UNIVERSITY OF CALIFORNIA
College of Engineering
Department of Electrical Engineering and Computer Sciences

EE143 Professor Ali Javey

Fall 2009

Exam 1

Name: <u>Answers</u>___________________________

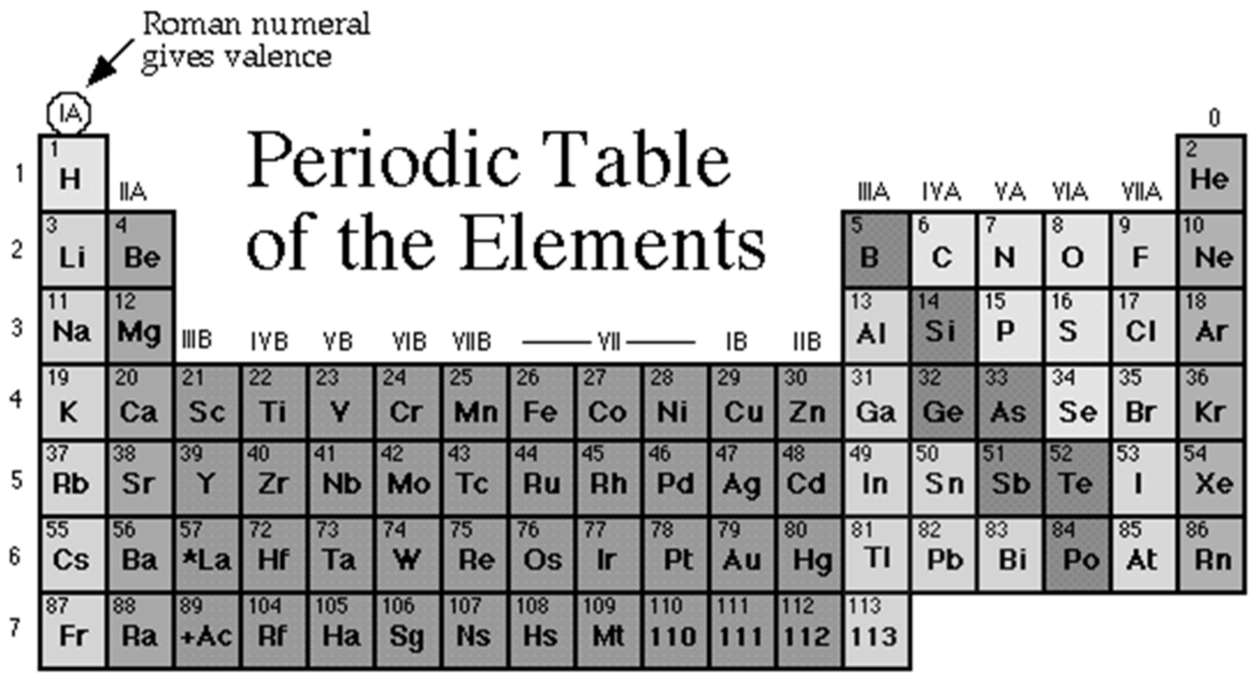
SID: <u>31337</u>____________________________

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

Problem 1	20
Problem 2	36
Problem 3	20
Problem 4	24
Total	100

Physical Constants

Electronic charge	q	1.602×10^{-19} C
Permittivity of vacuum	ε_0	8.845×10^{-14} F cm^{-1}
Relative permittivity of silicon	$\varepsilon_{Si}/\varepsilon_0$	11.8
Boltzmann's constant	k	8.617×10^{-5} eV/ K or 1.38×10^{-23} J K^{-1}
Thermal voltage at T = 300K	kT/q	0.026 V
Effective density of states	N_c	2.8×10^{19} cm^{-3}
Effective density of states	N_v	1.04×10^{19} cm^{-3}
Intrinsic carrier concentration of Silicon at T=300K	n_i	10^{10} cm^{-3}



Roman numeral gives valence
Periodic Table of the Elements
IA IIA IIIB IVB VB VIB VIIB VII IB IIB IIIA IVA VA VIA VIIA 0
1 1 H 2 He
2 3 Li 4 Be 5 B 6 C 7 N 8 O 9 F 10 Ne
3 11 Na 12 Mg 13 Al 14 Si 15 P 16 S 17 Cl 18 Ar
4 19 K 20 Ca 21 Sc 22 Ti 23 V 24 Cr 25 Mn 26 Fe 27 Co 28 Ni 29 Cu 30 Zn 31 Ga 32 Ge 33 As 34 Se 35 Br 36 Kr
5 37 Rb 38 Sr 39 Y 40 Zr 41 Nb 42 Mo 43 Tc 44 Ru 45 Rh 46 Pd 47 Ag 48 Cd 49 In 50 Sn 51 Sb 52 Te 53 I 54 Xe
6 55 Cs 56 Ba 57 *La 72 Hf 73 Ta 74 W 75 Re 76 Os 77 Ir 78 Pt 79 Au 80 Hg 81 Tl 82 Pb 83 Bi 84 Po 85 At 86 Rn
7 87 Fr 88 Ra 89 +Ac 104 Rf 105 Ha 106 Sg 107 Ns 108 Hs 109 Mt 110 110 111 111 112 112 113 113

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 $1x10^{16}$ 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]

$$\boldsymbol{p = N_a = 1E16}$$
$$\boldsymbol{n = \frac{n_i^2}{p} = 1E4}$$

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

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

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

$$\boldsymbol{E_c - E_f = kTln\left(\frac{N_v}{p}\right) = \frac{8.617E-5\ eV}{K} * 1300\ K * ln\left(\frac{1.04E19}{1E16}\right) = 0.56\ eV}$$

Or quite simply, ~Eg/2 since the intrinsic carrier concentration becomes dominant, making the semiconductor effectively intrinsic.

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

$$E_f - E_i = kTln\left(\frac{5E16 - 1E16}{1E10}\right)$$

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

$$E_c - E_f = 0.166\ eV$$

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 (Eg~0.6 eV), Si (Eg~1.1 eV), and GaAs (Eg~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 (Eg~0.6 eV), Si (Eg~1.1 eV), and GaAs (Eg~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 ~ 1.4 eV corresponds to red light.

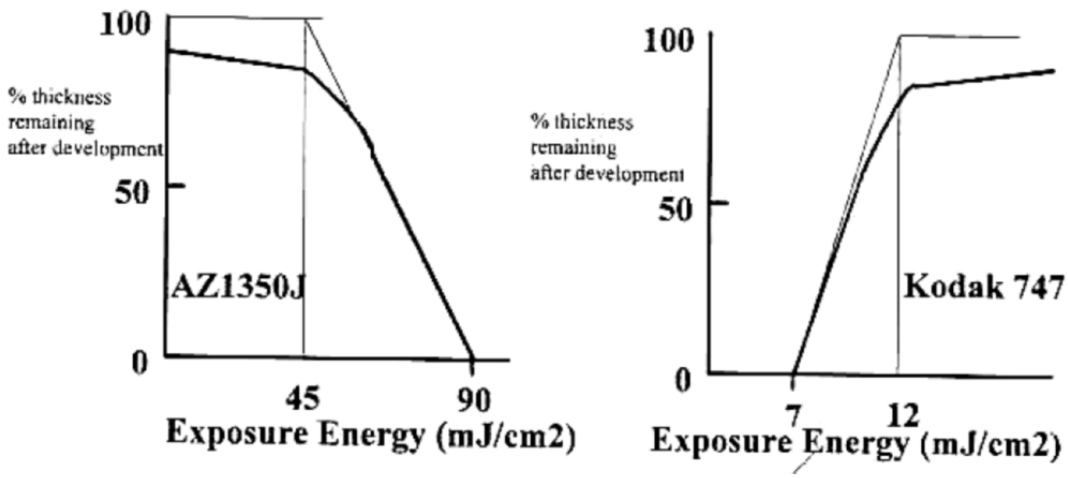
Note: However, Si at Eg~1.1 eV corresponds to green light for indirect bandgap.

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: $\frac{\Delta y}{\Delta x} = \frac{100-0}{90-45} = \frac{100}{45} = 2.22$

For negative: $\frac{\Delta y}{\Delta x} = \frac{100-0}{12-7} = \frac{100}{5} = 20$

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

Kodak 747

iv) A stepper with λ =365nm and NA=0.7 can produce L_{min} 0f 0.3 μ m with DOF = 0.4 μ m. If we change to a new stepper with λ =248nm and NA=0.5, what are the new values for L_{min} and DOF? [4 pts]

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

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

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

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

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

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

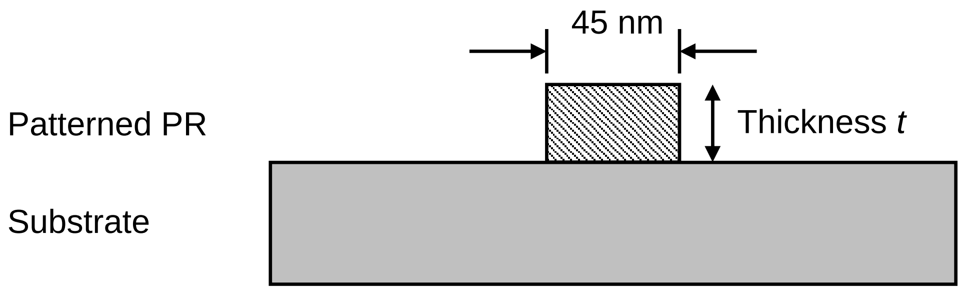
v) Optical steppers have to be maintained at a constant temperature for operation. Briefly explain why that is the case (2 sentences max)? [4 pts]

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 nm x 10 = 450 nm

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

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

(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]

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

(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.