EE 482 W 2011

Home Work 3 Solutions:

1(a) Scattering lifetime $\tau = 3ps$

$$\frac{1}{\tau} = \frac{1}{\tau_{lattice}} + \frac{1}{\tau_{impurities}}$$

Since both are "equally probable"

$$\tau_{lattice} = \tau_{impurities} = 2\tau = 6ps$$

after the temperature change:

1) Probability of lattice scattering is halved:

$$\frac{1}{\tau_{new,lattice}} = \frac{1}{2\tau_{lattice}} \Rightarrow \underline{\underline{\tau_{new,lattice} = 12ps}}$$

2) Pobability of scattering due to ionized impurities increased by factor of 1.5:

$$\frac{1}{\tau_{new-impurities}} = 1.5 \times \frac{1}{\tau_{impurities}} \Rightarrow$$

$$\tau_{new,impurities} = \frac{6ps}{1.5} = \underline{\underline{4ps.}}$$

$$\frac{1}{\tau_{new}} = \frac{1}{4ps} + \frac{1}{12ps} \Rightarrow \tau_{new} = \left(\frac{1}{4} + \frac{1}{12}\right)^{-1} ps.$$

$$= \underline{\underline{3ps.}}$$

The temperatue has been $\underline{\underline{\text{lowered}}}$, because →

1(a) Scattering due to ionized impurities increased ($\tau_{impurity} \propto T^{n}$), and also lattice Scattering ($\tau_{lattice} \propto T^{-n}$) decreased.

1(b) $m_h^* = 0.5 m_o$ $\quad p = 10^{17} cm^{-3}$ $\quad \mathcal{E} = 1000 V/cm$

$$v_d = \frac{q \tau_h}{m_e^*} \mathcal{E}$$

@ both temperatures, $\tau_p = 3ps$.

$$\Rightarrow v_d = \frac{(1.6 \times 10^{-19} C)(3ps)(1000 V/cm)}{(0.5)(9.11 \times 10^{-31} kg)} = 1053.9 \frac{CVs}{kg\,cm}$$

$\left(1 CV = 1 J = kg \frac{m^2}{s^2}\right)$ unit conversion $\Rightarrow$ $= 1053.9 \times 10^{4} \frac{cm}{s}$

$p \gg n$, ignoring minority carriers,

$$J = J_p = p q v_d = (10^{17} cm^{-3}) \times (1.6 \times 10^{-19} C)(1053.9 \times 10^{4} \frac{cm}{s})$$

$$= 1686.24 \times 10^{2} Acm^{-2} = 1.69 \times 10^{5} Acm^{-2}$$

1(c) $J_{max} = p\,q\,v_{d\,max} = (10^{17}\,cm^{-3})(1.6\times10^{-19}\,C)(6\times10^{6}\,cm\,s^{-1})$

$= \underline{9.6\times10^{4}}\ A\,cm^{-2}$

2) $E = 100\,V/cm$, $\mu_n = 8000\,cm^2/Vs$

$J_{total} = J_{drift} + J_{diff}$

Einstein relationship:

$D_n = (25\,meV)(8000\,cm^2/Vs) = 200\,cm^2/s$

$$100\,A/cm^2 = \overset{q}{(1.6\times10^{-19}\,C)}\overset{\mu_n}{(8000\,cm^2/Vs)}\overset{E}{(100\,V/cm)}\,n(x)$$

$$+ \underset{q}{(1.6\times10^{-19}\,C)}\underset{D_n}{(200\,cm^2/s)}\frac{dn(x)}{dx}$$

$$= 1.28\times10^{-13}\,A\,cm\;n(x) + 3.2\times10^{-17}\,A\,cm^2\,\frac{dn(x)}{dx}$$

The solution of this differential equation is:

$$n(x) = A + B\exp\left(\frac{-x}{d}\right) \Longrightarrow \frac{dn(x)}{dx} = \frac{-B}{d}\exp\left(\frac{-x}{d}\right)$$

Substituting:

$$100\,A\,cm^{-2} = (1.28\times10^{-13}\,A\,cm)\left(A + B\exp\left(\frac{-x}{d}\right)\right)$$

$$+ (3.2\times10^{-17}\,A\,cm^2)\left(-\frac{B}{d}\exp\left(\frac{-x}{d}\right)\right)$$

Since this is true for all x, (using $x=0$)

$$100\,A\,cm^{-2} = 1.28\times10^{-13}\,A \Longrightarrow \underline{A = 7.81\times10^{14}\,cm^{-3}}$$

$\overrightarrow{2(a)}$ AND $0 = 1.28\times10^{-13}B - 3.2\times10^{-17}\frac{B}{d}$

$\Longrightarrow \underline{d = 0.25\times10^{-13}\ cm}$

@ $x=0$, drift current $= 50\ A/cm^2$

$50 = 1.28\times10^{-12}(A+B) \Longrightarrow B = \underline{-3.90\times10^{14}}\ cm^{-3}$

$\underline{n(x) = 7.81\times10^{14} - 3.90\times10^{14}\exp\left(\frac{-x}{0.25\times10^{-3}}\right) cm^{-3}}$

2(b)

$n(0) = 3.91\times10^{14}\ cm^{-3}$

careful with units

$n(20) = 7.81\times10^{14} - 3.9\times10^{14}\exp\left(-\frac{20}{2.5\mu m}\right)$

$= 7.81\times10^{14}\ cm^{-3}$

$J_{drift}(20) = \underbrace{(1.6\times10^{-19}C)}_{q}\underbrace{(8000\ cm^2/Vs)}_{\mu_n}\underbrace{(7.81\times10^{14}\ cm^{-3})}_{n(20)}\underbrace{(100\ Vcm^{-1})}_{E}$

$= \underline{99.97\ Acm^{-2}}$

$J_{diff} = 100 - 99.97\ Acm^{-2} = \underline{32\times10^{-3}\ Acm^{-2}}$

3 $\rho = \frac{1}{\sigma} = \frac{1}{q\mu_p p + q\mu_n n}$

Assuming Uniform doping profile $\longrightarrow$ Need to find average Arsenic Concentration:

$$\underset{\text{average}}{N_d^{As}} = \frac{1.5\times10^{12}\,cm^{-2}}{20\times10^{-7}\,cm} = \underline{7.5\times10^{17}\,cm^{-3}}$$

$$n = N_d - N_a = (7.5-2)\times10^{17}\,cm^{-3} = \underline{5.5\times10^{17}\,cm^{-3}}$$

$$p = \frac{n_i^2}{n} = \underline{181.8\ cm^{-3}}$$

a) In the substrate, $p = N_a = 2\times10^{17}\,cm^{-3} \Longrightarrow \mu_p = 175\,\frac{cm^2}{Vs}$

$n = 500\,cm^{-3} \longrightarrow$ negligible

$$\rho \simeq \frac{1}{(1.6\times10^{-19}C)(2\times10^{17}cm^{-3})(175\frac{cm^2}{Vs})} = \underline{0.18\ \Omega cm}$$

3 (b) The main point is to note that mobility is base on $\underline{\text{Total}}$ doping.

$$N_{total} = 7.5\times10^{17}\,cm^{-3} + 2\times10^{17} = 9.5\times10^{17}\,cm^{-3}$$

$$\text{P.5 of notes} \Longrightarrow \begin{cases} \mu_n = \underline{275}\ cm^2/Vs \\ \mu_p = \underline{100\ cm^2}/Vs \end{cases}$$

3(b) $R_{\square} = \dfrac{1}{\int_0^{x_j} q\mu_n n(x)} = \dfrac{1}{q\mu_n n x_j}$

$$= \frac{1}{(1.6\times10^{-19}C)(275\ cm^2/Vs)(5.5\times10^{17}cm^{-3})(20\times10^{-7}cm)}$$

$= \underline{20.66\ k\Omega}$

3(c) $R = \dfrac{L}{W} R_{\square} = \dfrac{L}{W}\, 20.66\ k\Omega = 100\ k\Omega$

$\Longrightarrow \dfrac{L}{W} = \underline{4.84}$

4(a) $N_A = 10^{17} cm^{-3} \Longrightarrow p_0 \cong 10^{17} cm^{-3},\ n_0 = \dfrac{n_i^2}{p_0} = 5.76\times10^{-5} cm^{-3}$

assuming low level injection:

@ Steady State $\Longrightarrow \Delta n = \Delta p = \dfrac{G}{k(p+n)} \cong \dfrac{10^{20}}{10^{-8}\times10^{17}} = \underline{10^{11} cm^{-3}}$

$\Delta n, \Delta p \ll p_0 \Longrightarrow$ Low level Assumption is fine.

% change for $p = \dfrac{\Delta p}{p_0}\times100 = \underline{10^{-4}\ \%}$

% change for $n = \dfrac{\Delta n}{n_0}\times100 = \underline{17.36\times10^{16}\ \%}$

4(b) $\Delta P(t_0) = 0 \qquad \Delta P(\infty) = \underline{\underline{10^{11}\,cm^{-3}}}$

$$\frac{d\Delta P}{dt} = G_L - \frac{\Delta P}{\tau_p}$$

$$\tau_p = \frac{1}{K(n_0+p_0)} = \frac{1}{(10^{-8}\,cm^3/s)(10^{17}\,cm^{-3})} = \underline{\underline{10^{-9}\,s}}$$

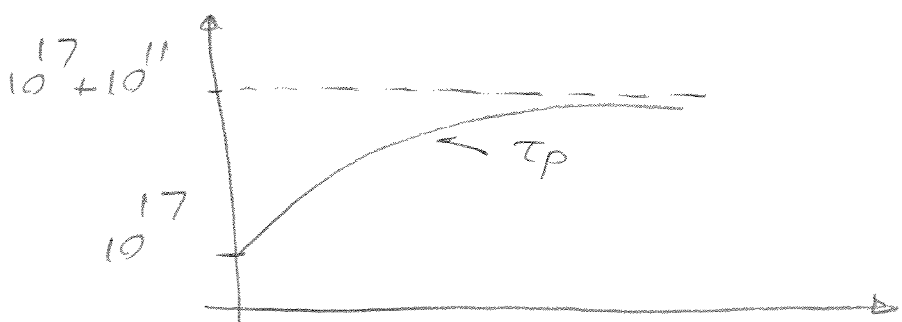
Solution: $\Delta P(t) = A\exp\left(-\frac{t}{\tau_p}\right) + B$

@ $t=0 \Longrightarrow \Delta P(0) = 0 = A+B \Longrightarrow A = -B$

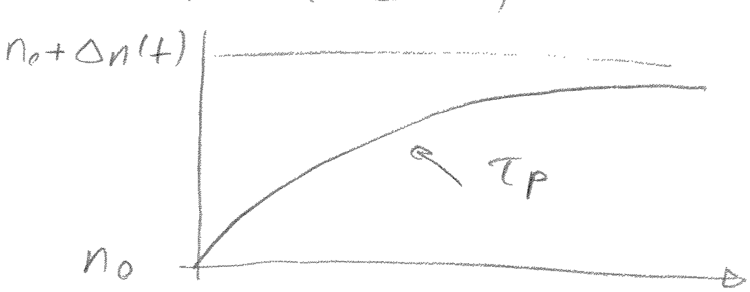
@ $t=\infty \Longrightarrow \Delta P(\infty) = \underline{\underline{10^{11} = B}}$

$$\Longrightarrow \Delta P(t) = 10^{11}\left(1 - e^{\left(-\frac{t}{\tau_p}\right)}\right) = \Delta n(t)$$

$P(t) = P_0 + \Delta P(t)$



$n(t) = n_0 + \Delta n(t)$



4(b) For Conc. of $\bar{e}$ to increase to $\frac{1}{2} \times 10^{11} cm^{-3}$

$$\frac{1}{2} \times 10^{11} cm^{-3} = 10^{11}(1 - e^{-\frac{t}{\tau_p}}) \Longrightarrow \underline{t = 0.693 ns}$$

4(c) $G_L = 10^{28} cm^{-3} s^{-1}$ (The light generation is 10^8 times of part (a), so, L.L.I is likely not the case)

$$\Longrightarrow \Delta n^2 + \Delta n P_o - \frac{G_L}{k} = 0$$

$$\Rightarrow \Delta n^2 + \Delta n (10^{17} cm^{-3}) - \frac{10^{28} cm^{-3} s^{-1}}{10^{-8} cm^3/s} = 0$$

$$\Longrightarrow \Delta n = \Delta P = \underline{9.5 \times 10^{17} cm^{-3}}$$

$$\Rightarrow \% \text{ change for } P = \frac{\Delta P}{P_o} \times 100 = \underline{950\%}$$

$$\Rightarrow \% \text{ change for } n = \frac{\Delta n}{n_o} \times 100 = \frac{9.5 \times 10^{17}}{5.76 \times 10^{-5}} \times 10^2 \% = \underline{1.6 \times 10^{24} \%}$$