4.4 SCHOTTKY DIODE

Schottky diode can switch on and off much faster than the p-n junction diode. Also, the schottky diode produces less unwanted noise than p-n junction diode. These two characteristics of the schottky diode make it very useful in high-speed switching power circuits.

When sufficient voltage is applied to the schottky diode, current starts flowing in the forward direction. Because of this current flow, a small voltage loss occurs across the terminals of the schottky diode. This voltage loss is known as voltage drop.

A silicon diode has a voltage drop of 0.6 to 0.7 volts, while a schottky diode has a voltage drop of 0.2 to 0.3 volts. Voltage loss or voltage drop is the amount of voltage wasted to turn on a diode.

In silicon diode, 0.6 to 0.7 volts is wasted to turn on the diode, whereas in schottky diode, 0.2 to 0.3 volts is wasted to turn on the diode. Therefore, the schottky diode consumes less voltage to turn on.

The voltage needed to turn on the schottky diode is same as that of a germanium diode. But germanium diodes are rarely used because the switching speed of germanium diodes is very low as compared to the schottky diodes.

Symbol of Schottky Diode

The symbol of schottky diode is shown in the below figure. In schottky diode, the metal acts as the anode and n-type semiconductor acts as the cathode.

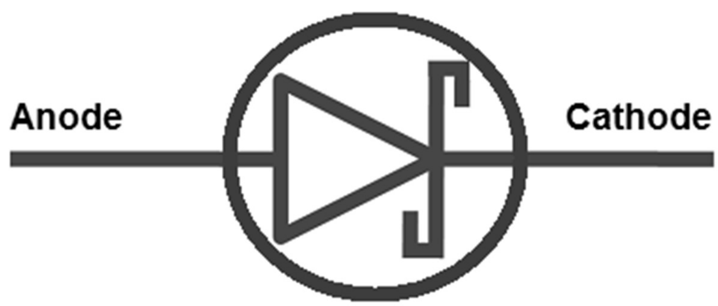

Fig:4.4.1 Symbol of Schottky Diode

Metal-semiconductor (M-S) junction

Metal-semiconductor (M-S) junction is a type of junction formed between a metal and an n-type semiconductor when the metal is joined with the n-type semiconductor. Metal-semiconductor junction is also sometimes referred to as M-S junction.

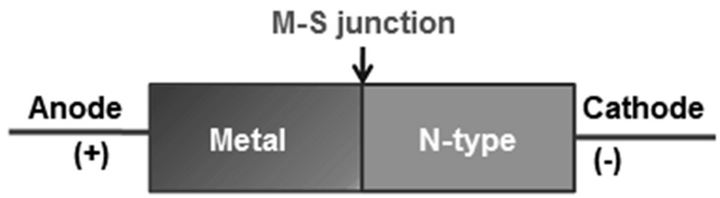

Fig:4.4.2 Metal-Semiconductor (M-S) Junction

The metal-semiconductor junction can be either non-rectifying or rectifying. The non-rectifying metal-semiconductor junction is called ohmic contact. The rectifying metal-semiconductor junction is called non-ohmic contact.

schottky barrier

Schottky barrier is a depletion layer formed at the junction of a metal and n-type semiconductor. In simple words, schottky barrier is the potential energy barrier formed at the metal-semiconductor junction. The electrons have to overcome this potential energy barrier to flow across the diode.

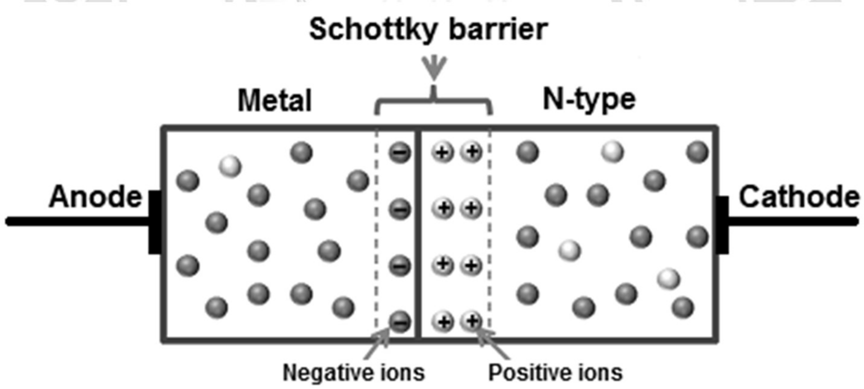

Fig:4.4.3 Construction of Schottky Diode

The rectifying metal-semiconductor junction forms a rectifying schottky barrier. This rectifying schottky barrier is used for making a device known as schottky diode. The non-rectifying metal-semiconductor junction forms a non-rectifying schottky barrier.

One of the most important characteristics of a schottky barrier is the schottky barrier height. The value of this barrier height depends on the combination of semiconductor and metal.

The schottky barrier height of ohmic contact (non-rectifying barrier) is very low whereas the schottky barrier height of non-ohmic contact (rectifying barrier) is high.

In non-rectifying schottky barrier, the barrier height is not high enough to form a depletion region. So depletion region is negligible or absent in the ohmic contact diode.

On the other hand, in rectifying schottky barrier, the barrier height is high enough to form a depletion region. So the depletion region is present in the non-ohmic contact diode.

The non-rectifying metal-semiconductor junction (ohmic contact) offers very low resistance to the electric current whereas the rectifying metal-semiconductor junction offers high resistance to the electric current as compared to the ohmic contact.

The rectifying schottky barrier is formed when a metal is in contact with the lightly doped semiconductor, whereas the non-rectifying barrier is formed when a metal is in contact with the heavily doped semiconductor.

The ohmic contact has a linear current-voltage (I-V) curve whereas the non-ohmic contact has a non-linear current-voltage (I-V) curve.

Energy band diagram of schottky diode

The energy band diagram of the N-type semiconductor and metal is shown in the below figure.

The vacuum level is defined as the energy level of electrons that are outside the material.

The work function is defined as the energy required to move an electron from Fermi level (EF) to vacuum level (E0).

The work function is different for metal and semiconductor. The work function of a metal is greater than the work function of a semiconductor. Therefore, the electrons in the n-type semiconductor have high potential energy than the electrons in the metal.

The energy levels of the metal and semiconductor are different. The Fermi level at N-type semiconductor side lies above the metal side.

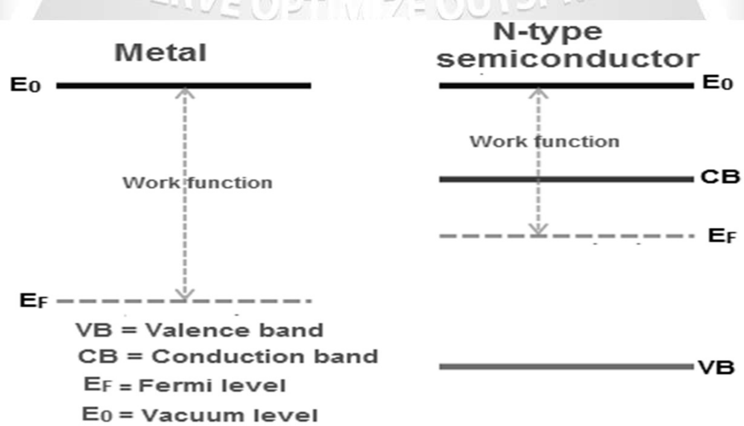

Fig:4.4.4 Energy Band Diagram of Schottky Diode

The electrons in the higher energy level have more potential energy than the electrons in the lower energy level. So the electrons in the N-type semiconductor have more potential energy than the electrons in the metal.

When the metal is joined with the n-type semiconductor, a device is created known as schottky diode. The built-in-voltage (Vbi) for schottky diode is given by the difference between the work functions of a metal and n-type semiconductor.

Working of schottky diode

When the metal is joined with the n-type semiconductor, the conduction band electrons (free electrons) in the n-type semiconductor will move from n-type semiconductor to metal to establish an equilibrium state.

When a neutral atom loses an electron it becomes a positive ion similarly when a neutral atom gains an extra electron it becomes a negative ion.

The conduction band electrons or free electrons that are crossing the junction will provide extra electrons to the atoms in the metal. As a result, the atoms at the metal junction gains extra electrons and the atoms at the n-side junction lose electrons.

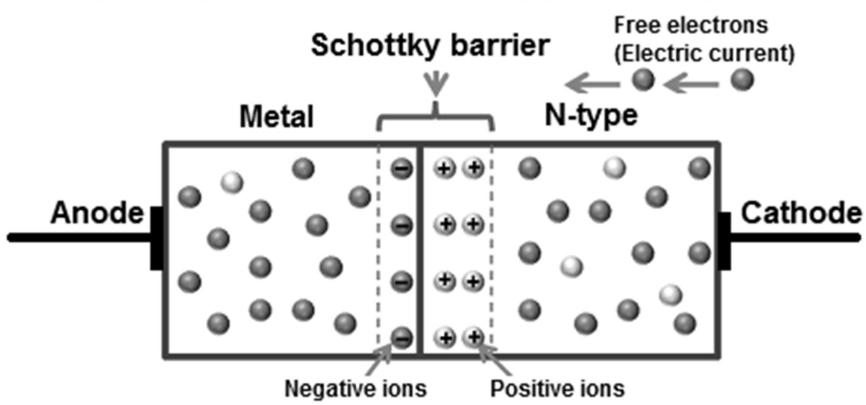

Fig:4.4.5 Unbiased Schottky Diode

The atoms that lose electrons at the n-side junction will become positive ions whereas the atoms that gain extra electrons at the metal junction will become negative ions. Thus, positive ions are created the n-side junction and negative ions are created at the metal junction. These positive and negative ions are nothing but the depletion region.

Since the metal has a sea of free electrons, the width over which these electrons move into the metal is negligibly thin as compared to the width inside the n-type semiconductor. So the built-in-potential or built-in-voltage is primarily present inside the n-type semiconductor. The built-in-voltage is the barrier seen by the conduction band electrons of the n-type semiconductor when trying to move into the metal.

To overcome this barrier, the free electrons need energy greater than the built-in-voltage. In unbiased schottky diode, only a small number of electrons will flow from n-type semiconductor to metal. The built-in-voltage prevents further electron flow from the semiconductor conduction band into the metal.

The transfer of free electrons from the n-type semiconductor into metal results in energy band bending near the contact.

Forward biased schottky diode

If the positive terminal of the battery is connected to the metal and the negative terminal of the battery is connected to the n-type semiconductor, the schottky diode is said to be forward biased.

When a forward bias voltage is applied to the schottky diode, a large number of free electrons are generated in the n-type semiconductor and metal. However, the free electrons in n-type semiconductor and metal cannot cross the junction unless the applied voltage is greater than 0.2 volts.

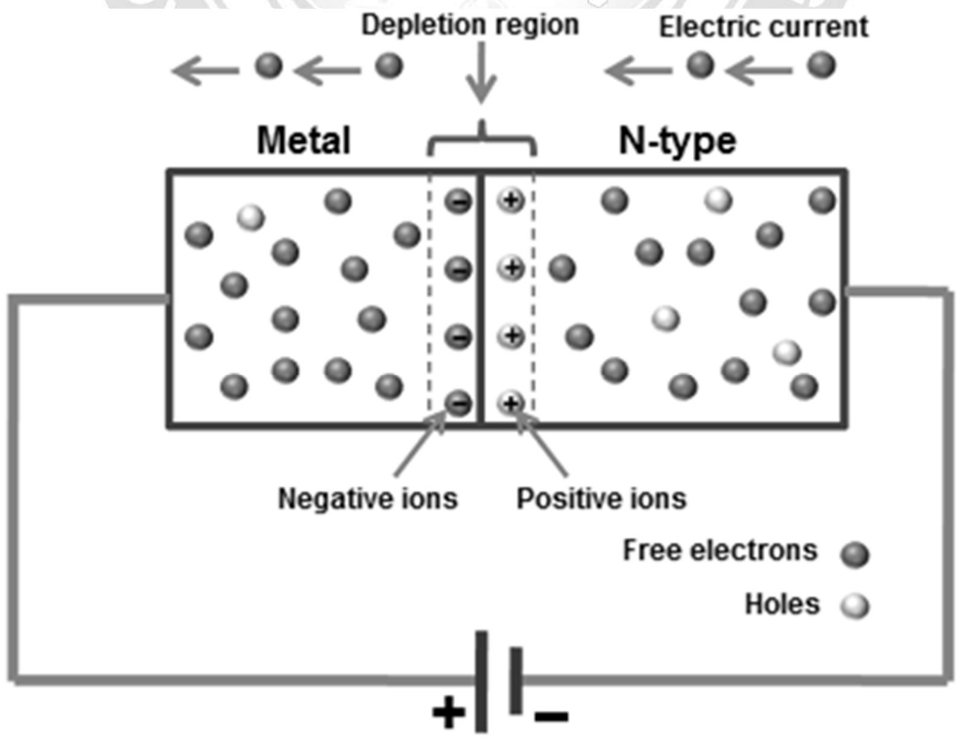

Fig:4.4.6 Forward Biased Schottky Diode

If the applied voltage is greater than 0.2 volts, the free electrons gain enough energy and overcomes the built-in-voltage of the depletion region. As a result, electric current starts flowing through the schottky diode.

If the applied voltage is continuously increased, the depletion region becomes very thin and finally disappears.

Reverse bias schottky diode

If the negative terminal of the battery is connected to the metal and the positive terminal of the battery is connected to the n-type semiconductor, the schottky diode is said to be reverse biased.

When a reverse bias voltage is applied to the schottky diode, the depletion width increases. As a result, the electric current stops flowing. However, a small leakage current flows due to the thermally excited electrons in the metal.

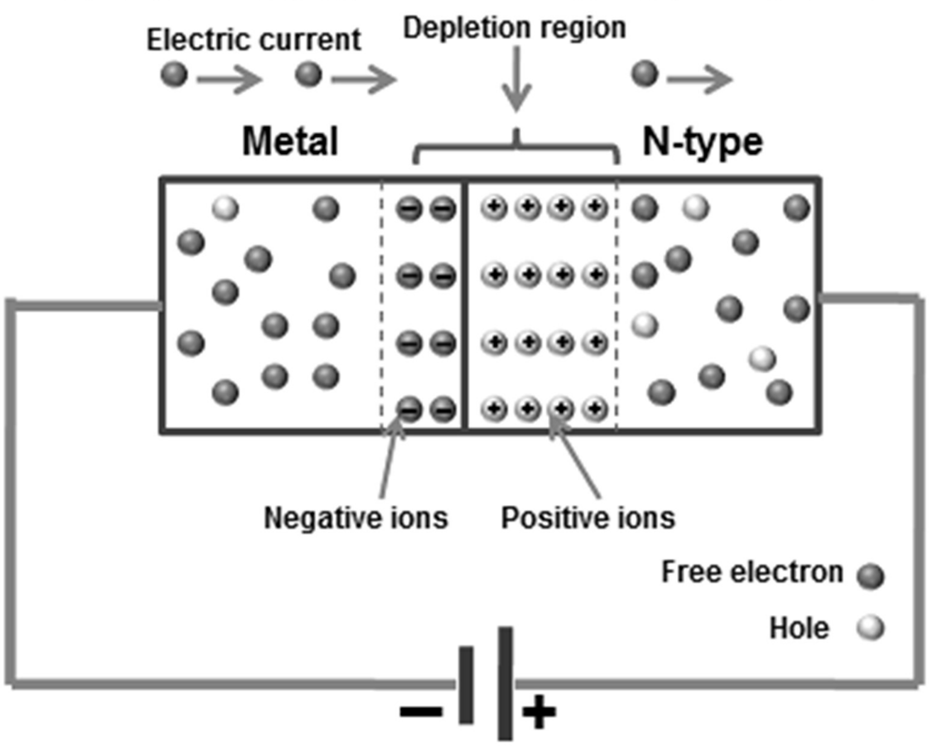

Fig:4.4.7 Reverse Biased Schottky Diode

If the reverse bias voltage is continuously increased, the electric current gradually increases due to the weak barrier.

If the reverse bias voltage is largely increased, a sudden rise in electric current takes place. This sudden rise in electric current causes depletion region to break down which may permanently damage the device.

V-I characteristics of schottky diode

The V-I (Voltage-Current) characteristics of schottky diode is shown in the below figure. The vertical line in the below figure represents the current flow in the schottky diode and the horizontal line represents the voltage applied across the schottky diode.

The V-I characteristics of schottky diode is almost similar to the P-N junction diode. However, the forward voltage drop of schottky diode is very low as compared to the P-N junction diode.

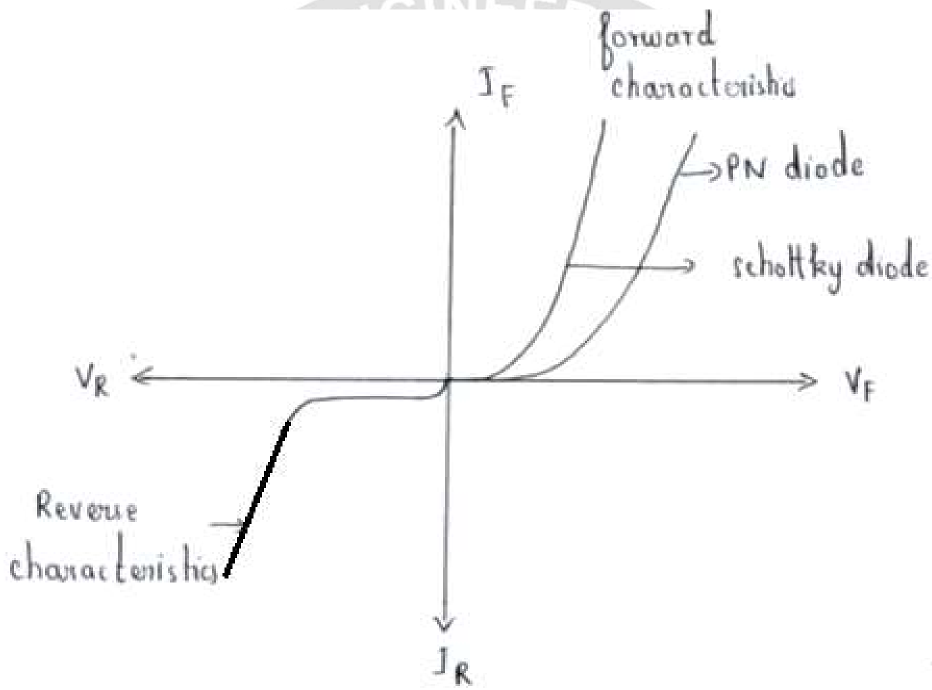

Fig:4.4.8 V-I Characteristics of Schottky Diode

The forward voltage drop of schottky diode is 0.2 to 0.3 volts whereas the forward voltage drop of silicon P-N junction diode is 0.6 to 0.7 volts.

If the forward bias voltage is greater than 0.2 or 0.3 volts, electric current starts flowing through the schottky diode.

In schottky diode, the reverse saturation current occurs at a very low voltage as compared to the silicon diode.

Difference between schottky diode and P-N junction diode

The main difference between schottky diode and p-n junction diode is as follows:

In schottky diode, the free electrons carry most of the electric current. Holes carry negligible electric current. So schottky diode is a unipolar device. In P-N junction diode, both free electrons and holes carry electric current. So P-N junction diode is a bipolar device.

The reverse breakdown voltage of a schottky diode is very small as compared to the p-n junction diode.

In schottky diode, the depletion region is absent or negligible, whereas in p-n junction diode the depletion region is present.

The turn-on voltage for a schottky diode is very low as compared to the p-n junction diode.

In schottky diode, electrons are the majority carriers in both metal and semiconductor. In P-N junction diode, electrons are the majority carriers in n-region and holes are the majority carriers in p-region.

Advantages of schottky diode

- Low junction capacitance

Capacitance is the ability to store an electric charge. In a P-N junction diode, the depletion region consists of stored charges. So there exists a capacitance. This capacitance is present at the junction of the diode. So it is known as junction capacitance.

In schottky diode, stored charges or depletion region is negligible. So a schottky diode has a very low capacitance.

- Fast reverse recovery time

The amount of time it takes for a diode to switch from ON state to OFF state is called reverse recovery time.

In order to switch from ON (conducting) state to OFF (non-conducting) state, the stored charges in the depletion region must be first discharged or removed before the diode switch to OFF (non-conducting) state.

The P-N junction diode do not immediately switch from ON state to OFF state because it takes some time to discharge or remove stored charges at the depletion region. However, in schottky diode, the depletion region is negligible. So the schottky diode will immediately switch from ON to OFF state.

- High current density

The depletion region is negligible in schottky diode. So applying is small voltage is enough to produce large current.

- Low forward voltage drop or low turn on voltage

The turn on voltage for schottky diode is very small as compared to the P-N junction diode. The turn on voltage for schottky diode is 0.2 to 0.3 volts whereas for P-N junction diode is 0.6 to 0.7 volts. So applying a small voltage is enough to produce electric current in the schottky diode.

- High efficiency
- Schottky diodes operate at high frequencies.
- Schottky diode produces less unwanted noise than P-N junction diode.

Application of Schottky diode

- Rectifier
- Voltage clamping
- TTL in digital devices
- Fast switching
- Digital computers.