EE - 207

BASIC QUESTIONS:

1. Assume the semiconductor to be non-degenerate, find the energy level (E) at which peak electron and hole distribution (maximum no. of holes and electrons) lies in the conduction and valence bands respectively. (Assume Maxwell-Boltzmann approximation is valid).

2. Consider two materials in intimate contact such that electrons can move between the two. Show that there is no discontinuity in the equilibrium Fermi level, E_F.

3. A new semiconductor has Nc = 10^{19} cm^{-3}, Nv = 5 x 10^{18} cm^{-3}, and Eg = 2 eV. If it is doped with 10^{17} donors (fully ionized), calculate the electron, hole, and intrinsic carrier concentrations at 627°C. Sketch the simplified band diagram showing the position of E_F.

4. (a) For a semiconductor(undoped) we know that at 300k the Fermi level will be in the center of band gap. If the temperature is increases to 600k . what is the position of Fermi level?
   (b) Take a semiconductor and dope with phosphorous N_d=10^{13}. Now the temperature is increased to 600k.Calculate the intrinsic concentration. Comment whether the semiconductor is n-type or p-type or intrinsic?

5. (a) A Si sample is doped with 10^{16} cm^{-3} boron atoms and a certain number of shallow donors. The Fermi level is 0.36 eV above E_i, at 300 K. What is the donor concentration N_d ?
   (b) A Si sample contains 10^{16} cm^{-3} In (Indium)acceptor atoms and a certain number of shallow donors.The In acceptor level is 0.16 eV above *Ev*, and E_F *is* 0.26 eV above *Ev* at 300 K. How many (cm^{-3}) In atoms are un-ionized (i.e.,neutral)?

6. (a) Under equilibrium conditions and T> 0 K, what is the probability of an electron state being occupied if it is located at the Fermi level?
   (b) If E_F is positioned at E_c, determine (numerical answer required) the probability of finding electrons in states at E_c + kT.
   (c) The probability a state is filled at E_c + kT is equal to the probability a state is empty at E_c + kT. Where is the Fermi level located?

7. A semiconductor material has the following E-k relations for the conduction and valence bands: $E - E_C = 2(h/2\pi)^2k^2/2m_0$ and $E - E_V = -3(h/2\pi)^2k^2/2m_0$, m_0 is the free electron mass (10^{-28}g). Find the effective masses of electrons and holes.

8. Consider an intrinsic semiconductor having the band structure of problem 7, with E_G=1eV, at T=300 ^{O}K. Calculate the Fermi level position, effective density of states in the conduction and valence bands (N_C, N_V) and intrinsic carrier concentration. Calculate the Fermi level position if the semiconductor is doped with 10^{16} /cm^3 donor atoms.

ADVANCED QUESTIONS:

9.Derive the DOS for 1D semiconductor?

10. The E-k relationship characterizing electrons near the vertice of brillouin zone in graphene is of the form

$$E(k) = \pm v_F \hbar \sqrt{k_x^2 + k_y^2}$$

Derive an expression for the density of states.
****Note:** In addition to spin-degeneracy factor of 2, here we have valley degeneracy factor(g_v) of 2 as well.Notice the brillouin zone highlighted in Figure 2(Left).We get to see 6 valleys in diagram, but the valley degeneracy factor is 2 because only 1/3 of each valley is present in the brillouin zone.

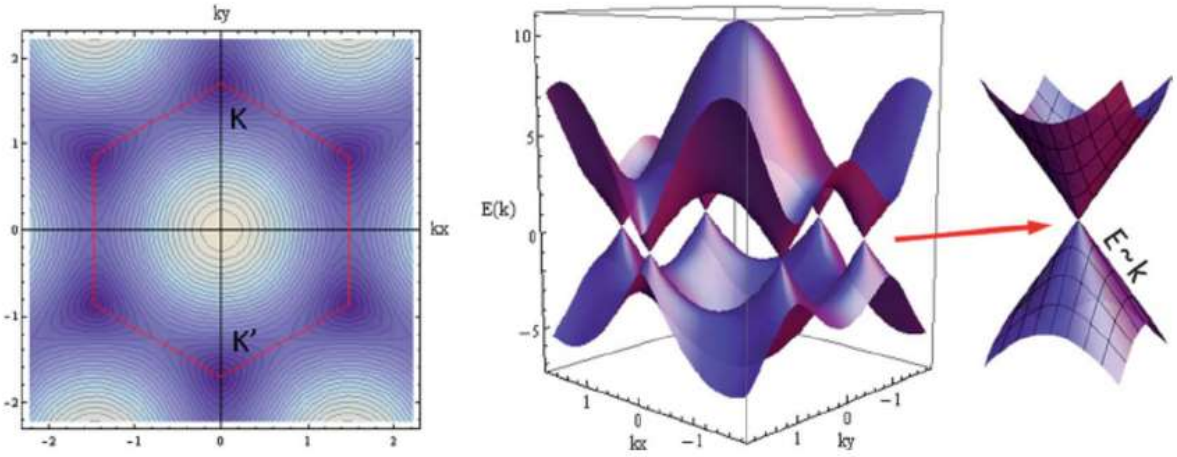

Figure 2

11. To better understand the origin of distribution functions, consider a specific system with equidistant energy levels at 0.5, 1.5, 2.5, 3.5, 4.5, 5.5, ...15.5 eV.This system contains 20 electrons.

The minimum energy of this system corresponds to the situation where all 20 electrons occupy the ten lowest energy levels without placing more than 2 in any given level. This situation occurs at T = 0 K and the total energy equals 100 eV.

Since we are interested in a situation where the temperature is not zero, we arbitrarily set the total energy at 106 eV.You may use Matlab/Python for this problem.

- Apply the basic postulate of statistical thermodynamics, namely that all possible configurations are equally likely to occur and _nd the expected con_guration
- Plot probability of occupation versus energy

- Overlap the above plot with Fermi-Dirac distribution(EF = 9:998 eV, kT=1.447eV).This is the best fit estimate for the above problem.**The agreement is surprisingly good considering the small size of this system
- Now change the number of total electrons in the system/use nonuniform energy level spacing. Note your observations

****Note**: Based on the construction of the distribution function in this example, one would expect the distribution function to be dependent on the density of states. This is the case for small systems.However, for large systems, the distribution function no longer depends on the density of states