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Sem - IV (H)
Paper - C10T

Topic - Semiconductor diodes

Semiconductor := A Semiconductor is a solid whose electrical conductivity lies between the very high conductivity of metals and very low conductivity of insulators.

The most commonly known Semiconductors are Germanium (Ge) and Silicon (Si).

Semiconductors are two types (i) Intrinsic Semiconductors
(ii) extrinsic Semiconductors.

Intrinsic Semiconductors :-

(i) Pure germanium and Silicon, in their natural form are called intrinsic Semiconductors.

(ii) There is no impurity doped in intrinsic Semiconductor

(iii) The electrical conductivity increases very slowly with temperature.

(iv) the conductivity is Zero at absolute Zero.

Extrinsic Semiconductors :=

(i) When a small amount of impurity ($10^6:1$) is introduced in a pure Semiconductor, then it is called extrinsic Semiconductor.

Remember that —— extrinsic semiconductors are of two types

i) p-type semiconductor.

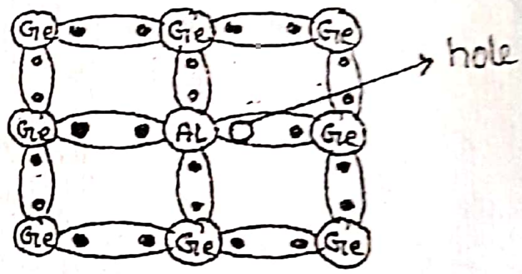
ii) n-type semiconductor,

Question —— What is p-type and n-type semiconductors? Give examples.

1 p-type semiconductors ——

- If a small amount of trivalent impurity is doped with the pure germanium (or silicon) crystal, then the conductivity increases appreciably, then it is called p-type semiconductor as the majority charge carriers are holes.
- Example —— Trivalent ~~alu~~ aluminium (Al) is doped with pure germanium.

- Explaination ——



Doped Al has three valence electrons which make three covalent bonds with with 3 adjacent Ge but there is a deficiency of electron to make 4th covalent bond with the 4th Ge thus create a "hole" Here electrons and holes are mobile charge carriers.

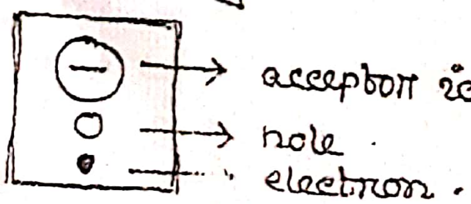
- Majority mobile charge carriers are ⇒ "holes"

Minority mobile charge carriers are ⇒ "electrons"

Thus called p-type semiconductors.

The impurity is called an "acceptor" because the impurity atoms accept electrons from the crystal.

Immobile charge carriers are ⇒ "acceptor impurity"

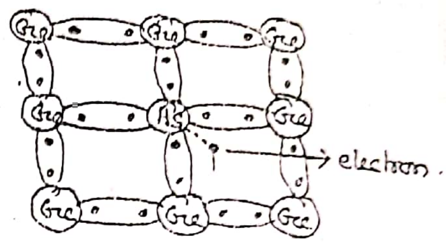


n-type semiconductors —

If a small amount of pentavalent impurity is doped with the pure germanium (or silicon) crystal, the conductivity increases appreciably, then it is called n-type semiconductor as the majority charge carriers are electrons which carries negative charge.

Example — Pentavalent arsenic (As) is doped with pure germanium.

Explaination —

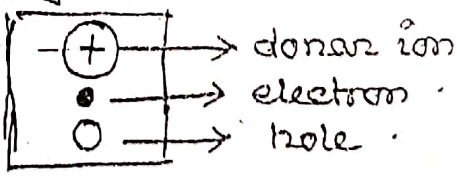


Doped As has five valence electrons which make four co-valent bonds with four neighbouring Ge. and the 5th extra electron is free. Here electrons and holes are mobile charge carriers.

— Majority mobile charge carriers are ⇒ "electrons"
— Minority mobile charge carriers are ⇒ "holes"

The impurity is called "donar ion" because the impurity atoms donate electrons to the crystal.

Immobile charge carriers are ⇒ "donar ion"



Difference —

P-type	n-type
1. Trivalent impurity is doped.	1. Pentavalent impurity is doped.
2. Majority charge carriers – hole.	2. Majority —— electron
3. Minority —— electron	3. Minority —— hole
4. Impurity is called – acceptor ion	4. Impurity —— donar ion.

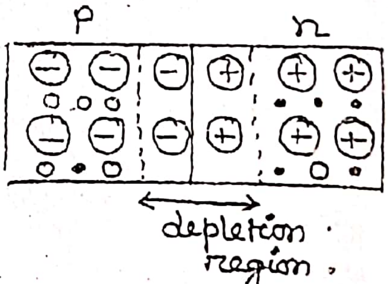
Q. What is p-n junction diode ?

Ⓐ p—n junction diode —— When a p-type semiconductor is joined with a n-type semiconductor so that they form one continuous crystal structure, then it is called p-n junction diode.

Q. How a potential barrier develops at the junction ?

As soon as the junction is formed, there is an — immediate diffusion of the charge carriers across the junction due to thermal agitation. Some of the electrons in the n-region diffuse into the p-region while some of the holes in the p- region diffuse into the n-region and combine.

Thus near the junction in the two sides there is formed "depletion region" as the region is depleted of mobile charge. But there are immobile charge carriers ie acceptor ~~at~~ atoms in the p-side and donar atoms in the n-side set up a potential difference across the junction. This potn. difference is called "potential barrier"



Q. Can a voltmeter read the barrier potn. of a p-n jn. diode

Answer ——

V.U - 1997, 2001

As there is no ~~a~~ mobile charge carriers in the depletion region, it only contains ~~ino~~ immobile charge carriers ie acceptor atoms (p-region) and donar atoms (n-region), the potn. difference can not be measure by a voltmeter. When the voltmeter is connected at the two sides of the jn. in the depletion region no charge carrier will flow through the external circuit.

Different types of p-n junction diodes are —

i) Ordinary p-n junction diode.
ii) Breakdown diode (Zener diode)
iii) Light-emitting diode (LED)
iv) Varactor diode.
v) P-n junction laser.
vi) Photo diode.
vii) Solar cell.
viii) Tunnel diode.
ix) Backward diode.
x) Switching diode.
xi) Schottky diode.

Biasing of a p-n junction diode —

Connection of a battery (d.c. source) with the p-n junction diode is called biasing of a p-n jn diode.

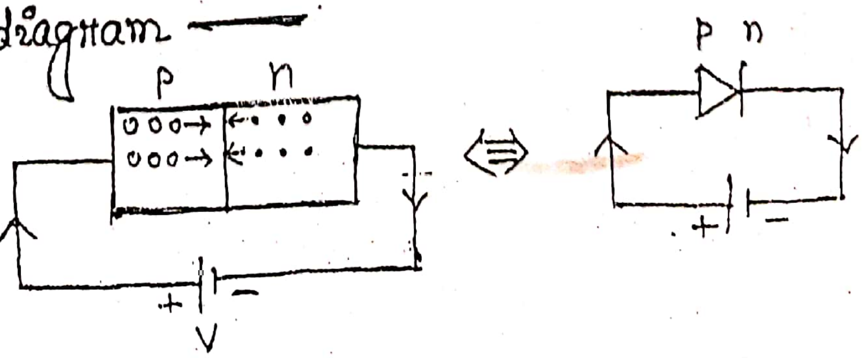
There are two types of biasing —
i) Forward biasing.
ii) Reverse biasing.

Explain what happens when a dc bias voltage is applied between p and n portion of a junction. V.U - 1995

1. Forward biased p-n junction —

When the positive pole of a battery is connected to the p-side and the negative pole to the n-side of the junction, then it is known as forward biased p-n junction diode.

Circuit diagram —



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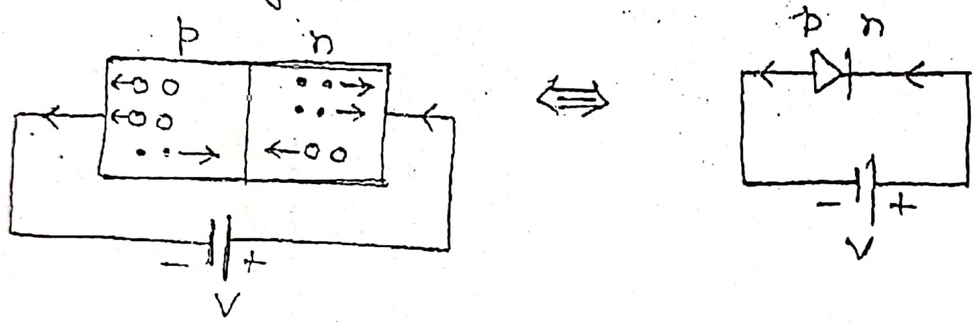
The majority carriers (holes) in the p-region ~~attrac~~ repealed by the "+ve" terminal of the battery and majority carriers (electrons) in the n-region repealed by the "−ve" terminal of the battery, crosses the junction and recombine with the opposite charge carriers., hence we get a current from p-to n region through the junction.

Due to increase in forward voltage, the forward current increases.

2. Reversed-biased p-n junction — (V.U-1996 also)

When the negative pole of the battery is connected with the p-region and positive pole with the n-region ~~than~~ of the junction, then it is called reverse-biased p-n junction.

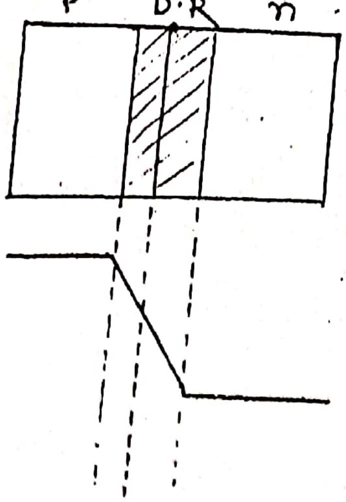
Circuit diagram —



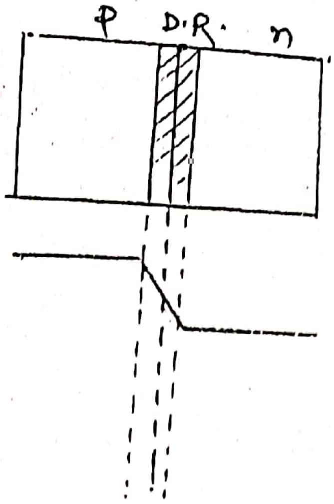
The majority carriers (holes) in the p-region and majority carriers (electrons) in the n-region attracted by the battery get away from the junction, thus we get no current due to majority carriers.

— But we get a small amount of current (in μA range) due to flow of minority carriers. ~~Thus the curr~~ This current is not affected by the reverse voltage. This current is thus called reverse bias saturation current (I_{co})

(3) Variation of potn. barrier —

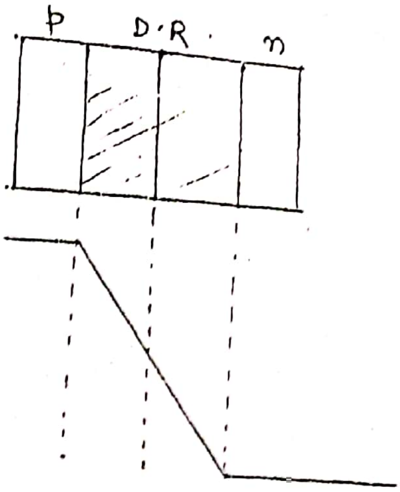


Potn. barrier without bias.



Potn. barrier Forward bias.

[Width of depletion region is decreased]



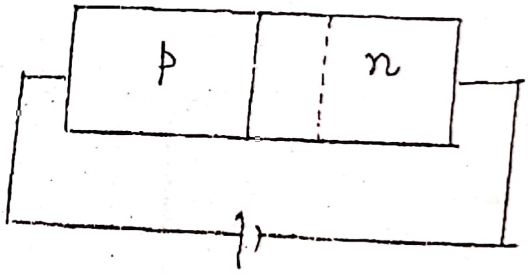
Potn. barrier. Reverse bias:

[Width of depletion region is increased]

Current voltage relationship of a p-n junction diode.

Shockley equation : ⟹

V.U - 1996 (2 marks)
V.U - 2005, 2007 (4 marks)



Let p_{no} is the concentration of holes in n-region. With the application of a forward bias V the height of the potn. barrier (V_b) across the junction is reduced to $V_b - V$.

According to Boltzman statistics, the concentration of holes at the space charge boundary ($x=0$) in the n-region,

$$p_n(0) = p_{no}\, e^{\frac{eV}{\eta KT}} \quad \text{——— (1)}$$

The excess concentration of holes $[p_n(0) - p_{no}]$ diffuse through the n-region according to the law,

$$p_n'(x) = [p_n(0) - p_{no}]\, e^{-x/L_p} \quad \text{——— (2)}$$

Where L_p is the diffuse constant for holes.

∴ The hole concentration at any distance x is,

$$p_n(x) = p_{no} + p_n'(x)$$

$$= p_{no} + p_{no}\left(e^{\frac{eV}{\eta KT}} - 1\right) \cdot e^{-x/L_p} \quad \text{——— (3)}$$

Therefore, the hole current density at the junction (x=0) is,

$$J_{pn}(0) = -eD_p \cdot \frac{d}{dx} \cdot p_n(x)\Big|_{x=0}$$

$$= \frac{eD_p\, p_{no}}{L_p} \cdot \left(e^{\frac{eV}{\eta KT}} - 1\right) \quad \text{——— (4)}$$

Similarly, the electron current density at the junction

$$J_{np}(0) = \frac{eD_n\, n_{po}}{L_n}\left(e^{\frac{eV}{\eta KT}} - 1\right) \quad \text{——— (5)}$$

Therefore, total forward current density

$$J = J_{pn}(0) + J_{np}(0)$$

$$\Rightarrow J = \left(\frac{eD_p\, p_{no}}{L_p} + \frac{eD_n\, n_{po}}{L_n}\right)\left(e^{\frac{eV}{\eta KT}} - 1\right).$$

$$\Rightarrow J = J_0\left(e^{\frac{eV}{\eta KT}} - 1\right) \quad \text{——— (6)}$$

If A be the area of the junction, then total forward current,

$$I = J_0 A\left(e^{\frac{eV}{\eta KT}} - 1\right).$$

$$\Rightarrow \boxed{I = I_0\left(e^{\frac{eV}{\eta KT}} - 1\right)} \quad \text{——— (7)}$$

This is known as Shockley equation.

Where I_0 ⇒ reverse bias saturation current.
e ⇒ electronic charge.
K ⇒ Boltzman constant.
T ⇒ absolute temp$^{\underline{r}}$ of the junction.
η ⇒ semiconductor constant (1 for Ge, 2 for Si).

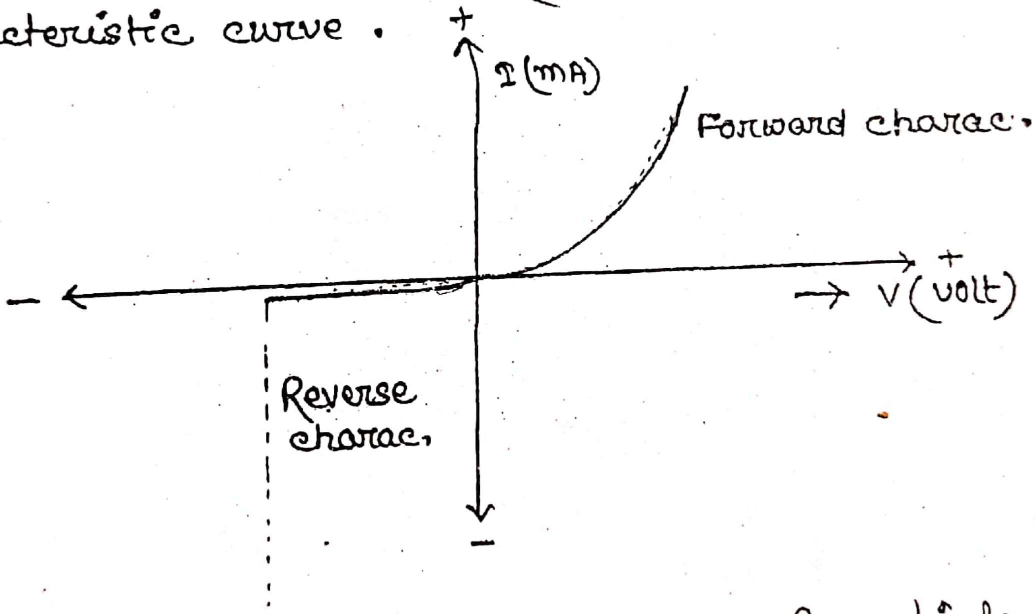
* At room temperature (T = 300 K), substituting above values,

$$I = I_0 \left(e^{\frac{39V}{\eta}} - 1 \right)$$

* If V is positive, the p-n junction is forward biased.
* If V is negative, the p-n junction is reverse biased.

Draw the nature of static volt-ampere characteristics curve and resistance characteristics curve of a semi-conductor diode. V.U - 1995

The plot of the current (I) versus the voltage (V) of a semiconductor diode is known as static volt-ampere characteristic curve.



* The static or d.c. resistance ($r_{d.c}$) of a diode is defined as the ratio of voltage to the current i.e

$$r_{d.c} = \frac{V}{I}$$

Since the diode is a non-linear device, its d.c or static resistance varies with current.

Dynamic resistance is defined as $r = \frac{\Delta V}{\Delta I}$.

As $I = I_0 \left(e^{\frac{eV}{\eta KT}} - 1 \right)$.

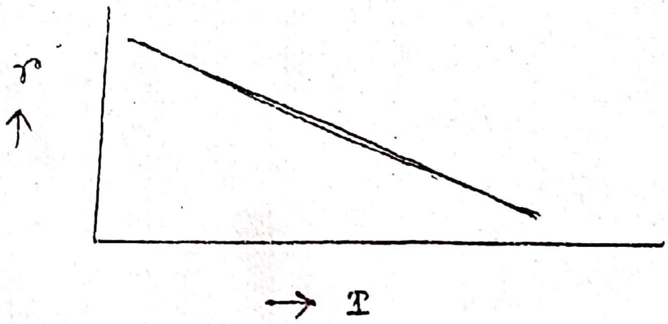
$$\Rightarrow \frac{dI}{dV} = \frac{e}{\eta KT} I_0 e^{\frac{eV}{\eta KT}}.$$

$$= \frac{e}{\eta KT} (I + I_0).$$

$$\therefore r = \frac{dV}{dI} = \frac{\eta KT}{e} \cdot \frac{1}{I + I_0}.$$

For forward biased condition $I \gg I_0$, hence

$$r = \frac{\eta KT}{e} \cdot \frac{1}{I}.$$



① Define reverse saturation current of a p-n junction diode? Is it temperature dependent? V.U – 2008

When the p-n junction diode is reverse biased then the width of depletion region is increased and majority charge carrier can't cross the junction but we get a very small current (μA) due to flow of minority charge carrier, opposite to the direction of forward current. This is known as reverse saturation current.

It is independent of reverse voltage.

* Reverse saturation current (I_0) increases with increase in temperature.