ECE344 Fall08
HOMEWORK 3
Carrier Densities and Carrier Transport

1 Carrier Densities

1. Let us consider two Silicon materials S1 and S2 at $T = 300K$ where $N_a = 0$ for both. S1 has $N_d = 10^{15}/cm^3$ and S2 has $N_d = 10^5/cm^3$ (donors are fully ionized). Justify if S1 and S2 are in the intrinsic or in the extrinsic regime ? Deduce what should be the values of the electron density n for S1 and S2 ?, What is happening for S1 if temperature increases significantly ?

2. Determine the temperature at which the intrinsic carrier density in (i) Silicon and (ii) GaAs are equal to the room temperature ($300K$) intrinsic carrier density of Germanium (Ge) $n_i = 2 * 10^{13}/cm^3$. You will use the data given in Table 2.1 and Fig 2.8 of your textbook (N_c, N_v, E_G and m^* are independent of the temperature).

3. Semiconductor A has a bang gap of $1eV$ and semiconductor B has a band gap of $2eV$. What is the ratio of the intrinsic carrier density in the two materials (n_i^A/n_i^B) at $300K$. We assume that all effective masses are equal (electrons and holes for both A and B). You will comment the result.

4. Determine the equilibrium electron and hole concentrations inside a uniformly doped sample of Silicon under the following conditions:

   a- T=300K, N-type Semiconductor, $N_D = 10^{15}/cm^3$
   b- T=300K, P-type Semiconductor, $N_A = 10^{16}/cm^3$
   c- T=300K, $N_A = 9 * 10^{15}/cm^3$, $N_D = 10^{16}/cm^3$
   d- T=450K, $N_A = 0$, $N_D = 10^{14}/cm^3$
   e- T=650K, $N_A = 0$, $N_D = 10^{14}/cm^3$

   Attention: You will consider that $n_i = 10^{10}/cm^3$ at $T = 300K$, $m_n^* = 1.18m_0$, $m_p^* = 0.81m_0$, and $E_g = 1.42eV$ at $T = 300K$, $E_g = 1.08eV$ at $T = 450K$ and $E_g = 1.015eV$ at $T = 650K$, every other material dependent quantities should be calculated.

5. Determine the concentration of donor atoms that must be added so that the Silicon is N-type and the Fermi energy is $0.2eV$ below the conduction band edge. Assume complete ionization, temperature $T = 300K$, $2.8 * 10^{19}/cm^3$ for the effective DOS for the electrons, and $n_i = 10^{10}/cm^3$.

6. A GaAs semiconductor is doped with $2.3 * 10^{17}$ donors per cm^3, assuming that this semiconductor is non-degenerate, calculate the electron and hole concentration at equilibrium. Calculate ($Ec - EF$). Comments about the obtained results and the assumption made to calculate these results.

7. In a nondegenerate Germanium at room temperature, we give $n_i = 10^{13}/cm^3$, $n = 2p$ and $N_a = 0$. Determine n, p, N_d and where is the Fermi level located from E_i ?

8. Consider a InAs semiconductor where $E_G = 0.36eV$, electron effective mass is $0.023m_0$, and the hole effective mass is $0.4m_0$. Find an ANALYTICAL expression of the intrinsic electron density of InAs in function of the intrinsic electron density of $GaAs$, the electron and holes effective masses, and energy bandgap of both semiconductors. Numerical Application.

2 Carrier Transport

1. Determine the resistivity of intrinsic Ge, Si and GaAs at $300K$ in $\Omega.cm$.
2. A piece of silicon is doped with boron ($N_a = 10^{17}/cm^3$). Calculate the resistivity of this P-type semiconductor (we consider $317cm^2/V.s$ for the mobility).
3. The hole density in an N-type silicon wafer ($N_d = 10^{17}/cm^3$) decreases linearly from $10^{14}/cm^3$ to $10^{12}/cm^3$ between $x = 0$ and $x = 1.5\mu m$. Calculate the hole diffusion current density at $T = 300K$ (the hole mobility is equal to $317cm^2/V.s$). You will give the result in A/cm^2.
4. Electrons in undoped gallium arsenide have a mobility of $8800cm^2/V.s$. Calculate the average time in picosecond between collisions (we will use $0.067m_0$ for the effective mass of the electrons). Calculate the distance traveled between two collisions in nanometer (also called the mean free path). Use an average velocity of $10^7cm/s$.