Homework 1

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EE3310 HW1
9/2/21

EE3310 Homework #1 Due: 9/3/2021

1) A) When we say "band gap" or "energy gap" when referring to semiconductors, to what are we referring?
   B) Explain why all semiconductors are insulators at T=0K.
   C) What is the primary difference between an "Acceptor" and a "Donor" atom?
   D) What does the "Fermi energy" or "Fermi Level" tell us about a material?

2) Silicon is doped with an Boron concentration of $3x10^{18}$ cm^{-3}.
   A) Is Boron a donor or acceptor impurity?
   B) What are the electron and hole concentrations?
   C) What are the electron and hole mobilities?
   D) What is the resistivity of this silicon material at 300K?
   E) Is this material n-type or p-type?

3) A piece of Si semiconductor has $N_A = 4x10^{16}$ cm^{-3}, $N_D = 4x10^{17}$ cm^{-3}, and $n_i = 1.5x10^{10}$ cm^{-3}.
   A) What are the free electron (n) and hole concentrations (p) at room temperature?
   B) Which is the majority carrier?
   C) Which is the minority carrier?

4) A Si sample is doped with $8x10^{18}$ cm^{-3} donor atoms and $8x10^{18}$ cm^{-3} acceptor atoms.
   A) What is the resistivity?
   B) Based on the resistivity, is this an insulator, conductor or semiconductor?
   C) Is this intrinsic material? Explain your answer.

5) A Si sample is doped with $5x10^{16}$ cm^{-3} donor atoms.
   A) Calculate the position of the Fermi level in the doped material relative to E_i.
   B) Sketch the band diagram including E_C, E_V, E_i and E_F
   C) Is this material degenerate or non-degenerate? How do you know?
   D) How would your equations/analysis change if the doping was $2x10^{18}$ cm^{-3}.

1. a. The bandgap is a section of electron energy where no states exist for e^- to occupy. It separates the C_b and the V_b

   b. At 0°k, the bandgap gets much wider as SC atoms lose all energy. No n or p can cross into the CB.

c. Acceptor atoms have a positive charge and can "accept" an electron while donor atoms have a negative charge and can therefore "donate" an electron

acceptor = $< 4e^-$
donor = $> 4e^-$
for Si and Ge

d. The fermi energy for a material is the energy at which a given state has a 50% chance of being occupied

2. Silicon doped w/ Boron conc. $3 \times 10^{18}\ cm^{-3}$

a. Boron is an acceptor because it only has 3 valence e^- (column 3) and can accept an electron.

$\therefore N_a = 3 \times 10^{18}$
$N_d = 0$

b. Find n_0 and p_0

$n_i = 10^{10}$

$N_a = 3 \times 10^{18}$

$N_d = 0$

Because $N_a \gg n_i$, $p_0 \approx 3 \times 10^{18}\ cm^{-3}$

$n_0 p_0 = n_i^2 = (1.5 \times 10^{10})^2$

$\therefore n_0 = \frac{(1.5 \times 10^{10})^2}{3 \times 10^{18}} = 75$

$$\therefore n_0 = \frac{(1.5\times10^{10})^2}{3\times10^{18}} = 75$$

$$n_0 = 75\ cm^{-3}$$

$$p_0 = 3\times10^{18}\ cm^{-3}$$

c. Find electron and hole mobilities for silicon with $N_d = 3\times10^{-18}$

$$\mu_n \approx 150 \quad cm^2/Vs$$

$$\mu_p \approx 60 \quad cm^2/Vs$$

d. Find the resistivity at $T = 300K$

$$\rho = \frac{1}{\sigma} = \frac{1}{N_a \mu_p q} = \frac{1}{(3\times10^{18})(60)(1.602\times10^{-19})}$$

$$\therefore \rho = 3.46\times10^{-2}\ \Omega cm$$

e. Because its doped with acceptor atoms, this material is a p-type SC.

3. Si sample $N_A = 4 \times 10^{16}\ cm^{-3}$

$N_D = 4 \times 10^{17}\ cm^{-3}$

$n_i = 1.5 \times 10^{10}\ cm^{-3}$

Notice $N_D > N_a$ (n-type sc)

a. $n_o p_o = n_i^2$ @ room temperature

$n_o \approx N_D$

$n_o = 4 \times 10^{17}\ cm^{-3}$

$$p_o = \frac{n_i^2}{n_o} = \frac{(1.5 \times 10^{10})^2}{4 \times 10^{17}} = 562.5$$

$p_o = 562.5\ cm^{-3}$

b. The majority carrier is electrons because $N_D > N_A$

c. The minority carrier is holes

4. Si doped $N_a = 8\times10^{18}\ cm^{-3}$

$N_D = 8\times10^{18}\ cm^{-3}$

a. Find resistivity $\quad q = 1.6\times10^{-19}$

$$\sigma = q(n\mu_n + p\mu_p)$$

$$= 1.6\times10^{-19}\left(8\times10^{18}(120) + 8\times10^{18}(50)\right)$$

$$\rho = \sigma^{-1}$$

$$\therefore \rho = 217.6\ \Omega cm$$

b. Because of its resistivity, its a semiconductor. And this is supported by $N_D = N_A$

c. Its not intrinsic because it contains impurities, even if in equal amounts

5. Si doped $N_D = 5\times10^{16}\ cm^{-3}$

a. $E_{f_n} - E_{f_i} = kT \ln\left(\frac{n_0}{n_i}\right)$

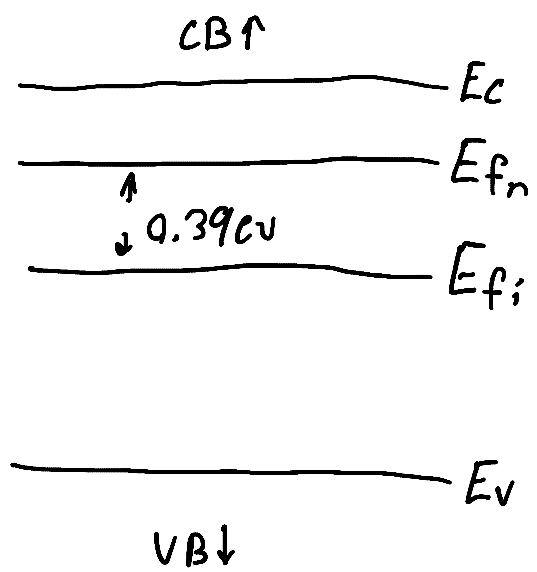
$n_i = 1.5\times10^{10}$

$kT = 0.026$ for Si @ room temperature

$\therefore E_{f_n} - E_{f_i} = 0.026 \ln\left(\frac{5\times10^{16}}{1.5\times10^{10}}\right)$

$\therefore E_{f_n} - E_{f_i} = 0.39$

b.



c. Because $E_c - E_{f_n} < 3kT$, this material is non-degenerate

If $N_D = 2\times10^{18}$, then $E_c - E_{f_n} > 3kT$ and the material would be degenerate

Would be able to use approxomations