EEE105 - Electronic Devices
Lecture 4

Current in a Solid

Current in a solid arises because of movement of charges in a solid

Consider a solid with (free) electrons in it (e.g. a metal)

What is the current density flowing in this solid

Current Density, *J,* is the current flowing per unit area: $J = I/A$

Let us now define v_d to be the "average" velocity of electrons in the solid, and now let us also take a longitudinal slice through the solid.

In some time, t, a number of electrons equivalent to all the electrons in the shaded region will move past our observation point (labelled 'O') where

$x = v_d t$

The number of electrons in this volume is

$n.VOL = nAx = nAv_d t$

where n is the density of free electrons in the material.

The charge on an electron = $-q$ (where $q=1.6\text{x}10^{19}$ C) so in a unit time (of one second) the amount of charge flowing past 'O' is equal to $nAqv_d$.

Which is the current, I.

Therefore the current density flowing through the material will be $\boxed{J = I/A = -nqv_d}$.

Note that J is in the opposite direction to v_d, as expected.

Note (2): Sometimes you will find v_d written as simply v, or v_D and the charge on the electron can be found written as e rather than q.

However, this equation above is ONLY useful if we can get a value for v_d. For example, as was explained in lecture 1, in a vacuum the electrons keep accelerating in an electric field, so we cannot define a drift velocity.

In a solid the behaviour of electrons is different and in time the electron population will have an average drift velocity, which is constant. Furthermore it can be shown that this ***average drift velocity will be proportional to the Electric Field***.

We will justify these statements later, but for the moment let us accept them, giving us $v_d \propto -E$

Next we need a constant of proportionality: This coefficient is called the ***mobility*** and is given the symbol μ. The mobility is a measure of how easily electrons move in a field. Its value depends on the material, (and often on the quality of the material too!).

Hence we have $\boxed{v_d = -\mu E}$

The value of the mobility of the electrons is:

$\mu_e = 0.12\ m^2V^{-1}s^{-1}$ in silicon (Si) and $\mu_e = 0.36\ m^2V^{-1}s^{-1}$ in germanium (Ge)

Combining the two equations $J = -nqv_d$ and $v_d = -\mu E$:

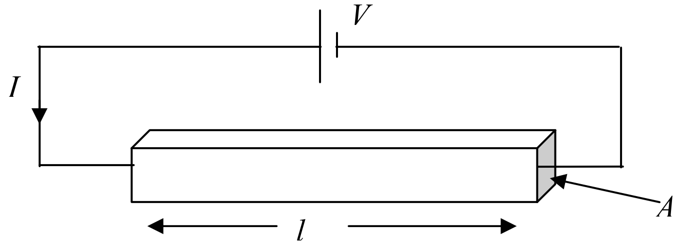
We obtain $J = nq\mu E$

So the current flowing in our solid depends on

This equation is often simplified to $\boxed{J = \sigma E}$ where σ is the conductivity given by $\sigma = nq\mu$

This equation is actually the genral form of a very famous equation in electronics:

Let us prove that this is the case by considering again the situation for current flowing through a rod of cross sectional area, A:



Thus we have Ohms Law, and the resistance in terms of σ, where σ is defined in terms of the physical parameters of the material:

$$\boxed{\sigma = nq\mu \qquad \sigma = {}^{1}\!/_{\rho} \qquad R = \frac{\rho l}{A}}$$

IMPORTANT EQUATIONS TO REMEMBER!

However there is still one thing we need to prove….

How do we justify this assumption…?

Before we can make this justification we need to introduce a new concept of: ***EFFECTIVE MASS.***

In a solid the electrons are accelerated differently than the would be if they were in a vacuum. This is because in the solid the electrons are inside a periodic array of atoms (a crystal) which means that they are in a periodic potential. This means they interact will an externally applied electric field differently.

Physicists have shown that the same equations of motion apply for electrons in a solid as for a vacuum ***BUT*** the electrons *act as if their mass is different.*

This new mass is called the *Effective Mass*.

The formal proof of this requires a detailed knowledge of quantum mechanics – you will get be basics of this proof in EEE207 next year.

Examples of the effective mass are:

Si	$m_e^* =$	$0.98\, m_e$
	$m_h^* =$	$0.59\, m_e$
Ge	$m_e^* =$	$0.22\, m_e$
	$m_h^* =$	$0.37\, m_e$

Note m_h^* is for the effective mass of *holes*, which is included here for completeness. We will discuss the concept of holes soon.

Key Points to Remember:

1. Current Density is current per unit area flowing in a material
2. In a solid electrons move with an average velocity called the DRIFT VELOCITY
    a. The Drift velocity depends on the Electric Field and the Mobility
3. MOBILITY is a measure of how easily a charge carrier can move in a particular solid.
4. CONDUCTIVITY is the reciprocal of RESISTIVITY and can be defined in terms of the density of charge carriers, the charge on one carrier and the mobility of the carriers. (***Remember equations boxed above***)
5. The current density is the product of the Electric field and conductivity of the material
6. Charge carriers behave differently in a solid compared to a vacuum. This can be accounted modifying the apparent mass of the charge carrier, using the concept of EFFECTIVE MASS.