Question 1 (30)

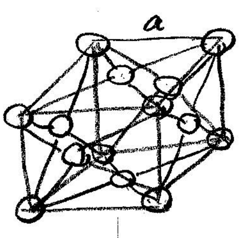
1.1. (5) What is the type of unit cell of silicon?

a. BCC   (b.) Diamond   c. FCC   d. Hexagonal closed pack

1.2. (5) How many atoms are there in silicon unit cell?

(a. 8)   b. 6   c. 4   d. 2

1.3. (13) Using a schematic show how atoms are arranged in a face-centered cubic (FCC) crystal. If atoms are hard spheres (with ~~diameter~~ radius r) and are closely-packed in a FCC unit cell with side a, find the relationship between r and a. What ratio of FCC unit cell is filled with atoms. Hint: volume of sphere: $4\pi r^3/3$.

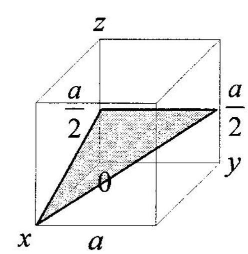


$$4r = \sqrt{2}a \rightarrow a = \frac{4}{\sqrt{2}}r$$

$$\text{ratio filled} = \frac{(8\times 1/8 + 1/2\times 6)\times 4/3\,\pi r^3}{a^3} = \frac{16/3\,\pi r^3}{4^3/\sqrt{2}^3\, r^3}$$

$$= \frac{2\sqrt{2}\pi}{3\times 4/2} = \frac{\pi}{3\sqrt{2}} = 74\%$$

1.4. (5) For a cubic unit cell with side a, what are the Miller's indices for the plane shown in the figure?

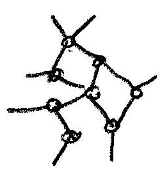


(x y z)

1 ∞ 1/2

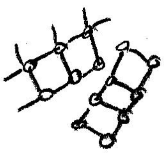
(1 0 2)

1.5. (7) Using a schematic explain the difference between the lattice structure of amorphous, polyscrystalline, and crystalline materials.



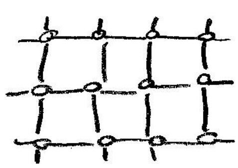
amorphous

no long range order



poly crystalline

pieces of crystal in contact with each other having a grain boundaries

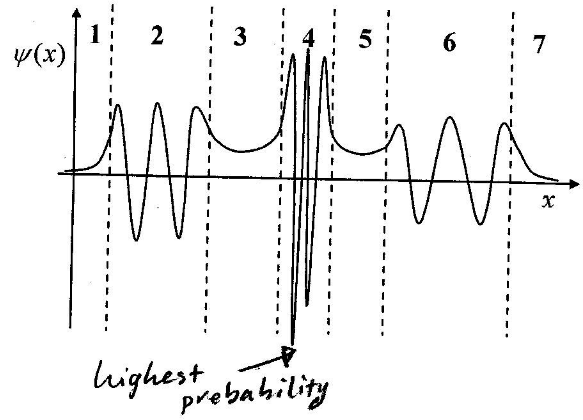


single crystal

high order in atomic arrangement

Question 2 (17)

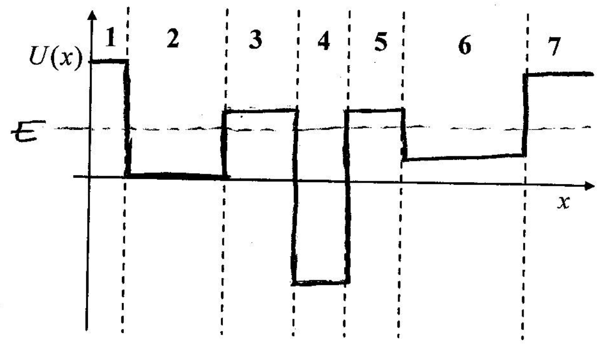
2.1. (6) The figure shows a wavefunction $\psi(x)$ for an electron with energy E. Using an arrow show the point with highest probability for finding the electron.



2.2. (6) For which regions we have $E < U_i(x)$, where $U_i(x)$ is the potential energy in region i. Why?

For $E<U$ we have exponential solution not oscillating.

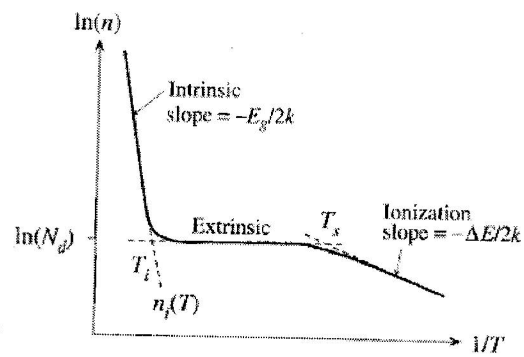
Regions: 1, 3, 5, 7



2.3. (5) Plot approximate $U(x)$ as a function of x.

Question 3 (32)

3.1. (9) Using the graph shown explain how the density of electrons change in a n-type semiconductor as a function of temperature.



As the temperature increases the density of electrons given by dopants increases until we reach Ts. At this temperature, most dopant electrons are given to the semiconductor. So the density of electrons will be constant as a function of temperature.

As we increase the temperature even further there is a temperature Ti, where the intrinsic electrons become more than dopant electrons. Beyond this point electron density increases exponentially.

3.2. (7) Show that the Fermi energy E_{Fi} for an intrinsic semiconductor is $\frac{3kT}{4}\ln\frac{m_p^*}{m_n^*}$ from the middle of the band gap.

$$n_i = N_c e^{\frac{E_{Fi}-E_c}{kT}}, \quad p_i = n_i = N_v e^{\frac{E_v - E_{Fi}}{kT}} \rightarrow N_c e^{\frac{E_{Fi}-E_c}{kT}} = N_v e^{\frac{E_v - E_{Fi}}{kT}}$$

middle of gap $= E_i$

$$kT \ln N_c + E_{Fi} - E_c = kT \ln N_v + E_v - E_{Fi} \rightarrow E_{Fi} = \frac{E_c + E_v}{2} + \frac{kT}{2}\ln\frac{N_v}{N_c}$$

$$E_{Fi} - E_i = \frac{kT}{2}\ln\frac{N_c}{N_v} = \frac{kT}{2}\ln\left(\frac{m_p^*}{m_n^*}\right)^{3/2} = \boxed{\frac{3kT}{4}\ln\frac{m_p^*}{m_n^*}}$$

$$N_c = 2\left(\frac{2\pi m_n^* kT}{h^2}\right)^{3/2}$$

$$N_v = 2\left(\frac{2\pi m_p^* kT}{h^2}\right)^{3/2}$$

3.3. (16) A semiconductor has an intrinsic carrier density of 10^{10} cm^{-3} at room temperature. This semiconductor is doped with a donor density of 10^{15} cm^{-3}. What are the density and type of majority and minority carriers and conductivity of this semiconductor if $\mu_n = 2\mu_p = 1000$? Find the density of acceptors needed to be added to this semiconductor to keep it n-type but decrease the conductivity by 10 times.

$N_D = 10^{15}$ → majority: electrons: $n_o = 10^{15}\ cm^{-3}$

minority: holes: $p_o = \frac{n_i^2}{n_o} = \frac{(10^{10})^2}{10^{15}} = 10^5\ cm^{-3}$

$$\sigma = q\mu_n n_o + q\mu_p p_o =$$

$$1.6\times10^{-19}\left(1000\times10^{15} + 500\times10^5\right) = 0.16\ \Omega^{-1}cm^{-1}$$

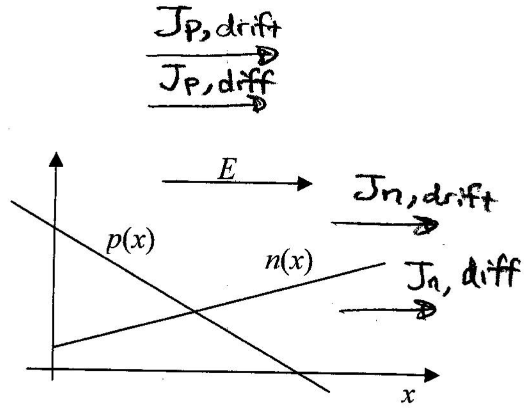
$$\sigma' = \frac{\sigma}{10} = \frac{0.16}{10} = 0.016\ \Omega^{-1}cm^{-1}$$

$$\sigma' = q\mu_n n_o' \rightarrow n_o' = \frac{\sigma'}{q\mu_n} = \frac{0.016}{1.6\times10^{-19}\times1000} = 10^{14}\ cm^{-3}$$

$$n_o' = N_{Do} - N_A \rightarrow N_A = N_{Do} - n_o' = 10^{15} - 10^{14} = \boxed{9\times10^{14}\ cm^{-3}}$$

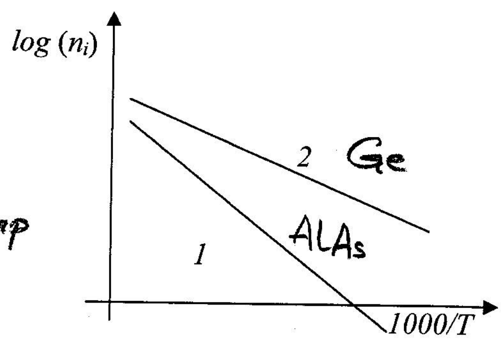
Question 4 (16)

4.1. (8) On the graph, show the direction of drift and diffusion hole and electron currents for the given electric field and electron and hole concentration as a function of x.



4.2. (8) Using the graph below for bandgap of different semiconductor, show which one of the two lines in the graph on right is for intrinsic electron density $n_i(T)$ of Ge and which one for $n_i(T)$ of AlAs.

Why?



AlAs has a higher bandgap and the slope is given by

$-E_g/2kT$