ECE 340 Homework V Spring 2003

Due: Monday, February 17, 2002

(30 points)

1. *(a) An n-type Si sample with $N_d$ = $1x10^{17}/cm^3$ is steadily illuminated such that $g_{op}$= $2x10^{21}$ EHP/$cm^3$-s. If $t_n$= $t_p$ =1 μ s for the excitation, calculate the separation in the quasi-Fermi levels, ($F_n$-$F_p$). Draw a band diagram such as Fig. 4-11.*
   *(b) At t=0, the illumination in part (a) is terminated. Assuming the carrier lifetimes remain the same, calculate the separation in the quasi-Fermi levels at t=3μ s. Draw a corresponding band diagram at 300K.*

Solution:

(a) $d\,n = d\,p = g_{op}t = 2\times10^{15}cm^{-3} \ll N_d$, indeed low level injection

$$p = p_0 + \Delta p = \Delta p = 2\times10^{15}cm^{-3}$$

$$n = n_0 + \Delta n = 1.02\times10^{17} \approx 1\times10^{17}cm^{-3}$$

$$F_n - E_i = 0.0259\ln\frac{n}{n_i} = 0.407eV$$

$$E_i - F_p = 0.0259\ln\frac{p}{n_i} = 0.306eV$$

$$F_n - F_p = 0.713eV$$

(b) After 3 μs, $n \approx n_0 = 1\times10^{17}cm^{-3}$

$$p \approx d\,p = \Delta p e^{-t/t} = 2\times10^{15}\times e^{-3} = 9.96\times10^{13}cm^{-3}$$

$$F_n - E_i = 0.0259\ln\frac{n}{n_i} = 0.407eV$$

$$E_i - F_p = 0.0259\ln\frac{p}{n_i} = 0.228eV$$

$$F_n - F_p = 0.635eV$$

2. *(a) A Si bar 0.1 cm long and 100 μ $m^2$ in cross-sectional area is doped with $5x10^{16}/cm^3$ arsenic atoms. Find the current at 300 K with 10 V applied. Repeat for a similar Si bar 1 μ m long.*
   *(b) Upon a steady illumination uniform excess carriers are generated in the Si bar. Assume that $t_n$= $t_p$ = 1 μ s for the excitation. Determine the percentage of increase in current in part (a) assuming an optical generation rate, $g_{op}$=$10^{21}$ EHP/$cm^3$-s is obtained.*

   Solutions:

   (a) As: donor, n type. Lookup graph, $m_n = 830cm^2/Vs$ $m_p = 280cm^2/Vs$

   Electric field: $\mathcal{E} = V/d$ .

   For 0.1 cm long Si bar, drift current:

$$I = Aq\left(nm_n + pm_p\right)\mathcal{E} \approx Aqnm_n\mathcal{E} = Aqnm_n\frac{V}{d}$$

$$= 10^{-6}cm^2 \times 1.6\times10^{-19}C \times 5\times10^{16}cm^{-3} \times 830cm^2\ /Vs \times (10V/0.1cm)$$

$$= 6.64\times10^{-4}A$$

For 1 µ m long Si bar, electrical field $\mathcal{E} = V/d = 10V/1mm = 10^5 V/cm$.
From Fig 3-24, the electron drift velocity is saturated at thermal velocity of about $10^7$ cm/s.

$$I = Aqnv_{sat} = 10^{-6}cm^2 \times 1.6\times10^{-19}C \times 6\times10^{16}cm^{-3} \times 10^7 cm/s$$
$$= 0.08A$$

(b), $\Delta n = \Delta p = g_{op}t = 10^{15}cm^{-3}$, since the percentage of change is a small quantity, we won't neglect $\Delta n, \Delta p$:
$p = p_0 + \Delta p \approx \Delta p = 10^{15}cm^{-3}$, $n = n_0 + \Delta n = 5.1\times10^{16}cm^{-3}$. Assume the mobility doesn't change.

$$PercentOfIncrease = \frac{Aq(nm_n + pm_p)_{After}\mathcal{E}}{Aq(nm_n + pm_p)_{before}\mathcal{E}} - 1 = \frac{(nm_n + pm_p)_{After}}{(nm_n + pm_p)_{before}} - 1$$
$$= \frac{5.1\times10^{16}\times830 + 10^{15}\times280}{5\times10^{16}\times830} - 1 = 2.7\%$$

3. *(a) Show that the minimum conductivity of a semiconductor sample occurs when $n_o = n_i\,(\mu_p/\mu_n)^{1/2}$ and find the expression for the minimum conductivity $s_{min}$.*
*(b) Calculate $s_{min}$ for Si at 300 K and compare with the intrinsic conductivity.*

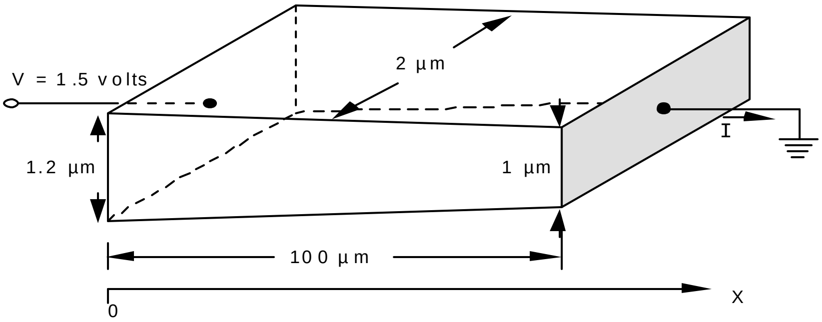
Solutions:

(a), $s = q\left(nm_n + pm_p\right) = q\left(nm_n + \dfrac{n_i^2}{n}m_p\right)$, minimum holds when $\dfrac{ds}{dn} = 0$.

$$\frac{ds}{dn} = q\left(m_n - \frac{n_i^2}{n^2}m_p\right) = 0$$
$$\Rightarrow n = n_i\sqrt{m_p/m_n}, \qquad s_{\min} = 2qn_i\sqrt{m_n m_p}$$

(b), $s_{\min} = 2\times1.6\times10^{-19}\times1.5\times10^{10}\sqrt{1350\times480} = 3.86\times10^{-6}\Omega^{-1}cm^{-1}$
$s_i = q\left(n_i m_n + n_i m_p\right) = 4.39\times10^{-6}\Omega^{-1}cm^{-1}$, $s_{\min}$ is $0.53\times10^{-6}\Omega^{-1}cm^{-1}$ lower than $s_i$

4. *A wedge-shape silicon slab, as shown below, is uniformly doped with $5x10^{16}/cm^3$ aluminum atoms.*
*(a) Find the current I, and determine the percentage of error if a uniform thickness of 1.1 µm for the slab is assumed to estimate the current.*



(b) *At which end do the majority carriers drift faster? At x=0 or x=100 μ m? What is the ratio of the drift velocity at x=0 to that at x=100 μ m?*

Solutions:

(a), p>>n, ignore n terms for drift current. $m_p = 280 cm^2/Vs$

At x μ m, the height of the silicon slab is $1.2 - \frac{0.2}{100}x = 1.2 - 0.002x$ μ m.

$$R = \frac{L}{wt}\frac{1}{s}$$

$$dR = \frac{dx}{wt}\frac{1}{s} = \frac{dx}{wt}\frac{1}{qpm_p}$$

$$= \frac{dx}{2\times10^{-4}\times(1.2-0.002x)}\frac{1}{1.6\times10^{-19}\times5\times10^{16}\times280}$$

$$= \frac{dx}{4.48\times10^{-4}(1.2-0.002x)}\Omega$$

$$R = \int_{0mm}^{100mm}\frac{dx}{4.48\times10^{-4}(1.2-0.002x)} = -1.117\times10^{6}\times\ln(1.2-0.002x)\Big|_{0mm}^{100mm} = 2.035\times10^{5}\Omega$$

$$I = \frac{V}{R} = \frac{1.5}{2.035\times10^{5}} = 7.37\times10^{-6}A$$

If assume t=1.1 um,

$$R = \frac{L}{wt}\frac{1}{s} = \frac{100}{2\times1.1\times10^{-4}}\frac{1}{1.6\times10^{-19}\times5\times10^{16}\times280} = 2.03\times10^{5}\Omega$$

$$I = \frac{V}{R} = \frac{1.5}{2.03\times10^{5}} = 7.39\times10^{-6}A$$

Error percentage $= \frac{7.39-7.37}{7.37} = 0.3\%$

(b), Majority carrier drift faster at x = 100 μm.

$I = Area\times J = Area\times qpv_x$ , current I is constant along x.

$$\frac{v_{x,0um}}{v_{x,100um}} = \frac{Area_{100um}}{Area_{0um}} = \frac{1}{1.2} = 0.833$$