UNIT II SEMICONDUCTING MATERIALS
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2.7. Carrier transport velocity –Electric field relation
Random motion and mobility

In the absence of electric field the free electron move in all random direction. They collide with each other or with positive ion. Hence the net velocity is zero.

When an electric field is applied electron gain drift velocity V_d.
Drift velocity is directly proportional to electric field (E)

$$V_d \propto E \quad \Rightarrow \quad V_d = \mu E$$

μ - proportionality constant called mobility of charge carrier

$$\mu = V_d/E$$

Mobility is defined as the drift velocity per unit electric field. Mobility of electron is greater than that of hole. Drift current density Jn due to electron is the charge flowing per unit area per unit time.

$$Jn = ne\, V_d$$

Electrical conductivity due to electron , σ_n= Jn/E

$$\sigma_n = (ne\, V_d) / E$$

$$\sigma_n = (ne\, \mu_n E) / E$$

$$\sigma_n = ne\, \mu_n$$

Conductivity due to holes $\sigma_p = pe\, \mu_p$

μ_n = mobility of electron, μ_p= mobility of holes

Total conductivity

$$\sigma = \sigma_n + \sigma_p$$

$$= ne\,\mu_n + pe\,\mu_p$$

$$= e\,(n\,\mu_n + p\,\mu_p)$$

For intrinsic semiconductor

$$n = p = n_i$$

$$\therefore \sigma_i = e\,(n_i\,\mu_n + n_i\,\mu_p)$$

$$\therefore \sigma_i = e\,n_i\,(\mu_n + \mu_p)$$

2.7.1. Drift and diffusion current

Drift current

Electric current produced by the motion of charge carrier on the application of electric field is called drift current.

When an electric field is applied, the charge carriers drifted towards the positive terminal of the battery, this is known as drift motion.

Drift current density due to the electron $Jn = n\,\mu_n eE$

$$Jp = p\,\mu_p eE$$

Total drift current density $J = Jn + Jp$

$$J = n\,\mu_n eE + p\,\mu_p eE$$

$$J = eE\,(n\,\mu_n + p\,\mu_p)$$

For intrinsic

$$Ji = eEn_i\,(\mu_n + \mu_p)$$

2.7.2. Diffusion current

The charge carriers move from the region of higher concentration to region of lower conscentration. This process is known as diffusion. The current produced by diffusion is known as diffusion current.

Consider a semiconductor with concentration gradient dn/dx

Charge carriers diffuse from higher concentration region to lower concentration region.

Rate of flow of electrons / unit area α dn/dx

$$= - D_n \, dn/dx$$

$-D_n$ – proportionality constant known diffusion coefficient,

Current density J= Rate of flow x charge of Electron

$$Jn = - D_n \, (dn/dx) \, (-e)$$

$$Jn = + D_n \, e \, (dn/dx)$$

Rate of flow of holes = $- D_p \, (dp/dx)$

Current density Jp= $-e \, D_p \, (dp/dx)$

2.7.3. Einstein's relation

Definition:

The relation between the mobility and diffusion coefficient of a semi conductor is known as Einsteins relation

We know that the drift current due to electrons = Jn = n μ_nEe

Diffusion current density = Jn= $eD_n \, (dn/dx))$

At equilibrium

Drift current = diffusion

$$n \, Ee = eD_n \, (dn/dx)) / \mu_n$$

Force on the charge carriers due to the internal field

$$F = eD_n \, (dn/dx)) / \mu_n \text{ --------------(1)}$$

From kinetic theory of gases

$$F = kT \; dn/dx \text{ --------------(2)}$$

K- Boltzmann constant

T absolute temperature

From (1) & (2)

$$kT\, dn/dx = eD_n\, (dn/dx)) / \mu_n$$

$$kT = eD_n / \mu_n$$

$$KT/e = D_n / \mu_n$$

For holes

$$kT / e = D_p / \mu_p$$

there fore

$$D_n / \mu_n = D_p / \mu_p$$

$$D_n / D_p = \mu_n / \mu_p$$

This is known as Einstein's relation

Unit II

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2.6 HALL EFFECT:

STATEMENT

When a magnetic field (B) is applied perpendicular to a current carrying conductor or semiconductor a potential difference (electric field) is developed inside the conductor in a direction perpendicular to both current and magnetic field. This phenomenon is known as Hall Effect and the voltage thus generated is called Hall voltage

THEORY

2.6.1. Hall effect in n- type semiconductor

Let us consider a n-type semiconductor material in the form of rectangular slab. In such a material current flows in X –direction and magnetic field B applied in Z- direction. As a result, Hall voltage is developed along Y –direction as shown in figure

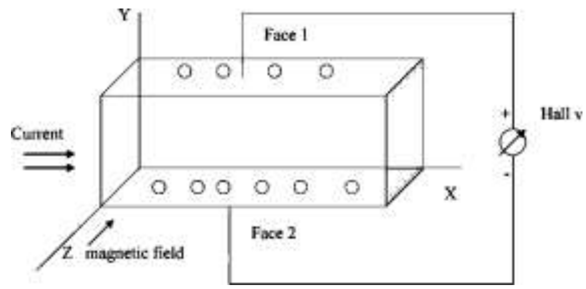

Fig 2,6.1-Hall Effect in N type semiconductor

Since the direction of current is from left to right the electrons moves fromright to left . When a magnetic field is applied the electrons are moving towards the bottom of the semi conductor.

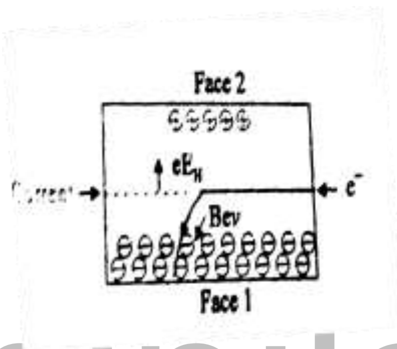

Fig 2,6.2-Hall Effect

Lorentz force= -e E_H ---(1)

Magnetic deflecting force = - Bev ---(2)

At equilibrium

$$-e E_H = -Bev$$

$$E_H = Bv \quad ---(3)$$

We know the current density J_x in the X- direction is

$$J_x = -ne\, v$$

$$v = - J_x / ne \quad \text{---(4)}$$

Substituting equation (4) in equation (3)

we get $E_H = - B J_x / ne$ --------------- (5)

$E_H = R_H . J_x . B$ ---------------- (6)

Where R_H is known as the Hall co –efficient, is given by $R_H = - (1/ne)$ (7)

The negative sign indicates that the field is developed in the negative Y –direction.

2.6.2 Hall effect in p –type semiconductor

Let us consider a p –type semiconducting material for which the current is passedalong X – direction from left to right and magnetic field is applied along Z – direction as shown in fig. since the direction of current is from left to right, the holes will also move in the same direction as shown in fig.

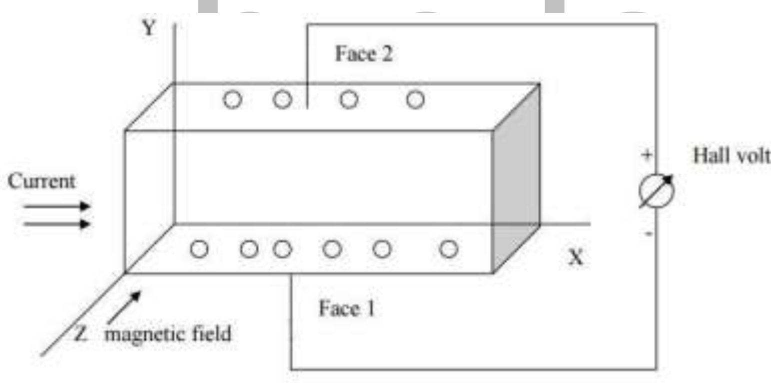

Fig 2,6.3-Hall Effect in P type semiconductor

Now due to magnetic field applied the holes moves towards downward directionwith velocity v and accumulates at the face (1). A potential difference is established between face (1) and (2) in the positive Y - direction.

Here, the force due to potential difference = $-e E_H$ (8)

Force due magnetic field = Bev----- (9)

At equilibrium equation (1) = equation (2)e E_H = Bev

$$E_H = Bv \text{ -------------- } (10)$$

We know the current density Jx in the X- direction is

$$J_x = nh\ ev$$

$$v = J_x / n_h\ e \text{ ------------- } (11)$$

Substituting equation (4) in equation (3) we get

$$E_H = B\ J_x / n_h\ e$$

$$E_H = R_H \cdot J_x \cdot B$$

Where R_H is known as the Hall co –efficient, is given by $R_H = (1 / n_h\ e)$ The positive sign indicates that the field is developed in the positive Y –direction

2.6.3. Hall coefficient in terms of hall voltage

If the thickness of the sample is t and the voltage developed is VH, then Hall voltage

$$V_H = E_H \cdot t$$

Substituting equation (6)in equation (13), we have

$$V_H = R_H\ Jx\ B\ .t$$

b is the width of the sample then

$$\text{Current density} = Jx = Ix / bt$$

There fore

$$V_H = R_H\ B\ .t\ Ix / bt$$

$$V_H = R_H\ B\ Ix / b$$

$$R_H = V_H\ b / I_x B$$

This is the expression for Hall coefficient.

2.6.4. EXPERIMENTAL DETERMINATION OF HALL EFFECT

A semiconducting material is taken in the form of a rectangular slab of thickness t and breadth b. A suitable current I_x ampere is passed through this sample alongX- axis by connecting it to a battery

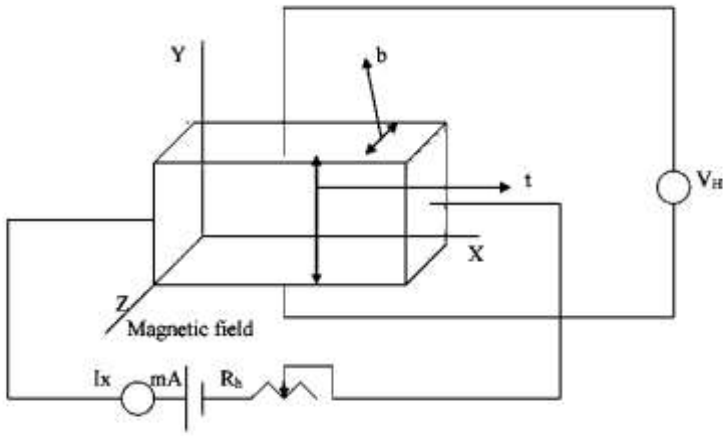

Fig 2,6.4-Experiment for Hall Effect

Now a semiconductor is placed in a magnetic field . A voltage is developed in the specimen which can be measured by using the voltmeter connecting with the specimen.

Then by using the formula

$$\text{Hall coefficient, } R_H = \frac{V_H\, b}{I_x\, B}$$

Hall coefficient can be calculated.

2.6.5. APPLICATIONS OF HALL EFFECT

- It is used to determine whether the material is p-type or n-type semiconductor. (ie) if RH is negative then the material n-type. If the RH is positive then the materialp-type.
- It is used to find the carrier concentration
- It is used to find the mobility of charge carriers μe, μh. It is used to find the sign of the current carrying charges.
- From the hall coefficient, carrier concentration and mobility can bedetermined.

UNIT II

SEMICONDUCTING MATERIALS

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2.1 Introduction

Definition:

Materials which are partially conductors and partially insulators are called semi conducting materials.

Based on energy band diagram

A semiconductor has nearly empty conduction band and almost filled valance band with very small energy gap (≈ 1eV).

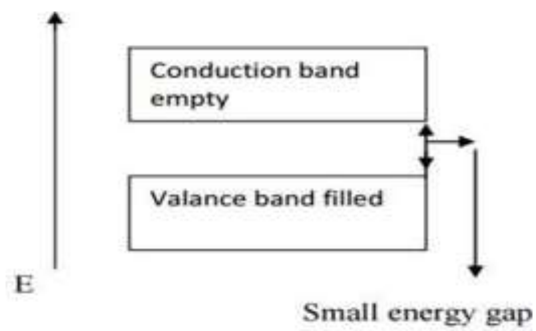

FIG 2.1-ENERGY GAP

General Properties of semiconductors:

1. They have empty conduction band and filled valence band at 0K
2. They are formed by covalent bonds.
3. They have small energy gap They possess crystalline structure
4. They have negative temperature co efficient of resistance

5. If the impurities are added to a semiconductor, its electrical conductivity increases. Similarly, if the temperature of the semiconductor increased, its electrical conductivity increases.

Elemental And Compound Semiconductors

Elemental Semiconductors (Indirect semiconductor)

Semiconductors which are made from a single element of fourth group elements of the periodic table. They are also known as indirect band gap semiconductors

Example –Germanium, silicon

Compound semiconductors(Direct semiconductor

Semiconductors which are formed by combining third and fifth group elements or second and sixth group elements in the periodic table are known as compound semiconductors. These compound semiconductors are also known as direct band gap semiconductors

Example –Gallium phosphide (GaP) , Gallium arsenide (GaAs)

2.2 TYPES OF SEMICONDUCTORS

Based on the purity semiconductors are classified in to the following two types.

1.Intrinsic semiconductors 2.Extrinsic semiconductors

INTRINSIC SEMICONDUCTORS

A semiconductor in pure form, is known as intrinsic semiconductors. Its electrical conductivity can bechanged due to thermal excitation.

EXTRINSIC SEMICONDUCTORS

A semiconductor in impure form, with the addition of impuritiesis known as extrinsic semiconductors.

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SEMICONDUCTING MATERIALS

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2.8. Schottky Diode

Definition

It is a junction formed between a metal and n-type semiconductor.

When the metal has a higher work function than that of n-type semiconductor then the junction formed is called schottky diode.

Figure shows schottky diode and its circuit symbol.

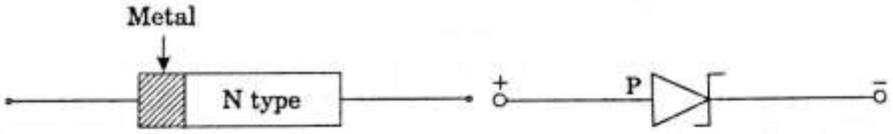


Fig2.8.1 schottky diode and its circuit symbol

The electrons in the conduction level of the semiconductor move to the empty energy states above the Fermi level of the metal.

This leaves a positive charge on the semiconductor side and a negative charge (due to the excess electrons) on the metal side as shown in figure. This leads to a contact potential.

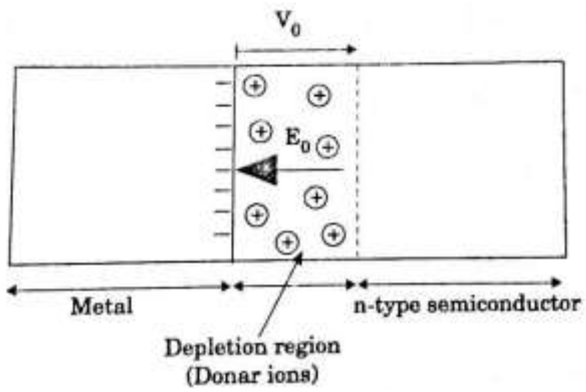


Fig 2.8.2Energy band diagram

When a Schottky junction is formed between metal and semiconductor, Fermi level lines up. Also a positive potential is formed on the semiconductor side. The formation of a depletion region of width W_D is shown below

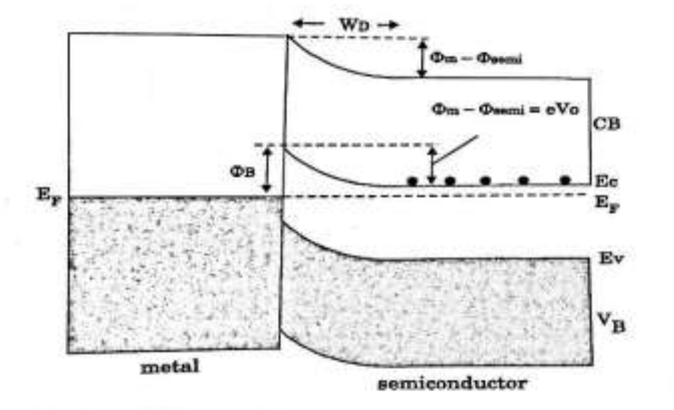


Fig 2.8.3 Formation of depletion layer

Working

The voltage is applied to the diode in two methods

(i) Forward bias

In this the metal is connected to positive terminal and n type semi conductor is connected to negative terminal of the battery.

The electrons injected from the external circuit into the n type semi-conductor.This leads to a current in the circuit.

(ii)Reverse bias:

A metal is connected to negative terminal and n type semiconductor is connected to the positive terminal of the battery.This increses the width of the depletion region and henc thee is npo flow of electron from semi conductor to metal.Now it acts as a rectifier.

V-I Characteristics

The V-I characteristics of the junction is shown in figure. There is an exponential increase in current in the forward bias while there is a very small current in reverse bias.

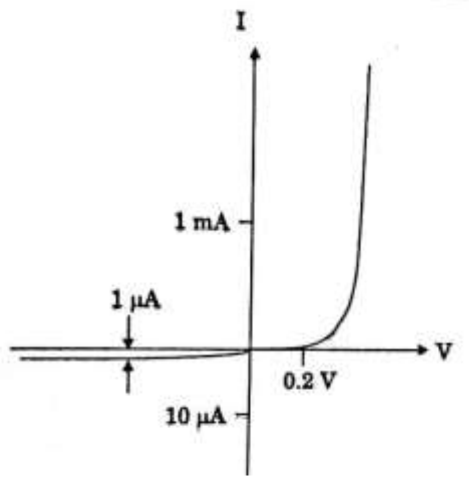


Fig 2.8.4-V-I Characteristics

Advantages of schottky diode

1. It has a very low cut-in voltage of about 0.3 V.
2. Schottky diode has very low switching time.
3. Schottky diode has very low power consumption.
4. it has a very rapid response to a change in bias.
5. The Schottky diode is closer to the ideal diode.
6. Schottky diode has negligible storage time.

The disadvantages of Schottky diode,

- Schottky diode is more expensive.

Application of Schottky diode

1. Schottky diode is used as a fast switching device in digital computers.
2. It can be used in clamping and clipping circuit.
3. The Schottky diode is used in AC to DC (ADC) converters.
4. It is used in mixer and detectors.
5. The Schottky diode is used in RADAR system.
6. It is used in switch mode power supply.
7. Schottky diodes are used as general-purpose rectifier.
8. It is used to detect signals.
9. It is used in logic circuit.

2.9. OHMIC CONTACT

Definition

An ohmic contact is a type of metal semiconductor junction. It is formed by a contact of a metal with a heavily doped semiconductor.

When the semiconductor has a higher work function than that of metal, then the junction formed is called the ohmic junction.

Here, the current is conducted equally in both directions and there is a very little voltage drop across the junction.

Before contact, Fermi levels of the metal and semiconductor are at different positions as shown in figure.

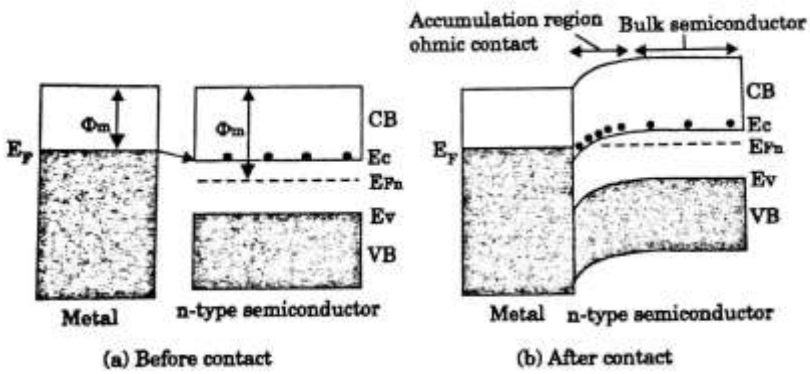


Fig 2.9.1 Ohmic contact before and after contact

Working

After contact, the ohmic junction is shown in figure(b). At equilibrium, the electrons move from the metal to the empty states in the conduction band of semiconductor. Thus, there is an accumulation region near the interface (on the side of conductor).

It results in line up of Fermi levels of metal and semiconductor as shown in figure (b).

The accumulation region has a higher conductivity than the bulk semiconductor due to this higher concentration of electrons.

Thus, a ohmic contact behaves as a resistor conducting in both forward and reverse bias. The resistivity is determined by the bulk resistivity of the semiconductor.

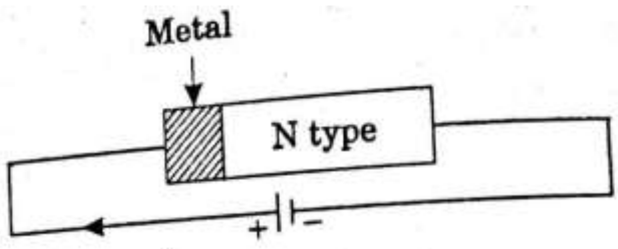
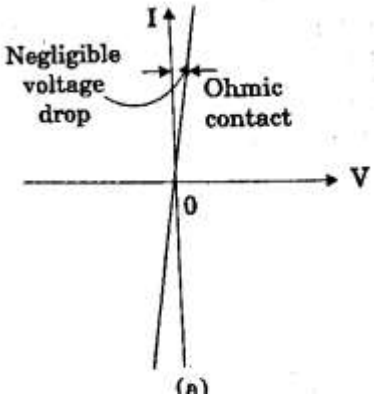


Fig 2.9.1.Symbol of ohmic contact

V-I Characteristics

The volt ampere (V-I) characteristic of the ohmic contact is shown in figure,

Fig 2.9.3;.V-I Characteristics



The current is directly proportional to the potential across the junction and it is symmetric about the region, as shown in figure.

Thus, ohmic contacts are non-rectifying and show negligible voltage drop and resistance irrespective of the direction and magnitude of current.