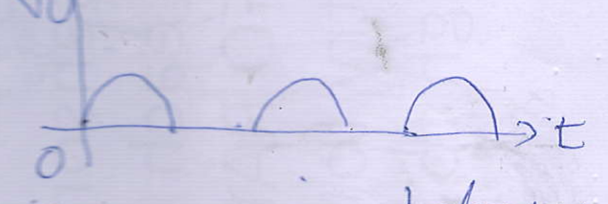
SPECIAL DIODES CONTINUED

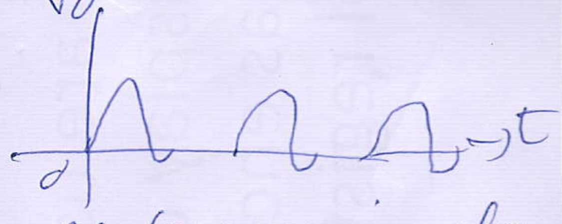
(6) SCHOTTKY DIODE

When ordinary P-N diode is forward biased, the charges are stored in different energy bands near the junction because of lifetime of minority carriers. This effect is referred as charge storage. When a forward biased diode is suddenly reverse biased, a large reverse current exists for a while because of this stored charge. The charge storage prolongs the reverse recovery time.

For ordinary diodes the reverse recovery time is in n secs. At low frequency below 10 MH_z, its effect is not even noticed. However at higher frequencies (more than 10 MH_z), its effect is noticable as output signals begin to deviate from its normal shape.



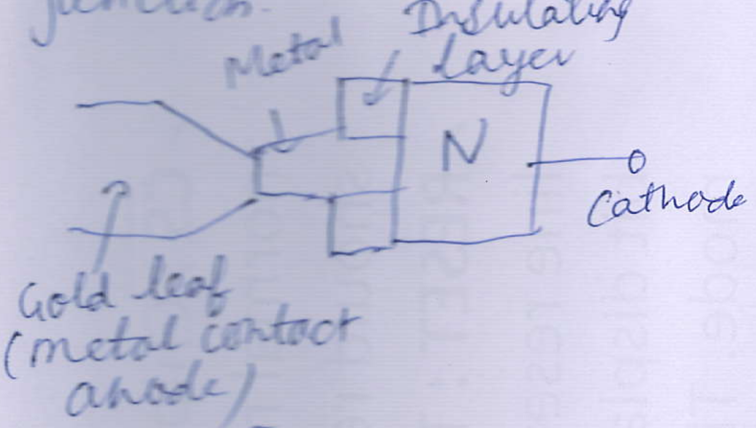
At frequencies below 10 MH_z

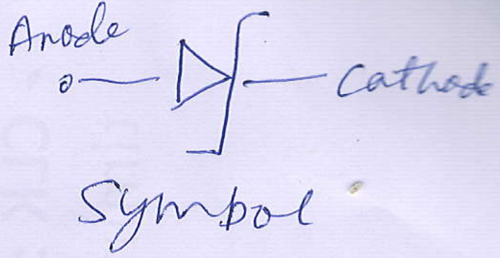


At frequencies above 10 MH_z.

The above problem is eliminated in Schottky diode

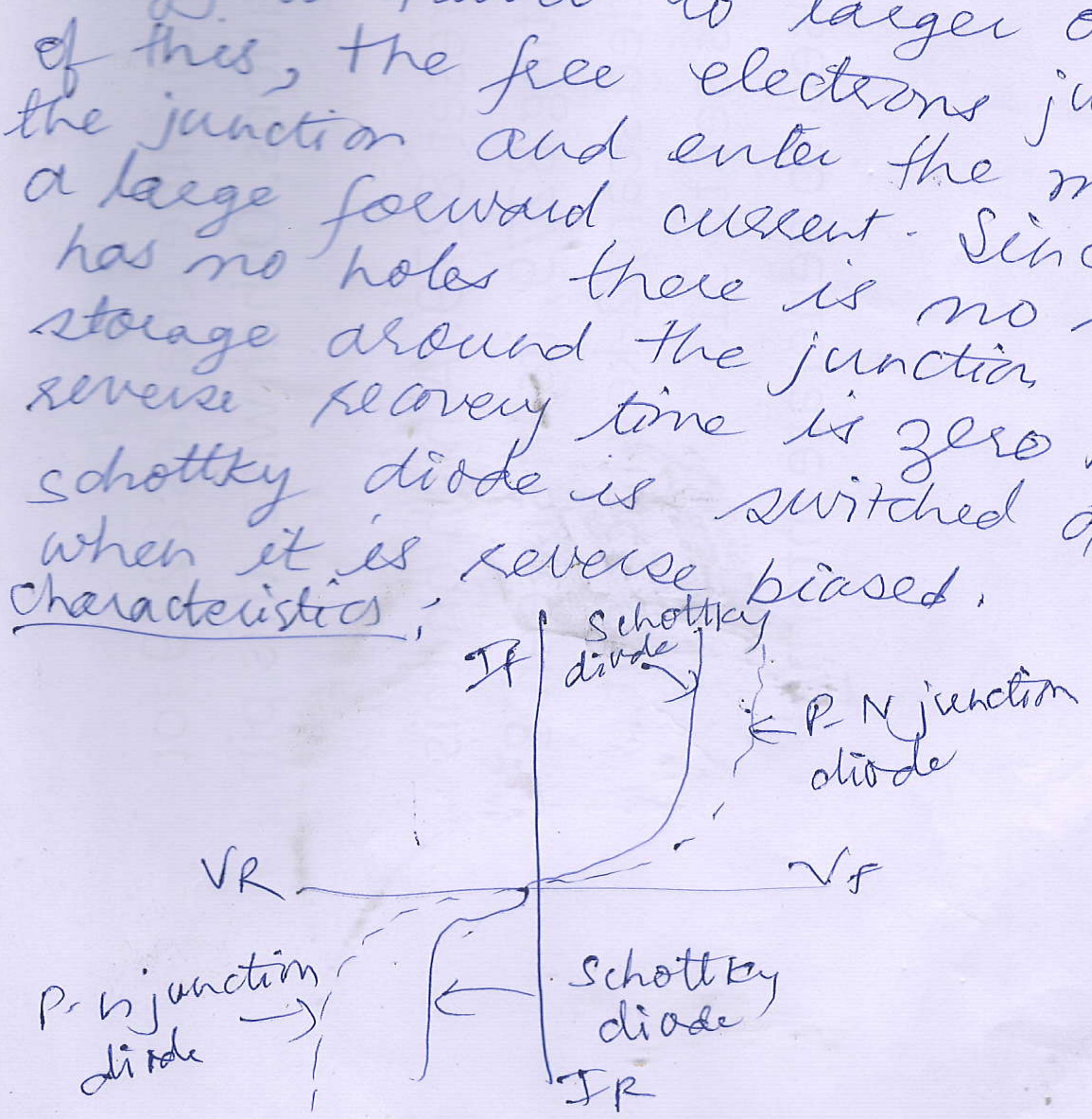
Construction: Schottky diode is formed by joining a doped semiconductor region (~~usual~~ (usually N type) with a metal such as gold, silver or platinum. Thus schottky diode is a metal ~~to~~ semiconductor junction.





Working: In an unbiased diode, the free electrons on N side are in smaller orbit than the free electrons on the metal side. The difference in orbit size creates a barrier potential called schottky barrier.
When the diode is forward biased free electrons on n side gain enough energy to travel to larger orbit. Because of this, the free electrons just cross the junction and enter the metal producing a large forward current. Since metal has no holes there is no charge storage around the junction and the reverse recovery time is zero. Hence the schottky diode is switched off at once when it is reverse biased.

<u>Characteristics</u>:



Applications:

(1) To rectify very high frequency above 300 MHz signals.
(2) As a switching device in digital computers
(3) In clipping & clamping circuits
(4) In low power schottky transistor transistor logic (Schottky TTL) circuits
(5) In low voltage power supply circuits

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(7) TUNNEL DIODE

A conventional P-N diode is doped by impurity atoms in the concentration 1 part in 10^8. With this order of doping, the depletion layer is relatively wide and there exists a potential barrier across the junction; Due to this potential barrier, holes from P to N region and electrons from N to P region cannot cross the junction.

If the concentration of impurity atoms is greatly increased in a P-N junction (~~by about 1000 times~~ i.e. to 1 part in 10^3 atoms then the depletion layer width is reduced to 10^{-6} cm and the device characteristics are completely changed.

Under this condition, many carriers

punch through the junction even when they do not have enough energy to overcome the potential barrier (0.3V Ge & 0.7V Si) Consequently large forward current is produced eventhough the applied bias is much less than 0.3 V or 0.7 V. The phenomenon is known as tunneling.

It is also called Esaki diode.

symbols:

These diodes are usually made of Ge or GaAs.

Volt-Ampere (V-I) characteristics.

Before we study V-I characteristics let us see the energy band structure of Tunnel diode.

To achieve tunneling barrier depth should be very low. However it is not the only condition to achieve tunneling. It is also required that occupied energy states exist on the side from which the electrons tunnel and that allowed empty ~~states~~ energy states exist on the other side at the same level.

In the heavily doped p-n junction E_F (Fermi level) lies outside the forbidden band

For p side:
The Fermi level lies in the valence band,
For n side:
The Fermi level lies in the conduction band

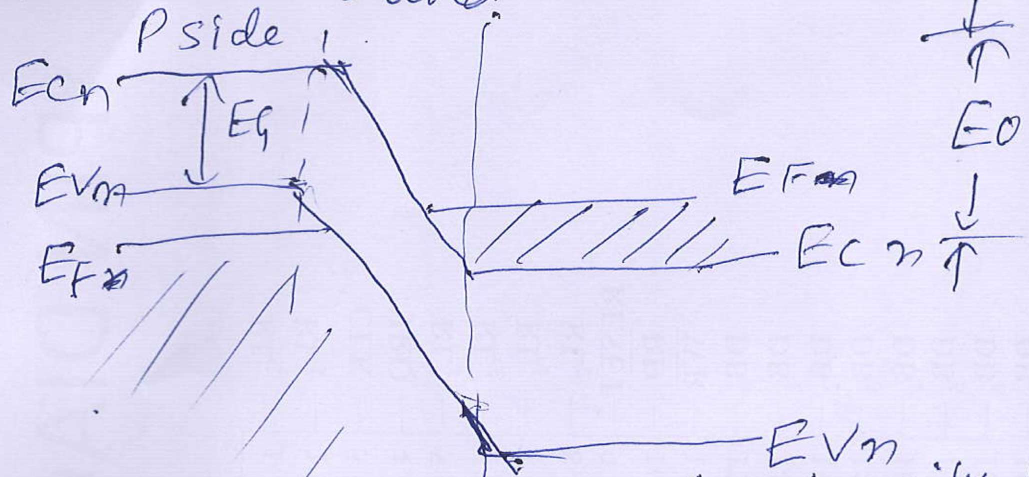
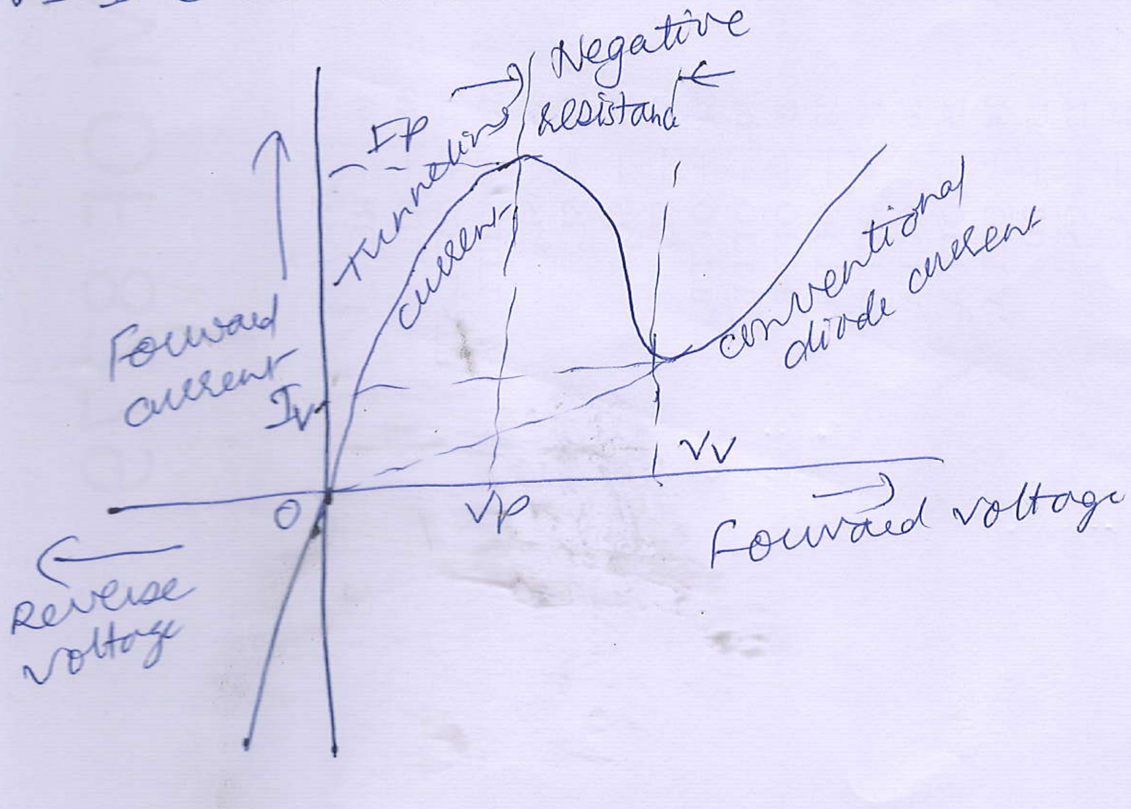


Fig: open circuited heavily doped junction

For tunnel diodes $E_0 > E_G$.

V-I characteristics:



V-I characteristics.

If the tunnel diode is reverse biased it acts as a good conductor i.e. the reverse current increases with increasing reverse voltage.

As soon as the forward bias is applied significant current is produced. The current quickly reaches the its peak value I_p when the applied voltage reaches a value of V_p.

When forward voltage is further increased the current starts decreasing. The current decreases as voltage increases. This results in a negative resistance. The current decreases to I_V corresponding to valley voltage V_V.

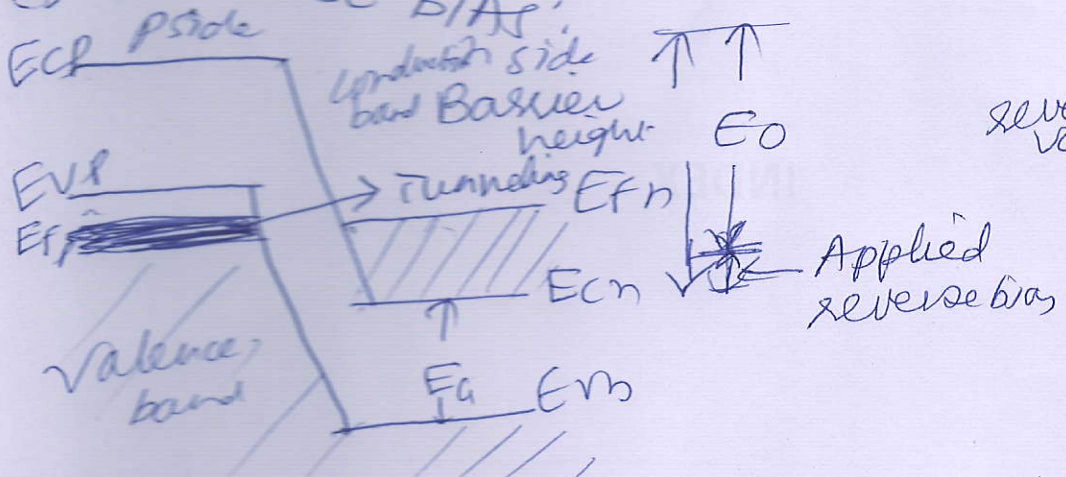
For voltages greater than V_V, current starts increasing as in ordinary p-n diode.

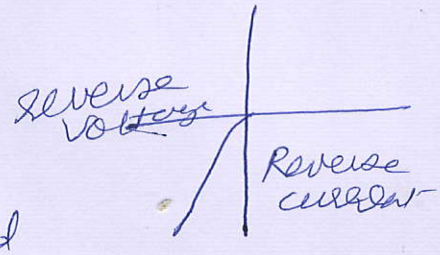
Explanation of V-I characteristics on the base of tunneling theory.

We have already seen in open-~~circu~~ circuited heavily doped junction (tunnel diode), Fermi levels lie in the valence band in case of p type material and conduction band in case of n type material.

As described earlier the condition for tunneling to occur is that empty allowed energy bands must lie opposite the filled energy levels on the other side.

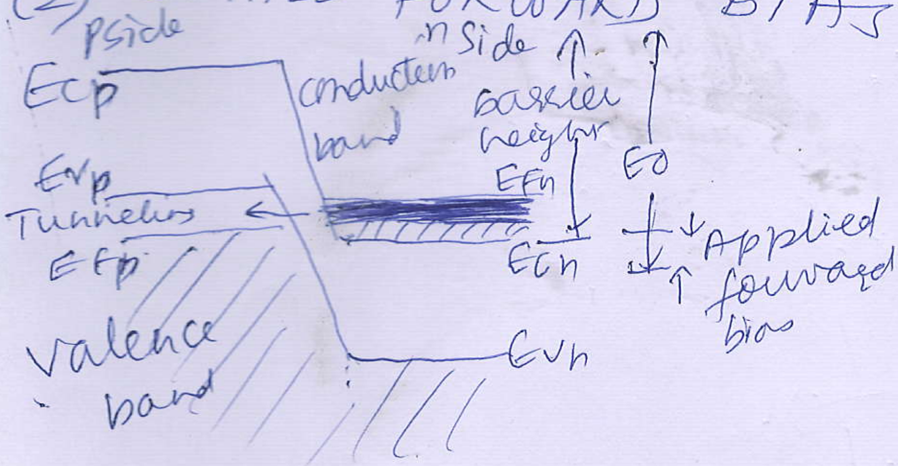
(1) REVERSE BIAS:

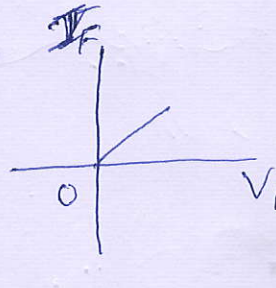




When reverse bias is applied, the height of the barrier is increased above the open circuit value Eo. Hence the 'n' side levels must shift downwards with respect to p side levels. There are some energy states in the valence band of the 'p' side which lie at the same level as allowed empty states in the conduction band of the n side. Hence these electrons will tunnel from the p to n side giving rise to reverse diode current. As the reverse bias increase, the number of electrons from p to n side increase causing reverse current to increase

(2) SMALL FORWARD BIAS

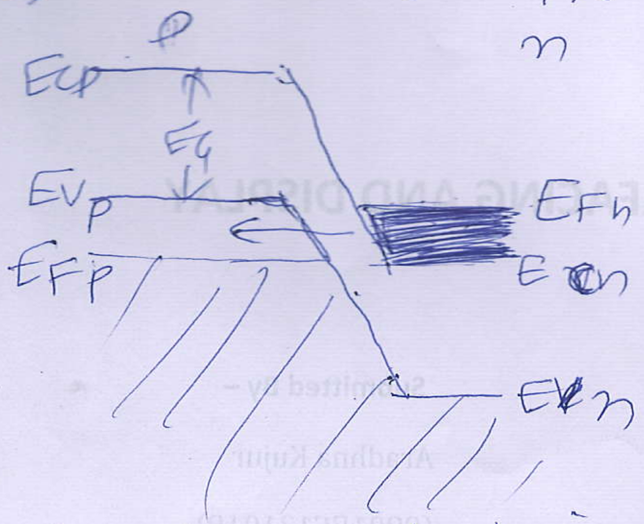


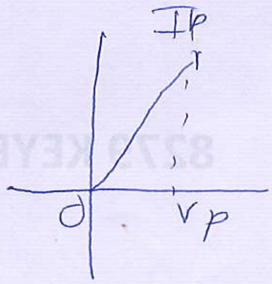


When the forward bias is applied, E_0 decreases. Hence the n side levels must shift upwards w.r.t. those on p side.

There are occupied states in the conduction band of the n material which are at the same energy as allowed empty states in the valence band of p side. Hence the electrons will tunnel from n to p side giving rise to forward current.

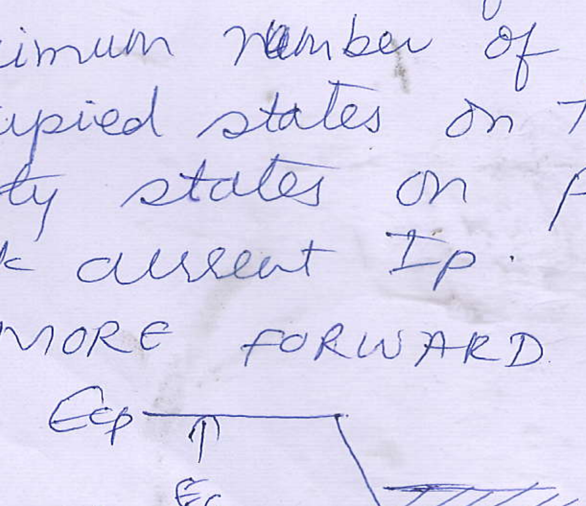
(3) INCREASE IN FORWARD BIAS

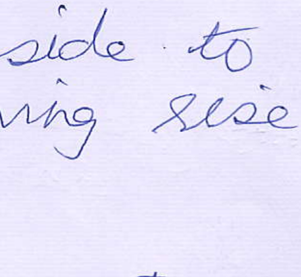




As forward bias is increased further n side levels shift further upward. Maximum number of electrons can leave occupied states on the ~~left~~ n side to empty states on p side giving rise to peak current Ip.

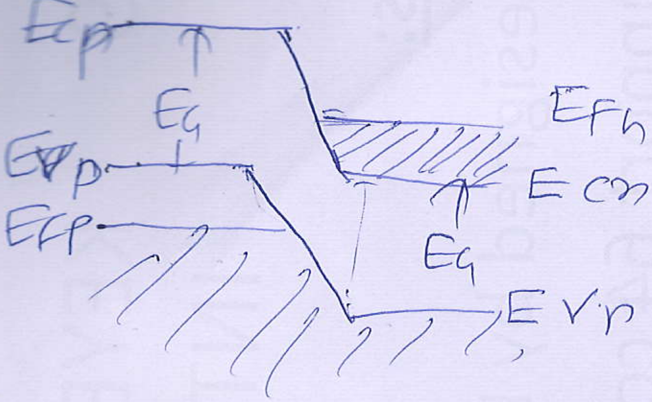
(4) MORE FORWARD BIAS

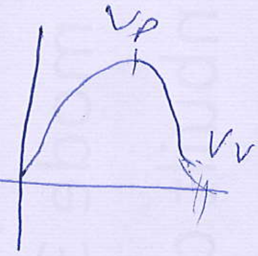




After V_p as the applied voltage is increased, the current starts decreasing because the number of occupied energy levels opposite empty levels on p side goes on decreasing.

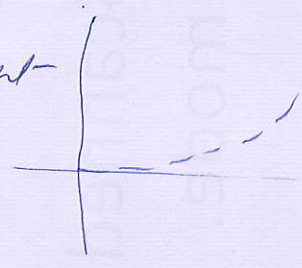
(5) LARGER FORWARD BIAS

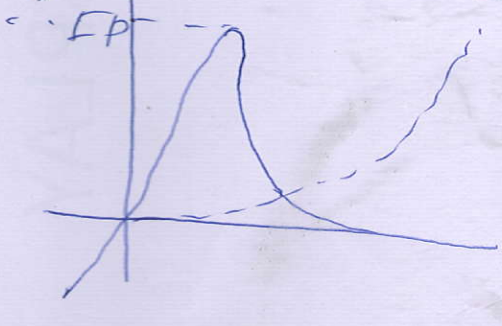


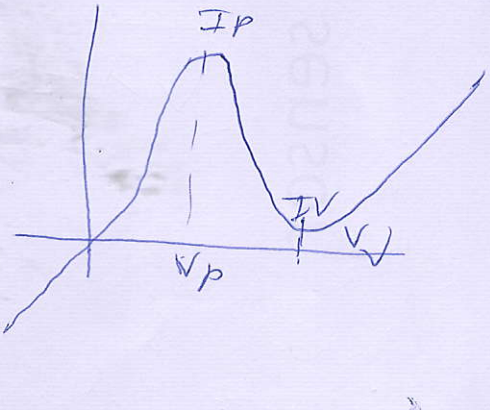


There are no empty allowed states on p side (You can see that now forbidden gap is lying opposite to filled states on n side). Hence the tunneling current drops to zero.

There is a regular current flowing as in the case of ordinary p-n junction.







Tunnel diode parameters

(1) Negative resistance; It is defined as the resistance offered by tunnel diode in negative resistance region.,

$$R_n = \frac{\Delta V_F}{\Delta I_F}$$

ΔV_F = change in forward voltage between any two points lying within negative resistance region of V-I characteristic

ΔI_F = corresponding change in ~~I_F~~ forward current

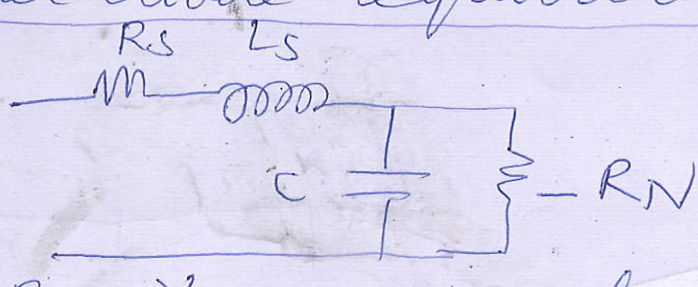
(2) current ratio I_r

It is the ratio of peak current I_P to valley current I_V

$$I_r = \frac{I_P}{I_V}$$

This parameter is important in high speed switching circuits

Tunnel diode equivalent circuit:



Rs = Resistance due to leads, contacts and semiconductor material

Ls = inductance due to lead lengths

C = due to diffusion capacitance and applied voltage

$-R_n$ = negative resistance offered by tunnel diode between I_P and I_V

Tunnel diode applications

(1) As an ultra high speed switching device. It is possible due to the tunneling mechanism which takes place at the speed of light. The switching time is of the order of 10^{-9} secs.

(2) As a logic memory storage device. It is possible because of the triple values of the curve for current between I_P & I_V

(3) As a microwave oscillator at frequencies in the order of 10GHz. It is possible due to extremely low values of inductance and capacitance of the device.

(4) In relaxation oscillator. It is possible due to negative resistance of the device.