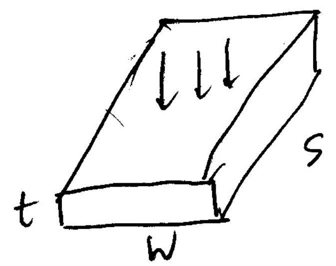
ECE 3040 HW3 Solution Supplement

1) $R = \dfrac{\rho S}{A}$



$$\rho = \frac{1}{q(\mu_n n + \mu_p p)} \quad \text{(pp.85 -3.7-)}$$

Since p-type with $N_a = 1e14\ cm^{-3}$. $n_i = 2e6\ cm^{-3}$.

$$\begin{cases} p = N_A = 1e14\ cm^{-3} \\ n = \dfrac{n_i^2}{p} = \dfrac{(2e^6)^2}{1e14} \doteq 4\times10^{-2}\ cm^{-3} \end{cases}$$

$$\Rightarrow \rho = \frac{1}{q(\underline{\underline{100\times4\times10^{-2}}} + \underline{\underline{500\times10^{14}}})} \doteq 125.0\ (\text{ohm-cm})$$

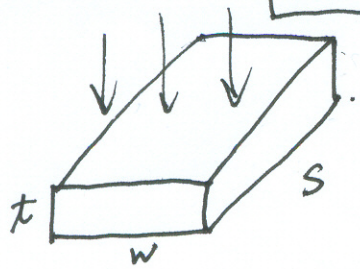
$$\left(\frac{500\times10^{14}}{100\times4\times10^{-2}} = 1.25\times10^{16} \gg 1\right)$$

$\therefore \rho$ can be approximated as $\dfrac{1}{q(500\times10^{14})} = \dfrac{1}{q\mu_p p} = 125$ (ohm-cm)

Thus, $R = \dfrac{\rho s}{A} = \dfrac{1}{q\mu_p p}\cdot\dfrac{s}{wt} = \boxed{\dfrac{1}{q\mu_p N_A}\cdot\dfrac{s}{wt}}$

ECE 3040 HW3 Solution

1)



$$R = \frac{\rho S}{A} = \frac{1}{q\mu_p N_A} \cdot \frac{S}{wt}$$

$$\Rightarrow S = R \cdot q\mu_p N_A \cdot wt$$

$$= 10^9 \times 1.6\times10^{-19} \times 500\times10^{14} \times 4\times10^{-4} \times 0.2\times10^{-1}$$

$$= 64 \ (cm)$$

---

2) $h\nu = E_g \Rightarrow$ 1 photon $\rightarrow$ 1 e-h pair

Number of photons/(Area · Time) $\doteq \dfrac{60\ mW \times 0.9 / cm^2}{1.60\times10^{-19}\times1.4\ J} = \dfrac{I_0}{h\nu}$

$$\doteq 2.41\times10^{17} \ /(cm^2 \cdot s).$$

Number of photons absorbed per time

$$N_p = 2.41\times10^{17} \times S \times W$$

$$= 2.41\times10^{17} \times 64 \times 0.2\times10^{-1}$$

$$= 3.08\times10^{17} \ (\#/s)$$

= Number of electrons generated per unit time

$$\Rightarrow G_L = \frac{3.08\times10^{17}}{V} = \frac{3.08\times10^{17}}{64\times0.02\times4\times10^{-4}} \doteq 6.01\times10^{20} \ (\#/(cm^3 \cdot s))$$

3) $n_0 = \frac{n_i^2}{P_0} = \frac{(2\times10^6)^2}{10^{14}} = 4\times10^{-2} \ cm^{-3}$

Light ON: $n_0 \rightarrow n_0 + \Delta n$ $\qquad \Delta n = \Delta P.$

$P_0 \rightarrow P_0 + \Delta P$

$$R_{Light} = \frac{1}{q(\mu_n n + \mu_p P)} \cdot \frac{S}{A}$$

where $S = 64$ cm. $A = wt$

$\mu_n = 100 \ cm^2/V\cdot s \qquad \mu_p = 500 \ cm^2/V\cdot s$

$n = n_0 + \Delta n \qquad P = P_0 + \Delta P \qquad \Delta n = \Delta P. \qquad R_{Light} = 3\times10^6 \ \Omega.$

$$\Rightarrow R_{light} = \frac{1}{q[\mu_n(n_0+\Delta n) + \mu_p(P_0+\Delta P)]} \cdot \frac{S}{A}$$

$$\Delta n \mu_n + \Delta P \mu_p + \mu_n n_0 + \mu_p P_0 = \frac{S}{A R_{light} q}$$

$$\Rightarrow \Delta n = \Delta P = \left[\frac{S}{A q R_{light}} - \mu_n n_0 - \mu_p P_0\right] / (\mu_n + \mu_p).$$

$$= \frac{1}{100+500}\left[\frac{64}{(4e^{-4})(0.02)(1.6\times10^{-19})(3e6)} - 100\times0.04 - 500e14\right]$$

$$\doteq 2.77\times10^{16} \ cm^{-3}$$

$$G_L = \frac{\Delta n}{\tau_n} \Rightarrow \tau_n = \frac{\Delta n}{G_L} = \frac{2.77\times10^{16} \ cm^{-3}}{6.01\times10^{20} \ cm^{-3}\cdot s^{-1}} \doteq 4.61e-5 \ (s)$$

4) In the dark:

$$P_0 = N_A = n_i e^{(E_i - F_p)/kT}$$

$$\Rightarrow F_p = E_i - kT \ln \frac{P_0}{n_i} = E_i - 0.0259 \times \ln(5\times10^{7}) = E_i - 0.459 \text{ (ev)}$$

Light ON:

$$\Delta n = \Delta p = 2.77\times10^{16} \text{ cm}^{-3}$$

$$p = \Delta p + P_0 = 2.77\times10^{16} + 10^{14} = 2.78\times10^{16} \text{ cm}^{-3}$$

$$n = \Delta n + n_0 = 2.77\times10^{16} + \cancel{10^{4}}\, 4\times10^{2} \approx 2.77\times10^{16} \text{ cm}^{-3}$$

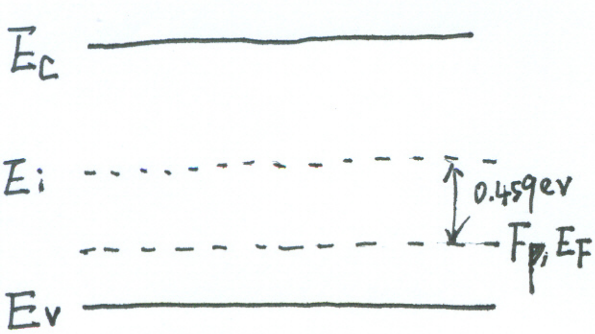
$$\therefore F_p' = E_i - kT \ln \frac{p}{n_i} = E_i - 0.0259 \times \ln\left(\frac{2.78\times10^{16}}{2\times10^{6}}\right)$$

$$\doteq E_i - 0.605 \text{ (ev)}$$

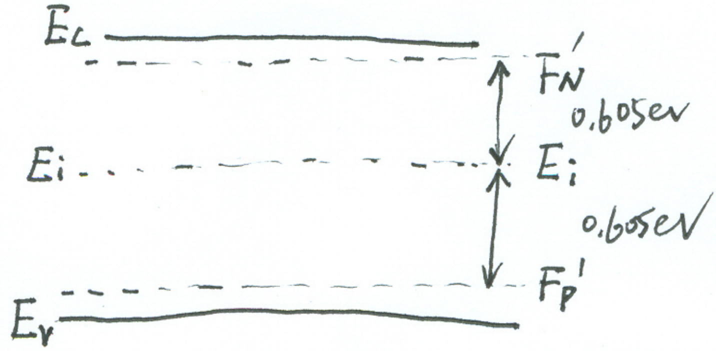
$$F_N' = E_i + kT \ln \frac{n}{n_i} = E_i + 0.0259 \times \ln\left(\frac{2.77\times10^{16}}{2\times10^{6}}\right)$$

$$\doteq E_i + 0.605 \text{ (ev)}$$

Plot.



Dark



Light ON

5) $T\uparrow$, μ_n & μ_p decrease $\Rightarrow \rho\uparrow \Rightarrow R\uparrow$

Resistance will increase.

6) a. $E = V/d = 120/64 \doteq 1.88\ (V/cm)$

b. $I_n = J_n A = q\mu_n n_0 E\cdot A$

$= (1.6\times10^{-19})(100)(0.04)(1.88)\times(4\times10^{-4}\times0.02)$

$= 9.62\times10^{-24}\ (A)$

c. $I_p = J_p A = q\mu_p p_0 E\cdot A$

$= (1.6\times10^{-19})(500)(10^{14})(1.88)\times(4\times10^{-4}\times0.02)$

$= 1.20\times10^{-7}\ (A)$

d. light ON: ~~n_0~~ $n_0 \rightarrow n = n_0 + \Delta n$

$p_0 \rightarrow p = p_0 + \Delta p$ $> n = p \doteq 2.77e^{16}$

$\therefore I_n' = J_n' A = q\mu_n n E\cdot A$

$= (1.6\times10^{-19})(100)(2.77\times10^{16})(1.88)\times(4\times10^{-4}\times0.02)$

$= 6.66\times10^{-6}\ (A)$

$I_p' = J_p' A = q\mu_p p E\cdot A$

$= (1.6\times10^{-19})(500)(2.77\times10^{16})(1.88)\times(4\times10^{-4}\times0.02)$

$= 3.33\times10^{-5}\ (A)$

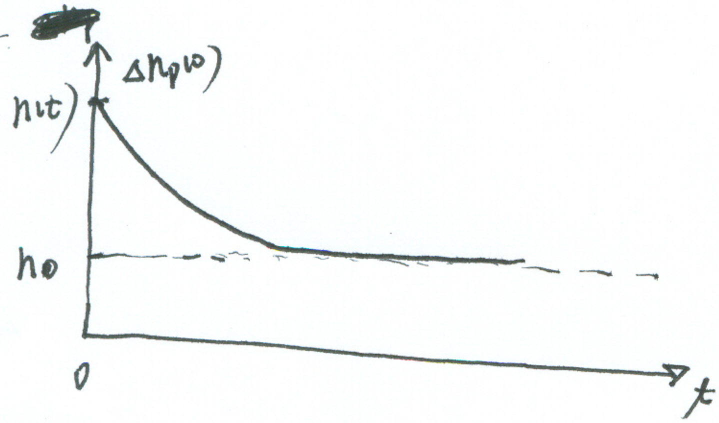
7). $\cancelto{0}{\frac{\partial \Delta n_p}{\partial t}} = D_N \cancelto{0}{\frac{\partial^2 (\Delta n_p)}{\partial x^2}} - \frac{\Delta n_p}{\tau_n} + G_L$: Light ON

$\Rightarrow \Delta n_p = G_L \tau_n = 2.77 \times 10^{16} \ cm^{-3}$

$\frac{\partial \Delta n_p}{\partial t} = D_N \cancelto{0}{\frac{\partial^2 (\Delta n_p)}{\partial x^2}} - \frac{\Delta n_p}{\tau_n} + \cancelto{0}{G_L}$: Light off

$\Delta n_p(t) = \Delta n_p(0)\, e^{-t/\tau_n}$, $\Delta n_p(0) = 2.77 \times 10^{16} \ cm^{-3}$

Plot



8). $J_N|_{diff} = q D_N \frac{dn}{dx}$

$J_N|_{diff} = \cancel{q} \cdot \frac{kT}{\cancel{q}} \cdot \mu_n \cdot \left[-10^{14} \cdot \frac{\pi}{2S} \cdot \sin\left(\frac{\pi x}{2S}\right) \right]$

$= -1.02 \cos\left(\frac{\pi x}{S}\right) (\mu A/cm^2)$, $S = 64 \ cm$