ECE 132: Introduction to Electronic Devices Fall 2018
Homework 2 Solutions

1. V_{AB} has an error associated with it due to the misaligned contacts. Let V_H represent the value of the Hall voltage without error.

   First, take the measurement when the B-field is in the +z direction. Then we can write,

   $$V_{AB1} = V_H - \Delta x\, E_x \qquad \text{----------------------- (1)}$$

   Where Δx represents the misalignment of the probe.

   Next, switch the direction of the B-field to the –z direction and again repeat the above measurement. We can then write,

   $$V_{AB2} = -V_H - \Delta x\, E_x \qquad \text{------------------------(2)}$$

   Subtracting the two equations, we get

   $$V_{AB1} - V_{AB2} = 2V_H$$

   $$V_H = (V_{AB1} - V_{AB2})/2$$

   Note that other solutions are possible as well.

2. n-type Silicon sample with $n_o = 4 \times 10^{16}$ cm^{-3}

   At t=0, 10^{14} EHP/cm^{-3} are generated as a result of a pulse of light.

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

   a) $\tau_p = 1\mu s$

      Since we know that for a semiconductor at equilibrium, $n_o p_o = n_i^2$

$$p_o = \frac{n_i^2}{n_o} = \frac{(1.5\ x\ 10^{10})^2}{(4\ x\ 10^{16})} = 5.6 \text{ x } 10^3\ cm^{-3}$$

   The hole concentration would decay exponentially due to the carrier lifetime.

$$p(t) = 10^{14}\ e^{\frac{-t}{1\mu s}} + 5.6\ x\ 10^3\ cm^{-3}$$

   b) At t = $1\mu s$, the hole carrier concentration can be calculated as:

$$p(1\mu s) = 10^{14}\ e^{\frac{-1\mu s}{1\mu s}} + 5.6\ x\ 10^3 = 3.7\ x\ 10^{13}\ cm^{-3}$$

3. Given: $N_D = 10^{17}$ cm^{-3}, $g_{op} = 10^{20}$ cm^{-3} s^{-1}, $\tau_p = \tau_n = 10$ μs, $D_p = 12$ cm^{2}s^{-1},

   $D_n = 36$ cm^{2}s^{-1}, n_i (450K) = 10^{14} cm^{-3}

   Assuming complete ionization of donors, $N_D = n_0 = 10^{17}$ cm^{-3}.

$$\mathrm{p}_o(450\mathrm{K}) = \frac{[n_i(450K)]^2}{n_o} = 10^{11}\ cm^{-3}$$

   The excess carriers generated in the system within the hole/electron lifetime
   $\delta n = \delta p = g_{op}\tau_n = 10^{20} \times 10 \times 10^{-6}$ s $= 10^{15}$ cm^{-3}

   n(450K) = n_0(450K) + $\delta n = 10^{17}$ cm^{-3} + 10^{15} cm$^{-3} \approx 10^{17}$ cm^{-3}

   p(450K) = p_o(450K) + $\delta p = 10^{11}$ cm^{-3} + 10^{15} cm$^{-3} \approx 10^{15}$ cm^{-3}

   Let us now find the position of the Quasi Fermi levels.

   At 450K, the thermal voltage V_T = kT = 1.38 x 10^{-23} x 450K = 0.039 eV.

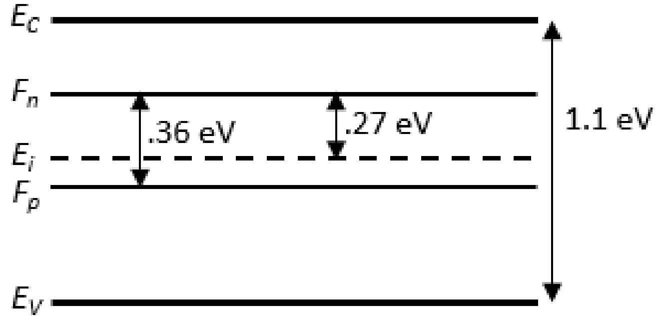
   From Streetman Eqn (4-15) as shown in the text, we can write:

$$n = n_i e^{(F_n - E_i)/kT} \rightarrow F_n - E_i = kT \ln\left(\frac{n}{n_i}\right)$$

   Therefore, $F_n - E_i = 0.039\ eV \ln\left(\frac{10^{17}}{10^{14}}\right) = 0.27\ eV.$

   Similarly, we can write: $p = n_i e^{(E_i - F_p)/kT} \rightarrow E_i - F_p = kT \ln\left(\frac{p}{n_i}\right)$

   Thus, $E_i - F_p = 0.039\ eV \ln\left(\frac{10^{15}}{10^{14}}\right) = 0.09eV$



Let us now calculate the change in conductivity of the sample.

$\Delta\sigma = q\{ [\mu_n(450K)\cdot n(450K) + \mu_p(450K)\cdot p(450K)] - [\mu_n(300K)\cdot n(300K) + \mu_p(300K)\cdot p(300K)] \}$

→ Calculate the mobility using Einstein's relation.

$$\frac{D_n}{\mu_n} = \frac{kT}{q} \rightarrow \mu_n(450K) = \frac{36\ cm^2 s^{-1}}{0.039V} = 923\ cm^2 V^{-1} s^{-1}$$

$$\mu_n(300K) = \frac{36\ cm^2 s^{-1}}{0.026V} = 1385\ cm^2 V^{-1} s^{-1}$$

Similarly, for holes, we can write,

$$\frac{D_p}{\mu_p} = \frac{kT}{q} \rightarrow \mu_p(450K) = \frac{12\ cm^2 s^{-1}}{0.039V} = 307\ cm^2 V^{-1} s^{-1}$$

$$\mu_p(300K) = \frac{12\ cm^2 s^{-1}}{0.026V} = 460\ cm^2 V^{-1} s^{-1}$$

$$n(450K) = N_D + \delta n \approx N_D = 10^{17}\ cm^{-3} = n(300K)$$

$$p(450K) = \frac{[n_i(450K)]^2}{n(450K)} + \delta p \approx \delta p = 10^{15}\ cm^{-3}$$

$$p(300K) = \frac{[n_i(300K)]^2}{n(300K)} = \frac{[1.5 \times 10^{10} cm^{-3}]^2}{10^{17}\ cm^{-3}} = 2.3 \times 10^{3}\ cm^{-3}$$

We can calculate the change in conductivity as,

$$\Delta\sigma = (1.6 \times 10^{-19}\ C) \times [\ (923\ cm^2 V^{-1}s^{-1} \times 10^{17}\ cm^{-3} + 307\ cm^2 V^{-1}s^{-1} \times 10^{15}\ cm^{-3}) - (1385\ cm^2 V^{-1}s^{-1} \times 10^{17}\ cm^{-3} + 460\ cm^2 V^{-1}s^{-1} \times 2.3 \times 10^{3}\ cm^{-3})\ ]$$

$\Delta\sigma$ = -7.42 S/cm (conductivity has dropped due to reduced electron mobility)

4. Every τ_p seconds, each hole of the charge distribution Q_p recombines and must therefore be replaced by injection of another hole.

Thus, we can write $I_p = \frac{Q_p}{\tau_p}$

From Figure (4-17), we know that $\delta\mathrm{p}(\mathrm{x}) = \Delta\mathrm{p}\, e^{-x/L_p}$

$$Q_p = qA \int_0^{\infty} \delta\mathrm{p}\,(x)\,dx$$

$$Q_p = qA \int_0^{\infty} \Delta\mathrm{p}\ e^{-x/L_p}\,dx$$

$$Q_p = qA\,\Delta\mathrm{p} \int_0^{\infty} e^{-x/L_p}\ dx$$

$$Q_p = -qA\,\Delta\mathrm{p}\,L_p$$

Now, we know that $L_p = \sqrt{D_p \tau_p}$ → $\tau_p = \frac{{L_p}^2}{D_p}$

Thus, $I_p = \frac{Q_p}{\tau_p} = \frac{-qA\,\Delta\mathrm{p}\,L_p}{({L_p}^2/D_p)} = \frac{-qA\,\Delta\mathrm{p}\,D_p}{L_p}$