8.28 Consider a silicon pn junction diode with an applied reverse-biased voltage of V_R = 5V. The doping concentrations are $N_a = N_d = 4 \times 10^{16}$ cm^{-3} and the cross-sectional area is $A = 10^{-4}$ cm^2. Assume minority carrier lifetimes of $\tau_0 = \tau_{n0} = \tau_{p0} = 10^{-7}$ s. Calculate the (*a*) ideal reverse-saturation current, (*b*) reverse-biased generation current, and (*c*) the ratio of the generation current to ideal saturation current.

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

From Table B.4, $n_i = 1.5 \times 10^{10}$ cm^{-3} and $\varepsilon_r = 11.7$ for silicon at 300 K.

From page 323 'Note', $D_n = 25$ cm^2/s and $D_p = 10$ cm^2/s. Use given τ_{n0} & τ_{p0}.

n region Since $N_d >> n_i \Rightarrow n_{n0} \cong N_d = 4 \times 10^{16}$ cm^{-3}.

Per (4.43), $p_{n0} = n_i^2 / n_{n0} = (1.5\times10^{10})^2 / 4\times10^{16}$ $\Rightarrow$ **p_{n0} = 5625 cm^{-3}**.

From p. 283, $L_p = \sqrt{D_p\, \tau_{p0}} = \sqrt{10\,(10^{-7})}$ $\Rightarrow$ **L_p = 0.001 cm = 10 μm**.

p region Since $N_a >> n_i \Rightarrow p_{p0} \cong N_a = 4 \times 10^{16}$ cm^{-3}.

Per (4.43), $n_{p0} = n_i^2 / p_{p0} = (1.5\times10^{10})^2 / 4\times10^{16}$ $\Rightarrow$ **n_{p0} = 5625 cm^{-3}**.

From p. 283, $L_n = \sqrt{D_n\, \tau_{n0}} = \sqrt{25\,(10^{-7})}$ $\Rightarrow$ **$L_n = 1.5811 \times 10^{-3}$ cm = 15.8114 μm**.

a) Per (8.26), the ideal reverse saturation current density is $J_s = \dfrac{e D_p\, p_{n0}}{L_p} + \dfrac{e D_n\, n_{p0}}{L_n}$.

$$J_s = \frac{1.602176634\times10^{-19}(10)\,5625}{0.001} + \frac{1.602176634\times10^{-19}(25)\,5625}{1.58113883\times10^{-3}} = 2.326 \times 10^{-11} \text{ A/cm}^2.$$

The ideal reverse saturation current is $I_s = J_s A = 2.3262 \times 10^{-11}\,(10^{-4})$

$\Rightarrow$ **$I_s = 2.3262 \times 10^{-15}$ A**.

b) Per (8.42), the reverse-biased generation current density is $J_{\text{gen}} = \dfrac{e n_i W}{2\tau_0}$.

Per (7.10), $V_t = \dfrac{k_B T}{e} = \dfrac{8.617333\times10^{-5}\text{ eV/K}\,(300\text{K})}{e} = 0.025852$ V, and

$$V_{bi} = V_t \ln\left(\frac{N_a N_d}{n_i^2}\right) = 0.025852 \ln\left(\frac{4\times10^{16}\,(4\times10^{16})}{(1.5\times10^{10})^2}\right) = 0.76503 \text{ V}.$$

Per (7.34),

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

$$= \left\{ \frac{2(11.7)8.8541878 \times 10^{-12}(0.76503 + 5)}{1.602176634 \times 10^{-19}} \left(\frac{4 \times 10^{22} + 4 \times 10^{22}}{4 \times 10^{22}(4 \times 10^{22})} \right) \right\}^{1/2}$$

$\Rightarrow W = 6.10538 \times 10^{-7}$ m.

$$J_{\text{gen}} = \frac{1.602176634 \times 10^{-19}(1.5 \times 10^{16})6.10538 \times 10^{-7}}{2(10^{-7})}$$ $\Rightarrow J_{\text{gen}} = 7.33643 \times 10^{-3}$ A/m^2.

$I_{\text{gen}} = J_{\text{gen}} A = 7.33643 \times 10^{-7} (10^{-8})$ $\Rightarrow$ **$I_{\text{gen}} = 7.33643 \times 10^{-11}$ A = 73.3643 pA**.

c) Per (8.24), $\frac{I_{\text{gen}}}{I_s} = \frac{7.33643 \times 10^{-11}}{2.3262 \times 10^{-15}}$ $\Rightarrow$ **$I_{\text{gen}} / I_s = 31{,}538$**.