Solved Problems EE 207., EE, IITB Prof. P. R. Nair

Topics - Carrier Statistics (Equilibrium).

Q1: For an undoped semiconductor, estimate the intrinsic carrier concentration.

Hint: Use $n_i = \sqrt{N_C N_V}\, e^{-E_g/2kT}$.

Q2: For a doped semiconductor with $N_D = 10^{18}\ cm^{-3}$ estimate the carrier densities.

Hint: Assume charge ~~neut~~ neutrality

$$p - n + N_d^+ - N_A^- = 0.$$

Also $np = n_i^2$. (law of mass action)

with the assumption of complete ionization of dopants, we have in this case

$$n \approx N_D$$

$$p \approx n_i^2/N_D.$$

Q3: A semiconductor is doped with $N_D = 10^{18}\ cm^{-3}$ and $N_A = 10^{17}\ cm^{-3}$, estimate carrier conc.

Hint: Using the approach in Q2, $p - n + N_d^+ - N_A^- = 0$; $np = n_i^2$ we have

$$\Rightarrow n \approx N_D - N_A.$$

$$p \approx \frac{n_i^2}{N_D - N_A}$$

**Q4:** Repeat the ~~above~~ Q3 with $N_D = 10^{12}\ cm^{-3}$ and $N_A = 5\times10^{11}\ cm^{-3}$.

Hint: In this case, the carrier densities are of similar magnitude and hence the approximations used in Q2 & Q3. So, you may want to solve, these eqns simultaneously.

$$p - n + N_D^+ - N_A^- = 0 \rightarrow ①$$

$$np = n_i^2 \rightarrow ②$$

$$\hookrightarrow \frac{n_i^2}{n} - n + N_D^+ - N_A^- = 0$$ Once $n$ is obtained, use the same in ② to obtain $p$.

**Q5:** Find the Fermi level of doped Si at 400°C. Assume complete ionization of ~~carriers~~ dopants at all temp. $N_D = 10^{17}\ cm^{-3}$.

$$\left(E_F\ \cancel{(\text{room temp})} - E_i\right) = kT \ln\left(\frac{N_D}{n_i}\right) \rightarrow ①$$

At room temp$(T_1)$ $n_i = 10^{10}\ cm^{-3}$

At ~~400~~ $T_2 = 400°C$, $n_i = \sqrt{N_c N_v}\, e^{-E_g/2kT_2}$.

If you ignore temp dependence of $N_c N_v$.

$$\frac{n_i(T_2)}{n_i(T_1)} = \frac{e^{-E_g/2kT_2}}{e^{-E_g/2kT_1}}$$

Use $n_i(T_2)$ in ① to obtain $(E_F - E_i)$ at $T = T_2$.

Q6: Consider Si doped with $N_d = 10^{17}\ cm^{-3}$. Estimate the temp at which this sample will stop being "extrinsic"?

Hint: when the intrinsic carrier density dominates that of carriers due to dopants, we ~~may~~ term the semiconductor has stopped being "extrinsic". So here

$$n_i(T_{ex}) \approx N_D.$$

$$\sqrt{N_c N_v}\, e^{-E_g/2kT_{ex}} \approx N_D.$$

this will give an approx estimate for the transition temp.

Q7: The fermi level of a sample changed from $E_F - E_i = 0.3\,eV$ to $E_F - E_i = -0.2\,eV$. Estimate the ionic densities in the sample.

Hint: For $(E_F - E_i) = 0.3\,eV$, all ions are due to donors $\Rightarrow$. $N_D = n_i e^{(E_F - E_i)/kT}$

For the second case

$$N_{A,eff} = n_i e^{+0.2/kT}.$$

But $N_{Aeff} = N_A - N_D$

$\therefore$ ~~$N_A$~~ $=$

$\Rightarrow N_A = N_{Aeff} + N_D.$