520/530/580.495
Microfabrication Laboratory
and
520.773
Advanced Topics in
Fabrication and Microengineering

Lecture 4

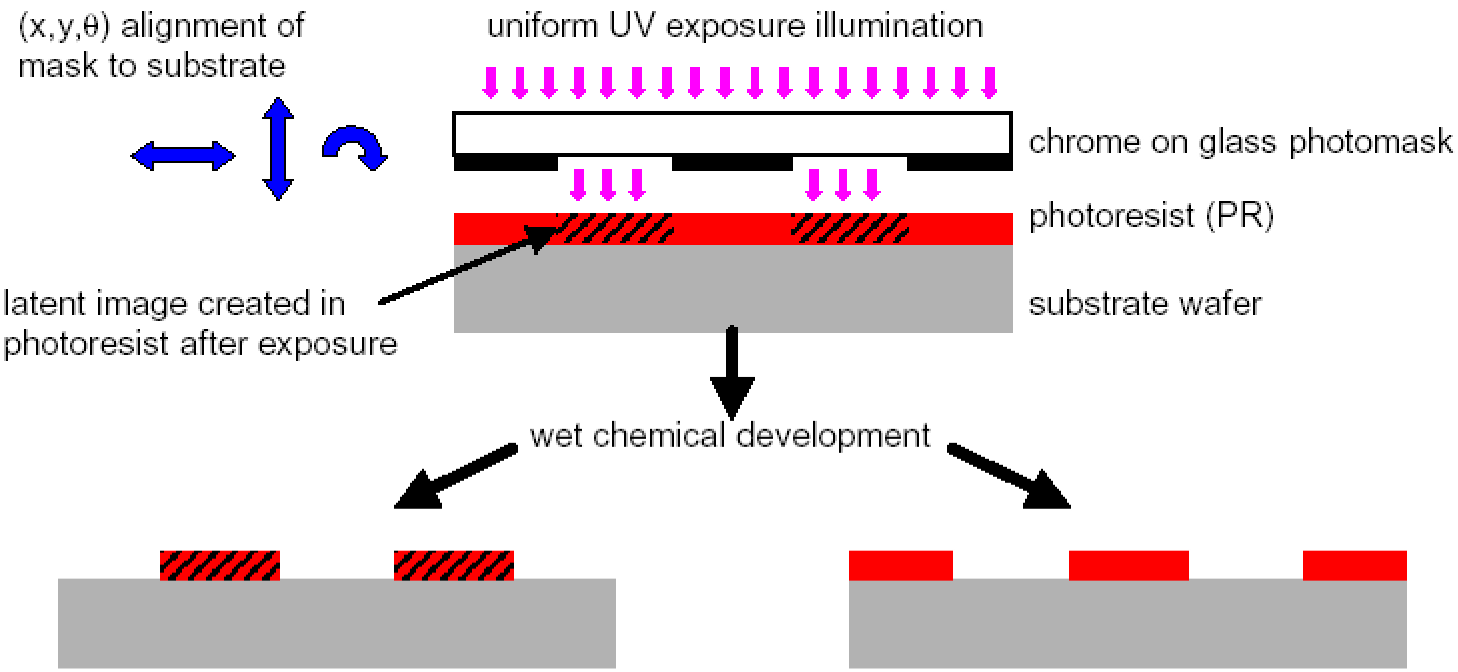
Photolithography (I)

Lecture Outline

Topics:

(1) Lithographic process
(2) Exposure tools

Photolithography



(x,y,θ) alignment of mask to substrate

uniform UV exposure illumination

chrome on glass photomask

photoresist (PR)

substrate wafer

latent image created in photoresist after exposure

wet chemical development

NEGATIVE PHOTORESIST
Photoresist is photopolymerized where exposed and rendered insoluble to the developer solution.

POSITIVE PHOTORESIST
Exposure decomposes a development inhibitor and developer solution only dissolves photoresist in the exposed areas.

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Pattern Transfer (I)

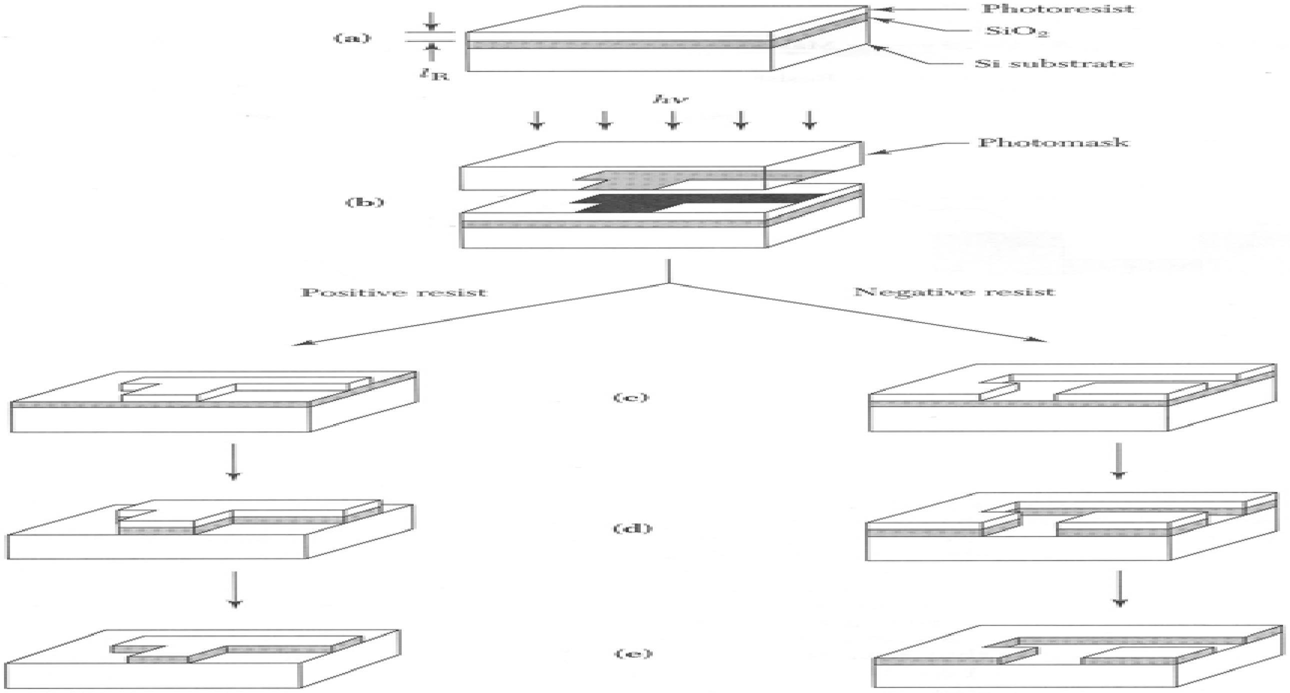


Figure 4.10 Details of the optical lithographic pattern transfer process.[5]

- The remaining image after pattern transfer can be used as a mask for subsequent process such as etching, ion implantation, and deposition

Pattern Transfer (II)

Liftoff Process

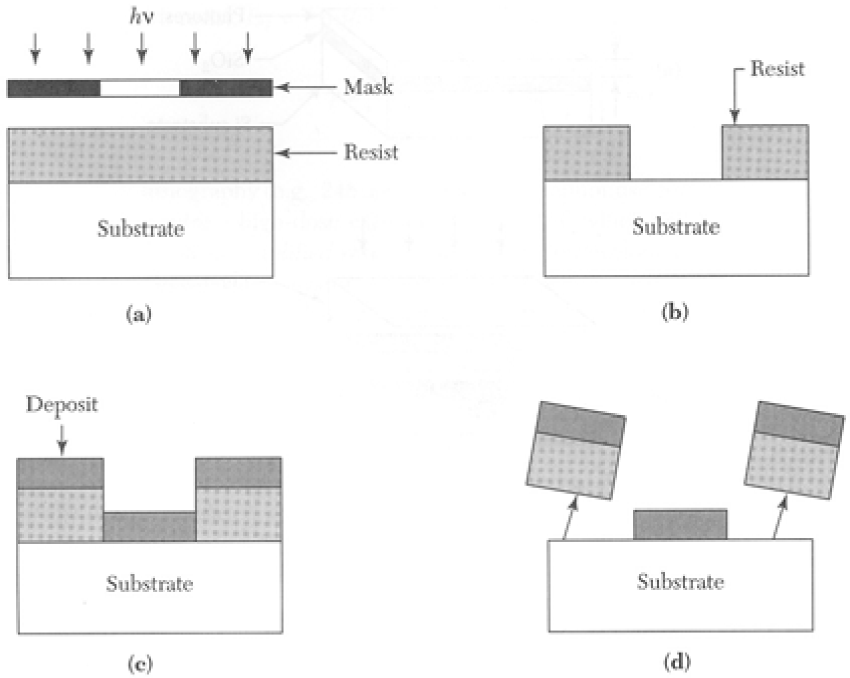


Figure 4.11 The liftoff process for pattern transfer.

- the film thickness must be smaller than that of the resist
- the potions of the film on the resist are removed by selectively dissolving the resist layer in an appropriate liquid enchant
- used extensively for high-power MOSFETs
- used for patterning the materials lacking a highly selective etchant.

Basic Steps

Clean wafer : to remove particles on the surface as well as any traces of organic, ionic, and metallic impurities

Dehydration bake: to drive off the absorbed water on the surface to promote the adhesion of PR

Coat wafer with adhesion promoting film (e.g., HMDS): (not always necessary)

Coat with PR:

Soft bake (or prebake): to drive off excess solvent and to promote adhesion

Exposure:

Post exposure bake (optional): to suppress standing wave-effect

Develop, clean, dry

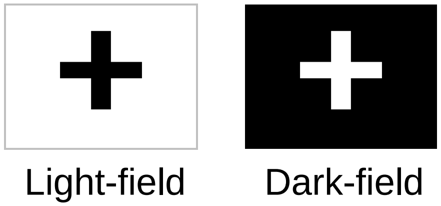
Hard bake: to harden the PR and improve adhesion to the substrate

Photomasks

- Types:
  - -photographic emulsion on soda lime glass (cheap)
  - -Fe_2O_3 on soda lime glass
  - -Cr on soda lime glass
  - -Cr on quartz glass (expensive)
  - -transparency film on glass (for large feature size >30µm , cheapest)

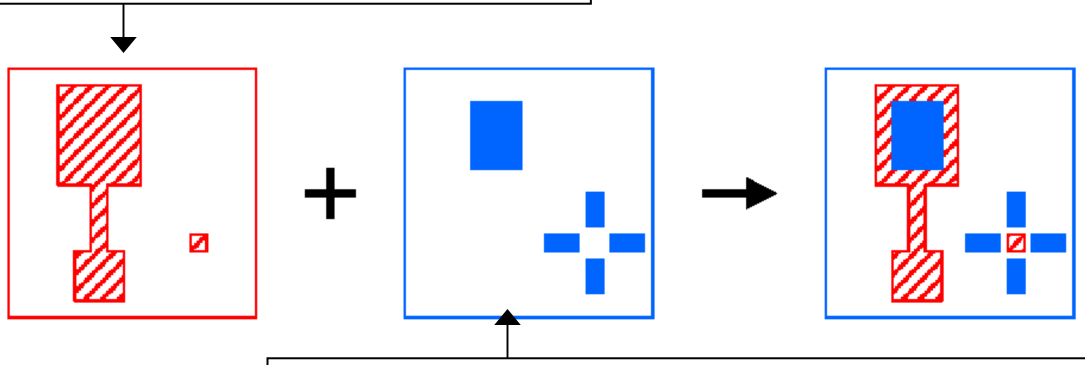
- Dimension:
  - -4” x 4” for 3-inch wafer
  - -5” x 5” for 4-inch wafer

- Polarity
  - -“light-field” = mostly clear, drawn feature = opaque
  - -“dark-field” = mostly opaque, drawn feature = clear



Mask to Wafer Alignment (I)

- 3 degrees of freedom between mask and wafer: (x,y,q)
- Use alignment marks on mask and wafer to register patterns prior to exposure.
- Modern process lines (steppers) use automatic pattern recognition and alignment systems.
  - Usually takes 1-5 seconds to align and expose on a modern stepper.
  - Human operators usually take 30-45 seconds with well-designed alignment marks.



alignment mark on wafer
Created from the prior processing step

Alignment mark on mask, open window in chrome through which mark on wafer can be seen

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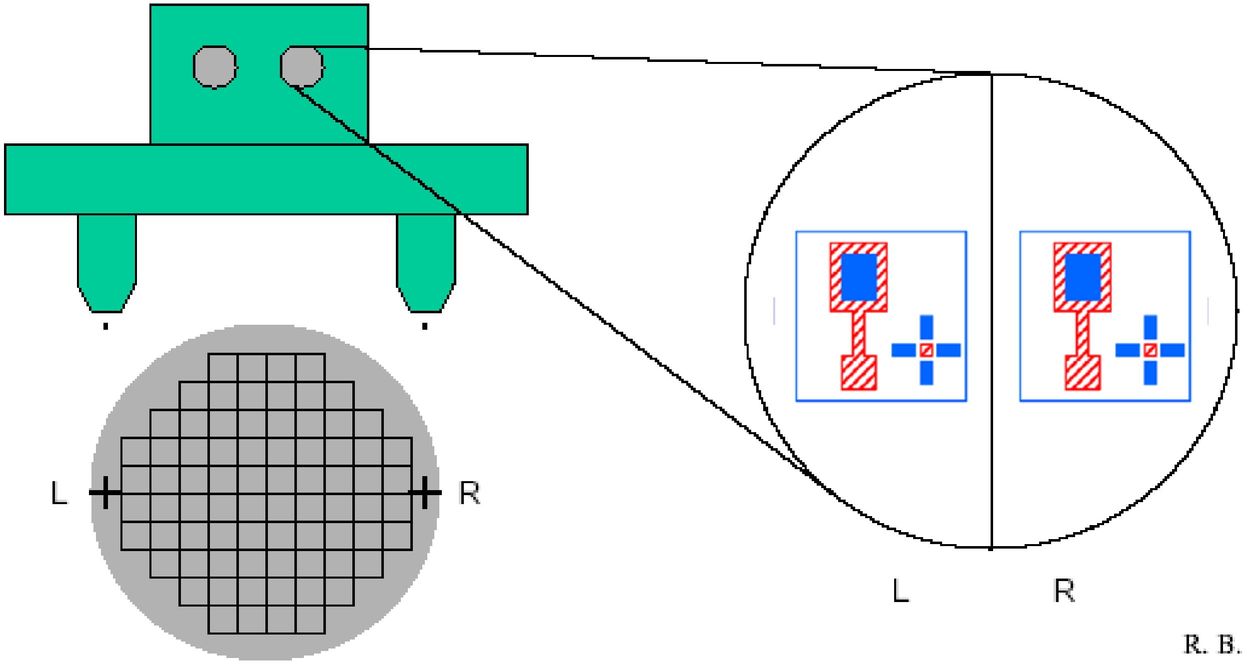
Mask to Wafer Alignment (II)

- Normally requires at least two alignment mark sets on opposite sides of wafer or stepped region

- Use a split-field microscope to make alignment easier



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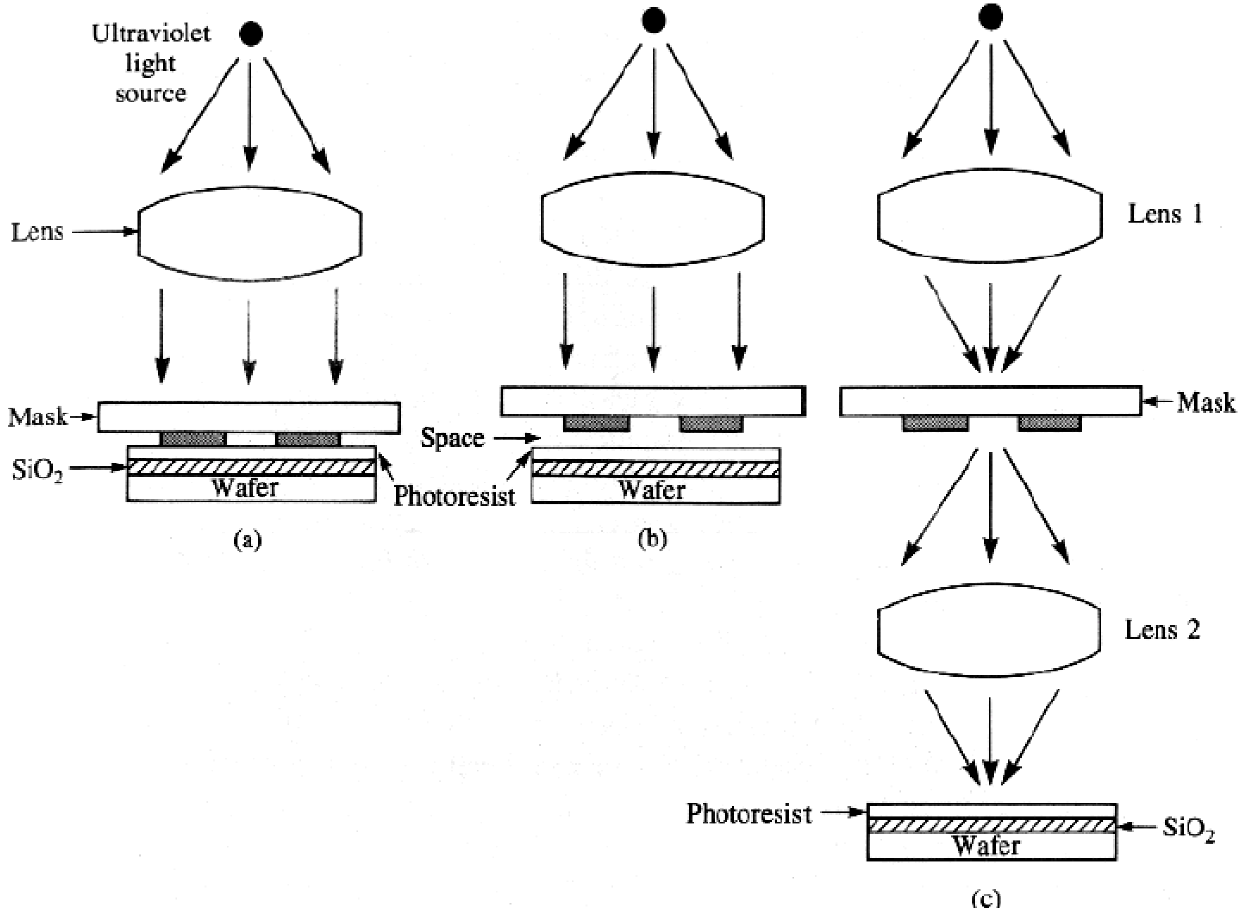
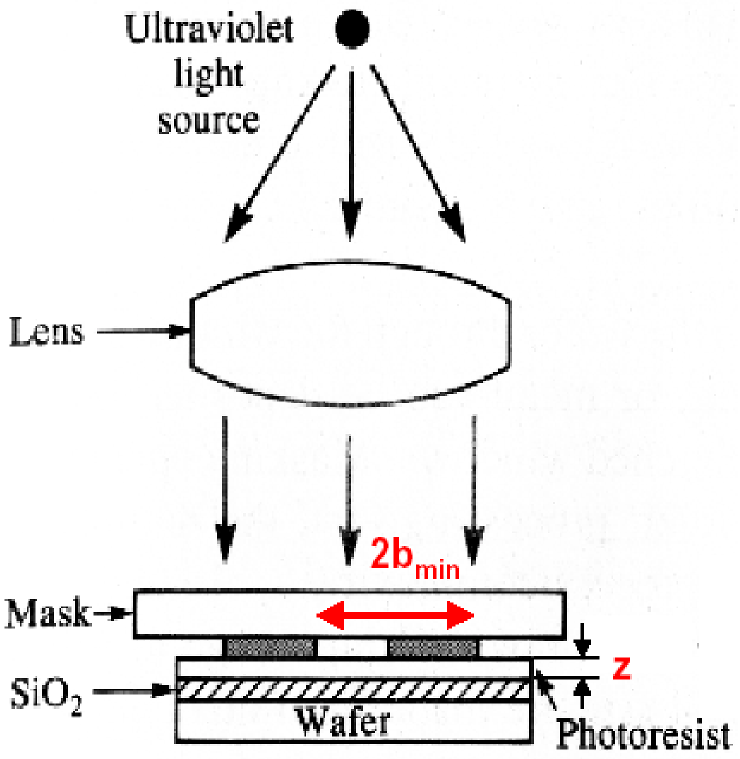
Printing (Exposure) Techniques

Contact Proximity Projection



Contact Printing



Min Line/Gap Period ($2 \cdot b_{min}$)

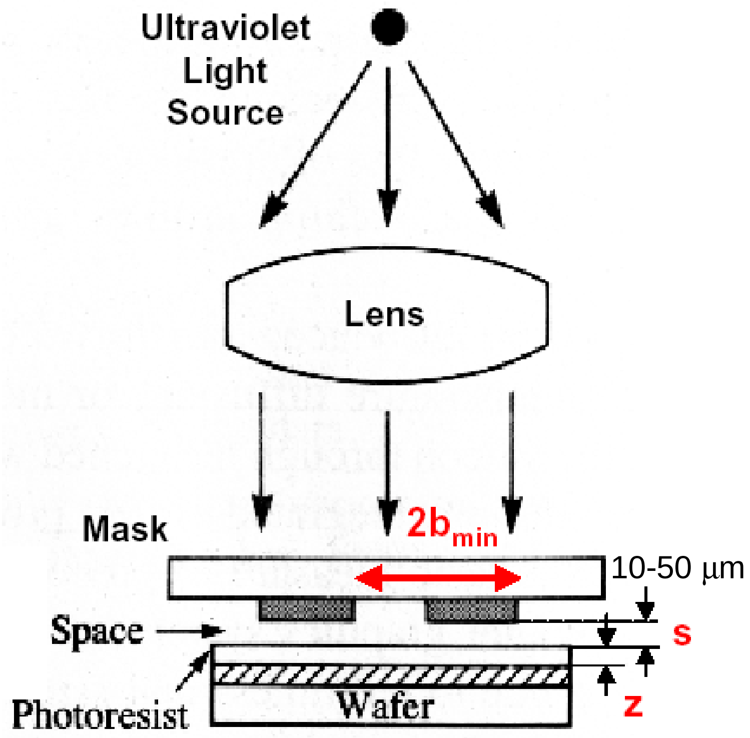
$$\boxed{2 \cdot b_{\min} = 3\sqrt{\lambda \cdot \frac{z}{2}}}$$

Resolution is primarily limited by light scattering in the resist

- Advantages:
  - not complex
  - inexpensive
  - fast : wafer exposed at once
  - diffraction effect is minimized as the gap between mask and wafer goes to zero

- Disadvantages:
  - mask wear and defect generation due to contamination
  - mask usually the same size as the wafer, large and expensive

Proximity Printing



Min Line/Gap Period ($2 \cdot b_{min}$)

$$2 \cdot b_{\min} = 3\sqrt{\lambda(s + \frac{z}{2})}$$

- Advantages:

-mask does not contact wafer

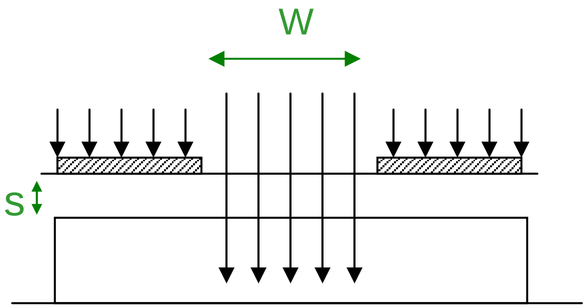
  - no mask wear or contamination

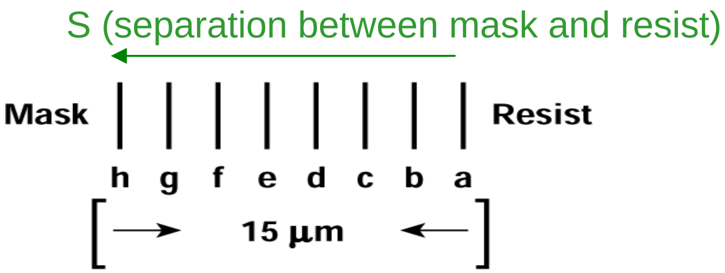
- fast : wafer exposed at once

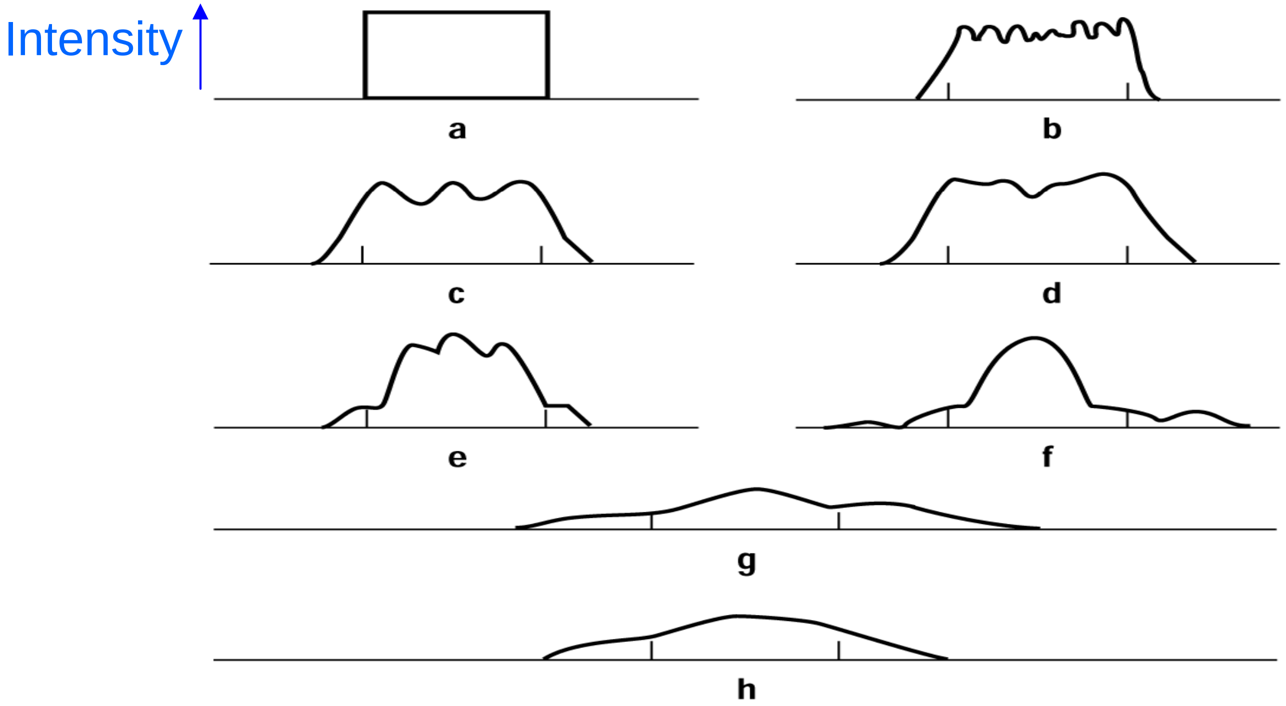
- Disadvantages:

- mask separated from wafer
  greater diffraction leads to less resolution
- mask usually the same size as the wafer,
  large and expensive

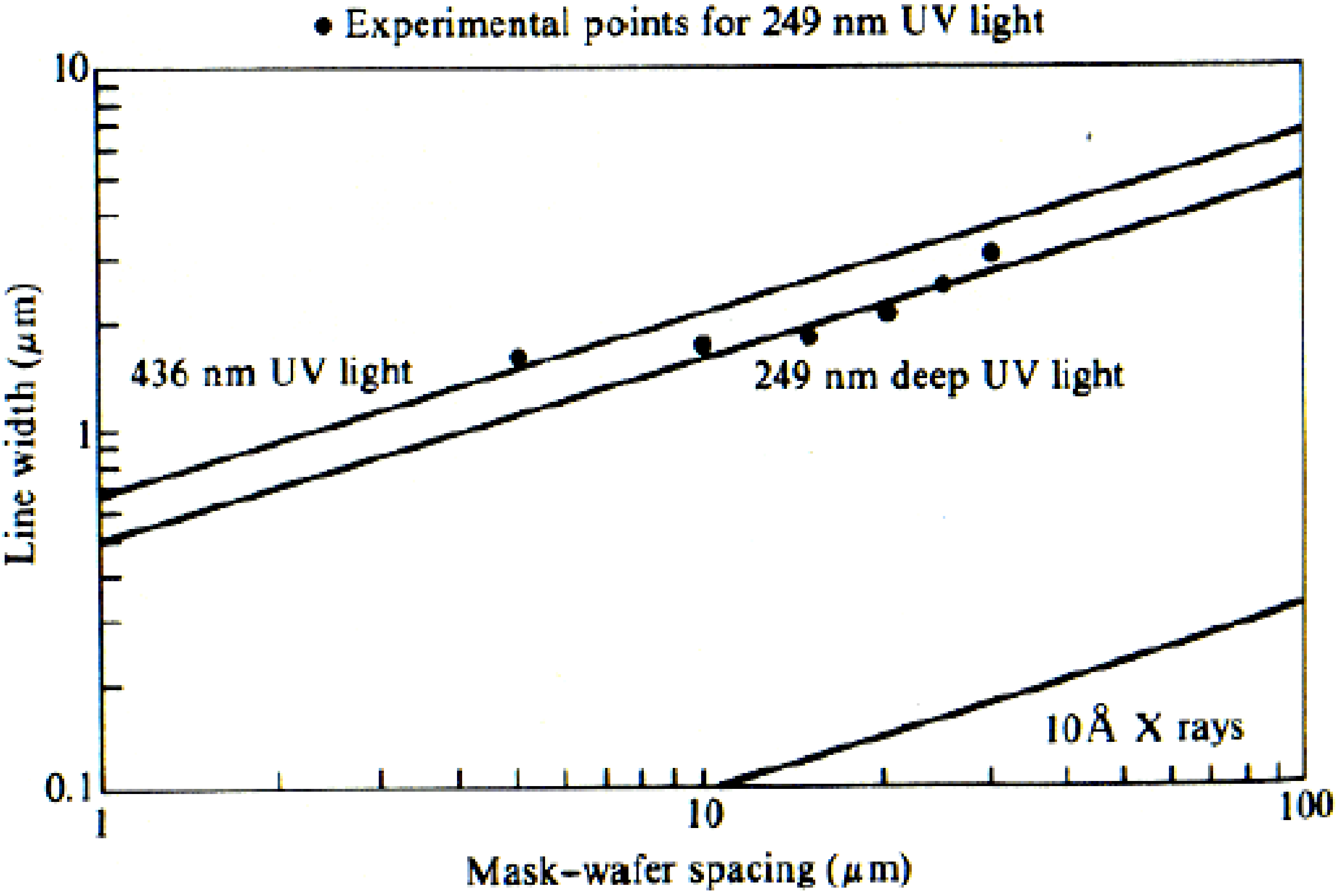
Diffraction Effect in Proximity Printing







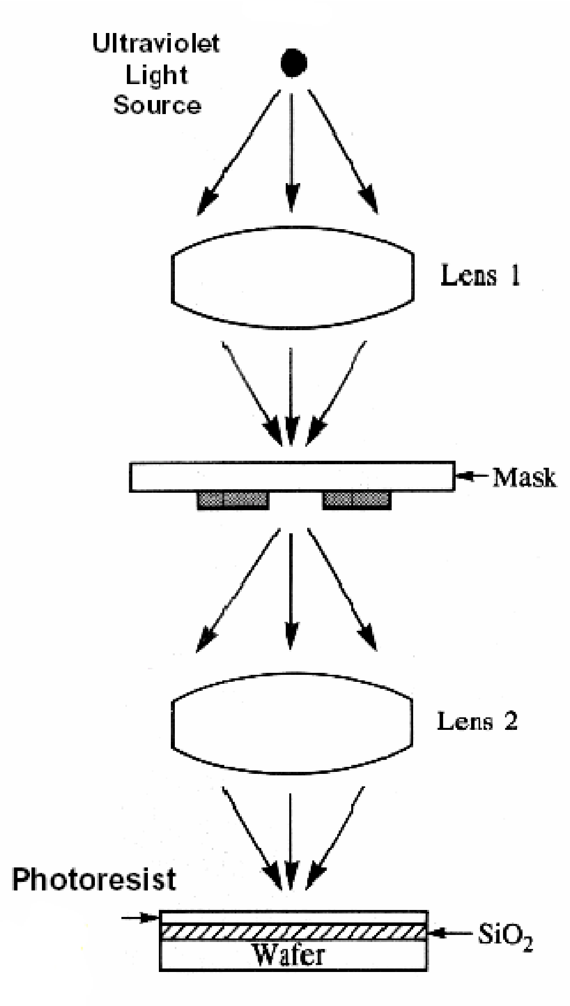
Resolution Limit : Proximity Printing

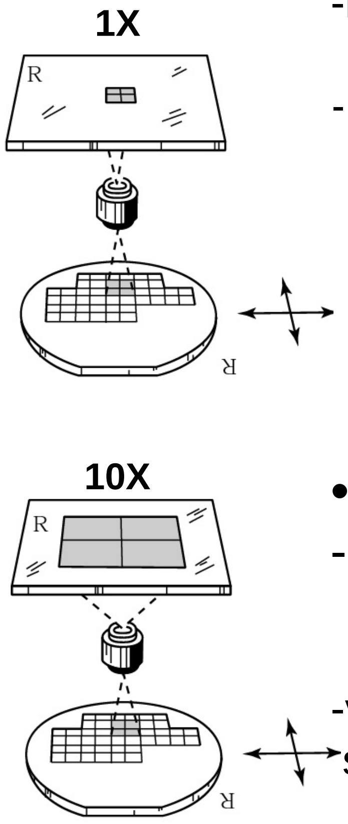


Min line/gap period ($2b_{min}$)

$$\boxed{2 \cdot b_{\min} = 3\sqrt{\lambda\left(s + \frac{z}{2}\right)}}$$

Projection Printing





(c)

- Advantages:

-mask does not contact wafer

  - no mask wear or contamination

- de-magnification : 1X to 10 X

  - easier to make defect-free mask at larger de-magnification
  - tolerate greater temperature difference (mask and wafer)

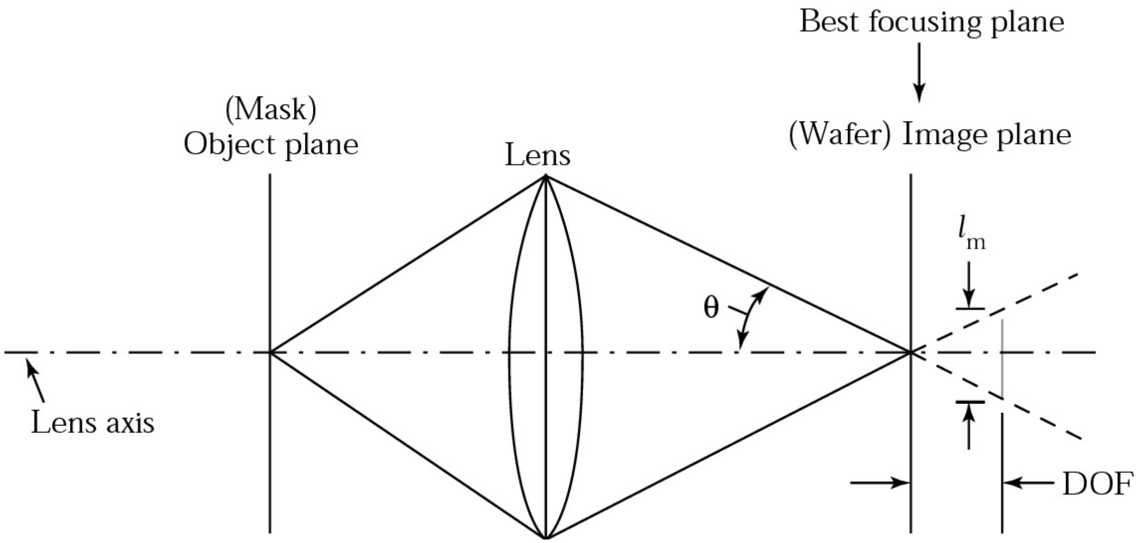
- Disadvantages:

- it takes longer time to exposure entire wafer each die need to be exposed separately due to high de-magnification

-very complex and expensive, requires precision stepper motor

- Mask damage problem is avoided
- To increase resolution, only a small portion of the wafer is exposed at a time

Projection: Resolution and Depth-of-Focus (DOF)



Resolution $l_m = k_1 \frac{\lambda}{NA}$

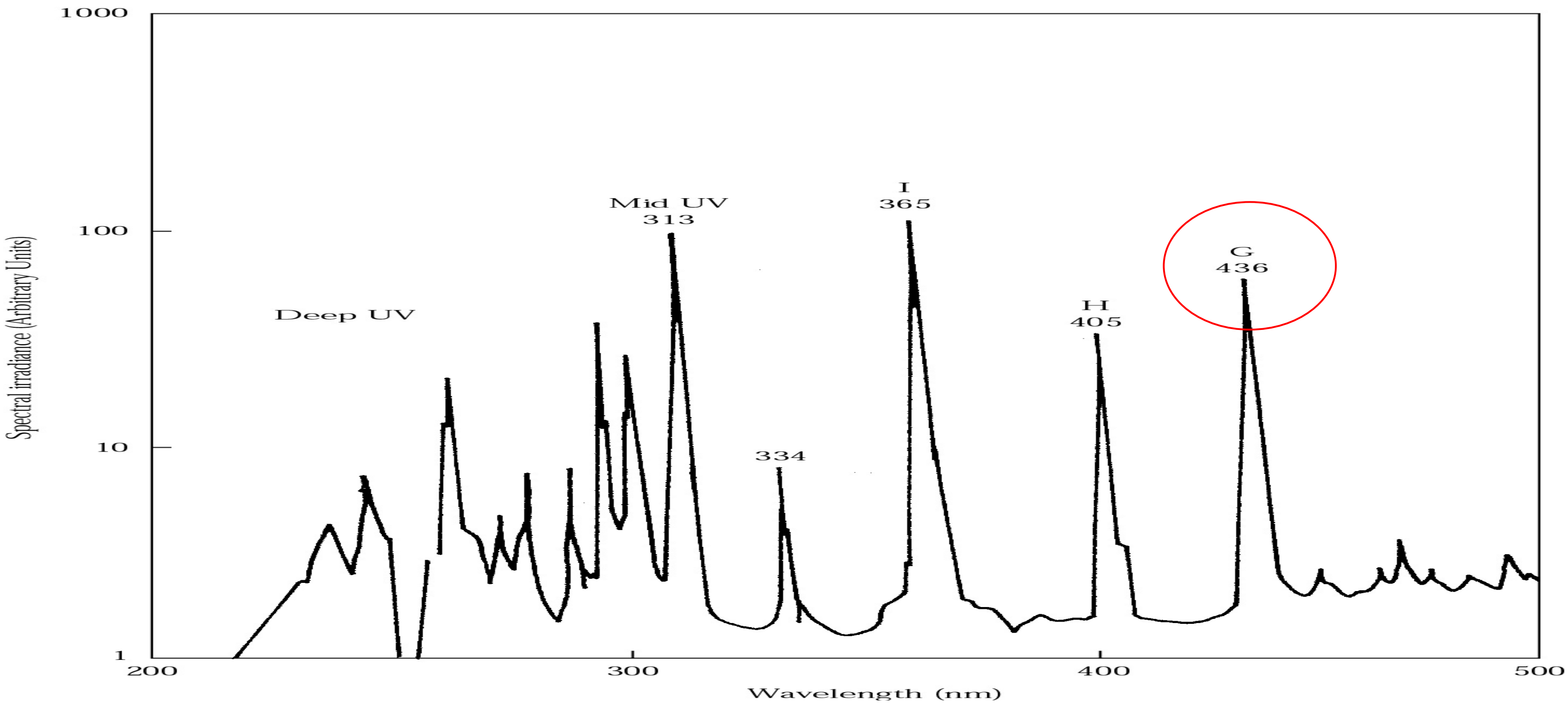
λ: the exposure wavelength
k_1: a process-dependent factor
NA: numerical aperture
NA= n sinθ, n=1 for air; θ : half-angle of the cone of light

$$\mathrm{DOF} = \frac{\pm l_m / 2}{\tan\theta} \approx \frac{\pm l_m / 2}{\sin\theta} = k_2 \frac{\lambda}{(NA)^2}$$

Tradeoff between Resolution and DOF

Light Sources

Mercury Lamp



Excimer laser source

Material	Wavelemngth	Max. Output (mJ/pulse)	Frequency (pulse/sec)
F2	157	40	500
ArF	193	10	2000
KrF	248	10	2000