TUTORIAL 2

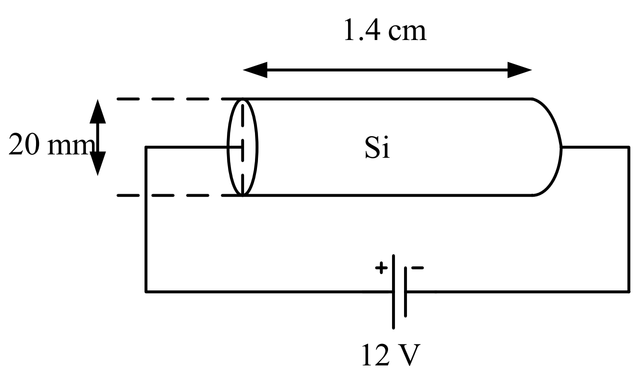
1. Draw the energy band diagram of a conductor, an insulator and a semiconductor. Comment on the conductivity of the 3 materials with reference to the number of free electrons in the materials at room temperature.

2. Discuss on the differences in the energy band structure of a conductor, an insulator and a semiconductor.

3. Name two examples of the elements that can be used as donor and acceptor impurities. Explain how the majority carriers are formed in the extrinsic semiconductors.

4. Define mobility and conductivity. Calculate the conductivity of an intrinsic Silicon at room temperature (27°C). Given the intrinsic Silicon concentration $n_i = 1.5x10^{10} cm^{-3}$, $\mu_n = 1300\ cm^2/Vs$, $\mu_p = 500\ cm^2/Vs$ and electronic charge, $q = 1.6x10^{-19}$ C.

5. Determine the current in an extrinsic Silicon bar shown below. The electron density in the bar is $2.6x10^{19}$ electron/m^{-3}. Given $\mu_n = 0.14\ m^2/Vs$, $\mu_p = 0.05\ m^2/Vs$, $q = 1.6x10^{-19}$ C and $n_i = 1.4x10^{16}$ electron/m^3.



6. Explain how the electrons and holes flow in a semiconductor crystal can occur.

7. Explain your understanding on the drift and diffusion currents.

8. Consider an intrinsic Silicon semiconductor that has:
   length, L = 0.8 cm
   cross-section area, s = 15x15 mm^2
   dc voltage across it, V = 10 V
   $n_i = 1.5x10^{16}$ electron/m^3
   $\mu_n = 0.14\ m^2/Vs$
   $\mu_p = 0.05\ m^2/Vs$

$q = 1.6x10^{-19}$ C

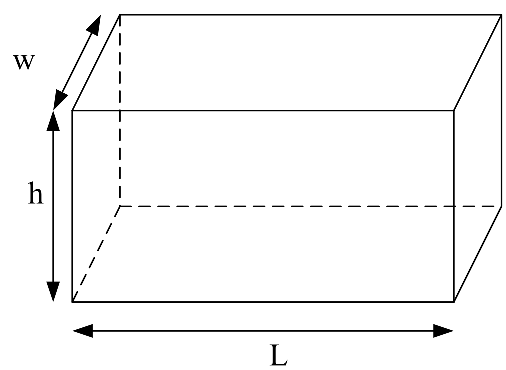
Calculate:

(a) electron and hole velocity

(b) total current flowing through the semiconductor

9. A germanium sample is doped with 10^{14} donor/cm^3 and $7x10^{13}$ acceptor/cm^3. At room temperature, the pure Germanium resistivity is 60 Ωcm. If the electric field is 2 Vcm^{-1}, determine the total current density. Assume that the electron and hole mobility is 3900 and 1900 cm^{2}V^{-1} s^{-1}, respectively.
   Note: Both donor and acceptor impurities can exist simultaneously. To preserve the electrical neutrality, the positive charge density is equals to the negative charge density, i.e. $p + N_D = n + N_A$

10. A Germanium bar has the following form:



   Given,

   L = 1 cm

   h = w = 0.1 cm

   $\mu_p = 2x10^3$ cm^2/Vs

   $\mu_n = 4x10^3$ cm^2/Vs

   If the bar is intrinsic, $n = p = n_i = 2x10^{13}$ cm^{-3} at 300°K. Determine conductivity, σ, and resistance, R, measured across the bar.
   Note: The end of the bar has a surface area of wh and $R = L/ \sigma wh$.

11. The resistance of a semiconductor at room temperature was 5.5 MΩ. The resistance was reduced to 125 Ω when the material was doped with acceptor impurities. If there were 10^{22} acceptor/m^3 of impurities and the mobility of the electron is 2.8 times more than the

mobility of holes, calculate the concentration of the electron-hole pair in the intrinsic specimen.

12. The conductivity of an intrinsic Silicon crystal at room temperature was $5x10^{-4}$ S/m. If the electron mobility was 0.14 m^2/Vs and the hole mobility was 0.05 m^2/Vs, determine the concentration of the electron-hole pair in the crystal. If the crystal is doped with donor atoms to give an impurity concentration of $10^{22}/m^3$, calculate the new value of the conductivity and the percentage of this conductivity that is contributed by the holes. Assume that all donor atoms are ionized and the mobility of both electrons and holes are maintained.

13. Prove that the probability of an electron occupying an energy level $E_F + \Delta E$ is equivalent to $1–f(E_F + \Delta E)$. E_F is the Fermi level and f(E) is the probability of an electron occupying an energy level E.

14. An intrinsic semiconductor has an energy gap of 1.0 eV. Calculate the probability that an electron will be occupying an energy level near to the lowest level of the conduction band at
    (a) 0°K
    (b) 293°K

15. An N-crystal has a width of 4 mm, a cross-section of 0.2 mm^2 and $3x10^{22}$ electrons/m^3. If the current that flows through this material is 50 mA and the Hall voltage is 100 mV, determine the magnetic field.

16. What is the Hall voltage, V_H, for a semiconductor that has majority carrier concentration of 10^{16} cm^{-3} if the width, w, is 1 mm , magnetic field, B, is 0.1 Weber/m^2 and the bar has 10 mA of current flowing through a cross-section area of $10^{-2}cm^2$?

17. An extrinsic semiconductor has a length of 30 mm, a width of 6 mm and a thickness of 1 mm with 500 Ω of resistance. If it is placed under a 0.5 T of magnetic field, a current of 10 mA and a Hall voltage of 5 mV, determine the Hall mobility and the semiconductor's carrier density.

18. The measurement of the Hall voltage, V_H, can be used to determine the type of extrinsic semiconductor. Explain.

19. Relate the Hall electrical field intensity with the current density and the magnetic field intensity.

20. Show that the conductivity, σ, and mobility, μ, can be determined from the measurement of Hall voltage, V_H.

21. Explain the Hall effect.

22. Explain the Hall effect in an extrinsic semiconductor. Draw diagrams and show the direction of the respective quantities. State two applications of the Hall experiment.

23. An intrinsic semiconductor has a resistance of 8 MΩ at room temperature. The resistance dropped to 15 Ω when acceptor impurities were added. Calculate the hole and electron densities in this p type material. Given electron-hole pair density as $5\text{x}10^{16}/m^3$, lifetime of the electron is $1.5\text{x}10^{-12}$ s and the lifetime of the hole is $5.5\text{x}10^{-13}$ s.
Note: Mobility of electron, $\mu_n = e\tau_n/m$, and mobility of hole, $\mu_p = e\tau_p/m$, where τ_n and τ_p is the lifetime of the electron in the P material and hole in the N material, respectively.

24. A Silicon sample was doped with phosphorus atoms that has a concentration of 10^{13} cm^{-3}. At a certain temperature, the intrinsic carrier concentration was $2\text{x}10^{12}$ cm^{-3}, electron mobility of 800 cm^2/Vs and hole mobility of 300 cm^2/Vs.
    (a) Determine the hole and electron concentration.
    (b) Determine the electrical conductivity.
    (c) Determine the fraction of current contributed by the hole electric field. (Give the answer in the form of percentage).

25. Explain how the electron or hole majority carriers are generated in an extrinsic n or p.

26. A Germanium sample was doped with 10^{14} donor/cm^3 and $7\text{x}10^{13}$ acceptor/cm^3. At a certain temperature, the resistivity of the pure Germanium is 60 Ωcm. If the supplied field is 2 Vcm^{-1}, determine the total current density. Assume that the mobility of electron and hole is 3900 $cm^2V^{-1}s^{-1}$ and 1900 $cm^2V^{-1}s^{-1}$, respectively.