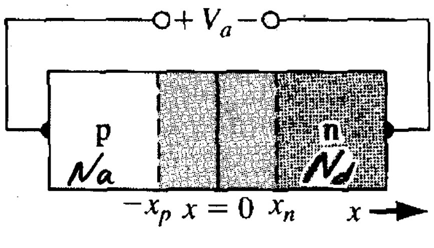
8.16 Consider an ideal silicon pn junction diode with the geometry shown in Figure P8.16. The doping concentrations are $N_a = 5 \times 10^{16}$ cm^{-3} and $N_d = 1.5 \times 10^{16}$ cm^{-3}, and the minority carrier lifetimes are $\tau_{n0} = 2 \times 10^{-7}$ s and $\tau_{p0} = 8 \times 10^{-8}$ s. The cross-sectional area is $A = 5 \times 10^{-4}$ cm^2. Calculate (*a*) the ideal reverse-saturation current due to holes, (*b*) the ideal reverse-saturation current due to electrons, (*c*) the hole concentration at $x = x_n$ for $V_a = 0.8V_{bi}$, (*d*) the electron current at $x = x_n$ for $V_a = 0.8\,V_{bi}$, and (*e*) the electron current at $x = x_n + (1/2)L_p$ for $V_a = 0.8\,V_{bi}$.

- First, calculate the minority thermal equilibrium carrier concentrations and diffusion lengths for the n & p regions.



From Table B.4 & p. 323

$n_i = 1.5 \times 10^{10}\,cm^{-3} = 1.5 \times 10^{16}\,m^{-3}$,

@ 300K $D_p = 10\,\frac{cm^2}{s}$, + $D_n = 25\,\frac{cm^2}{s}$

n region $\quad n_{n0} \cong N_d = 1.5 \times 10^{16}\,cm^{-3} = 1.5 \times 10^{22}\,m^{-3}$

(4.43) $p_{n0} = \frac{n_i^2}{n_{n0}} = \frac{(1.5\times10^{10})^2}{1.5\times10^{16}} = \underline{1.5\times10^{4}\,cm^{-3} = 1.5\times10^{10}\,m^{-3}}$

(6.63) $L_n = \sqrt{D_n \tau_{n0}} = \sqrt{25(2\times10^{-7})} = \underline{0.002236\,cm = 2.236\times10^{-5}\,m}$

p region $\quad p_{p0} \cong N_a = 5\times10^{16}\,cm^{-3} = 5\times10^{22}\,m^{-3}$

(4.43) $n_{p0} = \frac{n_i^2}{p_{p0}} = \frac{(1.5\times10^{10})^2}{5\times10^{16}} = \underline{4.5\times10^{3}\,cm^{-3} = 4.5\times10^{9}\,m^{-3}}$

(8.9) $L_p = \sqrt{D_p \tau_{p0}} = \sqrt{10(8\times10^{-8})} = \underline{0.0008944\,cm = 8.94427\times10^{-6}\,m}$

a) (8.26) $J_s = \underbrace{\frac{eD_p p_{n0}}{L_p}}_{holes} + \underbrace{\frac{eD_n n_{p0}}{L_n}}_{electrons}$

$J_{s,p} = \frac{1.6021766\times10^{-19}(10)1.5\times10^{4}}{0.0008944} = 2.68693\times10^{-11}\,A/cm^2$

$I_{s,p} = J_{s,p}(A) = 2.6869\times10^{-11}(5\times10^{-4}) = \underline{1.3435\times10^{-14}\,A}$

b) $$J_{s,n} = \frac{1.6021766\times10^{-19}(25)4.5\times10^{3}}{0.002236} = 8.0608\times10^{-12}\ \text{A/cm}^2$$

$$I_{s,n} = J_{s,n}(A) = 8.0608\times10^{-12}(5\times10^{-4}) = \underline{\underline{4.0304\times10^{-15}\ A}}$$

c) First, find V_{bi} using (7.10)

$$V_{bi} = \frac{k_B T}{e}\ln\left(\frac{N_a N_d}{n_i^2}\right) = \underbrace{\frac{8.617333\times10^{-5}\ \text{eV/K}\,(300\text{K})}{e}}_{0.025852}\ln\left(\frac{5\times10^{16}(1.5\times10^{16})}{(1.5\times10^{10})^2}\right)$$

$$= 0.745442\ V$$

$$V_a = 0.8V_{bi} = 0.8(0.745442) = 0.5963538\ V$$

Per (8.11a), $$p_n(x_n) = p_{n0}\, e^{V_a/k_BT/e}$$

$$= 1.5\times10^{4}\ \text{cm}^{-3}\ e^{\frac{0.5963538}{0.025852}}$$

$$\underline{\underline{p_n(x_n) = 1.56457\times10^{14}\ \text{cm}^{-3} = 1.565\times10^{20}\ \text{m}^{-3}}}$$

d) Per (8.24), $$J_n(-x_p) = \underbrace{\frac{eD_n n_{p0}}{L_n}}_{J_{s,n}\ (\text{part b})}\left[e^{V_a/k_BT/e} - 1\right]$$

Since current is continuous across depletion layer $J_n(x_n) = J_n(-x_p)$

$$J_n(x_n) = 8.0608\times10^{-12}\ \text{A/cm}^2\left[e^{\frac{0.5963538}{0.025852}} - 1\right]$$

$$= 0.0840777\ \text{A/cm}^2$$

$$I_n(x_n) = J_n(x_n)\,A = 0.0840777(5\times10^{-4})$$

$$\underline{\underline{I_n(x_n) = 4.20389\times10^{-5}\ A = 42.0389\ \mu A}}$$

e) The total diode current $I = I_n(-x_p) + I_p(x_n) = J(A)$

where (8.26) $J_s = \dfrac{e D_p p_{n0}}{L_p} + \dfrac{e D_n n_{p0}}{L_n}$ } use a) & b) results

$= 2.68693 \times 10^{-11} + 8.0608 \times 10^{-12}$

$= 3.49301 \times 10^{-11}\ A/cm^2$

per (8.27) $J = J_s \left[e^{V_a/k_BT/e} - 1 \right]$

$= 3.49301 \times 10^{-11} \left[e^{\frac{0.5963538}{0.025852}} - 1 \right]$

$= 0.364337\ A/cm^3$

$I = J(A) = 0.364337(5 \times 10^{-4}) = 1.82168 \times 10^{-4}\ A$

To get the electron current (majority carriers), we will subtract the minority current (holes) from the total current I.

Per (8.28), $J_p(x) = \dfrac{e D_p p_{n0}}{L_p} \left[e^{V_a/k_BT/e} - 1 \right] e^{\frac{x_n - x}{L_p}}$

$J_p(x_n + L_p/2) = 2.68693 \times 10^{-11} \left[e^{\frac{0.5963538}{0.025852}} - 1 \right] e^{\frac{x_n - x_n - L_p/2}{L_p}}$

$= 0.280259\ e^{-1/2} = 0.169986\ A/cm^2$

$I_p(x_n + L_p/2) = J_p(x_n + L_p/2) A = 0.169986(5 \times 10^{-4})$

$= 8.49929 \times 10^{-5}\ A$

$I_n(x_n + L_p/2) = I - I_p(x_n + L_p/2) = 1.82168 \times 10^{-4} - 8.4993 \times 10^{-5}$

$\underline{\underline{I_n(x_n + \frac{L_p}{2}) = 9.71755 \times 10^{-5}\ A = 97.176\ \mu A}}$