**ECE 340** # Homework Assignment #5 **Fall 2015**

DUE: FRIDAY, OCTOBER 2, 2015

Print your **name** and **NetID** legibly. Follow the guidelines and format given in the syllabus. Staple multiple pages. Show all units. Homework must be turned in at the **beginning** of class and any late homework assignments will not be accepted. Please contact the course director, Professor Dallesasse, should any issues with late homework arise.

## 1. MOBILITY CONTRIBUTION

A piece of Si is doped with $10^{18}$ cm$^{-3}$ donors. For the following questions, assume mobility can be determined by impurity scattering and phonon (lattice) scattering where the contribution from impurity scattering can be described as

$$\mu_I \propto \frac{T^{3/2}}{N_d^+} \tag{1.1}$$

and the contribution from acoustic phonon scattering can be described as

$$\mu_{AC} \propto T^{-3/2} \tag{1.2}$$

(A). Write an expression for the total mobility as a function of temperature and sketch log($\mu$) vs. log(T). For which temperature range does each mechanism dominate? Assume all donors are ionized.

(B). Remember that at lower temperatures, the donors are not fully ionized. That is,

$$N_d^+ = \frac{N_d}{1+\exp(E_d/kT)} \tag{1.3}$$

where $E_d$ is the donor ionization energy, usually on the order of 40 meV for Si. On the same plot from part (a), sketch the total mobility considering carrier freeze-out.

(C). Now, consider an additional contribution to the total mobility from optical phonons such that

$$\mu_{OP} \propto T^{-2} \tag{1.4}$$

Write an expression for the total mobility and sketch the curve on the same plot as parts (a) and (b).

## 2. EXCESS CARRIER RECOMBINATION TIMES

Using the Fig. 2.1 showing carrier concentration as a function of time in a uniformly illuminated Si sample, do the following calculations. Assume room temperature (T=300 K) and complete dopant ionization. The illumination of the sample ends at $t = 0$.

(A). Is the semiconductor $n-$ or $p-$type? What is the doping level? Calculate the carrier lifetime $\tau_n = \tau_p$ and find the optical generation rate. Write an equation for the excess minority carrier concentration as a function of time with the values found.

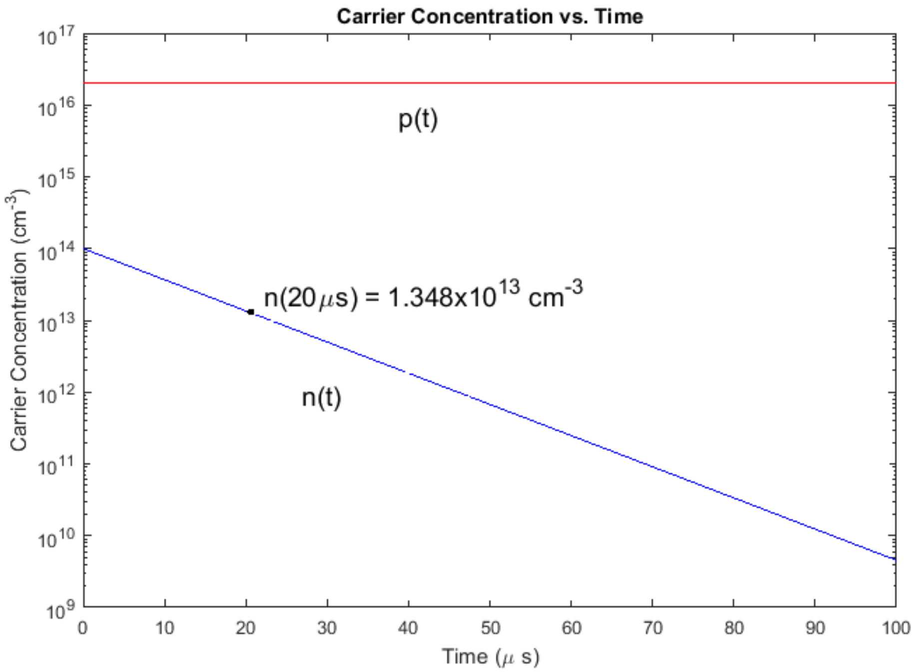


Figure 2.1: Schematic for Problem 2.

(B). Assuming that the carrier lifetime remains the same, calculate the quasi-Fermi level seperation after 10 $\mu$s.

(C). Find the time elapsed before the minority carrier concentration reaches the intrinsic carrier concentration.

## 3. Steady State Illumination

Consider a 4 $\mu$m thick Silicon sample with cross-sectional area of $1\times10^{-2}$ cm$^2$ at room temperature doped with an acceptor concentration of $1\times10^{17}$ cm$^{-3}$. The constant of proportionality for recombination $\alpha_r$ is found to be $1\times10^{-11}$ cm$^3$s$^{-1}$.

(A). Find the carrier lifetime assuming $\tau_n = \tau_p$ and find the thermal generation rate.

(B). If the sample is illuminated by a light source producing $2\times10^{19}$ cm$^{-3}$s$^{-1}$ electron-hole pairs (EHPs), what is the excess carrier concentration?

(C). If the illumination is from an 800 nm laser, how much power is absorbed? Hint: Assume the transmitted power is negligible and the quantum efficiency is 1 (i.e. each absorbed photon generates an electron-hole pair). What fraction of this is given off as heat?

## 4. PHOTOCONDUCTIVITY

Consider a 1 mm GaAs sample with a cross-sectional area of 200 $\mu m^2$ and a donor concentration of $N_d = 1 \times 10^{17} cm^{-3}$. At room temperature,

(A). Calculate the current if 10 V is applied along the length of the sample.

(B). Given that the excess carrier lifetime is $\tau_n = \tau_p = 5\ \mu s$, find the increase in current if the sample is illuminated with a steady-state light source resulting in an optical generation rate of $5 \times 10^{21}\ cm^{-3}s^{-1}$.

## 5. DRIFT AND DIFFUSION

In order to independently measure mobility and diffusion coefficients of minority carriers in a semiconductor, the following experiment is conducted: A pulse of EHPs is created in an *n*-type Si bar by using a flash of light. An electric field is applied across the bar so the holes created by the pulse drift towards the end of the bar as well as diffuse due to the presence of a concentration gradient. The hole current is monitored at the end of the bar in order to determine the peak of the pulse as well as its width (defined later in part (c)). Show each step of derivations requested and make sure the logic is clear for each step. Refer to section 4.4.1 of the text.

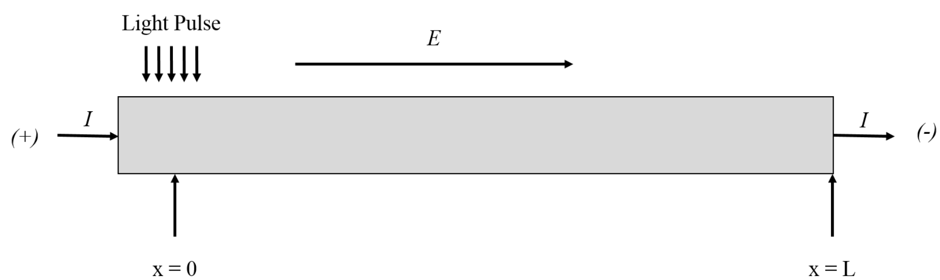


Figure 5.1: Schematic for Problem 5.

(A). Assume that the flash creates a pulse of EHPs at $t = 0$ ns and that the pulse is spatially and temporally confined to $x = 0$ at $t = 0$. Also assume that the excess carriers have a negligible effect of electron concentration but a significant one on the hole concentration ($n_0 >> p_0$). The holes drift and diffuse along the bar. The peak is detected at $t = t_d$. Sketch the *approximate* shape of the pulse at $t = 0, t_1, t_2, t_d$ where $t_1, t_2 < t_d$ on an axis from 0 to L. You may want to sketch the bar and use it as reference.

(B). If the length of the bar is 0.5 cm and the voltage of the battery is 9 V, find the hole mobility if the peak of the pulse (denoted $\widehat{\partial p}$) is detected at $t_d = 0.170$ ms. Assume the battery voltage is applied from 0 to L.

(C). The equation describing the diffusion of holes in the sample is given by Eqn. 4-33(b) in the text (neglect the drift term $-\delta p/\tau_n$). This function is satisfied by a Gaussian distribution given as

$$\delta p(x,t) = \left[\frac{\Delta p}{2\sqrt{\pi D_p t}}\right] e^{-(x-L)^2/4D_p t} \tag{5.1}$$

where $\Delta p$ is the number of holes created by the pulse at $t = 0$. We define the width of the pulse to be the $x$ location where the function has dropped to $1/e$ of its maximum value $(\hat{\partial} p/e)$. Assume that the detected Gaussian function is symmetric about $x = L$ so the width on one side will be $\Delta x/2$. The maximum value of the pulse is $\hat{\partial} p$ corresponding to $x = L$ and $t = t_d$. Find the value of $\Delta x$ corresponding to the peak width in the Gaussian distribution and relate $\Delta x$ to a measurable variable $(t)$ given that the carriers are drifting in a uniform electric field.

(D). Using the result from part (c), determine the hole diffusion coefficient in terms of the spatial and temporal pulse widths ($\Delta x$ and $\Delta t$). If $\Delta t$ is 30.0 $\mu$s, find the diffusion coefficient.

(E). Using the Einstein relations (Section 4.4.2 in the text), find the temperature at which this measurement was performed.