Course: EE3013 Semiconductor Devices and Processing

School: School of Electrical and Electronic Engineering

Lithography 3 – Lithography Technology

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Lithography Technology – Lesson Overview

Lithography technology:

- Lithography equipment
- Resolution and its critical parameters
- Mask and reticle

Lithography Equipment

Lithography Equipment – Aligners

Aligners

Single Exposure:

- Contact Aligner
- Proximity Aligner

Multiple Exposure:

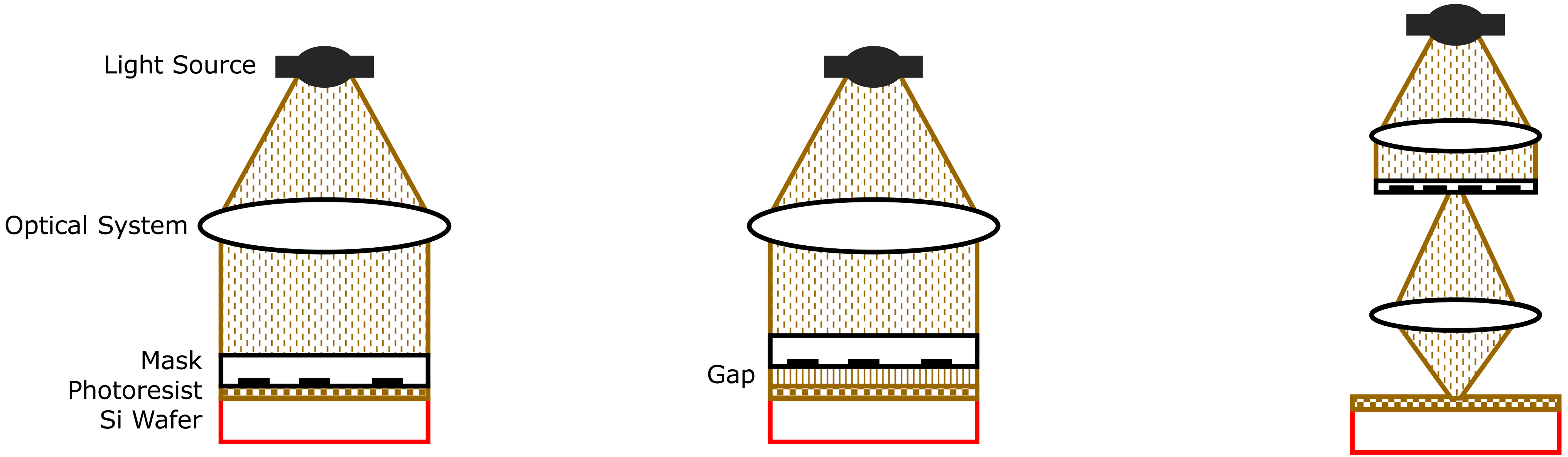
Step-and-Repeat Aligner (Stepper)

UV Exposure - Printing

UV exposure is sometimes known as “printing” because it “prints” the desired pattern onto the substrate using UV source.

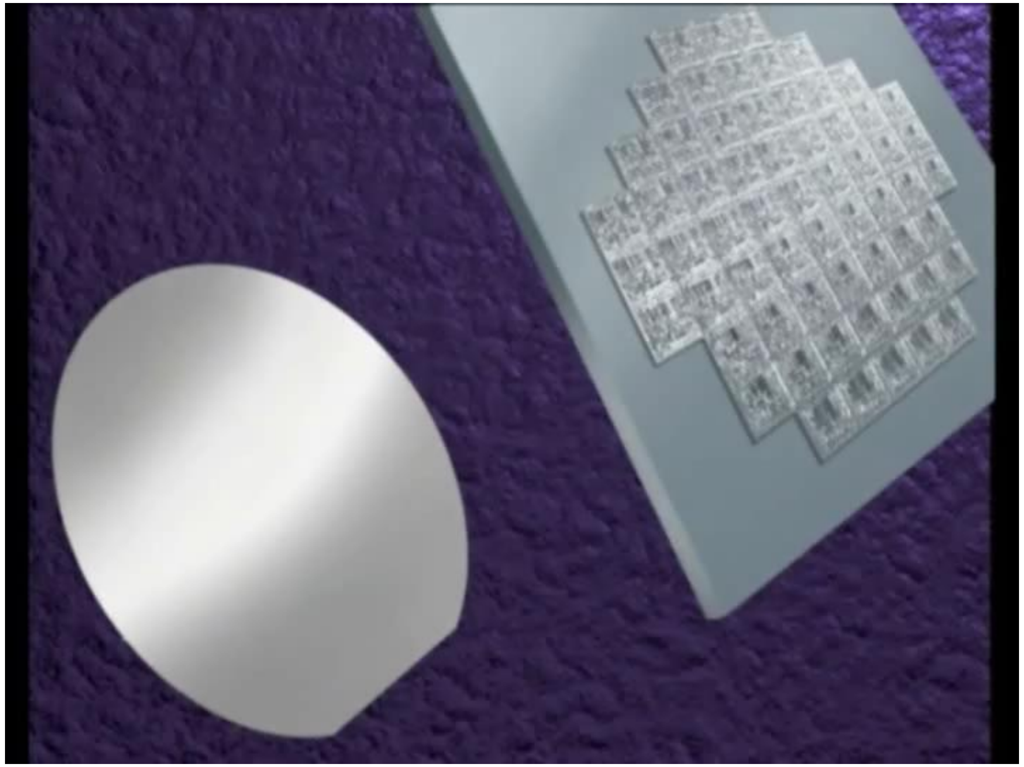
Three Basic UV Exposure Methods

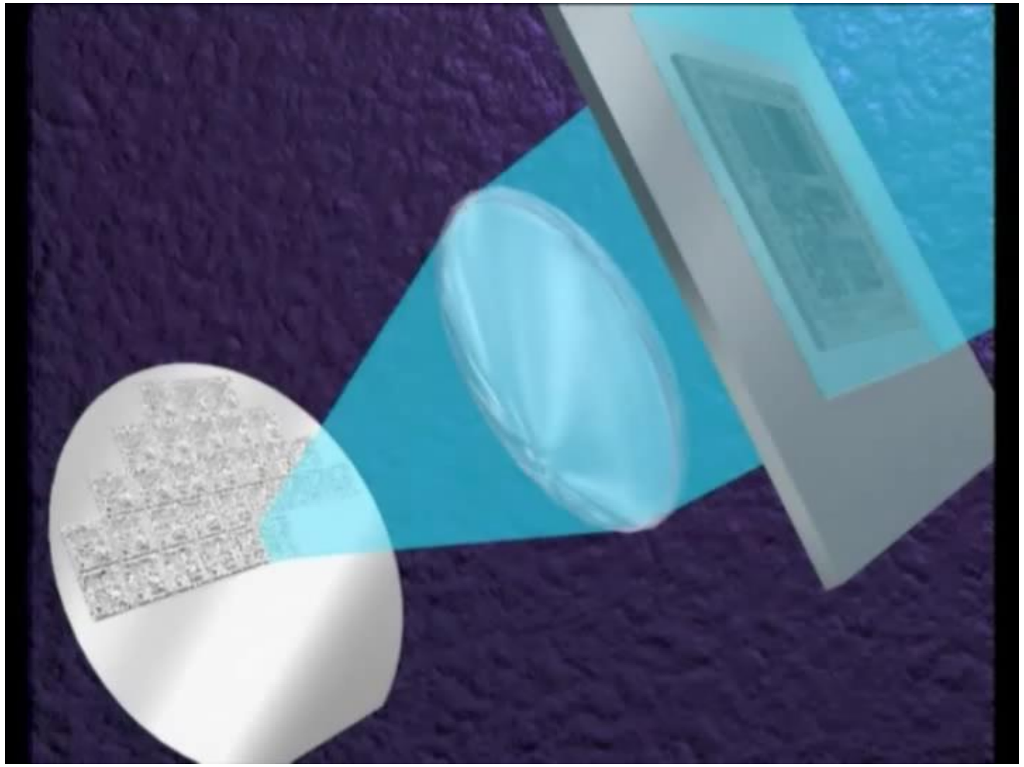
Single Exposure | **Single Exposure** | **Multiple Exposures**



Contact Printing | **Proximity Printing** | **Projection Printing**

Lithography Equipment: Single and Multiple Exposure





Single Exposure

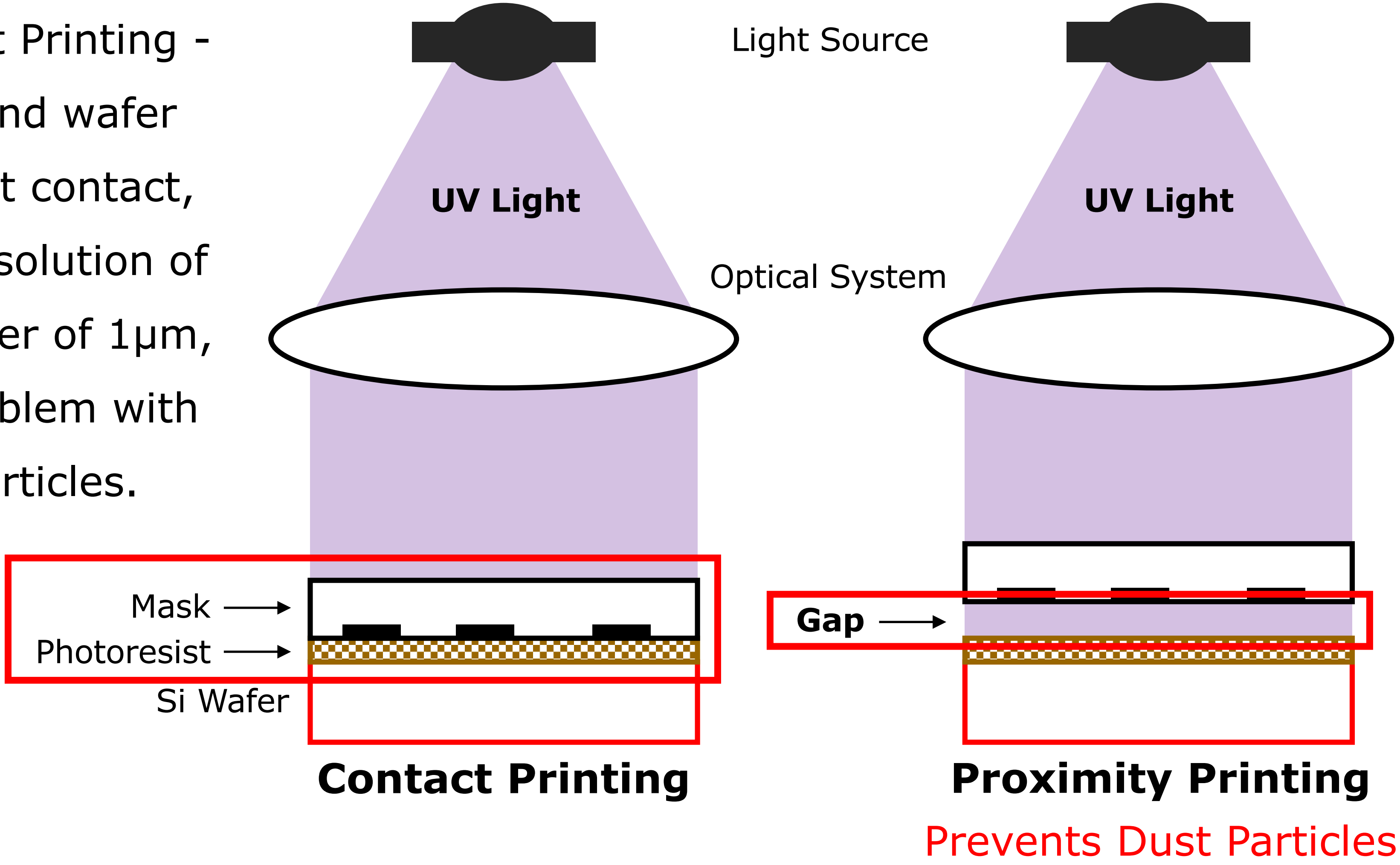
- Contact Aligner/ Printer
- Proximity Aligner/ Printer

Multiple Exposure

- Step-and-Repeat Aligner (Stepper)

Contact and Proximity Aligners

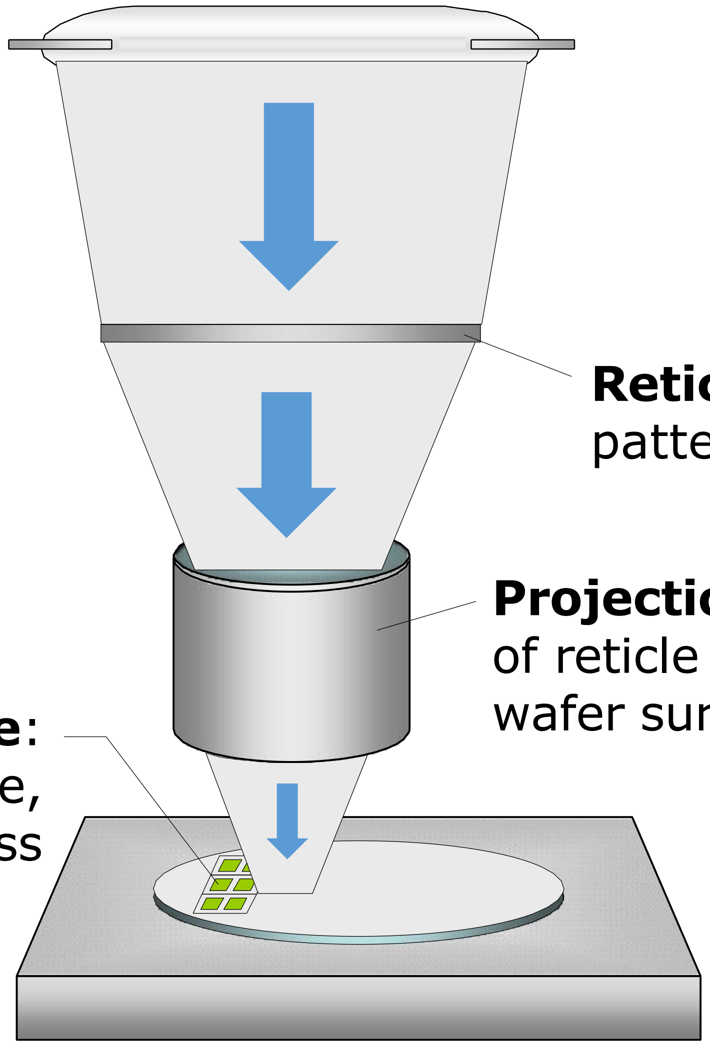
Contact Printing - mask and wafer in direct contact, high resolution of the order of 1µm, the problem with dust particles.



Proximity Printing - mask and wafer in close proximity (a small gap of 10-50µm between mask and wafer), less damage by dust particles, the low resolution of the order of 2-5µm due to the fringe.

Multiple Exposure: Step and Repeat Printing

UV Light Source



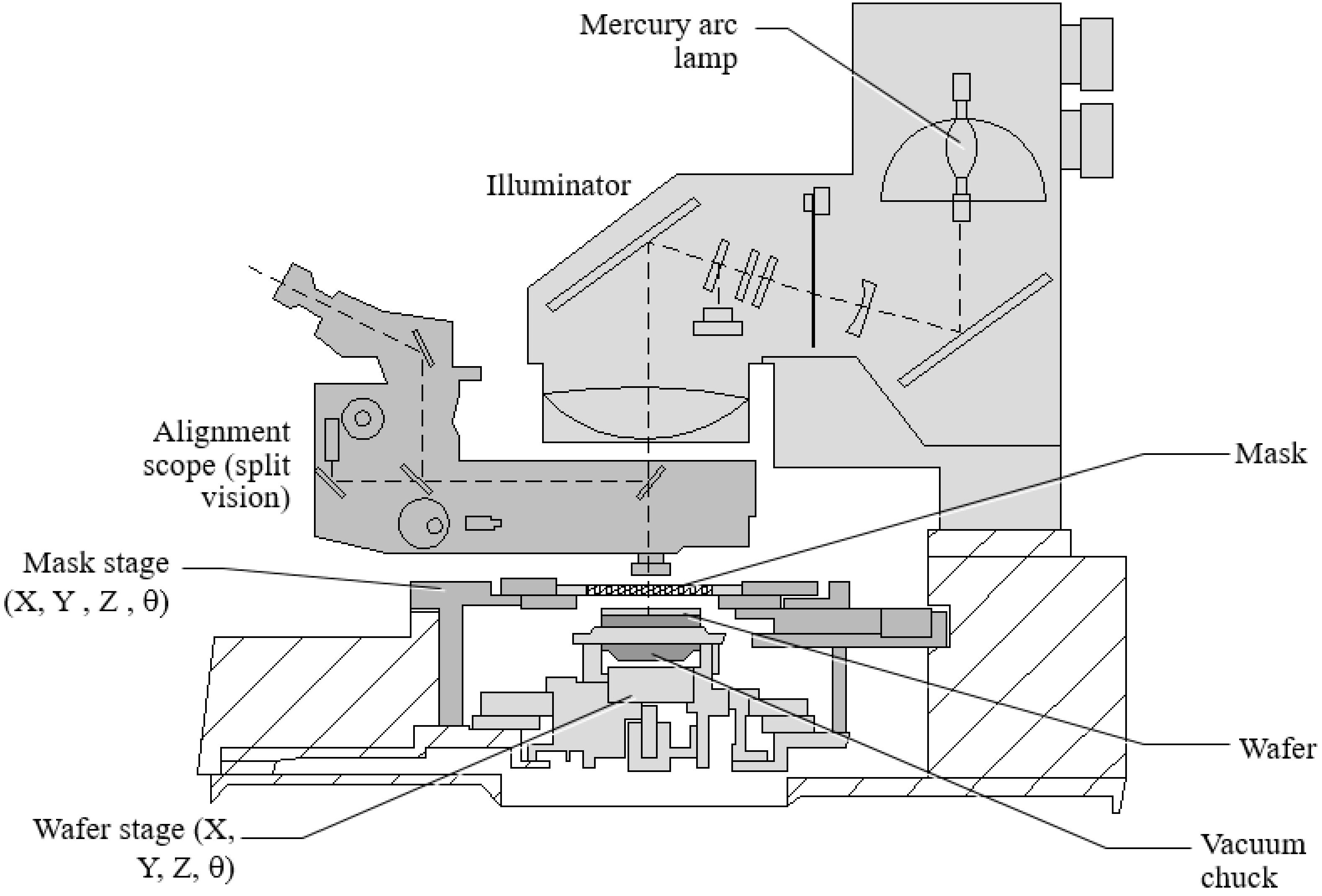
Reticle: May contain the pattern of one or more die

Projection Lens: Reduces the size of reticle field to be printed onto the wafer surface

Single Field Exposure: Includes focus, align, expose, step, and repeat process

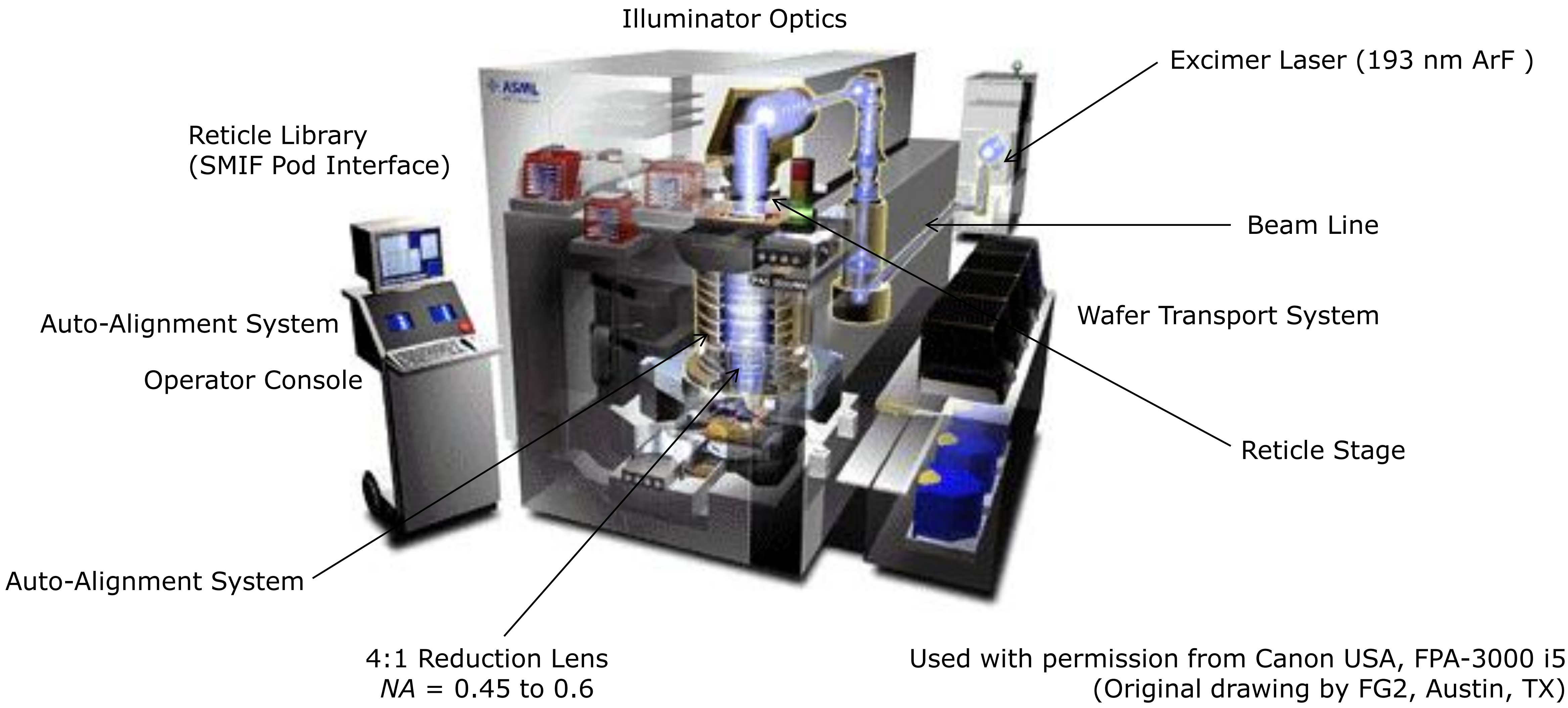
Wafer stage controls the position of the wafer in $X, Y, Z,$ and θ

Contact/ Proximity Aligner



Used with permission from Canon USA,

Step-and-Repeat Projection Aligner



Used with permission from Canon USA, FPA-3000 i5
(Original drawing by FG2, Austin, TX)

Resolution and its Critical Parameters

Resolution

The ability of an optical system to distinguish closely spaced objects.

More challenging to distinguish small pattern.

Minimum Linewidth/ Resolution for Proximity Aligner

- Resolution is the minimum linewidth achievable by the lithography equipment.
- Minimum linewidth (Resolution) for the proximity printer:

$$W_{min} \approx \sqrt{k_1 \lambda g}$$

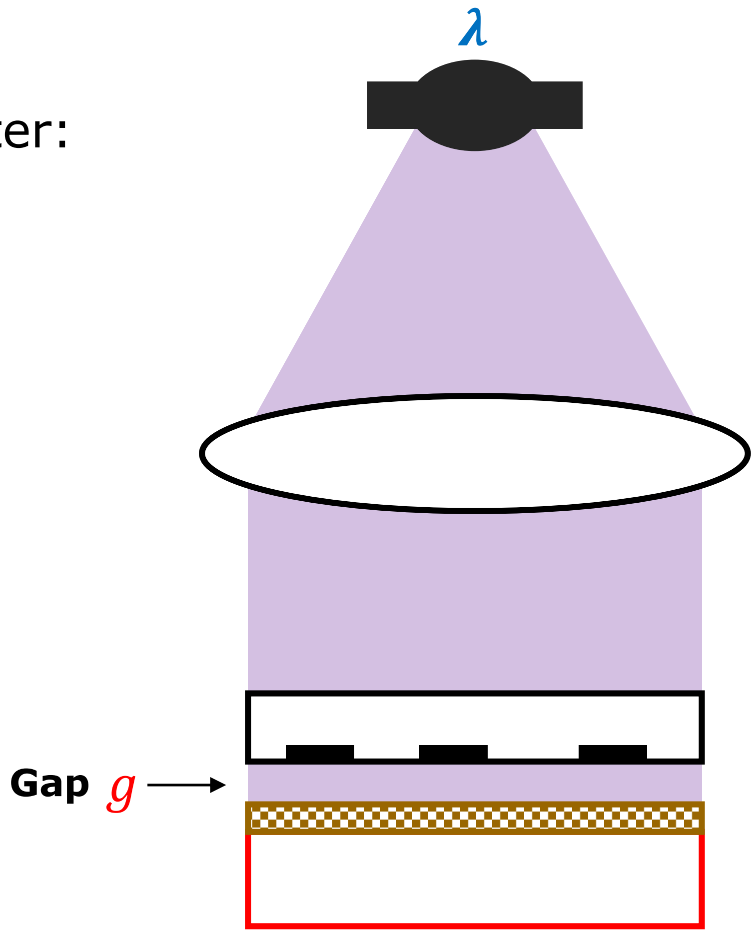
k_1 = Constant

λ = Wavelength of the exposure source

g = Gap between the mask and the wafer surface (in the range of **µm**)

k_1 factor has no well-defined physical meaning. It is an experimental parameter, depends on the lithography system and resist properties. Typical values are close to 1.

Proximity Aligner



Proximity Printing

Pause and read carefully

Practice Question 1

Determine the maximum allowable proximity gap for near and deep UV sources as a function of the feature size. $(k_1 = 1)$

Near UV: $\lambda = 0.405\ \mu m$ **Deep UV:** $\lambda = 0.248\ \mu m$ (Linewidth) $W_{min} \approx \sqrt{k_1 \lambda g}$

Pause and try out this question

Linewidth (µm)	**Maximum Gap for Near UV Source (µm)**	**Maximum Gap for Deep UV Source (µm)**
2.5	15.43	25.2
2.0	9.88	16.13
1.0	2.47	4.03
0.5	0.62	1.01

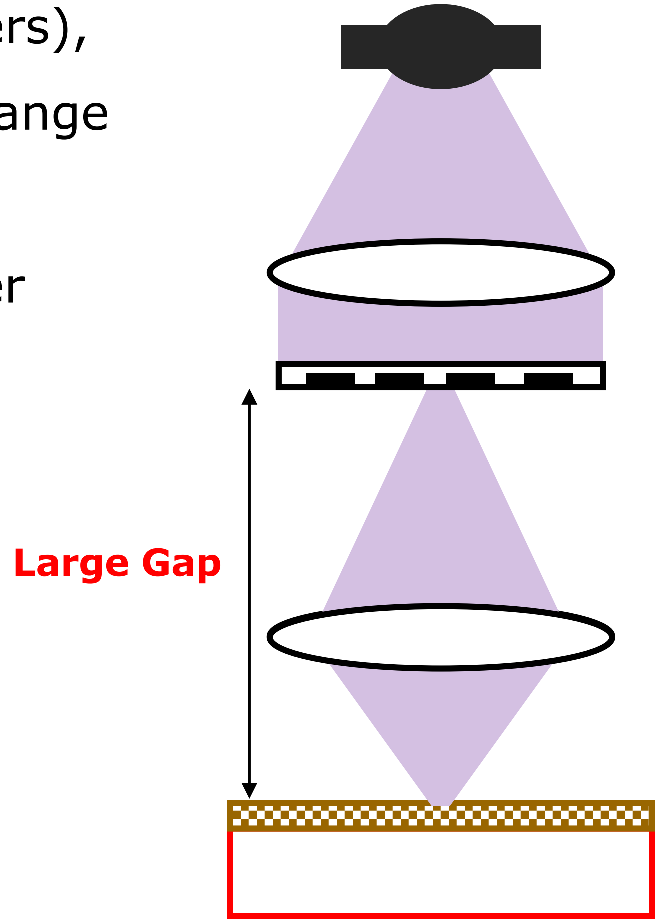
- As **feature size decreases**, **the maximum allowable gap decreases**.
- A **light source of lower wavelength** is better to overcome the above constraints in the maximum allowable gap.

Minimum Linewidth/ Resolution for Projection Aligner

- In projection aligner (also called step-and-repeat aligners), the gap between mask and wafer is very large (in the range of cm).
- Minimum linewidth (resolution) for the projection printer can be calculated using:

$$W_{min} \approx k_1 \frac{\lambda}{NA}$$

Where *NA* is called the numerical aperture.



Projection Printing

Pause and read carefully

Numerical Aperture

- The numerical aperture (NA) of an optical system is a measure of the ability to collect light, which is a measure of the light gathering power.
- Numerical Aperture, (NA) can be defined as:

$$NA = n \sin\theta$$

Where n = refraction index (the medium in which the system is immersed, in this $n = 1$ for air), and θ = one half the angle of acceptance of the objective lens.

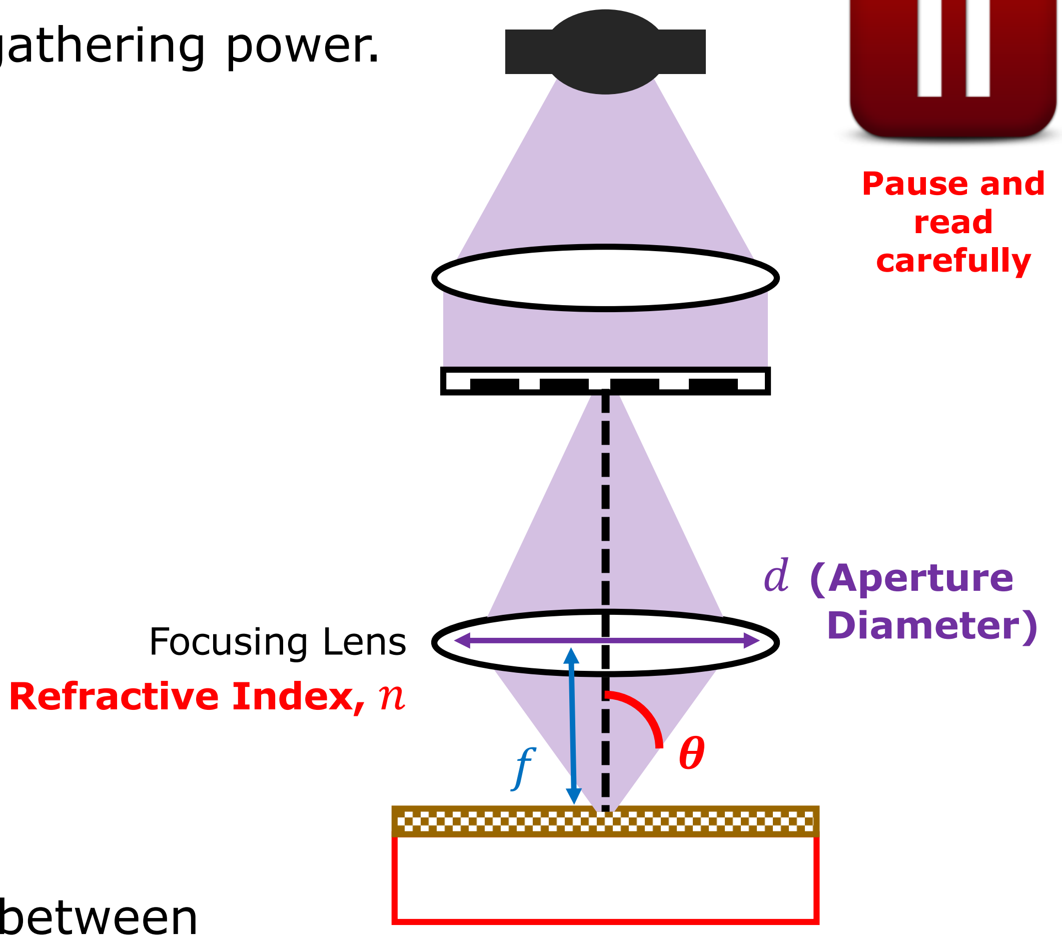
When n = 1, the NA can be defined as

$$NA = \sin\theta \approx \tan\theta = \frac{d/2}{f} = \frac{d}{2f}$$

$\tan\theta \simeq \sin\theta$ *since* θ *is less than 12°*

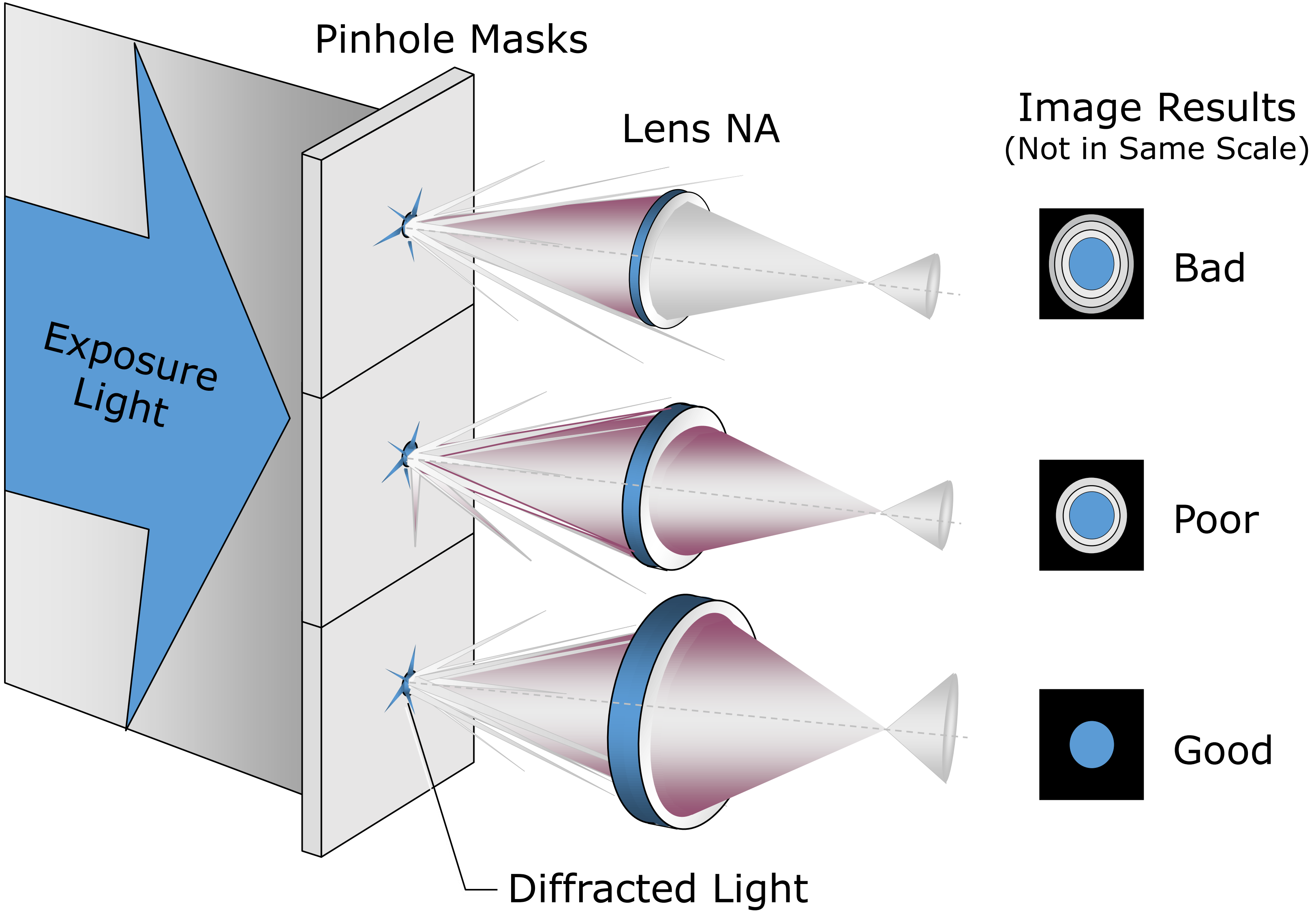
NA for projector objective is also the geometrical ratio between aperture and focal length.

Pause and read carefully



Projection Printing

Effect of Numerical Aperture on Imaging



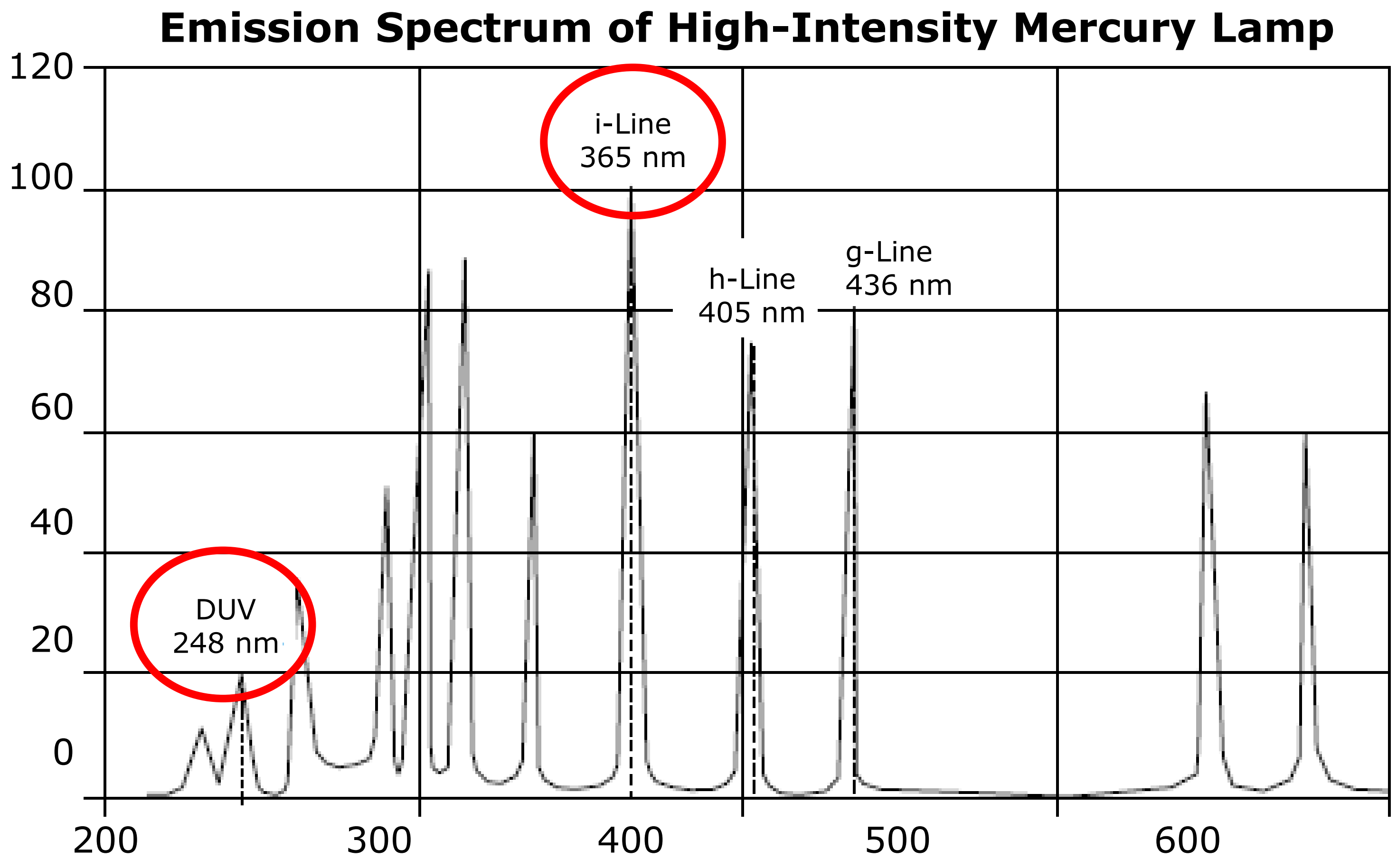
Typical *NA* Values for Photolithography Tools

Type of Equipment	***NA* Value**
Step-and-Repeat	0.60 - 0.68

Practice Question 2

A step-and-repeat aligner has an *NA* value of 0.6. By assuming k_1=1, which of the followings is/ are the most suitable UV source(s) to achieve resolution of **0.62 µm**?

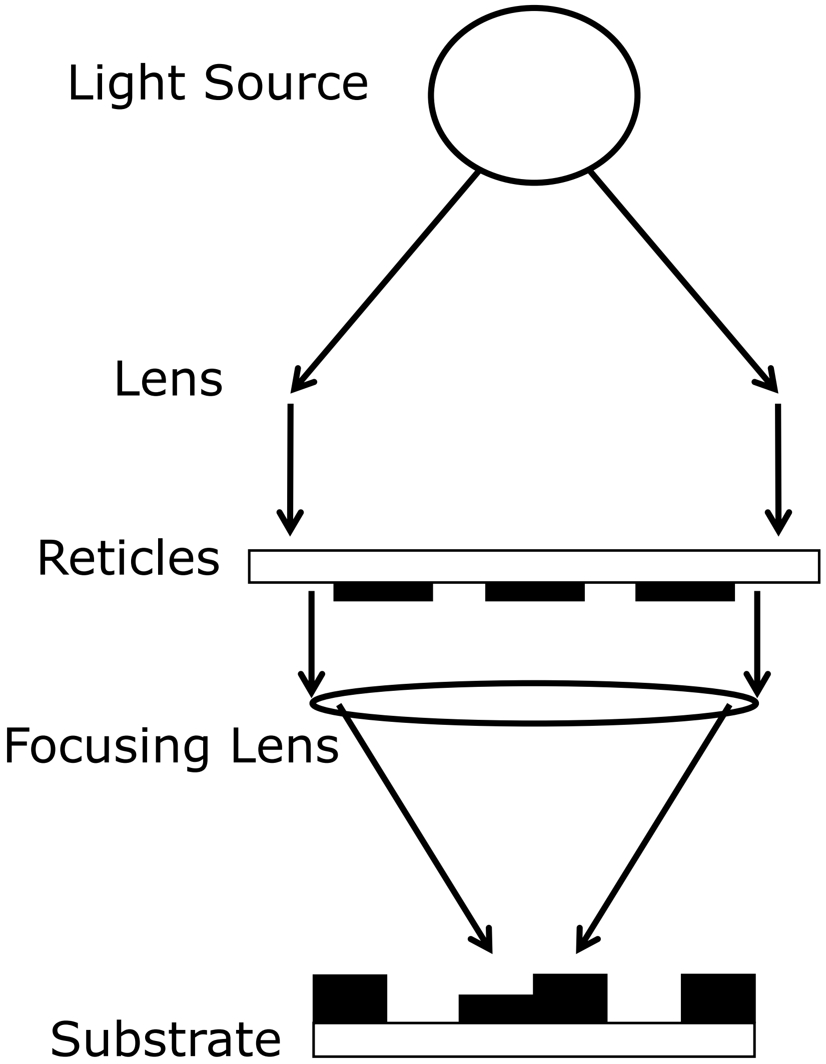
Pause and try out this question



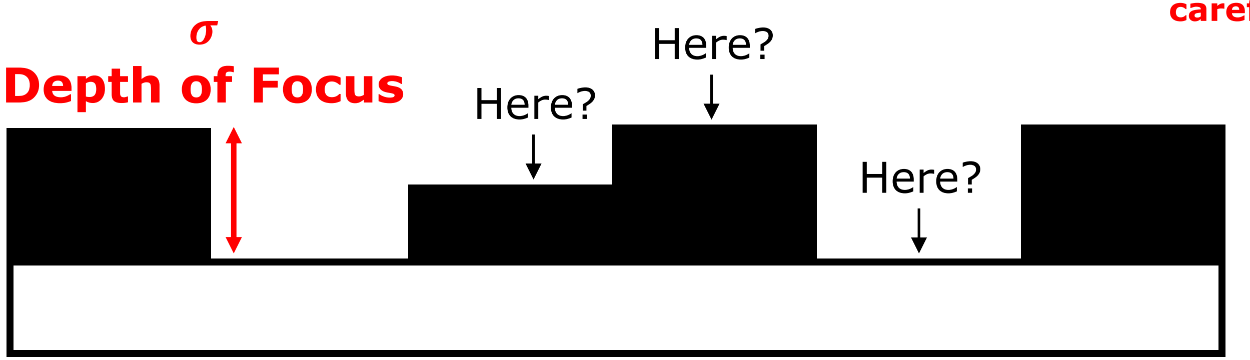
$$W_{min} \approx k_1 \frac{\lambda}{NA}$$

- The obtained λ value is 372 nm. UV sources with wavelengths smaller than 372 nm can be used. Both i-line and DUV can achieve such resolution.
- DUV has a lower intensity.
- Excimer laser which has a higher intensity can be used.

Lithography on Uneven Surface



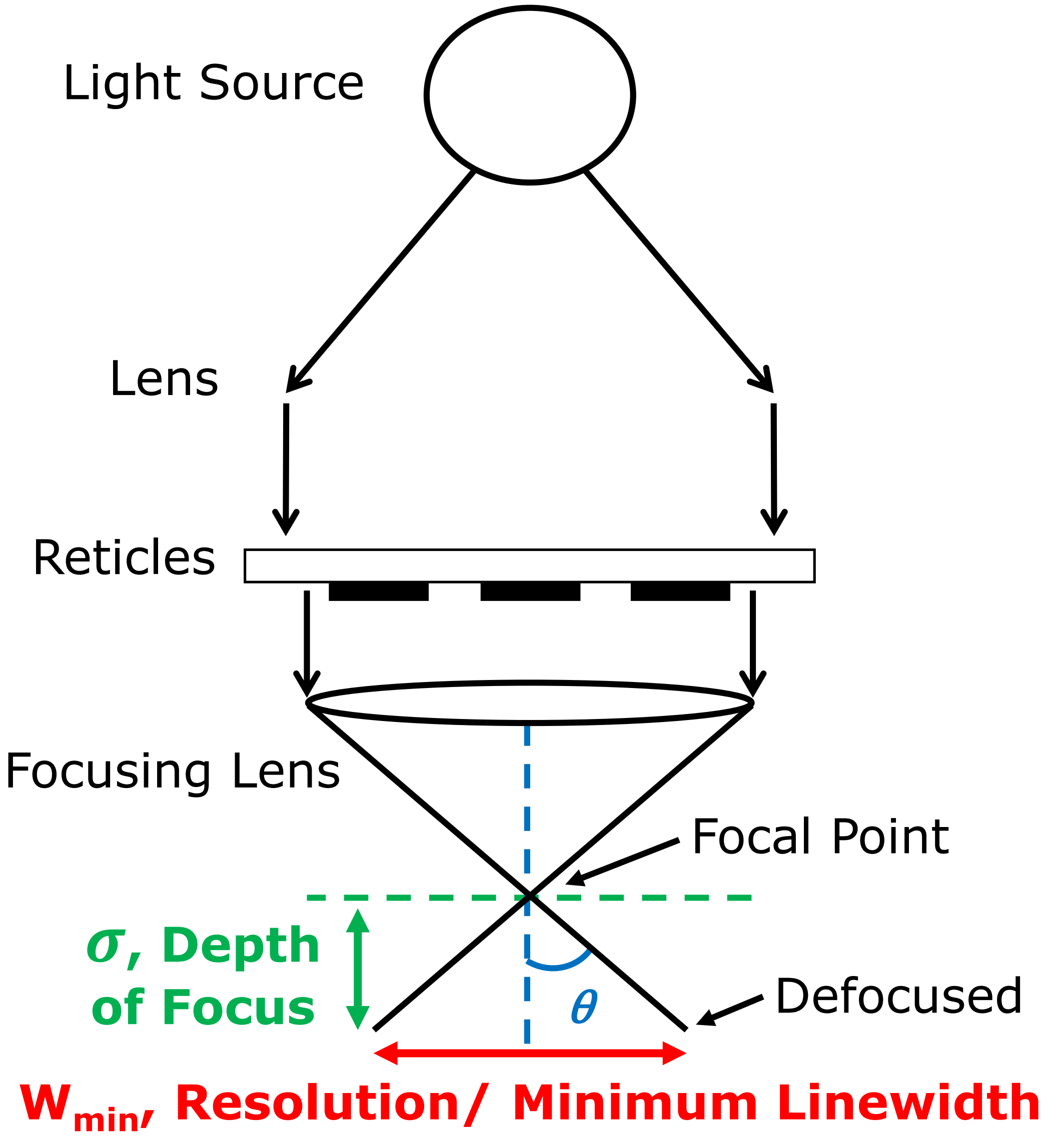
Where should be focused?



Pause and read carefully

Depth of focus: Range of focus error that a process can tolerate.

Depth of Focus – How to Deal With It?



Depth of focus:

$$\sigma = \pm \frac{W_{min}/_2}{\tan\theta} \cong \pm \frac{k\lambda/_{2NA}}{\sin\theta}$$

$$\sigma = \pm \frac{k\lambda/_{2NA}}{NA/n} \cong \pm \frac{k_2\lambda}{(NA)^2}$$

Pause and read carefully

$\tan\theta \sim \sin\theta$ for θ < 12°

k and k_2 are constant , n = 1 (for air)

Again, like the case of resolution, we used k_2 factor as an experimental parameter. It has no well-defined physical meaning.

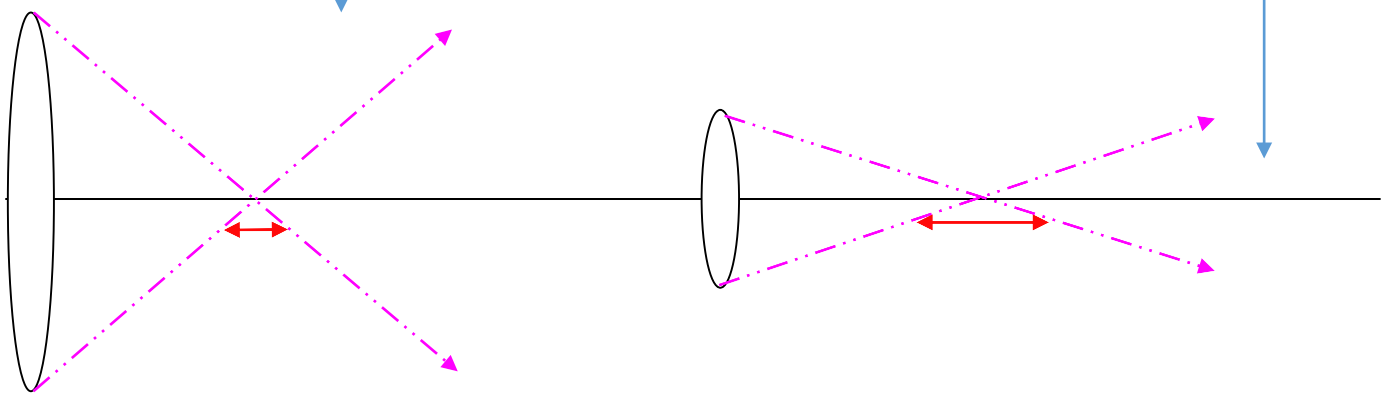
Depth of Focus for Projection Photolithography

$$DOF = \delta = \pm k_2 \frac{\lambda}{(NA)^2}$$

- Large NA gives smaller depth of focus.
- This is also true for the camera. A cheap camera takes photos that are always in focus no matter where the subject is. This is because it has small lenses.

Small DOF
(Background Blurred)
What one need here is a telephoto lens at its widest aperture.

Large DOF
A small aperture was used to ensure the foreground stones were as sharp as the ones in the distance.



Large Lens (Large NA), Small DOF

Small Lens (Small NA), Large DOF

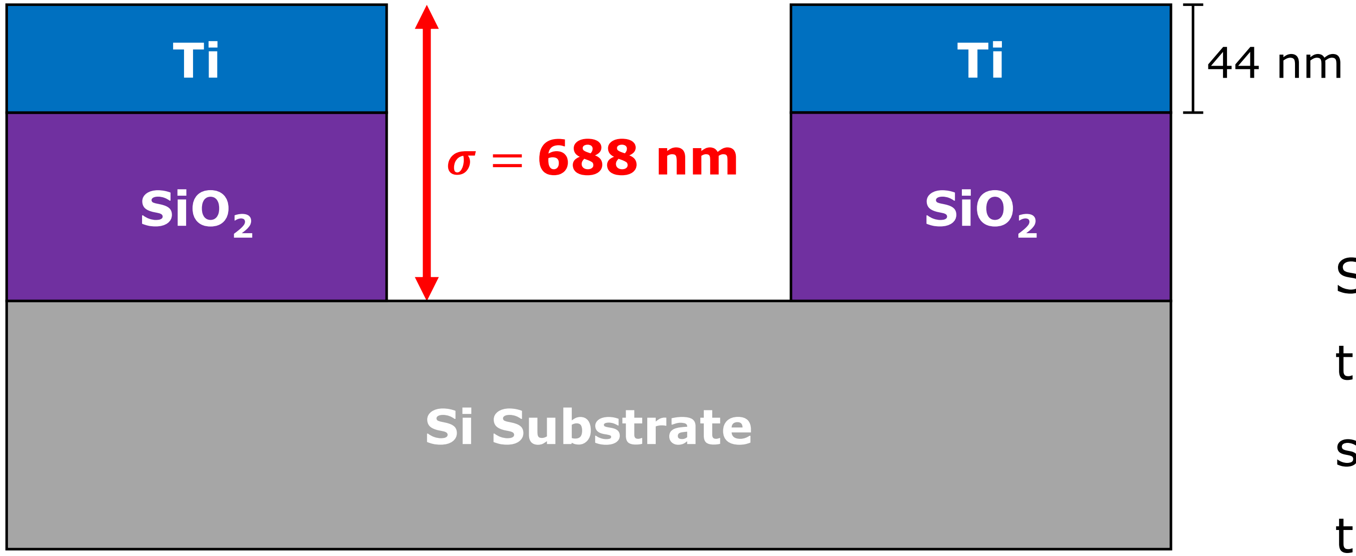
Practice Question 3

We need to perform lithography patterning on a structure illustrated below using a step-and-repeat aligner ($NA = 0.6$, $k_2 = 1$). The exposure source is excimer laser (248 nm). To obtain a sharp image, what is the maximum thickness of the SiO_2 layer?

Pause and try out this question

$$\sigma = \frac{k_2 \lambda}{(NA)^2}$$

$$\sigma = 688\ \text{nm}$$



Since titanium has a thickness of 44 nm, the total thickness of titanium and SiO_2 should not exceed 688 nm. Therefore, the SiO_2 layer should be ≤ 600 nm.

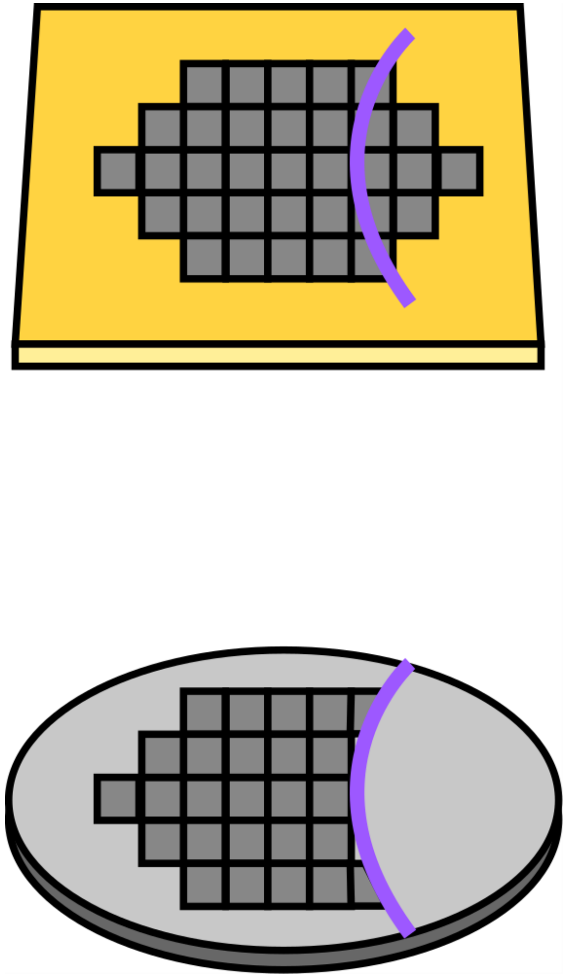
Mask and Reticle

Mask and Reticle for Lithography

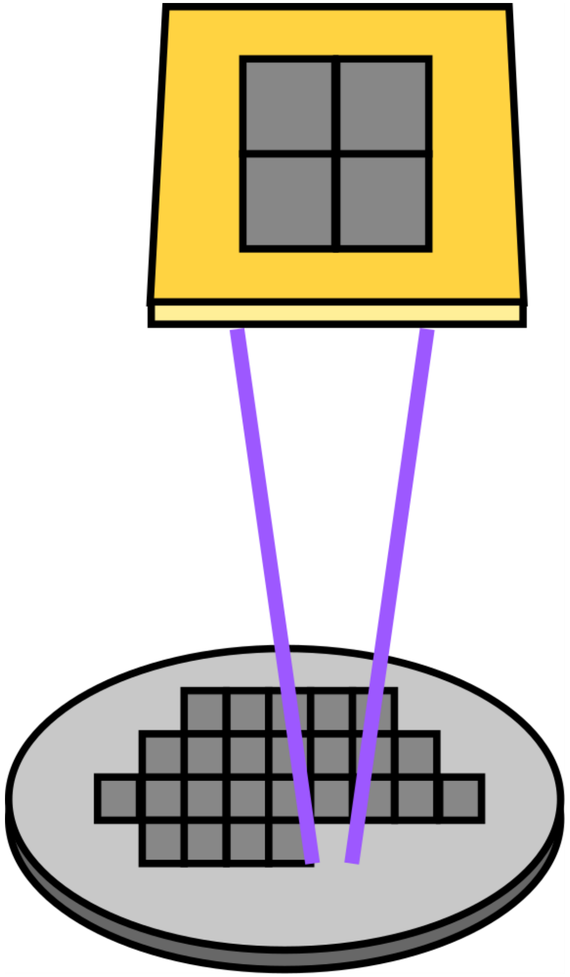
Mask
Single Exposure:
1:1 Mask

Pattern for a Complete Wafer

Same Size Pattern


Wafer

Scanner



Reduction Stepper

Reticle
Multiple Exposure:
Reticle (Typically 4:1)

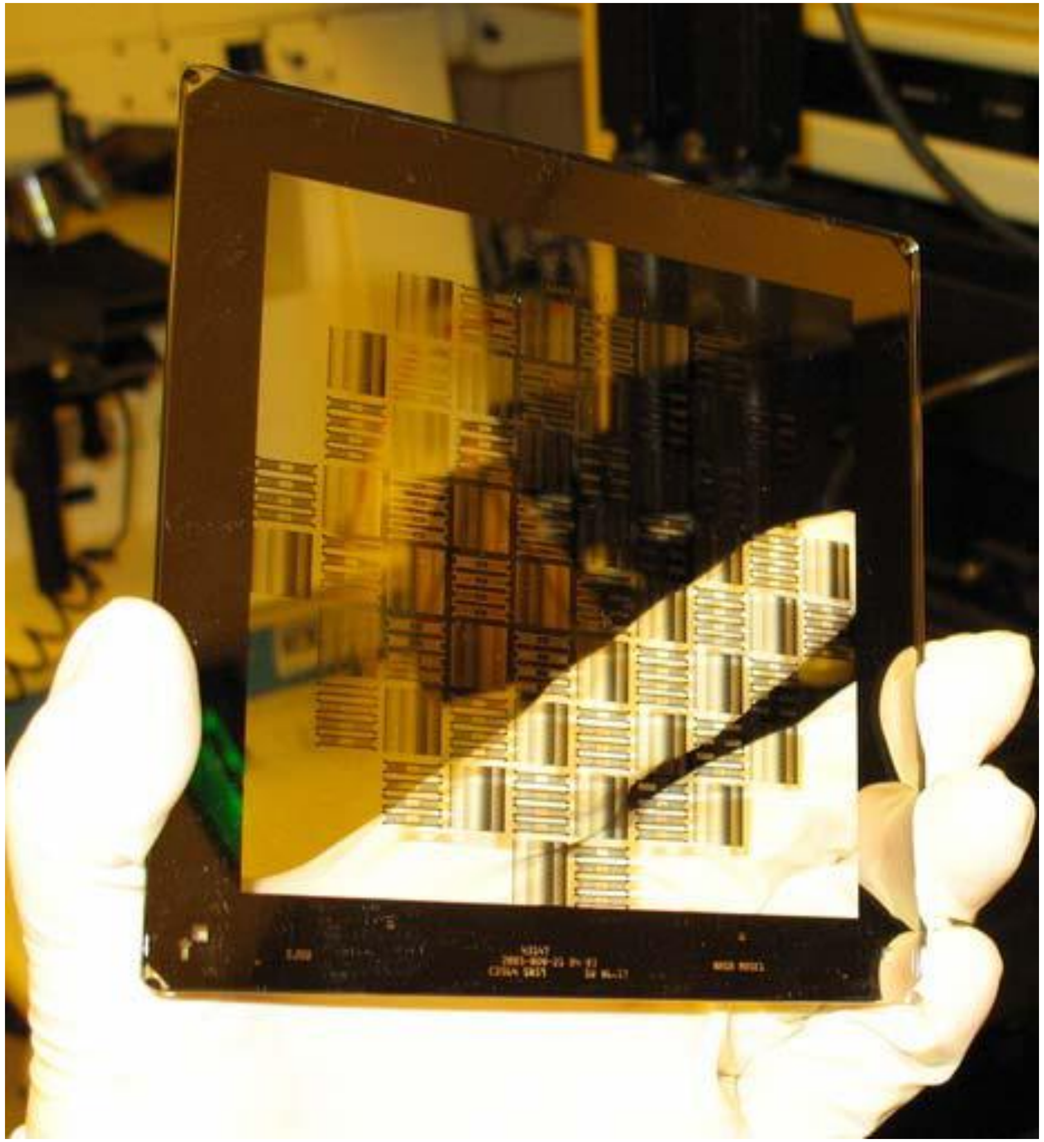
Pattern for Only Part of the Wafer

Reduced Size Pattern

Achieve Higher resolution

Mask and Reticle – Required Properties

- Flat and highly polished
- One surface of glass is patterned with opaque chromium
- High degree of transparency for optimal usage, better exposure, higher transmitted power to PR



Lithography Technology – Summary

Lithography technology:

- Lithography aligners can be single exposure or multiple exposures.
- The resolution of lithography determines the smallest feature size it can print, whereas the depth of focus determines the range of tolerable focus error.
- Masks are used in single exposure aligners, whereas reticles are used in multiple exposure aligners.