Solutions HW #7

ECE 606

Fall 2012
\[ I_o = A q n_i^2 \left[ \frac{D_p}{N_D w_n} + \frac{D_n}{N_A w_p} \right] \]

In a \( p^n \) diode, \( N_A \gg N_D \)

\[ I_o = A q n_i^2 \left[ \frac{D_p}{N_D w_n} \right] \text{ (approx.)} \quad (i) \]

Also \( D_p = \mu_p kT/q \)

At 300 K, \( D_p = 0.026 \times 358 \text{ cm}^2/\text{s} = 9.1 \text{ cm}^2/\text{s} \)

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

\[ I_o = 1.638 \times 10^{-14} A \text{ (using eq } i) \]

At 400 K, \( D_p = 12.25 \text{ cm}^2/\text{s} \), \( n_i = 5.185 \times 10^{12} \text{ cm}^{-3} \)

\[ n_i \propto T^{3/2} \exp\left(-\frac{E_g}{2kT}\right) \]

\[ I_o = 2.635 \times 10^{-9} A \]

Saturation current increases by five orders when the rise in temperature is 100°C.
(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

\[ |\Delta n_p|_{\text{max}} = n_{p0} << p_p \quad \text{... for } x \leq -x_p \]

\[ |\Delta p_n|_{\text{max}} = p_{n0} << n_n \quad \text{... for } x \geq x_n \]

(c) Since we have low level injection,

\[ N_A \equiv p_{p0} \equiv p_p = 10^{14}/\text{cm}^3 \]

\[ N_D \equiv n_{n0} \equiv n_n = 10^{15}/\text{cm}^3 \]

(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

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

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

\[ V_A = (0.0259) \ln \left( \frac{(10^3)(10^{14})}{10^{20}} \right) = -0.18V \]
Under reverse bias \( V_R = 1\) V.

\[ \Phi_j = V_T \ln \left[ \frac{N_A N_D}{N_A^{\frac{1}{2}}} \right] = 0.89 \text{V} \]

\[ \varepsilon_S = \varepsilon_{\text{silicon}} \times \varepsilon_0 = 11.68 \times 8.85 \times 10^{-14} \text{ F/cm} = 1.03 \times 10^{-12} \text{ F/cm} \]

\[ W_{do} = \sqrt{\frac{2 \varepsilon_S}{q} \left( \frac{1}{N_A} + \frac{1}{N_D} \right) \Phi_j} = 15.4 \mu m \]

\[ Q_{\text{def}} \approx \sqrt[4]{\frac{N_A N_D}{N_A + N_D}} w_j A \]

\[ = \sqrt[4]{\frac{N_A N_D}{N_A + N_D}} A W_{do} \sqrt{1 + \frac{V_R}{\Phi_j}} \]

\[ \Rightarrow Q_{\text{def}} = 3.5 \times 10^{-22} \text{c} \]

**Injection (Diffusion charge)**

\[ Q_{D}(V_D) = q A n_e^2 \left[ \frac{w_p^1}{2N_A} + \frac{L_p}{N_D} \right] (e^{qV_D/kT} - 1) \]

\[ Q_{D}(-1\text{V}) = 2.13 \times 10^{-53} \text{C} \]
This is one-dimensional Gauss theorem.

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

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

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

The only integral that remains is:

$$\int_{-x_p}^{x_n} P(x) \, dx = \int_{-x_p}^{x_n} \varepsilon \cdot \frac{d\varepsilon}{dx} \, dx = \int_{-x_p}^{x_n} d\varepsilon$$

$$= \varepsilon(x_n) - \varepsilon(-x_p) = 0 - 0$$

Total charge enclosed within space-charge layer is zero.
\[
\Delta E = E_I - E_f = kT \ln \frac{p_F}{n_i}
\]

Intrinsic Fermi level

Inserting values \(E_I - E_f = 470.74 \text{ meV}\).

Q6. For two materials, say material 1 and 2, having band gap energies \(E_{g1}\) and \(E_{g2}\), the ratio of their intrinsic carrier concentrations is given by:

\[
\frac{n_{i1}}{n_{i2}} = \frac{\sqrt{N_c N_V}}{\sqrt{N_{c2} N_{V2}}} \frac{\exp \left[ -E_{g1} / 2kT \right]}{\exp \left[ -E_{g2} / 2kT \right]}
\]

\[
= \sqrt{\frac{N_c N_V}{N_{c2} N_{V2}}} \exp \left[ \frac{E_{g2} - E_{g1}}{2kT} \right]
\]

Assuming differences in values of \(N_c\) and \(N_V\) are small \(\Rightarrow \frac{n_{i1}^2}{n_{i2}^2} = \exp \left[ \frac{E_{g2} - E_{g1}}{kT} \right] \)
Considering the band gap of the three materials:

\[
\frac{n_{\text{Ge}}^2}{v_n} \approx \exp \left[ \frac{1.12 - 0.66}{0.026} \right] = 4.83 \times 10^7
\]

Similarly, \( \frac{n_{\text{Si}}^2}{v_n} = 1.03 \times 10^5 \)

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

\[\text{I} \quad \text{Ge} \quad \text{Si} \quad \text{GaAs} \]

\[\text{I} \quad \text{v} \]

\( \text{Close} \)