EEE105 - Electronic Devices
Lecture 6

Drift Velocity Example

Last time we derived a number of equations for the which allow us to examine the behaviour of charge carriers in a solid. In order to practice using these let us consider the following problem:

A 2 cm long Si rod with a cross-sectional area of 5 mm^2 has a voltage of 10 V applied across its length, giving a current of 3 mA. The rod is known to have a uniform density of free electrons throughout its length.

a) What is the average time between collisions in the material

b) What is the average drift velocity of the electrons in the rod

c) What is the concentration of the electrons in the material.

Answer

a) We need to first consider what fundamental information we already know about Si: Looking back to Lecture 4 we can find values for both the mobility and effective mass of electrons in the rod:

μ =0.12 m^{2}V^{-1}s^{-1} and m_e^* =0.98m_e

From lecture 5 we have: $\mu = \frac{q\tau}{m^*}$ and therefore: $\tau_e = \frac{m_e^* \mu_e}{q}$.

Substituting in the appropriate numbers gives:

b) We know that the drift velocity and electric field are simply related by: $v_d = -\mu E$.

Now 10 V is applied across a rod that is 2 cm long. If the doping is uniform then we can expect the resistivity along the rod to be uniform and thus the voltage to be dropped uniformly along it. (Constant Electric Field in the rod) Hence we can simply use $E = V/l$ where l is the length of the rod.

Substituting in the numbers it is simple to show that

And hence that the drift velocity will be:

c) For the final part we know the voltage and the current, and therefore can use Ohm's law to get resistance: $R=V/I=3.33\text{x}10^3\ \Omega$.

Knowing the dimensions of the rod the conductivity of the material can be calculated:

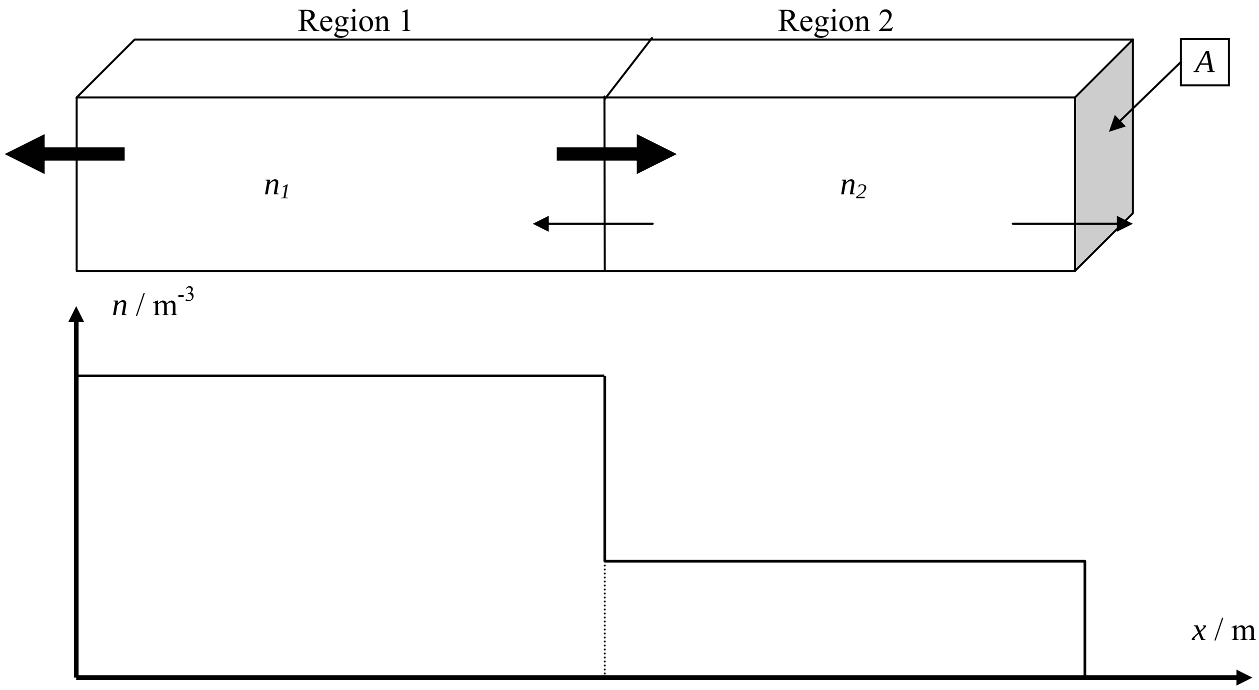
We also know a relationship between conductivity and charge carrier concentration allowing the density of free electrons to be calculated in our example:

Diffusion of Charge Carriers

(CAL: Diff(a), Diff(b))

Originally we said there were two methods we could get a net flow of electrons from one region to another. The first was due to the presence of an E-field (so-called *DRIFT* current), discussed above. The second is when we have a non-uniform distribution of charge carriers in some material. This will lead to so-called *DIFFUSION* current.

Let us consider two neighbouring regions in a crystal, with a constant, <u>but different</u> electron concentration in each region. Let us also assume that the material forms a bar of cross-sectional area, *A*.



Now in region 1 electrons flow equally to the right and left due to

The same will happen in region 2.

However in our example $n_1 > n_2$. Thus there is a *net* flow of charge carriers from region 1 to region 2 through a cross-sectional area *A*, even though there is no filed driving the electrons. (This assumes that there are no repulsive forces opposing this net diffusion).

The diffusion process acts to cancel out non-uniform particle distributions and occurs in any free-moving system, e.g.:

If the particles are charged then clearly a current flow will result.

This ***diffusion current*** is important in considering diode and (bipolar junction) transistor operation.

Equation for Diffusion Current

Let us now look more formally at this situation. Consider a concentration profile

The net movement (or ***flux***) of particles is proportional to the local concentration gradient:

$$flux \propto -{dn}/{dx}$$

Therefore, assuming a constant of proportionality, *D*, where D is the ***DIFFUSION COEFFICIENT:***

$$flux = -D\,{dn}/{dx}$$

If the particles are electrons and therefore charges we will get from this flux of electrons a diffusion current density. (Here we define flux as particle flow per unit area, current density is charge flow per unit area)

Hence: $J = -q.\,flux = -q.-D_e \, {}^{dn}\!/_{dx} = qD_e \, {}^{dn}\!/_{dx}$

Where $D_e = \dfrac{kT}{q}\mu_e$ ← Einstein Relation

We will not prove this equation for D_e, but let us consider if it is reasonable.

D_e is a measure of how easily carriers can diffuse in the material, where the driving force for diffusion is given by the concentration gradient *dn/dx*. There are two key parameters affecting D_e in the Einstein relation:

Competition between Drift and Diffusion.

Let us consider the situation where we have both an E-field and a concentration gradient:

In this case the total current density flowing in the material will be the sum of the drift and diffusion current densities: $J = J_{drift} + J_{diff} = nq\mu_e E + D_e q \, {}^{dn}\!/_{dx}$

Let us now consider an example where electrons are the charge carriers and the concentration gradient and E-field are acting in opposition to each other

In this situation

the concentration gradient will drive the electrons from

the E-field will be acting to drive the electrons from

There is an important case where these two will cancel each other out and the current density

$J = nq\mu_e E_x + D_e q \, {}^{dn}\!/_{dx} =$

From the above we can therefore get

$-nq\mu_e E_x = D_e q \, {}^{dn}\!/_{dx}$ and hence:

$E_x = -\dfrac{D_e}{n\mu_e} . {}^{dn}\!/_{dx}$.

This situation is important to remember as it arises in semiconductor p-n junctions (or diodes). We will discuss this later

Key Points to Remember:

1. In addition to drifting in an E-field, a net motion of charge carriers can be obtained if the charge carrier density is non-uniform
    a. The net motion (or net flux of charge carriers from one region to another) leads to a diffusion current
2. The diffusion current density at any point in the material is proportional to the concentration gradient of the charge carriers
3. We can have a situation where the net motion of charge carriers is zero where the concentration gradient giving diffusion is opposed by the E-field creating drift.