Chapter 4

Exercise Solutions

E4.1

$$n_o = 2.8x10^{19}\exp\left(\frac{-0.22}{0.0259}\right)$$

or

$$\underline{n_o = 5.73x10^{15}\ cm^{-3}}$$

Now

$$E_F - E_v = 1.12 - 0.22 = 0.90\ eV$$

So

$$p_o = 1.04x10^{19}\exp\left(\frac{-0.90}{0.0259}\right)$$

or

$$\underline{p_o = 8.43x10^{3}\ cm^{-3}}$$

E4.2

$$p_o = 7.0x10^{18}\exp\left(\frac{-0.30}{0.0259}\right)$$

or

$$\underline{p_o = 6.53x10^{13}\ cm^{-3}}$$

Now

$$E_c - E_F = 1.42 - 0.30 = 1.12\ eV$$

So

$$n_o = 4.7x10^{17}\exp\left(\frac{-1.12}{0.0259}\right)$$

or

$$\underline{n_o = 0.0779\ cm^{-3}}$$

E4.3

(a)

$$\text{For } 200K:\quad kT = (0.0259)\left(\frac{200}{300}\right) = 0.01727$$

Now

$$n_i^2 = \left(2.8x10^{19}\right)\left(1.04x10^{19}\right)\left(\frac{200}{300}\right)^3\exp\left(\frac{-1.12}{0.01727}\right)$$

or

$$n_i^2 = 5.90x10^{9}$$

Then

$$\underline{n_i = 7.68x10^{4}\ cm^{-3}}$$

(b)

$$\text{For } 400K:\quad kT = (0.0259)\left(\frac{400}{300}\right) = 0.03453$$

Now

$$n_i^2 = \left(2.8x10^{19}\right)\left(1.04x10^{19}\right)\left(\frac{400}{300}\right)^3\exp\left(\frac{-1.12}{0.03453}\right)$$

or

$$n_i^2 = 5.65x10^{24}$$

Then

$$\underline{n_i = 2.38x10^{12}\ cm^{-3}}$$

E4.4

(a) $200K$

$$n_i^2 = \left(4.7x10^{17}\right)\left(7x10^{18}\right)\left(\frac{200}{300}\right)^3\exp\left(\frac{-1.42}{0.01727}\right)$$

or

$$n_i^2 = 1.904$$

Then

$$\underline{n_i = 1.38\ cm^{-3}}$$

(b) $400K$

$$n_i^2 = \left(4.7x10^{17}\right)\left(7x10^{18}\right)\left(\frac{400}{300}\right)^3\exp\left(\frac{-1.42}{0.03453}\right)$$

or

$$n_i^2 = 1.08x10^{19}$$

Then

$$\underline{n_i = 3.28x10^{9}\ cm^{-3}}$$

E4.5

(a) $200K$

$$n_i^2 = \left(1.04x10^{19}\right)\left(6x10^{18}\right)\left(\frac{200}{300}\right)^3\exp\left(\frac{-0.66}{0.01727}\right)$$

or

$$n_i^2 = 4.67x10^{20}$$

Then

$$\underline{n_i = 2.16x10^{10}\ cm^{-3}}$$

(b) $400K$

$$n_i^2 = \left(1.04x10^{19}\right)\left(6x10^{18}\right)\left(\frac{400}{300}\right)^3\exp\left(\frac{-0.66}{0.03453}\right)$$

or

$$n_i^2 = 7.39x10^{29}$$

Then

$$\underline{n_i = 8.6x10^{14}\ cm^{-3}}$$

E4.6

$$E_{Fi} - E_{midgap} = \frac{3}{4} kT \ln\left(\frac{m_p^*}{m_n^*}\right)$$

$$= \frac{3}{4}(0.0259)\ln\left(\frac{0.067}{0.48}\right)$$

or

$$\underline{E_F - E_{midgap} = -38.2\ meV}$$

E4.7

$$\frac{r_n}{a_o} = n^2 \in_r \left(\frac{m_o}{m^*}\right) = (1)(13.1)\left(\frac{1}{0.067}\right)$$

so

$$\underline{\frac{r_1}{a_o} = 195.5}$$

E4.8

For $\eta_F = 0$, $F_{1/2}(\eta_F) = 0.60$

Then

$$n_o = \frac{2}{\sqrt{\pi}} N_C F_{1/2}(\eta_F) = \frac{2}{\sqrt{\pi}}\left(2.8x10^{19}\right)(0.60)$$

or

$$\underline{n_o = 1.9x10^{19}\ cm^{-3}}$$

E4.9

$$\frac{p_a}{p_o + p_a} = \frac{1}{1 + \frac{N_V}{4N_a}\exp\left[\frac{-(E_a - E_v)}{kT}\right]}$$

$$= \frac{1}{1 + \frac{1.04x10^{19}}{4(10^{17})}\exp\left[\frac{-0.045}{0.0259}\right]}$$

or

$$\underline{\frac{p_a}{p_o + p_a} = 0.179}$$

E4.10 Computer plot

E4.11

$$p_o = N_a - N_d = 2x10^{16} - 5x10^{15}$$

or

$$\underline{p_o = 1.5x10^{16}\ cm^{-3}}$$

Then

$$n_o = \frac{n_i^2}{p_o} = \frac{\left(1.8x10^6\right)^2}{1.5x10^{16}}$$

or

$$\underline{n_o = 2.16x10^{-4}\ cm^{-3}}$$

E4.12 (b)

$$n = \frac{N_d}{2} + \sqrt{\left(\frac{N_d}{2}\right)^2 + n_i^2}$$

Then

$$1.1x10^{15} = 5x10^{14} + \sqrt{\left(5x10^{14}\right)^2 + n_i^2}$$

which yields

$$n_i^2 = 11x10^{28}$$

and

$$n_i^2 = N_C N_V \exp\left[\frac{-E_g}{kT}\right] = 11x10^{28}$$

$$= \left(2.8x10^{19}\right)\left(1.04x10^{19}\right)\left(\frac{T}{300}\right)^3$$

$$\times \exp\left[\frac{-1.12}{(0.0259)(T/300)}\right]$$

By trial and error

$$\underline{T \cong 552K}$$

E4.13

$$E_F - E_v = (0.0259)\ln\left[\frac{7x10^{18}}{5x10^{16} - 4x10^{15}}\right]$$

$$\underline{= 0.130\,eV}$$

E4.14

$$E_F - E_{Fi} = (0.0259)\ln\left[\frac{1.7x10^{17}}{1.5x10^{10}}\right]$$

or

$$\underline{E_F - E_{Fi} = 0.421\ eV}$$