EEE105 Tutorial Questions & Review Topics – W5

Fundamental Constants

Charge on Electron, $q = 1.602\text{x}10^{-19}$ C
Mass of the Electron, $m_e = 9.11\text{x}10^{-31}$ kg

For germanium;
$\mu_e = 0.39\ m^2V^{-1}s^{-1}$
$\mu_h = 0.19\ m^2V^{-1}s^{-1}$

Note: A key point is that for metals we consider only one charge carrier – the electron. For intrinsic semiconductors we have to consider both the electron and the hole as both contribute to conduction.

1). A silver wire has a conductivity of $6.7\times10^7\ \Omega^{-1}m^{-1}$. An electric field of 100 V/m is applied to the wire. The free carrier density of the metal is $10^{29}\ m^{-3}$ and the effective mass of electrons in this material is 1.

a. Calculate the current density
b. Calculate the mobility
c. Calculate the average drift velocity of electrons
d. Calculate the mean time between collisions

2). A bar of intrinsic germanium has $2.5\text{x}10^{19}$ free electrons per m^3 . An electric field of 500 Vm^{-1} is applied

a. Calculate the conductivity of the material.
b. Find the net drift current density.
c. What fraction of the drift current is due to electrons?
d. What are the drift velocities of the electrons and holes?

Review the differences in some of the parameters for a metal and an intrinsic semiconductor.

Review Topics – Keywords

Conductivity, mobility, drift current, drift velocity, electrons, holes, intrinsic semiconductor

Solutions

1).

a). The current density is given by-

$$J = \sigma E$$

so,

$$J = 6.7x10^{7} \text{ x } 100 = 6.7x10^{9} \text{ A/m}^2$$

b) The conductivity and mobility are related by;

$$\sigma = nq\mu$$

$$\therefore \mu = \frac{\sigma}{nq} = \frac{6.7x10^{7}}{10^{29} x1.6x10^{-19}} = 4.2x10^{-3} \text{m}^2\text{/Vs}$$

c). We can obtain the drift velocity by

$$v_d = -\mu E = -4.2x10^{-3} x10^{2} = -0.42\text{m/s}$$

d). To get the mean time between collisions we need to remember the physical origin of mobility and

$$\mu = \frac{q\tau}{m^*}$$

$$\therefore \tau = \frac{4.2x10^{-3} x9.1x10^{-31}}{1.6x10^{-19}} = 2.38x10^{-14} s$$

2.

a) The conductivity of a semiconductor is given by;

$$\sigma = nq\mu_e + pq\mu_h = n_i q(\mu_e + \mu_h)$$

$$\sigma = 2.5x10^{19} \text{ x } 1.6x10^{-19} \text{ x } (0.39 + 0.19)$$

$$\sigma = 2.3 \ \Omega^{-1}\text{m}^{-1}$$

b) The electron current density in a metal is given by:

$$J = \sigma E$$

so, inserting from above

$$J = n_i qE(\mu_e + \mu_h)$$

$$\therefore J = 2.5x10^{19} x1.6x10^{-19} x500x(0.39 + 0.19) = 1160 A/m^2$$

c) The total drift current can be split into an electron and hole component;

$$J_{Drift} = J_{Drift}^{electron} + J_{Drift}^{hole}$$

$$J_{Drift} = nqE\mu_e + pqE\mu_h$$

As we have an intrinsic semiconductor -

$$n = p = n_i$$

$$J_{Drift} = n_i qE(\mu_e + \mu_h)$$

The fraction of the drift current due to electrons is therefore given by

$$\frac{J_{Drift}^{electron}}{J_{Drift}} = \frac{n_i qE\mu_e}{n_i qE(\mu_e + \mu_h)}$$

So

$$\frac{J_{Drift}^{electron}}{J_{Drift}} = \frac{\mu_e}{\mu_e + \mu_h}$$

$$\frac{J_{Drift}^{electron}}{J_{Drift}} = \frac{0.39}{0.58} = 67\%$$

67% of the drift current is due to electrons in this case. Note that this is a special case where the electron and hole populations are equal. This result does not hold if these carrier densities are not equal.

d) For the drift velocity we can examine electrons and holes separately;

For electrons

$$v_d = -\mu E = 0.39 \ x \ 5x10^2 = 195ms^{-1}$$

For holes

$$v_d = -\mu E = 0.19 \ x \ 5x10^2 = 95ms^{-1}$$