Solutions HW #7

ECE 606

Fall 2012

Q1 $$I_0 = Aqn_i^2\left[\frac{D_p}{N_D W_n} + \frac{D_n}{N_A W_p}\right]$$

In a p^+n diode. $N_A >> N_D$

$$\therefore I_0 = Aqn_i^2\left[\frac{D_p}{N_D W_n}\right] \text{ (apbx.)} \quad \text{—— (1)}$$

Also $D_p = \mu_p KT/q$

At 300 K, $D_p = 0.026 \times 350 \text{ cm}^2/s = 9.1 \text{ cm}^2/s$.

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

$\therefore I_0 = 1.638 \times 10^{-14}$ A (using eq 1)

At 400k $\Rightarrow$ $D_p = 12.25 \text{ cm}^2/s$, $n_i = 5.185 \times 10^{12} \text{ cm}^{-3}$

[$\because$ $n_i \propto T^{3/2} \times \exp(-E_g/2KT)$]

$\therefore I_0 = 2.635 \times 10^{-9}$ A

Saturation current increases by five order when the rise in temperature is 100 C

Q2

6.10

(a) Reverse biased — there is a deficit of minority carrier in the quasineutral region immediately adjacent to the depletion region.

(b) Low-level injection DOES prevail. As required for low-level injection

$$|\Delta n_p|_{max} \cong n_{p0} << p_p \qquad \text{... for } x \le -x_p$$

$$|\Delta p_n|_{max} \cong p_{n0} << n_n \qquad \text{... for } x \ge x_n$$

(c) Since we have low level injection,

$$N_A \cong p_{p0} \cong p_p = 10^{14}/\text{cm}^3$$

$$N_D \cong n_{n0} \cong n_n = 10^{15}/\text{cm}^3$$

(d) Invoking the law of the junction,

$$n(-x_p)p(-x_p) = n_i^2 e^{qV_A/kT}$$

or

$$V_A = \frac{kT}{q}\ln\left[\frac{n(-x_p)p(-x_p)}{n_i^2}\right]$$

As deduced from Fig. P6.10,

$$n(-x_p) = 10^3/\text{cm}^3$$

$$p(-x_p) = 10^{14}/\text{cm}^3$$

and

$$n_i = \sqrt{n(\infty)p(\infty)} = \sqrt{n(-\infty)p(-\infty)} = \sqrt{10^{20}} = 10^{10}/\text{cm}^3$$

The foregoing manipulation to obtain n_i was necessary because the semiconductor used in fabricating the diode was not specified in the problem statement. Lastly, substituting into the V_A expression gives

$$V_A = (0.0259)\ln\left[\frac{(10^3)(10^{14})}{10^{20}}\right] = -\,0.18\text{V}$$

Q3 Under reverse bias $V_R = 1V$.

$$\phi_j = V_T \ln\left[\frac{N_A N_D}{n_i^2}\right] = 0.89V$$

$$\varepsilon_s = \varepsilon_{r(silicon)} * \varepsilon_0 = 11.68 \times 8.85 \times 10^{-14} \text{ F/cm} = 1.03 \times 10^{-12} \text{ F/cm}$$

$$W_{do} = \sqrt{\frac{2\varepsilon_s}{q}\left(\frac{1}{N_A} + \frac{1}{N_D}\right)\phi_j} = 15.4 \mu m$$

$$Q_{dep} = q\frac{N_A N_D}{N_A + N_D} w_d A$$

$$= q\frac{N_A N_D}{N_A + N_D} A\, w_{do}\sqrt{1 + \frac{V_R}{\phi_j}}$$

$$\Rightarrow Q_{dep} = 3.5 \times 10^{-22} \text{ C}$$

Injection (Diffusion charge)

$$Q_D(V_D) = qAn_i^2\left[\frac{W_p'}{2N_A} + \frac{L_p}{N_D}\right](e^{qV_D/kT} - 1)$$

$$Q_D(-1V) = 2.13 \times 10^{-53} \text{ c.}$$

Q4 This is one-dimensional Gauss Theorem

Let us begin by integrating Poisson eqn. from $-T_p$ to T_n.

$$\therefore \int_{-T_p}^{T_n} \rho(x)\,dx = \int_{-T_p}^{-x_p} \rho(x)\,dx + \int_{-x_p}^{x_n} \rho(x)\,dx$$

$$+ \int_{x_n}^{T_n} \rho(x)\,dx$$

In the region $-T_p < x < -x_p$ and $x_n < x < T_n$ the charge density is zero.

$\therefore$ The only integral that remains is

$$\int_{-x_p}^{x_n} \rho(x)\,dx = \int_{-x_p}^{x_n} \varepsilon_s \frac{dE}{dx}\cdot dx = \int_{-x_p}^{x_n} \varepsilon_s\,dE$$

$$= E(x_n) - E(-x_p) = 0 - 0$$

$\therefore$ Total charge enclosed within space-charge layer is zero.

Q5 $E_I - E_f = KT \ln \frac{p_p}{n_i}$

// Intrinsic   // Fermi-level

Inserting values $E_I - E_f = 470.74$ meV.

Q6 For two materials, say material 1 and 2 having band-gap energies E_{g1} and E_{g2}, the ratio of their intrinsic carrier concentration is given by

$$\frac{n_{i1}}{n_{i2}} = \frac{\sqrt{N_{C_1} N_{V_1}} \exp\left[-E_{g1}/2kT\right]}{\sqrt{N_{C_2} N_{V_2}} \exp\left[-E_{g2}/2kT\right]}$$

$$= \sqrt{\frac{N_{C_1} N_{V_1}}{N_{C_2} N_{V_2}}} \exp\left[\frac{E_{g_2} - E_{g_1}}{2kT}\right]$$

Assuming differences in values of N_c and N_v are small $\Rightarrow$ $\frac{n_{i1}^{2}}{n_{i2}} = \exp\left[\frac{E_{g_2} - E_{g_1}}{kT}\right]$

Considering the band gap of the three materials:

$$\frac{n_{i\,Ge}^2}{n_{i\,Si}^2} \cong \exp\left[\frac{1.12-0.66}{0.026}\right] = 4.83\times10^{7}$$

Similarly, $\frac{n_{i\,Si}^2}{n_{i\,GaAs}^2} = 1.03\times10^{5}$

Since the other terms in expression for I_0 have much smaller dependence on the material, we can say that $(I_0)_{Ge} \gg (I_0)_{Si} > (I_0)_{GaAs}$