Faculty of Engineering – Shoubra Department: **Electrical Eng.** Semester: **Fall 2012**		**Course:** **ECOM 111: Electronic Engineering Fundamentals** **Instructor**: **Dr.** Abdallah Hammad
Total Grade: **20**	**Mid Term Exam**	Number of questions: **4** - Time allowed: **90 Min**

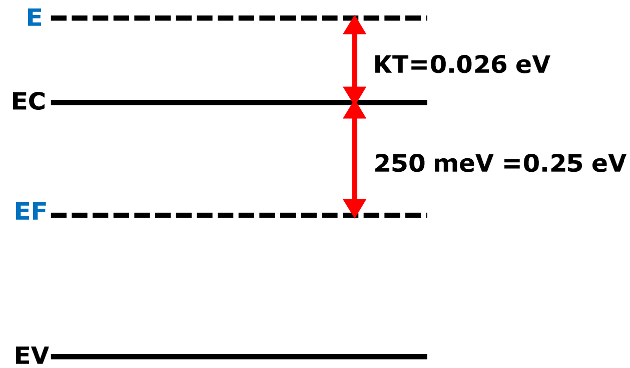
***Answer all questions*: write each question number and part number ahead of your answer**

$K=1.38\times10^{-23}$ J/K   **$h=6.64\times10^{-34}$ J.s**   **$q=1.6\times10^{-19}$ C**   **$m_o=9.1\times10^{-31}$ Kg**

For Si →   **$m_e=1.18\ m_o$**   **$m_h=0.81\ m_o$**   **$E_g=1.12$ eV**   **$ni=1.5\times10^{10}cm^{-3}$**

(1) In a semiconductor, the Fermi level is 250 meV below the conduction band. What is the probability of finding an electron in a state **kT** above the conduction band edge E_C at room temperature?

Solution



$$F(E)=\frac{1}{1+e^{\frac{E-E_F}{KT}}}$$

$$E-E_F=0.25+0.026=0.267eV$$

$$KT\Big|_{T=300(J)}=1.38\times10^{-23}\times300=4.14\times10^{-21}J$$

$$KT\Big|_{T=300(eV)}=\frac{4.14\times10^{-21}}{1.6\times10^{-19}}=0.025875=0.026eV$$

$$F(E)=\frac{1}{1+e^{\frac{0.267}{0.026}}}=\frac{1}{1+28831.7}=3.468\times10^{-5}$$

(2) The concentration of atoms in silicon is 5×10^{22} cm^{-3}. If we add such that the donor impurity is 1 part in 10^{6} silicon Atoms.

a. Find the change in resistivity.

b. Find the concentration of *Al* that should be added, so that the final silicon crystal becomes intrinsic.

Solution

a)

1 donor (phosphorous) ⟷ **10^{6} (Si atoms)**

ND (donors per cm^{-3}) ????? ⟷ **$5\text{x}10^{22}$ (Si atoms per cm^{-3})**

Then

$$N_D = \frac{5\times10^{22}}{10^{6}} = 5\times10^{16} cm^{-3}$$

Before we added the donors the material was intrinsic ($n=p=n_i=1.5\text{x}10^{10}$ cm^{-3})

$$\begin{aligned}\sigma_i &= q\mu_n n + q\mu_p p \\ &= qn_i(\mu_n + \mu_p) \\ &= 1.6\times10^{-19}\times1.5\times10^{10}(1600+600) = 5.28\times10^{-6}\ \ \Omega^{-1}cm^{-1}\end{aligned}$$

$$\rho_i = \frac{1}{\sigma_i} = 189393.9\ \ \Omega cm$$

After we add the donors the material will be n type

$$n = \frac{N_D}{2} + \sqrt{\left(\frac{N_D}{2}\right)^2 + n_i^2} \simeq N_D = 5\times10^{16} cm^{-3}$$

$$p = \frac{n_i^2}{n} = \frac{\left(1.5\times10^{10}\right)^2}{5\times10^{16}} = 4500$$

$$\begin{aligned}\sigma_n &= q\mu_n n + q\mu_p p \simeq q\mu_n n \\ &= 1.6\times10^{-19}\times1600\times5\times10^{16} = 12.8\ \ \Omega^{-1}cm^{-1}\end{aligned}$$

$$\rho_i = \frac{1}{\sigma_i} = 0.078125\ \ \Omega cm$$

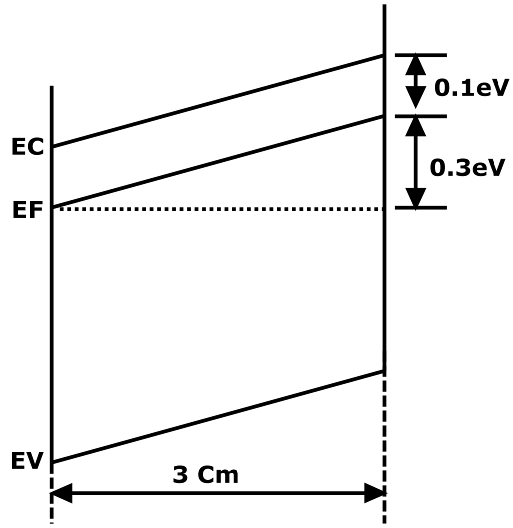
$$\Delta\rho = \rho_i - \rho_n = 189393.9 - 0.078125 = 189393.82\ \Omega cm$$

b) For the silicon sample to be intrinsic again we should add an equal amount of acceptors to donors so in this case ($N_D=5\text{x}10^{16}$), so N_A must be equal $5\text{x}10^{16}$ cm^{-3}

(3)

a. Find the value of the voltage source applied that causes the tilt shown in the energy band diagram shown in Fig.1

b. Find the electric field and the carrier concentration given that at T=300 K $n_i = 1.5 \times 10^{10}$ cm^{-3}.



$$qV_{BB} = 0.3\ eV = 0.3 \times 1.6 \times 10^{-19}\ J$$

$$V_{BB} = \frac{0.3 \times 1.6 \times 10^{-19}\ J}{1.6 \times 10^{-19}\ C} = 0.3\ V$$

$$E = \frac{V_{BB}}{L} = \frac{0.3\ V}{3\ cm} = 0.1\ V/cm$$

$$n = n_i e^{\frac{E_F - E_i}{KT}}$$

$$E_F - E_i = KT\ \ln\frac{n}{n_i}$$

$$E_i - \text{midgap} = \frac{3}{4}KT\ \ln\left(\frac{m_h}{m_e}\right) = \frac{3}{4} \times 0.026 \ln\frac{0.81 m_o}{1.18 m_o} = -7.33 \times 10^{-3} eV$$

$$E_F - E_i = \left(\frac{E_g}{2} + 7.33 \times 10^{-3}\right) - \left(E_C - E_F\right) = \left(0.56 + 7.33 \times 10^{-3}\right) - 0.1$$

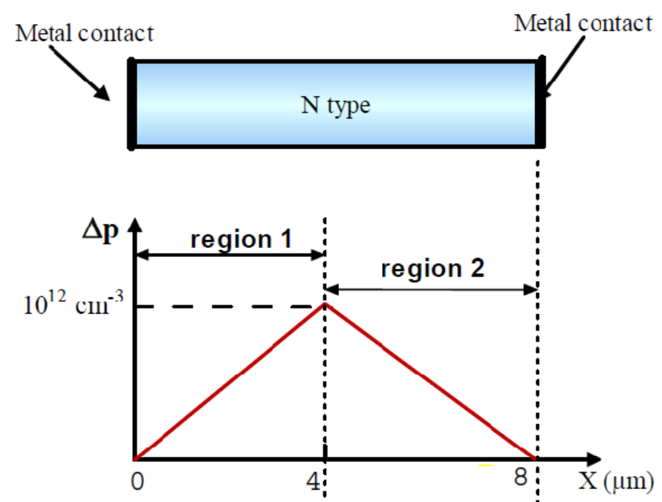
$$E_F - E_i = 0.46733 eV$$

$$n = 1.5 \times 10^{10} e^{\frac{0.46733 eV}{0.026}} = 9.59 \times 10^{17} cm^{-3}$$

$$p = \frac{n_i^2}{n} = \frac{\left(1.5 \times 10^{10}\right)^2}{9.59 \times 10^{17}} = 234.413 cm^{-3}$$

(4) An N-type silicon bar at 300 K is shown in Fig. 2. The donor's density is 5×10^{16} cm^{-3}. It is terminated by metal contacts at both ends. The electron's mobility is 1600 $cm^2/V.s$ while the hole mobility is 600 $cm^2/V.s$. The sample is excited with uniform constant illumination creating the excess minority carrier density distribution shown in Fig. 2. Calculate and sketch the minority carrier current density.

$T = 300\ ^oK$
$N_D = 5\times10^{16}\ cm^{-3}$
$\mu_e = 1600\ cm^2/V.s$
$\mu_h = 600\ cm^2/V.s$

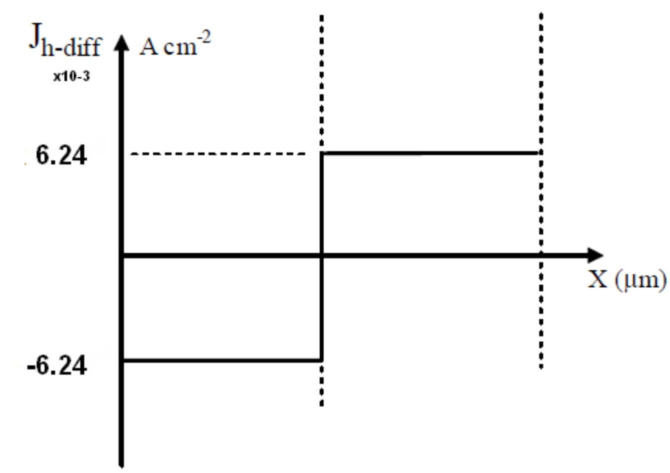


$$J_{h-diffusion} = -qD_h \frac{d\Delta p(x)}{dx}$$

The diffusion constant of holes D_h can be found using Einstein relation:

$$\frac{D_h}{\mu_h} = \frac{KT}{q} = 0.026$$

$$D_h = 0.026\times600 = 15.6\ \ cm^2s^{-1}$$



region 1 (0< x < 4 μm)

Slope $\frac{d\Delta p(x)}{dx}$ +Ve

$$J_{h-diff} = -1.6\times10^{-19}\times15.6\left(\frac{10^{12}-0}{4\times10^{-4}-0}\right)$$

$$J_{h-diff} = -\ 6.24\times10^{-3}\ \ A\ cm^{-2}$$

region 2 (4< x < 8 μm)

Slope $\frac{d\Delta p(x)}{dx}$ -Ve

$$J_{h-diff} = -1.6\times10^{-19}\times15.6\left(\frac{10^{12}-0}{4\times10^{-4}-8\times10^{-4}}\right)$$

$$J_{h-diff} = 6.24\times10^{-3}\ \ A\ cm^{-2}$$

Good Luck
Dr Abdallah Hammad