Exam 1

"I pledge my honor I have abided by the Stevens Honor system." - Alex Daskins

Wednesday, September 22, 2021 9:30 PM

1. What is meant by a substitutional impurity in a crystal?

When a single atom in the crystal structure is replaced by a different type of atom

2. What is meant by an interstitial impurity?

A different atom that fills a normally empty space between a crystal structure.

3. What is the difference between crystalline material and polycrystalline material?

A crystalline material is a material comprised of a single grain, typically from one crystal (acting as the seed crystal). A polycrystalline material has many grains with different orientations.

4. Describe a hole in a semiconductor.

A hole in a semiconductor is the absence of an electron in an atom. It's not actually a physical particle in the atom, it is an electric charge carrier with the same magnitude but opposing polarity to the charge of the electron.

5. What is meant by an indirect and direct band gap semiconductor and give examples of each?

For a direct band gap semiconductor, the top of the valence band and the bottom of the conduction band occur at the same momentum. Examples of direct bandgap materials include amorphous silicon or Gallium arsenide [GaAs].

With an indirect band gap semiconductor, the maximum energy value in the valence band occurs at a different momentum than the minimum energy value in the conduction band. Examples of indirect bandgap materials include crystalline silicon and Germanium [Ge].

6. What is the meaning of the Fermi Dirac probability function?

It represents the probability distribution of energies in quantum states in which electrons can reside at a given temperature. Essentially demonstrating what happens to electrons (speed and occupancy) as temperature changes.

7. What is the Fermi energy?

The Fermi energy is the energy difference between the highest and lowest occupied single particle states in a quantum system at absolute zero temperature.

8. The lattice constant of GaAs is 5.65 angstroms, determine the number of Ga atoms and As atoms per cm^3, what is the unit cell of GaAs, calculate the density of GaAs from this data.

GaAs is a diamond crystal structure with 4 Ga atoms and 4 As atoms

$$\text{Density} = \left[\frac{2.22\times10^{22}\,[69.72+74.92]}{6.022\times10^{23}}\right] = 5.33\ g/cm^3$$

m Ga: 69.72 g/mol
m As: 74.92 g/mol

$$\text{Number of Ga} = \left[\tfrac{4}{8}\left(4.44\times10^{22}\right)\right] = 2.22\times10^{22}\ \text{atoms}/cm^3$$

$$\text{Number of As} = \left[\tfrac{4}{8}\left(4.44\times10^{22}\right)\right] = 2.22\times10^{22}\ \text{atoms}/cm^3$$

$$\text{Volume Density} = \frac{8\ \text{atoms}}{5.65\times10^{-8}} = 4.44\times10^{22}\ \frac{\text{atoms}}{cm^3}$$

9. (2pts) Determine the total number (#/cm^3) of energy states in silicon between Ec and Ec+4kT at T=200K, T=300K and T=500 K.

m_e (Effective mass) = 1.08

k (Boltzmann's Constant) = 1.38×10^{-23}

h = Planck's constant = 6.626×10^{-34}

$$N = \frac{4\pi\,[2m]^{3/2}}{h^3}\left(\frac{2}{3}\right)\left(E^{3/2}\right)$$

(Bounded between E and E+4kT)

$$N = \frac{4\pi\,[2(9.1\times10^{-31})(1.08)]^{3/2}}{(6.626\times10^{-34})^3}\left(\frac{2}{3}\right)\left[E+4kT-E\right]^{3/2}$$

@ 200 K

$$4kT = 4\,(1.38\times10^{-23})(200) = 1.10\times10^{-20}$$

$$N = \frac{4\pi\left[2(9.1\times10^{-31})(1.08)\right]^{3/2}}{(6.626\times10^{-34})^3}\left(\frac{2}{3}\right)\left[1.10\times10^{-20}\right]^{3/2}$$

$$\boxed{N = 9.16\times10^{19}\,/\,\text{cm}^3}$$

@ 300 K

$$4kT = 4\,(1.38\times10^{-23})(200) = 1.66\times10^{-20}$$

$$N = \frac{4\pi\left[2(9.1\times10^{-31})(1.08)\right]^{3/2}}{(6.626\times10^{-34})^3}\left(\frac{2}{3}\right)\left[1.66\times10^{-20}\right]^{3/2}$$

$$\boxed{N = 1.70\times10^{20}\,/\,\text{cm}^3}$$

@ 500 K

$$4kT = 4(1.38\times10^{-23})(200) = 2.76\times10^{-20}$$

$$N = \frac{4\pi\left[2(9.1\times10^{-31})(1.08)\right]^{3/2}}{(6.626\times10^{-34})^3}\left(\frac{2}{3}\right)\left[2.76\times10^{-20}\right]^{3/2}$$

$$\boxed{N = 3.64\times10^{20} / cm^3}$$

10. (3pts)Determine the probability that an energy level is occupied by an electron if the state is above the Fermi level by
    a) .5kT
    b) 6kT
    c) 8kT

$$P = \frac{1}{1+\exp\left(\frac{E-E_f}{kT}\right)}$$

a.) $E = E_f + 0.5kT$

$$P = \frac{1}{1+\exp\left(\frac{(E_f+0.5kT)-E_f}{kT}\right)} = \frac{1}{1+\exp(0.5)} = 0.378 = \boxed{37.8\%}$$

b.) $E = E_f + 6kT$

$$P = \frac{1}{1+\exp\left(\frac{(E_f+6kT)-E_f}{kT}\right)} = \frac{1}{1+\exp(6)} = 0.00247 = \boxed{0.247\%}$$

c.) $E = E_f + 8kT$

$$P = \frac{1}{1+\exp\left(\frac{(E_f+8kT)-E_f}{kT}\right)} = \frac{1}{1+\exp(8)} = 0.00033 = \boxed{0.033\%}$$

11. (4pts) The Fermi energy for copper at T=300 K is 7.0 eV. The electrons in copper follow the Fermi Dirac distribution function.

a. Find the probability of an energy level at 7.15 eV being occupied by an electron
b. Repeat part a for T=1000 K (assume Ef is constant
c. Repeat part a for E=6.85 eV and T=300 K
d. Determine the probability of the energy sate at E=Ef being occupied at T=300 K and at T=1000 K

$kT\left(\frac{1}{1.6\times10^{-19}}\right)$ [Joules to eV]

$kT = 0.0259$

a.) $f(E) = \frac{1}{1+\exp\left(\frac{7.15-7.0}{0.0259}\right)} = 0.00304$

$f(E) = 0.304\%$

b.) $kT = 0.08633$

$f(E) = \frac{1}{1+\exp\left(\frac{7.15-7.0}{0.08633}\right)} = 0.1496$

$f(E) = 14.96\%$

c.) $f(E) = \frac{1}{1+\exp\left(\frac{6.85-7.0}{0.0259}\right)} = 0.997$

$f(E) = 99.7\%$

d.) $E = E_f$

$f(E) = \frac{1}{1+\exp\left(\frac{7-7}{kT}\right)} = \frac{1}{1+1}$

$f(E) = \frac{1}{2}$ @ all temps.