EE6601 - Lithography II

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.

(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).

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	

From the table, state the effect of the exposure wavelength on the resolution, W and the maximum allowable gap, g.

(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.

(c) Briefly describe the simplified formula for the resolution (W) and depth of focus (σ) of the Water Immersion lithography (IML) system.

(d) What are the advantages of 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).

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) Immerse the lithographic system in water as opposed to air used in the earlier case.

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.

   (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.

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

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.

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

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.

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, $k = 1$.

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

(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, $k = 1$.

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

(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.