Energy Band in Solid.

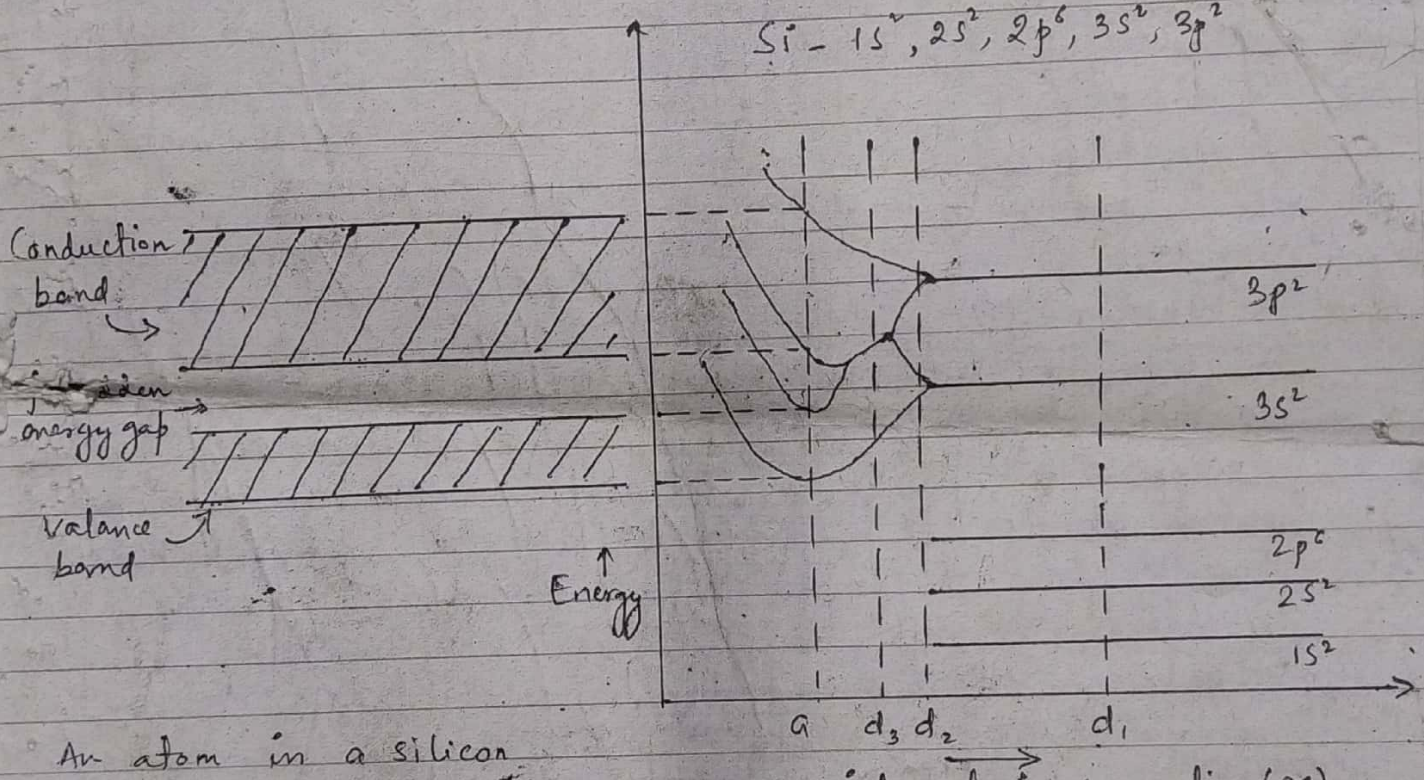

fig:

An atom in a silicon has electronic configuration $1s^2, 2s^2, 2p^6, 3s^2, 3p^2$. The various energy level of silicon atom is represented in fig above.

Now interatomic seperation between silicon atom is gradually reduced.

(i) When $r = d_1$:

At this stage there is no interaction between atoms and hence no change in energy level of atoms.

(ii) When $r = d_2$:

At this stage the interaction between the electrons of different atoms begins. Due to this energy level (3s and 3p) of each atom gets slightly modified. Therefore instead of single 3s or 3p levels, there occurs a large number of close spaced energy levels. The spreading of 3s and 3p energy levels decreases the energy gap between s and p levels.

(iii) When $r = d_3$:

When the interatomic seperation is further reduced to d_3 the energy gap between 3s and 3p levels completely disappears giving rise to contineous energy level or energy band. At this stage it is impossible to distinguish between 3s and 3p electrons.

(iv) When $r = a$:

When silicon atoms are at actual interatomic seperation the energy level splits into two bands such that the lower band is completely filled with valance electrons and upper band is empty. These two bands are seperated by small energy gap.

The lower energy band filled with valance electrons is called valance band and the upper band of empty level is called conduction band. The energy gap between valance band and conduction band is called forbidden energy gap.

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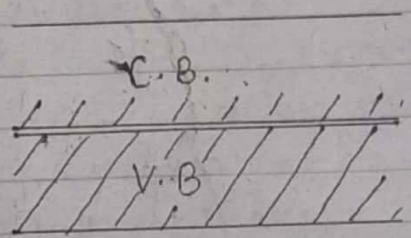
Conductor, Insulator and Semiconductor

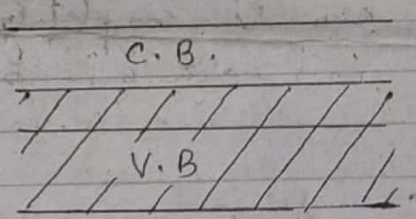
(i) Conductor :

In conductor :

(a) The valance band may be completely filled and conduction band partially filled with extremely small band gap.
For example, Na.

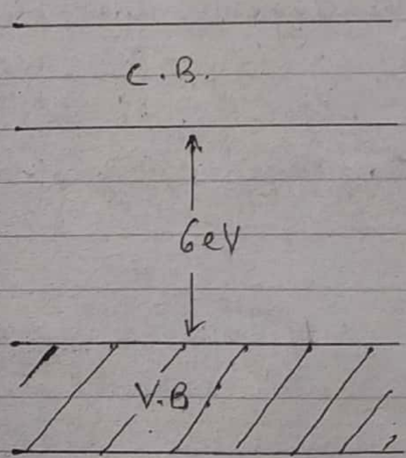


(b) The valandce band is completely filled and conduction band is completely empty but they overlap each other.

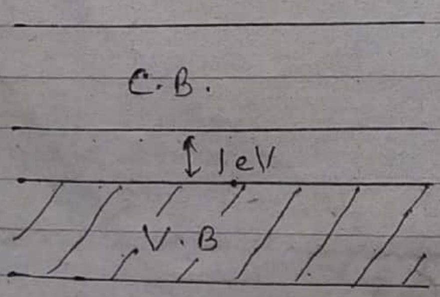


(ii) Insulator :

In insulator valance band is completely filled and conduction band is completely empty with large energy gap between them.



(iii) Semiconductor :



In semiconductor the valance band is completely filled and conduction band is completely empty with very small energy gap between them.

Semiconductor and Superconductivity

The term conductor is applied to any material that will support a generous flow of charge when a voltage source is applied across its terminals.
A insulator is a material that offers a very low level of conductivity under an applied voltage source.
A semiconductor, therefore, is a material that has a conductivity level somewhere between the extremes of an insulator and a conductor.

In pure semiconductor at 0k all electrons are present at their respective valance band and hence no free electrons are available for conduction. Therefore at 0K pure semiconductor have high resistance. As we increase the temperature some of the bond breaks and few free electrons become available for conduction and so the resistance decreases. Therefore with increase in temperature the resistance of the semiconductor decreases. Due to this reason a semiconductor are said to have a negative temperature coefficient.

Types of Semiconductor

- Intrinsic semiconductor (pure semiconductor)
- Extrinsic semiconductor (Impure semiconductor)

(i) Intrinsic Semiconductor :

The pure semiconductors are called intrinsic semi-conductors.

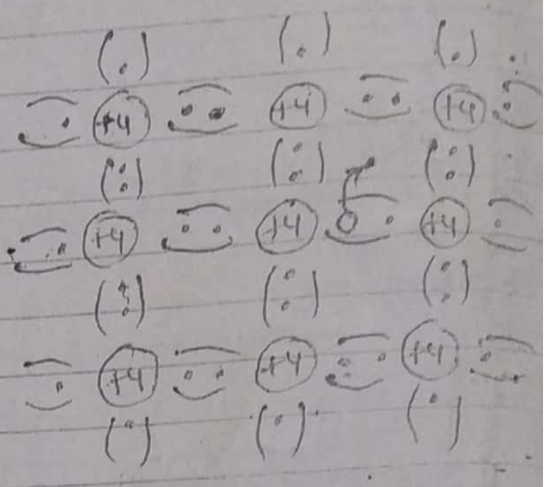


fig. 1

Figure 1 shows intrinsic semiconductor ~~of~~ ~~Ge~~. As the temperature increases, more thermal energy becomes available to the electrons and some of the electrons may breakaway (becoming free electrons contributing to the conduction). The thermal energy effectively ionizes only few atoms in the crystalline lattice and creates a vacancy in the bond as shown in fig. This vacancy with effective positive electronic charge is called hole.

In a pure intrinsic semiconductor, the number of free electrons is always equal to the number of holes. The free electrons and holes are called intrinsic charge carriers. In a pure semiconductor number of free electrons (n_e) is equal to number of holes (n_h).

i.e., $n_e = n_h$

(ii) Extrinsic Semiconductor

In intrinsic semiconductors the number of charge carriers (electrons and holes) are very small and hence low conductivity. In order to increase the conductivity

of intrinsic semiconductor a small amount of suitable impurity (atoms of other elements) is added to it. The deliberate addition of desirable impurity is called doping and the impurity atoms are called dopants. Depending on the type of dopants semiconductors are of two types:
(a) n-type semiconductor
(b) p-type semiconductor.

(a) n-type semiconductor :

The n-type semiconductor is formed or obtained when a pentavalent impurity is added to a pure semiconductor.

When a pentavalent element (such as As, Sb, P, etc) are added it sits substitutionally at the site of Si or Ge (a semiconductor atom). At this stage four electrons of pentavalent atom bond with the four silicon neighbours while the fifth electron is free to move. Thus a pentavalent dopant is donating one extra electron for conduction and hence is known as donor impurity.

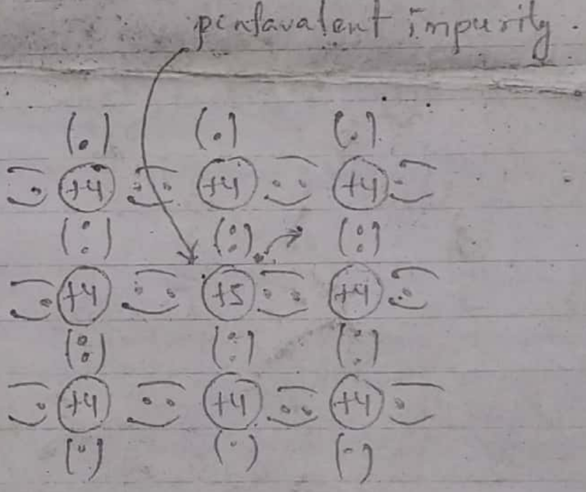


fig. 2

The total number of conduction electrons (n_e) is due to the combined contribution of the donor as well as the thermally generated free electrons while the holes (n_h) is only due to thermal process. Therefore the free electrons are majority charge carriers and holes are minority charge carriers. Therefore, in n-type semiconductor number of free electron (n_e) is more than number of holes (n_h)

i.e. $n_e >> n_h$

The total current in n-type semiconductor is

$$I = I_e + I_h$$

where, I_e - current due to majority charge carrier

I_h - current due to minority charge carrier

(b) p-type semiconductor:

The p-type semiconductor is obtained when a trivalent atom is added to pure semi-conductor.

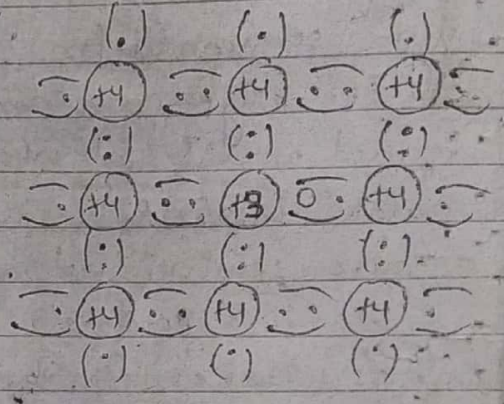


fig. 3.

When a trivalent element (such as In, B, Al, etc.) are added it sits substitutionally at the sites of Si or Ge atom (semiconductor atom). Here the dopant has one electron less than Si or Ge, and, therefore, this atom can form bond from three sides with Si or Ge atoms and fail to form bond on one side. In the incomplete bond some of the outer bond electron from the neighbourhood can slide in and leaving the vacancy at its own site. This vacancy is called hole. The atom with hole has strong tendency to capture an electron and hence it is called acceptor.

The total number of conduction holes (n_h) is due to the combined contribution of the acceptors as well as the

the thermally generated holes while the free electrons (n_e) is only due to thermal process. Therefore, holes are majority charge carriers and the free electrons are minority charge carriers. In this type of semiconductor, number of holes (n_h) is more than number of free electrons,

i.e. $n_h >> n_h$

The total current in p-type semiconductor is

$$I = I_h + I_e$$

where, I_h = current due to majority charge carriers
I_e = current due to minority charge carriers.

p-n junction

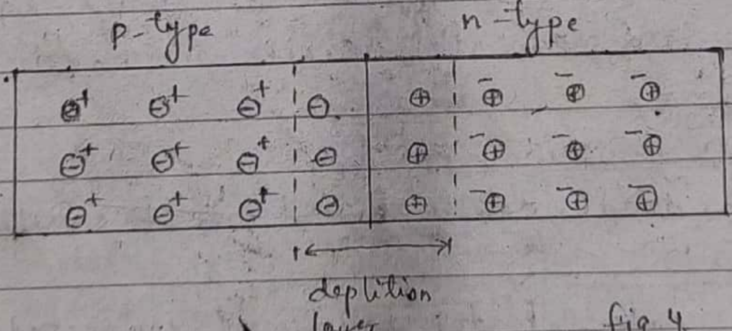


fig 4.

When a p-type semiconductor is placed in contact with n-type semiconductor in such a way that it remains continuous at the boundary. The plane at the boundary seprating p-type and n-type side is called p-n junction. Practically p-n junction is obtained by doping a pure semiconductor by pentavalent impurity (one side) and trivalent impurity (other side). A pn junction is also called p-n junction diode or simply junction diode.

At the junction due to concentration difference the charge carriers (free electron in n-type and holes in p-type) diffuse from region of higher concentration to the region of lower concentration. This means the holes from p-region diffuse into n-region and electrons from ~~p-region~~ n-region diffuse to p-region. In both the cases when electron meet a hole the two cancles the effect of each other. As a result, a thin layer at the junction becomes devoid charge carriers. This is called deplition layer.

Due to the diffusion of holes and electrons the p-section of the junction becomes slightly negative and n-section becomes slightly positive. The potential difference thus developed due to the diffusion of charge carriers at the junction is called potential barrier or barrier potential.

Biasing of p-n junction

A junction diode can be biased in two different ways

(i) Forward Bias:

When an external d.c. source is connected to the p-n junction diode with p-type connected to positive pole and n-type connected to negative pole, the junction diode is said to be forward biased.

In this mode of biasing the positive terminal of the battery repels the free holes from p-side to n-side and the negative terminal repels the free electron from n-side to p-side. Due to this the size of deplition layer decreases. When the applied potential is greater than the barrier potential,

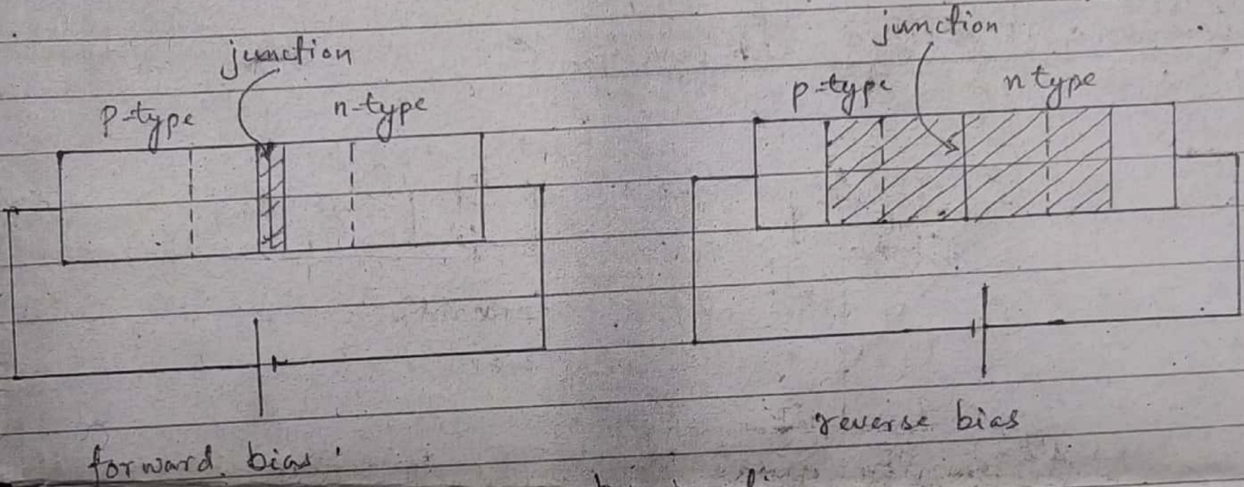


fig 5. Biasing of p-n junction

the hole and free electron will combine with each other. This result in flow of current in the circuit.

(ii) Reverse Bias;

When a battery is connected to the diode with p-type connected to the negative terminal and n-type to the positive terminal, the junction is said to be reverse biased.

In this case, the free electron in n-type and hole in p-type are attracted toward the battery terminals. This results in widening of deplition layer. Therefore, in this case very small current flows due to minority charge carriers, called leakage current.

Thus when p-n junction is forward biased a large current flows through it and when it is reverse biased almost no current flow through it.

Characteristics of a pn junction

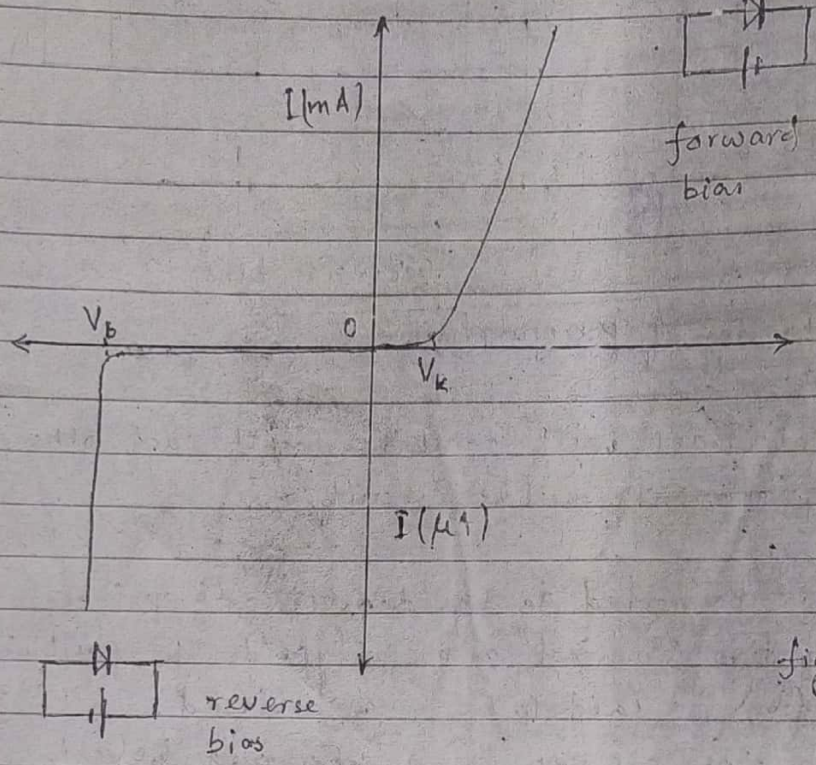


fig 6.

(i) Knee Voltage(V_k): It is defined as forward biasing voltage above which current starts rising almost linearly.

(ii) Leakage Current: In reverse bias condition small current flows through diode which is due to minority charge carriers. This current is called leakage current.

(iii) Breakdown voltage: It is defined as reverse bias voltage at which the current through diode rises suddenly.

or storage capacitance.

Reverse Recovery Time

In a p-n junction diode under forward bias condition
there are a large number of electrons from n-type
material progressing through the p-type material and
a large number of holes in the n-type which is requirement
for conduction. The electrons in p-type and and the holes
progressing through the n-type material establish a
large number of minority charge carriers in each material.
if the applied voltage should be reversed to establish
the reverse bias situation, we would ideally like to
see the diode change instantaneously from conduction
state to the nonconduction state. However, because of
large number of minority carriers in each material, the
diode current will simply reverse and ~~staly~~ stay at
this measurable level for a period of time t_s (storage
time). After this time the current will reduce in level
to that associated with non conduction state. This second
period of time is transition interval t_t. The reverse
recovery time is the sum of these two interval
i.e $t_{rr} = t_s + t_t$

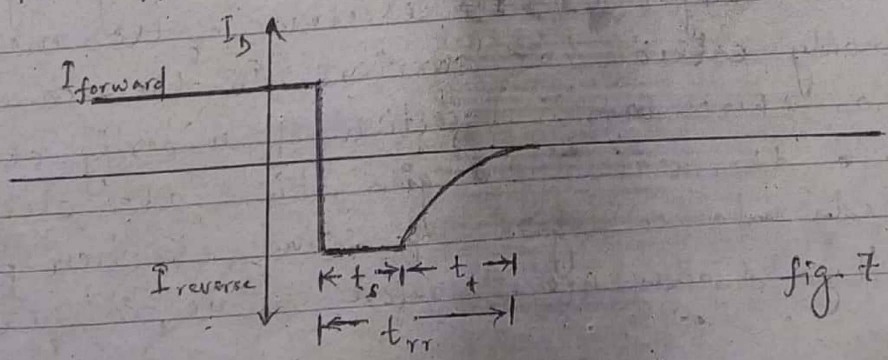


fig. 7

Metal Semiconductor Junction

A metal semiconductor junction is formed between metal and semiconductor. Depending on the type of metal and level of doping in semiconductor there are two different type of contacts. They are:

(I) Schottky barrier

(II) Ohmic contact.

(I) Schottky barrier:

A schottky barrier, named after Walter H. Schottky, is a potential barrier formed at a metal semiconductor junction which has rectifying characteristics, suitable for use as diode. The semiconductor is normally n-type silicon (although p-type silicon is sometimes used), while a host of different metals, such as molybdenum, platinum, chrome, tungsten, etc, are used.

In both materials, the electron is the majority carriers. When the materials are joined the electrons in the n-type silicon semiconductor material immediately flow into the adjoining metal, establishing the heavy flow of majority carriers. Since the injected carriers have very high kinetic energy level compared to the electrons of the metal, they are commonly called hot "carriers". In the conventional p-n junction there ~~was~~ is injection of minority charge carriers into the adjoining region. Here the electrons are injected into a region of same electron plurality. The schottky diodes are therefore unique, in that conduction is entirely by majority carriers. The heavy flow of electrons into the metal creates a region near the junction surface depleted of charge carriers in the silicon material, much like the depletion region in the p-n junction diode. The additional carriers in the metal establish a "negative wall" in the metal at the boundary between two materials. The net result is a "surface barriers" between the two materials, preventing any further current. That is, any electron (negatively charged) in the silicon material face a carrier free region and a "negative wall" at the surface of the metal.

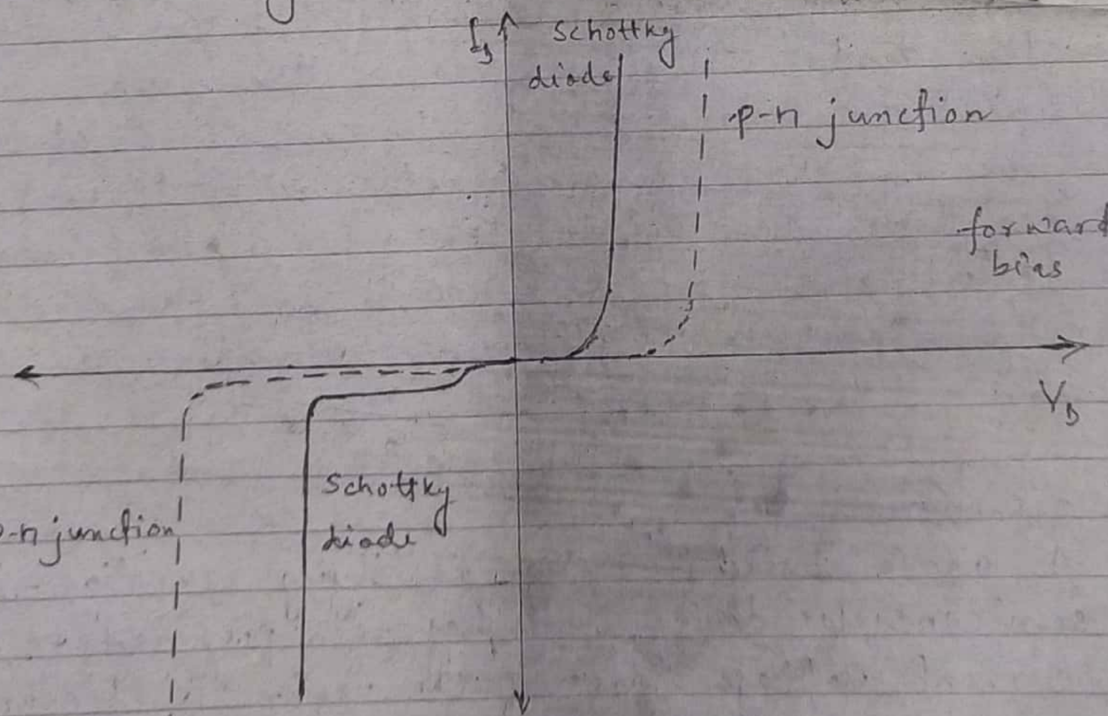


fig. 8.

The application of forward bias as shown in fig 8 will reduce the strength of negative barrier through the attraction of applied positive potential for electrons from this region. The result is a return to a heavy flow of electrons accross the boundary, the magnitude of which is controlled by the level of the applied bias potential. The barrier at the junction for a schottky diode is less than ~~that~~ that of a p-n junction diode in both forward and reverse bias regions. The result is, therefore, a higher current at the same applied bias in the forward and reverse regions. This is desirable effect in forward bias region but highly undesirable in reverse bias region.

The most important difference between the p-n and schottky diode is reverse recovery time, when diode switches from non-conducting to conducting state or vice versa. Where in p-n junction diode the reverse recovery time can be in the order of hundreds of nanosecond and less than 100 ns for faster diode, schottky diode do not have recovery time as there is nothing to recover from.

(4) Ohmic Contact:

An ohmic contact is a non rectifying junction - a region in semiconductor device that has been prepared so that the current voltage curve of the region is linear and symmetric. If the I-V curve is non-linear and asymmetric then contact is not ohmic but schottky barrier. Usually ohmic contact is a metal semiconductor junction between a metal lead and semiconductor material,

Superconductivity:

Superconductivity is phenomenon of exactly zero electrical resistance and expulsion of magnetic field occuring in certain materials when cooled below characteristics critical temperature. Superconductivity is quantum mechanical phenomenon. It is characterized by Meissner effect, the completely ejection of magnetic field lines from interior of superconductor as it transitions into superconducting state.

By their response to the magnetic field super conductors are divided into:

(i) Type I super conductor:

Type I superconductor have a single critical field above which superconductivity is lost.

(ii) Type II superconductor:

Type II superconductor have two critical fields, between the two critical fields they allow partial penentration of magnetic fields.

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