EE 280 Homework 3

Si: $n_i = 1.5\times10^{10}\ cm^{-3}$; $N_c = 2.8\times10^{19}\ cm^{-3}$ $N_V = 1.04\times10^{19}\ cm^{-3}$;
$E_g = 1.12eV$; GaAs: $n_i = 1.8\times10^{6}\ cm^{-3}$

Problem #1

Silicon at T = 300 k is doped with arsenic atoms such that the concentration of electrons in n = 7 x 10^15 cm^-3

A) Find Ec - Ef

$$kT\ln\left(\frac{N_c}{N_d}\right) = (8.62\times10^{-5})(300k)\ln\left(\frac{2.8\times10^{19}}{7\times10^{15}}\right)$$

$$= 0.2145eV$$

B) Find Ef - EV;

$$kT\ln\left(\frac{p}{N_V}\right) = (300)(8.62\times10^{-5})\ln\left(\frac{3.2\times10^{4}}{1.04\cdot10^{19}}\right) = 0.87eV$$

C) Calculate p;

$$n_i^2 = np \rightarrow p = \frac{n_i^2}{n} = \frac{(1.5\times10^{10})^2}{(7\times10^{15})} = 3.21\times10^{4}\ cm^{-3}$$

D) Which carrier is the minority carrier?

Vb is the minority as Ef is closer

E) Find Ef-Efi

$$kT\ln\left(\frac{N_d}{n_i}\right) = (300)(8.62\times10^{-5})\left(\frac{7\times10^{15}}{1.5\times10^{10}}\right) = 0.34eV$$

n_i

Problem #2

A) The Fermi energy level in silicon at T = 300 k is 0.22 eV above the Efi. Determine n and p.

Find N: $n = n_C \exp\left(\frac{-(E_C - E_F)}{kT}\right)$

$\rightarrow n = 2.8\times10^{9} \exp\left(\frac{-(.34)}{(300)(8.62\cdot10^{-5})}\right) = 5.6\cdot10^{13}\ cm^{-3}$

Find p:

$p = N_v \exp\left(\frac{-(E_F - E_v)}{kT}\right)$

$1.04\times10^{19} \exp\left(-\frac{.78}{(300)(8.62\cdot10^{-5})}\right) = 8.7\times10^{5}\ cm^{-3}$

B) Repeat part a for GaAs

$E_g = 1.42 eV$

$n_i = 1.8\times10^{6}\ cm^{-3}$

$N_c = 4.7\times10^{17}$

$N_v = 9\times10^{18}$

$E_C - E_F = 1.42 - .932 = .490$

$E_F - E_V = .712 + 0.22 = .932\ eV$

Find N: $N = 4.7\times10^{17} \exp\left(-\frac{(.490)}{kT}\right) = 2.77\cdot10^{9}\ cm^{-3}$

Find p: $9\times10^{18} \exp\left(\frac{-(.932)}{kT}\right) = 2\times10^{3}\ cm^{-3}$

Problem #3

A) The material is a p-type

majority: $1.5\times10^{16}\,cm^{-3}$

minority: $1.5\times10^{4}\,cm^{-3}$

$p = N_a - \cancel{N_d} = 3\times10^{16} - 1.5\times10^{16} = 1.5\times10^{16}\,cm^{-3}$

$$n = \frac{(1.5\times10^{10})^2}{1.5\times10^{16}} = 1.5\times10^{4}\,cm^{-3}$$

B) Add boron atoms

$p = 5\times10^{16} - 1.5\times10^{16} = 3.5\times10^{16}\,cm^{-3}$

$5\cdot10^{16} - 3\times10^{16} = 2\times10^{16}$ atoms

$$n = \frac{(1.5\times10^{10})^2}{3.5\times10^{16}} = 6.4\times10^{3}\,cm^{-3}$$

Problem #4

A) $T = 300\,K$ with donor concentrations of $N_d = 10^{14}, 10^{15}, 10^{16}$, & $10^{17}\,cm^{-3}$. $N_a = 0$

$$(300)(8.62\times10^{-5})\ln\left(\frac{2.8\times10^{19}}{N_d}\right)$$

$N_d = 10^{14} \rightarrow (300)(8.62\times10^{-5})\ln\left(\frac{2.8\times10^{19}}{10^{14}}\right) = 0.32435eV$

$N_d = 10^{15} \rightarrow (300)(8.62\times10^{-5})\ln(2.8\times10^{19}/10^{15}) = 0.26480eV$

$N_d = 10^{16} \rightarrow (300)(8.62\times10^{-5})\ln(2.8\times10^{19}/10^{16}) = .205eV$

$N_d = 10^{17} \rightarrow (300)(8.62\times10^{-5})\ln(2.8\times10^{19}/10^{17}) = .146eV$

B)

$n_i = 1.8\times10^{6}$

$(300)(8.62 \times 10^{-5})(\ln(\frac{1^{10}}{1.8 \cdot 10^{6}})$

Calculations just replace Nd I did it on Symbolab

10^{14} : 0.46115 eV

10^{15} : 0.5207 eV

10^{16} : 0.58029 eV

10^{17} : 0.63979 eV

Problem #5

The concentration of donor impurity atoms in silicon is Nd = 10^15 cm^-3 .

$\mu_e = 1300\ cm^2/Vs$ & $\mu_h = 450\ cm^2/Vs$

A) Calculate the resistivity of the material

$$\rho = \frac{1}{\sigma} = \frac{1}{.208} = 4.807$$

B) What is the conductivity of the material

$$\sigma = qN_d\mu_e + q\left(\frac{n_i^2}{n}\right)\mu_h$$

$$\to (1.6 \times 10^{-19})(10^{15})(1300) + (1.6 \times 10^{-19})\left(\frac{(1.8 \times 10^{6})^2}{10^{15}}\right)450$$

$= .208\ \Omega^{-1} cm$

Problem #6 $\sigma = 1.80\ (\Omega\text{-}cm)^{-1}$ $\mu_e = 1250\ cm^2/Vs$

$\mu_h = 380\ cm^2/Vs$

acceptor impurity:

$$\sigma = qN_d\mu_e + q\left(\frac{n_i^2}{N_d}\right)\mu_n$$

$$\rightarrow \sigma = q\left(\frac{n_i^2}{N_A}\right)\mu_e + qN_a\mu_r$$

$$\rightarrow \sigma = q\left(\frac{n_i^2}{N_a}\right)\mu_e + qN_a\mu_i$$

$$\rightarrow N_a^2\mu_n q - N_a\sigma + qn_i\mu_e = 0$$

$$N_a^2(300)(1.6\times10^{-19}) - N_a(1.8) + (1.6\times10^{-19})(1.5\times10^{10})^2(1250)$$

$$= 6.08\times10^{-17}N_a^2 - 1.8N_a + 4500 = 0$$

I solved Na using quadratic formula

$$N_a = 2.96\times10^{16}\,cm^{-3}$$

Problem #7 $N_d = 10^{16}$ $N_a = 0$ $N_i =$

A) $n = 10^{16}$ $p = \frac{n_i^2}{n} = \frac{(2\cdot10^6)^2}{10^{16}} = 4\cdot10^{-4}\,cm^{-3}$

B) drift

$$J_{de} = qn\mu_e E = (1.6\cdot10^{-19})(10^{16})(8.5\times10^3)(10)$$

$= 136\ A/cm^2$

hole: $J_{h,x} = q p \mu_h E = (1.6 \cdot 10^{-19})(9 \cdot 10^{4})(400)(10)$

$= 2.6 \cdot 10^{-19}\ A/cm^2$

( ) $N_d = 0\ N_a = 10^{16}\ cm^{-3}$

$J_{e,x} = (1.6 \cdot 10^{-19})(4 \cdot 10^{-5})(8.5 \times 10^{3})(10) = 5.4 \cdot 10^{-18}\ \frac{A}{cm^2}$

$J_{h,x} = (1.6 \cdot 10^{-19})(10^{16})(400)(10) = 6.4\ A/cm^{-2}$