Solutions to Chapter 3:

Exercise 3.1: Charge Carriers in Semiconductors

a) Insertion in Equation (3.3):

$$n_\mathrm{i} = N_0 \cdot e^{-\frac{\Delta W_\mathrm{G}}{2 \cdot k \cdot T}} = 3 \cdot 10^{19}/\mathrm{cm}^3 \cdot e^{-\frac{1.12\ \mathrm{eV}}{2 \cdot 8.63 \cdot 10^5\ \mathrm{eV/K} \cdot (273.15\ \mathrm{K} + 100\ \mathrm{K})}} = \underline{84 \cdot 10^{10}/\mathrm{cm}^3}$$

b) Reason for the diffusion current is a concentration gradient of charge carriers; the process is supported by the thermal lattice movement. Cause of the field current or drift current is an electrical field which accelerates the charged particles. A stronger lattice movement reduces the mobility of the carriers and therefore diminishes the field current.

Exercise 3.2: p-n Junction

a) Electrons diffuse due to the concentration gradient as a diffusion current from the n- into the p-doped region and leave behind in the n-region positively charged donator atoms. As soon as the electrons arrive in the p-region they fall into holes which results in the generation of fixed negative charges. Based on the space charges an electric field comes into existence which pushes the electrons as a field current back into the n-region. After a while a balance is built up between diffusion and field current and a space charge region is established in the p-n junction.

b) See Figure 3.16.

c)
$$V_\mathrm{D} = \frac{\Delta W_\mathrm{G}}{q} - \frac{k \cdot t}{q} \cdot \ln \frac{N_0{}^2}{N_\mathrm{D} \cdot N_\mathrm{A}} = \frac{\Delta W_\mathrm{G}}{q} - V_\mathrm{D} \cdot \ln \frac{N_0{}^2}{N_\mathrm{D} \cdot N_\mathrm{A}}$$
$$= 1.12\ \mathrm{V} - 0.026\ \mathrm{V} \cdot \ln \frac{(3 \cdot 10^{19}/\mathrm{cm}^3)^2}{5 \cdot 10^{16}/\mathrm{cm}^3 \cdot 10^{18}/\mathrm{cm}^3} = \underline{0.865\ \mathrm{V}}$$

Exercise 3.3: Light Absorption in Semiconductors

a) At a penetration depth $x = x_\mathrm{P}$ the initial irradiance E_1 is reduced to E_1/e.

Thus:

$$E(x = x_\mathrm{P}) = E_1 \cdot e^{-\alpha \cdot x_\mathrm{P}} \overset{!}{=} E_1 / e = E_1 \cdot e^{-1} \quad \Rightarrow \quad -\alpha \cdot x_\mathrm{P} = -1 \quad \Rightarrow \quad \underline{x_\mathrm{P} = \frac{1}{\alpha}}$$

b) With Equation (3.1) and (3.2):

$$W_\mathrm{Ph} = \frac{h \cdot c_0}{\lambda} = \frac{6.6 \cdot 10^{-34}\,\mathrm{Ws}^2 \cdot 3 \cdot 10^8\,\mathrm{m/s}}{560 \cdot 10^{-9}\,\mathrm{m}} = 3.536 \cdot 10^{-19}\,\mathrm{Ws} = \frac{3.536 \cdot 10^{-19}\,\mathrm{Ws} \cdot q}{1.6 \cdot 10^{-19}\,\mathrm{As}} = \underline{2.21\,\mathrm{eV}}$$

c) Taken out of Figure 3.22:

c-Si: $\alpha(W_\mathrm{Ph} = 2.21\ \mathrm{eV}) = 6 \cdot 10^3/\mathrm{cm} \Rightarrow X_\mathrm{P} = 1/\alpha = \underline{1.67\ \mu\mathrm{m}}$

a-Si: $\alpha(W_\mathrm{Ph} = 2.21\ \mathrm{eV}) = 7 \cdot 10^4/\mathrm{cm} \Rightarrow X_\mathrm{P} = 1/\alpha = \underline{0.14\ \mu\mathrm{m}}$

Exercise 3.4: Anti-Reflection Films

a) $R = \left(\frac{n_1 - n_2}{n_1 + n_2} \right)^2 = \left(\frac{1 - 4.6}{1 + 4.6} \right)^2 = 0.413$

Of the incident 500 W/m^2 about 41.3 % are reflected, thus E_R = <u>206.5 W/m^2</u>.

b) Optimum refractive index: $n_S = \sqrt{n_1 \cdot n_2} = \sqrt{1 \cdot 4.6} = \underline{2.145}$;

Optimum film thickness: $d = \frac{\lambda}{4 \cdot n_S} = \frac{600\text{ nm}}{4 \cdot 2.145} = 69.9\text{ nm} \approx 70\text{ nm}$

c) Film thickness: $d = \frac{\lambda}{4 \cdot n_S} = \frac{600\text{ nm}}{4 \cdot 2.0} = 75\text{ nm}$

Remaining reflection factor: $R = \left(\frac{n_S{}^2 - n_1 \cdot n_2}{n_S{}^2 + n_1 \cdot n_2} \right)^2 = \left(\frac{2^2 - 1 \cdot 4.6}{2^2 + 1 \cdot 4.6} \right)^2 = 0.487\ \% \approx 0.49\ \%$