PH4044 2022/2023 - TUTORIAL III

Question 1 [4]

For a semiconductor at $T = 23°\text{C}$, in which the effective mass m_e^* is equal to the electron mass at rest m_0, plot in a suitable scale the concentration of electrons in the conduction band against the parameter $\eta_f = \frac{E_F - E_C}{kT}$, using both the Fermi-Dirac distribution and the Boltzmann approximation. Calculate the numerical value for the concentration of electrons for $E_F = E_C - 100$ meV and $E_F = E_C + 50$ meV using both distributions and comment on the results.

Question 2 [3]

Consider the Hall Effect experiment shown in the figure below, with $L = 10^{-1}$cm, $W = 10^{-2}$cm and $d = 10^{-3}$ cm. Also assume that $I = 1.0$ mA, $V = 12.5$ V, $B = 5 \times 10^{-2}$ T and $V_H = -4$ mV.
a) State whether the semiconductor is n-type or p-type.
b) Calculate the majority carrier concentration.
c) Determine the majority carrier mobility.

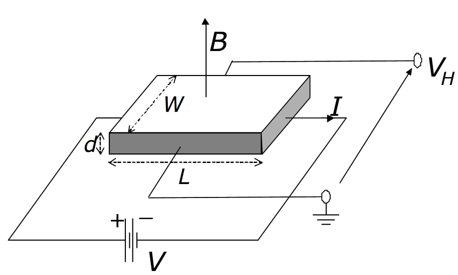

FIGURE 1. Experimental setup for Hall Effect experiment.

Question 3 [8]

The equation that describes the spatio-temporal dynamics of excess minority hole carriers, in an n-doped semiconductor is:

$$D_p \frac{\partial^2(\delta p)}{\partial x^2} - \mu_p E_0 \frac{\partial(\delta p)}{\partial x} - \frac{\delta p}{\tau_p} = \frac{\partial(\delta p)}{\partial t}, \tag{1}$$

where D_p is the holes diffusion coefficient, $\tau_p = 1\ \mu$s is the hole recombination lifetime, $\mu_p = 300$ cm^2/(Vs) is the holes mobility and E_0 is the externally applied electric field, pointing along $x > 0$. Making reasonable assumptions on the initial boundary conditions, integrate numerically the differential equation and plot the excess hole concentration $\delta p(x,t)$, as a function of time and space for different temperatures and applied electric field conditions.
Validate the numerical results with the analytical solution of the differential equation obtained when a finite number of holes P_0=1 is generated at t=0 and x=0.

$$\delta p(x,t) = \frac{e^{-t/\tau_p}}{(4\pi D_p t)^2} \exp[\frac{-(x - \mu_p E_0 t)^2}{4 D_p t}]. \tag{2}$$

[Hint: to tackle the integration, it is useful to assume that the excess carrier concentration has the shape $\delta p(x,t) = p^*(x,t)e^{-t/\tau_p}$].

Question 4 [5]

A silicon p^+n diode of junction area $A = 1$ mm^2 is forward biased at room temperature. The mobility of the holes is $\mu_p = 480$ cm^2/(Vs) and their lifetime is $\tau_p = 10\ \mu$s.

a) Calculate the hole diffusion length into the n-region.

b) If the forward current is 10 mA, and the injection ratio is close to unity, find the excess hole concentration at the n-side of the depletion region.

c) If the doping concentration in the diode is $N_D = 10^{15}$ cm^{-3} and $N_A = 10^{17}$ cm^{-3}, calculate the reverse saturation current for this diode ($n_i = 1.5 \times 10^{10}$ cm^{-3}).

d) What is the current under a forward bias voltage of 0.5 V?

e) If the diode is used as a solar cell, how many photons per second must be absorbed to give an open-circuit voltage of 0.5 V?