

## UNIT :-03

## FIELD EFFECT TRANSISTOR

## INTRODUCTION:-

Field effect transistor is a three terminal unipolar semiconductor device. Whereas BJT is 3 terminal Bipolar semiconductor device.

Bipolar device:- Bipolar device means In this device the current is produced due to both majority and minority charge carriers.

Unipolar device:- Unipolar device means in this device the current is produced due to only majority charge carriers.

FET's are two types. They are

- \* Junction Field effect transistor (JFET)
  - \* Metal oxide semiconductor field effect transistor (MOSFET)
- JFET's are classified into two types. They are,

\* N - channel JFET

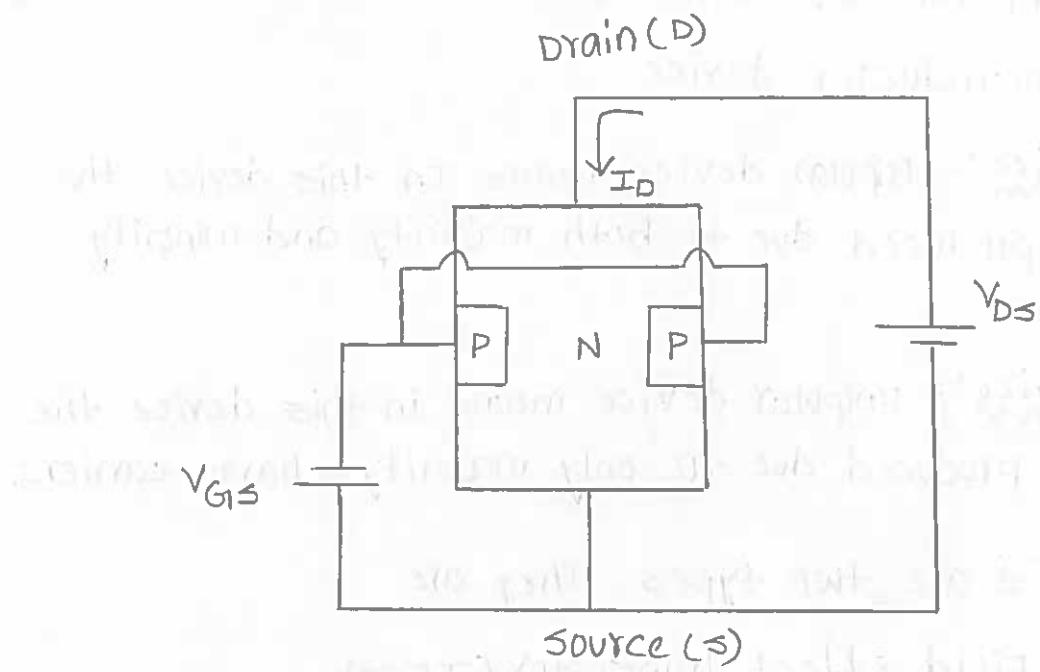
\* P - channel JFET

CONSTRUCTION AND WORKING OF N-CHANNEL JFET:-

JFET is a Three terminal semiconductor device in which current conduction is due to only majority charge carriers.

In N-channel JFET the current is produced due to electrons.

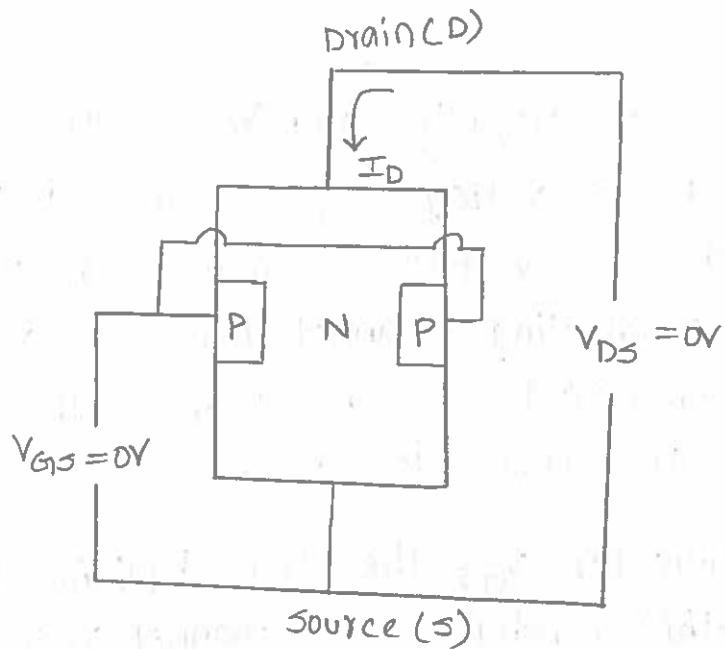
N-channel JFET consist of a N-type silicon bar consist of two terminals each side. one is called "source" another one is called "Drain". It consist two highly dopped P-type materials both of forming a gate terminal in N-channel JFET the input circuit [Gate to source] is always forward bias.



case 1 :-

$$V_{GS} = 0 \quad ; \quad V_{DS} = 0$$

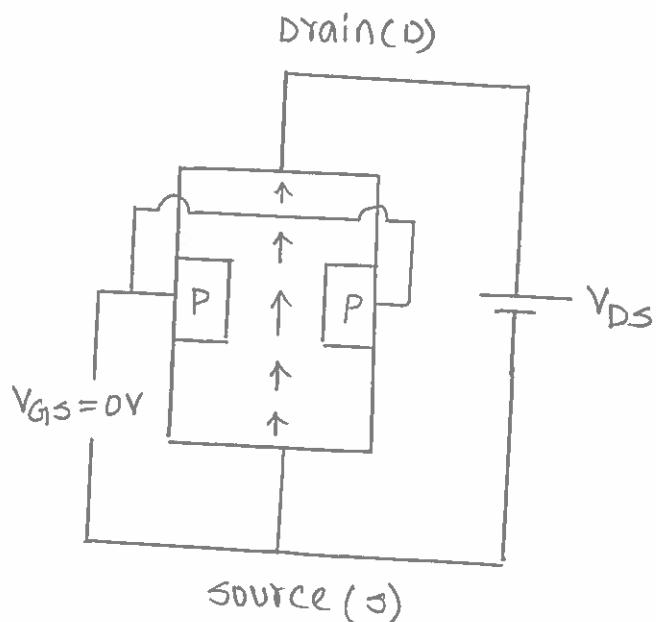
When no voltage applied between drain and source , Gate and source the drain current will be zero ( $I_D = 0$ ).



case 2:-

When  $V_{GS} = 0$  and  $V_{DS}$  is increased from "0".

When  $V_{DS}$  is voltage is applied between Drain and source terminal the majority charge carriers electrons flows from source to drain through the channel between two P types materials . Hence the drain current flows through the channel from drain to source.

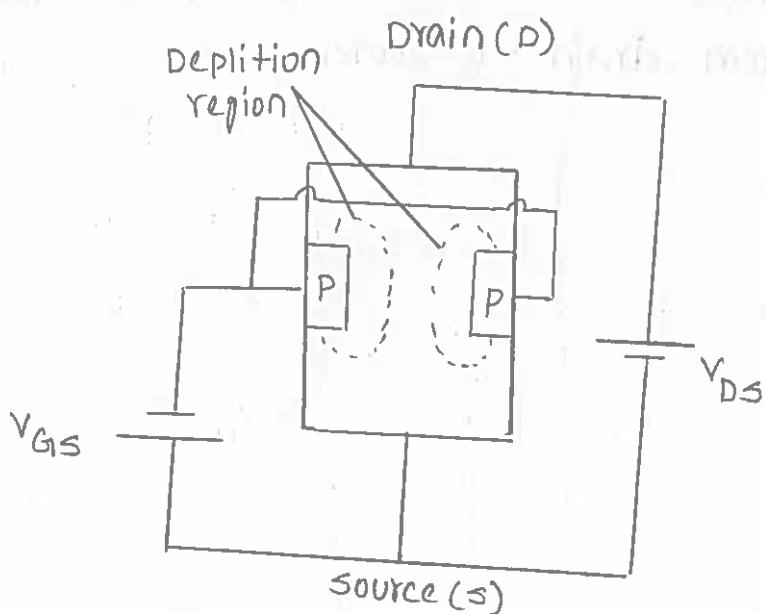


CASE 3:-  
m.m

When  $V_{GS}$  is negative and  $V_{DS}$  is increase from zero. When Reverse bias voltage  $V_{GS}$  is applied between Gate and source and  $V_{DS}$  voltage is increased this reduces the width of conducting channel for small value of  $V_{DS}$  the N-type channel act as a resistor so the Drain current  $I_D$  from drain to source is decrease.

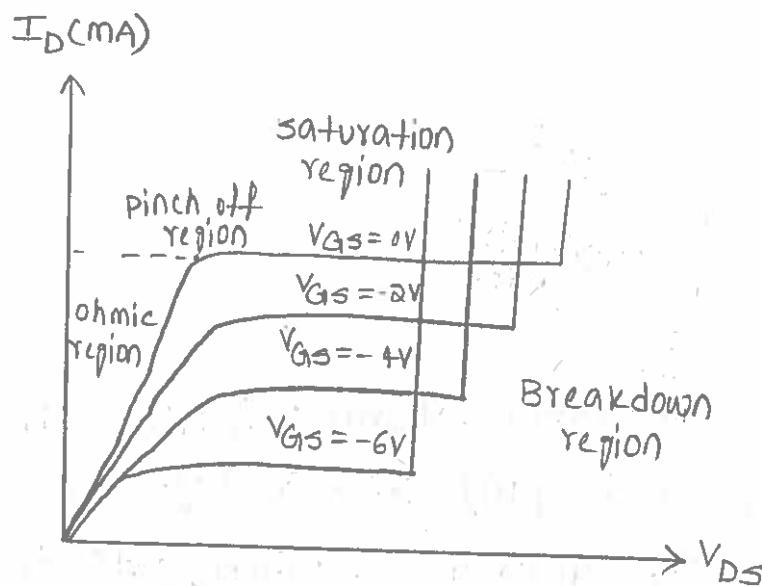
At particular  $V_{GS}$  the two depletion layers touch each other at this condition the channel resistance is infinity the corresponding  $V_{GS}$  is called pinch off voltage at this condition the  $I_D$  current is constant.

If the reverse bias voltage at gate terminal is decrease the width of the depletion region also decrease and width of the channel is increase. Hence the drain current will increase. so the current from drain to source is controlled by the application voltage at gate terminal.



## Drain characteristics:-

Drain characteristics drawn between drain to source voltage ( $V_{DS}$ ) and drain current ( $I_D$ ) by keeping  $V_{GS}$  voltage is constant.

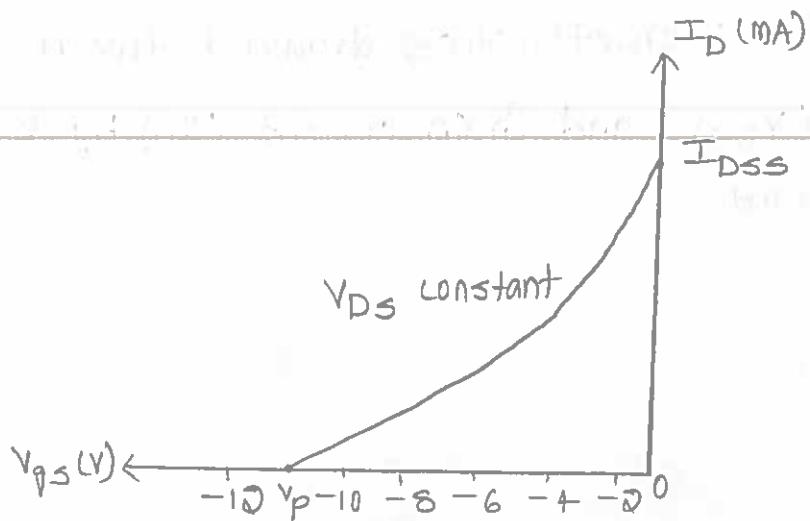


Ohmic region:- In this region the current ( $I_D$ ) is proportional to drain to source voltage that means  $V_{DS}$  voltage increased from zero. The  $I_D$  current increase and follow the ohm's law.

Pinch off region:- After pinch off voltage the current  $I_D$  is constant and it is independent of  $V_{DS}$  in this region JFET act as a constant current device.

Breakdown region:- When drain to source voltage is high and  $V_{GS}$  voltage also high and the channel will break hence the drain current will increase suddenly and JFET enters into breakdown region.

Transfer characteristics (or) Mutual characteristics:-



Transfer characteristics drawn between  $I_D$  and  $V_{GS}$  by keeping  $V_{DS}$  voltage is constant. The drain current " $I_D$ " decreases when gate to source voltage  $V_{DS}$  increases the pinch off voltage " $V_p$ " is also called gate cut-off voltage

$$V_p = V_{GS}|_{OFF}$$

The drain current  $I_D$  is represented as

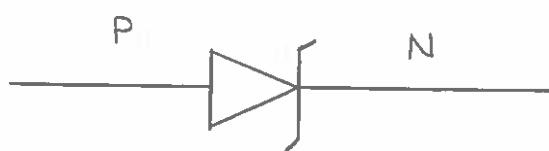
$$I_D = I_{DSS} \left[ 1 - \frac{V_{GS}}{V_{GS}|_{OFF}} \right]^2$$

Where  $I_{DSS}$  is value of  $I_D$  when  $V_{GS} = 0$

## Zener diode:-

PN diodes are work in the forward bias direction and produce large currents in forward bias condition holding. In reverse bias condition normal PN diodes produced small amount of current. Which is called reverse saturation current. If reverse bias voltage is exceeds the reverse breakdown voltage large current flows through the junction the diode get damaged to overcome this problem particular type of diode is formed which is called zener diode.

Zener diode mainly operates in reverse bias condition and this diode does not get damaged even reverse bias voltage exceeds the reverse breakdown voltage. Zener diode having more doping compare to PN junction diode.



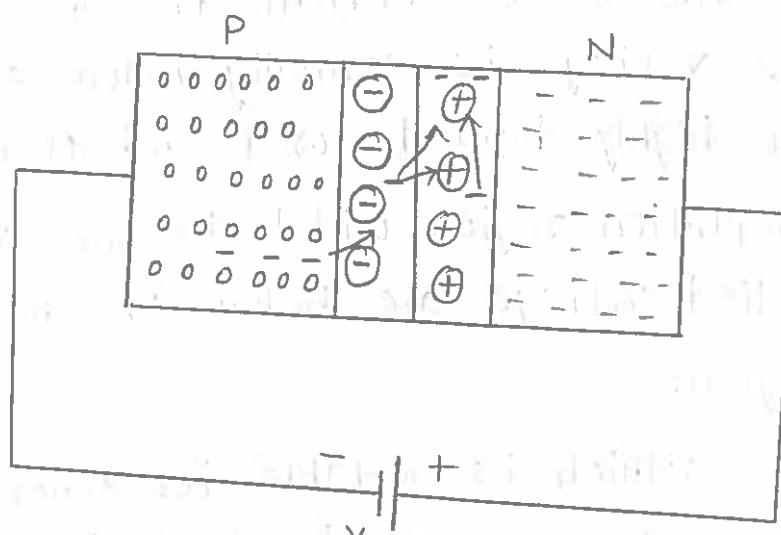
The sharp increase in current under breakdown condition are due to two mechanism.

- \* Avalanche breakdown
- \* Zener breakdown.

comparison of BJT and FET :-

SI.NO	FET	BJT
01	It is a unipolar device	It is a bipolar device
02	Its input resistance is very high	Its input resistance is very low.
03	It is a voltage controlled device	It is a current controlled device
04	It has negative temperature coefficient at high current level.	It has positive temperature coefficient at high current level.
05	It does not suffer from minority carrier storage effects.	It suffers from minority carrier storage effect
06	It has higher switching speed and cut off frequency	It has lower switching speed and cut off frequency
07	It is much simpler to fabricate as an integrated circuit	It is more complicated to fabricate as an integrated circuit
08	It is less noisy	It is more noisy.
09	It is relatively immune to radiation	It is susceptible to radiation
10	It has lower gain bandwidth product	It has higher gain bandwidth product

## Avalanche breakdown:-



As the applied reverse bias voltage increases the electric field across the junction increases. When minority charge carriers present in P-type move into the electric field region acquire large amount of kinetic energy from the field as a result the velocity of these electrons increases these electrons breaks. The covalent bond by colliding with immobile ions and creates new electron hole pair. These new electrons again acquire sufficient energy from the field and collide with other immobile ions and generating further electrons pair. These process is cumulative and generate more amount of charge carriers with in short time. These Mechanism is called avalanche multiplication. These process produce large amount of current at the same value of reverse bias voltage.

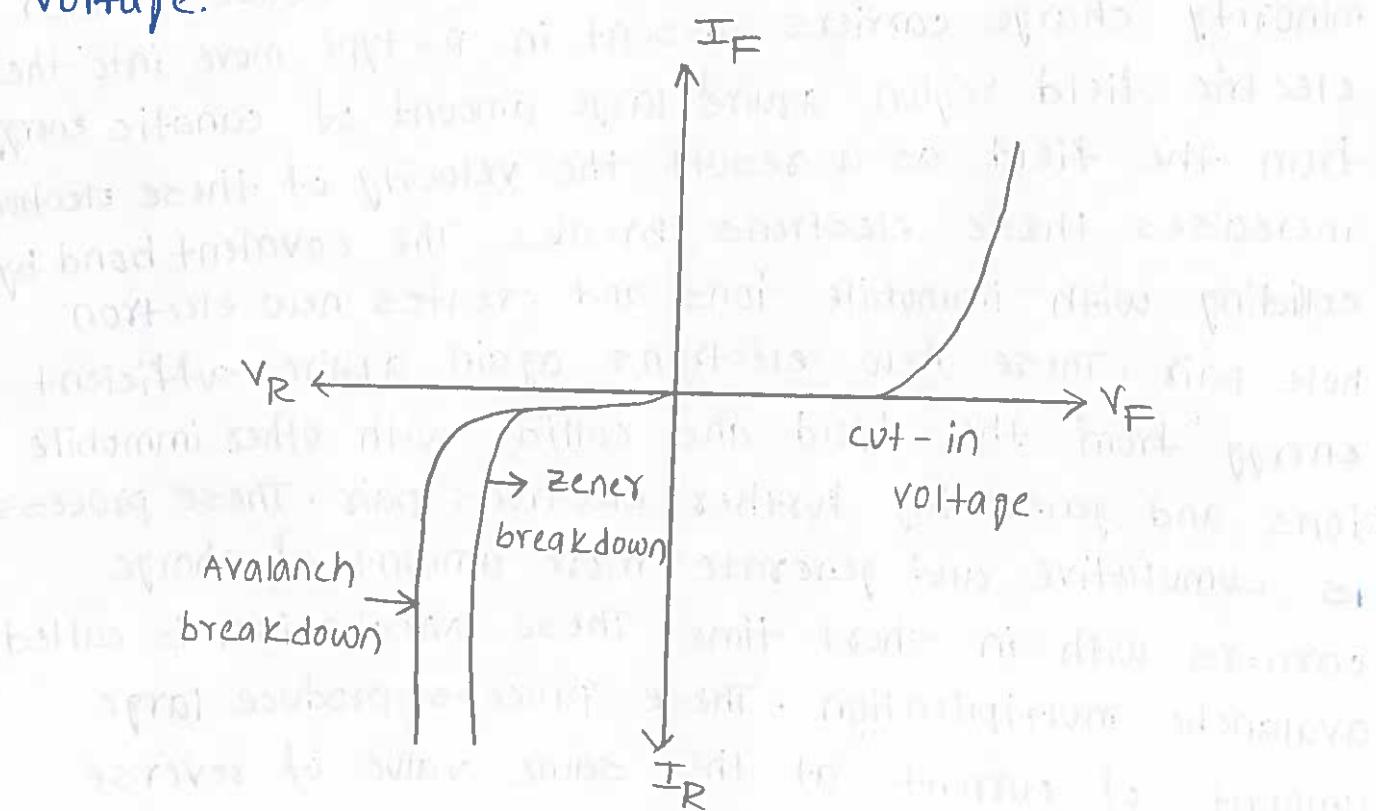
## Zener breakdown:-

When the P and N regions are highly dopped direct breakdown of covalent bond takes place because of strong electron electric field at

the junction. The new electron hole pairs are created and increase the reverse current at same breakdown voltage. These voltage is normally below 6V for zener diode due to highly dopped for P and N region.

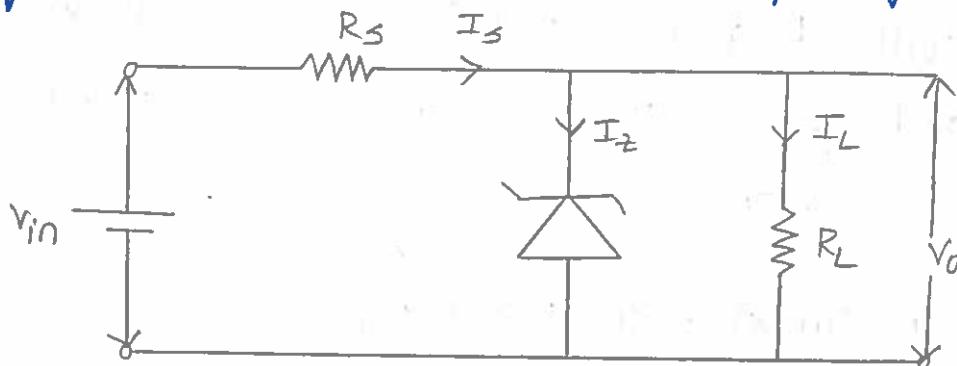
The depletion region width becomes very small and for applied voltage are below 6V. The field across depletion region.

which is suitable for zener breakdown. The zener breakdown occurs for lower breakdown voltage and avalanche breakdown occurs for higher breakdown voltage.



Zener diode as a voltage regulator! -

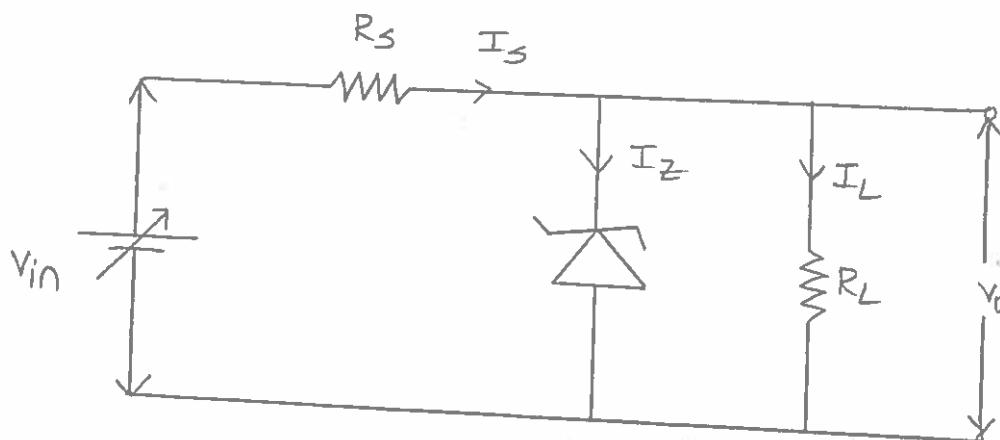
In reverse bias condition the current will suddenly increases at constant voltage by using this property zener diode is used as voltage regulator.



Voltage regulation are two types. They are

- \* Line regulation
- \* Load regulation

Line regulation! -



Regulation of input voltage variations by keeping load resistance is constant then that regulation is called line regulation.

When input voltage increases input current "I\_s" will increase but load current "I\_L" should be constant for obtaining constant output voltage

the excess input current will be drawn by zener diode i.e., zener current "I<sub>Z</sub>" increases and voltage across zener diode is constant.

When input voltage decreases "I<sub>S</sub>"

current will decrease and zener diode draws minimum current and output current "I<sub>L</sub>" is constant

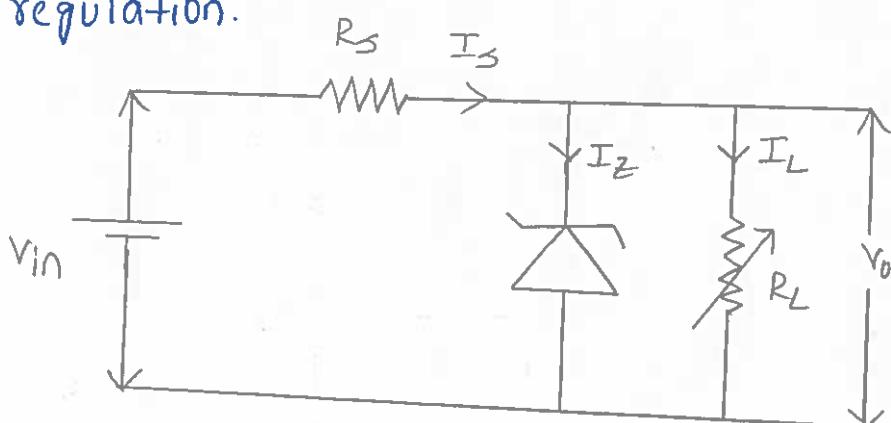
$$I_S = I_Z + I_L$$

$$I_S (\text{max}) = I_Z (\text{max}) + I_L$$

$$I_S (\text{min}) = I_Z (\text{min}) + I_L$$

Load regulation!:-

Regulation of load variations by keeping input voltage is constant then that regulation is called load regulation.



When load resistance increases load current "I<sub>L</sub>" will decreases by keeping current with output voltage is constant the excess load current will drawn by zener diode so "I<sub>Z</sub>" will increase but voltage across zener diode will constant.

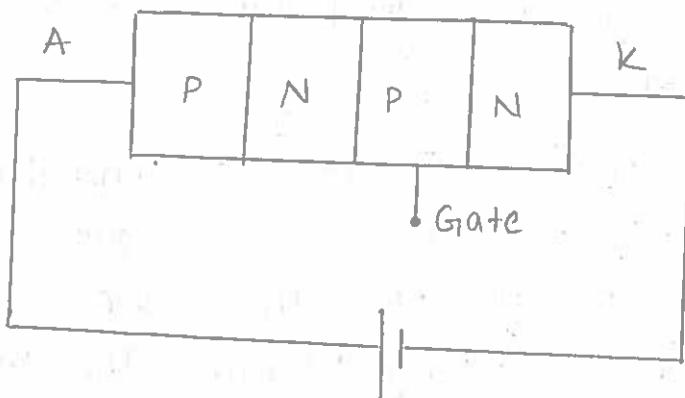
(50)

When load resistance value decreases "I<sub>L</sub>" current should be increases by keeping output voltage is constant. In this case zener diode draws minimum current so "I<sub>Z</sub>" current is decreases. but voltage across zener diode is constant.

$$I_S = I_Z(\text{max}) + I_L(\text{min})$$

$$I_S = I_Z(\text{min}) + I_L(\text{max})$$

SILICON CONTROLLED RECTIFIER! -



SCR is a four layer Three terminal device and it having Three junctions J<sub>1</sub>, J<sub>2</sub> & J<sub>3</sub> for this device p layer act as a anode and N layer act as a cathode.

Characteristics of SCR! -

When no voltage applied between anode and cathode , no gate voltage then no current produced in the SCR.

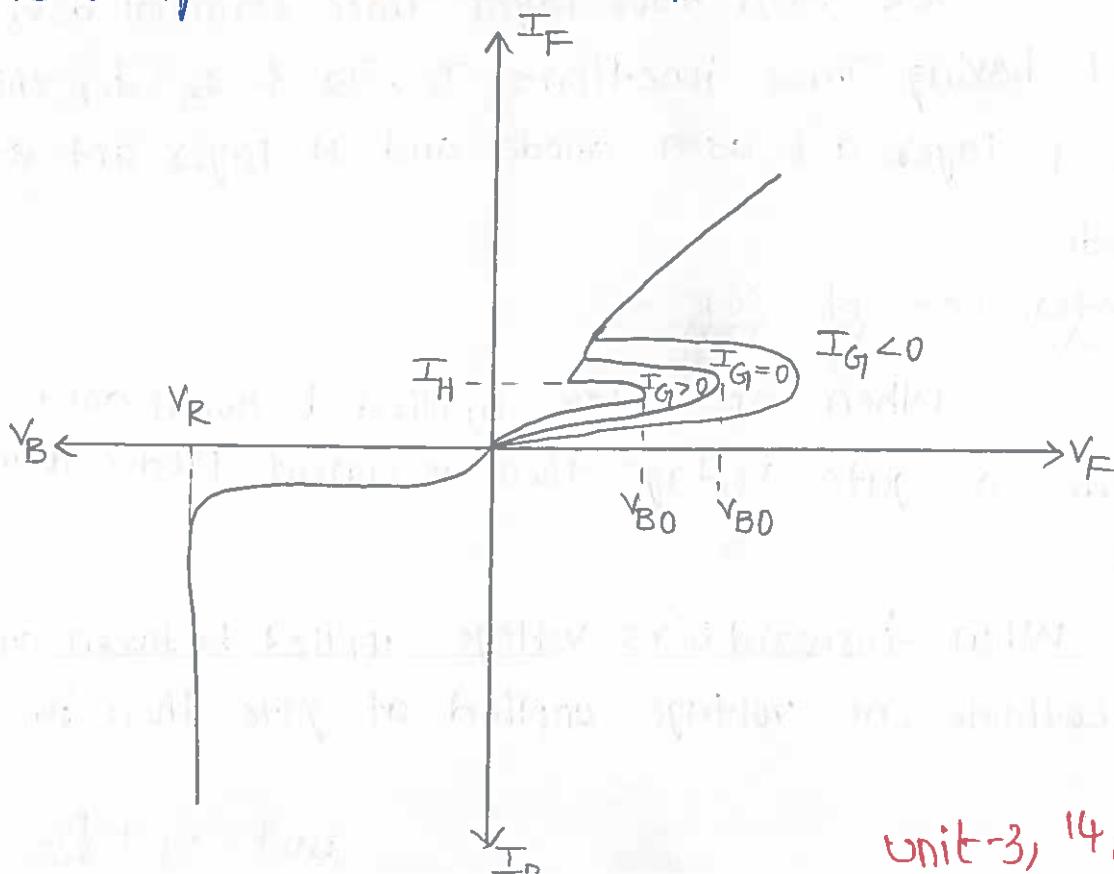
When forward bias voltage applied between anode and cathode , no voltage applied at gate then junction

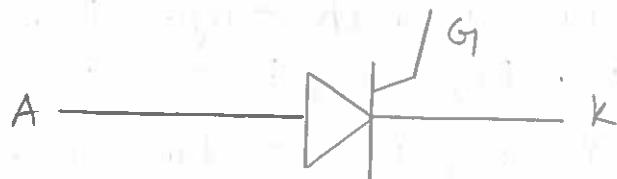
$J_1$  and  $J_3$  are forward bias and junction  $J_2$  is reverse bias so only small amount of reverse saturation current produced in the circuit upto breakdown voltage  $V_{BO}$

When forward bias voltage greater than breakdown voltage then the current increases rapidly in the circuit in this condition the SCR act as a "ON" switch.

When negative gate voltage applied at gate terminal ( $I_G > 0$ ) then the breakdown voltage  $V_{BO}$  decreases similarly when positive voltage applied gate terminal ( $I_G < 0$ ) then breakdown voltage  $V_{BO}$  increases that means the current in the SCR controlled by gate voltage across the gate terminal.

Once's SCR is "ON" condition the gate terminal losses its control i.e., the gate terminal can not be used to switch OFF the device. One way to turn "ON" the device is by lowering the anode current by reducing the forward voltage.





Holding current ( $I_H$ ):-

Holding current is the minimum current to hold the device in "ON" state for turning off the device the current should be below holding current.

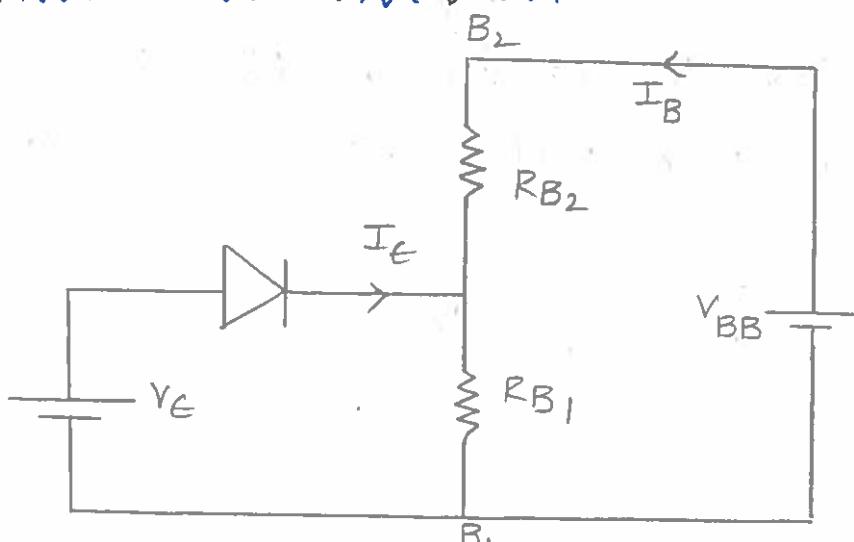
UNI JUNCTION TRANSISTOR!:-

UJT is a Three terminal device and having only one junction between P-type and N-type.

construction of UJT!:-

UJT having lightly doped N-type silicon bar with an electrical connection on each end the terminals to this connections are called base 1 ( $b_1$ ) and base 2 ( $b_2$ ). There is highly doped P-type material at one side of N-type silicon bar which is close to the base 2 terminal. The terminal at P-type material is called emitter terminal. The resistance between base 1 and emitter terminal is more compared with resistance between base 2 and emitter terminal because emitter terminal is near to base 2 terminal.

Equivalent circuit of UJT:-



VJT is replaced with single diode and two resistances  $R_{B_1}$  and  $R_{B_2}$ .  $R_{B_2}$  is resistance in between emitter and base 2.  $R_{B_1}$  is resistance in between emitter and base 1. Voltage in between Base 1 and Base 2  $V_{BB}$  and voltage across  $R_{B_1}$  is given by

$$V_{RB_1} = \frac{V_{BB} R_{B_1}}{R_{B_1} + R_{B_2}}$$

$$V_{RB_1} = \eta \cdot V_{BB}$$

→ intrinsic stand off region

$$\boxed{\eta = \frac{V_{RB_1}}{V_{BB}}}$$

Working of VJT! -

case 1! - If no voltage applied between Base 1 and Base 2 at the emitter the current "I<sub>E</sub>" is equal to "0"

case 2! - If a voltage  $V_{BB}$  is applied across base terminal with emitter ( $V_E = 0$ ). The voltage drop across  $R_{B_1}$  and  $R_{B_2}$ . The voltage across  $R_{B_1}$  reverse bias the PN junction diode. Therefore small reverse leakage current flows through emitter to base to due to minority carriers

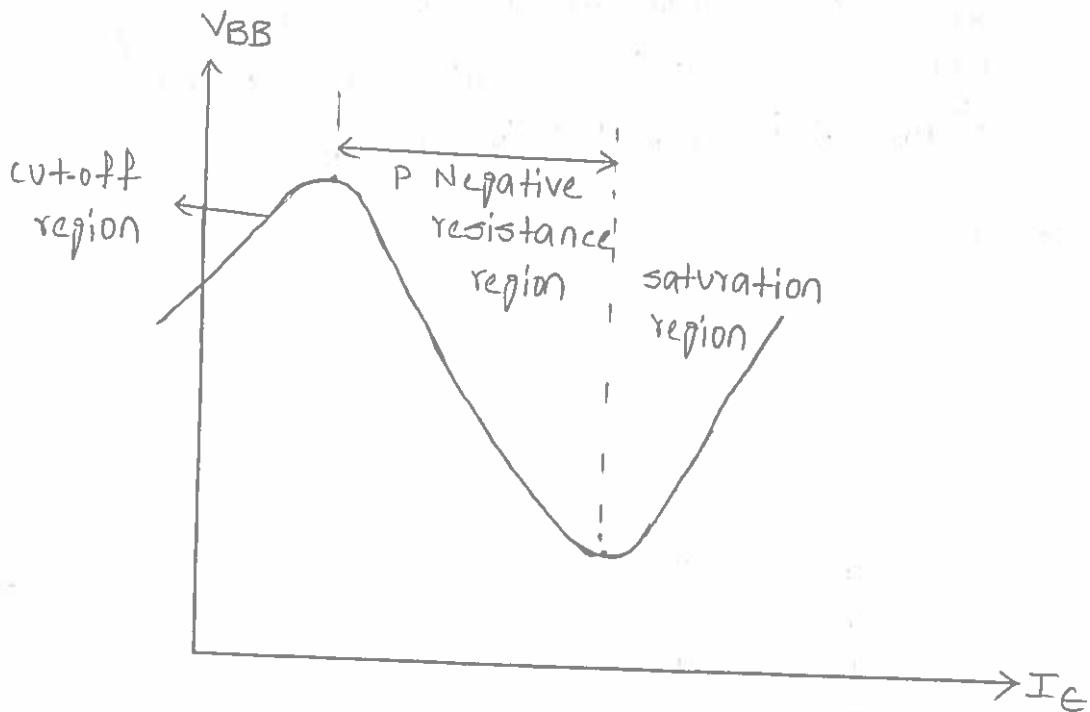
case 3! - If positive voltage is applied across emitter terminal the diode become forward bias if the input voltage exceeds peak voltage. The peak voltage is given by

$$\boxed{V_p = V_S + V_{RB_1}}$$

(50)

When the diode restarts conducting  $R_B$ , resistance decreases and internal voltage drop from emitter to base will decrease and device will now in the ON state.

### Characteristics of VJT



The graph between emitter current  $I_E$  and  $V_{BB}$  is called output characteristics of VJT the operation of VJT mainly divided into 3 regions.

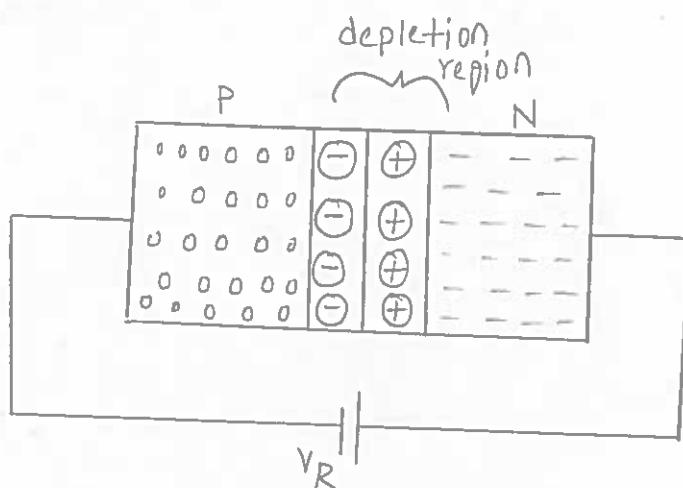
- \* Cut-off region
- \* Negative resistance region
- \* Saturation region.

Cut-off region:- The region to the left of the peak point is called cut-off region. upto the peak point "P" the diode is reverse bias and hence small leakage current flows through the circuit due to minority charge carriers.

Negative resistance region! - The region between peak point to valley point is called negative resistance region. In this region the diode is forward bias. Hence the emitter current  $I_E$  increases and  $V_{BB}$  voltage decreases.

Saturation region! - The region to the right of valley point is called saturation region. After the valley point VJT behaves like forward biased PN junction diode.

Varactor Diode:-



When PN junction diode is Reverse bias depletion region is created at the junction. Since there are no charge carriers within the depletion region that can act as an insulator. The P-type material with holes as a majority carriers consider as positive plate of a capacitor and N-type material with electrons are majority charge carriers consider as a negative plate of a capacitor then this diode maybe consider as a capacitor having depletion region as an insulator. Capacitance of a varactor diode.

$$C = \frac{EA}{d}$$

Where

$C$  :- capacitance

$\epsilon$  :- permittivity of a material

$A$  :- Area of a junction

$d$  :- width of the depletion region.

The depletion region width is directly proportional to reverse bias voltage and capacitance "C" is inversely proportional to width of the region.

When the reverse voltage across the diode is increase the width of the depletion region increase so the total capacitance at the junction increases.

If the reverse voltage across the diode is decrease the width of the depletion region decreases and total capacitance at the junction increases.

So varactor diode is also called varact or voltage variable capacitor.

TUNNEL DIODE -

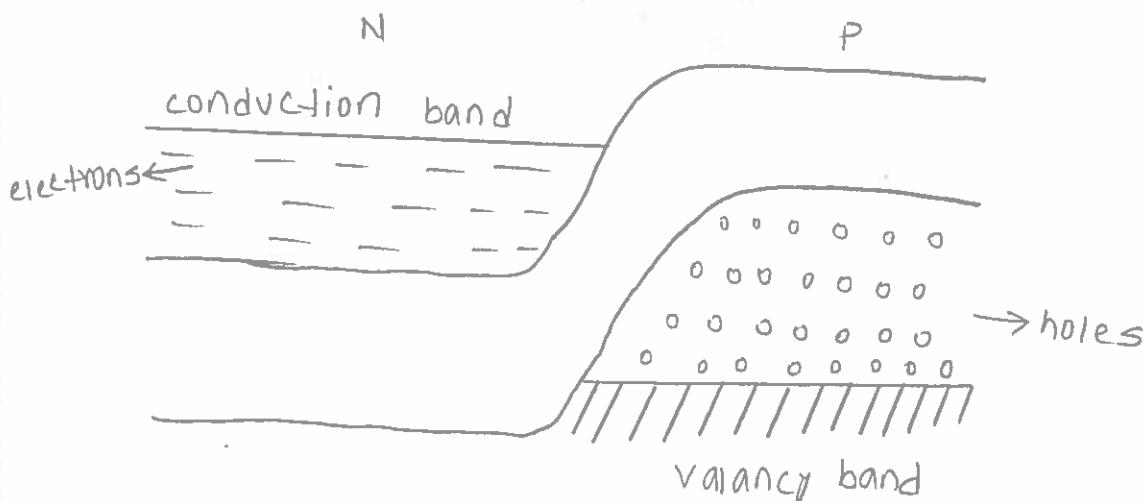
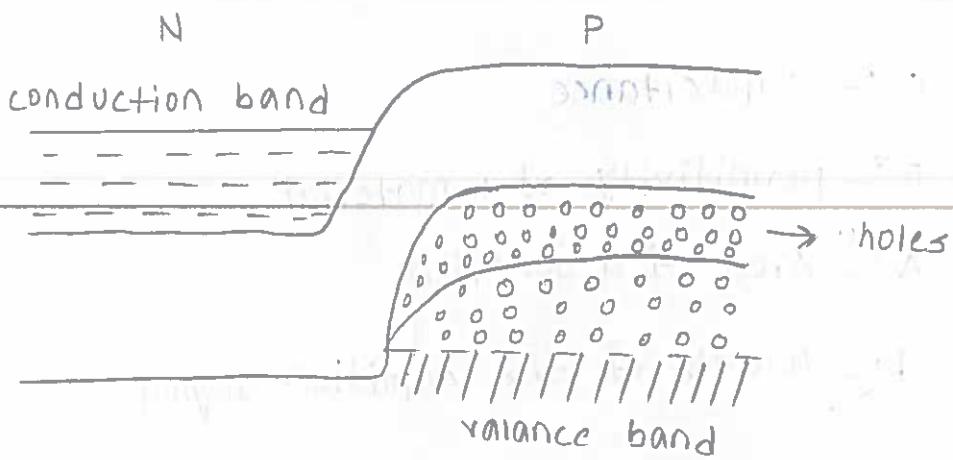


Fig:- Tunnel diode with ND bias condition  
Date : 10/12/2022



By applying forward bias voltage or peak voltage,  
doping is  $1:10^8$  in PN diode

Dopping is  $1:10^3$  in Tunnel diode, dopping is  
high in Tunnel diode compare to PN diode.

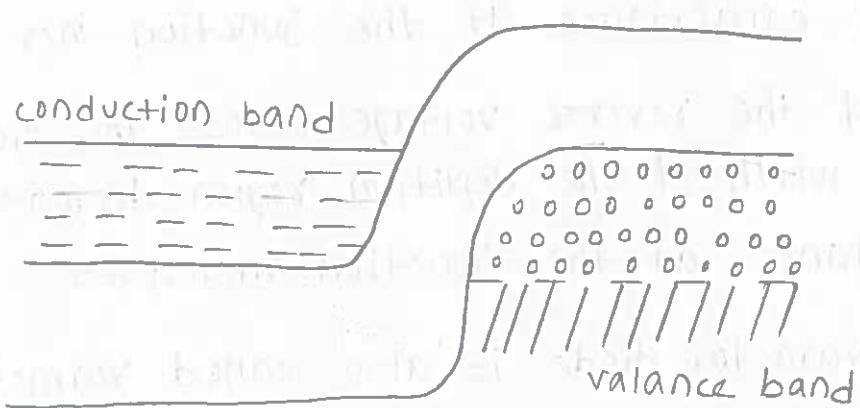
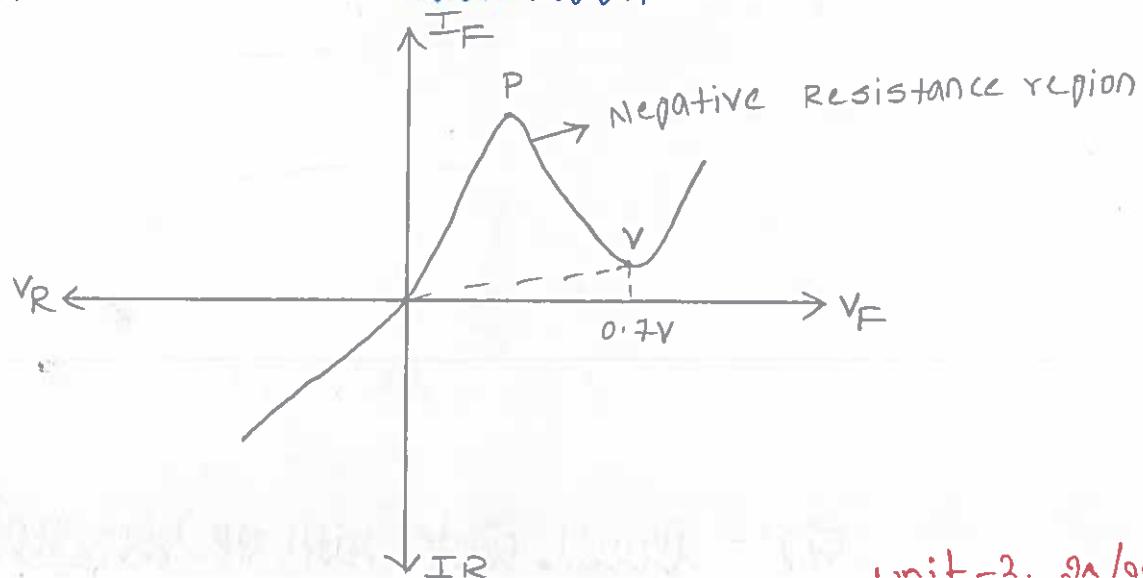


Fig:- Tunnel diode at valley point  
characteristics of Tunnel diode:-



The tunnel diode also called Esaki diode. Which exhibits negative resistance region under forward bias condition.

An ordinary PN junction diode has an impurity concentration  $1:10^8$  with this amount of doping the depletion region width is 5 micro Amps (μA) if the concentration of impurity atoms increased to  $1:10^3$  then the depletion region width reduced to 100 Å.

This thickness is very thin so the electrons and holes cross the junction easily compare to PN-junction diode.

When the bias voltage is zero the electrons and holes did not move either side and the current is zero.

When small amount of forward bias voltage is applied the energy level of the P-side is lower than n-side. hence the electrons in the conduction band of the n-side move towards holes present in the valency band and current will increase upto peak point "p".

When the forward bias voltage raised beyond peak point then tunneling will decrease the current will decrease upto valley point, After valley point the tunnel diode behaves like ordinary PN junction diode.

The region between peak - point and valley point is called Negative resistance region.

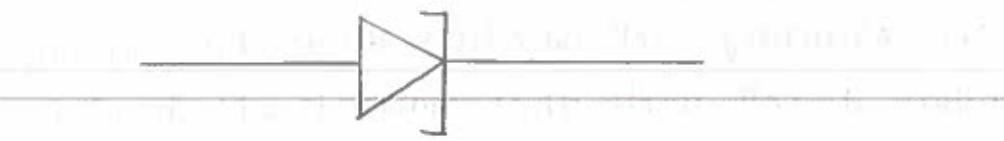


Fig:- symbol of tunnel diode