EE 105 HW 07

1

$$L = 1\,\mu\text{m} \tag{1}$$
$$N_a = 4 \times 10^{10}\,\text{cm}^{-3} \tag{2}$$
$$T = 300\,\text{K} \tag{3}$$
$$n_i = 1 \times 10^{10}\,\text{cm}^{-3} \tag{4}$$
$$\mu_n = 1400\,\text{cm}^2\,\text{V}^{-1}\,\text{s}^{-1} \tag{5}$$
$$\mu_p = 500\,\text{cm}^2\,\text{V}^{-1}\,\text{s}^{-1} \tag{6}$$

(a) This semiconductor is p-type.

(b)

$$p_0 - n_0 + \cancelto{0}{N_d} - N_a \approx 0 \tag{7}$$
$$p_0 - \frac{n_i^2}{p_0} - N_a \approx 0 \tag{8}$$
$$p_0^2 - N_a p_0 - n_i^2 \approx 0 \tag{9}$$
$$\implies p_0 = \frac{N_a}{2} + \sqrt{\left(\frac{N_a}{2}\right)^2 + n_i^2} = 4.24 \times 10^{10}\,\text{cm}^{-3} \tag{10}$$
$$n_0 = \frac{n_i^2}{p_0} = 2.36 \times 10^{9}\,\text{cm}^{-3} \tag{11}$$

(c) $\rho = (q(n_0\mu_n + p_0\mu_p))^{-1} = 2.55 \times 10^5\,\Omega\,\text{cm} = 2.55 \times 10^3\,\Omega\,\text{m}$

(d) $J = \frac{1}{\rho}\frac{V}{L} = 3.92 \times 10^2\,\text{A}\,\text{m}^{-2}$

(e) There are more holes, so the electron mean free time should decrease. Since $J \propto \rho^{-1} \propto \mu \propto \tau$, the current density should decrease.

(f) We now have $N_d = 1 \times 10^{11}\,\text{cm}^{-3}$.

$$p_0 - n_0 + N_d - N_a \approx 0 \tag{12}$$
$$\frac{n_i^2}{n_0} - n_0 + N_d - N_a \approx 0 \tag{13}$$
$$n_i^2 - n_0^2 + (N_d - N_a)n_0 \approx 0 \tag{14}$$
$$n_0^2 - (N_d - N_a)n_0 - n_i^2 \approx 0 \tag{15}$$
$$\implies n_0 = \frac{N_d - N_a}{2} + \sqrt{\left(\frac{N_d - N_a}{2}\right)^2 + n_i^2} = 6.16 \times 10^{10}\,\text{cm}^{-3} \tag{16}$$
$$p_0 = \frac{n_i^2}{n_0} = 1.62 \times 10^{9}\,\text{cm}^{-3} \tag{17}$$

2

$$n_i = 1 \times 10^{10}\,\mathrm{cm^{-3}} \tag{18}$$
$$\frac{kT}{q} = 26\,\mathrm{mV} \tag{19}$$
$$\epsilon_0 = 8.85\,\mathrm{F\,m^{-1}} \tag{20}$$
$$\epsilon_s = 11.7\epsilon_0 \tag{21}$$

(a) For PN junction A, we have $N_a = 1 \times 10^{16}\,\mathrm{cm^{-3}}$ and $N_d = 1 \times 10^{17}\,\mathrm{cm^{-3}}$. For PN junction B, we have $N_a = 1 \times 10^{18}\,\mathrm{cm^{-3}}$ and $N_d = 1 \times 10^{17}\,\mathrm{cm^{-3}}$.

$$\phi_{bi,A} = \frac{kT}{q}\ln\left(\frac{N_d N_a}{n_i^2}\right) = 0.78\,\mathrm{V} \tag{22}$$
$$\phi_{bi,B} = 0.90\,\mathrm{V} \tag{23}$$

(b)

$$X_{d0,A} = \sqrt{\frac{2\epsilon_s\phi_{bi,A}}{q}\left(\frac{1}{N_a}+\frac{1}{N_d}\right)} = 3.33 \times 10^{-4}\,\mathrm{cm} \tag{24}$$
$$X_{d0,B} = 1.13 \times 10^{-4}\,\mathrm{cm} \tag{25}$$

Meaning that PN junction A has a larger depletion width.

(c)

$$\max_x\{E_{0,A}(x)\} = -\frac{qN_a}{\epsilon_s}\sqrt{\frac{2\epsilon_s\phi_{bi}}{qN_a}\left(\frac{N_d}{N_d+N_a}\right)} = -\sqrt{\frac{2qN_a\phi_{bi}}{\epsilon_s}\left(\frac{N_d}{N_d+N_a}\right)} = -4.68 \times 10^3\,\mathrm{V\,cm^{-1}} \tag{26}$$
$$\max_x\{E_{0,B}(x)\} = -1.59 \times 10^4\,\mathrm{V\,cm^{-1}} \tag{27}$$

Meaning that PN junction B has a higher electric field strength.

(d)

$$X_d(V_d) = X_{d0}\sqrt{1-\frac{V_D}{\phi_{bi}}} = 1.51 \times 10^{-4}\,\mathrm{cm} \tag{28}$$
$$C_j = \frac{\epsilon_s}{X_d(V_D)} = 6.87 \times 10^{-5}\,\mathrm{F\,m^{-2}} \tag{29}$$

(e) Since $N_a = 1 \times 10^{20}\,\mathrm{cm^{-3}}$, the new built-in potential and depletion width are

$$\phi_{bi,A} = 1.018\,\mathrm{V} \tag{30}$$
$$X_{d0,A} = \sqrt{\frac{2\epsilon_s\phi_{bi,A}}{q}\left(\frac{1}{N_a}+\frac{1}{N_d}\right)} = 1.15 \times 10^{-4}\,\mathrm{cm} \tag{31}$$
$$X_{d,A}(V_D) = X_{d0,A}\sqrt{1-\frac{V_D}{\phi_{bi}}} \tag{32}$$
$$C_{j0}(V_D) = \frac{\epsilon_s}{X_{d,A}(V_D)} \tag{33}$$

3

$$n(x) = 5 \times 10^{16} - \frac{5 \times 10^{16}}{2 \times 10^{-4}\,\mathrm{cm}} x \tag{34}$$

$$p(x) = \frac{3 \times 10^{16}}{2 \times 10^{-4}\,\mathrm{cm}} x \tag{35}$$

$$D_n = 36\,\mathrm{cm}^2\,\mathrm{s}^{-1} \tag{36}$$

$$D_p = 12\,\mathrm{cm}^2\,\mathrm{s}^{-1} \tag{37}$$

(a)

$$J = q\left(D_n \frac{\mathrm{d}n}{\mathrm{d}x} - D_p \frac{\mathrm{d}p}{\mathrm{d}x}\right) = -1.73 \times 10^3\,\mathrm{A\,cm}^{-2} \tag{38}$$

(b) Since all regeneration and combination has balanced out, we have $J = 0\,\mathrm{A\,m}^{-2}$.

(c)

$$\frac{C}{A} = \frac{\epsilon}{d} \implies d = \frac{\epsilon A}{C} = \frac{3.9\epsilon_0}{40\,\mathrm{fF\,\mu m}^{-2}} = 8.63 \times 10^{-10}\,\mathrm{m} = 0.863\,\mathrm{nm} \tag{39}$$

(d) Converting the capacitance density, we have $40\,\mathrm{fF\,\mu m}^{-2} = 4 \times 10^{-2}\,\mathrm{F\,m}^{-2}$.

$$\epsilon = d \cdot \frac{C}{A} = (1 \times 10^{-9}\,\mathrm{m}) \cdot (4 \times 10^{-2}\,\mathrm{F\,m}^{-2}) = 4 \times 10^{-11}\,\mathrm{F\,m}^{-1} = 4.52\epsilon_0 \tag{40}$$