

UNIVERSITY OF CALIFORNIA
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EE143

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Exam 1

Name: Answers

SID: 31337

Closed book. One sheet of notes is allowed.
There are a total of 11 pages on this exam, including the cover page.

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Physical Constants

Electronic charge	q	$1.602 \times 10^{-19} \text{ C}$
Permittivity of vacuum	ϵ_0	$8.845 \times 10^{-14} \text{ F cm}^{-1}$
Relative permittivity of silicon	$\epsilon_{\text{Si}}/\epsilon_0$	11.8
Boltzmann's constant	k	$8.617 \times 10^{-5} \text{ eV/K}$ or $1.38 \times 10^{-23} \text{ J K}^{-1}$
Thermal voltage at $T = 300\text{K}$	kT/q	0.026 V
Effective density of states	N_c	$2.8 \times 10^{19} \text{ cm}^{-3}$
Effective density of states	N_v	$1.04 \times 10^{19} \text{ cm}^{-3}$
Intrinsic carrier concentration of Silicon at $T=300\text{K}$	n_i	10^{10} cm^{-3}

	I A	II A											III A	IV A	V A	VI A	VII A	0
1	H																	2 He
2	Li	Be											B	C	N	O	F	Ne
3	Na	Mg	III B	IV B	V B	VI B	VII B	VIII		IB	IIB		Al	Si	P	S	Cl	Ar
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
6	Cs	Ba	*La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
7	Fr	Ra	+Ac	Rf	Ha	Sg	Ns	Hs	Mt	110	111	112	113					

Problem 1. True/False (20 pts)

Circle either (T) rue or (F) alse (2 pts each)

- 1) Mixing acid and solvents should be done carefully in the sink area. T / **F**
- 2) Piranha removes both organic AND metallic contaminants from the wafers **T** / F
- 3) Partially coherent light improves the resolution of smaller feature sizes for projection lithography as compared to a fully coherent light. **T** / F
- 4) n-type Si has zero hole concentration T / **F**
- 5) When a positive photoresist is exposed to light, cross-linking of the polymeric chains is resulted. T / **F**
- 6) Band-gap of semiconductors increase with temperature T / **F**
- 7) We can use pyrex glassware to perform HF etching of substrates T / **F**
- 8) If your skin is brought in contact to HF, then rinse your exposed body part under water for 15 min. T / **F**
- 9) You wear a gown in the clean room mainly to protect yourself from hazardous and corrosive chemicals. T / **F**
- 10) For an ideal exposure, contact printing can provide a higher image contrast than the proximity printing. **T** / F

Problem 2. Introduction to Materials (36 pts)

- a) Suppose we have a piece of silicon doped with Indium at a concentration of $1 \times 10^{16} \text{ cm}^{-3}$. Is this semiconductor p-type, n-type, or intrinsic? Briefly explain in one sentence. [2 pts]

p-type, Indium is a group III element.

- b) What are the majority and minority carrier concentrations for the semiconductor in part a? [2 pts]

$$p = N_a = 1E16$$

$$n = \frac{n_i^2}{p} = 1E4$$

- c) Find $E_c - E_f$ at $T=300\text{K}$ for the semiconductor in part a. [4 pts]

$$E_c - E_f = kT \ln \left(\frac{N_v}{p} \right) = 0.026 \ln \left(\frac{1.04E19}{1E16} \right) = 0.92 \text{ eV}$$

- d) Find $E_c - E_f$ at $T=1300\text{K}$ for the semiconductor in part a. [4 pts]

Quite simply, $\sim E_g/2$ since the intrinsic carrier concentration becomes dominant, making the semiconductor effectively intrinsic.

- e) Now we add Antimony at a concentration of $5 \times 10^{16} \text{ cm}^{-3}$ to the semiconductor in part a. Find $E_c - E_f$ at $T=300\text{K}$. [4 pts]

$$E_f - E_i = kT \ln \left(\frac{5 \times 10^{16} - 1 \times 10^{16}}{1 \times 10^{10}} \right)$$

$$E_c - E_f = 0.56 - (E_f - E_i)$$

$$E_c - E_f = 0.166 \text{ eV}$$

- f) Intrinsic carrier concentration of semiconductors increase with temperature. Briefly explain why that is the case (2 sentences max). [4 pts]

At higher temperature, electrons from the valence band have more thermal energy and thus, higher probability of jumping to the conduction band

- g) Do amorphous and crystalline germanium have the same band gap? Briefly explain (2 sentences max). [4 pts]

No. Band gap depends on the spacing and bonding of the atoms in the lattice.

- h) Ge ($E_g \sim 0.6$ eV), Si ($E_g \sim 1.1$ eV), and GaAs ($E_g \sim 1.4$) are all popular semiconductor. Which of these materials would be most suitable for an integrated circuit to be placed in an Earth orbit satellite? Briefly explain your answer (2 sentences max) [4 pts]

GaAs because it has the largest bandgap. This makes it less sensitive to changes in temperature.

- i) Ge ($E_g \sim 0.6$ eV), Si ($E_g \sim 1.1$ eV), and GaAs ($E_g \sim 1.4$) are all popular semiconductor. Which of these materials would be most suitable for use a visible light emitting diode (LED)? Briefly explain your answer (2 sentences max) [4 pts]

GaAs. $E_g \sim 1.4$ eV corresponds to red light.

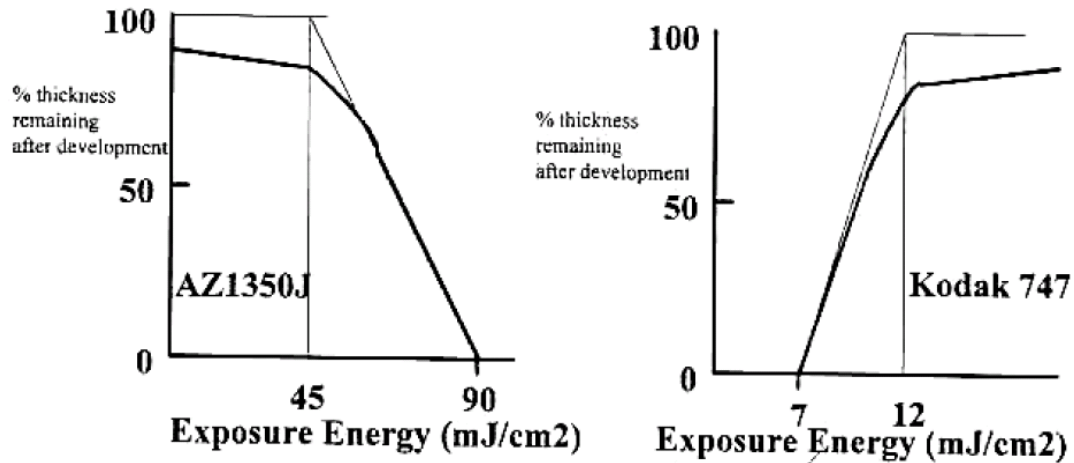
Note: However, Si at $E_g \sim 1.1$ eV corresponds to green light for indirect bandgap.

- j) Gold is a forbidden material in IC manufacturing. Briefly explain how gold affects the properties of Si. (2 sentences max) [4 pts]

Gold produces deep level traps. This increases the Recombination-Generation current.

Problem 3. Photolithography (20 pts)

- a) The following plots show percentage of resist remaining after exposure and development versus the exposure energy for Resist AZ1350J and Resist Kodak747.



- i) Which one of the above resists is a positive resist? [2 pts]

AZ1350J

- ii) Find the resist contrast for each of the resists. [4 pts]

For positive: $1/\log(90/45) = 3.32$

For negative: $1/\log(12/7) = 4.27$

- iii) Which resist has a higher sensitivity? [3 pts]

Kodak 747

- iv) A stepper with $\lambda = 365\text{nm}$ and $NA=0.7$ can produce L_{\min} of $0.3\ \mu\text{m}$ with $DOF = 0.4\ \mu\text{m}$. If we change to a new stepper with $\lambda = 248\text{nm}$ and $NA=0.5$, what are the new values for L_{\min} and DOF ? [4 pts]

$$L_{\min} = \frac{k_1 \lambda}{NA}$$

$$DOF = \frac{k_2 \lambda}{NA^2}$$

$$k_1 = \frac{300\text{nm}(0.7)}{365} = 0.57$$

$$k_2 = \frac{400(0.7)^2}{365} = 0.54$$

$$L_{\min} = \frac{0.57(248)}{0.5} = 283\text{ nm}$$

$$DOF = \frac{0.54(248)}{0.25} = 536\text{ nm}$$

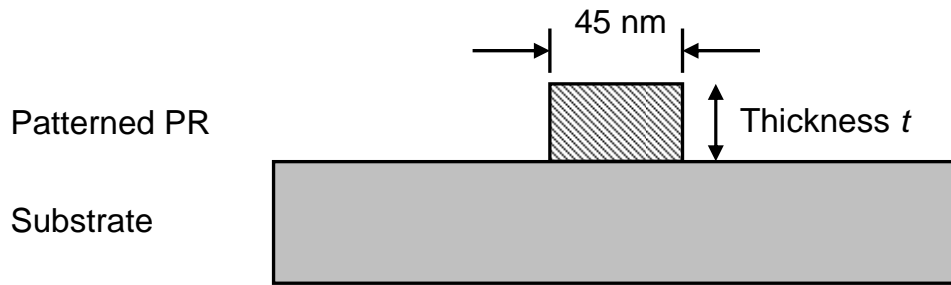
- v) Optical steppers have to be maintained at a constant temperature for operation. Briefly explain why that is the case (2 sentences max)? [4 pts]

Thermal expansion coefficients of mask, optics, and wafer are all different. This leads to critical dimension and overlay error.

- vi) Describe three techniques one can use to minimize the proximity effect in optical lithography. [3 pts]

- **Use absorption dyes in photoresist**
- **Use anti-reflection coating (ARC)**
- **Use multi-layer resist process**
 - thin planar layer for high-resolution imaging
 - thin develop-stop layer, used for pattern transfer to 3
 - thick layer of hardened resist

Problem 4. Photolithography (24 pts)



The profile above was created using a projection photolithographic method. The light source was an ArF excimer laser at 193nm.

- (a) If the projection system is 10:1, what is the actual width of the mask feature shown in the above figure? [4 pts]

$$45 \text{ nm} \times 10 = 450 \text{ nm}$$

- (b) Calculate the numerical aperture, NA, necessary to produce this patterned feature size. (assume $k_1=0.5$) [4 pts]

$$NA = \frac{k_1 \lambda}{L_{min}} = \frac{0.5(195 \text{ nm})}{45 \text{ nm}} = 2.14$$

- (c) If the half-angle of the maximum cone of light that can enter or exit the objective lens is 70° , what is the index of refraction between the lens and the photoresist? [4 pts]

$$n = \frac{NA}{\sin(70^\circ)} = \frac{2.14}{0.94} = 2.28$$

- (d) Experimentally, how do you achieve the index of refraction of part (c). (1 sentence max) [4 pts]

Immersion lithography (most likely solid immersion lithography)

- (e) Give one major advantage and one disadvantage of having a large NA. Briefly explain (3 sentences max). [4pts]

Small resolution, but also small DoF. Limits topography for small features.

- (f) Assume you have a perfectly flat surface (meaning the DOF is not relevant). You would like to get the maximum possible resolution by lowering your wavelength. What challenges will you face? [4 pts]

Absorption in the optical system for the small wavelengths means we need to use mirror optics. This makes the tool quite complex. The light source for such small wavelengths will be also a source of problem along with the appropriate high contrast resist.