VE320 HW5 Solution

1.

(a) $V_B = \dfrac{\epsilon_s \mathrm{E}_{crit}^2}{2eN_B}$

or

$$N_B = \frac{\epsilon_s \mathrm{E}_{crit}^2}{2eV_B} = \frac{(11.7)(8.85\times10^{-14})(4\times10^5)^2}{2(1.6\times10^{-19})(40)}$$

Then $N_B = N_a = 1.294\times10^{16}\ \mathrm{cm}^{-3}$

(b) $N_B = \dfrac{(11.7)(8.85\times10^{-14})(4\times10^5)^2}{2(1.6\times10^{-19})(20)}$

Or $N_B = N_a = 2.59\times10^{16}\ \mathrm{cm}^{-3}$

2.

(a) V_{bi}.

$$V_{bi} = kTln\left(\frac{N_a N_d}{n_i^2}\right) = 0.731V.$$

(b) the junction capacitance at reverse bias V_R
(i) $V_R = 1V$,
(ii) $V_R = 3V$,
(iii) $V_R = 5V$,

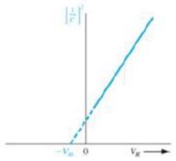
$$C = A\sqrt{\frac{q\varepsilon}{2(V_{bi}+V_R)}\frac{N_a N_d}{N_a+N_d}}\ (F), \varepsilon = \varepsilon_0\varepsilon_r = 11.7\times8.85\times10^{-14}$$

(c) plot $1/C^2$ versus V_R and identify how the slope and intercept at the voltage axis are related to N_d and V_{bi}, respectively.

$$\frac{1}{C^2} = \frac{2(V_{bi}+V_R)}{q\varepsilon A^2}\frac{N_a+N_d}{N_a N_d}$$

$$slope \approx \frac{2}{q\varepsilon A^2 N_d}$$

$$intercept = -V_{bi}$$



3.

(a) $J_s = en_i^2\left[\dfrac{1}{N_a}\sqrt{\dfrac{D_n}{\tau_{no}}} + \dfrac{1}{N_d}\sqrt{\dfrac{D_p}{\tau_{p0}}}\right]$

$$= (1.6\times10^{-19})(1.5\times10^{10})^2 \times\left[\frac{1}{5\times10^{17}}\sqrt{\frac{25}{10^{-7}}} + \frac{1}{8\times10^{15}}\sqrt{\frac{10}{8\times10^{-8}}}\right]$$

$$J_s = 5.145\times10^{-11}\ \mathrm{A/cm^2}$$

$$I_s = AJ_s = (2\times10^{-4})(5.145\times10^{-11}) = 1.029\times10^{-14}\ \mathrm{A}$$

(b) $I = I_s \exp\left(\dfrac{V_a}{V_t}\right)$

(i) $I = (1.029\times10^{-14})\exp\left(\dfrac{0.45}{0.0259}\right) = 3.61\times10^{-7}\ \mathrm{A}$

(ii) $I = (1.029\times10^{-14})\exp\left(\dfrac{0.55}{0.0259}\right) = 1.72\times10^{-5}\ \mathrm{A}$

(iii) $I = (1.029\times10^{-14})\exp\left(\dfrac{0.65}{0.0259}\right) = 8.16\times10^{-4}\ \mathrm{A}$

4.

(a) $$\frac{J_n}{J_n+J_p} = \frac{\dfrac{eD_n n_{po}}{L_n}}{\dfrac{eD_n n_{po}}{L_n} + \dfrac{eD_p p_{no}}{L_p}} = \frac{\sqrt{\dfrac{D_n}{\tau_{no}}}\cdot\dfrac{n_i^2}{N_a}}{\sqrt{\dfrac{D_n}{\tau_{no}}}\cdot\dfrac{n_i^2}{N_a} + \sqrt{\dfrac{D_p}{\tau_{po}}}\cdot\dfrac{n_i^2}{N_d}}$$

$$0.90 = \frac{1}{1+\sqrt{\dfrac{D_p\tau_{no}}{D_n\tau_{po}}}\cdot\left(\dfrac{N_a}{N_d}\right)}$$

$$\sqrt{\frac{D_p\tau_{no}}{D_n\tau_{po}}}\cdot\left(\frac{N_a}{N_d}\right) = \frac{1}{0.90} - 1$$

$$\frac{N_a}{N_d} = \sqrt{\frac{D_n\tau_{po}}{D_p\tau_{no}}}\left(\frac{1}{0.90}-1\right) = \sqrt{\frac{(25)(10^{-7})}{(10)(5\times10^{-7})}}(0.1111)$$

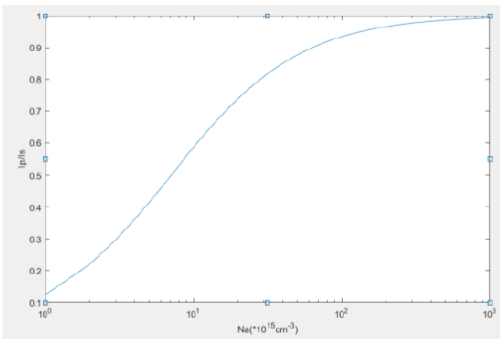
$$\frac{N_a}{N_d} = 0.07857 \text{ or } \frac{N_d}{N_a} = 12.73$$

(b) From part (a),

$$\frac{N_a}{N_d} = \sqrt{\frac{D_n\tau_{po}}{D_p\tau_{no}}}\left(\frac{1}{0.20}-1\right) = \sqrt{\frac{(25)(10^{-7})}{(10)(5\times10^{-7})}}(4)$$

$$\frac{N_a}{N_d} = 2.828 \text{ or } \frac{N_d}{N_a} = 0.354$$

5.



6.

(a) $I_s = Aen_i^2\left[\frac{1}{N_a}\sqrt{\frac{D_n}{\tau_{n0}}}+\frac{1}{N_d}\sqrt{\frac{D_p}{\tau_{p0}}}\right]$

$$=\left(10^{-4}\right)\left(1.6\times10^{-19}\right)\left(1.5\times10^{10}\right)^2$$

$$\times\left[\frac{1}{4\times10^{16}}\sqrt{\frac{25}{10^{-7}}}+\frac{1}{4\times10^{16}}\sqrt{\frac{10}{10^{-7}}}\right]$$

$$I_s = 2.323\times10^{-15}\ \text{A}$$

(b) $I_{gen} = \frac{Aen_iW}{2\tau_0}$

We find

$$V_{bi} = (0.0259)\ln\left[\frac{\left(4\times10^{16}\right)\left(4\times10^{16}\right)}{\left(1.5\times10^{10}\right)^2}\right]$$

$$= 0.7665\ \text{V}$$

and

$$W = \left\{\frac{2\in_s\left(V_{bi}+V_R\right)}{e}\left(\frac{N_a+N_d}{N_aN_d}\right)\right\}^{1/2}$$

$$= \left\{\frac{2(11.7)\left(8.85\times10^{-14}\right)(0.7665+5)}{1.6\times10^{-19}}\right.$$

$$\left.\times\left[\frac{4\times10^{16}+4\times10^{16}}{\left(4\times10^{16}\right)\left(4\times10^{16}\right)}\right]\right\}^{1/2}$$

$$W = 6.109\times10^{-5}\ \text{cm}$$

Then

$$I_{gen} = \frac{\left(10^{-4}\right)\left(1.6\times10^{-19}\right)\left(1.5\times10^{10}\right)\left(6.109\times10^{-5}\right)}{2\left(10^{-7}\right)}$$

$$= 7.331\times10^{-11}\ \text{A}$$

(c) $\frac{I_{gen}}{I_s} = \frac{7.331\times10^{-11}}{2.323\times10^{-15}} = 3.16\times10^4$

7.

$$D_n = \left(\frac{kT}{e}\right)\cdot\mu_n = (0.0259)(5500)$$

$$= 142.5\ \text{cm}^2/\text{s}$$

$$D_p = (0.0259)(220) = 5.70\ \text{cm}^2/\text{s}$$

(a)

(i) $I_s = Aen_i^2\left[\frac{1}{N_a}\sqrt{\frac{D_n}{\tau_{n0}}}+\frac{1}{N_d}\sqrt{\frac{D_p}{\tau_{p0}}}\right]$

$$= \left(2\times10^{-4}\right)\left(1.6\times10^{-19}\right)\left(1.8\times10^6\right)^2$$

$$\times\left[\frac{1}{7\times10^{16}}\sqrt{\frac{142.5}{2\times10^{-8}}}+\frac{1}{7\times10^{16}}\sqrt{\frac{5.70}{2\times10^{-8}}}\right]$$

$$I_s = 1.50\times10^{-22}\ \text{A}$$

(ii) $I_D = I_s\exp\left(\frac{V_a}{V_t}\right)$

$$= \left(1.50\times10^{-22}\right)\exp\left(\frac{0.6}{0.0259}\right)$$

$$= 1.726\times10^{-12}\ \text{A}$$

(iii) $I_D = \left(1.50\times10^{-22}\right)\exp\left(\frac{0.8}{0.0259}\right)$

$$= 3.896\times10^{-9}\ \text{A}$$

(iv) $I_D = \left(1.50\times10^{-22}\right)\exp\left(\frac{1.0}{0.0259}\right)$

$$= 8.795\times10^{-6}\ \text{A}$$

(b) $I_{gen} = \frac{Aen_iW}{2\tau_0}$

$$V_{bi} = (0.0259)\ln\left[\frac{\left(7\times10^{16}\right)\left(7\times10^{16}\right)}{\left(1.8\times10^6\right)^2}\right]$$

$$= 1.263\ \text{V}$$

$$W = \left\{\frac{2(13.1)\left(8.85\times10^{-14}\right)(1.263+3)}{1.6\times10^{-19}}\right.$$

$$\left.\times\left[\frac{7\times10^{16}+7\times10^{16}}{\left(7\times10^{16}\right)\left(7\times10^{16}\right)}\right]\right\}^{1/2}$$

$$= 4.201\times10^{-5}\ \text{cm}$$

(i)Then

$$I_{gen} = \frac{\left(2\times10^{-4}\right)\left(1.6\times10^{-19}\right)\left(1.8\times10^6\right)\left(4.201\times10^{-5}\right)}{2\left(2\times10^{-8}\right)}$$

$$= 6.049\times10^{-14}\ \text{A}$$

(ii) $I_{rec} = I_{ro}\exp\left(\frac{V_a}{2V_t}\right)$

$$= \left(6\times10^{-14}\right)\exp\left(\frac{0.6}{2(0.0259)}\right)$$

$$= 6.436\times10^{-9}\ \text{A}$$

(iii) $I_{rec} = \left(6\times10^{-14}\right)\exp\left(\frac{0.8}{2(0.0259)}\right)$

$$= 3.058\times10^{-7}\ \text{A}$$

(iv) $I_{rec} = \left(6\times10^{-14}\right)\exp\left(\frac{1.0}{2(0.0259)}\right)$

$$= 1.453\times10^{-5}\ \text{A}$$

8.