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

Lecture 4

Photolithography (I)

Lecture Outline

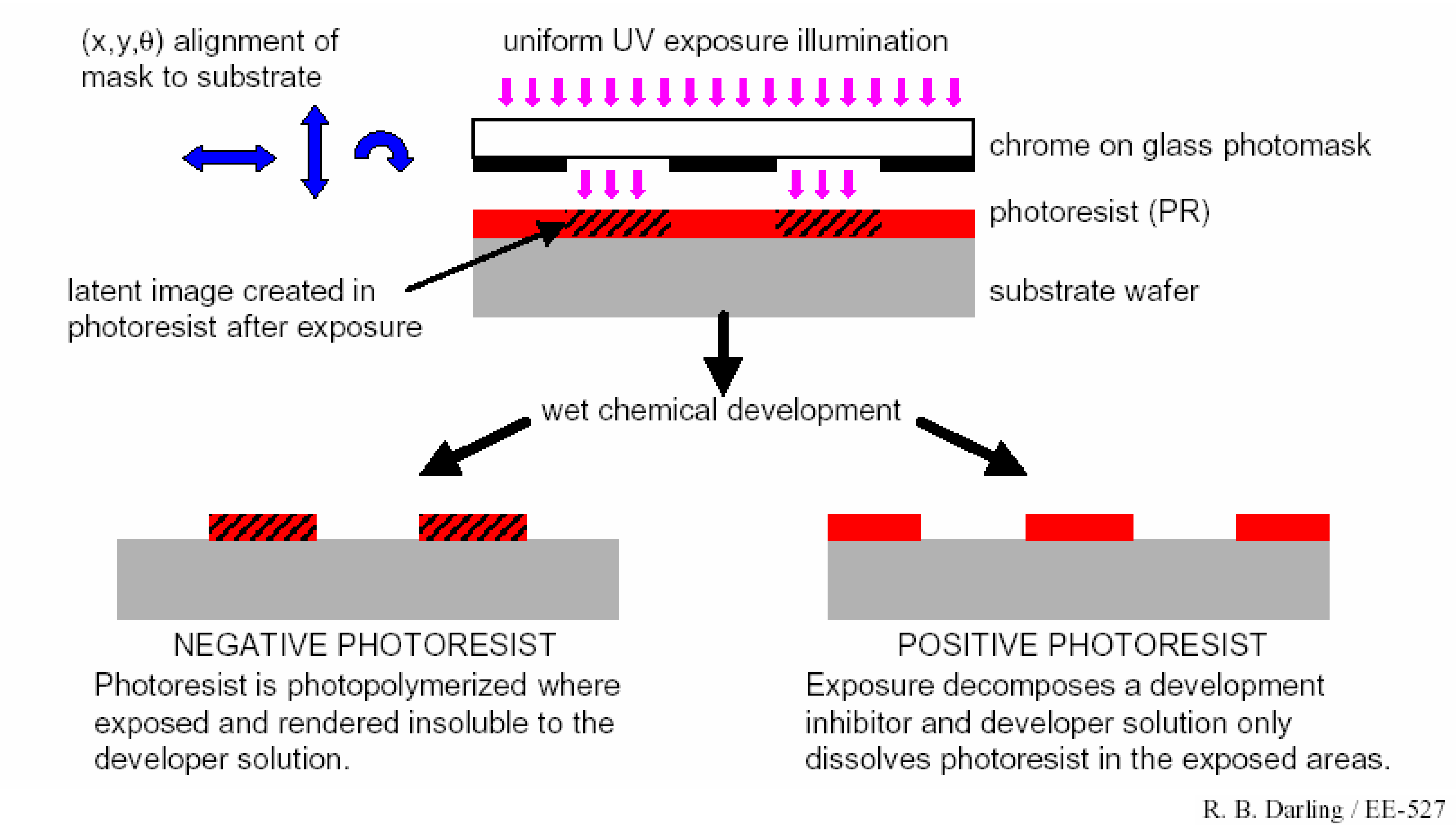
Reading for this lecture:
(1) May, Chapter 4.1
(2)Jaeger, Chapter 2

Topics:
(1) Lithographic process
(2) Exposure tools

HW #2 : Due Oct. 2

Office Hour : 11-12 Wed.

Photolithography



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:

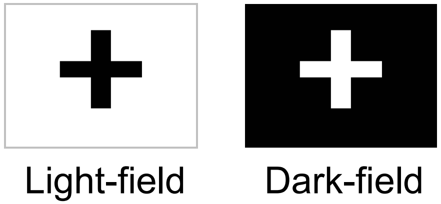
-4” x 4” for 3-inch wafer

-5” x 5” for 4-inch wafer

•Polarity

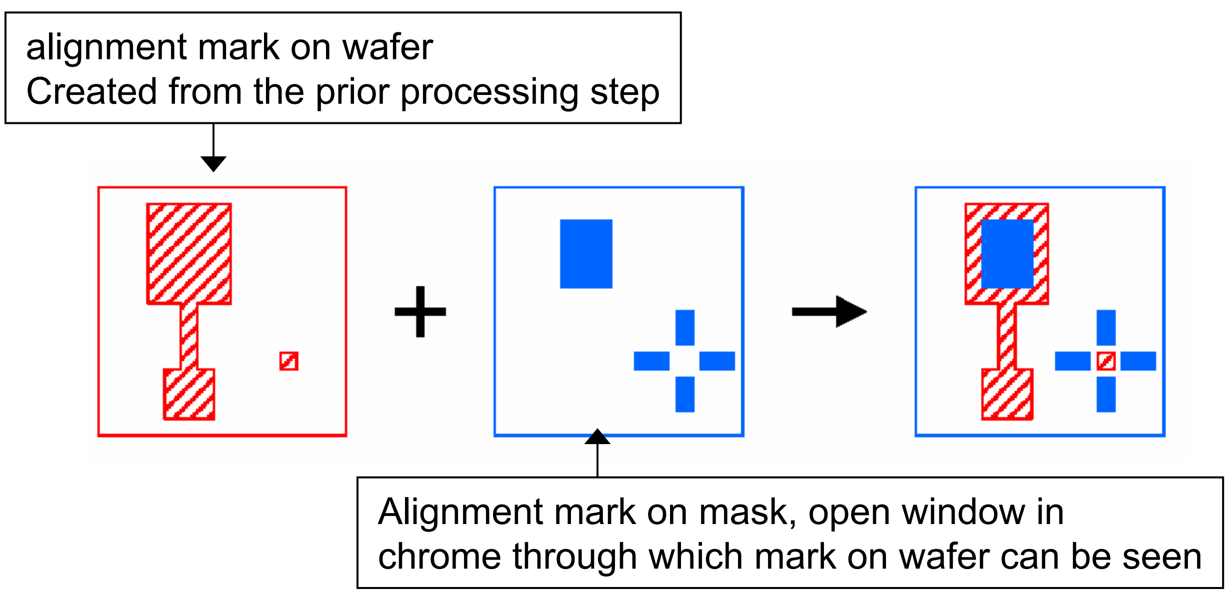
-“light-field” = mostly clear, drawn feature = opaque

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



Mask to Wafer Alignment (I)

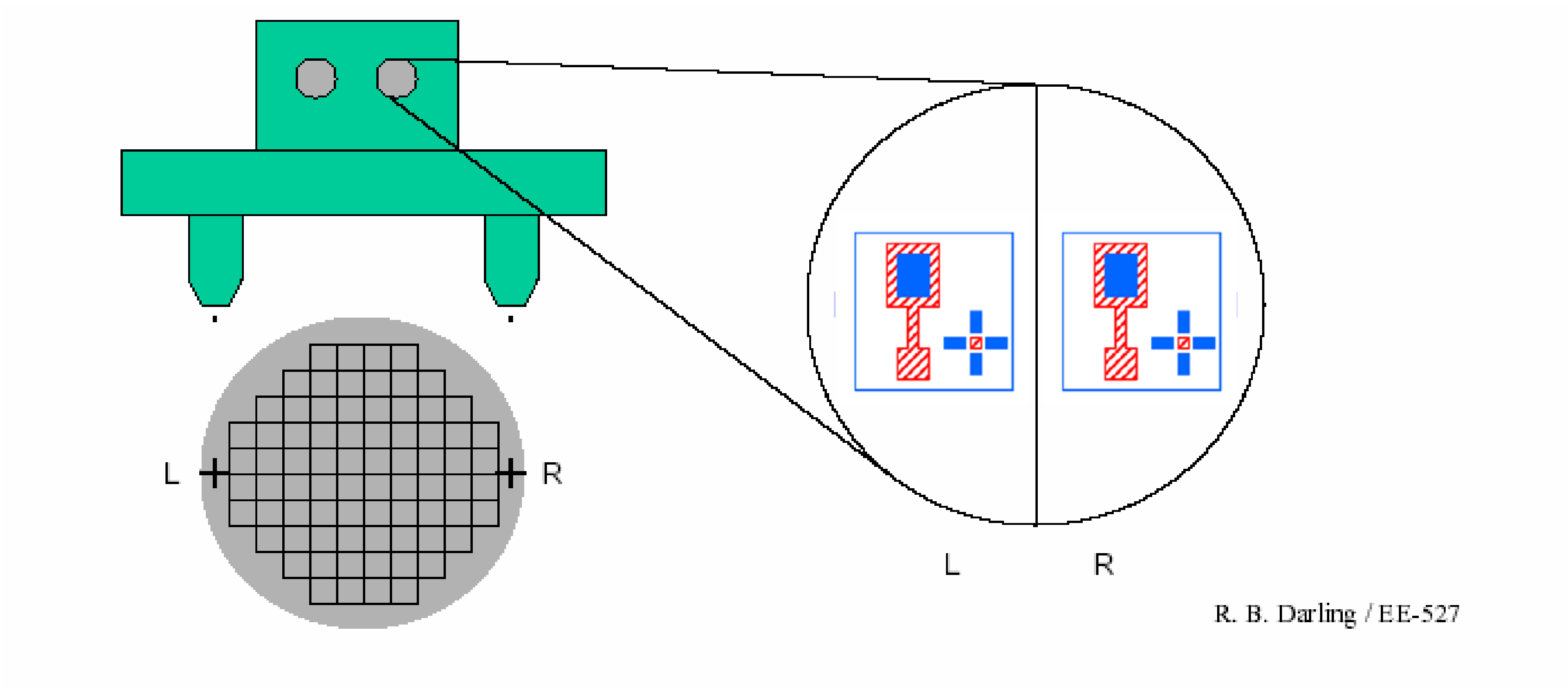
– 3 degrees of freedom between mask and wafer: (x,y,q)
– Use alignment marks on mask and wafer to register patterns prior to exposure.
– Modern process lines (steppers) use automatic pattern recognition and alignment systems.
  - Usually takes 1-5 seconds to align and expose on a modern stepper.
  -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



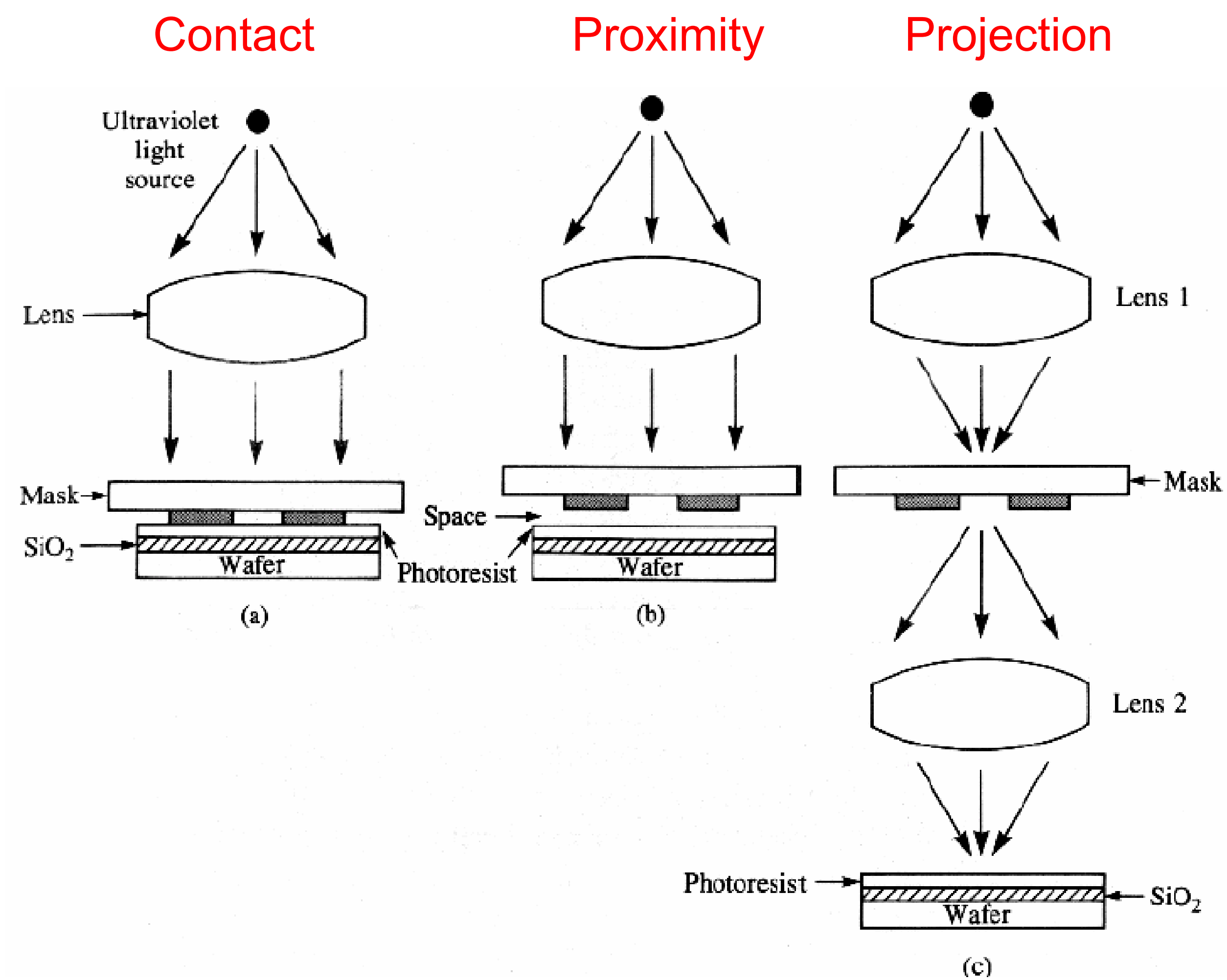
Mask to Wafer Alignment (II)

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

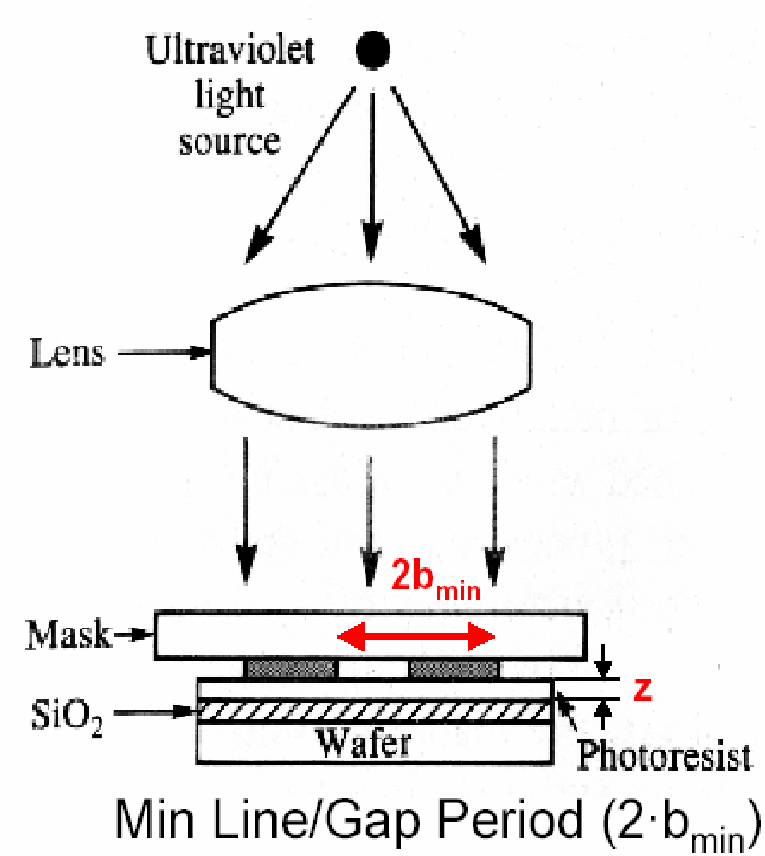
- Use a split-field microscope to make alignment easier



Printing (Exposure) Techniques



Contact Printing

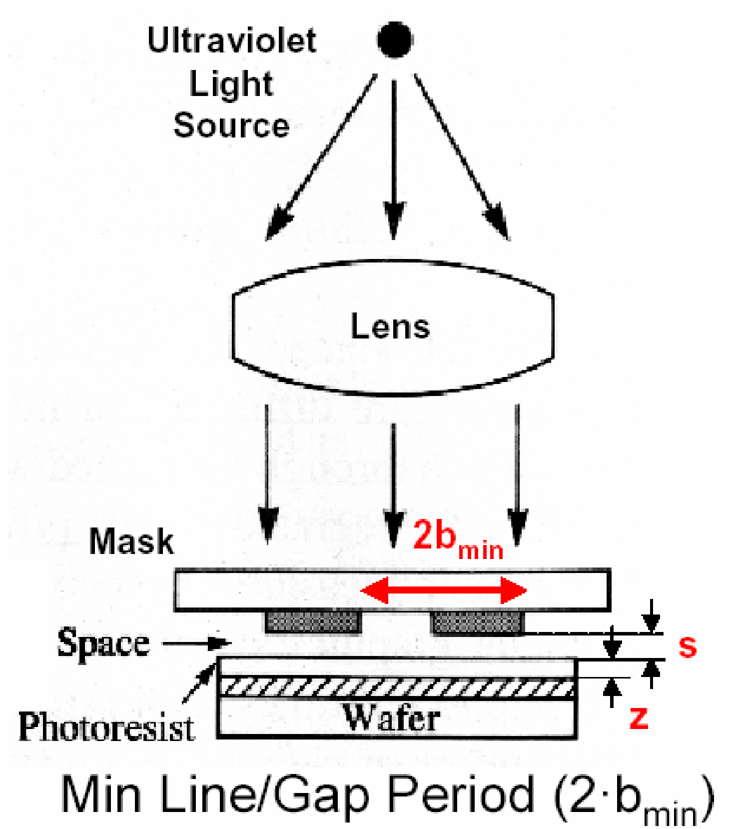


- Advantages:
  - not complex
  - inexpensive
  - fast : wafer exposed at once
  - diffraction effect is minimized as the gap between mask and wafer goes to zero
- Disadvantages:
  - mask wear and defect generation due to contamination
  - mask usually the same size as the wafer, large and expensive

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

Resolution is primarily limited by light scattering in the resist

Proximity Printing



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

- Advantages:

-mask does not contact wafer

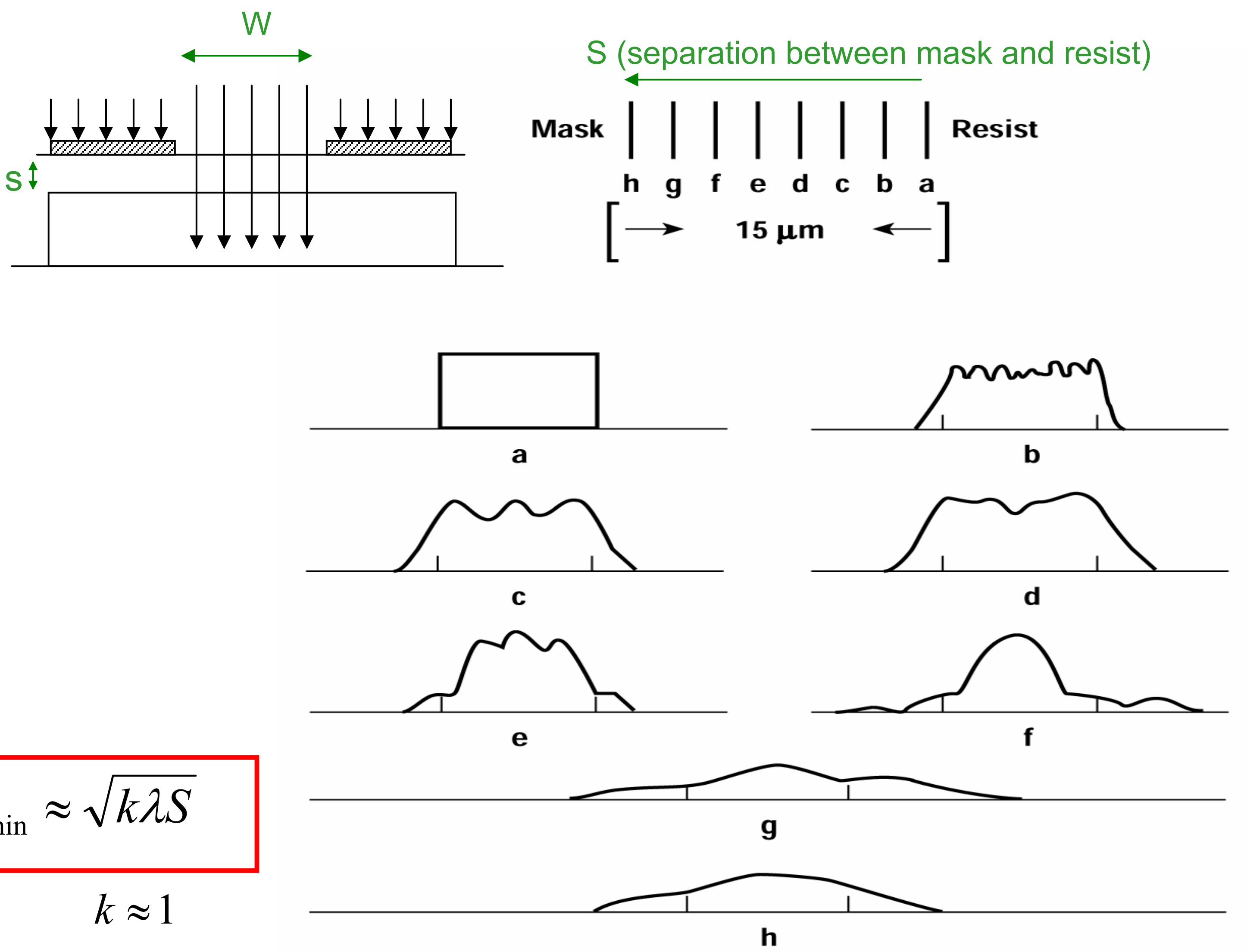
  - no mask wear or contamination

- 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

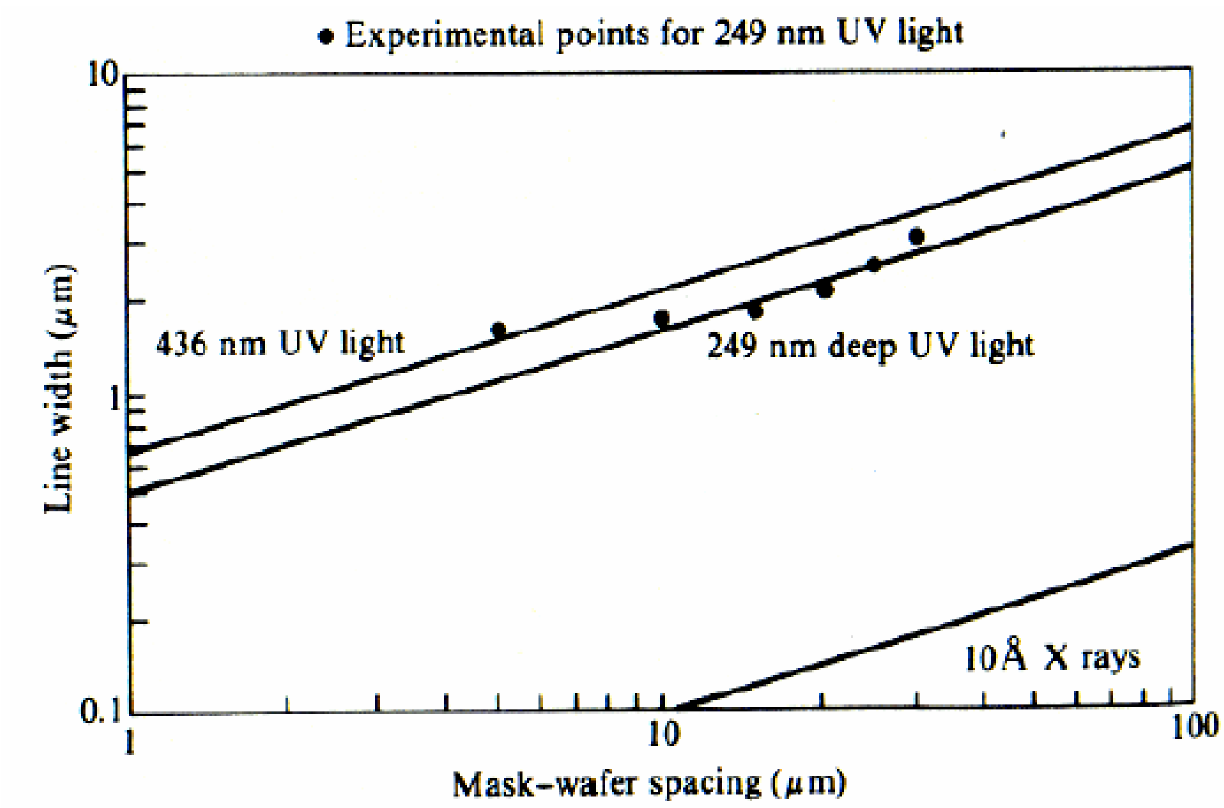
Diffraction Effect in Proximity Printing



$$W_{\min} \approx \sqrt{k\lambda S}$$

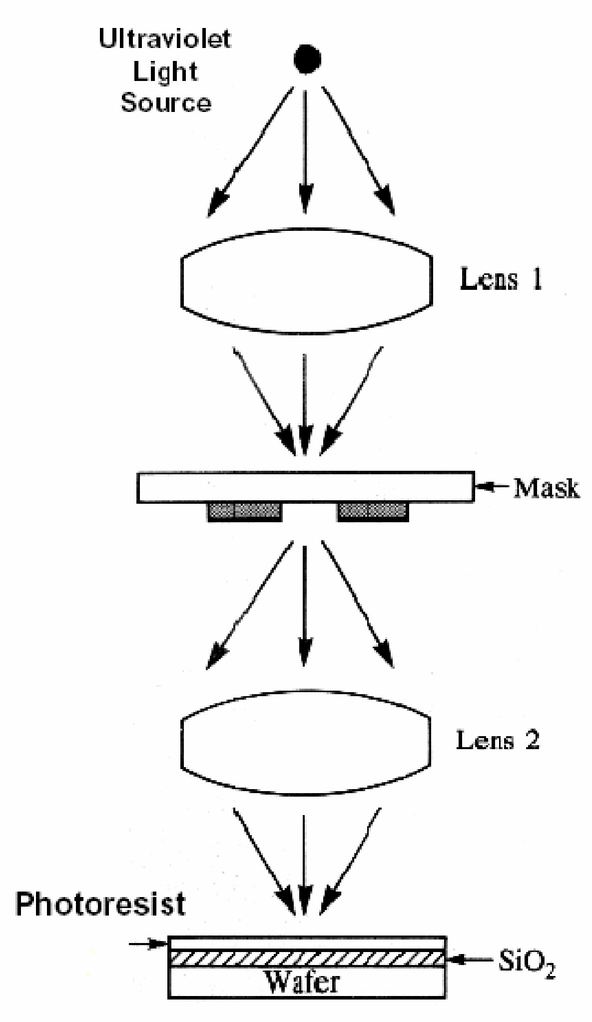
$$k \approx 1$$

Resolution Limit : Proximity Printing



Min line/gap period ($2b_{min}$) $$2 \cdot b_{\min} = 3\sqrt{\lambda(s + \frac{z}{2})}$$

Projection Printing



• 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)

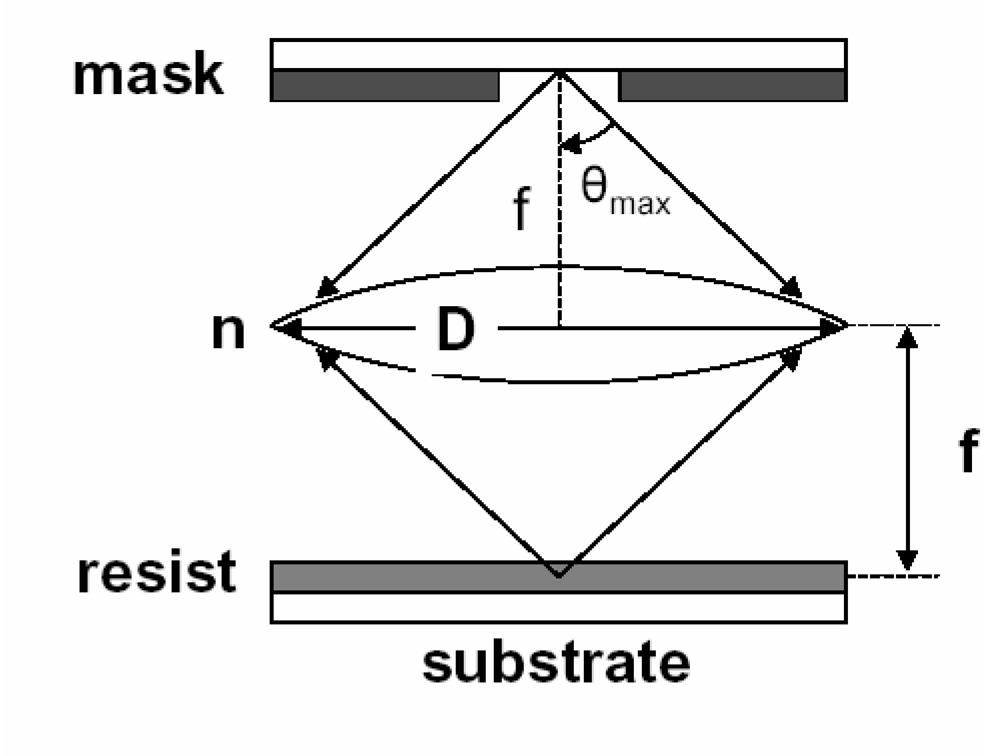
• Disadvantages:

- 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

Projection Optics Basics

Numerical Aperture (NA)



$$NA = n \cdot \sin(\theta_{max})$$

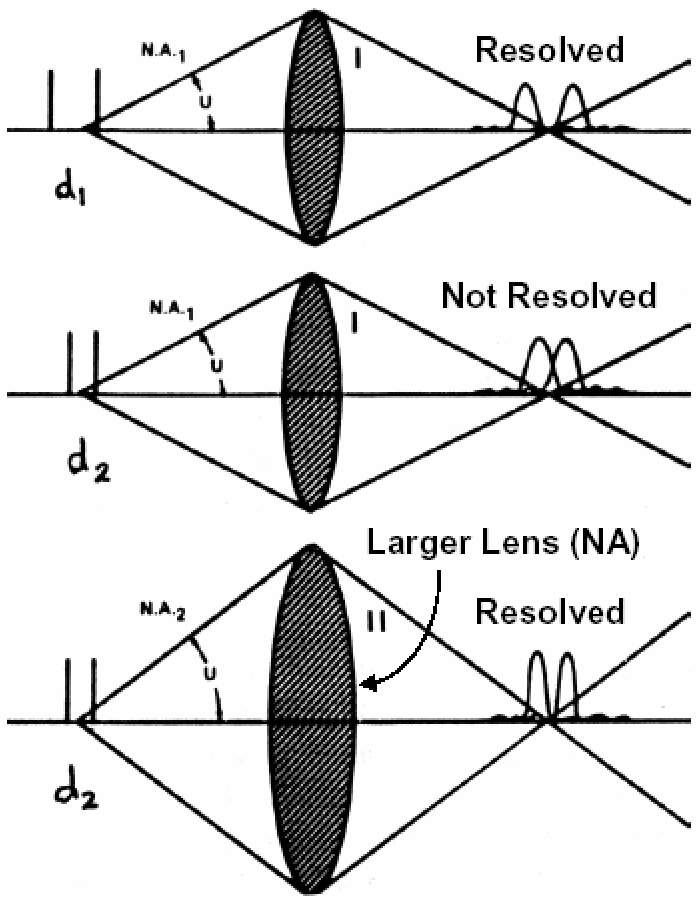
$$\frac{NA}{n} = \frac{\frac{D}{2}}{\sqrt{\left(\frac{D}{2}\right)^2 + f^2}}$$

$$F = \frac{1}{2 \cdot NA} = (1 + M) \cdot f$$

n = index of refraction
M = magnification
f = focal distance
F = F-Number
D = lens diameter

•Measure of the light collection angle of a lens or optical system

Resolution Limitation : Projection Printing

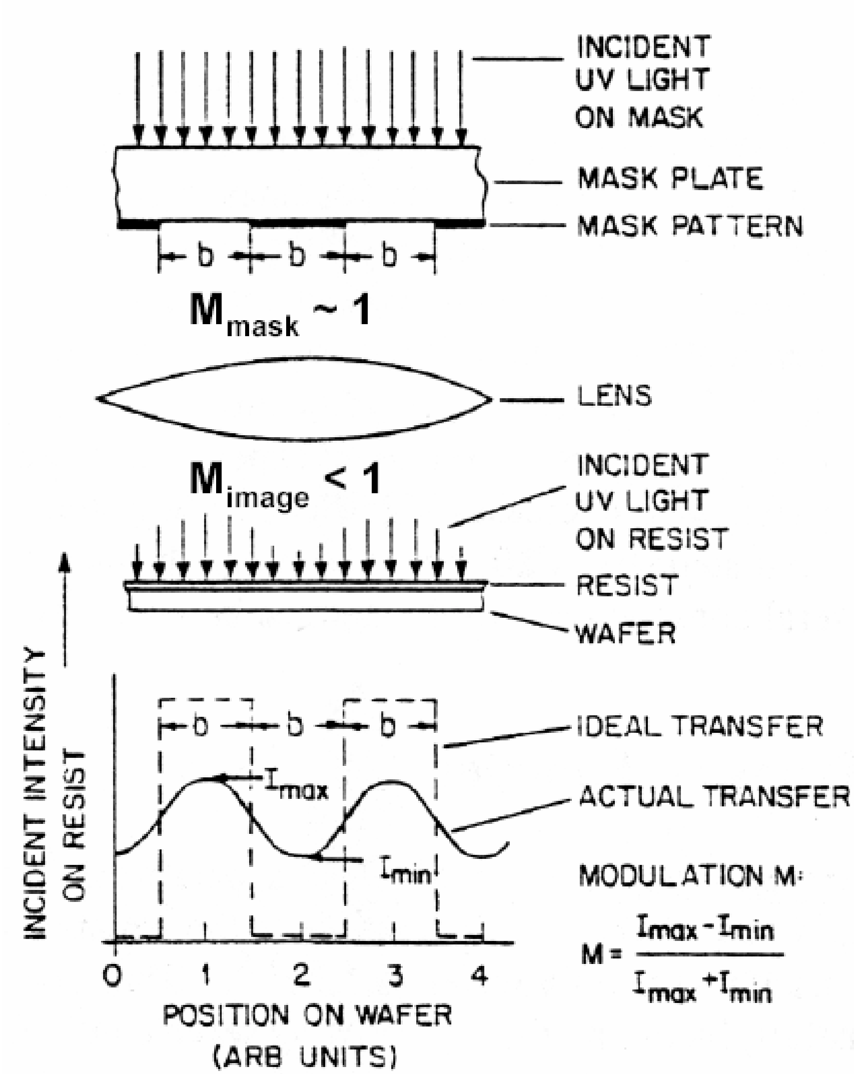


Object Separation $2 \cdot b_{min} = \dfrac{0.6 \cdot \lambda}{NA}$
(resolution)

Depth of Focus $\delta := \dfrac{\lambda}{2 \cdot (NA)^2}$

Trade off exists between resolution and DOF

Modulation Transfer Function (MTF)



$$S \sim \frac{\text{Source Diameter}}{\text{Pupil Diameter}}$$

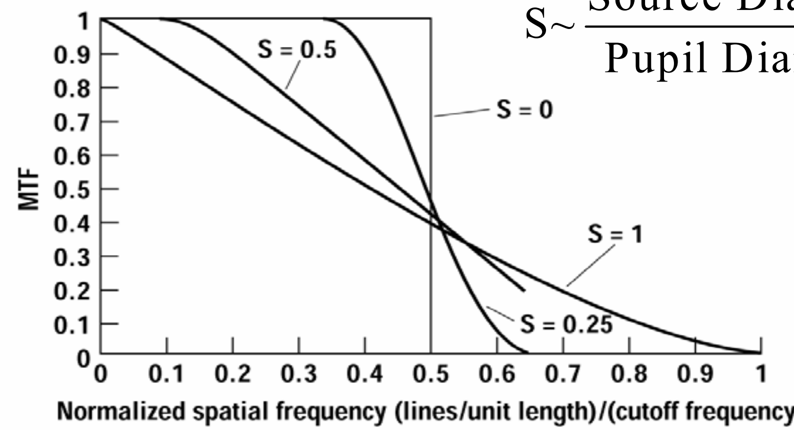


Figure 7.18 Modulation transfer function as a function of the normalized spatial frequency for a projection lithography system with spatial coherence as a parameter.

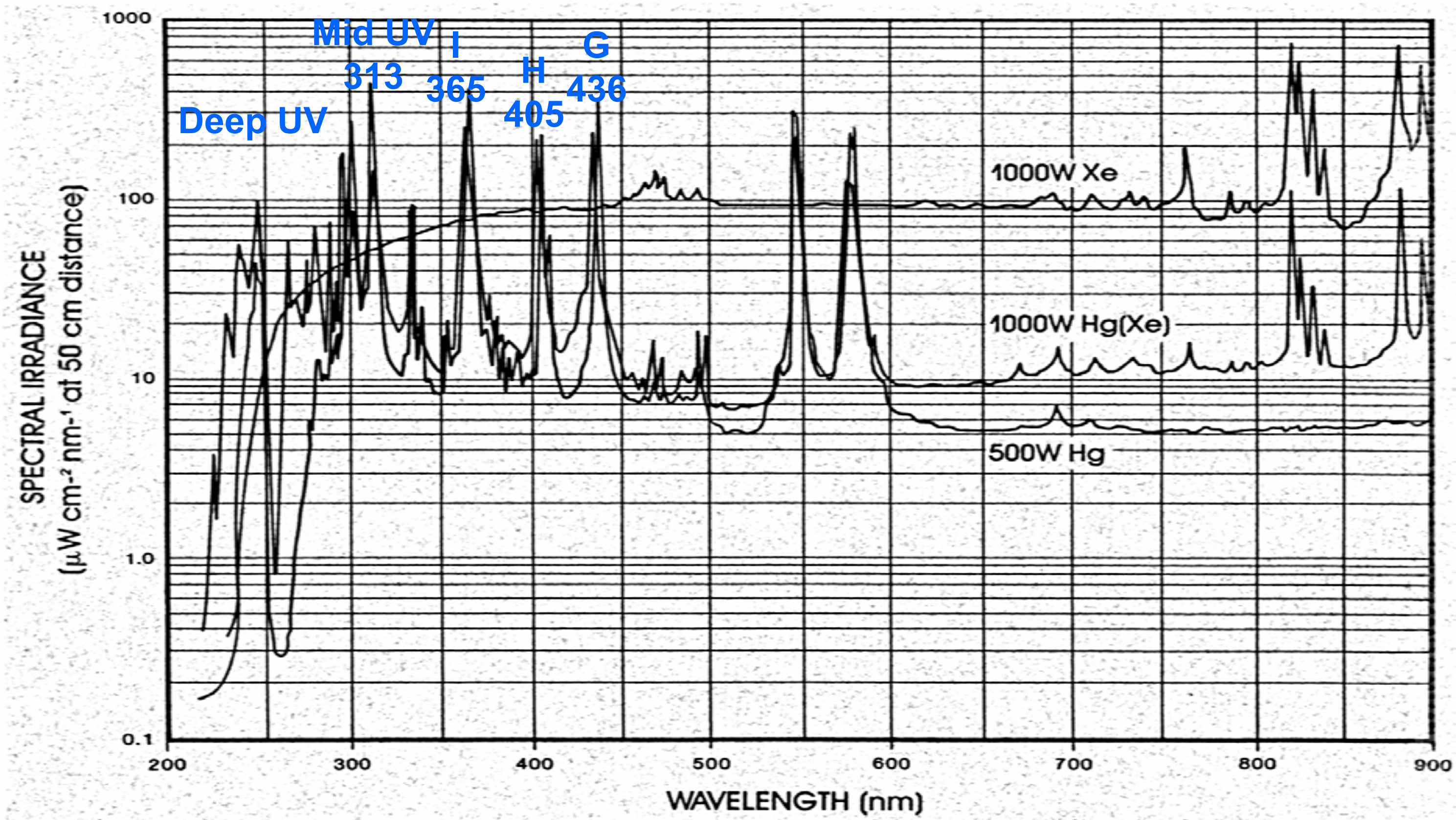
- MTF is the ratio between
  - -image intensity modulation
  - -object intensity modulation

$$MTF = \frac{M_{image}}{M_{mask}} \qquad MTF = \left(\frac{I_{max} - I_{min}}{I_{max} + I_{min}}\right)$$

- Parameter indicates the capability of an optical system

Light Sources

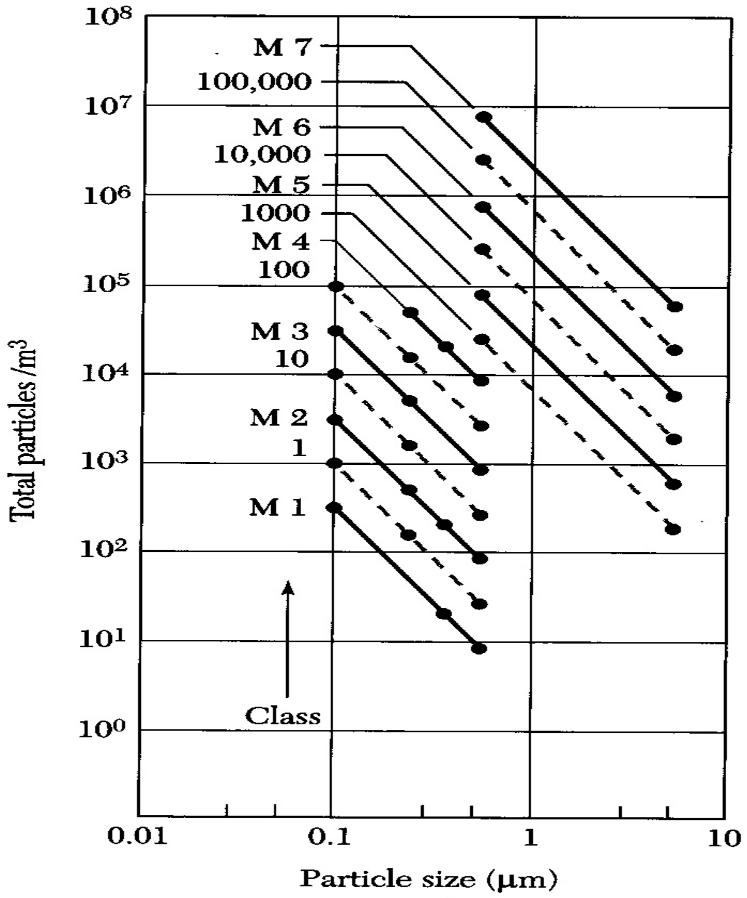
Mercury Lamp



Excimer laser source

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

Clean Room Classification



English system:

Numerical designation of the class is maximum allowable number of particles that are 0.5 µm and larger per cubic foot of air.

Metric system:

Numerical designation of the class is taken from the Logarithm (base 10) of the maximum allowable number of particles that are 0.5 µm and larger per cubic foot of air

IC is very sensitive to particles. It usually requires Class 10 or better

MEMS is more robust to particulates

Decrease in Minimum Feature Size with Time (Moore's law)