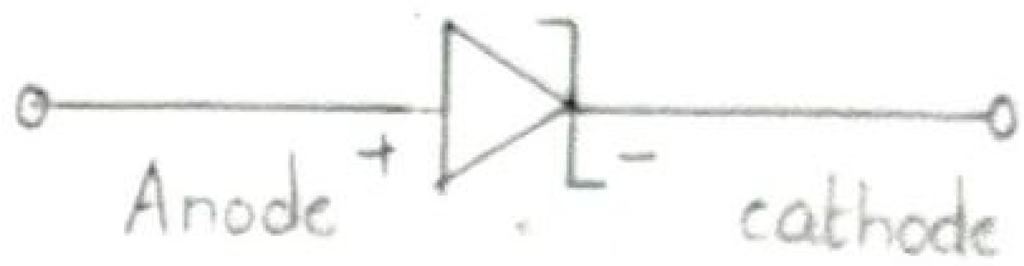
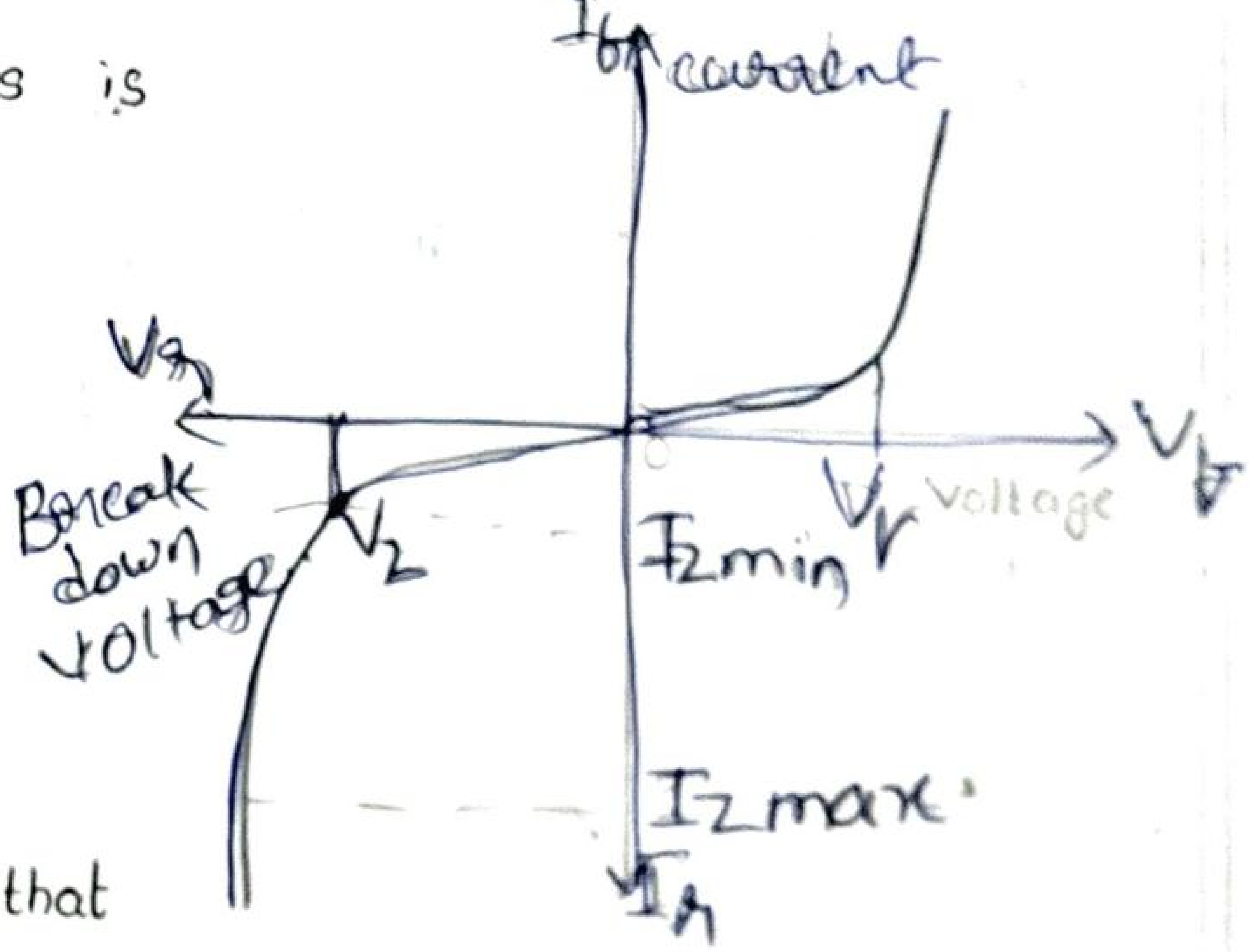
Zener Diode Characteristics:-

Zener diode is a reverse biased heavily-doped silicon (or germanium) p-n junction diode which is operated in the breakdown region. Due to higher temperature and current capability, silicon is preffered in comparison to germanium. The symbol of a zener diode is shown in figure



This is similar to a normal diode except the line representi--ng the cathode is bent at both ends i.e. like the letter z for zener. The V-I characteristics is shown in figure.



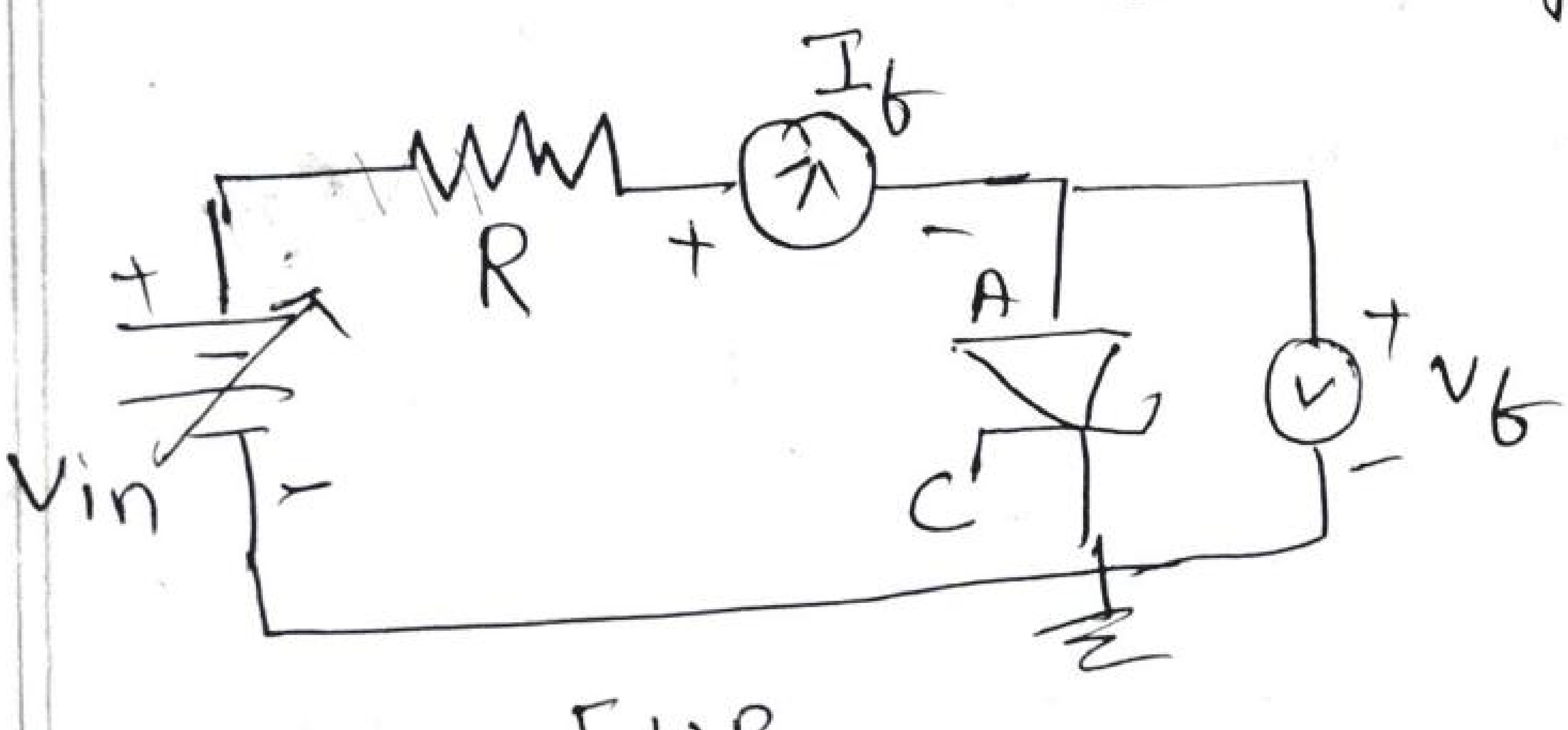
When a zener is forward biased its charact--eristics are just as those of ordinary diode.

It is also obvious from fig. that as the reverse voltage applied to p-n junction is increased, a value is reached at which the current increases greatly from its normal cut-off value. This voltage is called a zener voltage (V_z) or breakdown voltage. So, when a zener diode is reverse biased it has sharp breakdown voltage called zener voltage (V_z).

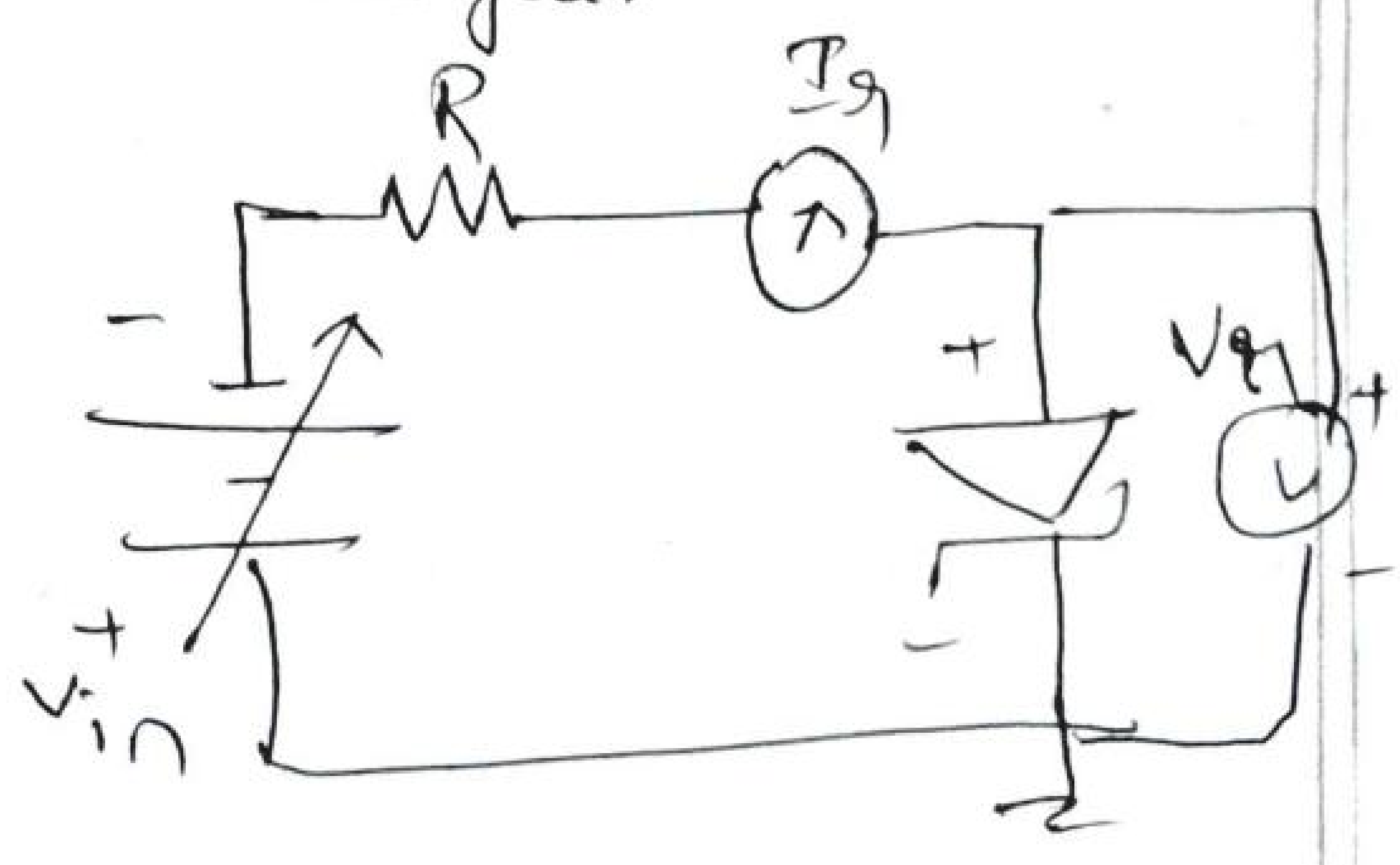
It is observed from the figure that knee, the breakdown voltage (V_z) remains practically constant. The ability of the diode is called as "regulating ability". The regulating ability of zener diode is an important feature. This feature is used to maintain a constant voltage across its terminal over a operated range of zener current values $I_{z(min)}$ and $I_{z(max)}$. We consider the following two important points :-

(i) There is a minimum value of zener current $I_{z(min)}$ called breakover current which must be maintained to keep the diode in breakdown or regulation region. If the current is reduced below the knew of the curve, the voltage changes drastically. So, the regulation is lost.

(ii) There is a maximum value of zener current $I_{z(max)}$ above which the zener may be damaged.



F.W.B



R.B.

ZENER DIODE SHUNT REGULATOR

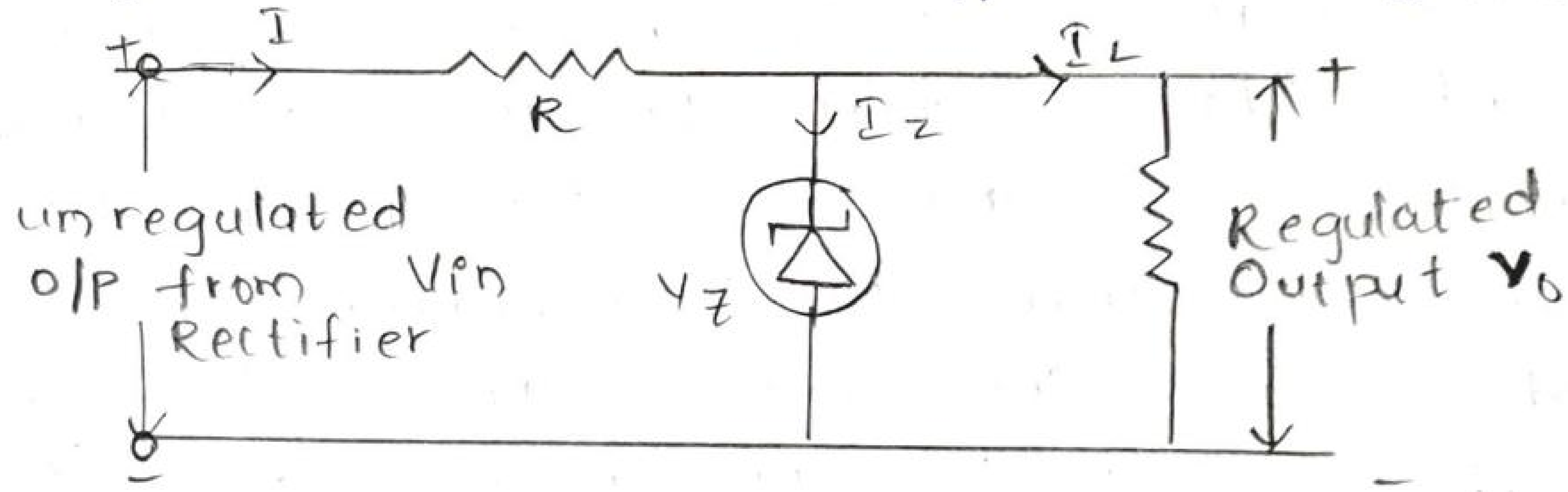
A zener diode shunt regulator shown in fig. In the circuit, the series limiting Resistance R limits the i/p current.

⇒ The principle of this regulator is that when a zenerdiode operates in breakdown regions (Zener region i.e. $V_{in} > V_Z$) The voltage across zenerdiode is constant for a large change in current through it.

⇒ So long as the i/P voltage V_{in} is greater than V_Z, the zener operates in breakdown region and maintains constant voltage across R_L even that there is a change in i/P voltage V_{in} or in load current.

Working of Zener diode shunt Regulator:-

i) Regulation with varying i/P voltage (i.e. R_L fixed).
Let us suppose that i/P voltage V_{in} ↑ within the limits while the load resistance R_L being fixed.
As V_i increases the i/P current I increases.



$$I = \frac{V_{in} - V_Z}{R}$$

fig: Zener diode shunt Regulator

Now more current flows through zenerdiode i.e. I_Z increases of course, load current I_L remains the same. As a result, the voltage drop across R increases in such a way that the voltage across R_L remains constant. On the other hand, if input voltage decreases, the current I also decreases. Now, the current I_Z through zener also decreases. Consequently, the voltagedrop across R also decreases. As a result, the I_L and

and voltage drop across R_L (V_L) remain constan

⇒ For fixed value of R_L, the i/P voltage V_i mu be sufficiently large to turn the zener diode ON. The minimum turn on voltage Vin min is determined by,

$$V_Z = V_{in\,min} \frac{R_L}{R+R_L} \qquad V_{in\,min} = V_Z \frac{R+R_L}{R_L}$$

V_{max} is limited by zener current $I_{Z\,max}$

$I_R = I_Z + I_L$ or $I = I_Z + I_R$

I_L = fixed

$$I_{max} = I_{Z\,max} + I_L \qquad I_L = \frac{V_Z}{R_L}$$

$$V_{in\,max} = V_{R\,max} + V_Z$$

$$= I_{max} R + V_Z$$

for $R = 0$, I is max

So,

$$R_{min} = \frac{V_{in\,max} - V_Z}{I_{max}} = \frac{V_{in\,min} - V_Z}{I_{Z\,max} + I_{L\,min}}$$

ii) Regulation with varying load current: [R_L varying]

Let the i/P voltage V_i is kept fixed while the R_L is varies. The variation in R_L produces a change in load current. This is turn produces a change in O/P ~~curr~~ voltage Vout across load. If the load resistance decreases then the load current increases. This ~~current~~ causes the zener current to decrease such that the current I through Resistance "R" is constant.

$$V_{out} = V_{in} - IR$$

This expression shows that O/P voltage being constant since I is constant. On the other hand, if the load resistance increases then the loadcurrent decreases. This in turn increases the zener current such that the i/p current I and voltage drop R remain constant. Therefore, the O/P voltage remains constant.

Scanned by TapScanner

We know,

$$V_Z = \frac{V_{in}\, R_L}{R + R_L} = I_L \cdot R_L = V_o$$

Diode will be in the breakdown ~~voltage~~ region only when $V_{in} \geq V_Z$

When the diode is in the breakdown region $V_o = V_Z$. However, if the load resistance R_L is less than a certain value $R_{L\,min}$, The voltage $V_o = I_L \cdot R_{L\,min}$ across the R_L may become less than V_Z which implies that diode is not in it's operating region.

For example $R_L \to 0$ (short circuted) $V_o \to 0$ inorder to maintain a constant voltage V_o across R_L for different values of R_L. We have to maintain min value. R_L min of Load resistance to ensure that the ~~region~~ zener diode operates in breakdown region.

$$R_{L\,min} = \frac{R V_Z}{V_{in} - V_Z} \qquad R_{L\,max} = \frac{V_Z}{I_{L\,min}}$$

$$I_{L\,max} = \frac{V_Z}{R_{L\,min}} = \frac{V_{in} - V_Z}{R} \qquad R_{L\,min} = \frac{V_Z}{I_{L\,max}}$$

$$I_{L\,min} = I - I_{Z\,max} = \left(\frac{V_{in} - V_Z}{R}\right) - I_{Z\,max}$$

$$R_{min} = \frac{V_{in\,max} - V_Z}{I_{Z\,max} + I_{L(min)}}$$

$$I_{Z\,min} = \frac{(V_{in\,min} - V_Z)}{R} = I_{L\,max}$$

$$R_{max} = \frac{V_{in\,min} - V_Z}{I_{Z\,min} + I_{L\,max}}$$

R is chosen in such a way that it's value should be between Rmax and Rmin i.e.

$R_{min} < R < R_{max}$

We know,

$$P = V_Z \cdot I_Z$$

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The maximum power rating of zener diode is

$P_{max} = V_z I_{z max} = I_{z max}^2 \cdot r_z$

(r_z = zener diode Resistance)

Zener diode Specifications :-

1. Zener Voltage V_z : The reverse voltage at which r reverse current increases sharply is known as zener voltage. Comercially Zener diodes have available ratings from 3V to 200V. The value of breakd (or zener) voltage depends upon doping.
   More the doping, lesser the breakdown voltage

2. Max. Power Dissipation: The max. power dissipation of zener diode is defined as product of zener volt (V_z) and zener current (I_z) $[P_z = I_z \cdot V_z]$.
   Every device has a limited capability to dissipate heat energy produced by it. If the pow exceeds $P_{z max}$. The device may burn out.

/RISTORS

Thyristors are solid state devices which have two (or) more junctions and which may be switched from ON state to OFF state and vice versa between two conducting states. They are capable of handling large currents upto hundreds of amperes.

The thyristors are divided into the following two types:

1) uni directional thyristors :- The thyristors which conduct in forward direction are known as uni directional thyristors.

Example : Silicon controlled rectifier (SCR)

2) Bidirectional thyristors :- The thyristors which conduct in both directions (forward as well as reverse) are known as bidirectional thyristors

Example : TRIAC

SILICON CONTROLLED RECTIFIER (SCR)

It is a four layer semiconductor device being alternate of P-type and N-type silicon.

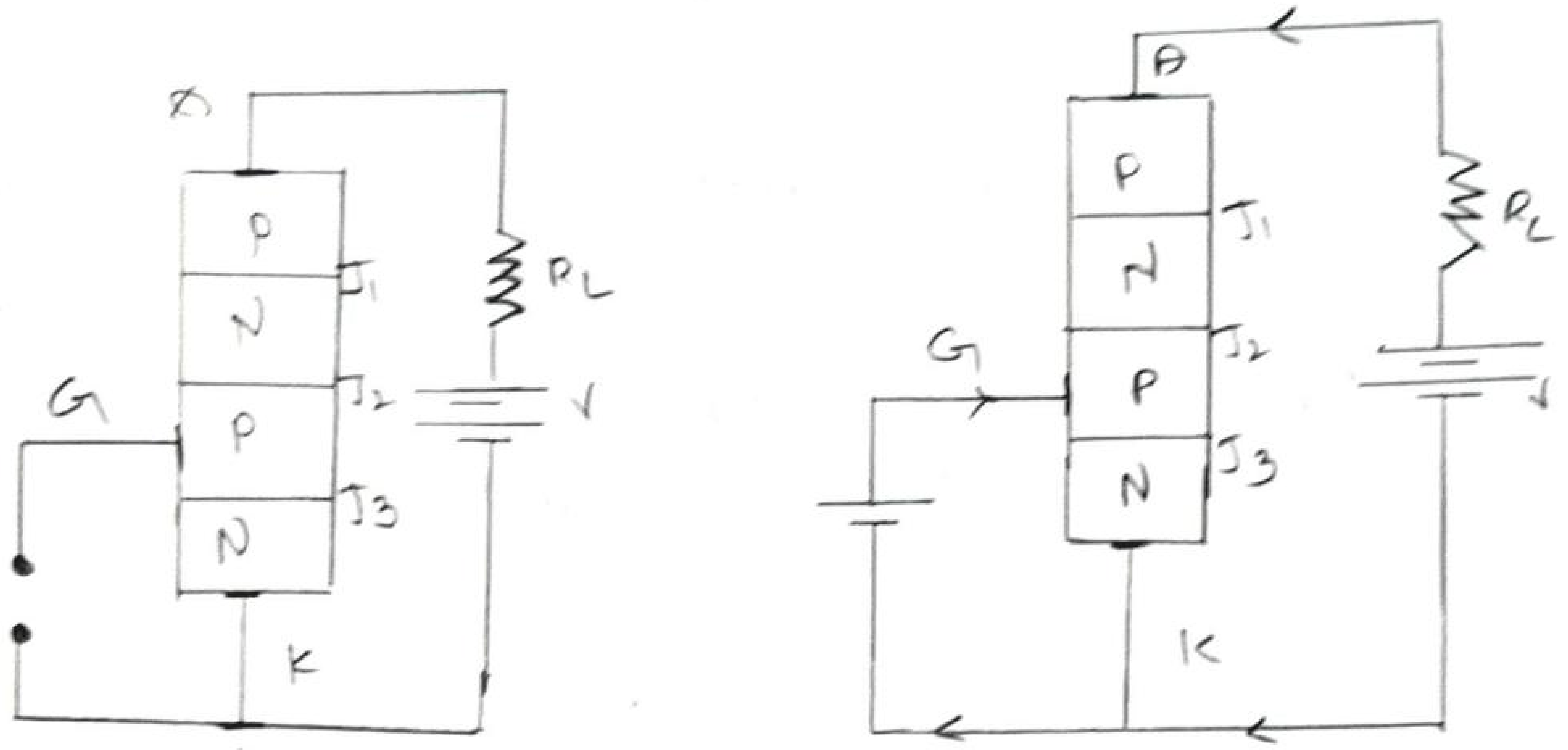
fig 2(a) shows the structure of SCR while in fig 2(b) shows symbolic representation

It is obvious from the figure that it consists of three junctions $J_1 \cdot J_2$ and J_3 (J_1 and J_3 operate in forward direction while middle operates in reverse direction) and three terminals known as anode A, cathode k and gate G.

[Fig: energy band diagram of two type]

The function of gate is to control the firing of SCR. It conducts only in one direction i.e from anode to cathode and hence constitutes unidirectional device.

Operation of SCR.



(a) gate is open

(b) gate is positive

fig ② operation of SCR

In SCR a load is connected in series with anode and anode is kept at positive potential with respect to cathode with the help of a battery

The operation of SCR can be studied when the gate is open and when the gate is positive w.r.t cathode. The situation are shown in fig ②.

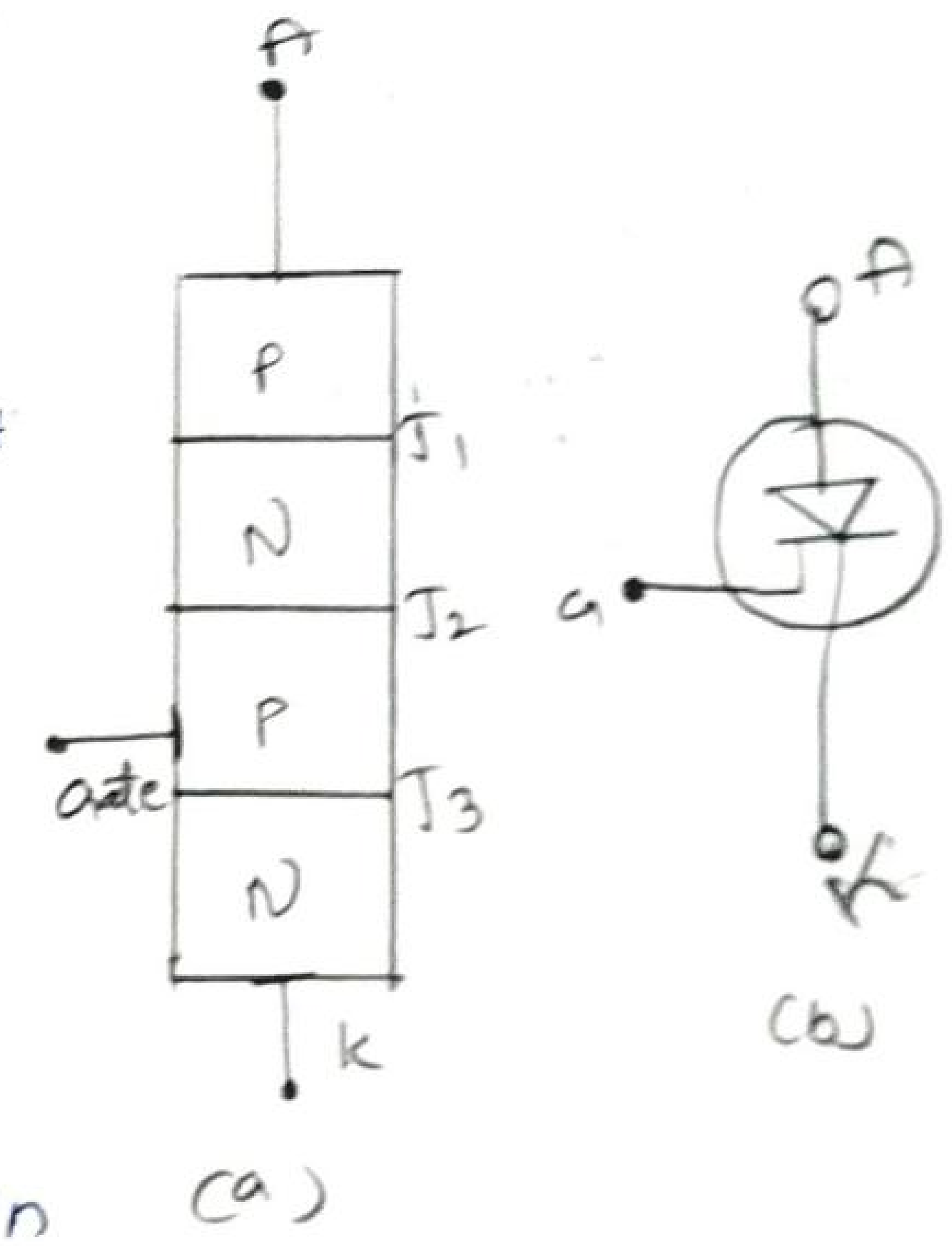


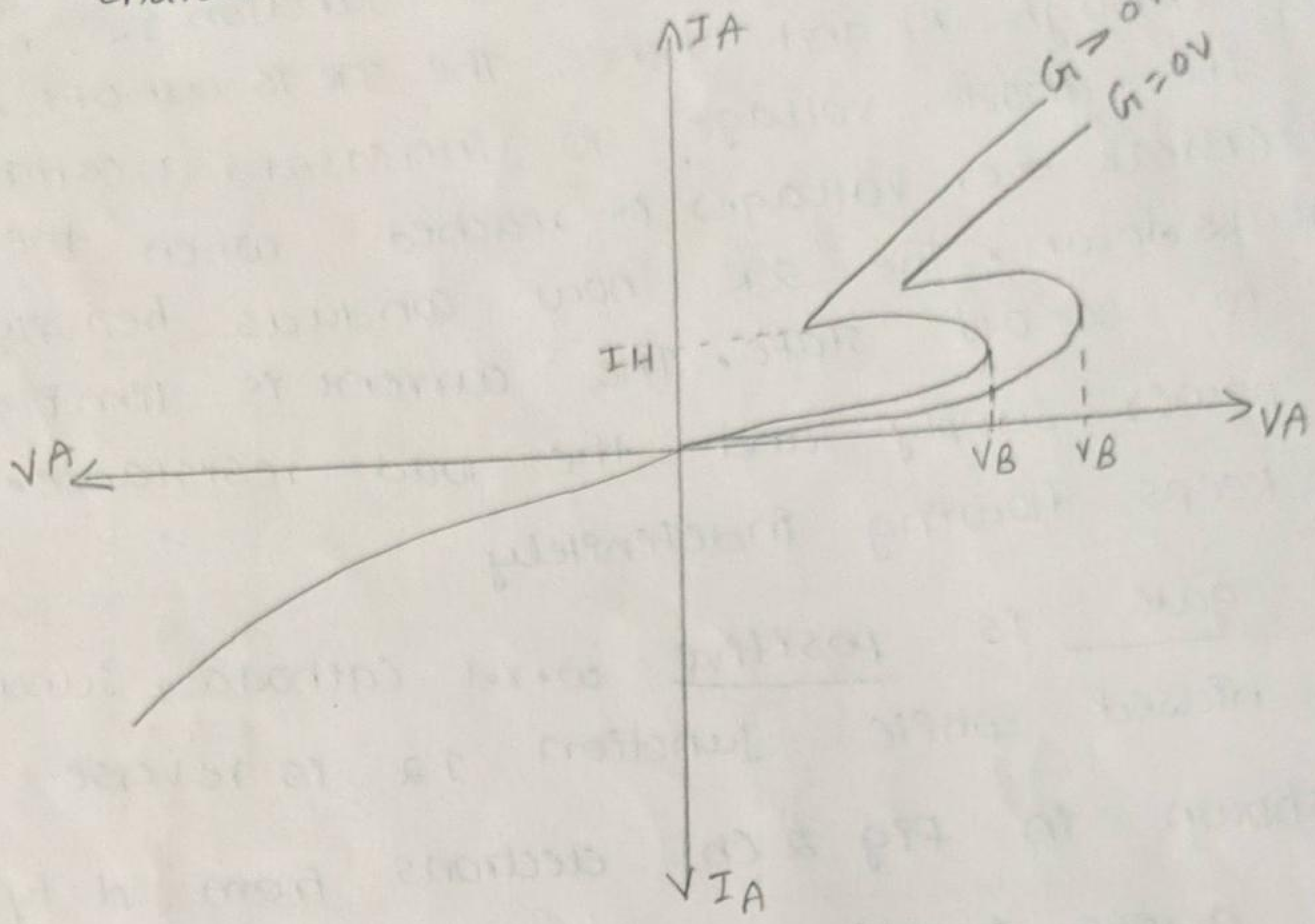
fig ①: structure and symbolic representation of SCR

When the gate is open, no voltage is applied at the gate. Under this condition, junctions J_1

J3 are forward biased while the junction J2 is reverse biased. Due to reverse biased of junction J2 no current flows through R_L and hence The SCR is cut OFF. However when the anode voltage is increased, a certain critical value (Break over voltage) is reached when the junction J2 breaks down. The SCR now conducts heavily and is said to be ON state. The current is limited only by the power supply and the load resistance. The current keeps flowing indefinitely

When the gate is positive w.r.t cathode, junction j3 is forward biased while junction J2 is reverse biased. As shown in Fig 2(b) electrons from n type material move across junction j3 forward gate while hole from p-type material moves across junction j3 towards cathode. So gate current, anode current increases. This in turn makes more electrons available at junction J2. In an extremely small time, junction J2 breaks down and SCR conducts heavily. once SCR starts conducting the loses all controls. The current keeps flowing indefinitely until the circuit is open.

VI charecterestics of SCR.



TUNNEL DIODE OR ESAKI DIODE:

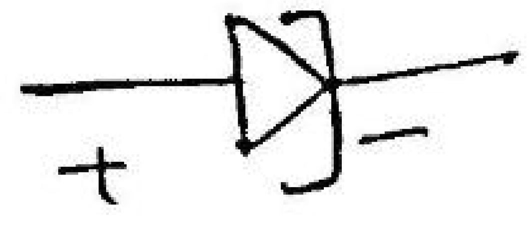
→ A Tunnel diode is a heavily doped diode about 1000 times higher than a normal P.N Diode.

→ Esaki, a Japanese scientist in 1957 invented such a new diode.

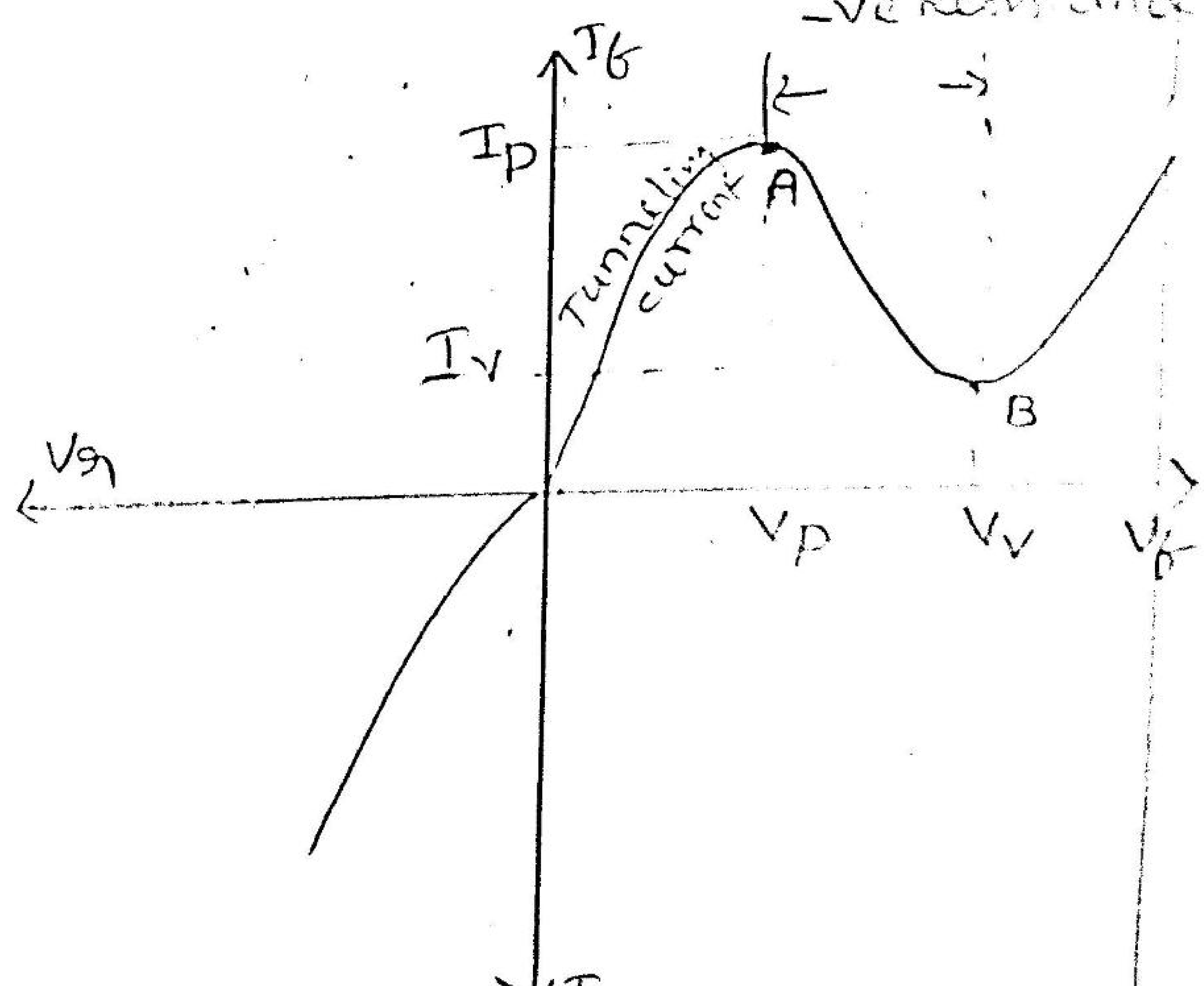
→ If doping concentration is increases, its depletion width is decreases low to about 10^{-6} cm and device characteristics are completely changed.

→ Under this condition, many carriers punch through the junction for small amount of forward voltage (i.e less than 0.3V or 0.7V). consequently large forward current is produced. This phenomenon is known as Tunnelling.

→ This phenomenon utilizes the diode so this diode is called Tunnel diode. or Esaki diode.



symbol



A small forword voltage is applied, Large c
is produced : The current quickly reaches to its
Peak value Ip when applied forward voltage
reaches to a peak value Vp. it is denoted by
point A.

→ when forward voltage is further increased, the
diode current starts decreasing. The current
decreases to Iv corresponding to valley voltage Vv.
This is denoted by point B.

→ The portion from point A to B, current decreases
as voltage increases.. so Tunnel diode has
-ve Resistance.

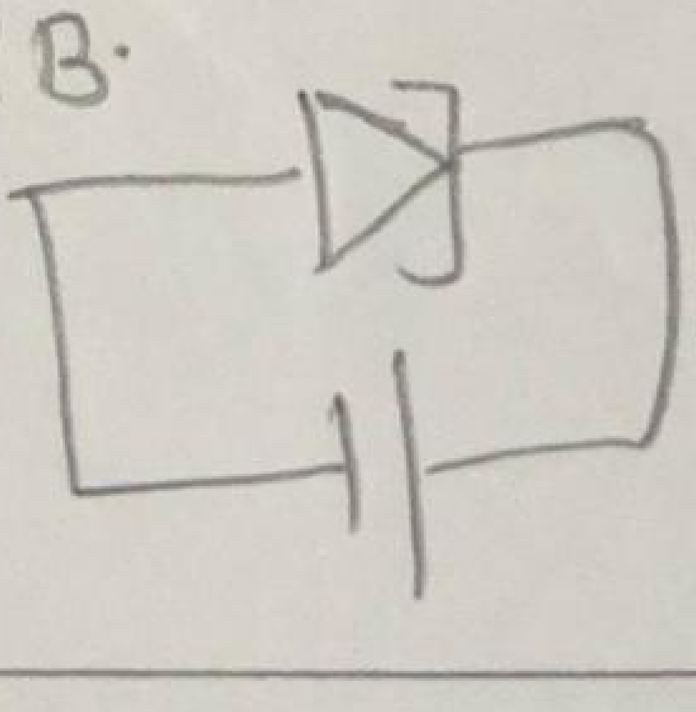
→ It is most usefull property of the diode
beacuse instead of power absorbing, -ve Resistan
Produces power.

→ Hence Tunnel diode can be used as a
very high frequency oscillator.

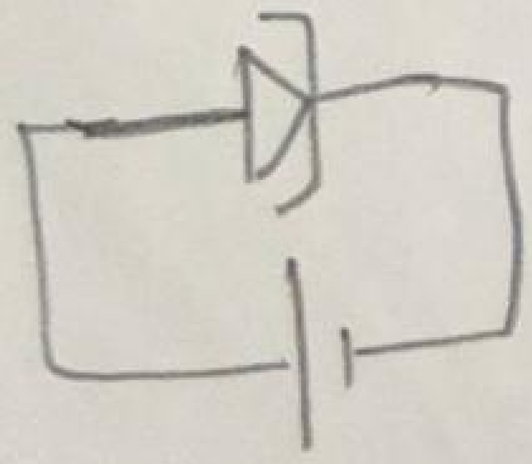
→ For Greater than Vv, the current start incre
in case of a conventional diode.

→ If Tunnel diode is reverse biased, it acts
as a good conductor i.e reverse current increas
with increse in reverse voltage.

RB.



FWB



Explanation of V-I Characteristics Using Energy Band Diagrams

⇒ Due to heavily doping, In P-type material, hole concentration is increased in valance band, In N-Type Material ē concentration is increased in conduction band.

⇒ When P-Type and N-Type Materials are Joined the energy level diagrams shown in fig. There in a rough alignment of respective valance band and conduction band.

→ NO forward current flows across Junction, when NO forward voltage is applied.

⇒ When a small forward voltage is applied ($\approx 0.1V$), Due to upward motion of energy levels of N-region, (at the same time downward motion of P-Type energy le There is some what alignment b/w P & N type energy le so ē in conduction band on N-side cross the barrie and enter in to valance band resulting get som current.

⇒ Further, Increasing in forward voltage, valance band of P-side and conduction band of N-side there two are in exact alignment. at this stag electrons tunneling through depletion layer with velocity of light and gives rise to Large curren This tunneling current reaches to maximum value at a forward bias voltage V_P of the order of 0.1V

⇒ After peak voltage V_P, Further increase the applied forward voltage, the current starts decreasing beacuse of N- region energy levels are raised so high. again there is out of alingment in b/w two energy levels. Forward voltage reaches to valley voltage V_V, the tunneling is stoped, the current reaches to minimum values beacuse of out of alingment in b/w P-Type energy levels and N-Type energy levels.

⇒ B/w Peak current I_P and valley current I_V, Negative dynamic resistance is obtained.

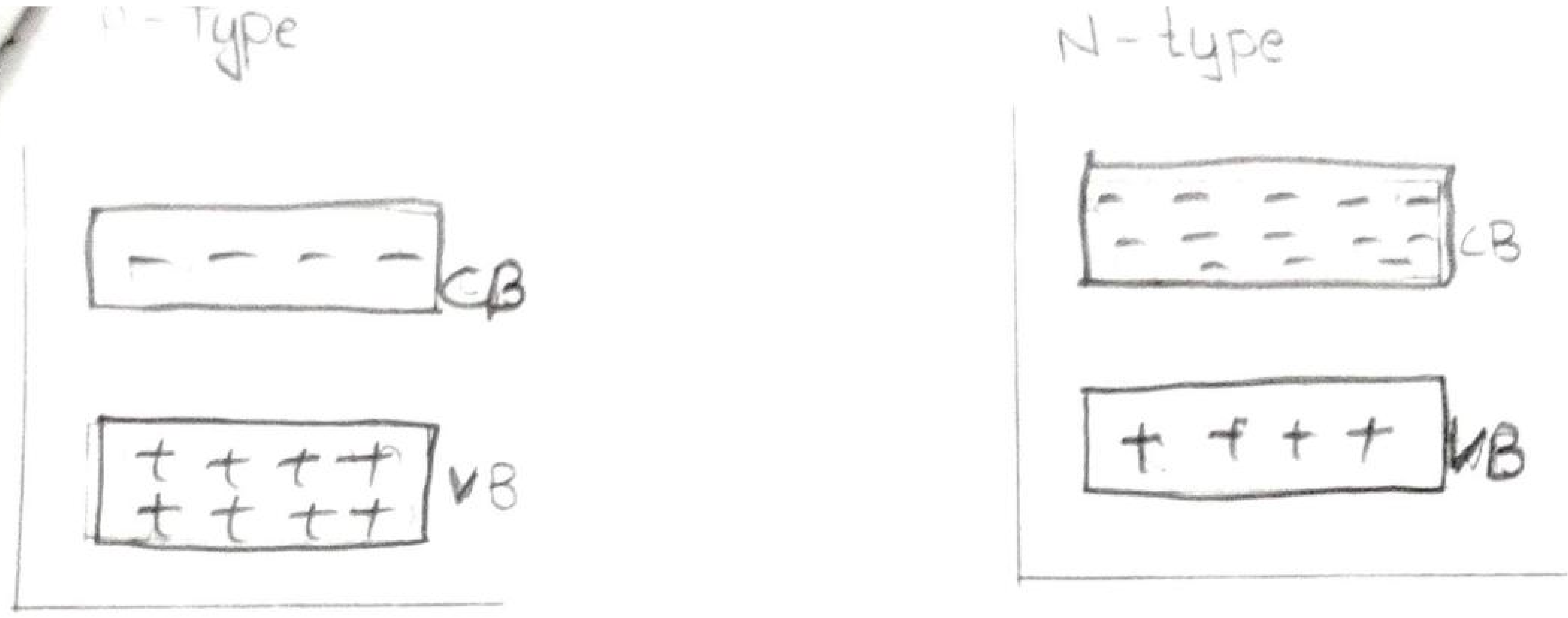
⇒ For voltage greater than V_V, it acts as a normal P-N Junction diode.

Tunneling is much faster than normal crossing. ~~so This is used to Faster swit~~ This enables the tunnel diode to switch on and OFF much faster than ordinary P-N Diode.

Applications

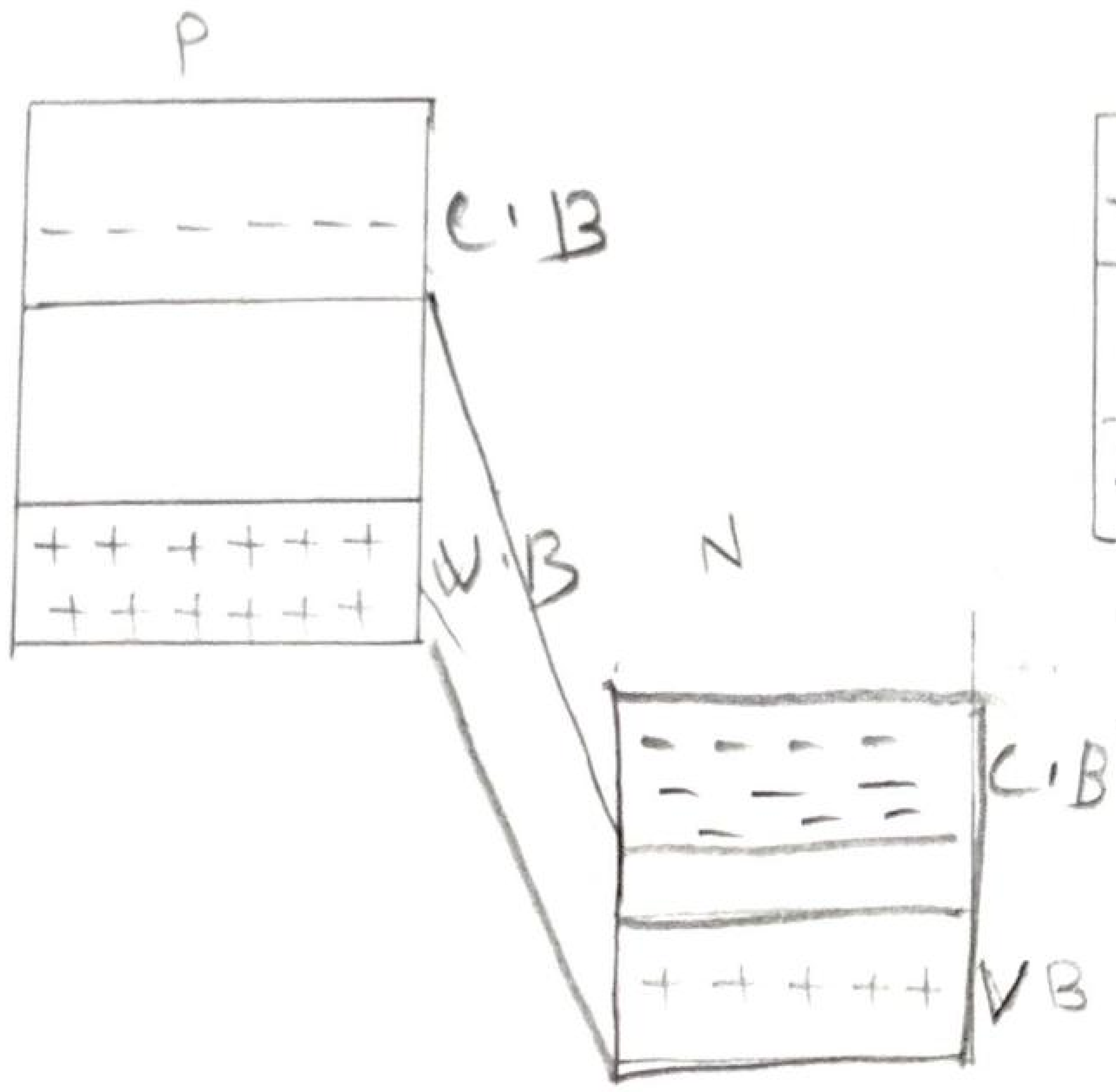
→ High speed computer memories

→ High frequency oscillators.

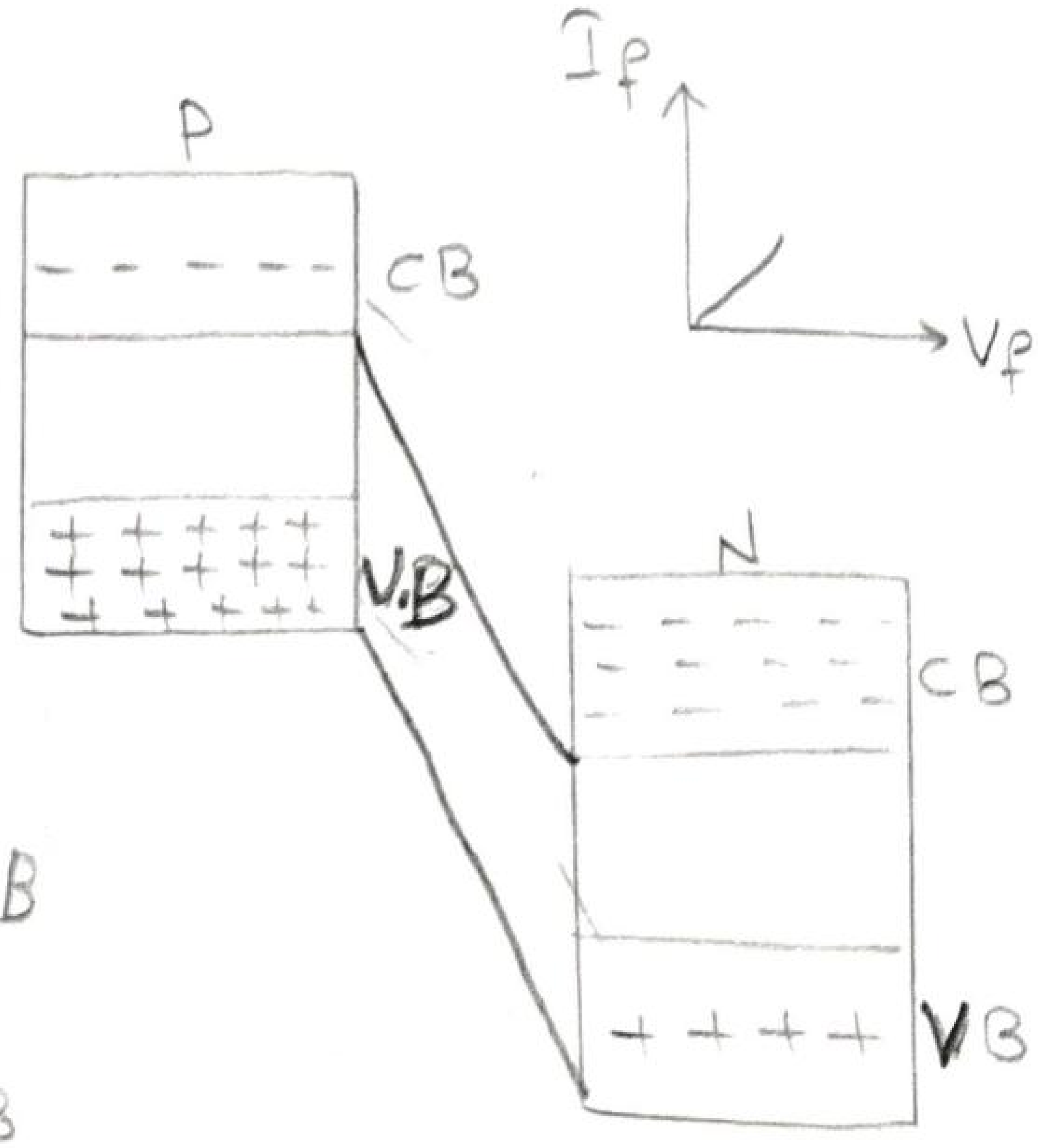


a) Energy band diagram of two types of silicons

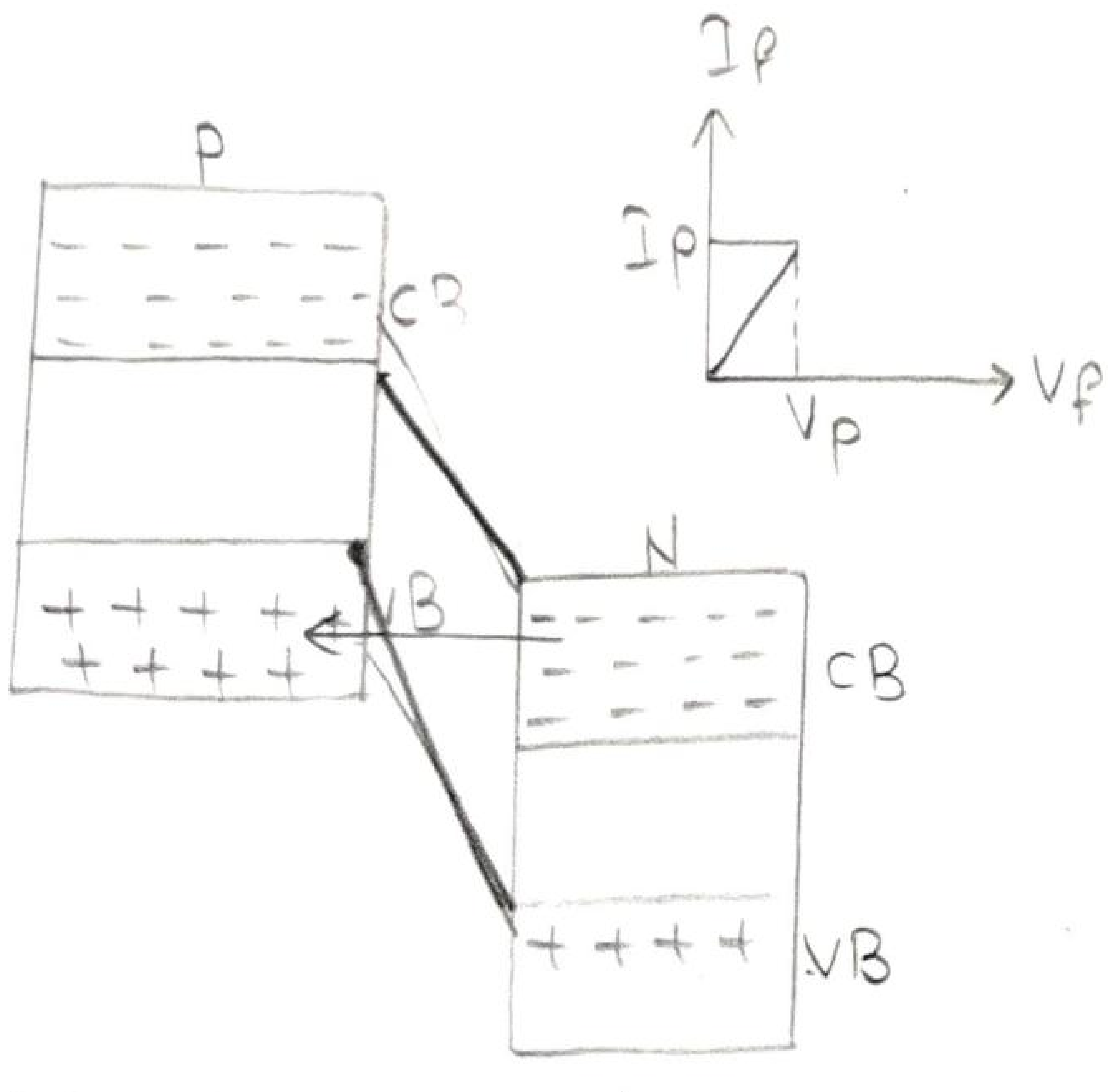
b)

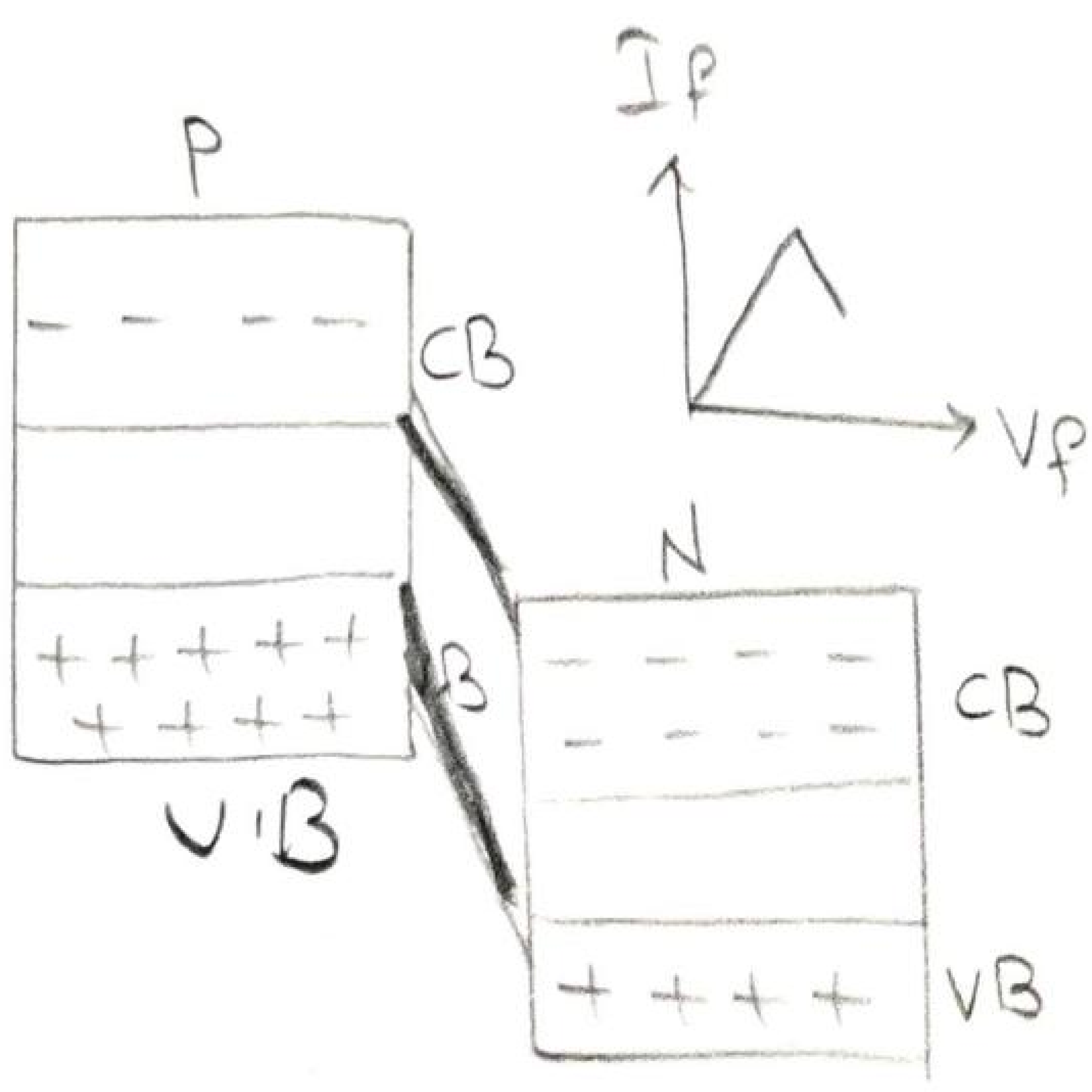


f(2): Without forward voltage



fig(3) small forward voltage





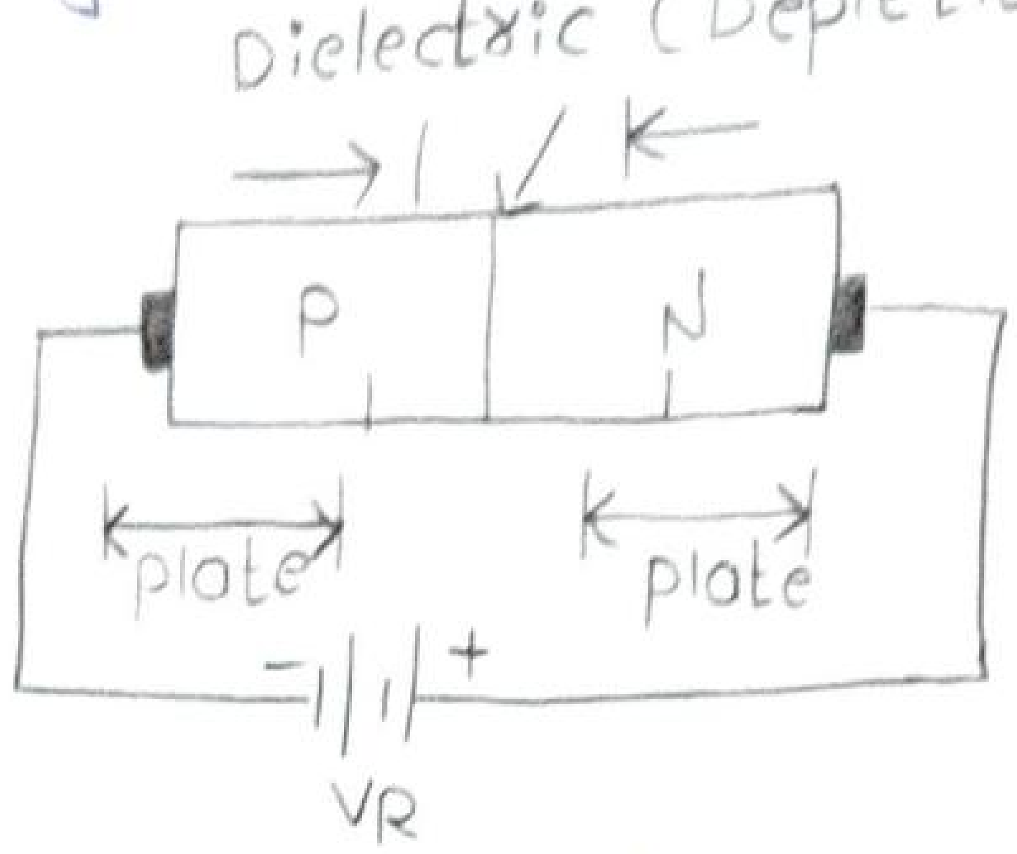
or diode:

We know that the depletion region in a p-N junction forms barrier which separates the positive and negative charges on each side of the junction. Now, the charges can be compared to the charges on the opposite plates of capacitor and the depletion region acting like a dielectric. Thus a p-N junction possesses junction capacitance. When a reverse biased is applied, the junction capacitance decreases because the depletion region width increases. A varactor diode is specially manufactured p-N junction with suitable impurity concentration profile and operated under reverse-biased conditions so as to yield a variable junction capacitance. Special impurity concentration profile ensures negligible junction resistance (which is ordinarily 10 MΩ or more) in comparison with the capacitive reactance of the junction. These diodes are used in low noise parametric amplifiers, harmonic frequency generators and frequency converters or mixers. The symbol with equivalent circuit is shown in fig (5.27)

(a) symbol   b) equivalent circuit

Working:

The circuit of reverse biased varactor diode is shown in fig. We know that on applying a reverse bias to junction, the depletion layer created acts as a capacitor dielectric and P and N regions as the capacitor plates.



When the reverse bias voltage is increased, the depletion layer becomes widened. This increases the dielectric thickness. As a result the capacitance is reduced. On the other hand when reverse bias voltage is decreased, the depletion layer becomes narrower. This decrease the dielectric thickness. In this case, the capacitance is increased.

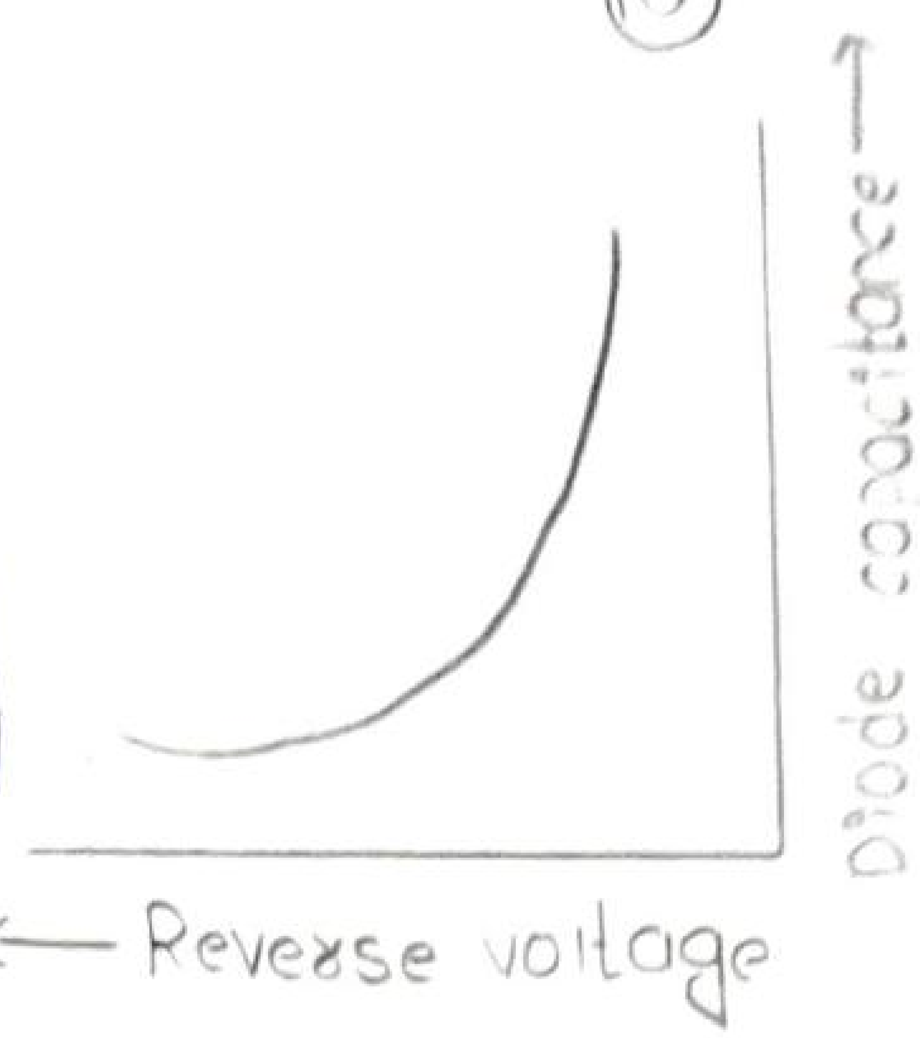
Figure shows the variation of diode capacitance as a function of applied reverse bias voltage. It is obvious from the figure that the variation of capacitance is maximum when reverse bias voltage is zero and it reduces non-linearly as the reverse-biased voltage increases.

The transition capacitance C_T of a reversed biased P-N junction is given by

$$\boxed{C_T = \frac{\epsilon A}{x}}$$

Where ϵ is the permittivity of the semiconductor material, A is the area of P-N junction and x is the width of the space charge region. In terms of applied reverse bias v, the transition capacitance is approximated by the following ession

$$\boxed{C_T = \frac{k}{(V_T + V)^n}}$$



Where, k is the a constant determined by the semiconductor material and fabricated technique, V_T is the volt equivalent temperature, V is the reverse bias applied in Volts. Here $n = (1/2)$ for alloyed junctions and $n = 1/3$ for diffused junctions.

In terms of the capacitance at zero bias condition $C_T(0)$, the capacitance as a function of reverse bias voltage is given by

$$\boxed{C_T = \frac{C_T(0)}{[1 + (V/V_K)]^n}}$$

Where V_K is the diode barrier potential (e.g 0.7 V for Si)

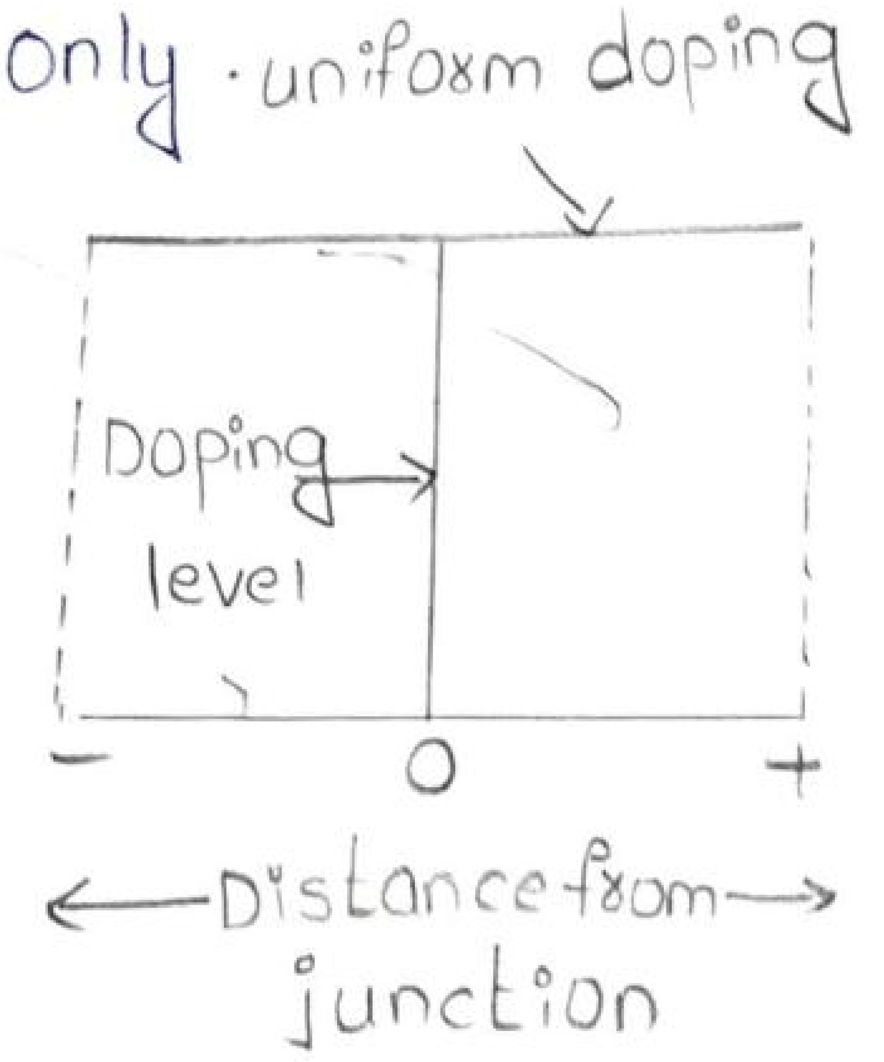
Types of varactor diode.

There are two types of Varactor diode profile

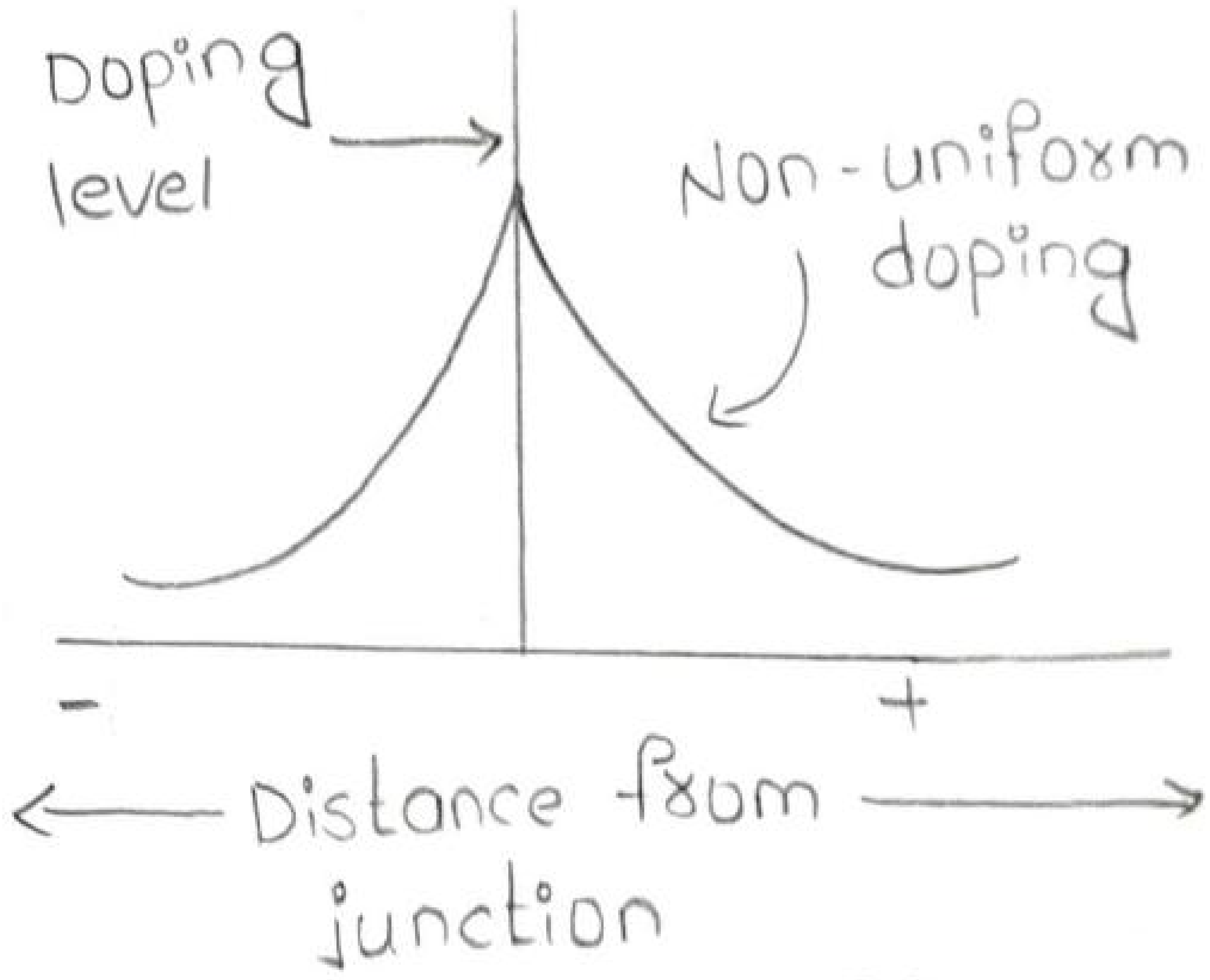
i. Abrupt doping profile ii. Hyper abrupt profile.

In abrupt doping profile, the doping is uniform on both sides of junction while in case of hyper abrupt profile, the doping level increases towards the junction as shown in figure.

In case of hyper abrupt profile, due to narrower depletion layer, a larger capacitance occurs at the junction. so, in this case, a small change in reverse bias voltage makes a larger variation capacitance. Due to this reason, the tuning range for hyper abrupt junction is 10:1. This range is enough to tune a broad cast type receiver over the medium wave band of 550kHz to 1650kHz. It should be remembered that the tuning range of capacitance of an abrupt profile diode is



a) Abrupt doping profile



b) Hyper abrupt profile

Applications:

1. used in parametric amplifier
2. Varactor diode is used in automatic frequency control
3. It is used in tuning circuits
4. used in adjustable band pass filter.