Fall Semester 2003 **Name:** SOLUTIONS

UNIVERSITY OF CALIFORNIA AT BERKELEY
College of Engineering
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Engineering 45

Exam #1 (40 pts.), Sept. 26

1.) (2 pts.) Gallium, one of the most important components of optoelectronic semiconductors, has an atomic weight of 69.75. It consists of the two isotopes ^{69}Ga and ^{71}Ga. What are the relative abundances of these two isotopes?

$$69.75 = x\,69 + (1-x)\,71$$

$$= -2x + 71$$

$$x = 0.625$$

62.5 % ^{69}Ga

37.5 % ^{71}Ga

2.) (5 pts.) The hydrogen atom consists of one proton binding one electron with an energy of $E_1 = -13.6\text{eV}$ in the ground state. There are higher lying bound states with energies

$$E_n = \frac{1}{n^2} E_1 \ (n = 2,\ 3,\ ....)$$

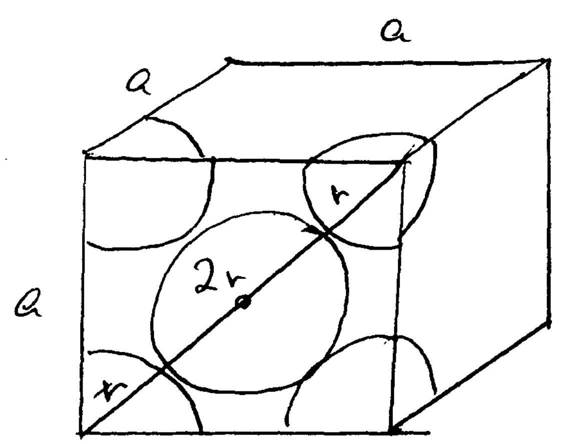
Assume the hydrogen atom has been excited into the n = 2 state. Will shining visible light onto this excited hydrogen atom lead to full ionization? (visible range: $2\text{eV} < E_{photon} < 3\text{eV}$) $E_{photon} = h\nu = hc/\lambda$, with $h = 4.1375 \times 10^{-15}$ eV·s
Show your work!

$$E_2 = \frac{1}{2^2}(-13.6\text{ eV})$$

$$= -3.4\text{eV}$$

Visible light ($2\text{eV} < E < 3\text{ eV}$) cannot ionize H in its $n = 2$ state

3.) (4 pts.) Calculate the atomic packing factor (APF) for a FCC metal. (Hint: make a sketch of the FCC unit cell and figure out how many atoms occupy the cell.)



$$a\sqrt{2} = 4r \qquad r = \frac{1}{4}a\sqrt{2}$$

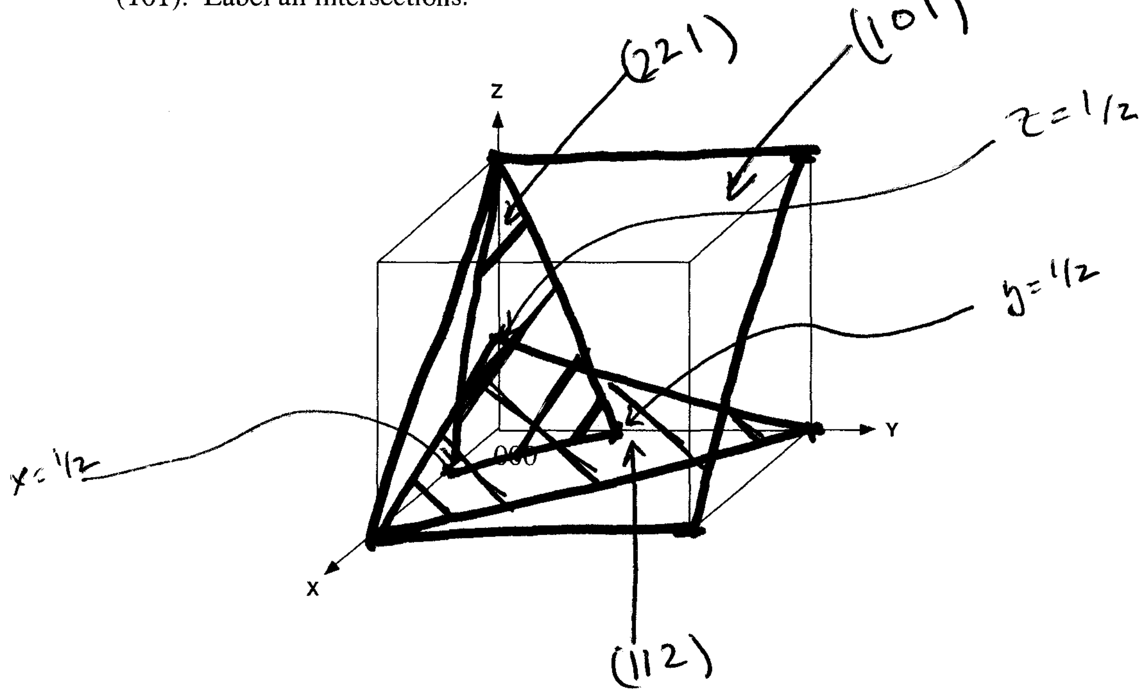
there are 4 atom volumes in the FCC unit cell

Total atom volume: $4 \times \frac{4\pi r^3}{3} = \frac{16}{3}\pi\left(\frac{1}{4}a\sqrt{2}\right)^3$

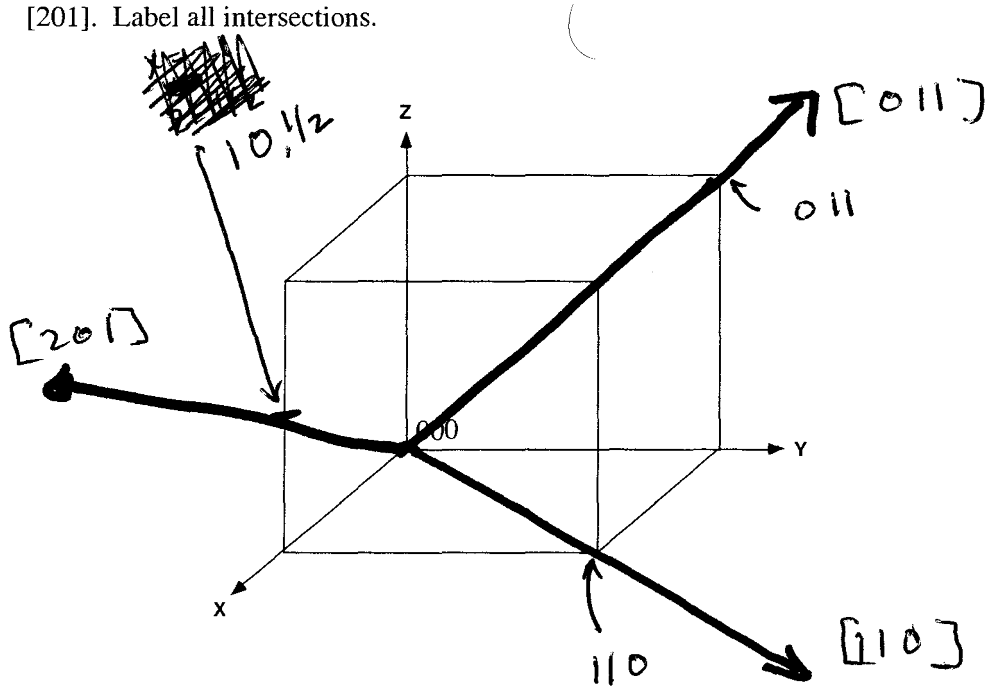
Total unit cell volume: a^3

$$\text{AFP} = \frac{16}{3}\pi\left(\frac{\sqrt{2}}{4}\right)^3 = 0.74$$

4.) (3 pts.) Using the cube below, show the following crystal planes: (112), (221) and (101). Label all intersections.



5) (3 pts.) Using the cube below, show the following crystal directions: [110], [011], and [201]. Label all intersections.



6.) (4 pts.) Consider the family of directions <111>. Which ones of these directions lie in the $(10\bar{1})$ plane?

use the dot product!

$[10\bar{1}]\cdot[111] = 0$

" $[1\bar{1}1] = 0$

" $[\bar{1}1\bar{1}] = 0$

" $[\bar{1}\bar{1}\bar{1}] = 0$

7.) (5 pts.) The vacancy concentration in silicon is rising exponentially with temperature.

$$n_v = N_{Si}\ \exp\left(-\frac{E_v}{k_B T}\right)$$

with $N_{Si} = 5 \times 10^{22}$ cm^{-3}, $k_B = 8.62 \times 10^{-5}$eV/K and $E_V = 2$eV.

By what factor does n_V drop when the Si crystal cools down from 1600K to 1000K?

$1600 \to 1000$

$\frac{n_v^{1600}}{n_v^{1000}}$

$$\frac{n_v(1600K)}{n_v(1000K)} = \frac{N_{Si}}{N_{Si}} \cdot \frac{\exp[-E_v/k_B T_1]}{\exp[-E_v/k_B T_2]}$$

$$= \exp\left(-E_v/k_B\right)\left(\frac{1}{1600} - \frac{1}{1000}\right)$$

equation in the ratio

$$\ln\left(\frac{n_v(1600)}{n_v(1000)}\right) = -\frac{E_v}{k_B}\left(\frac{1}{1600} - \frac{1}{1000}\right)$$

$\underbrace{6.25\times10^{-4} - 10^{-3}}_{-3.75\times10^{-3}}$

$= 8.700$

$$\frac{n_v(1600)}{n_v(1000)} = 6003$$

8.) (5 pts.) Today I measured the resistances of the filaments of a 150W and a 40W incadescent light bulb. My Ohm Meter showed 7Ω and 30Ω, respectively. Calculate the resistances of these two light bulbs based on their specifications running at 110V.

The power P disspated in Watts (W) is:

$$P = I \cdot V$$

The resistance R is: $R = \frac{V}{I}$

Compare your calculated result with the measurements. In case there are differences, explain these with physical arguments.

$$P = I V = \frac{V^2}{R}$$

150 Watt bulb: $R = \frac{(110)^2}{150} = 80.7\ \Omega$ + 2

compared to the 7 Ω ! reading.

40 watt bulb: $R = \frac{(110)^2}{40} = 302.5\ \Omega$ + 2

as compared to 30 Ω !

The big difference in resistivity is related to the fact that the resistivity increases with temperature. + 1

An operating light bulb is very hot → R large;

the Ohm Meter does not heat the light bulb filament → R small.

9.) (6 pts.) (a) The possibility to find an electron at energy E is given by the Fermi function F(E):

$$F(E) = \frac{1}{1 + \exp \frac{E - E_F}{k_B T}}$$

Determine F(E) at room temperature 300K for the following energies:

$$E\text{-}E_F = k_BT,\ 2k_BT,\ -k_BT,\ -2k_BT$$

$F(E) = 0.269$

$= 0.119$

$= 0.731$

$= 0.881$

(b) Assume the Fermi level E_F lies in the middle of the bandgap of Si (E_G = 1.1eV). Calculate the probability to find at room temperature (T = 300K) an electron at the conduction band edge.

$$F(E) = \frac{1}{1 + \exp\left[\frac{0.55\,eV}{8.62\cdot 10^{-5}\,eV/K \cdot 300\,K}\right]}$$

21.268

$= 5.8 \times 10^{-10}$

(c) as (b) but calculate the probability to find a hole at the valence band edge.

$1 - F(E)$ = prob. to find a hole

$$= 1 - \frac{1}{1 + \exp\left[\frac{-0.55\,eV}{k_B \cdot 300\,K}\right]}$$

$= 5.8 \times 10^{-10}$

10.) (3 pts.) True or False

	T	F
– Phosphorus forms a donor in silicon.	(X)	( )
~~– Silicon forms a donor on an As site in GaAs.~~	( )	(X) deleted
– Germanium forms a donor on a Ga site in GaP.	(X)	( )
– For a given temperature, intrinsic silicon contains more free carriers than intrinsic germanium.	( )	(X)
– A semiconductor containing the same amount of donors as acceptors exhibits a free carrier concentration large than the intrinsic carrier concentration.	( )	(X)
– A given doped semiconductor is dominated by the dopants over a finite temperature range.	(X)	( )