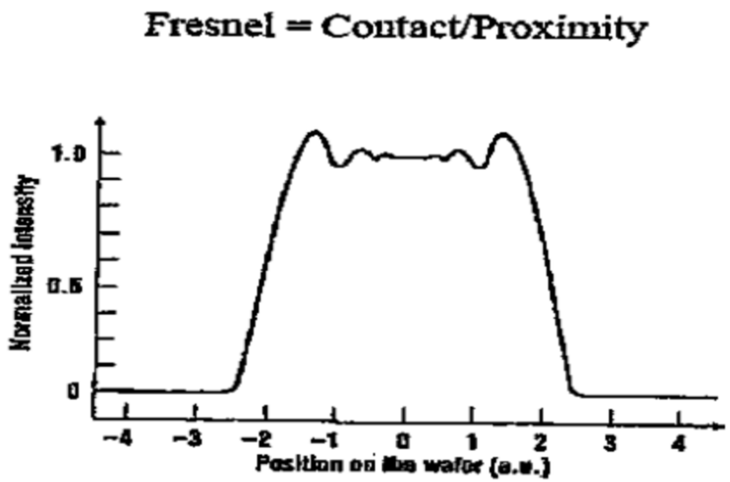
Tutorial 2

1. a) **(i) Write the generalized formula for the Resolution (W) of a proximity exposure system used in air. Sketch the intensity image profile on a wafer for this type of exposure system.**

(i) $w_{min} = \sqrt{k\lambda g}$



Tutorial 2

1. a) (ii) Complete the following table for the Resolution (W) of a proximity system using the following exposure wavelength, g-line, i-line, KrF and ArF without using Resolution Enhancement Technique (RET). From the table, state the effect of the exposure wavelength on the resolution, W and the maximum allowable gap, g.

Exposure Light source			Process Parameters		Performances
	Wavelength nm	Means of UV light generation	k_1	g µm	W µm
g-line	436		0.42	1.0	
i-line			0.42	1.0	0.395
KrF	248		0.42		0.395
ArF	193		0.35	1.5	

Tutorial 2

1. (ii)

Exposure Light source			Process Parameters		Performances
	Wavelength nm	**Means of UV light generation**	**k_1**	**g μm**	**W μm**
g-line	436	**UV Mercury Lamp**	0.42	1.0	**0.428**
i-line	**365**	**UV Mercury Lamp**	0.42	1.0	0.395
KrF	248	**UV Excimer Laser**	0.42	**1.5**	0.395
ArF	193	**UV Excimer Laser**	0.35	1.5	**0.318**

As the exposure source changes from g-line to i-line, resolution improves even though process parameters remain the same. Also one can work with a higher separation distance, g as exposure source changes from UV mercury lamp to excimer laser.

Tutorial 2

1\. b) **State the Optical Resolution Enhancement Technique (RET) that were implemented for the ArF DUV photolithography technology, which helped to realize the CMOS technology nodes beyond submicron range.**

(b) Optical Resolution Enhancement Technique (RET)

- Phase Shift Mask
- Off Axis Illumination
- Optical Proximity Correction

Tutorial 2

1. c) **Briefly describe the simplified formula for the resolution (W) and depth of focus (σ) of the Water Immersion lithography (IML) system (using same lens column design)**

c) In IML

$$W_{min} = k_1 \frac{\lambda}{(NA)} \qquad \sigma = \frac{k_2 \lambda}{NA^2} \left(\frac{n_{water}}{1}\right)$$

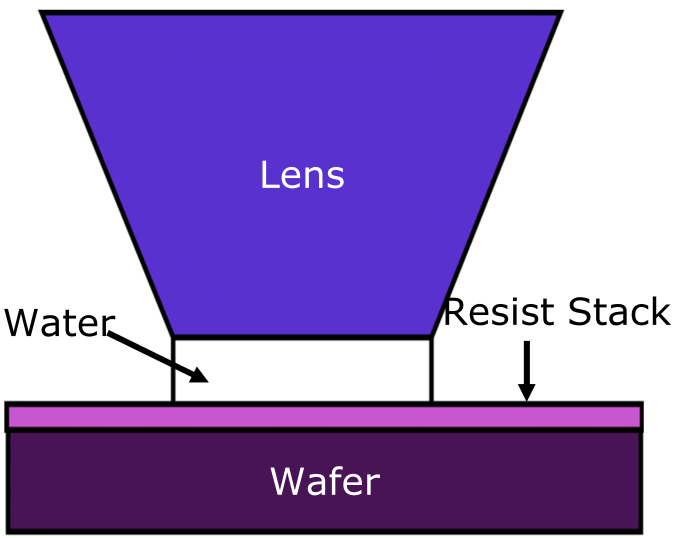
n_{water} is the refractive index of water between the lens and the photoresist layer on top of the water.

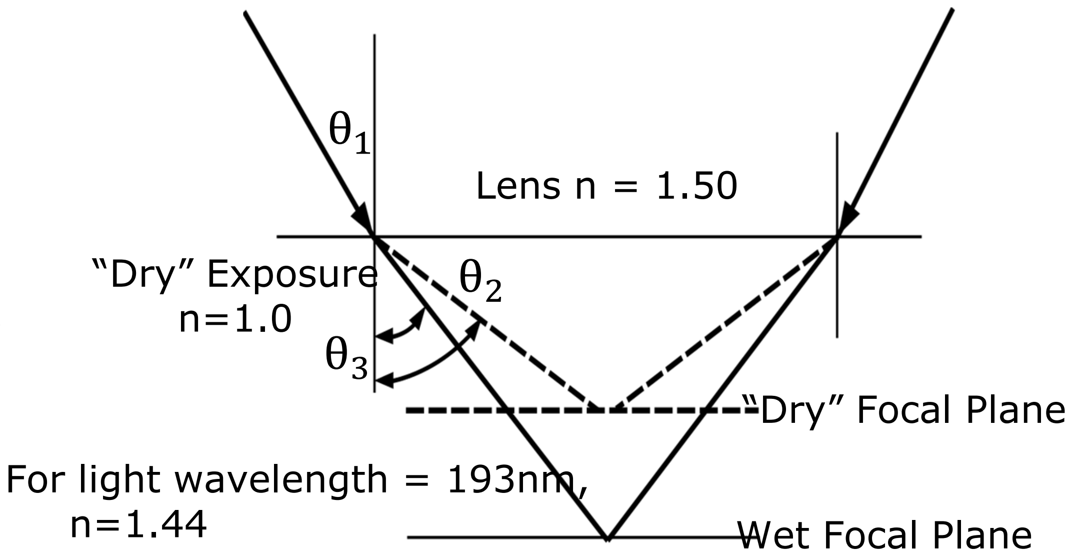
In IML, bubble free liquid (DI water) with higher refractive index is used between the lens and the photoresist layer on the wafer surface, the exit angle of the light coming out from the bottom lens element into the liquid (water) will be smaller due to the larger refractive index of the water. In other words , the focal length of the projected image onto the wafer plane is longer as compared with the Dry system. The longer focal length allows large Depth of Focus in IML.

Tutorial 2

1. d) **What are the advantages of above Immersion Lithography (IML) over the standard step and repeat projection exposure system used in air? Explain, using schematics to show the effect on the Depth of Focus (σ).**

Lens of same NA as in air





$$W_{min} = k_1 \frac{\lambda}{(NA)}$$ (Maintained)

$$NA = n \sin\theta$$

Improvement in DOF

Tutorial 2

2. **Several possibilities are being explored to achieve lower minimum line widths for projection lithography. You are in charge of evaluating some of these approaches. The nominal optical source is a Hg-vapour lamp with appropriate filters to enable it to operate in i-line. The Rayleigh equation governing the minimum line width is:**

$$w_{min} = k\frac{\lambda}{NA}$$ **where the symbols have their usual meanings**

In each of the following approaches, identify the parameter affecting the Rayleigh equation and explain the rationale.

(i) Change of the optical source to ArF excimer laser.

(ii) Double the lens diameter while maintaining the same focal length.

(iii) Use of phase shift masks.

(iv) Use of immersion liquid in the lithographic system as opposed to air (based on modified lens column design)

Tutorial 2

2.

(i) Change of the optical source to ArF excimer laser.

Lower wavelength , lower ω_{min}, hence improve resolution

(ii) Double the lens diameter while maintaining the same focal length.

Increase NA, lower ω_{min} hence improve resolution

(iii) Use of phase shift masks.

Decrease k, lower ω_{min} hence improve resolution

(iv) Immerse the lithographic system in water as opposed to air (based on modified lens column design)

Increase NA, , lower ω_{min} hence improve resolution

Tutorial 2

3. **An engineer uses a lithography projection system to fabricate nano-sized T-shaped imprint. The minimum feature size needed is 500 nm. Before the exposure of the glass photomask and the lift-off process, he needs to spin-coat a thin layer of negative resist onto a silicon wafer.**

   (a) What are the primary components of a resist? At 4500 rpm, a given photoresist coater produces a layer of resist 500nm thick. Determine the final resist thickness assuming the engineer deployed a spin speed of 3000 rpm.

Generally consist of 3 components:
- Inactive resin
- Photoactive compound (PAC)
- Solvent - used to adjust viscosity

Resist Layer Thickness $$I_{R_1} = \frac{\sqrt{spin\ speed_2}}{\sqrt{spin\ speed_1}} x I_{R_2}$$

$$= \frac{\sqrt{4500}}{\sqrt{3000}} \times 500 = 612\ nm$$

Tutorial 2

3. **An engineer uses a lithography projection system to fabricate nano-sized T-shaped imprint. The minimum feature size needed is 500 nm. Before the exposure of the glass photomask and the lift-off process, he needs to spin-coat a thin layer of negative resist onto a silicon wafer.**

   (b) Given the numerical aperture (NA) of the system is 0.75 and the resist constant (k) is 0.9, determine the wavelength of the projection system for the above specified feature size.

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

$$\lambda = \frac{w_{min}\ NA}{k} = \frac{500\ x\ 0.75}{0.9} = 416.7\ nm$$

Tutorial 2

3. An engineer uses a lithography projection system to fabricate nano-sized T-shaped imprint. The minimum feature size needed is 500 nm. Before the exposure of the glass photomask and the lift-off process, he needs to spin-coat a thin layer of negative resist onto a silicon wafer.

(c) Determine the depth of focus for this projection system, assuming k_2 is also 0.9. Explain, giving reasons, whether the depth of focus can be improved by increasing the diameter of the objective lens in the system?

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

$$= \frac{0.9\ x\ 416.7}{(0.75)^2} \quad = 666 \text{ nm}$$

If the diameter of the objective lens is increased, NA will increase. Correspondingly, the depth of focus will be reduced (i.e. cannot be improved)

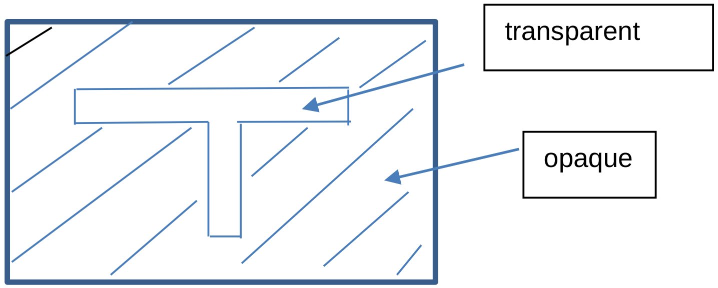
Tutorial 2

3. **An engineer uses a lithography projection system to fabricate nano-sized T-shaped imprint. The minimum feature size needed is 500 nm. Before the exposure of the glass photomask and the lift-off process, he needs to spin-coat a thin layer of negative resist onto a silicon wafer.**

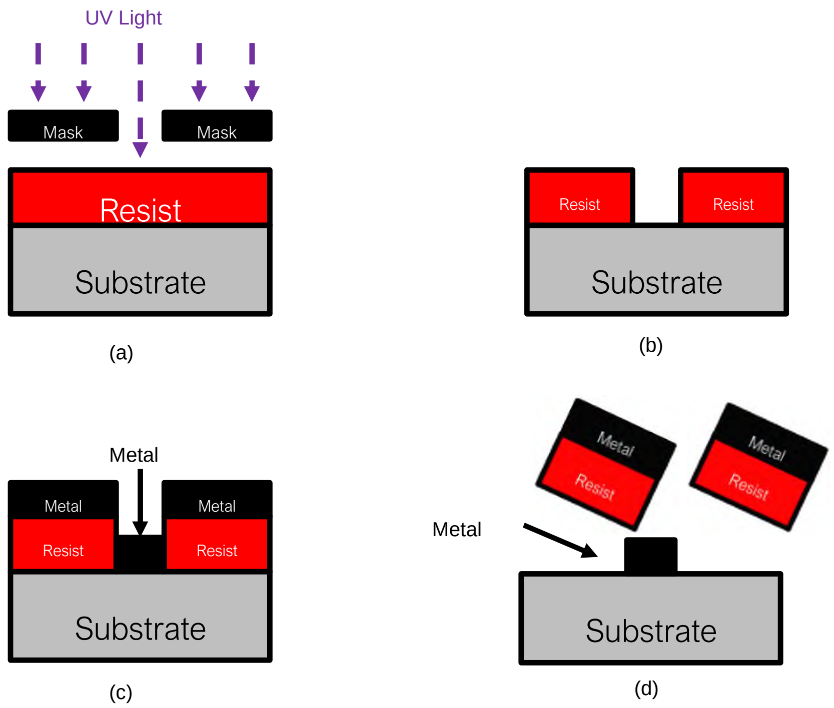
   However, during the exposure and development process, he realized he cannot achieve the minimum feature size requirement and was advised to use (i) a positive resist and (ii) optical enhancement techniques.

   (d) Explain why a negative resist is not preferred in this case. Re-design the photomask, identifying the region where the photomask is transparent should a positive resist be used in defining a T-shaped imprint.

(d) Negative resist suffered from swelling effect during the development phase. Hence for submicron features, positive resists are preferred.



Lift-off Process



Note that the transparent part of the mask (used with a positive resist) is where the T-shaped imprint to be placed on the wafer.

a) The substrate is coated with resist. Then the resist is exposed through a mask with the desired pattern.

b) The resist is developed to obtain the desired pattern on the substrate.

c) The metal film is deposited onto the resist-patterned substrate.

d) The metal-deposited resist is removed (acetone is usually used). The metal pattern will remain on the substrate.

Tutorial 2

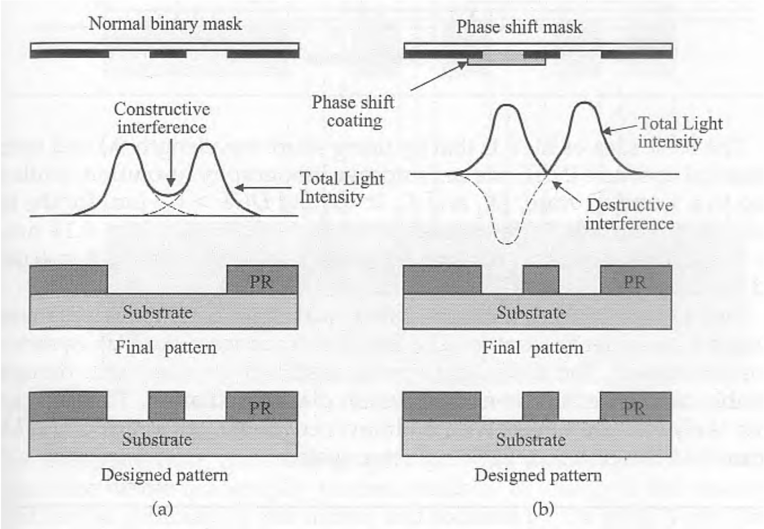
3. **An engineer uses a lithography projection system to fabricate nano-sized T-shaped imprint. The minimum feature size needed is 500 nm. Before the exposure of the glass photomask and the lift-off process, he needs to spin-coat a thin layer of negative resist onto a silicon wafer.**

   However, during the exposure and development process, he realized he cannot achieve the minimum feature size requirement and was advised to use (i) a positive resist and (ii) optical enhancement techniques.

   (e) Discuss in details, one possible optical enhancement techniques that he can deployed.

Phase shift mask (PSM) is a method used to overcome problems associated with light diffraction through small openings patterned on the reticle.

With PSM, the reticle is modified with an additional transparent layer so that alternating clear regions cause the light to be phase-shifted 180°. This causes destructive interference, where light diffracted into the nominally dark area on the left will encounter destructive interference with the light diffracted from the right clear area.



phase shift masks help bring down k -the smaller the k, the smaller the feature size

Tutorial 2

4. An engineer decides to replace an imaging system with a 40 kV electron beam lithography system (SCALPEL) to handle submicron printable pattern.

(i) State the formulae for the de Broglie wavelength of a particle.

(ii) What are the advantages and disadvantages of using e-beam lithography?

(iii) Given that the resists used have a k value of 1, and that the minimum line-width is 10 nm determine the gap between the mask and the wafer.

(i) $$\lambda = \frac{h}{\sqrt{2meV}}$$

where m is the mass of electron, e is electronic charge, h is Plank's constant

(ii) **Advantages :** High resolution

Disadvantages :

Extremely low throughput

Proximity effect

(iii)

$$\lambda = \frac{h}{\sqrt{2meV}}$$

$$\lambda = \frac{6.625x10^{-34}}{\sqrt{2x9.11x10^{-31}x1.6x10^{-19}x40x10^{3}}} = 6.13x10^{-12}$$

$$W_{\min} = \sqrt{k\lambda g}$$

$$g = (W_{\min})^2 / \lambda$$

$$= 16.31\mu m$$

Tutorial 2

5. **An engineer first used a proximity lithography system to try printing a submicron pattern with a minimum feature size of 0.5 μm. He found that the resolution is bad and attempted some optical enhancement techniques, but image reproduction still remains poor. Realizing soon the futility of achieving the required resolution, he decided to switch to a projection lithography system instead.**

   (a) If the optical source of the proximity lithography system has a wavelength of 405 nm, what is the minimum allowable gap that can be deployed? Assume the process dependent factor, k =1.

(a)

$$W_{\min} = \sqrt{k\lambda g}$$

$$g = \frac{(W_{\min})^2}{k\lambda}$$

$$= \frac{0.5x0.5x10^{-12}}{1x405x10^{-9}} = 0.62\mu m$$

Tutorial 2

5. **An engineer first used a proximity lithography system to try printing a submicron pattern with a minimum feature size of 0.5 μm. He found that the resolution is bad and attempted some optical enhancement techniques, but image reproduction still remains poor. Realizing soon the futility of achieving the required resolution, he decided to switch to a projection lithography system instead.**

   (b) Why is the proximity lithography system unable to achieve the required resolution? What are the possible optical enhancement techniques that he had attempted?

(b) (i) Due to diffraction , Maximum allowable proximity of 0.62μm difficult to implement in practice.

Possible enhancement techniques are (i) phase shift masks (ii) optical proximity correction (iii) off-axis illumination

Tutorial 2

5. **An engineer first used a proximity lithography system to try printing a submicron pattern with a minimum feature size of 0.5 μm. He found that the resolution is bad and attempted some optical enhancement techniques, but image reproduction still remains poor. Realizing soon the futility of achieving the required resolution, he decided to switch to a projection lithography system instead.**

   (c) Will the above-mentioned projection lithography system be able to meet the resolution requirement? Assume the optical source of the projection lithography system has a wavelength of 248 nm, its optics components have a light gathering power of 0.60 and process dependent factor, k =1.

(c) $$W_{\min} \approx k\frac{\lambda}{NA}$$

$$= \frac{1x\ 248\ x10^{-9}}{0.6} = 0.41\ \mu m$$

Yes, the projection lithography system is able to meet the resolution requirement.

Tutorial 2

5. An engineer first used a proximity lithography system to try printing a submicron pattern with a minimum feature size of 0.5 μm. He found that the resolution is bad and attempted some optical enhancement techniques, but image reproduction still remains poor. Realizing soon the futility of achieving the required resolution, he decided to switch to a projection lithography system instead.

(d) Suggest suitable optical sources for the above-mentioned proximity and projection lithography systems.

(d) (i) Hg lamp for the proximity lithography system

(ii) Excimer laser for the projection lithography system

Tutorial 2

5. **An engineer first used a proximity lithography system to try printing a submicron pattern with a minimum feature size of 0.5 μm. He found that the resolution is bad and attempted some optical enhancement techniques, but image reproduction still remains poor. Realizing soon the futility of achieving the required resolution, he decided to switch to a projection lithography system instead.**

   (e) Discuss the implication to the depth of focus for the projection lithography system if (i) the projection lens diameter is doubled while maintaining its focal length (ii) phase shift masks are used in the exposure and (iii) the system is immersed in oil as opposed to air used in the earlier case.

(i) Increase NA, hence depth of focus worse off

(ii) Decrease k, hence depth of focus worse off

(iii) Increase NA, since refractive index of oil is higher than that of air, depth of focus worse off