2. Semiconducting Materials

Part – A

1. Define drift current

The electric current produced due to the motion of charge carriers under the influence of an external electric field is known as drift current

2. Define diffusion current

The non-uniform distribution of charge carriers creates the regions of uneven concentrations in the semiconductor. The charge carriers moving from the region of higher concentration to the regions of lower concentration leading to diffusion current.

3. Differentiate Schottky diode and ohmic contacts?

S.No	Schottky diode	Ohmic contact
1.	It acts as a rectifier	It acts as a resistor
2.	Resistance is low during forward bias an very high during reverse bias	Resistance remains same in both the biasing voltage
3.	Work function $\varphi_m > \varphi_{semi}$	Work function $\varphi_m < \varphi_{semi}$
4.	Formed by the combination of metal and *n* – type semiconductor	Formed by the combination of metal and heavily doped semiconductor

4. Differentiate Schottky diode and *p* –*n* diode

S.No	Schottky diode	***p* –*n* diode**
1.	Forward current due to thermionic current	Forward current due to diffusion current
2.	Charge carriers are only due to thermal agitation	Charge carriers are due to impurities and thermal agitation
3.	Reverse current is due to majority charge carrier that overcome the barrier	Reverse current due to minority carriers diffusing to the depletion layer and rifting to the other side
4.	Cut in voltage is ~ 0.3 V	Cut in voltage is ~ 0.7 V
5.	High switching speed	Switching speed is limited

5. What is meant by ohmic contact?

It is a type of metal semiconductor junction formed by a contact of a metal with heavily doped semiconductor. When the semiconductor has a higher work function than that of metal, then the junction formed is called the Ohmic junction

6. What is Schottky diode?

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.

7. Mention any three hall devices?

Gauss meter, Electronic watt meter an electronic multiplier

8. What are the advantages of Schottky diode?

(i) It has very low capacitance
(ii) It will immediately switch from ON to OFF state
(iii) Small voltage is enough to produce high current
(iv) It has high efficiency
(v) It operates at high frequencies
(vi) It produces less noise

9. What are the uses of ohmic contact?

It is used to connect one semiconductor device to another, an IC, or to connect an IC to its external terminals.

10. What are the applications of Schottky diode?

(1)It is used for rectification of signals of frequencies even exceeding 300 MHz
(2)It is used in switching device at frequencies of 20 GHz
(3)It is used in radio frequency applications
(4)It is widely used in power supplies

Part – B

1. Derive an expression to find the total current density due to drift and difussion of electrons and holes in semiconductor?

The net current flow in semiconuctor is due to drift and diffusion transport.

Drift transport

In the absence of electric field, the random motion of charge carriers will not contribute current because the charge movement in one direction is balance by the charge movement in the other direction. When the external field is applied, the electrons are attracte to the positive terminal and the holes are attracte to the negative terminal. This net movement is termed as drift transport. This transport overcomes the thermal movement and produces current density

Therefore, current density due to electron drift is $J_e = n_e\, e\, v_d$ (1)

Since $v_d = \mu_e E$ (2)

Substitute (2) in (1), we get

$J_e = n_e\, e\, \mu_e E$ (3)

Similarly, for holes, $J_h = n_h\, e\, \mu_h E$ (4)

Then the total drift current is $j_{dr} = n_e\, e\, \mu_e E + n_h\, e\, \mu_h E$ (5)

We know that $J = \sigma E$ (6)

Therefore $\sigma_{dr} = n_e\, e\, \mu_e + n_h\, e\, \mu_h$ (7)

For an intrinsic semiconductor $n_e = n_h = n_i$

& Hence $\sigma_{dr} = n_i\, e[\, \mu_e + \mu_h\,]$ (8)

Diffusion transport

The non-uniform distribution of charge carriers creates the regions of uneven concentrations in the semiconductor. The charge carriers moving from the region of higher concentration to the regions of lower concentration leading to diffusion current

Hence the concentration of charge carrier (Δn_e) varies with distance x in a semiconductor.

The rate of flow of charge carriers is $\infty \frac{\partial}{\partial x}(\Delta n_e)$

Rate of flow of electrons = $-D_e \frac{\partial}{\partial x}(\Delta n_e)$

Where D_e is the electron diffusion coefficient

Current density due to electrons = charge X rate of flow of electrons

i.e., $J_e = D_e e \frac{\partial}{\partial x}(\Delta n_e)$

Similarly for holes, $J_h = -D_h e \frac{\partial}{\partial x}(\Delta n_h)$

Thus, if an electric field is applied to the semiconductor, the total current contribution is due to both drift and diffusion transport.

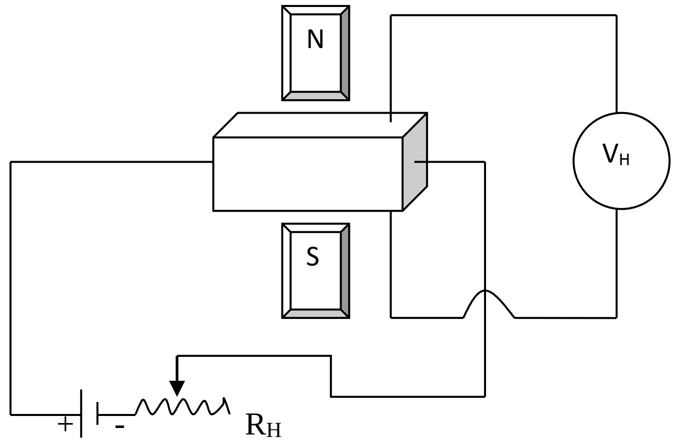
Net current due to both electrons and holes can be obtained as

$$J_{total} = n_e \mu_e e E + e D_e \frac{\partial}{\partial x}(\Delta n_e) + n_h e \mu_h E - D_h e \frac{\partial}{\partial x}(\Delta n_h)$$

2. Explain any three hall devices?

(a) **Gauss meter**

The hall voltage, we have $V_H = \frac{R_H B_Z I_X}{b}$. In this, $V_H \infty B_z$ for a given hall element; R_H an b are constant. The current I through Hall element is also kept constant. This principle is used in Gauss meter. It is used for measuring magnetic field. The variation of Hall voltage with magnetic field is shown in figure. The voltmeter which is used to measure V_H can be directly calibrated in terms of Gauss. The graph can be also used to measure any unknown magnetic fields.



(b) Electronic Multipliers

From Hall effect, we have $V_H = \frac{R_H B_Z I_1}{b}$. Since R_H an b are constant for an element

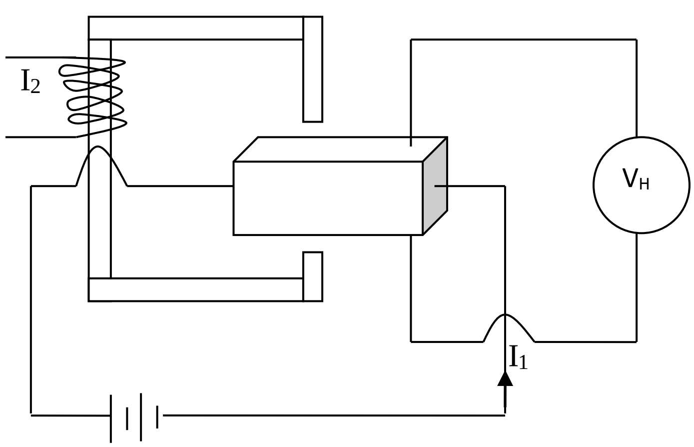
$V_H \infty B_z I_1$

But the magnetic field B_Z is proportional to current (I_2) through the coil.

i.e., $V_H \infty I_2$

$\therefore V_H \infty I_1 I_2$

V_H is a measure of the product of two currents. This is the basic principle used in analog electronic multipliers. The figure shows the circuit diagram for electronic multiplier.



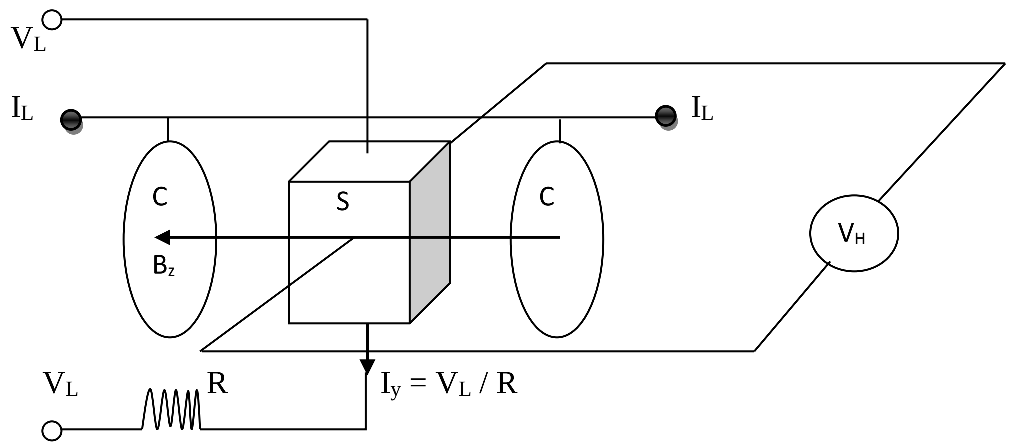
(c) Electronic Wattmeter

Hall effect is used to measure electrical power dissipate in a load. The instrument used to measure the power in a circuit using Hall effect principle is known as Hall effect – Wattmeter.

S is Hall element sample. It is place in a magnetic field B_z produce by the load current I_L passing through the coils *CC* as shown in figure. The voltage cross the load V_L drives the current $I_y = V_L / R$ through the sample. *R* is a series resistance which is >> than the resistance of the sample and that of the load. Also, $I_y << I_L$. If *b* is the breadth of the sample, then the measured Hall voltage $V_H = \frac{R_H B_Z I_y}{b}$. Since V_H and *b* are constant, $V_H \propto B_z I_y$

Since $B_z \propto I_L$ and $I_y \propto V_L$ & hence $V_H \propto I_L V_L$

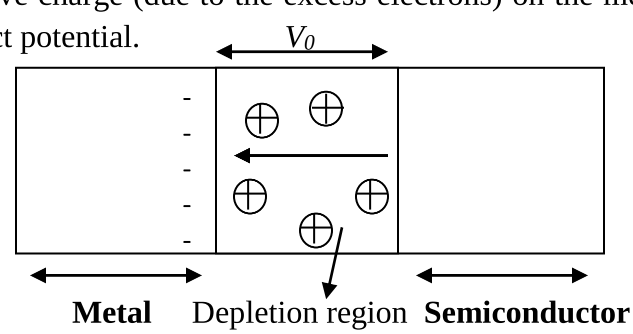
This is the electric power dissipated by the load. The voltmeter that measures V_H can be calibrate to read power directly.



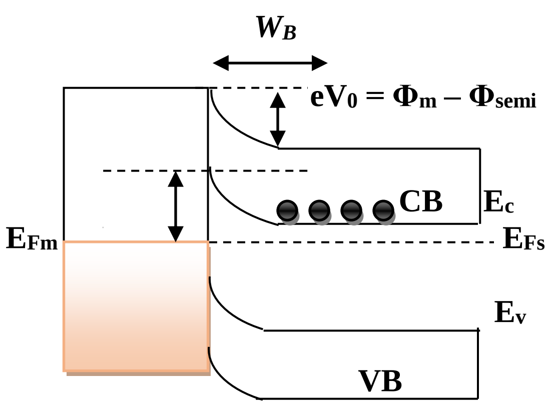
3. **Describe the construction and working of Schottky diode? What are its advantages?**

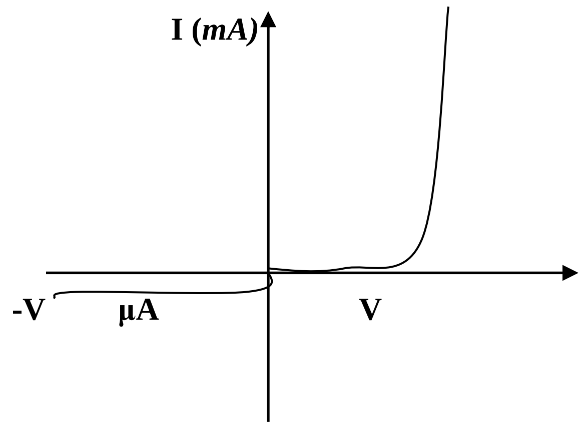
It is the junction formed between a metal and n – type semiconductor. When the metal has a higher work function than that of n – type semiconductor then the junction forme is called Schottky diode. The fermi level of the semiconductor is higher (since its work function is lower) than the metal. Figure shows 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 sie as shown in figure. This leads to a contact potential.



Energy 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 within the semiconductor is shown in figure. Because the depletion region extends within a certain depth in the semiconductor, there is bending of the energy bands on the semiconductor side. *Band* bend up in the direction of the electric field produced in depletion region. There is a built in potential V_o in the Schottky junction. From the figure this is given by the difference in work functions $eV_0 = \varphi_m - \varphi_{semi}$

Working

The behaviour of Schottky diode is further studied by forward and reverse bias.

(a)Forward Bias

In this bias, metal is connected to positive terminal and n – type semiconductor is connected to negative terminal of the battery. In the forward biased Schottky junction, the external potential opposes the in- built potential. The electrons injected from the external circuit into the *n – type* semiconductor have a lower barrier to overcome before reaching the metal. This leads to a current in the circuit which increases with increasing external potential.

(b) Reverse Bias

In reverse bias, metal is connected to negative terminal and *n – type* semiconductor to positive terminal of the battery. In the case of reverse bias, the external potential is applied in the same direction as the junction potential. This increases the width of depletion region further and hence there is no flow of electron from semiconductor to metal. So Schottky junction acts as rectifier. i.e., it conducts in forward bias but not in reverse bias.

***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.

Advantages

It has very low capacitance
It will immediately switch from ON to OFF state (fast recovery time)

Applying a small voltage is enough to produce large current
It has high efficiency
It operates at high frequencies
It produces less noise.

4.Write a note on ohmic contact?

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.

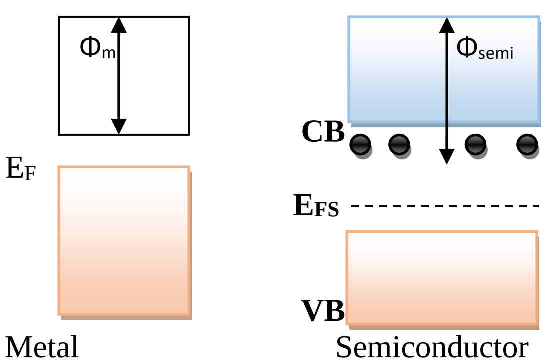
Here, the current is conducted equally in both directions and there is a very little voltage drop across the junction. Before contact, fermi levels of the metal and semiconductor are at different positions as shown in figure.

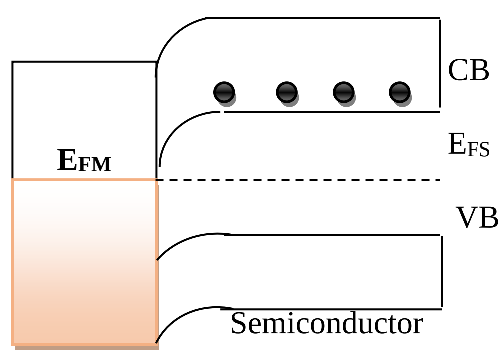
Working

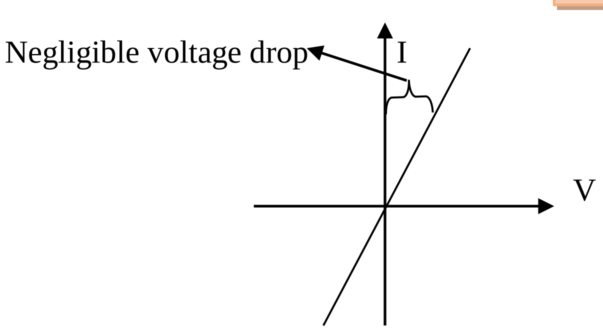
After contact, the ohmic junction is shown in figure. At equilibrium, the electrons move from the metal to the empty states in the conduction band of semiconductor. Thus, there is an accumulation region near the interface (on the semiconductor side). The accumulation region has higher conductivity than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

_V_ – _I_ Characteristics

The *V-I* characteristics of the ohmic contact is shown in figure. The current is directly proportional to the potential across the junction and it is symmetric about the origin, 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.







Applications

The use of ohmic contacts is to connect one semiconductor device to another, an IC, or to connect an IC to its external terminals.