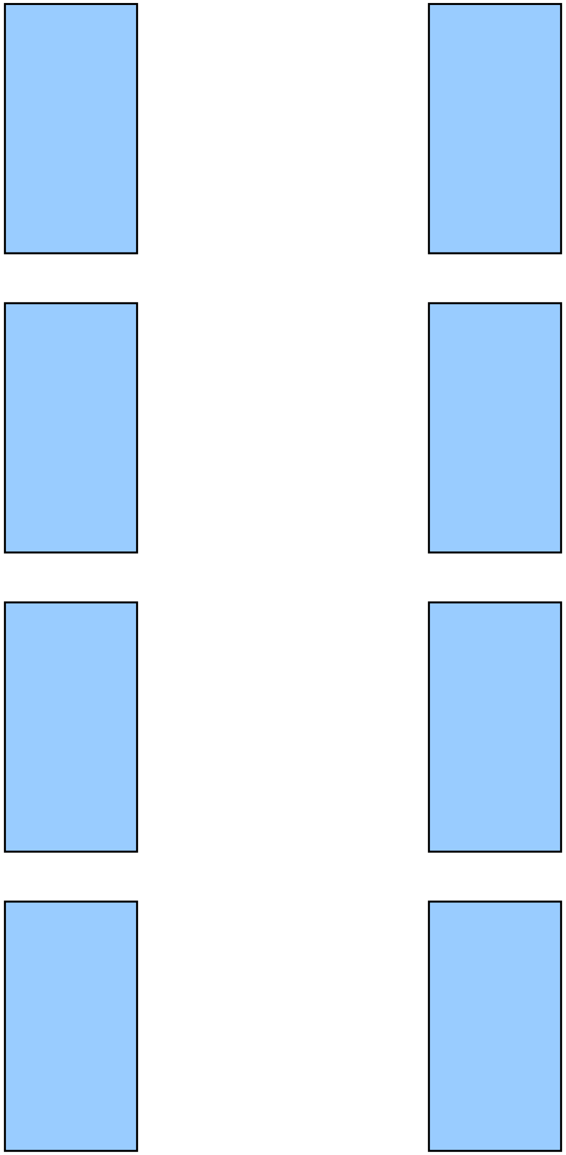


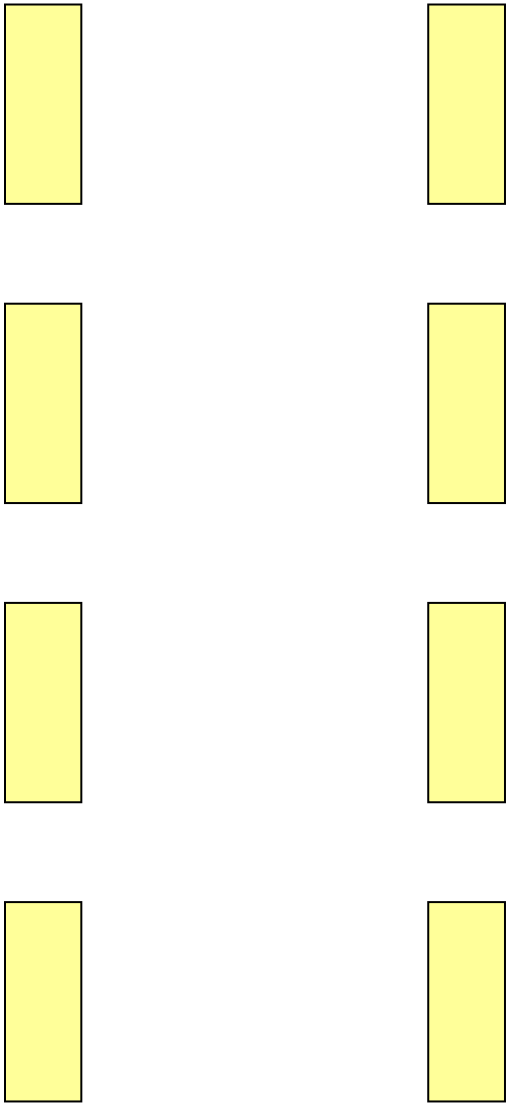
Wafer

Mask 1
pWell

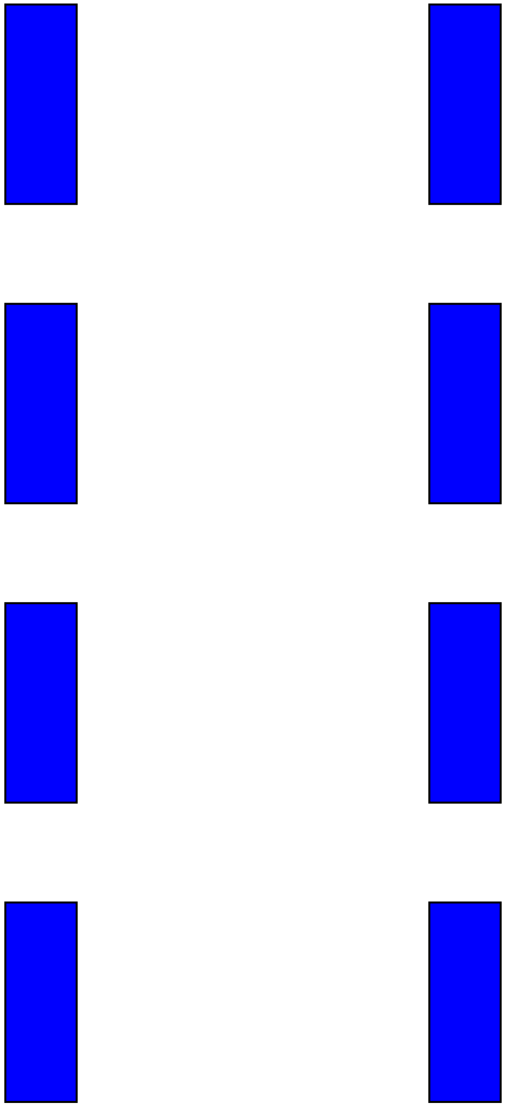


Mask 2
nWell

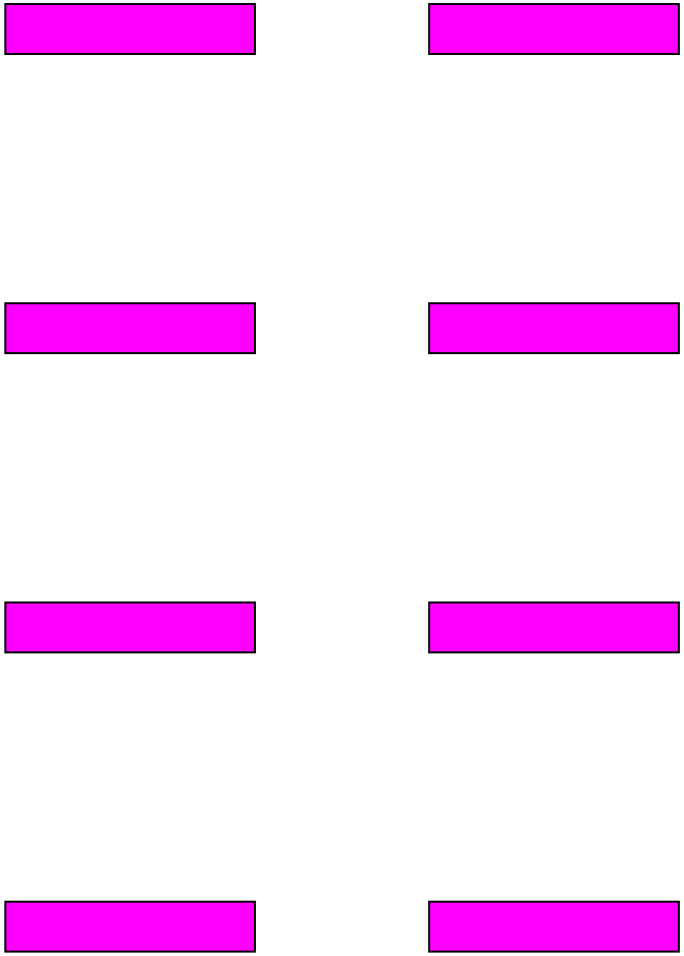




Mask 3
pMOS S & D

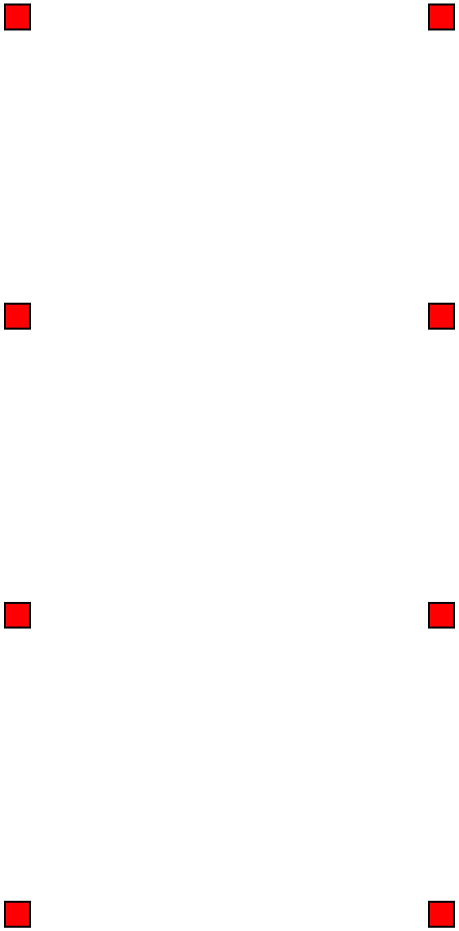


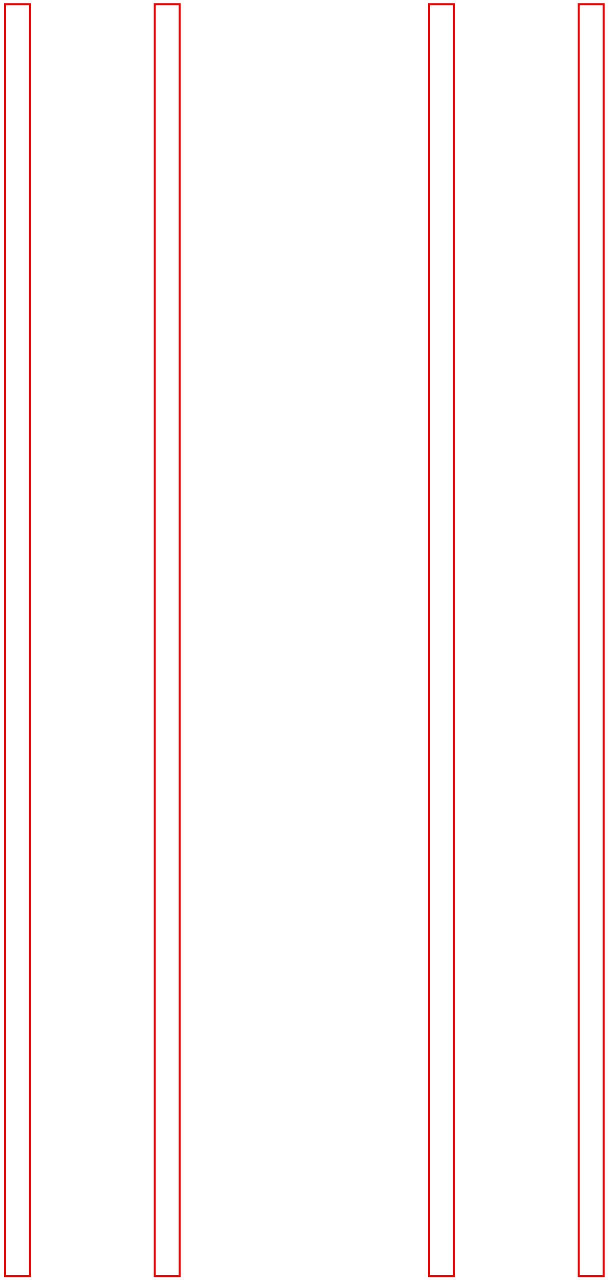
Mask 4
nMOS S & D



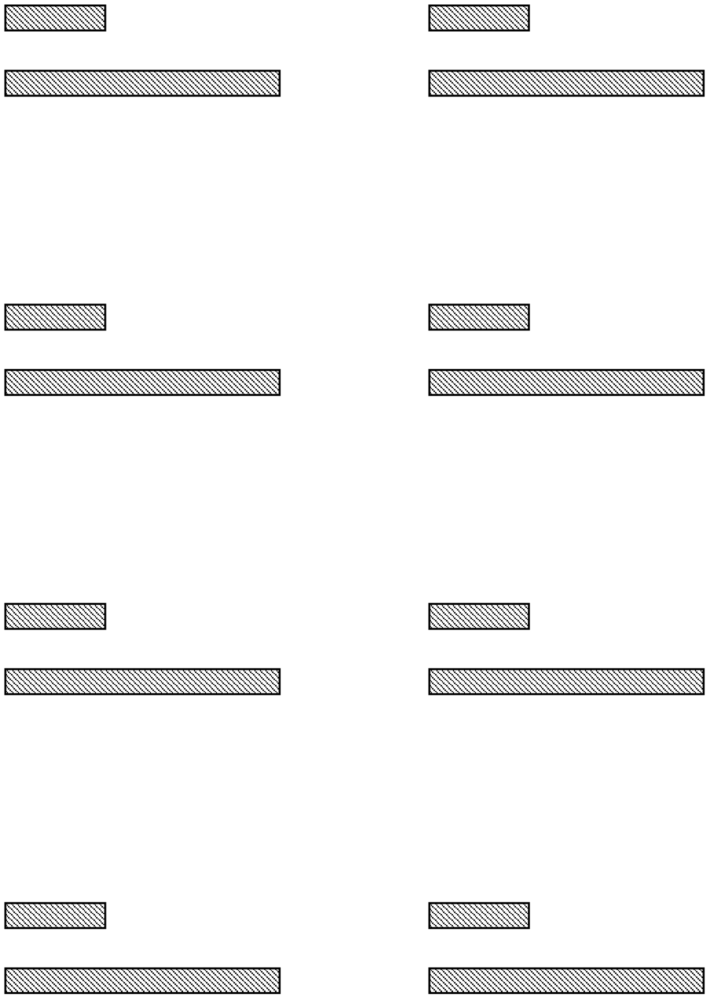
Mask 5
Poly

Mask 6 Contacts

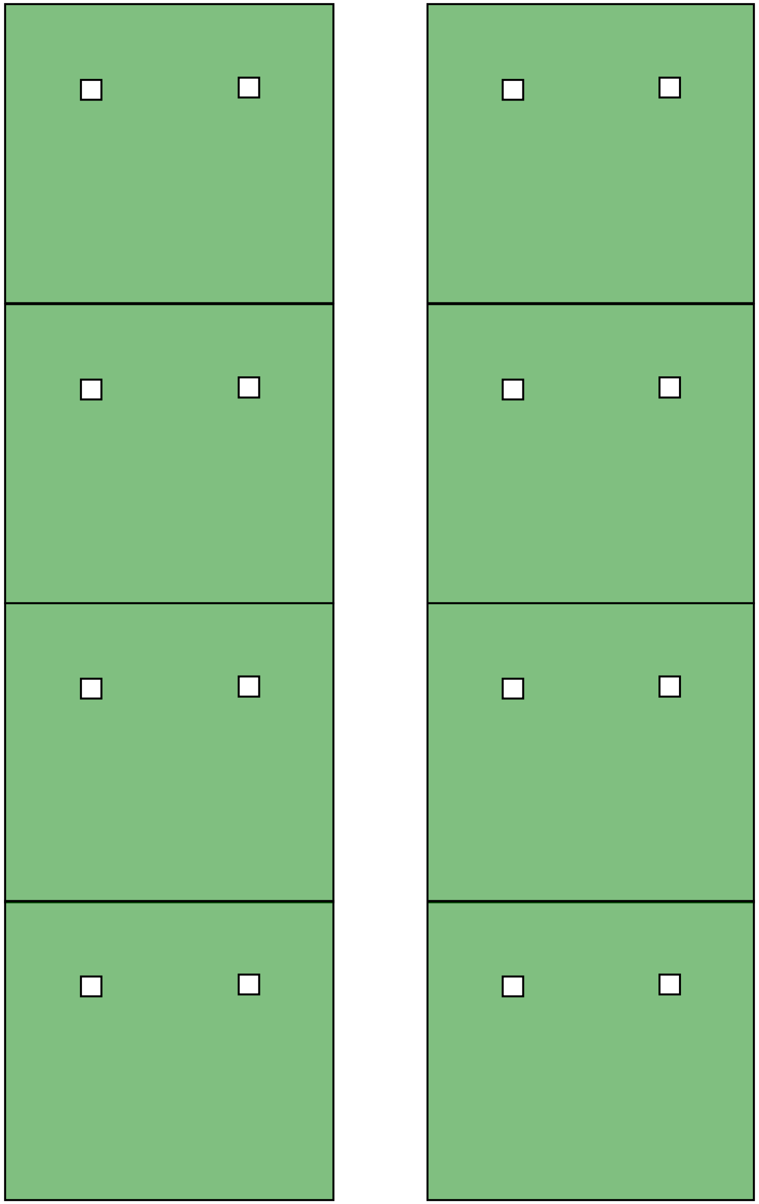




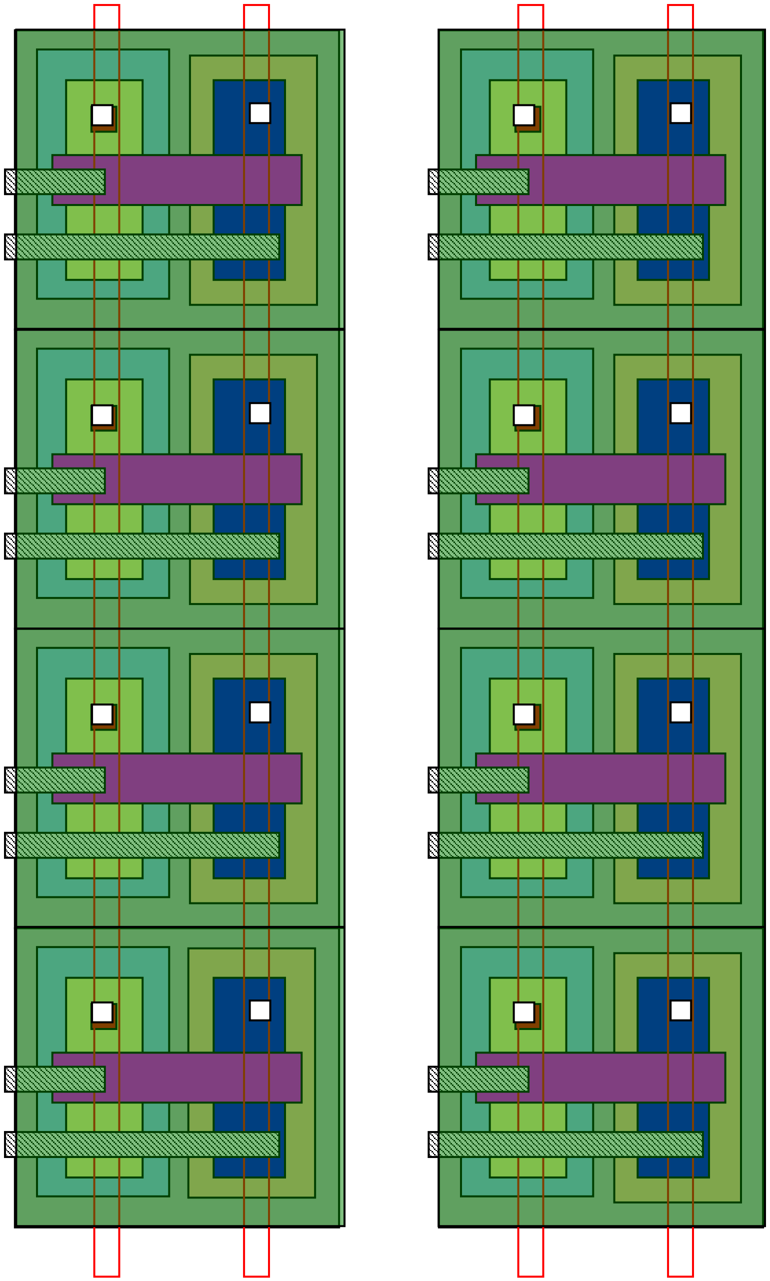
Mask 7
Metal Lines



Mask 8
Metal Lines



Mask 9
Contact Holes



Alignment of Masks

Electron-Beam Lithography

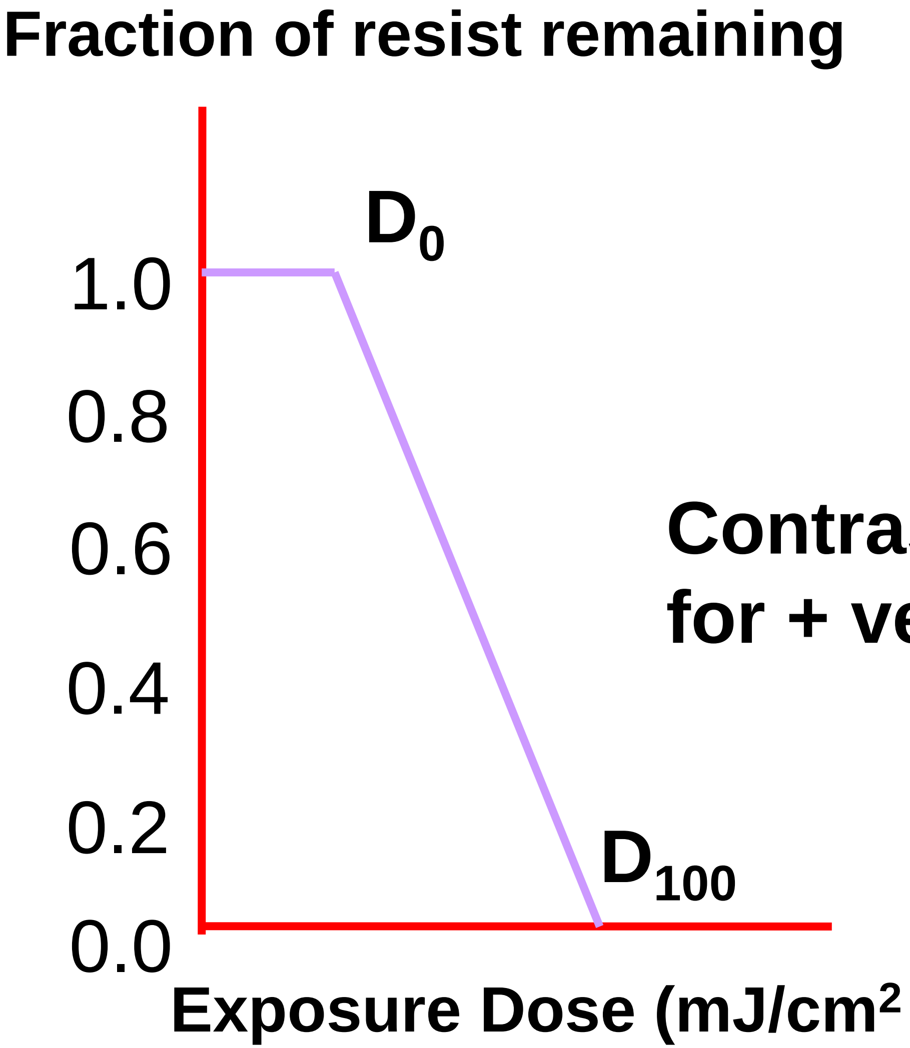
Photoresist Parameters (contd. ..)

- Contrast –is the difference in appearance of two or more parts of a field seen simultaneously or successively.

Contrast: $\gamma = 1 / [\log10(D100/D0)]$

Where D100 = lowest energy density for which all the resist is removed,

D0 = lowest energy density needed to begin photo chemistry



Contrast curve for + ve resist

Critical Modulation Transfer Function (CMTF)

CMTF is the minimum optical modulation transfer function necessary to obtain a pattern. It is defined by:

$$\text{CMTF} = (D100 - D0)/(D100 + D0)$$

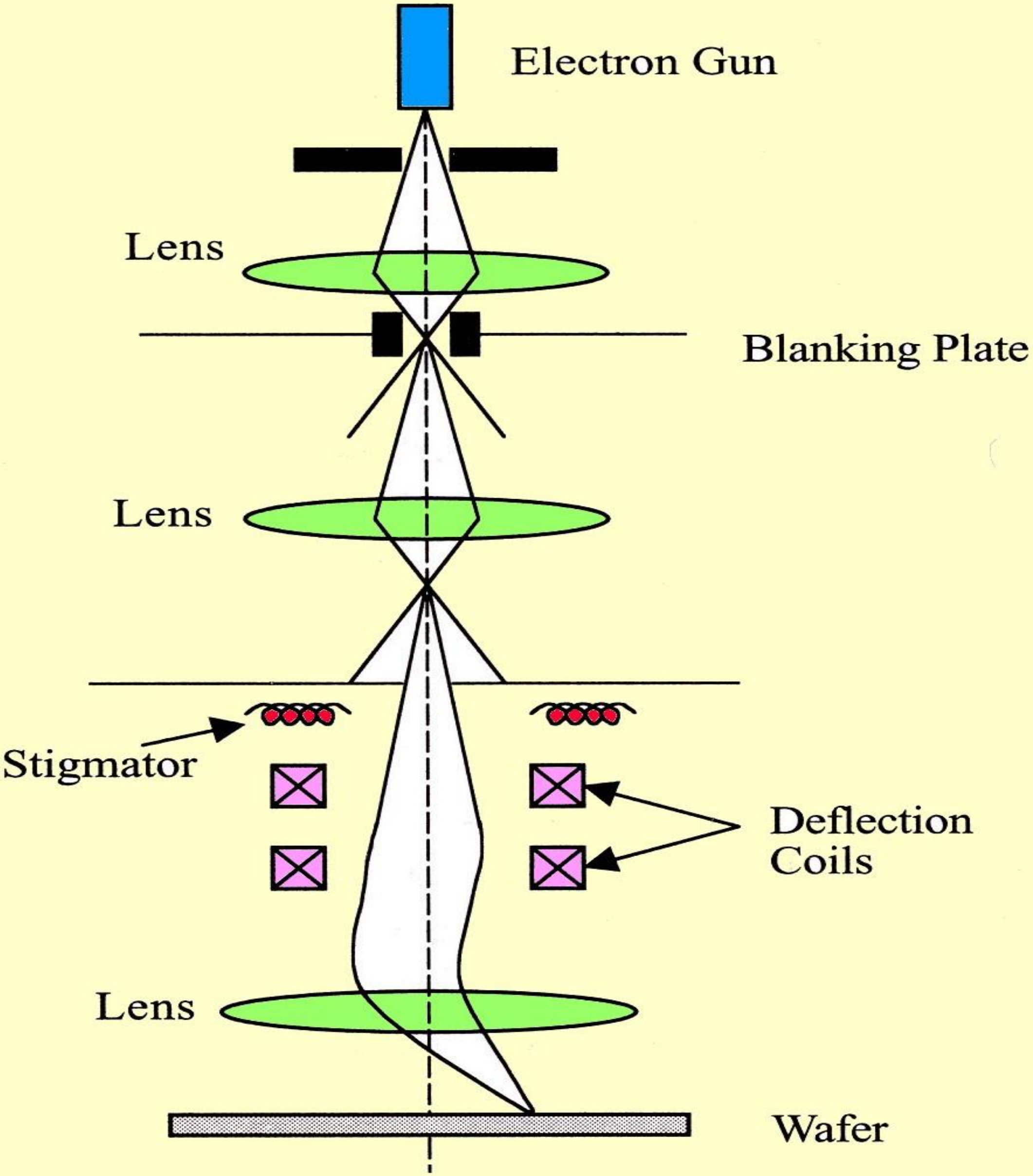
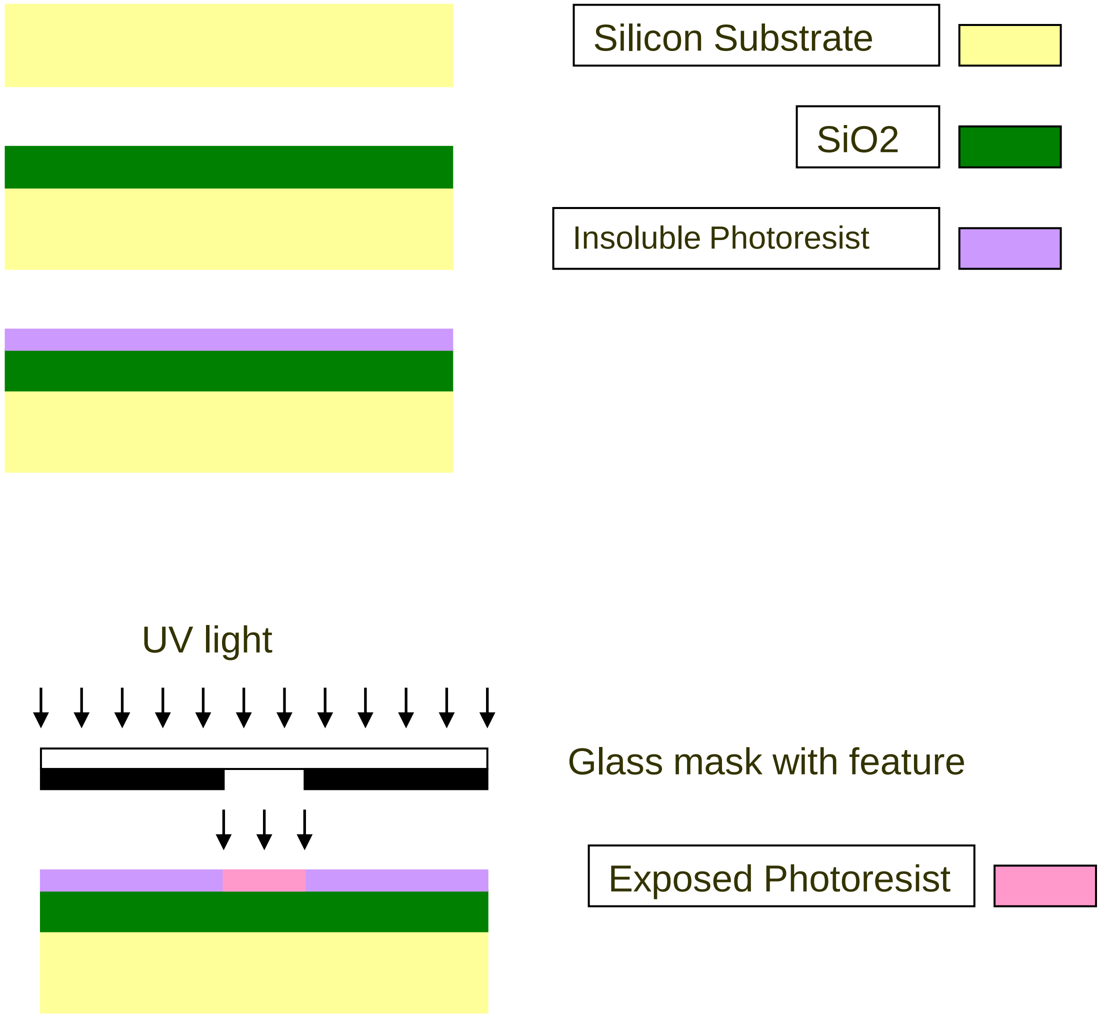


Fig 47: The e-beam direct writing system

Alignment Systems
and
Misalignments

Photolithography



Silicon Substrate

SiO2

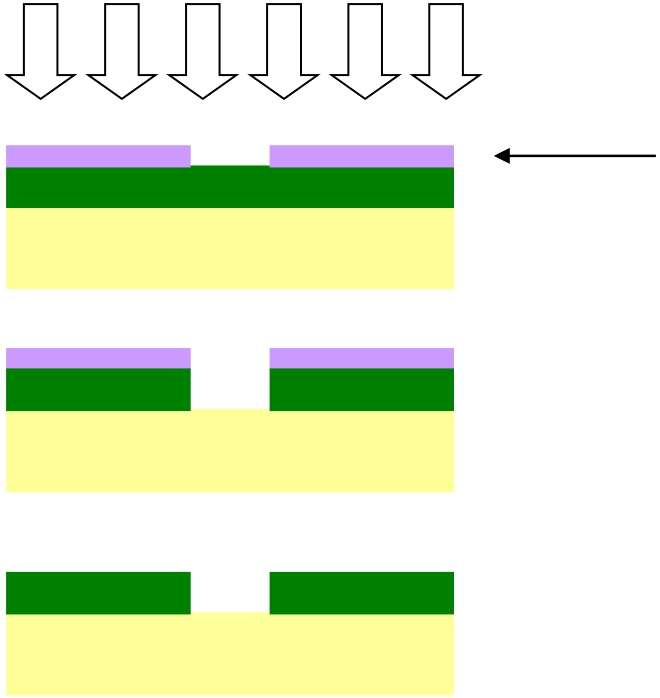
Insoluble Photoresist

UV light

Glass mask with feature

Exposed Photoresist

Photolithography (continued)

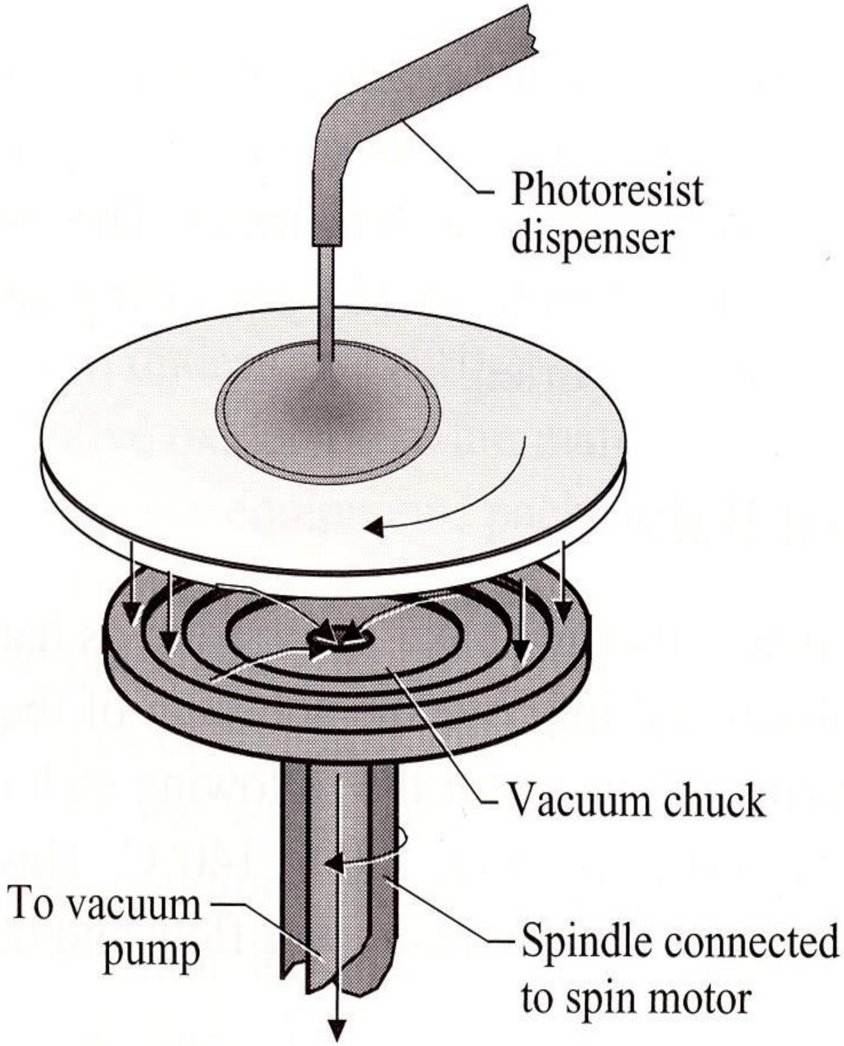


Chemical Etch or Dry Etch

Hardened
Photoresist

Process Summary:

- Wafer is held onto vacuum chuck
- Dispense ~ 5ml of photoresist
- Slow spin ~ 500 rpm
- Ramp up to ~ 3000 to 5000 rpm
- Quality measures:
  - time
  - speed
  - thickness
  - uniformity
  - particles and defects



Spin coat

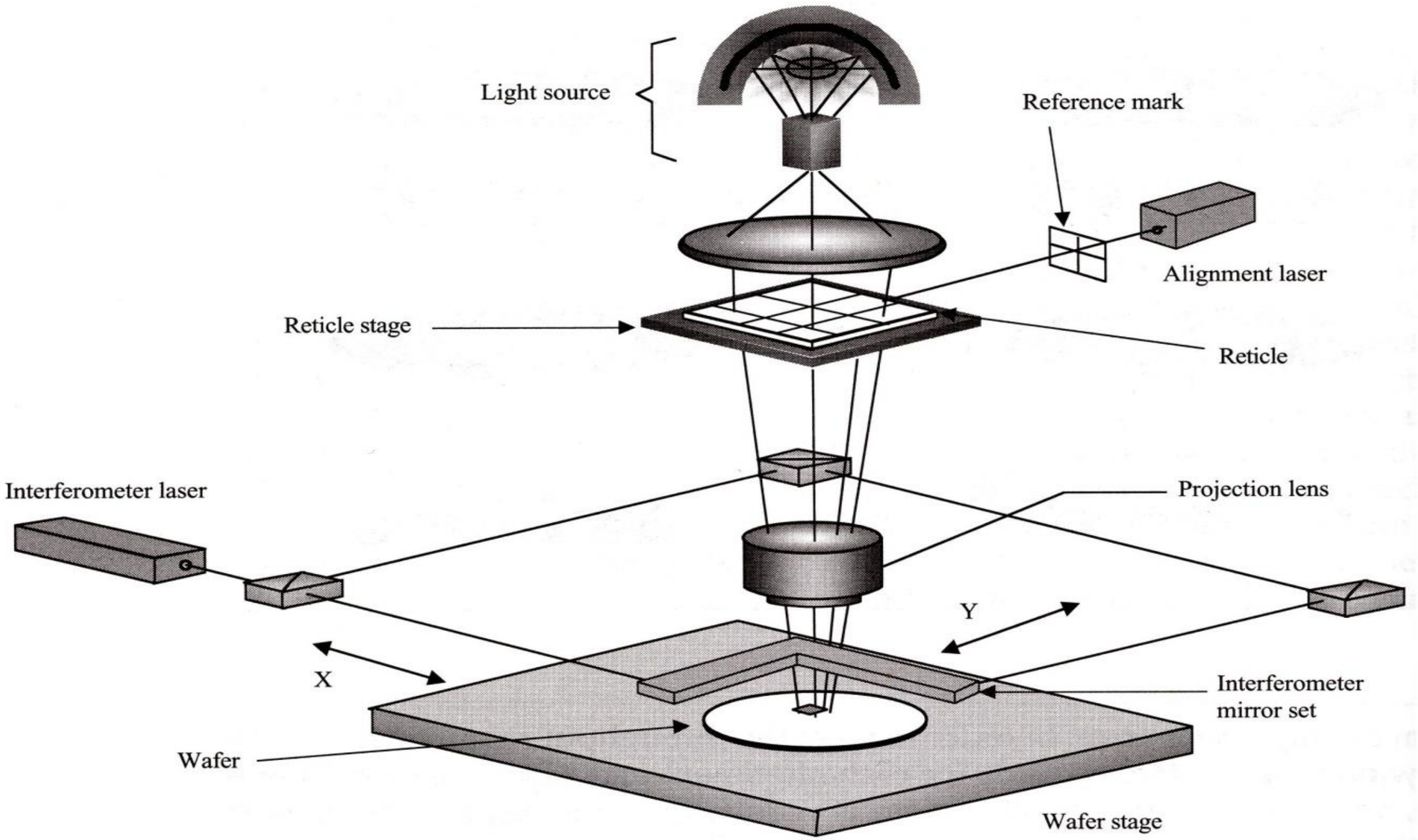
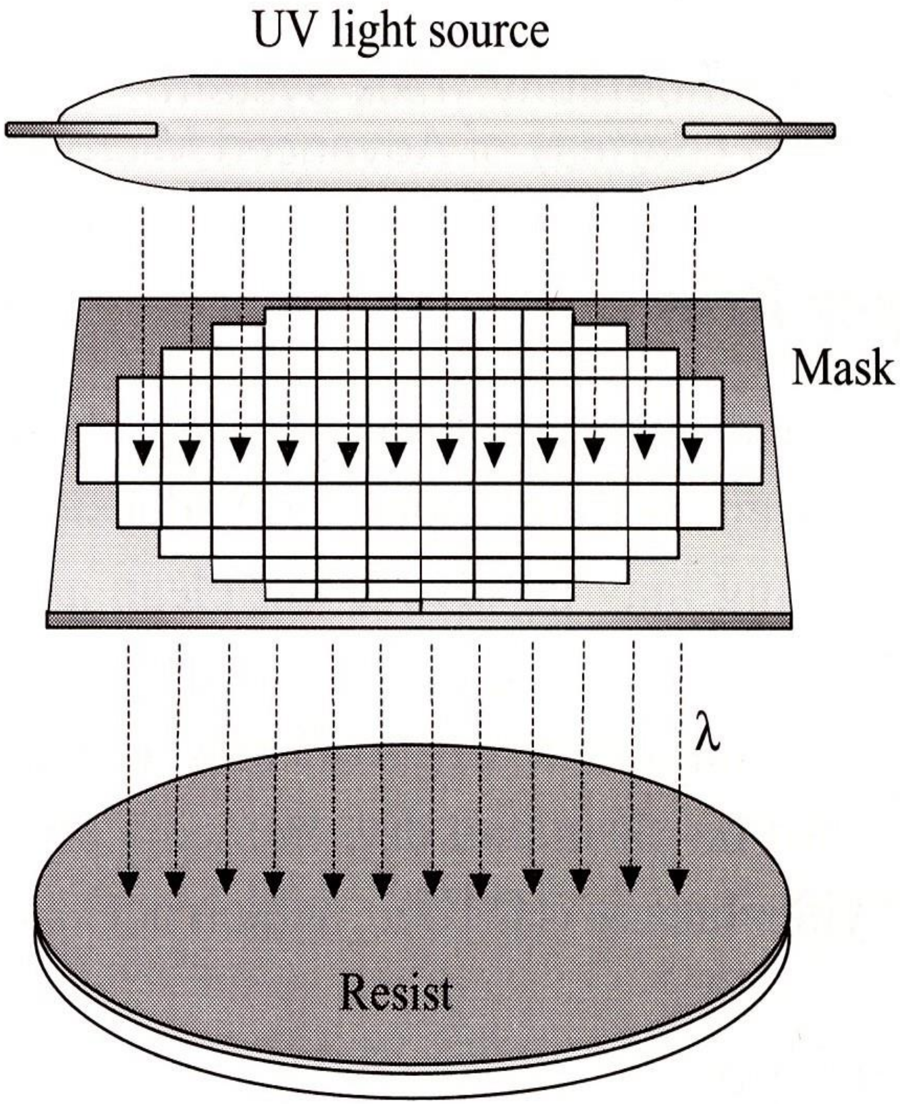


Fig 20:
Schemetic of a step and repeat alignment and exposure system

Process Summary:

- Transfers the mask image to the resist-coated wafer
- Activates photo-sensitive components of photoresist
- Quality measures:
  - linewidth resolution
  - overlay accuracy
  - particles and defects



Alignment and Exposure

- What is PEB ?
- How it works ?
- Why is it useful?

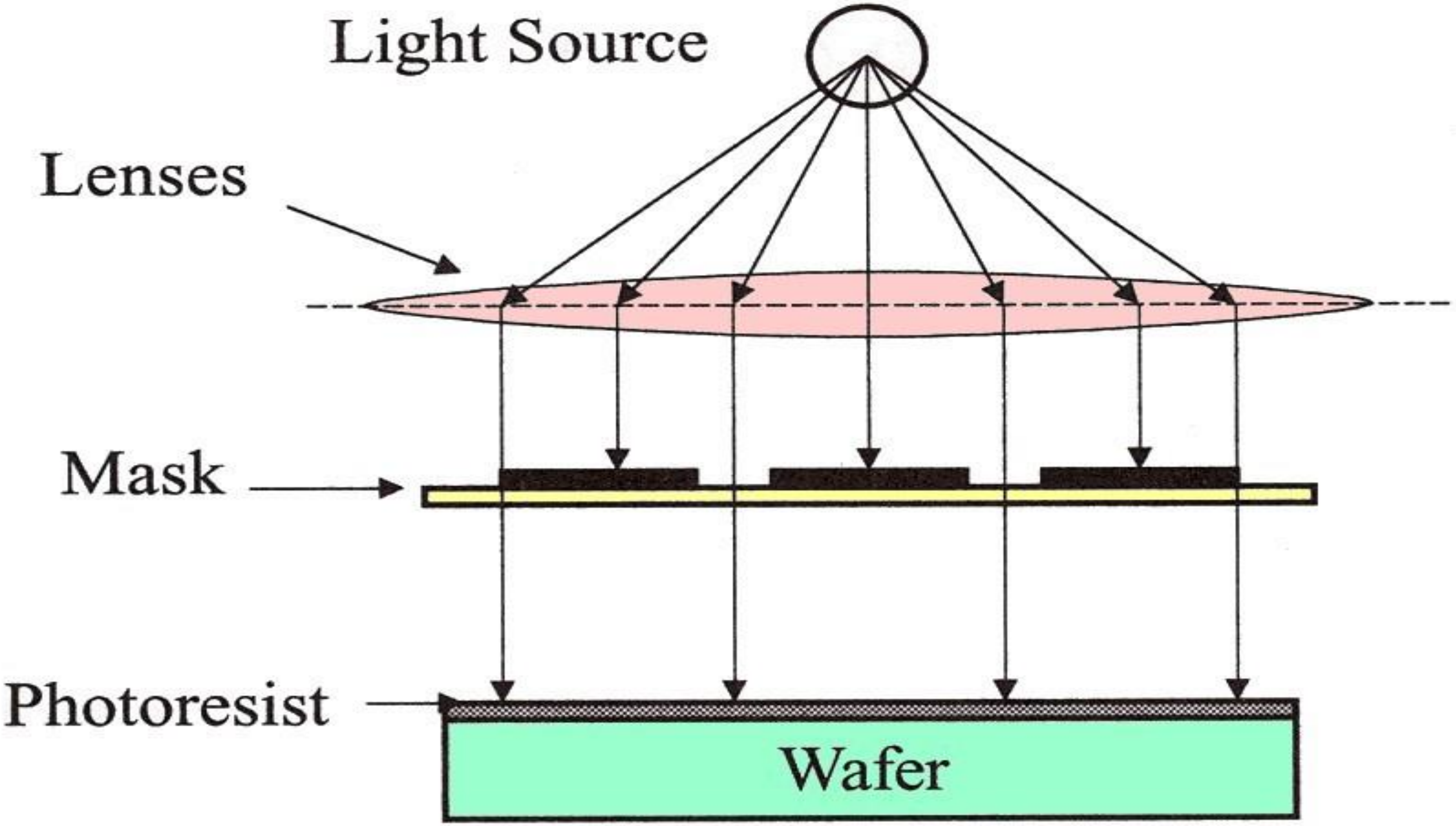
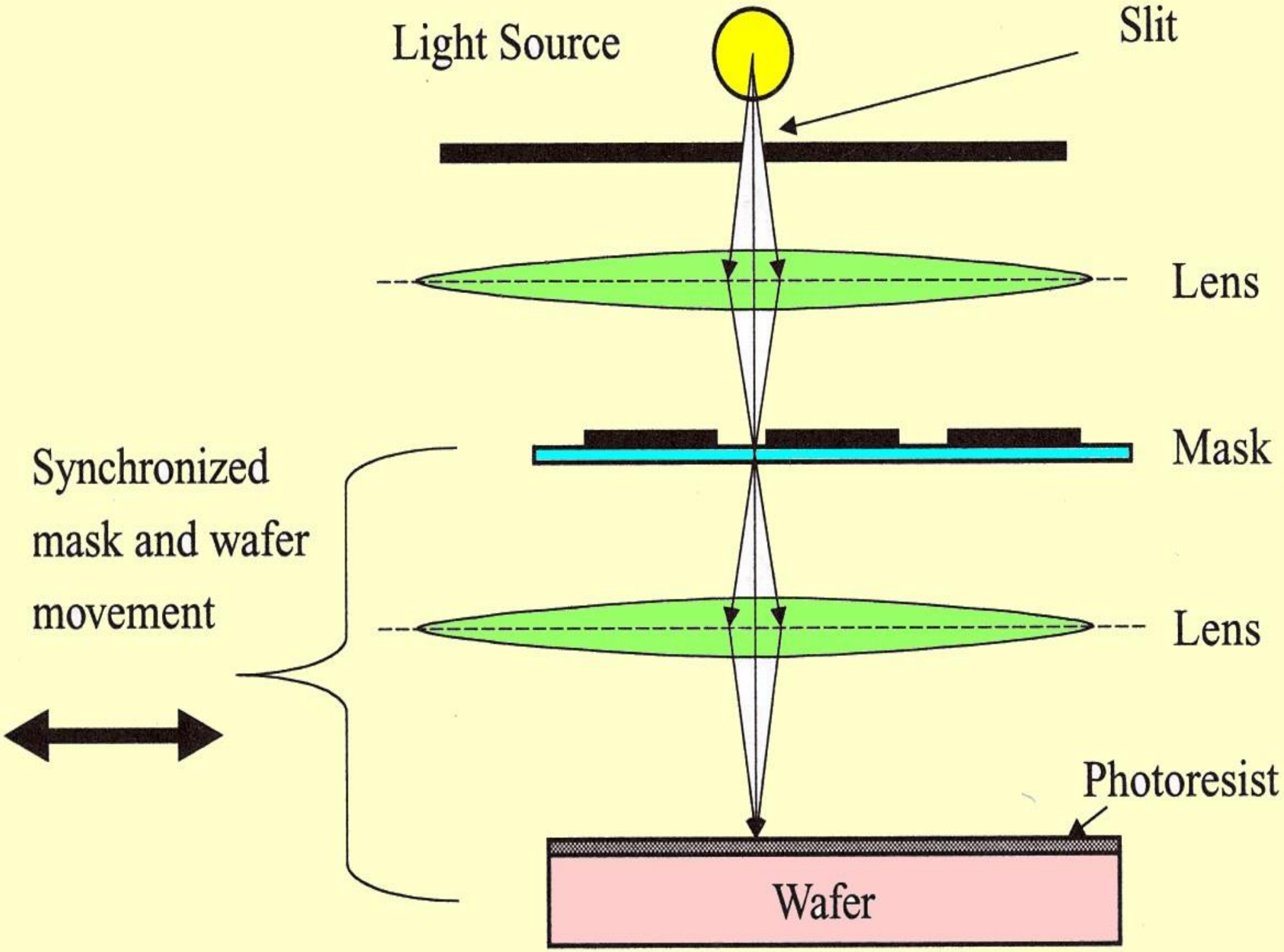


Fig 17: Schemetic of a projection exposure system



Schemetic of a scanning projection exposure system

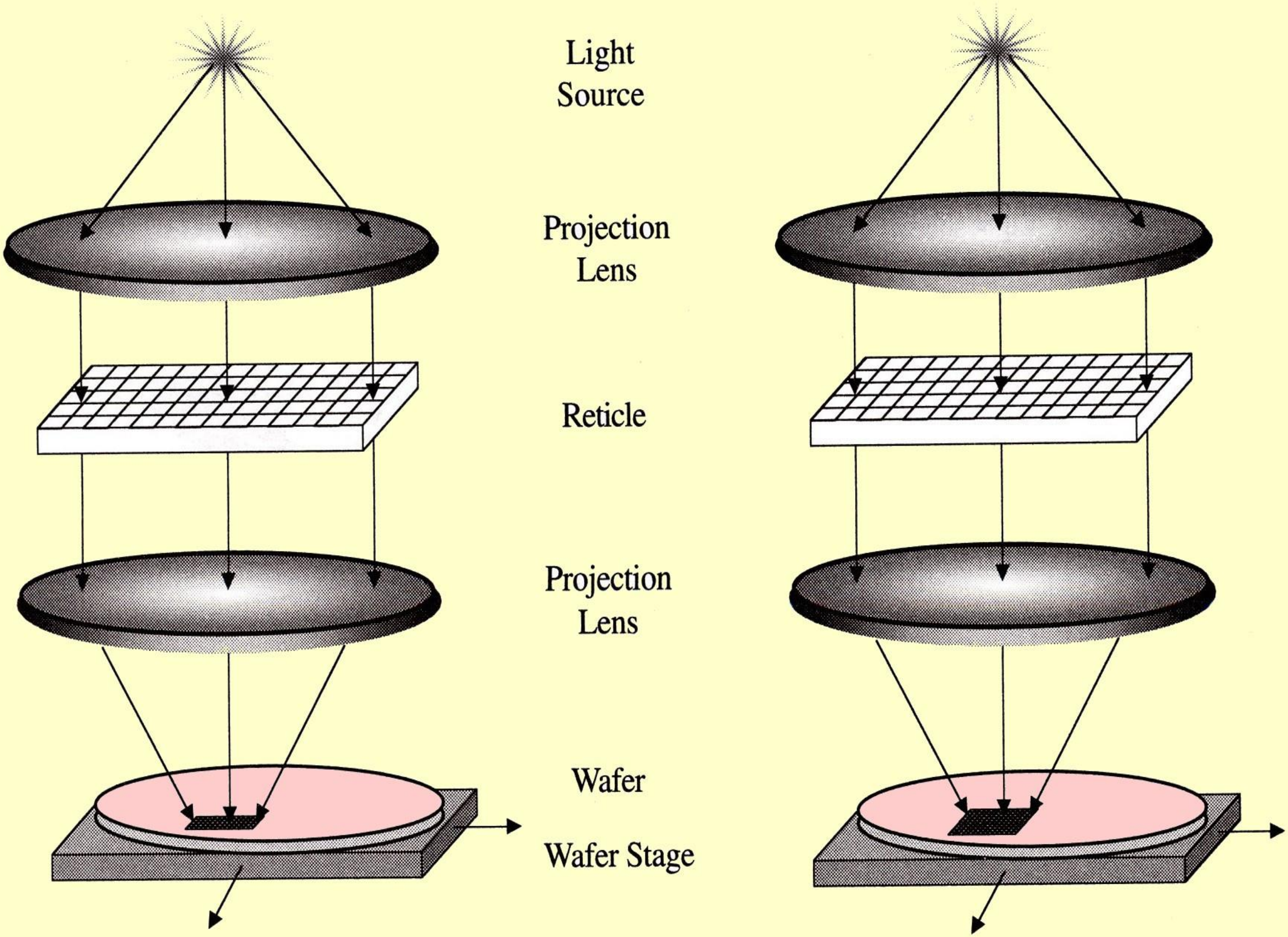


Fig 19: Step and repeat exposure system

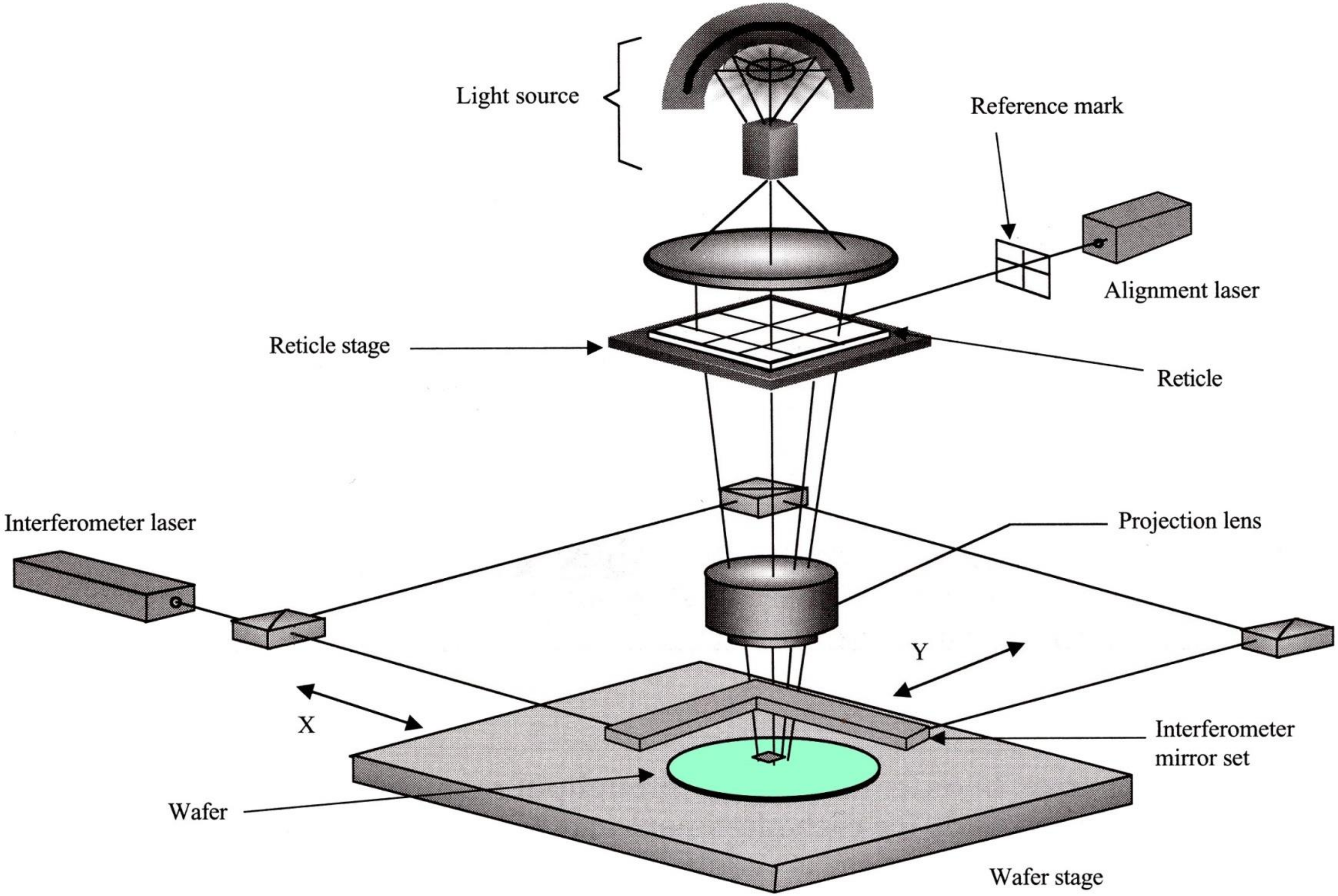


Fig 20:

Schemetic of a step and repeat alignment and exposure system

Questions

- Explain the working of +ve & -ve PR
- Why + PR gets higher resolution
- What is resolution?
- Two (2) basic techniques for transferring resist features into a layer with proper schematic representation
- Working of electron lithography

Resolution and Focusing

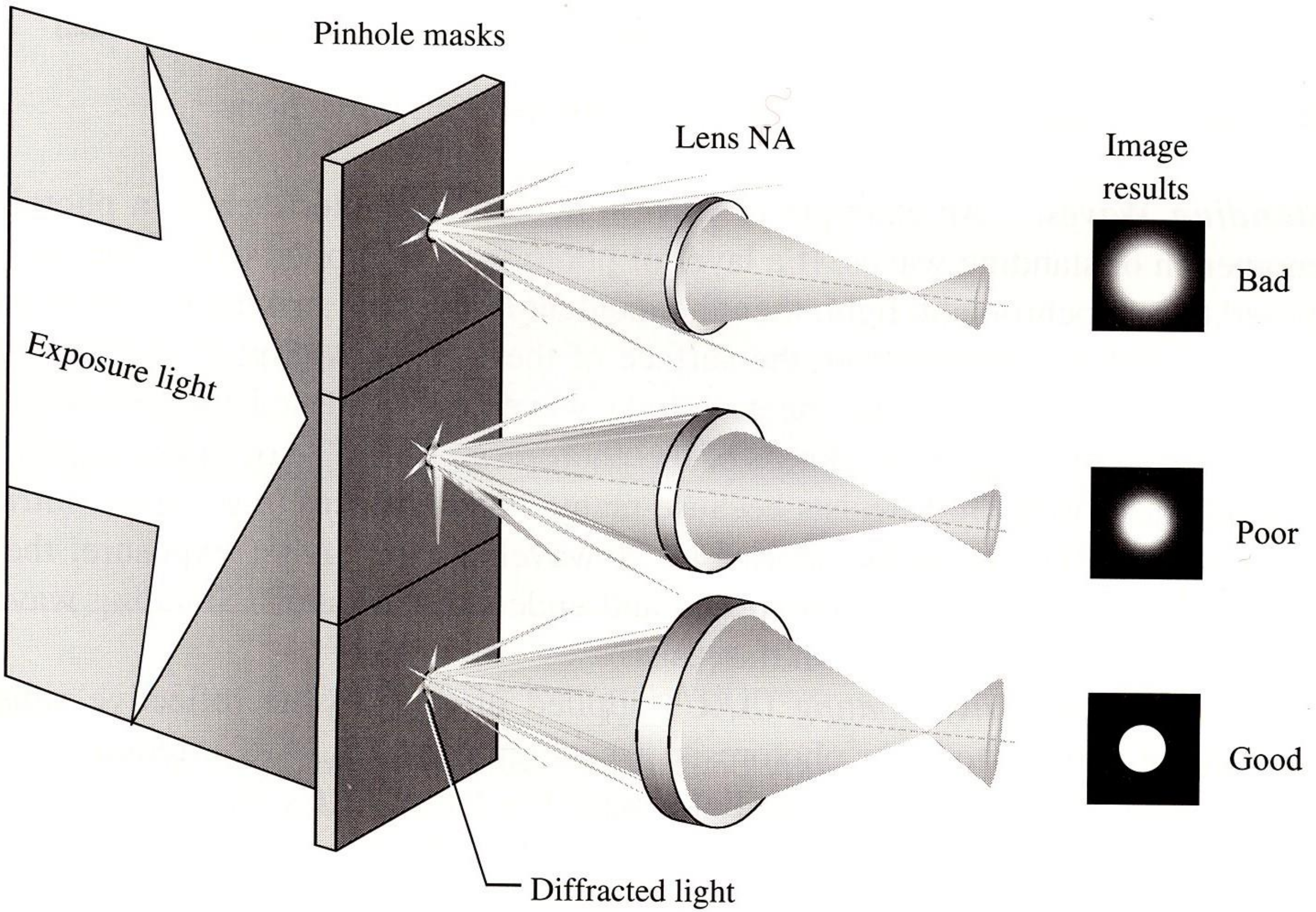


Fig q1421: Effect of Numerical Aperture on Imaging

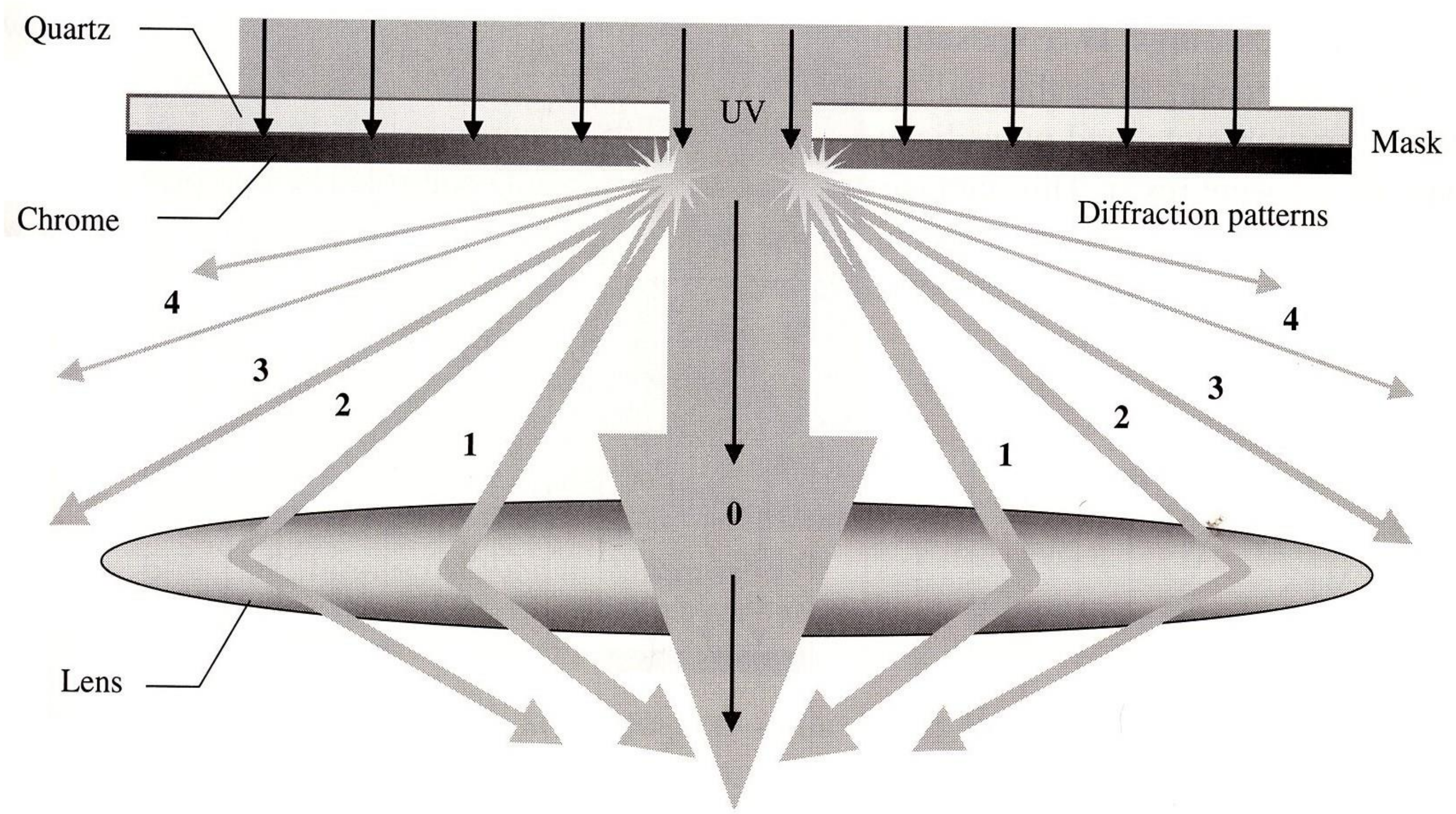


Fig q1420: Lens Capturing Diffracted Light

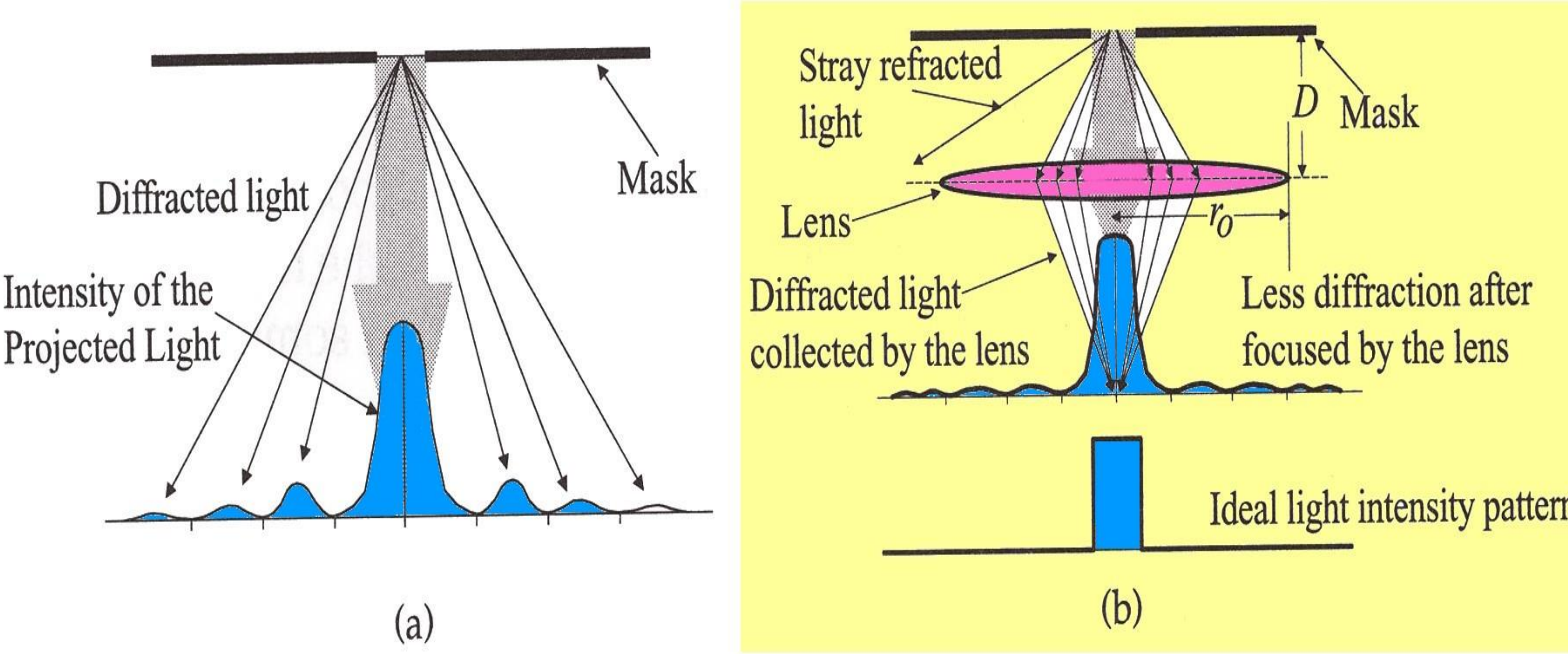
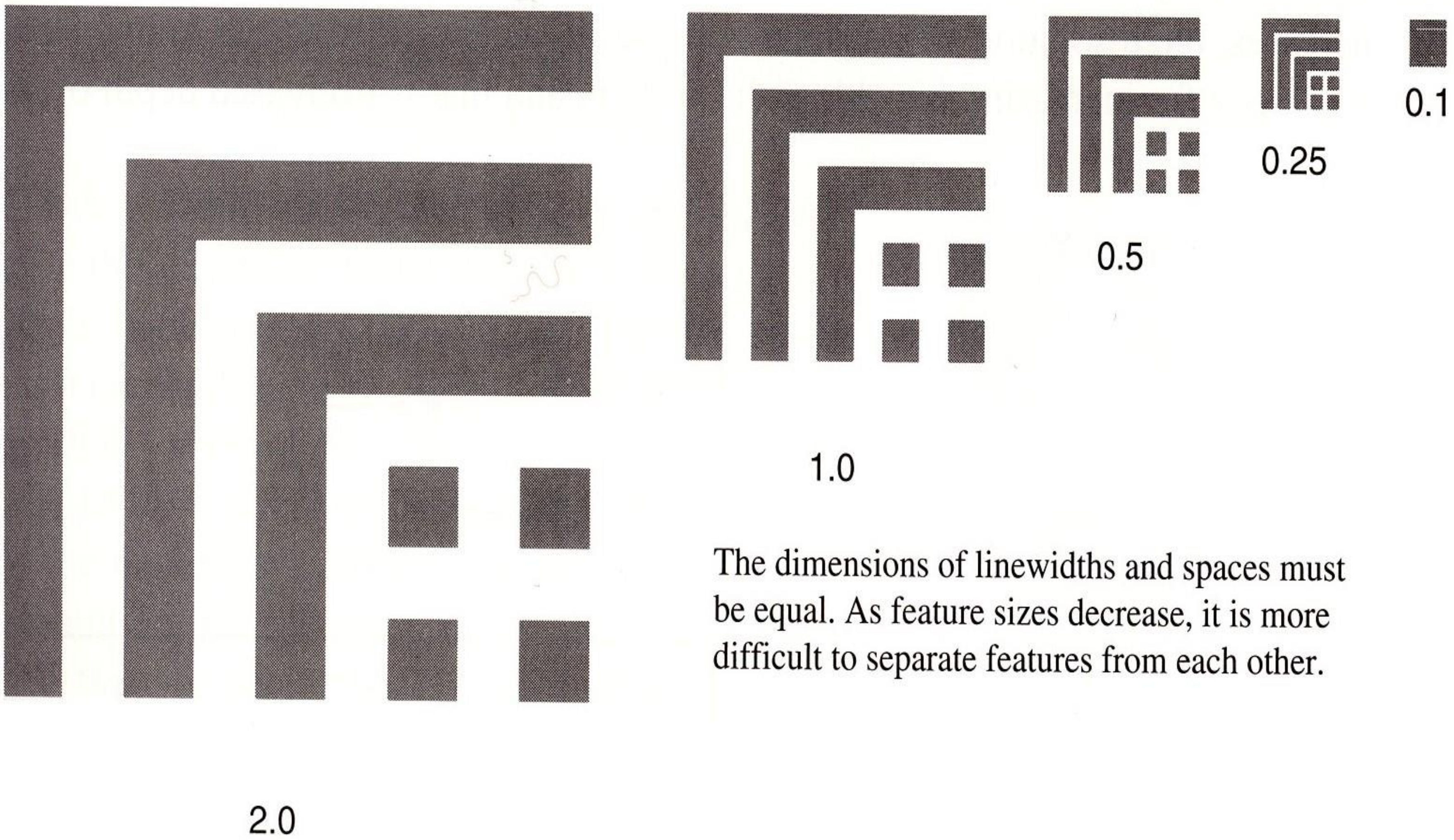


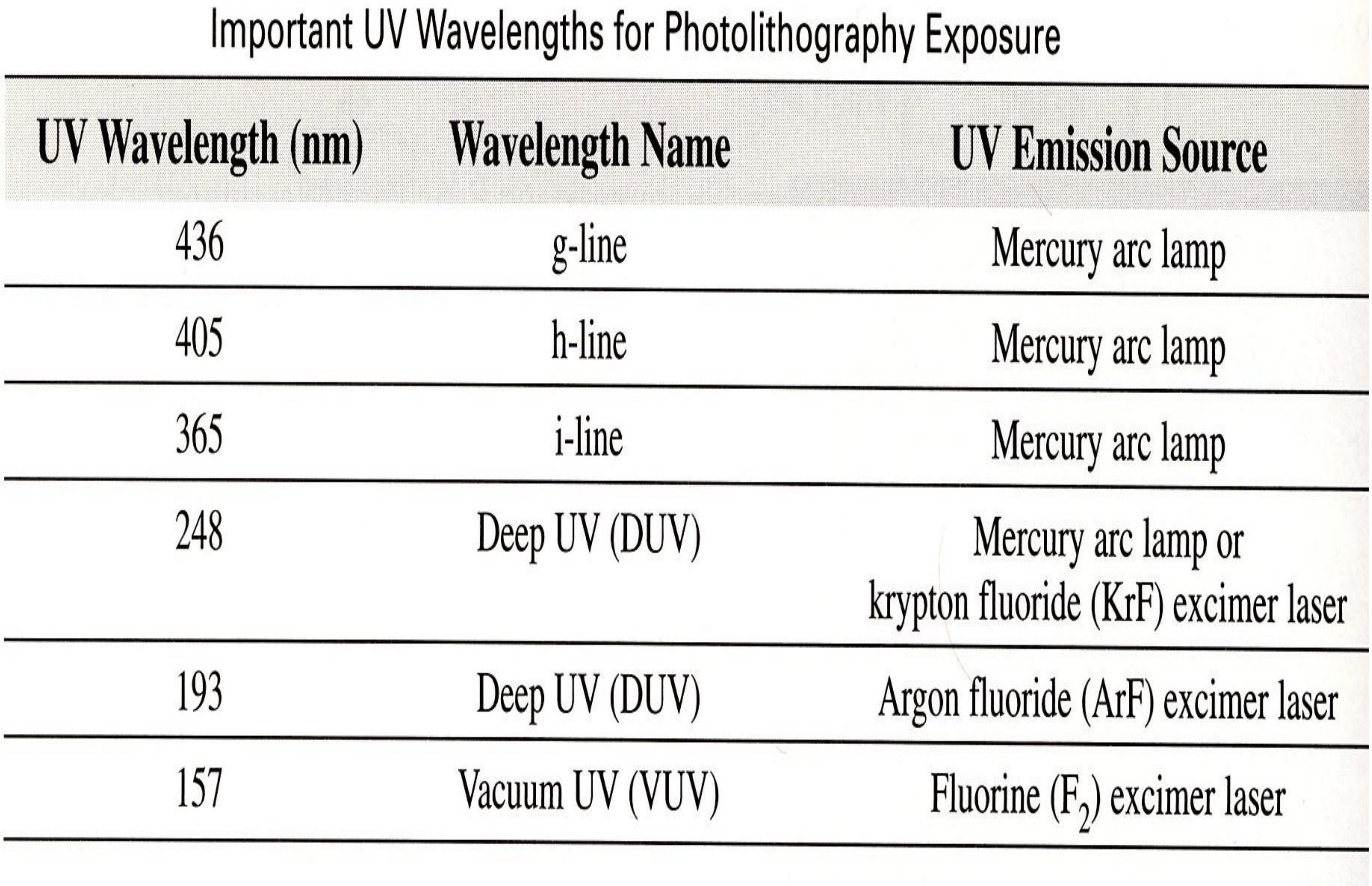
Fig 36: (a) Light diffraction and (b) effect of lens

$$NA = 2\,r_o / D$$



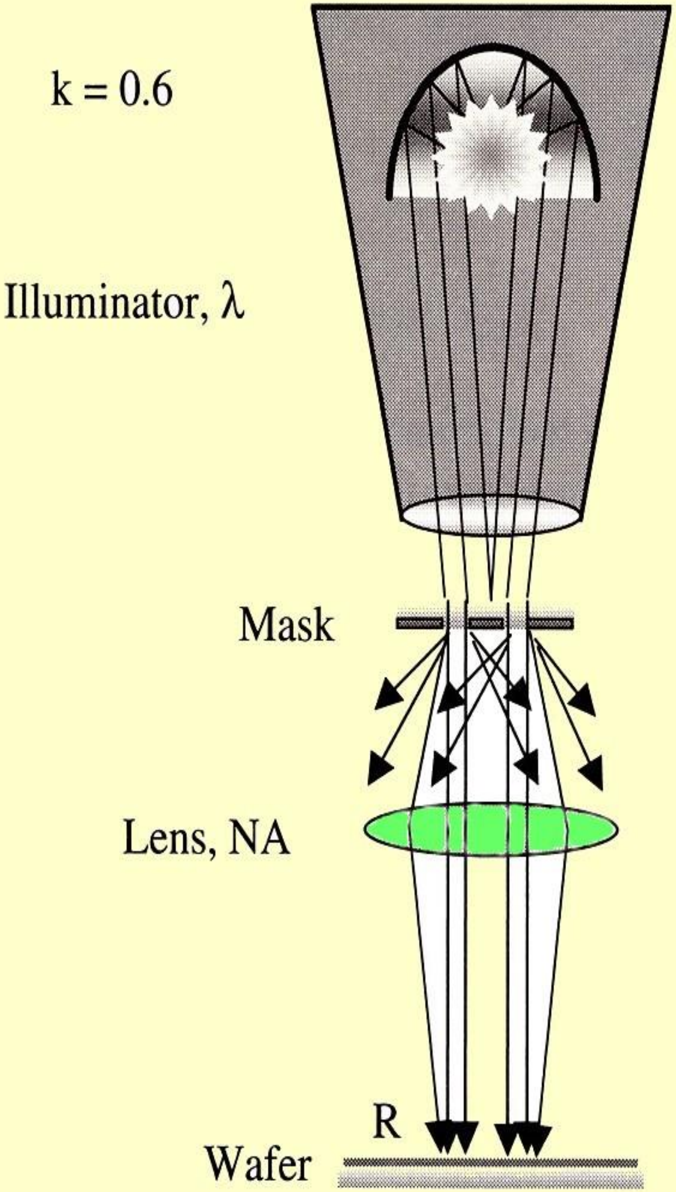
The dimensions of linewidths and spaces must be equal. As feature sizes decrease, it is more difficult to separate features from each other.

Fig q1428: Resolution of Features



Important UV Wavelengths for Photolithography Exposure

UV Wavelength (nm)	Wavelength Name	UV Emission Source
436	g-line	Mercury arc lamp
405	h-line	Mercury arc lamp
365	i-line	Mercury arc lamp
248	Deep UV (DUV)	Mercury arc lamp or krypton fluoride (KrF) excimer laser
193	Deep UV (DUV)	Argon fluoride (ArF) excimer laser
157	Vacuum UV (VUV)	Fluorine (F_2) excimer laser



Resolution $R = \frac{k\,\lambda}{NA}$

k is system constant,
NA is numerical aperture

	λ	NA	R
i-line	365 nm	0.45	486 nm
	365 nm	0.60	365 nm
DUV	193 nm	0.45	257 nm
	193 nm	0.60	193 nm

Fig q1429: Calculating Resolution for a given NA, k and λ

Q. Can we continue to reduce wave length to improve resolution?

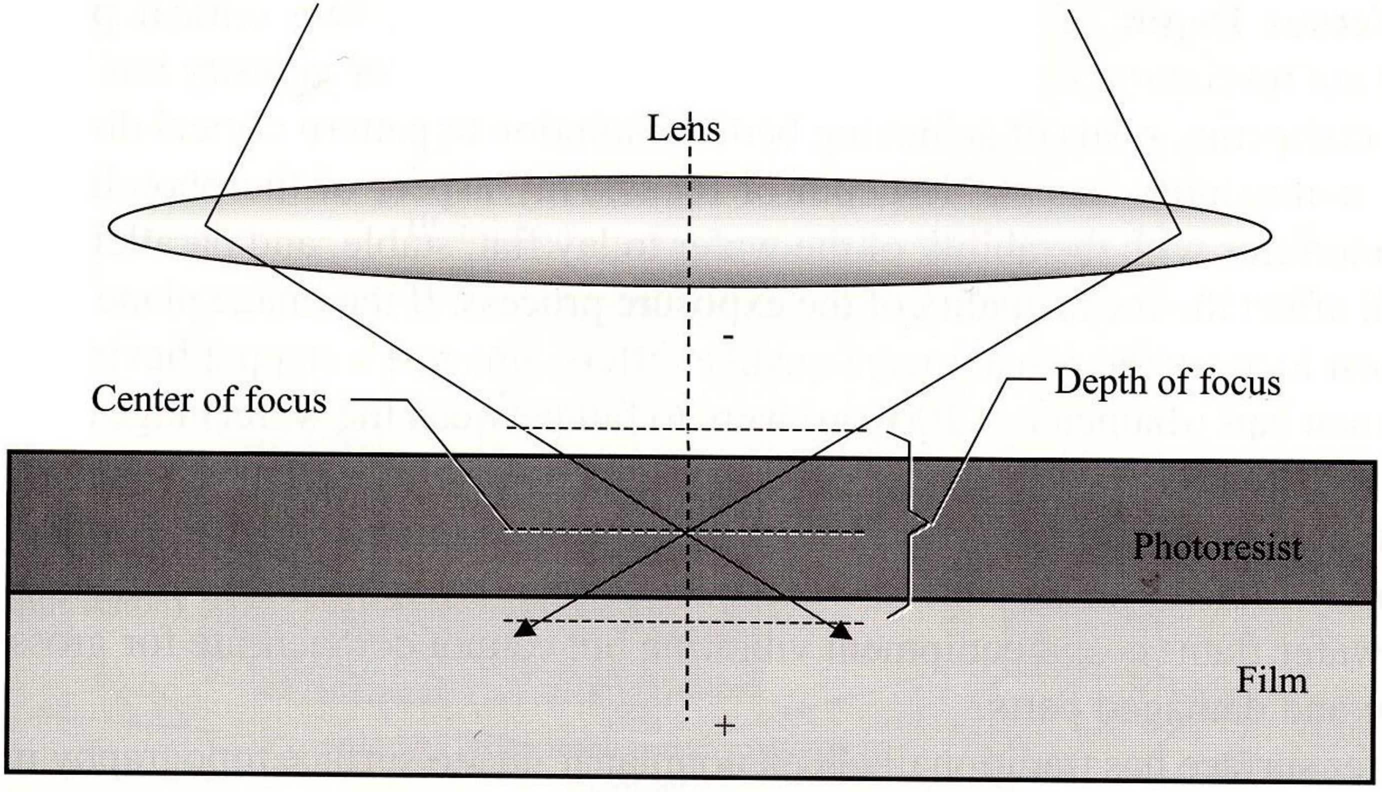
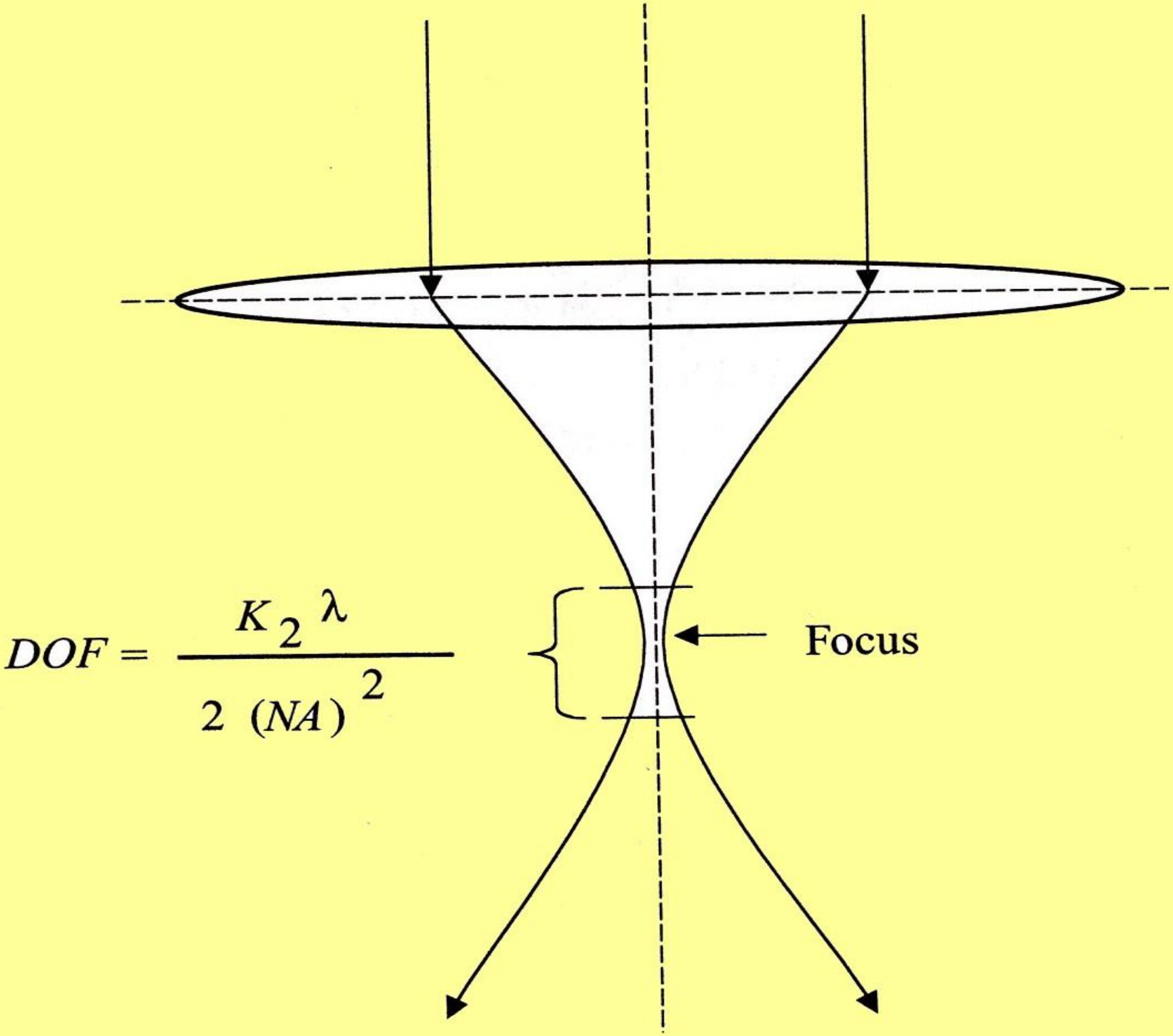


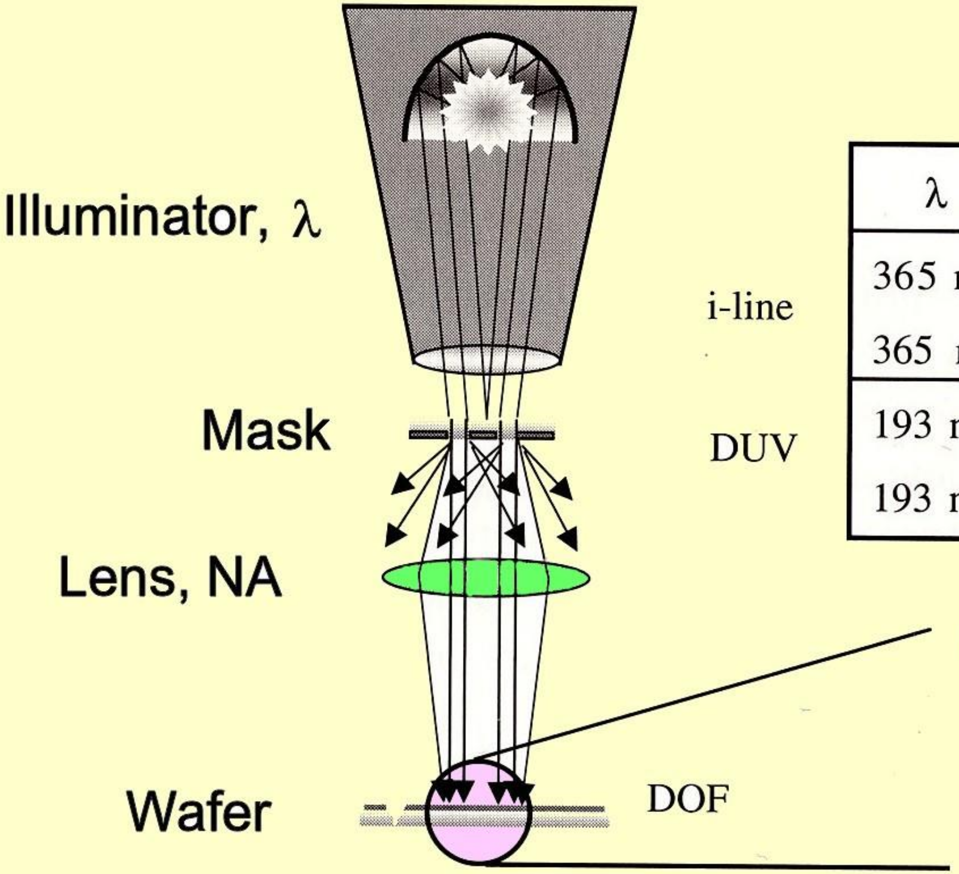
Fig q1430: Depth of Focus



$$DOF = \frac{K_2 \lambda}{2\,(NA)^2}$$

Fig 38: Depth of focus of an optical system

$$\text{DOF} = \frac{\lambda}{2(\text{NA})^2}$$



	λ	NA	R	DOF
i-line	365 nm	0.45	486 nm	901 nm
	365 nm	0.60	365 nm	507 nm
DUV	193 nm	0.45	257 nm	476 nm
	193 nm	0.60	193 nm	268 nm

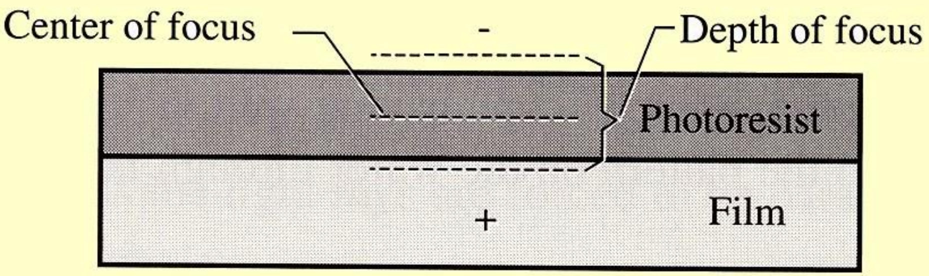


Fig q1431: Resolution versus Depth of Field for varying NA

Focus the light on the mid-plane of PR to optimize resolution

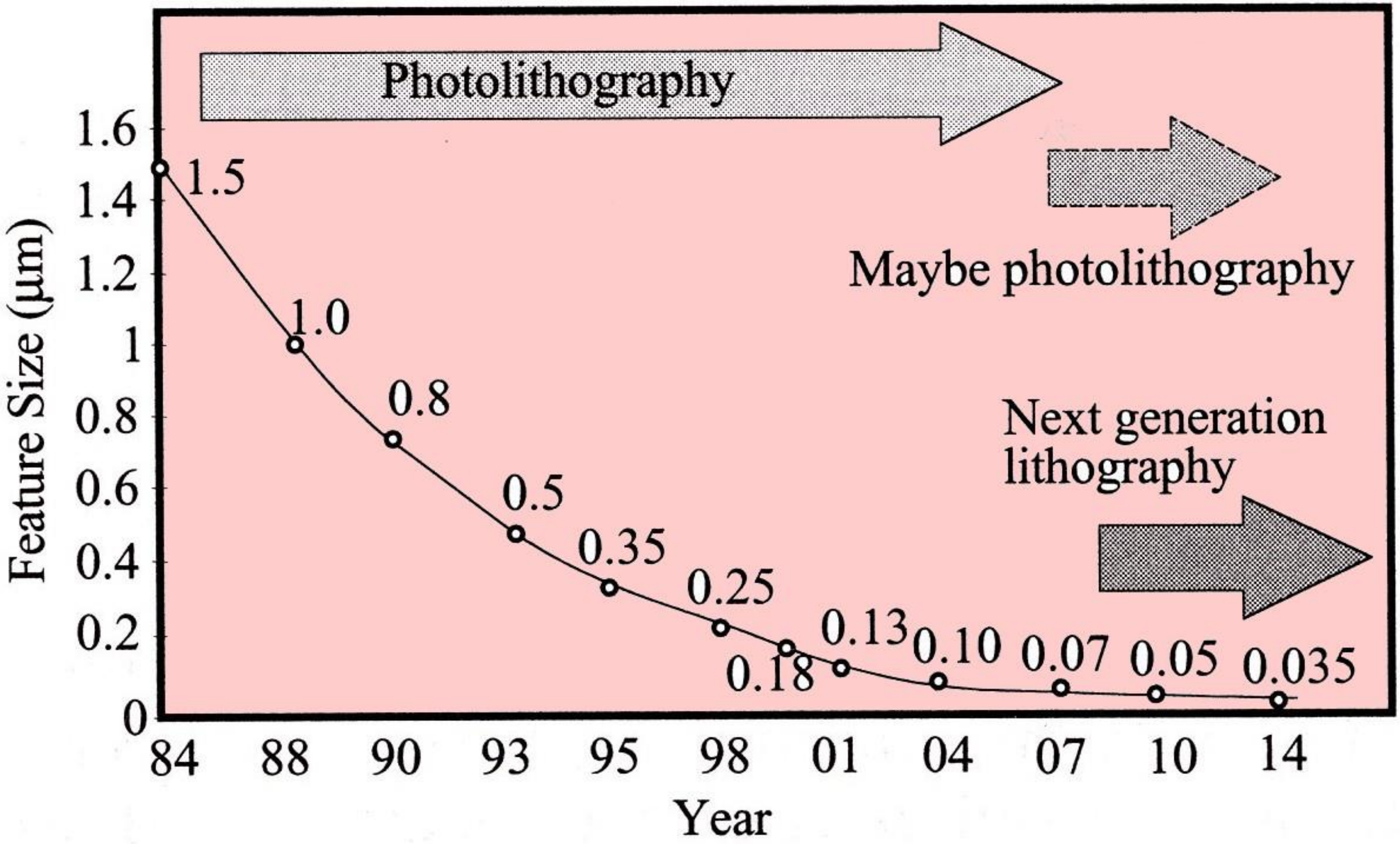


Fig 40: Feature sizes and lithography technology trends

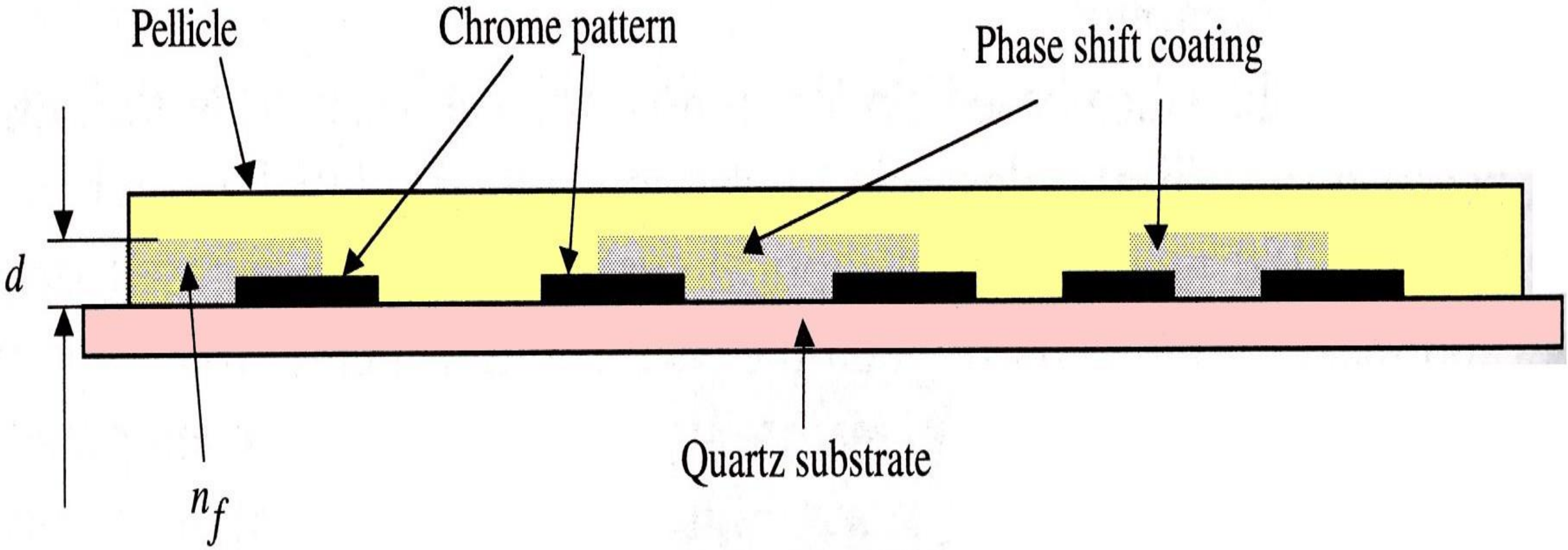


Fig 41: A phase shift mask

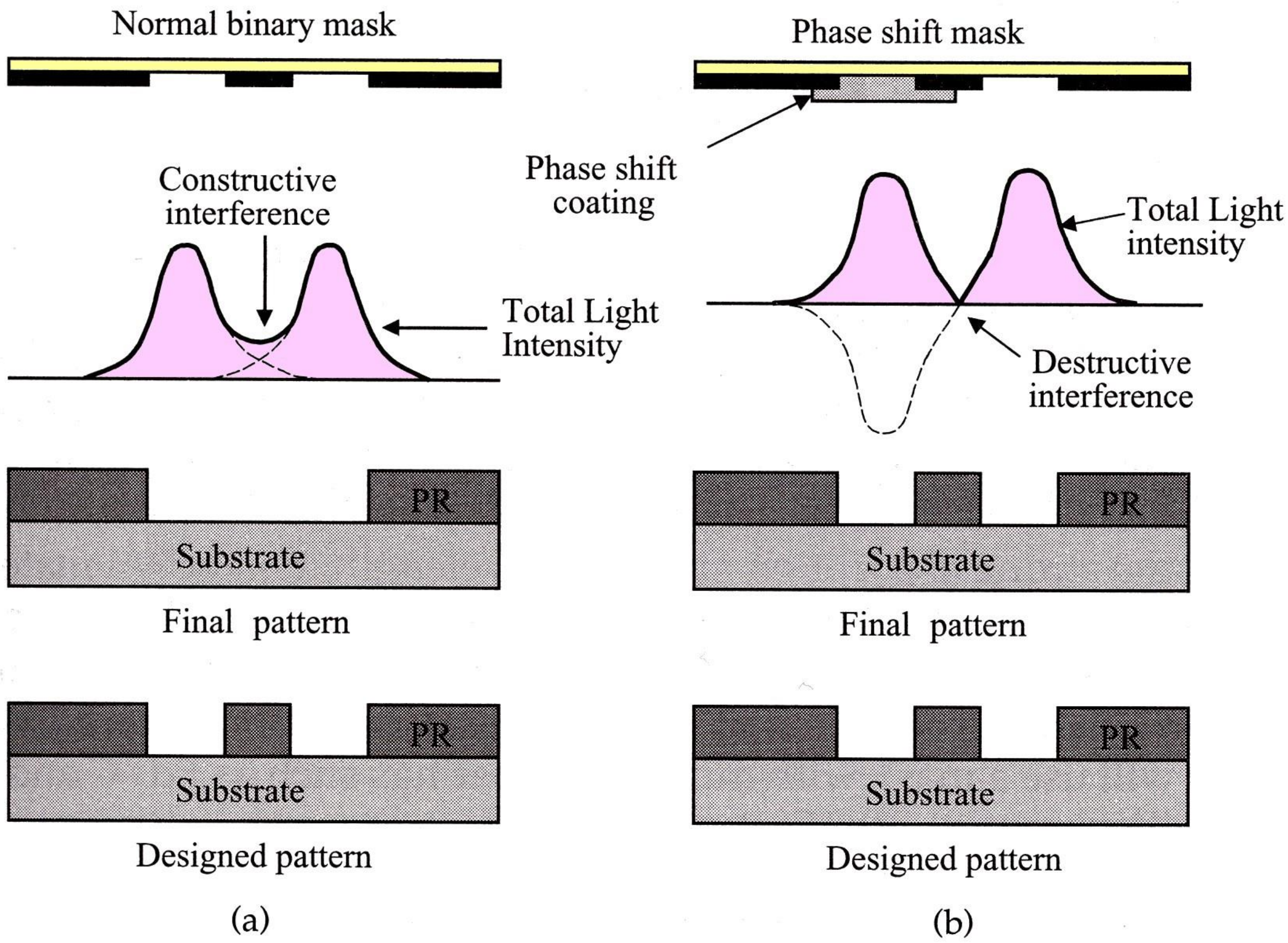


Fig 42: (a) Normal Mask and (b) Phase-shift mask photolithography processes

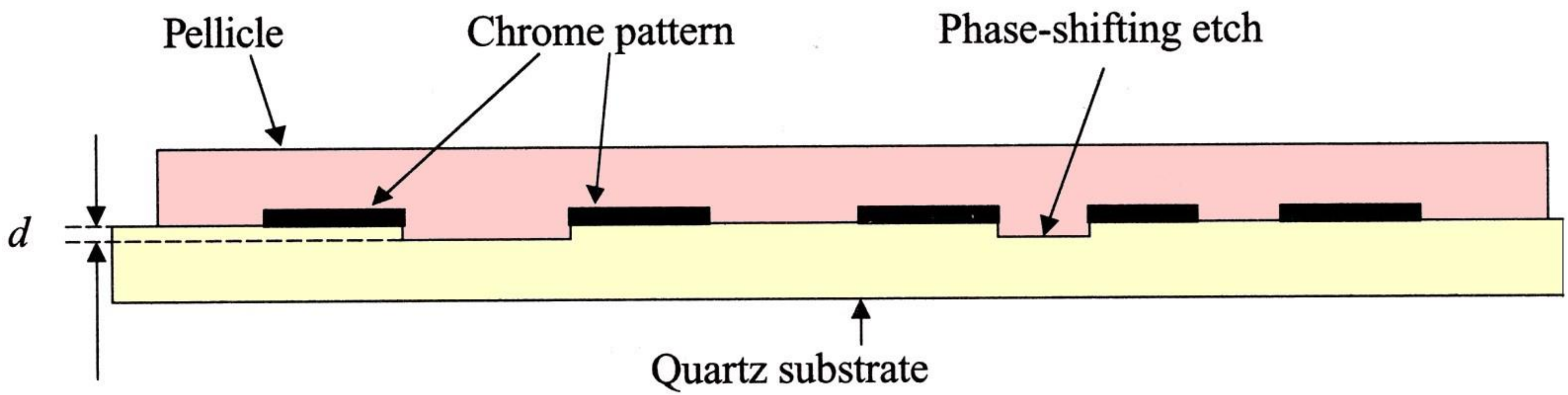
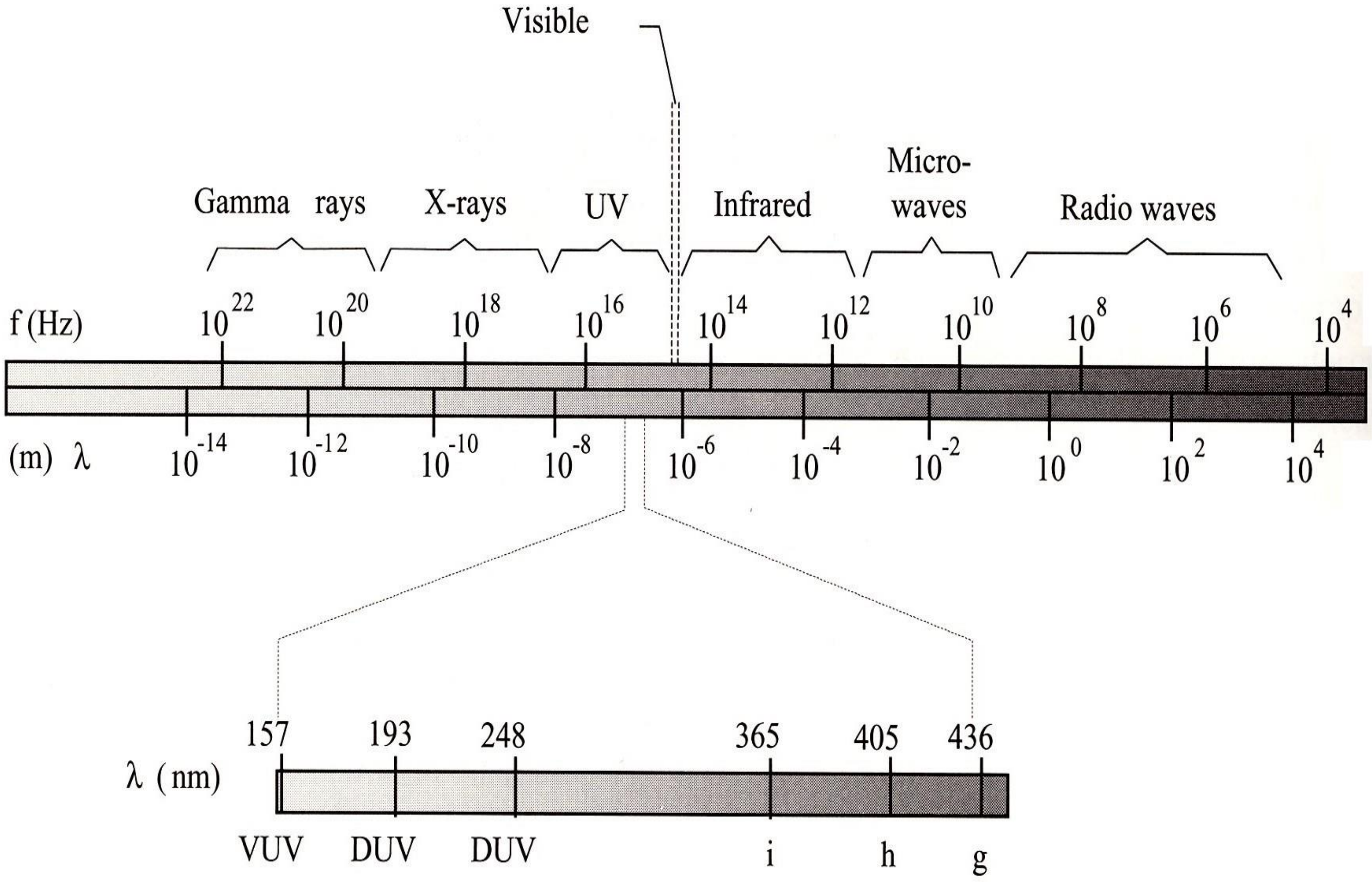


Fig 43: Phase-shift mask formed by quartz etch

Reducing Wave Length



Common UV wavelengths used in optical lithography.

Section of the Electromagnetic Spectrum

- Intensity of DUV sources << mercury lamps
- DUV requires different PR
- Chemically amplified PR for DUV
- Catalysis effect is used to increase the effective sensitivity of the PR
- A photo acid is created in the PR when it is exposed to the DUV light.
- In the post exposure bake (PEB) process, the wafer is heated, and the heat drives acid diffusion and amplification in a catalytic reaction.

p186

F 6.04

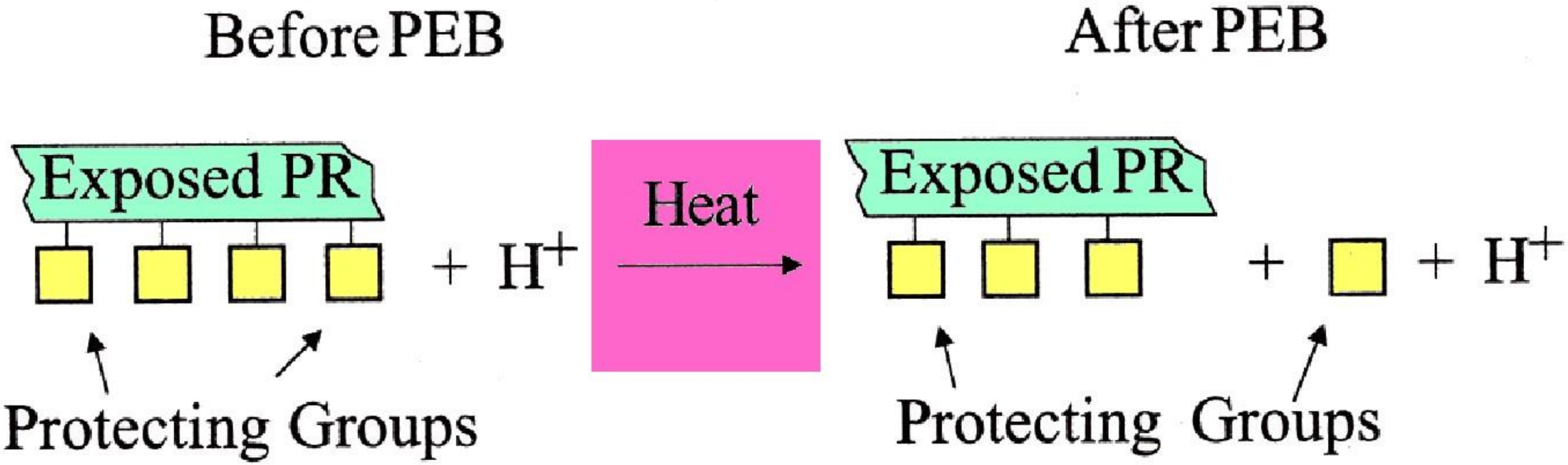


Fig 4: Chemically amplified photoresist

X-ray Lithography

X-ray Lithography

- Wavelength < 5 nm; Higher resolution
- No materials that can reflect or refract x-rays
- Must be accomplished by the direct printing process – similar to proximity printing

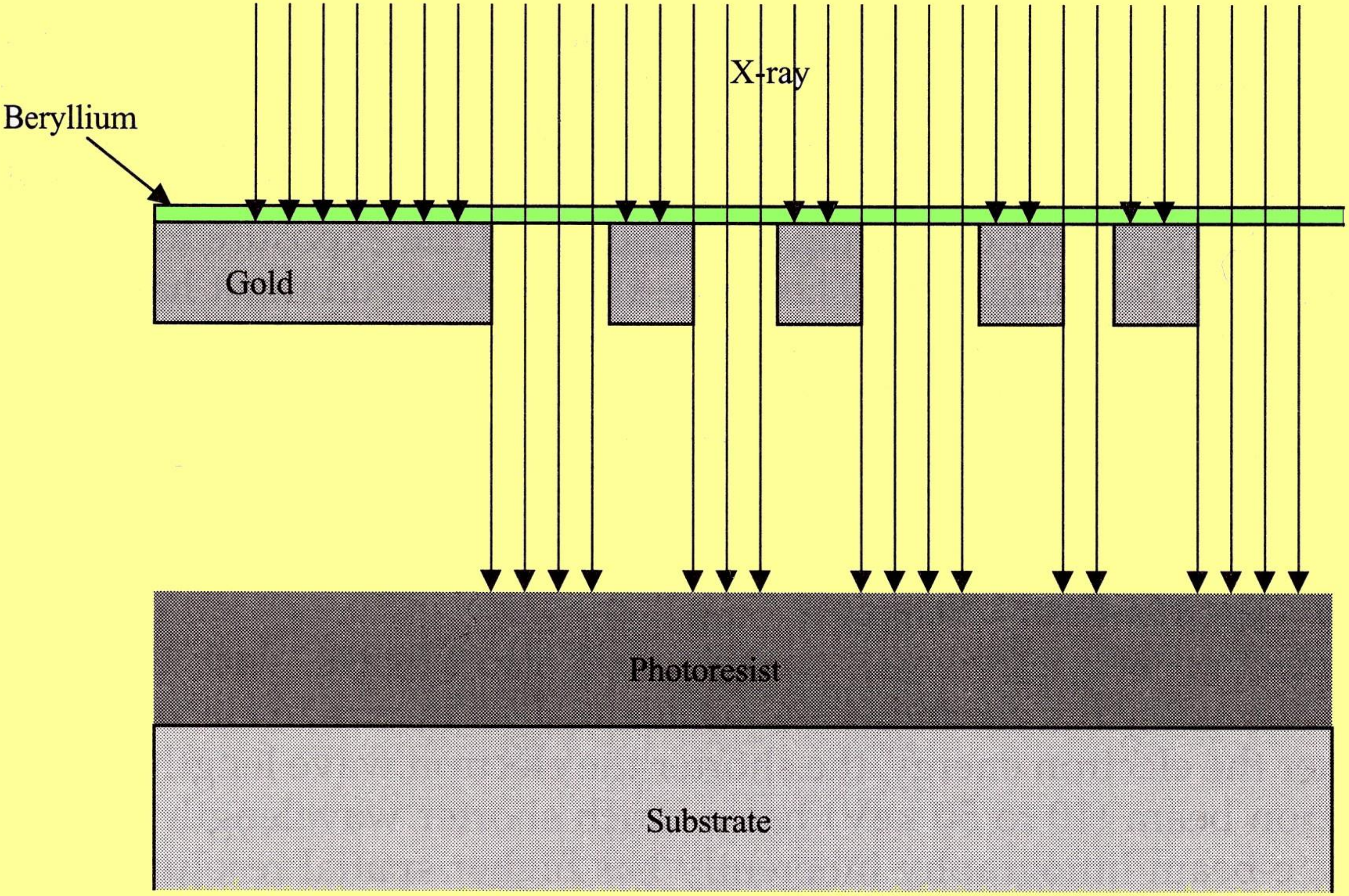


Fig 45: X-ray lithographic process

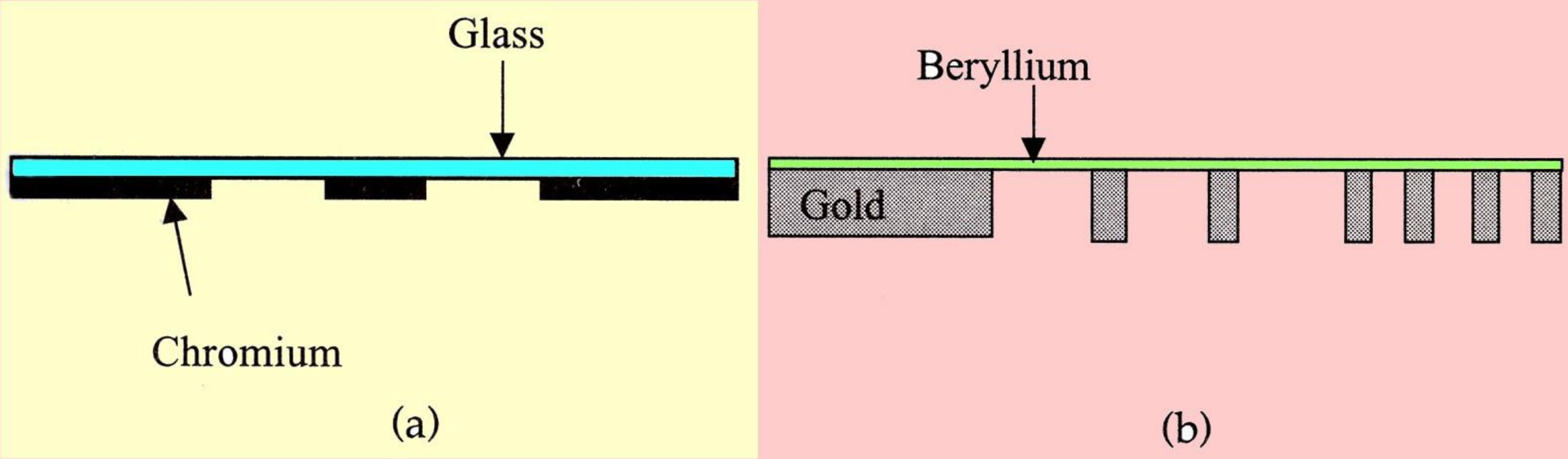


Fig 46 comparison of (a) the photo mask and (b) the X-ray mask

- Thin layers of chromium can block UV light
- Thick layer of gold is required to block X – rays. Therefore thickness to gap ratio changes.

Extreme Ultra Violet (EUV) radiation (11 – 14 nm) for sub-0.1 micron features

- No known material can be used to make lenses for EUV – strong absorption at short wave lengths
- Therefore EUV systems must be mirror-based
- Light sources still under development
- Material of masks – multilayer coatings such as Pd/C , Mo/Si

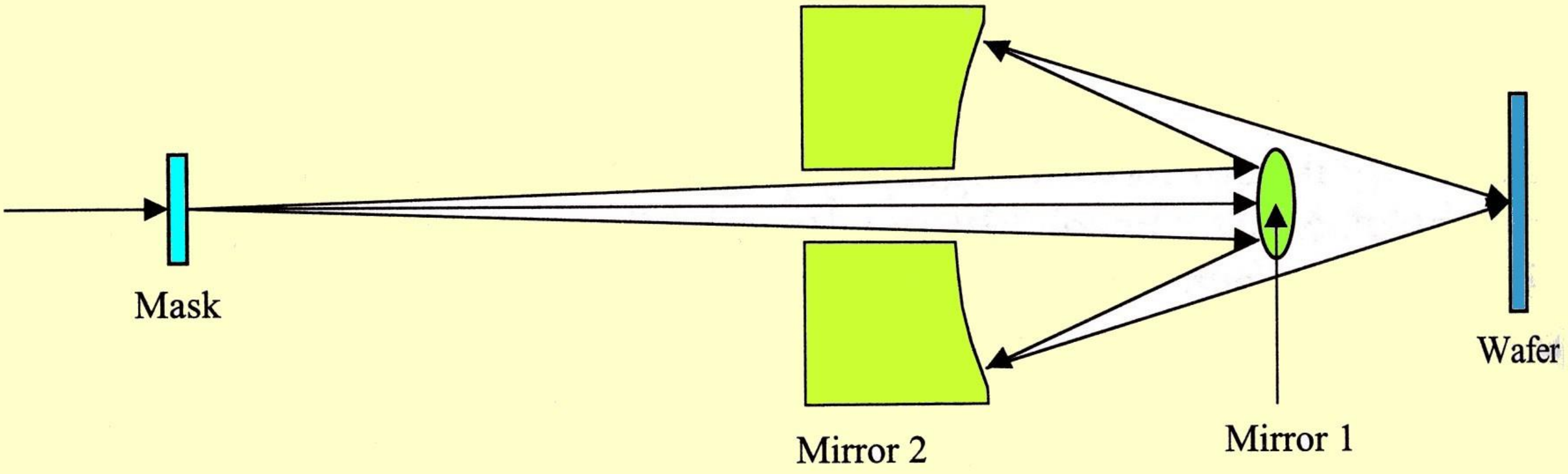


Fig 44: EUV lithography system

Ion-beam Lithography

Ion-Beam Lithography

- Similar to e-beam lithography – higher resolution
- Can be both – direct writing and projection resist exposing
- Advantage – direct ion implantation and ion-beam sputtering patterned etch
- Disadvantage – throughput is very low
- Application – mask/reticle repair

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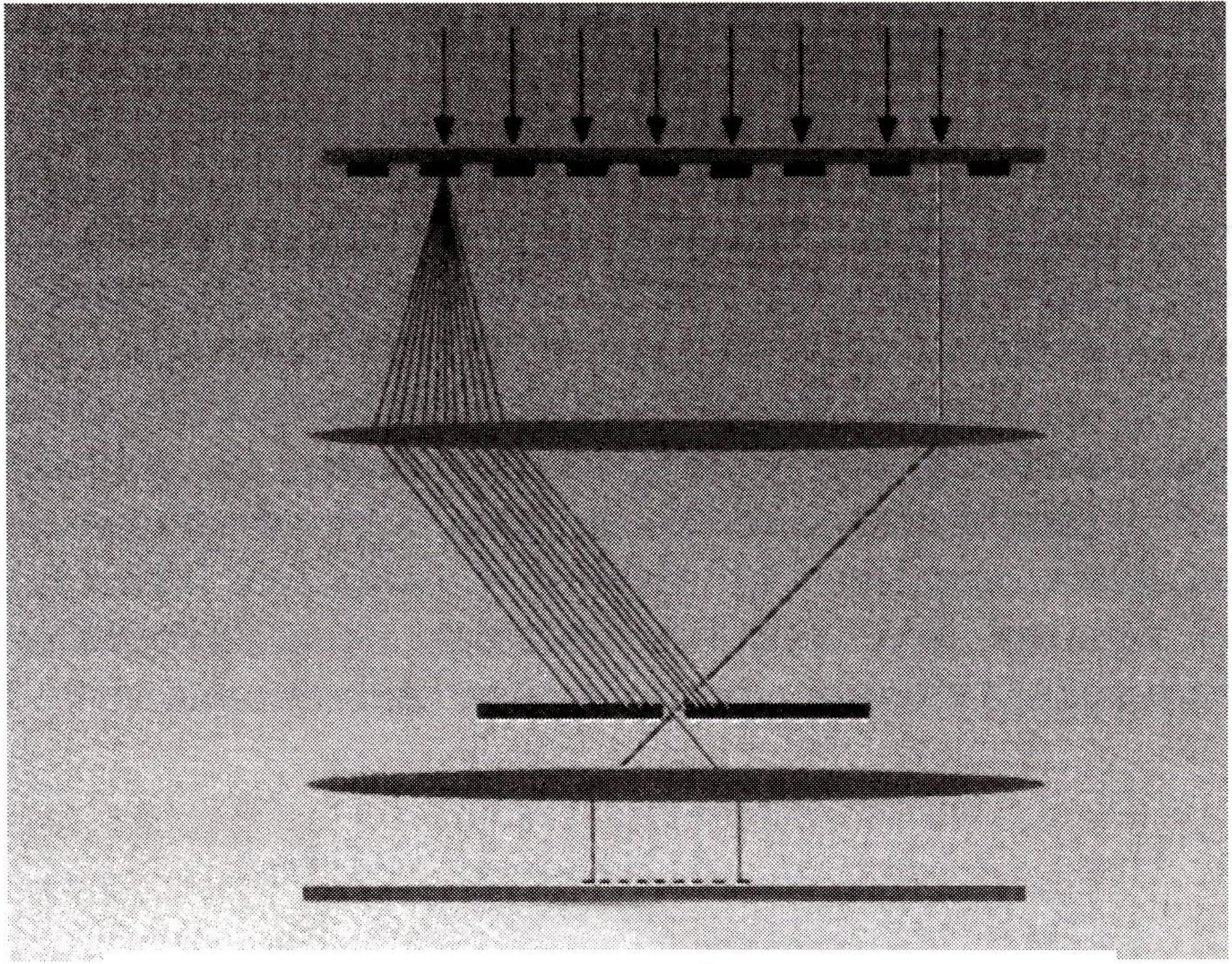

Fig 48: Schemetic of SCALPEL e-beam lithography

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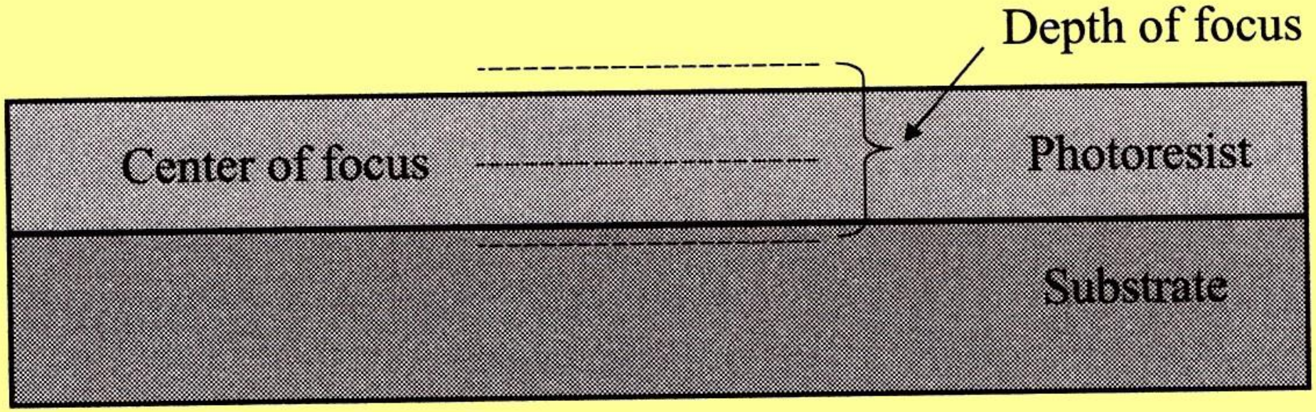


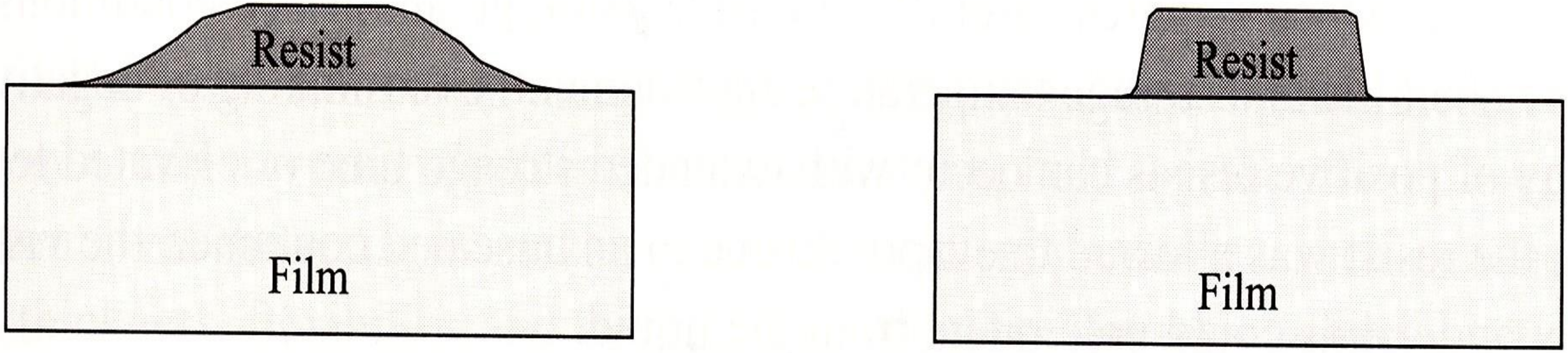
Fig 39: Focus the light on the midplane of the PR to optimize the resolution

Poor Resist Contrast

- Sloped walls
- Swelling
- Poor contrast

Good Resist Contrast

- Sharp walls
- No swelling
- Good contrast



Resist Contrast

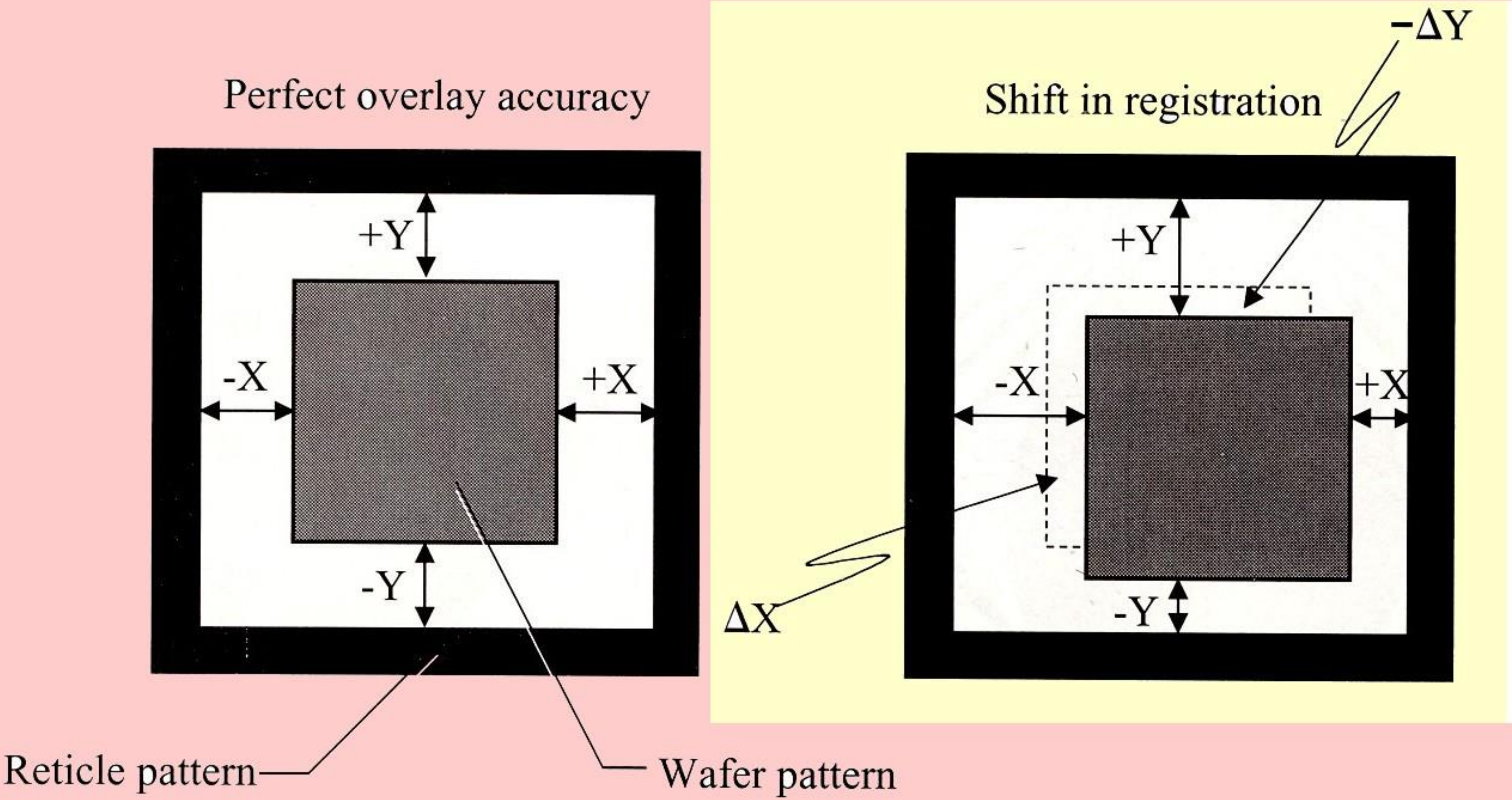
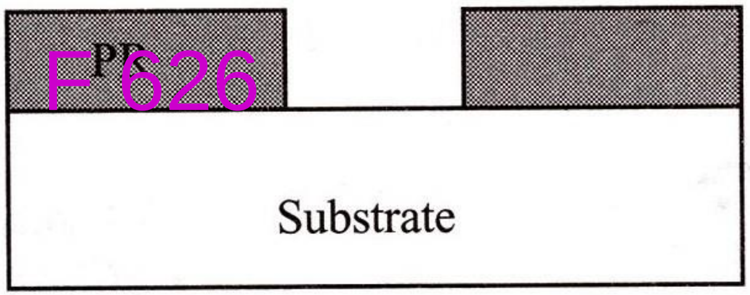
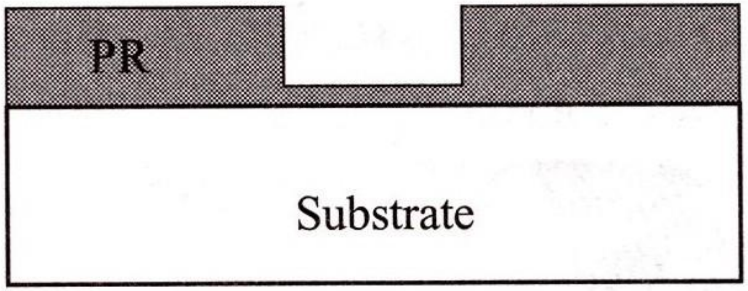


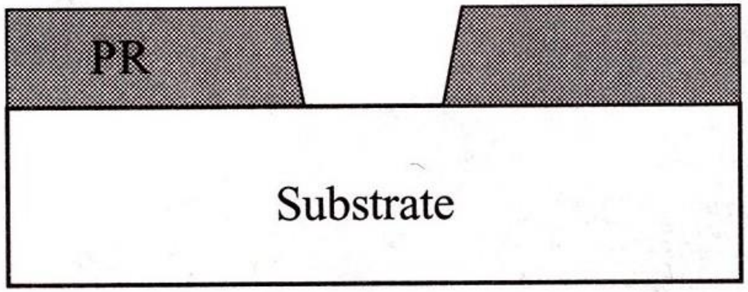
Fig q 1446: Overlay Budget

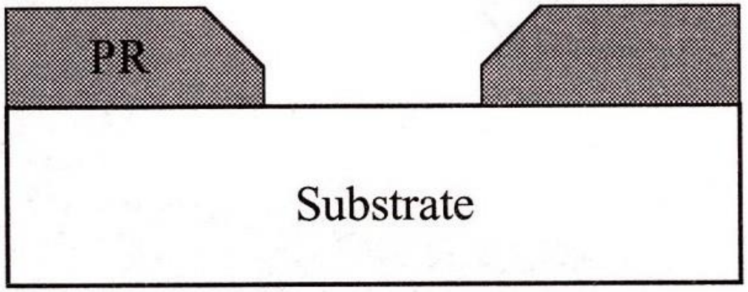




Normal development

Incomplete development





Under development

Over development

Fig 26: Photoresist profile for different developments

Thank You