Hw4 Solution

1.

(a) $$n_i^2 = N_c N_\upsilon \exp\left(\frac{-E_g}{kT}\right)$$

$$= \left(2\times10^{19}\right)\left(1\times10^{19}\right)\exp\left(\frac{-1.10}{0.0259}\right)$$

$$= 7.18\times10^{19}$$

or

$$n_i = 8.47\times10^{9}\ \text{cm}^{-3}$$

For $N_d = 10^{14}\ \text{cm}^{-3} >> n_i \Rightarrow n_o = 10^{14}\ \text{cm}^{-3}$

Then

$$J = \sigma \mathrm{E} = e\mu_n n_o \mathrm{E}$$

$$= \left(1.6\times10^{-19}\right)(1000)\left(10^{14}\right)(100)$$

or

$$J = 1.60\ \text{A/cm}^2$$

(b) A 5% increase is due to a 5% increase in electron concentration, so

$$n_o = 1.05\times10^{14} = \frac{N_d}{2} + \sqrt{\left(\frac{N_d}{2}\right)^2 + n_i^2}$$

which becomes

$$\left(1.05\times10^{14} - 5\times10^{13}\right)^2 = \left(5\times10^{13}\right)^2 + n_i^2$$

and yields

$$n_i^2 = 5.25\times10^{26}$$

$$= \left(2\times10^{19}\right)\left(1\times10^{19}\right)\left(\frac{T}{300}\right)^3 \exp\left(\frac{-E_g}{kT}\right)$$

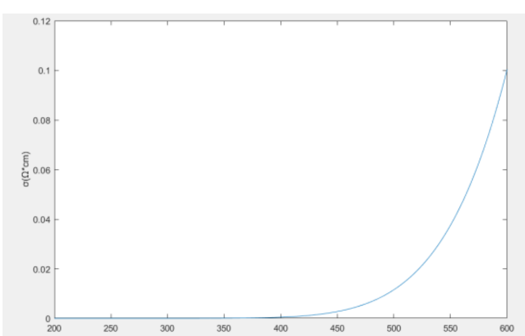
or

$$2.625\times10^{-12} = \left(\frac{T}{300}\right)^3 \exp\left[\frac{-1.10}{(0.0259)(T/300)}\right]$$

By trial and error, we find

$$T = 456\ \text{K}$$

2.



3.

$$J_n = eD_n \frac{dn}{dx} = eD_n \frac{\Delta n}{\Delta x}$$

$$J_n = \left(1.6\times10^{-19}\right)(27)\left[\frac{2\times10^{16} - 5\times10^{15}}{0 - 0.012}\right]$$

$$J_n = -5.4\ \text{A/cm}^2$$

4.

(a) $$\mathrm{E}_X = -\left(\frac{kT}{e}\right)\cdot\frac{1}{N_d(x)}\cdot\frac{dN_d(x)}{dx}$$

$$= \frac{-(0.0259)}{N_{do}e^{-x/L}}\cdot\frac{d}{dx}\left[N_{do}e^{-x/L}\right]$$

$$= \frac{-(0.0259)}{N_{do}e^{-x/L}}\cdot\left(\frac{-1}{L}\right)N_{do}e^{-x/L}$$

$$= \frac{0.0259}{L} = \frac{0.0259}{10\times10^{-4}}$$

or $\mathrm{E}_X = 25.9\ \text{V/cm}$

(b) $$\phi = -\int_0^L \mathrm{E}_X\,dx = -(25.9)(L-0)$$

$$= -(25.9)\left(10\times10^{-4}\right) = -0.0259\ \text{V}$$

or $\phi = -25.9\ \text{mV}$

5.

$$p_o = N_a = 2\times10^{16}\ \text{cm}^{-3}$$

$$n_o = \frac{n_i^2}{p_o} = \frac{\left(1.8\times10^{6}\right)^2}{2\times10^{16}} = 1.62\times10^{-4}\ \text{cm}^{-3}$$

(a) $$R' = \frac{\delta n}{\tau_{n0}} = \frac{5\times10^{14}}{5\times10^{-7}} = 10^{21}\ \text{cm}^{-3}\,\text{s}^{-1}$$

(b) $$R_p = \frac{p}{\tau_{pt}} = \frac{n}{\tau_{nt}} = \frac{\delta n}{\tau_{n0}}$$

$$\tau_{pt} = \frac{p_o}{\delta n}\cdot\tau_{n0} = \frac{\left(2\times10^{16}\right)}{\left(5\times10^{14}\right)}\cdot\left(5\times10^{-7}\right)$$

$$= 2\times10^{-5}\ \text{s}$$

6.

(a) $$E = h\nu = \frac{hc}{\lambda} = \frac{\left(6.625\times10^{-34}\right)\left(3\times10^{8}\right)}{6300\times10^{-10}}$$

or

$$E = 3.15\times10^{-19}\ \text{J; energy of one photon}$$

Now

$1 \text{ W} = 1 \text{ J/s} \Rightarrow 3.17 \times 10^{18}$ photons/s

Volume = (1)(0.1) = 0.1 cm^3

Then

$$g = \frac{3.17 \times 10^{18}}{0.1}$$

$$= 3.17 \times 10^{19} \quad \text{e-h pairs/cm}^3\text{-s}$$

(b)

$$\delta n = \delta p = g\tau = \left(3.17 \times 10^{19}\right)\left(10 \times 10^{-6}\right)$$

or

$$\delta n = \delta p = 3.17 \times 10^{14} \text{ cm}^{-3}$$

7.

From Equation (6.18),

$$\frac{\partial p}{\partial t} = -\nabla \bullet F_p^+ + g_p - \frac{p}{\tau_p}$$

For steady-state, $\frac{\partial p}{\partial t} = 0$

Then

$$0 = -\nabla \bullet F_p^+ + g_p - R_p$$

For a one-dimensional case,

$$\frac{dF_p^+}{dx} = g_p - R_p = 10^{20} - 2 \times 10^{19}$$

or

$$\frac{dF_p^+}{dx} = 8 \times 10^{19} \text{ cm}^{-3}\text{ s}^{-1}$$

8.

(a) From Equation (6.56)

$$D_p \frac{d^2(\delta p)}{dx^2} + g' - \frac{\delta p}{\tau_{pO}} = 0$$

Solution is of the form

$$\delta p = g'\tau_{pO} + A\exp\left(\frac{-x}{L_p}\right) + B\exp\left(\frac{+x}{L_p}\right)$$

At $x = +\infty$, $\delta p = g'\tau_{pO}$ so that $B = 0$,

Then

$$\delta p = g'\tau_{pO} + A\exp\left(\frac{-x}{L_p}\right)$$

We have

$$D_p \left.\frac{d(\delta p)}{dx}\right|_{x=0} = s(\delta p)\Big|_{x=0}$$

We can write

$$\left.\frac{d(\delta p)}{dx}\right|_{x=0} = \frac{-A}{L_p} \text{ and } (\delta p)\Big|_{x=0} = g'\tau_{pO} + A$$

Then

$$\frac{-AD_p}{L_p} = s\left(g'\tau_{pO} + A\right)$$

Solving for A, we find

$$A = \frac{-sg'\tau_{pO}}{\frac{D_p}{L_p} + s}$$

The excess concentration is then

$$\delta p = g'\tau_{pO}\left[1 - \frac{s}{\left(D_p/L_p\right) + s} \cdot \exp\left(\frac{-x}{L_p}\right)\right]$$

where

$$L_p = \sqrt{D_p \tau_{pO}} = \sqrt{(10)\left(10^{-7}\right)} = 10^{-3} \text{ cm}$$

Now

$$\delta p = \left(10^{21}\right)\left(10^{-7}\right)$$
$$\times \left[1 - \frac{s}{\left(10/10^{-3}\right) + s} \cdot \exp\left(\frac{-x}{L_p}\right)\right]$$

or

$$\delta p = 10^{14}\left[1 - \frac{s}{10^4 + s} \cdot \exp\left(\frac{-x}{L_p}\right)\right]$$

(i) For $s = 0$,

$$\delta p = 10^{14} \text{ cm}^{-3}$$

(ii) For $s = 2000$ cm/s,

$$\delta p = 10^{14}\left[1 - 0.167 \exp\left(\frac{-x}{L_p}\right)\right]$$

(iii) For $s = \infty$,

$$\delta p = 10^{14}\left[1 - \exp\left(\frac{-x}{L_p}\right)\right]$$

(b)

(i) For $s = 0$,

$$\delta p(0) = 10^{14} \text{ cm}^{-3}$$

(ii) For $s = 2000$ cm/s,

$$\delta p(0) = 0.833 \times 10^{14} \text{ cm}^{-3}$$

(iii) For $s = \infty$,

$$\delta p(0) = 0$$

9.

(a) p-type

$$E_{Fi} - E_F = kT\ln\left(\frac{p_o}{n_i}\right)$$

$$= (0.0259)\ln\left(\frac{5 \times 10^{15}}{1.5 \times 10^{10}}\right)$$

or

$$E_{Fi} - E_F = 0.3294 \text{ eV}$$

(b)

$$\delta n = \delta p = 5 \times 10^{14} \text{ cm}^{-3}$$

and

$$n_o = \frac{n_i^2}{p_o} = \frac{\left(1.5 \times 10^{10}\right)^2}{5 \times 10^{15}} = 4.5 \times 10^4 \text{ cm}^{-3}$$

Then

$$E_{Fn} - E_{Fi} = kT \ln\left(\frac{n_o + \delta n}{n_i}\right)$$

$$= (0.0259)\ln\left(\frac{4.5 \times 10^4 + 5 \times 10^{14}}{1.5 \times 10^{10}}\right)$$

or

$$E_{Fn} - E_{Fi} = 0.2697 \text{ eV}$$

and

$$E_{Fi} - E_{Fp} = kT \ln\left(\frac{p_o + \delta p}{n_i}\right)$$

$$= (0.0259)\ln\left(\frac{5 \times 10^{15} + 5 \times 10^{14}}{1.5 \times 10^{10}}\right)$$

or

$$E_{Fi} - E_{Fp} = 0.3318 \text{ eV}$$

10.

(a) $R' = \frac{\delta p}{\tau_{p0}} = \frac{1 \times 10^{13}}{100 \times 10^{-6}} = 10^{17} \text{ cm}^{-3} \text{ s}^{-1}$

11.

(a) $n=p=0, R=rnp=0, U=R-G=-G$, Net generation
(b) n or $p=0, R=rnp=0, U=R-G=-G$, Net generation
(c) $G=rni2<$ $R=rnp=0, U=R-G>0$, Net recombination