ECE 25500: Homework I

Fundamentals of Semiconductor Device Modelling

Due on: Aug. 30^{th}, 2019 *by* 5:00 PM

Note: Scan your work (there is a scanner in the EE computer lab for student use) and submit it on Blackboard by the deadline indicated above. Late homework is **not** accepted. Make sure that the scan is readable. Please email the course GTA at `rchatrie@purdue.edu` if you have any questions about this assignment.

Problem 1 (Review) (10 pts) : Before attempting this problem or the next, you should review the basics of Thévenin's theorem and equivalent circuits. Note that our use of Thévenin's theorem will be **very frequent** throughout the semester. Consider the sub-circuit shown in **Fig.1** below. What is its Thévenin equivalent resistance R_{th}?

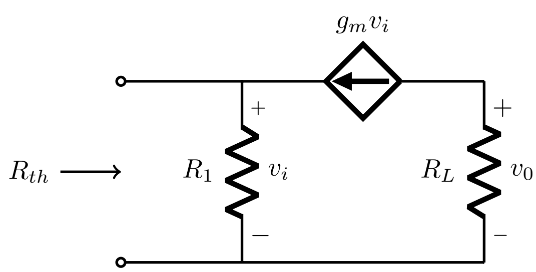

Fig.1 - A Sub-circuit with a Controlled Current Source.

Problem 2 (Review) (10 pts) : Consider the sub-circuit shown in **Fig.2** below.

(a) Suppose that $R_1 = R_2 = \cdots = R_5 = 2$ kΩ. What is the Thévenin equivalent resistance R_{th} of this sub-circuit? (**Hint:** the desired value of R_{th} can be obtained by inspection in this symmetrical case).

(b) Suppose that $R_1 = R_2 = R_3 = R_4 = 2$ kΩ and $R_5 = 1$ kΩ. What is the Thévenin equivalent resistance R_{th} of this sub-circuit?

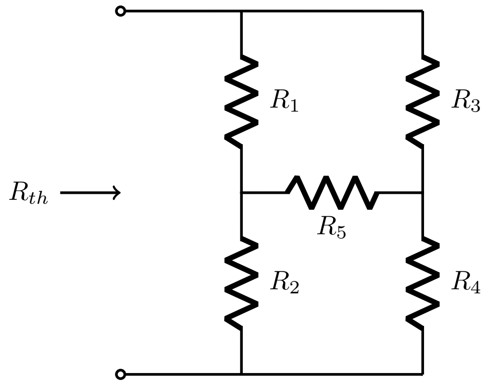

Fig.2 - A Passive Sub-circuit.

Problem 3 (15 pts) : The intrinsic carrier concentration parameter n_i is an important parameter for a semiconductor device. An approximate expression for n_i is given below.

$$n_i = BT^{(3/2)} e^{(-E_G/2k_BT)},$$

where T is the temperature of the semiconductor in Kelvins (K), E_G is the material's bandgap energy in electron-volt (eV), and k_B is Boltzmann's constant (1.38×10^{-23} J/K). Suppose a semiconductor device is made out of silicon (Si), for which $B = 4.87 \times 10^{15}$ cm^{-3}K$^{-3/2}$ and $E_G = 1.12$ eV (assume that E_G is independent of temperature for this problem).

(a) Compute n_i at room temperature ($T = 27$ °C) using the expression above for this device.

(b) Suppose that the temperature T in Celsius of the device is raised by 10%. By what percentage does the intrinsic carrier concentration n_i in cm^{-3} increase?

(c) Suppose that the temperature is brought back down to room temperature, and that the bandgap energy E_G in Joules of the material is increased by 10%. By what percentage does the intrinsic carrier concentration n_i in cm^{-3} increase?

(d) Doped semiconductor devices usually fail to operate as designed when n_i becomes comparable to the doping density. Suppose our silicon device is doped with $N_D = 10^{17}$ cm^{-3}. Around what temperature would the intrinsic carrier concentration reach a tenth of the doping concentration?

Problem 4 (15 pts) : Suppose there are two silicon semiconductor devices, one at a temperature of 300 K, and the other at a temperature of 600 K. You know that

$$n_i(300 \text{ K}) = 1.0 \times 10^{10} \text{ cm}^{-3} \quad \text{and} \quad n_i(600 \text{ K}) = 4.0 \times 10^{15} \text{ cm}^{-3}.$$

For each of the following doping configurations, compute the corresponding electron and hole carrier concentrations (n_0 and p_0) in each of the two silicon devices. Assume that the dopants are fully ionized in the silicon crystal. The units will always be cm^{-3} in the following.

(a) $N_D = N_A = 0$ (intrinsic material).

(b) $N_D = 1.00 \times 10^{13}$ and $N_A = 0$.

(c) $N_D = 5.00 \times 10^{15}$ and $N_A = 0$.

(d) $N_D = 0$ and $N_A = 5.00 \times 10^{15}$.

(e) $N_D = 1.00 \times 10^{18}$ and $N_A = 3.00 \times 10^{18}$.

Problem 5 (10 pts) : Suppose a region in a silicon device is uniformly doped with $N_D = 10^{17}$ cm^{-3} (assume that the temperature is low enough that the hole carrier concentration in the material is negligible). Let the electron mobility be 1000 cm^2/V · s. Suppose further that an electric field of magnitude 100 V/cm is uniformly applied across this region in a given direction (call it the $+x$ direction). What is the magnitude of the resulting drift current density? Include the correct units in your answer.

Problem 6 (10 pts) : Suppose that a piece of semiconductor material is at room temperature such that $k_BT/q = 26$ mV, and that its electron mobility is 1000 cm^2/V · s. What is its electron diffusion coefficient D_n?

Problem 7 (15 pts) : Consider an n-type semiconductor material with an excess non-uniform minority carrier hole concentration given by

$$p(x) = (10^{14})e^{-x/L_p}$$

where $L_p = 10^{-5}$ cm^{-3} and x represents the depth into the material from an edge situated at $x = 0$. Note that this hole concentration is added on top of the existing hole concentration p_0 within the material (these contribute no macroscopic diffusion current however). The hole diffusion coefficient is 2.6 cm^2/s. What is the sign (positive direction is towards increasing x) and magnitude of the hole diffusion current density at $x = 0$?

Problem 8 (15 pts) : Suppose that a semiconductor material has the energy band diagram profile shown in **Fig.3** below. The electron carrier concentration at x_1 is $n_0 = 10^{18}$ cm^{-3}. Assume that the material is at room temperature such that $k_BT/q = 26$ mV and that the intrinsic carrier concentration of the material is $n_i = 10^{10}$ cm^{-3}.

(a) What is the equilibrium hole concentration at $x = x_1$?

(b) What is equilibrium hole concentration at $x = 0$?

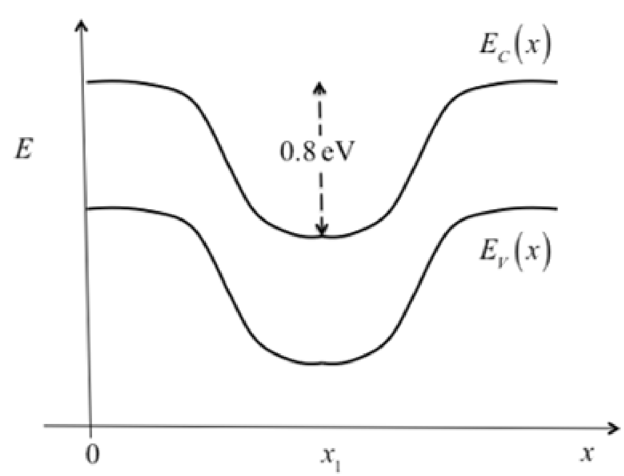

Fig.3 - Energy Band Diagram for Q8.