8.30 Consider a GaAs pn junction diode with a cross-sectional area of $A = 2 \times 10^{-4}$ cm^2 and doping concentrations of $N_a = N_d = 7 \times 10^{16}$ cm^{-3}. The electron and hole mobility values are $\mu_n = 5500$ cm^2/V-s and $\mu_p = 220$ cm^2/V-s, respectively, and the lifetime values are $\tau_0 = \tau_{n0} = \tau_{p0} = 2 \times 10^{-8}$ s. (*a*) Calculate the ideal diode current at a (*i*) reverse-biased voltage of $V_R = 3$ V, (*ii*) forward-bias voltage of $V_a = 0.6$ V, (*iii*) forward-bias voltage of $V_a = 0.8$ V, and (*iv*) forward-bias voltage of $V_a = 1.0$ V. (*b*) (*i*) Calculate the generation current at $V_R = 3$ V. Assuming the recombination current extrapolated to $V_a = 0$ is $I_{ro} = 6 \times 10^{-14}$ A, determine the generation current at (*ii*) $V_a = 0.6$ V, (*iii*) $V_a = 0.8$ V, and (*iv*) $V_a = 1.0$ V.

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

From Table B.4, $n_i = 1.8 \times 10^6$ cm^{-3} and $\varepsilon_r = 13.1$ for GaAs at 300 K.

n region Since $N_d >> n_i \Rightarrow n_{n0} \cong N_d = 7 \times 10^{16}$ cm^{-3}.

Per (4.43), $p_{n0} = n_i^2 / n_{n0} = (1.8\times10^6)^2 / 7\times10^{16}$ **$p_{n0} = 4.62857\times10^{-5}$ cm^{-3}**.

Per (5.47), $\dfrac{D_p}{\mu_p} = \dfrac{k_B T}{e} \Rightarrow D_p = 220 \dfrac{8.617333\times10^{-5}\,\text{eV/K}\,(300\,\text{K})}{e} \Rightarrow$ **$D_p = 5.687$ cm^2/s**.

From p. 283, $L_p = \sqrt{D_p\,\tau_{p0}} = \sqrt{5.687\,(2\times10^{-8})} \Rightarrow$ **$L_p = 3.37267\times10^{-4}$ cm $= 3.37267$ µm**.

p region Since $N_a >> n_i \Rightarrow p_{p0} \cong N_a = 7 \times 10^{16}$ cm^{-3}.

Per (4.43), $n_{p0} = n_i^2 / p_{p0} = (1.5\times10^{10})^2 / 7\times10^{16} \Rightarrow$ **$n_{p0} = 4.62857\times10^{-5}$ cm^{-3}**.

Per (5.47), $\dfrac{D_n}{\mu_n} = \dfrac{k_B T}{e} \Rightarrow D_n = 5500 \dfrac{8.617333\times10^{-5}\,\text{eV/K}\,(300\,\text{K})}{e} \Rightarrow$ **$D_n = 142.186$ cm^2/s**.

From p. 283, $L_n = \sqrt{D_n\,\tau_{n0}} = \sqrt{142.187\,(2\times10^{-8})} \Rightarrow$ **$L_n = 1.6863\times10^{-3}$ cm $= 16.8863$ µm**.

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

$$J_s = \frac{1.6021766\times10^{-19}(5.687)4.6286\times10^{-5}}{3.37267\times10^{-4}} + \frac{1.6021766\times10^{-19}(142.186)4.6286\times10^{-5}}{1.6863\times10^{-3}}$$

$\Rightarrow J_s = 7.5033 \times 10^{-19}$ A/cm^2.

Ideal reverse saturation current $I_s = J_s A = 7.5033\times10^{-19}\,(2\times10^{-4}) = 1.50066 \times 10^{-22}$ A.

Using (8.27), $I = J\,A = J_s A\left[e^{V_a/V_t} - 1\right] = I_s\left[e^{V_a/V_t} - 1\right]$.

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

(i) $V_a = -V_R = -3$ V, $I_i = 1.50066\times10^{-22}\left[e^{-3/0.025852} - 1\right]$ $\Rightarrow$ **$I_i = -1.50066\times10^{-22}$ A**.

(ii) $V_a = 0.6$ V, $I_{ii} = 1.50066\times10^{-22}\left[e^{0.6/0.025852} - 1\right]$ $\Rightarrow$ **$I_{ii} = 1.80235\times10^{-12}$ A = 1.802 pA**.

(iii) $V_a = 0.8$ V, $I_{iii} = 1.50066\times10^{-22}\left[e^{0.8/0.025852} - 1\right]$ $\Rightarrow$ **$I_{iii} = 4.1275\times10^{-9}$ A = 4.1275 nA**.

(iv) $V_a = 1$ V, $I_{iv} = 1.50066\times10^{-22}\left[e^{1/0.025852} - 1\right]$ $\Rightarrow$ **$I_{iv} = 9.4524\times10^{-6}$ A = 9.4524 μA**.

b)

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

Per (7.10), $V_{bi} = V_t \ln\left(\dfrac{N_a N_d}{n_i^2}\right) = 0.025852 \ln\left(\dfrac{7\times10^{16}(7\times10^{16})}{(1.8\times10^{6})^2}\right) = 1.260749$ V.

Per (7.34),

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

$$= \left\{\frac{2(13.1)8.8541878\times10^{-12}(1.260749+3)}{1.602176634\times10^{-19}}\left(\frac{7\times10^{22} + 7\times10^{22}}{7\times10^{22}(7\times10^{22})}\right)\right\}^{1/2}$$

$\Rightarrow W = 4.19835\times10^{-7}$ m.

$$J_{\text{gen}} = \frac{1.602176634\times10^{-19}(1.8\times10^{12})4.19835\times10^{-7}}{2(2\times10^{-8})}$$ $\Rightarrow J_{\text{gen}} = 3.02693\times10^{-6}$ A/m^2.

$I_{\text{gen}} = J_{\text{gen}} A = 3.02693\times10^{-6}\,(2\times10^{-8})$ $\Rightarrow$ **$I_{\text{gen}} = 6.05385\times10^{-14}$ A**.

Using (8.34), $I_{\text{rec}} = J_{\text{rec}} A = J_{r0} A e^{V_a/2V_t} = I_{r0} e^{V_a/2V_t} = 6\times10^{-14} e^{V_a/2(0.025852)}$ A.

(ii) $V_a = 0.6$ V, $I_{\text{rec},ii} = 6\times10^{-14} e^{0.6/0.051704}$ $\Rightarrow$ **$I_{\text{rec},ii} = 6.57551\times10^{-4}$ A = 6.5755 nA**.

(iii) $V_a = 0.8$ V, $I_{\text{rec},iii} = 6\times10^{-14} e^{0.8/0.051704}$ $\Rightarrow$ **$I_{\text{rec},iii} = 3.1467\times10^{-7}$ A = 0.31467 μA**.

(iv) $V_a = 1$ V, $I_{\text{rec},iv} = 6\times10^{-14} e^{1/0.051704}$ $\Rightarrow$ **$I_{\text{rec},iv} = 1.50585\times10^{-5}$ A = 15.0585 μA**.