Lithography I

1. List the various steps for a photolithography process. Give a short explanation for each processing step. What are the consequences of overbaking and under baking during a soft bake process?

Step	Purpose
1. Vapour Prime	De-bakes and primes wafer surface with HMDS to improve photoresist to wafer adhesion
2. Spin Coat	Spin coat photoresist to the target thickness
3. Soft Bake	• Partial evaporation of photoresist solvents • Improves photoresist-to-wafer adhesion promotes resist uniformity on the wafer • Optimises light absorbance characteristics of photoresist (exposure speed) • Improves etch resistance and linewidth control during etching
4. Alignment and Exposure	Transfers the mask image to the resist-coated wafer activates photo-sensitive components of photoresist

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Step	Purpose
5. Post-Exposure Bake (PEB)	Required for DUV resist preventing non-uniform exposure along the thickness of the photoresist film
6. Develop	Dissolves the exposed photoresist
7. Hard Bake	• Evaporates the residual solvent in the photoresist • Hardens the resist for subsequent ion implant or etch processing • Improves resist-to-wafer adhesion
8. Develop Inspect	Checks the quality of process to ensure the desired pattern is transferred to photoresist layer

- A short prebake will prevent UV light from reaching the PAC due to an excess of solvent remaining in the PR.
- Over-baking the sample will increase the sensitivity to UV light and, in severe cases, may destroy the PAC and reduce the solubility of the PR in the developer.

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2. A basic photolithography process using automatic track systems has the following steps: vapor prime, photoresist spin coat, dehydration bake, soft-bake, develop, alignment and exposure, hard-bake, develop inspect and post-exposure bake.

i. Rearrange these steps in a proper sequence.

ii. What chemical is used in the vapor priming and what is the purpose of this step?

iii. What is the purpose of the dehydration bake?

iv. What is the purpose of the soft-bake step?

v. What is the purpose of the hard-bake step?

i. Dehydration bake → Vapor Prime→ Photoresist spin coat → Soft-bake → Alignment and Exposure → Post-exposure bake → Develop → Hard bake → Develop inspect

ii. Primes Wafer with Hexamethyldisilazane, HMDS. Promotes Good Photoresist-to-Wafer Adhesion

iii. Ensures Wafer Surface is clean and dry - removal of water molecules on the wafer surface

iv. Drives off most of solvent in photoresist, improves adhesion, uniformity, etch resistance, linewidth control and optimizes light absorbance characteristics of photoresist

v. Evaporate remaining solvent, improve resist-to-wafer adhesion

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3. Figure 1 shows the various steps in a lithographic process. What are the two process steps indicated in boxes (3) and (4)? Provide typical process parameters used in these steps.

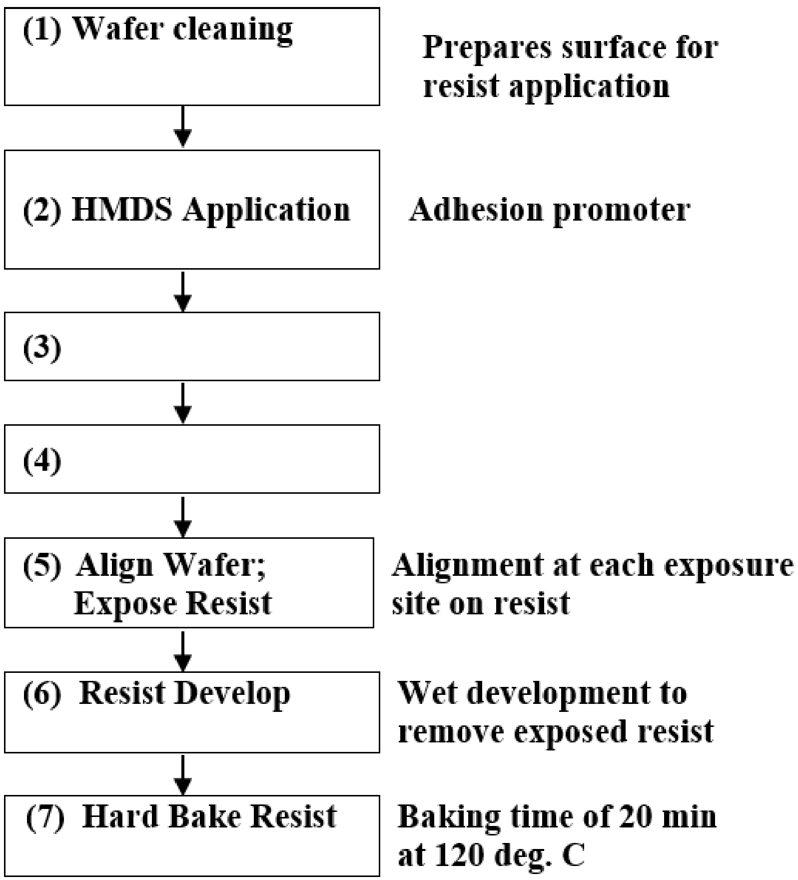

Figure 1

Spin Coat	Spin coat photoresist to the target thickness • Dispense ~5 ml of the resist at static or slow spread speed of ω1~500 rpm • Ramp up to ω2~3000 to 5000 rpm
Soft Bake	Partial evaporation of photoresist solvents • Typical bake temperatures are 90˚ C to 100˚ C: • For about 30 seconds • On a hot plate • Followed by a cooling step on a cold plate

Lithography I

4. Figure 2 shows a wafer undergoing the various steps of a photolithography process. (i) List the steps involved in the process from (a) to (d). (ii) Identify the type of resist used. (iii) Recommend a suitable method from Step (e) to Step (f). Explain your recommendation. (iv) Identify the type of exposure system used and briefly explain its relevance in today's semiconductor manufacturing.

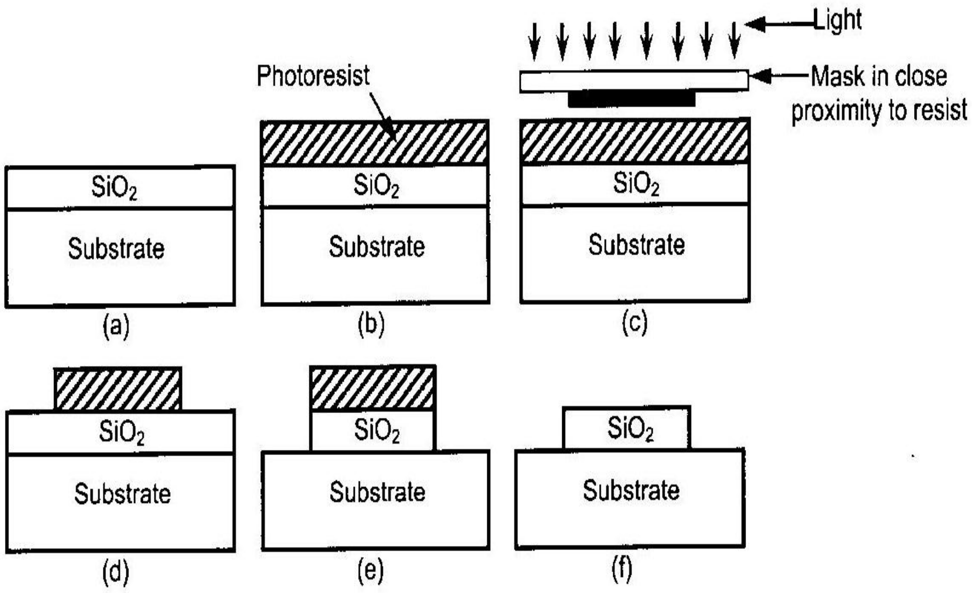

Figure 2

i. (a) Vapour prime
   (b) Spin coat
   (c) Soft bake, alignment and exposure, post exposure bake.
   (d) Develop, hard bake.

ii. Positive resist

iii. Dry Etching – use oxygen plasma to remove carbon based resist

iv. Proximity Printer / Projection Printer – relatively high throughput and good printing resolution

5. Given that:

(i) A Hg lamp with dominated photon energy of 7.936 x 10^{-19} J,

(ii) An ArF excimer laser with frequency of 1.55 x 10^{15} Hz, and

(iii) X-rays produced by a 50 kV X-ray machine

Construct a table of the wavelength of these sources. Given that the proximity gap of 10 μm, predict the proximity printing diffraction limited minimum feature size for each source, if the resists used have $k_1$value of 1.

(Plank's constant, = 6.625 x 10^{-34} J.s, electron charge, = 1.602 x 10^{-19} C, and electron mass, = 9.11 x 10^{-31} kg, speed of light, c = 3 x 10^{8} ms^{-1})

(i) $E_{Photon} = h\nu = \dfrac{hc}{\lambda}$

$$\lambda = \frac{hc}{E_{Photon}} = \frac{6.625x10^{-34} \times 3x10^{8}}{7.936x10^{-19}} = 250nm$$

For Proximity Printing:

$$W_{\min} = \sqrt{k\lambda g} = \sqrt{250x10^{-9} \times 10x10^{-6}} = 1.58\mu m$$

NOTE:
Take k (resist const.) = 1

5. Given that:

(i) A Hg lamp with dominated photon energy of 7.936 x 10^{-19} J,

(ii) An ArF excimer laser with frequency of 1.55 x 10^{15} Hz, and

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(ii) $\lambda = \frac{c}{v} = \frac{3x10^8}{1.55x10^{15}} = 194nm$ ➔ $W_{\min} = \sqrt{k\lambda g} = \sqrt{194x10^{-9} \times 10x10^{-6}} = 1.40\mu m$

(iii) *From 50kV, the energy will be* $\rightarrow 50x10^3 \times 1.6x10^{-19} = 8x10^{-15}\,J$

$$\lambda = \frac{hc}{E} = \frac{6.625x10^{-34} \times 3x10^8}{8x10^{-15}} = 0.25\text{Å}$$

$$W_{\min} = \sqrt{k\lambda g} = \sqrt{0.25x10^{-10} \times 10x10^{-6}} = 15.8nm$$

6. An exposure is performed using a step-and-repeat aligner printing system with a light source that has a wavelength of 365 nm (I-line of a mercury lamp). The pattern obtained is a grating with a line-to-line spacing of 1 µm. Assume that the resist constant k_1 and k_2 = 1. (i) Calculate the value of the numerical aperture that will provide contrast at the image plane (i.e. the plane of the resist). (ii) Determine the depth of focus (DOF) of the image. (iii) Explain how the DOF of the exposure system is influenced by the numerical aperture of the imaging lens and the wavelength of the exposing light. How will an improvement in DOF affect the resolution of the system?

(i) *For Projection printing*

$$1x10^{-6} = \frac{365x10^{-9}}{NA}$$

$$NA = \frac{365x10^{-9}}{1x10^{-6}} = 0.365$$

(ii) $$\sigma_{(DOF)} = \frac{k_2\lambda}{(NA)^2}$$

$$= \frac{365x10^{-9}}{(0.365)^2}$$

NOTE: take n = 1

$$= 2739nm \quad (2.74\mu m)$$

(iii) *Increase in DOF leads to higher wavelength and smaller NA. This in turn results in lower resolution of the system.*