Homework - Chapter 14

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"I pledge my honor I have abided by the Stevens Honor system."
- Alex Gaskins

14.4 A light source with $h\nu = 1.3$ eV and at a power density of 10^{-2} W/cm^2 is incident on a thin slab of silicon. The excess minority carrier lifetime is 10^{-6} s. Determine the electron–hole generation rate and the steady-state excess carrier concentration. Neglect surface effects.

$$g' = \frac{\alpha I(x)}{h\nu} \qquad \lambda = \frac{1.24}{1.3} = 0.95\ \mu m$$

$$\alpha = 3\times10^2/cm$$

$$g' = \frac{(3\times10^2)(10^{-2})}{(1.6\times10^{-19})(1.3)} = 1.44\times10^{19}/cm\cdot s$$

$$\Delta n = g'\tau = (1.44\times10^{19})(10^{-6})$$

$$\boxed{\Delta n = 1.44\times10^{13}/cm^3}$$

14.5 An n-type GaAs sample has a minority carrier lifetime of $\tau_p = 2 \times 10^{-7}$ s. Incident photons with energies $h\nu = 1.65$ eV generate an excess carrier concentration of $\delta p = 5 \times 10^{15}$ cm^{-3} at the surface of the semiconductor. (*a*) Determine the incident power required. (*b*) At what distance in the semiconductor does the generation rate drop to 10 percent of that at the surface?

(a) $\Delta p = g'\tau_{po}$

$$g' = \frac{\Delta p}{\tau_{po}} = \frac{5\times10^{15}}{2\times10^{-7}} = 2.5\times10^{22}/cm^3\cdot s$$

a.) $h\nu = 1.65$ eV

$$\lambda = \frac{1.24}{1.65} = 0.752\ \mu m$$

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$$I_{\nu 0} = \frac{g'(h\nu)}{\alpha} = \frac{(2.5\times10^{22})(1.6\times10^{-19})(1.65)}{9\times10^{3}}$$

$$= \boxed{0.733\ W/cm^2}$$

b.) $$\frac{I_\nu(d)}{I_{\nu 0}} = 0.1 = \exp(-\alpha d)$$

$$0.1 = \exp\left[-(9\times10^{3})d\right]$$

$$d = \frac{1}{9\times10^{3}} \ln\left(\frac{1}{0.1}\right)$$

$$= \boxed{2.56\times10^{-4}\ cm.}$$

14.10 A long silicon pn junction solar cell at $T = 300$ K has the following parameters: $N_a = 10^{16}$ cm^{-3}, $N_d = 10^{15}$ cm^{-3}, $D_n = 25$ cm^2/s, $D_p = 10$ cm^2/s, $\tau_{n0} = 10^{-6}$ s, and $\tau_{p0} = 5 \times 10^{-7}$ s. The cross-sectional area of the solar cell is 5 cm^2. The entire junction is uniformly illuminated such that the generation rate of electron–hole pairs is $G_L = 5 \times 10^{21}$ cm^{-3} s^{-1}. (*a*) Calculate the short circuit photocurrent generated in the space charge region. (*b*) Using the results of part (*a*), calculate the open-circuit voltage. (*c*) Determine the ratio of V_{oc} to V_{bi}.

$$L_n = \sqrt{D_n \tau_{n0}} = \sqrt{(25)(10^{-6})} = 5\times10^{-3}\ cm$$

$$L_p = \sqrt{D_p \tau_{p0}} = \sqrt{(10)(5\times10^{-7})} = 2.236\times10^{-3}\ cm$$

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$$J_s = en_i^2\left(\frac{D_n}{L_n N_a} + \frac{D_p}{L_p N_d}\right)$$

$$J_s = (1.6\times10^{-19})(1.5\times10^{10})^2\left[\frac{25}{(5\times10^{-3})(10^{16})} + \frac{10}{(2.236\times10^{-3})(10^{15})}\right]$$

$$J_s = 1.790\times10^{-10} \text{ A/cm}^2$$

$$I_s = AJ_s = 5(1.79\times10^{-10}) = 8.95\times10^{-10} \text{ A}$$

a.) $I_L = eG_L AW$

$$V_{bi} = (0.0259)\ln\left[\frac{(10^{16})(10^{15})}{(1.5\times10^{10})^2}\right] = 0.635 \text{ V}$$

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

$$W = \left[\frac{2(11.7)(8.85\times10^{-14})(0.635)}{1.6\times10^{-19}}\right]\left[\frac{10^{16}+10^{15}}{(10^{16})(10^{15})}\right]^{1/2}$$

$$W = 9.508\times10^{-5} \text{ cm}$$

$$I_L = (1.6\times10^{-19})(5\times10^{21})(5)(9.508\times10^{-5})$$

$$I_L = \boxed{0.380\ A.}$$

b.) $$V_{oc} = V_t \ln\left(1+\frac{I_L}{I_S}\right) = (0.0259)\ln\left[1+\frac{0.380}{8.95\times10^{-10}}\right]$$

$$\boxed{V_{oc} = 0.5145\ V.}$$

c.) $$\frac{V_{oc}}{V_{bi}} = \frac{0.5145}{0.635} = \boxed{0.81}$$

14.14 A long silicon pn junction solar cell with an area of 2 cm² has the following parameters:

$$N_d = 10^{19}\ \text{cm}^{-3} \qquad N_a = 3\times10^{16}\ \text{cm}^{-3}$$
$$D_p = 6\ \text{cm}^2/\text{s} \qquad D_n = 18\ \text{cm}^2/\text{s}$$
$$\tau_{p0} = 5\times10^{-7}\ \text{s} \qquad \tau_{n0} = 5\times10^{-6}\ \text{s}$$

Assume that excess carriers are uniformly generated in the solar cell and that $J_L = 25$ mA/cm². Let $T = 300$ K. (*a*) Plot the *I*–*V* characteristics of the diode, (*b*) determine the maximum power output of the solar cell, and (*c*) calculate the external load resistance that will produce the maximum power.

a.) $$I_L = J_L A = (25\times10^{-3})(2) = 50\times10^{-3}\ A$$

$$J_s = en_i^2\left[\frac{1}{N_a}\sqrt{\frac{D_n}{\tau_n}} + \frac{1}{N_d}\sqrt{\frac{D_p}{\tau_p}}\right]$$

$$J_s = (1.6\times10^{-19})(1.5\times10^{10})^2\left[\frac{1}{3\times10^{16}}\sqrt{\frac{18}{5\times10^{-6}}} + \frac{1}{10^{19}}\sqrt{\frac{6}{5\times10^{-7}}}\right]$$

$$J_s = 2.289\times10^{-12}\ A/cm^2$$

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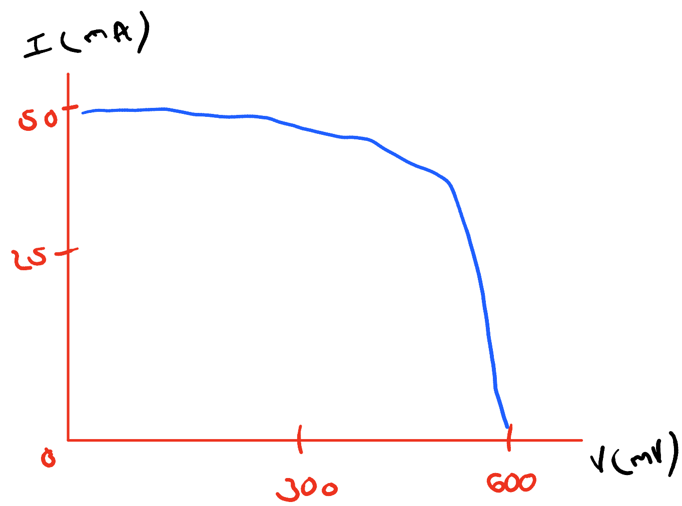
$I_s = 4.579 \times 10^{-12}\ A$

$$I = I_L - I_S\left[\exp\left(\frac{V}{V_t}\right) - 1\right]$$

$$I = 50 \times 10^{-3} - (4.579 \times 10^{-12})\left[\exp\left(\frac{V}{V_t}\right) - 1\right]$$

$I = 0\ A \qquad V = V_{oc} = 0.599\ V$

V (V)	I (mA)
0	50
0.1	50
0.2	50
0.3	50
0.4	49.98
0.45	49.84
0.50	48.89
0.55	42.36
0.57	33.46
0.59	14.19



b.)

$$\left[1 + \frac{V_m}{V_t}\right]\exp\left(\frac{V_m}{V_t}\right) = 1 + \frac{I_L}{I_S}$$

$$= 1 + \frac{50 \times 10^{-3}}{4.58 \times 10^{-12}} = 1.092 \times 10^{10}$$

$V_m \approx 0.52\text{ V}$ from substitution

$I_m = 47.6\text{ mA}$

$$P_m = I_m V_m = (47.6)(0.52) = \boxed{24.8\text{ mW}}$$

c.)

$$V = IR$$

$$R = \frac{V_m}{I_m} = \frac{0.52}{47.6\times10^{-3}} = \boxed{10.9\ \Omega}$$

14.20 Excess carriers are uniformly generated in a GaAs photoconductor at a rate of $G_L = 10^{21}$ cm^{-3}-s^{-1}. The area is $A = 10^{-4}$ cm^2 and the length is $L = 100\ \mu$m. The other parameters are:

$$N_d = 5\times10^{16}\text{ cm}^{-3} \qquad N_a = 0$$
$$\mu_n = 8000\text{ cm}^2/\text{V-s} \qquad \mu_p = 250\text{ cm}^2/\text{V-s}$$
$$\tau_{n0} = 10^{-7}\text{ s} \qquad \tau_{p0} = 10^{-8}\text{ s.}$$

If a voltage of 5 volts is applied, calculate (*a*) the steady-state excess carrier concentration, (*b*) the photoconductivity, (*c*) the steady-state photocurrent, and (*d*) the photoconductor gain.

a.)

$$\Delta p = G_L \tau_p = 10^{21}(10^{-8}) = \boxed{10^{13}/\text{cm}^3}$$

b.)

$$\Delta\sigma = e(\Delta p)(\mu_n + \mu_p)$$

$$= (1.6\times10^{-19})(10^{13})(8000 + 250)$$

$$= \boxed{1.32 \times 10^{-2} / \Omega \cdot cm}$$

c.) $I_L = J_L A = \Delta\sigma (A E) = \dfrac{\Delta\sigma (A V)}{L}$

$$= \frac{(1.32 \times 10^{-2})(10^{-4}) 5}{100 \times 10^{-4}} = \boxed{0.66 \times 10^{-3} A}$$

d.)

$$\Gamma_{ph} = \frac{I_L}{e G_L A L} = \frac{0.66 \times 10^{-3}}{(1.6 \times 10^{-19})(10^{21})(10^{-4})(100 \times 10^{-4})} = \boxed{4.125}$$

14.26 A silicon PIN photodiode at $T = 300$ K has the geometry shown in Figure 14.19. The intrinsic region width is 20 μm and is fully depleted. (*a*) The electron–hole pair generation rate in the intrinsic region is $G_L = 10^{21}$ cm^{-3} s^{-1} and is uniform throughout the intrinsic region. Calculate the steady-state photocurrent density for this condition. (*b*) The generation rate of electron–hole pairs is $G_L = 10^{21}$ cm^{-3} s^{-1} at $x = 0$ and the absorption coefficient is $\alpha = 10^3$ cm^{-1}. Determine the steady-state photocurrent density for this situation.

a.) $J_L = e W G_L = (1.6 \times 10^{-19})(20 \times 10^{-4})(10^{21})$

$$= \boxed{0.32 \ A/cm^2}$$

b.) $J_L = e \Phi_0 [1 - \exp(-\alpha W)]$

$$= \frac{e G_{L0}}{\alpha} [1 - \exp(-\alpha W)]$$

$$= \frac{(1.6\times 10^{-19})(10^{21})}{(10^{-3})}\left[1-\exp\left(-(10^{3})(20\times 10^{-4})\right)\right]$$

$$= \boxed{0.138\ A/cm^2}$$