HOMEWORK 2 ECE255

1. (3.4) $n_n = n = N_D$

$$P_n = P = \frac{n_i^2}{n} = \frac{n_i^2}{N_D}$$

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

$$P = \frac{1.5 \times 10^{10}}{10^7} = 1.5 \times 10^3 \text{ cm}^{-3}$$

$$\Rightarrow N_D = n_i^2 / p = \frac{1.5 \times 10^{10} \times \cancel{1.5} \times 10^{\cancel{10}\,7}}{\cancel{1.5} \times 10^{\cancel{3}}} = 1.5 \times 10^{17} \text{ cm}^{-3} \,//$$

↳ concentration of P/Donor atoms

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2. (3.6) $L = 10\mu m = 10 \times 10^{-6} m$ (Length)

$t = 1 \times 10^{-6} m$, $w = 3 \times 10^{-6} m$

$A = t \times w = 3 \times 10^{-12} m^2$ (Area)

(a) Intrinsic Silicon $(p = n = n_i)$

$$\rho = \frac{1}{q(p\mu_p + n\mu_n)} = \frac{1}{q n_i (\mu_n + \mu_p)} = \frac{1}{1.6 \times 10^{-19} \times \underset{\uparrow\, \text{cm}^{-3}}{1.5 \times 10^{10}} \times \underset{\uparrow\, \text{cm}^2/Vs}{1680}}$$

$\mu_n = 1200 \text{ cm}^2/Vs$

$\mu_p = \frac{1200}{2.5} \text{ cm}^2/Vs = 480 \text{ cm}^2/Vs$

$$= (4032)^{-1} \times 10^9 \,\Omega cm = 248 \times 10^3 \,\Omega cm$$

$$= 2480 \,\Omega m$$

$$R = \frac{\rho L}{A} = 2480 \times \frac{10}{3} \times 10^6 \,\Omega = 8.26 \times 10^9 \,\Omega \,//$$

(b) n-doped with $N_D = 10^{16} \text{ cm}^{-3}$

$$n = N_D = 10^{16} \text{ cm}^{-3}$$

$$p = \frac{n_i^2}{N_D} = \frac{2.25 \times 10^{20}}{10^{16}} = 2.25 \times 10^4 \text{ cm}^{-3}$$

$$\rho = \frac{1}{q(\underbrace{\cancel{p\mu_p}}_{\text{negligible}} + n\mu_n)} = \frac{1}{1.6 \times 10^{-19} \times 10^{16} \times 1200} = .5208 \,\Omega cm = .521 \times 10^{-2} \,\Omega m$$

$$R = \frac{\rho L}{A} = .521 \times 10^{-2} \times \frac{10}{3} \times 10^6 \,\Omega = .174 \times 10^5 = 1.74 \times 10^4 \,\Omega \,//$$

(d) p-doped with $N_A = 10^{16} \text{ cm}^{-3}$

$$p = N_A = 10^{16}, \quad n = 2.25 \times 10^4 \text{ cm}^{-3}$$

$$\rho = \frac{1}{q(p\mu_p + \cancel{n\mu_n})} = \frac{1}{1.6 \times 10^{-19} \times 10^{16} \times 480} = 1.302 \,\Omega cm = 1.302 \times 10^{-2} \,\Omega m$$

$$R = \frac{\rho L}{A} = 1.302 \times 10^{-2} \times \frac{10}{3} \times 10^6 \,\Omega = 4.34 \times 10^4 \,\Omega \,//$$

c) $N_D = 10^{18}\ cm^{-3}$

$n = N_D = 10^{18}\ cm^{-3}$, $p = 2.25\times10^{2}\ cm^{-3}$

$\rho = \frac{1}{q(n\mu_n + p\mu_p)} = \frac{1}{1.6\times10^{-19}\times10^{18}\times1200} = .00528\ \Omega cm = 5.28\times10^{-5}\ \Omega m$

$R = \frac{\rho L}{A} = 5.28\times10^{-5}\times\frac{10}{3}\times10^{6}\ \Omega = 1.736\times10^{2}\Omega \simeq 174\Omega$ //

e) $\rho_{Aluminium} = 2.8\times10^{-6}\ \Omega cm = 2.8\times10^{-8}\ \Omega m$

$R = \frac{\rho L}{A} = 2.8\times10^{-8}\times\frac{10}{3}\times10^{6} = \frac{0.28}{3}\ \Omega = 0.09\bar{3}\ \Omega$ //

. (3.8) $L = 10\mu m = 10^{-5}\ m$

$A = 20\times10^{-12}\ m^{2}$

$n = 10^{5}\ cm^{-3}$, $p = 10^{15}\ cm^{-3}$

$\mu_n = 1200\ cm^{2}/Vs$, $\mu_p = 500\ cm^{2}/Vs$

$\rho = \frac{1}{q(n\mu_n + p\mu_p)} = \frac{1}{1.6\times10^{-19}(10^{5}\times1200 + 10^{15}\times500)}$

$= \frac{1}{1.6\times10^{-19}\times10^{15}\times500} = \frac{1}{800}\times10^{4} = \frac{100}{8}\ \Omega cm = \frac{1}{8}\ \Omega m$

$R = \frac{\rho L}{A} = \frac{\frac{1}{8}\times10^{-5}}{20\times10^{-12}} = \frac{10^{7}}{160} = 6.25\times10^{4}\ \Omega$

$V/I = R \Rightarrow I = \frac{V}{R} = \frac{1V}{6.25\times10^{4}} = 1.6\times10^{-5} A = 16\mu A$ //

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4. (3.12) $p = n = 10^{16}$ atom cm^{-3} , $n_i = 1.5\times10^{10}\ cm^{-3}$

(after no 5) Junction built-in voltage $= V_0 = V_T \ln\left(\frac{N_A N_D}{n_i^{2}}\right) = 26mV \ln\left(\frac{10^{\cancel{32}\ 12}}{2.25\times10^{\cancel{20}}}\right)$

V_T → 26mV

$= 26\cancel{m}\times10^{-3}\times12\times\ln(10/2.25) = 0.4265V$

Terminals left open ⇒ $V_R = 0\ V$

$W = x_n + x_p = \sqrt{\frac{2\varepsilon_s}{q}\left(\frac{1}{N_A}+\frac{1}{N_D}\right)V_0} = \sqrt{\frac{2\times11.7\times8.854\times10^{\cancel{-14}}\times2\times10^{\cancel{-16}\ -11}\times0.426\times10^{-6}}{1.6\times10^{\cancel{-19}}}}$

ε_s → $11.7\times8.854\times10^{-14}$

$= 3.32\times10^{-8}\ m$

$\frac{x_n}{x_n+x_p} = \frac{N_A}{N_D+N_A} \Rightarrow x_n = \frac{N_A}{N_D+N_A}W$, $x_p = W - x_n$

$= W/2 = 1.66\times10^{-8}\ m = x_p$

Charge stored in depletion Region one either side of $= q\frac{N_A N_D}{(N_A+N_D)}AW$

A → $100\times10^{-12}\ m^{2}$

$= \frac{\overset{0.8}{\cancel{1.6\times10^{-19}}}\times10^{\cancel{32}\ 16}\times100\times10^{\cancel{-12}\ 20}\times3.32\times10^{\cancel{-8}}}{\cancel{2}\times10^{\cancel{16}}}$

$= 26.56\times10^{-19}\ C$ //

$26.56\times10^{-19}\times10^{-3}/10^{-6}$

$= 26.56\times10^{-16}\ C$ //

5. (3.22) $J = J_p = I_S(e^{V/V_T} - 1)$ where $I_S = Aqn_i^2\left(\frac{D_p}{L_pN_D} + \cancel{\frac{D_n}{L_nN_A}}\right)$ → as $N_A >> N_D$ for p^+n diode

$$\Rightarrow \quad I_S = \frac{Aqn_i^2 D_p}{L_p N_D} = \frac{\cancel{10^4} \times \cancel{10^{-12}} \times 1.6 \times \cancel{10^{-19}} \times 2.25 \times \cancel{10^{20}} \times \cancel{10 \times 10^{-4}}}{\cancel{10^{-5}} \times \cancel{10^{16}} \times \cancel{10^{6}}} \times 10^{-15}$$

$$= 3.6 \times 10^{-15}\,A \;//$$

$$I = 0.5\,A = 3.6 \times 10^{-15}\,A\,(e^{V/V_T} - 1)$$

$$\Rightarrow 10^{15} \times \frac{0.5}{3.6} = e^{V/V_T} - 1 \simeq \quad V = V_T\,Ln\left(\frac{10^{15}}{7.2}\times\right)$$

$$= 26mV \times 15 \times Ln\left(\frac{10}{7.2}\right)$$

$$= 0.128V \;//$$

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4 (3.12) $p = n = 10^{16}$ atoms cm^{-3}, $n_i = 1.5 \times 10^{10}\,cm^{-3}$

Junction built-in voltage $= V_0 = V_T\,Ln\left(\frac{N_AN_D}{n_i^2}\right) = 26mV\;Ln\left(\frac{10^{32}}{2.25 \times 10^{20}}\right)$

$$= 26 \times 10^{-3} \times 12 \times Ln(10/2.25)$$

$$= 0.465V$$

Terminals left open ⇒ $V_R = 0V$

$$W = x_n + x_p = \sqrt{\frac{2\varepsilon_s}{q}\left(\frac{1}{N_A} + \frac{1}{N_D}\right)V_0} = \sqrt{\frac{2 \times 11.7 \times 8.854 \times 10^{-14} \times 2 \times 10^{-16} \times 0.426 \times 10^{-6}}{1.6 \times 10^{-19}}}$$

ε_s ← $11.7 \times 8.854 \times 10^{-14}$

$$= 3.466 \times 10^{-8}m$$

$$x_n = x_p = W/2 = 1.733 \times 10^{-8}m$$

Charge stored on either side of depletion region $= q\frac{N_AN_D}{N_A + N_D}AW$

A ↳ $100 \times 10^{-12}m^{-2}$

$$= \frac{1.6 \times 10^{-19} \times 10^{32} \times 100 \times 10^{-12} \times 3.32 \times 10^{-8}}{2 \times 10^{16}}$$

$$= 27.12 \times 10^{-16}\;C$$