Project-I Report
On

# Tunnel Diode

*Submitted towards the partial fulfillment of requirement for the award of the degree of*

## Bachelor of Technology

*IN*

***Information Technology***

*Submitted by:*



| Name | Roll number |
|---|---|
| ***Ankit Khatri*** | ***2K20/B9/73*** |
| ***Ankit Kumar*** | ***2K20/B9/74*** |

Under the Supervision

*Of*

**D.C. Meena**

**Department of Electrical Engineering**

Delhi Technological University

Bawana Road, Delhi - 110034

# DECLARATION

We hereby certify that the work, which is presented in the Project-I entitled ***Tunnel Diode*** in fulfilment of the requirement for the award of the Degree of Bachelor of Technology in Engineering Physics and submitted to the Department of Applied Physics, Delhi Technological University, Delhi is carried out under the supervision of **D.C Meena.**

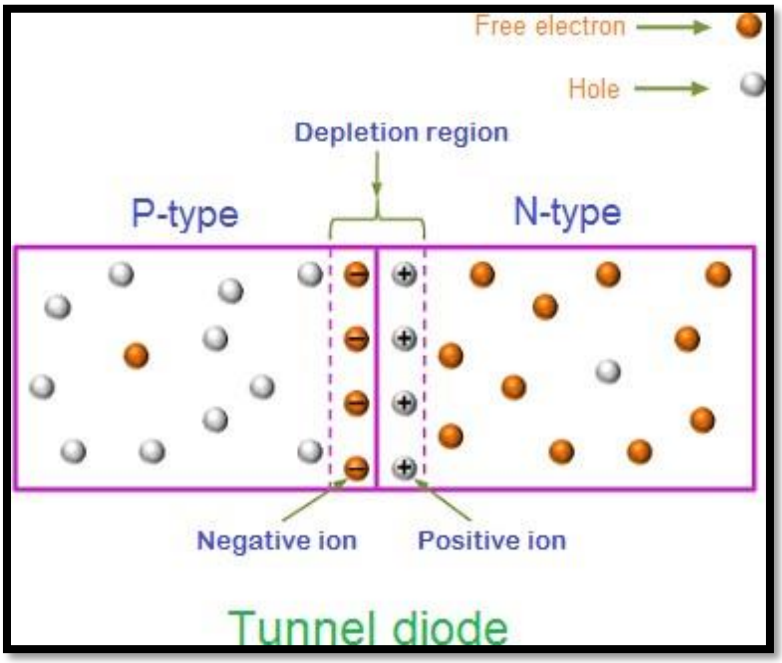
The work presented in this report has not been submitted and not under consideration for the award for any other course/degree of this or any other Institute/University.

| **Name** | **Roll number** |
|---|---|
| ***Ankit Khatri*** | ***2K20/B9/73*** |
| ***Ankit Kumar*** | ***2K20/B9/74*** |

# Tunnel diode

## Tunnel diode: Introduction

Tunnel diode is one of many types of semiconductor diode that has effective “negative resistance” due to the quantum mechanical effect which is called tunneling. Tunnel diodes have a heavily doped pn junction i.e, about 10 nm wide.



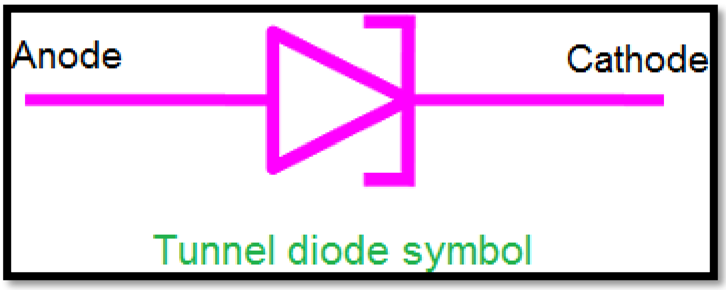

For the high frequency applications many devices use the negative conductance property of semiconductors . A tunnel diode is one of the most commonly used negative conductance devices in today times.

It another name is Esaki diode after scientist named L. Esaki for his work on this effect.

The concentration of holes and electrons in p and n region respectively is very high. The p-n junction is also abrupt. For this reasons, the depletion layer width is kept very small. Characteristics of **tunnel diode** in the current voltage, has a negative slope region when a forward bias is applied.

## Symbol of tunnel diode

In tunnel diode, the p-type semiconductor behave as an anode and the n-type semiconductor behave as a cathode as shown in the figure below.

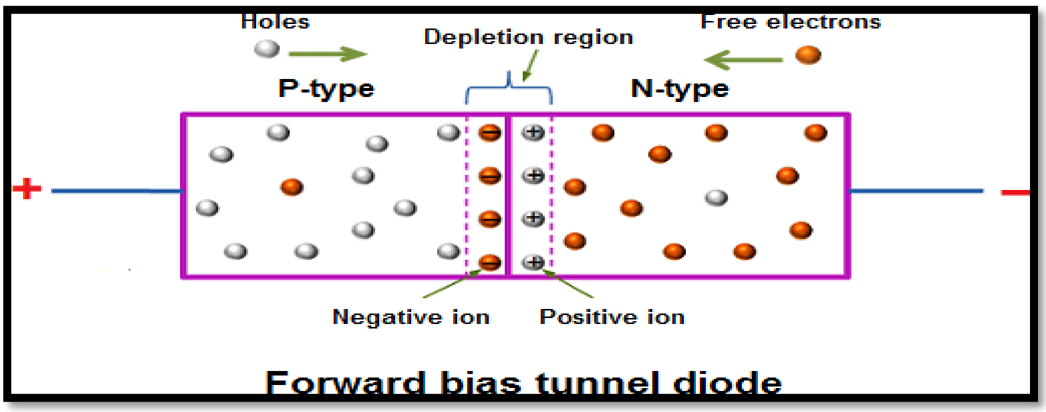



## Depletion region

The depletion region is found in a p-n junction diode where mobile charge carriers (free electrons and holes) are not present.

The width of a depletion region depends on the quantity of impurities added. We add impurities into the p-type and n-type semiconductor so as to increase electrical conductivity.

If impurities added to the p-n junction diode are small (p-type and n-type semiconductor), a wide depletion region is formed. On the other hand a narrow depletion region is formed ,if large number of impurities are added to the p-n junction diode.



The p-type and n-type semiconductor in tunnel diode,is heavily doped which means a large number of impurities are added to the p-type and n-type semiconductor. This heavy doping process produces an extremely narrow depletion region. The concentration of impurities in tunnel diode is thousand times greater than the normal p-n junction diode.

In normal p-n junction diode, the depletion width is large as compared to the tunnel diode. This wide depletionlayerordepletion region innormal diodeopposes the flowof current. Hence,depletionlayer acts asabarrier.Toovercomethisbarrier,weneedtoapplysufficientvoltage.Whensufficientvoltage is applied, electric current starts flowing through the normal p-n junction diode.

Unlike the normal p-n junction diode, the width of a depletion layer in tunnel diode is extremely narrow. So applying a small voltage is enough to produce electric current in tunnel diode.

Tunnel diodes are capable of remaining stable for a long duration of time than the ordinary p-n junction diodes. They are also capable of high-speed operations.

### Concept of tunneling

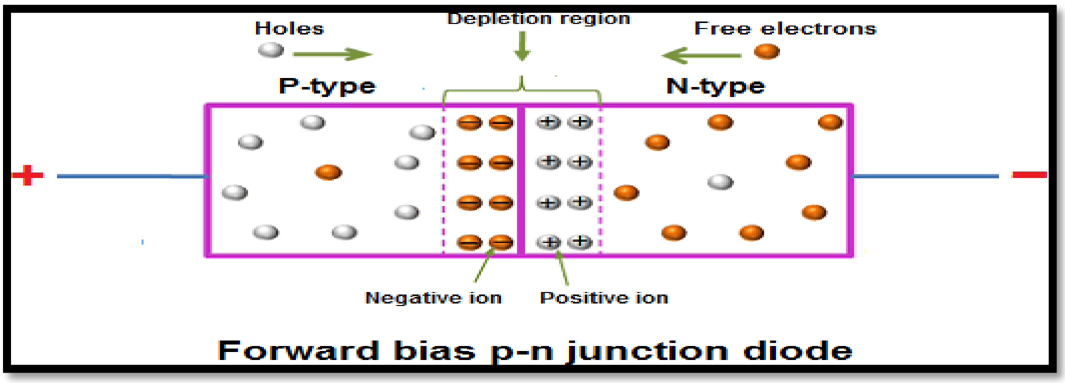
Thedepletion region or depletion layer inap-n junction diode ismadeup of positiveions andnegative ions. Becauseofthesepositiveandnegativeions,thereexistsabuilt-in-potentialor electricfield inthe depletion region. This electric field in the depletion region exerts electric force in a direction opposite to that of the external electric field (voltage).

Anotherthing we need to rememberis thatthe valence band and conduction band energylevels in the n-type semiconductor are slightly lower than the valence band and conduction band energy levels in thep-typesemiconductor.Thisdifferenceinenergylevelsisduetothedifferencesintheenergylevels of the dopant atoms (donor or acceptor atoms) used to form the n-type and p-typesemiconductor.

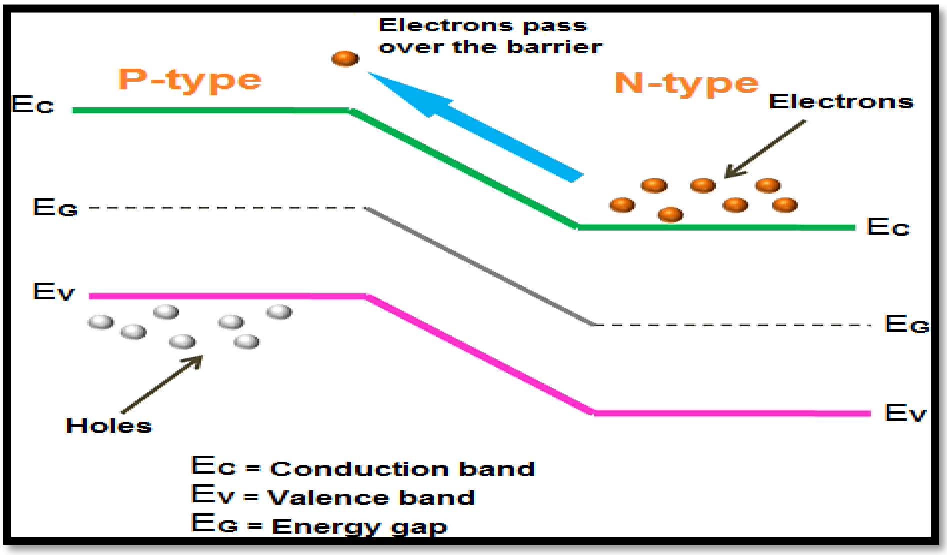
## Ordinary p-n junction vs Tunnel diode

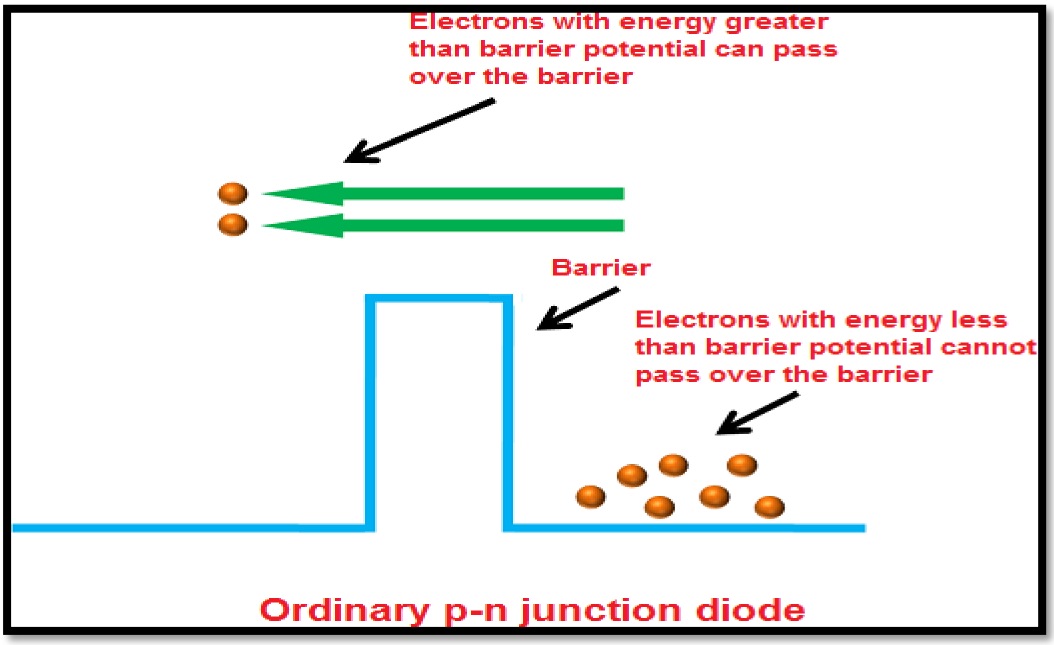
### Electric current in ordinary p-n junction diode

When a forward bias voltage is applied to the ordinary p-n junction diode, the width of depletionregiondecreasesandatthesametimethebarrierheightalsodecreases.However, the electrons in the n-type semiconductor cannot penetrate through the depletion layer because the built-in voltage of depletion layer opposes the flow ofelectrons.




If the applied voltage is greater than the built-in voltage of depletion layer, the electrons from n-side overcomes the opposing force from depletion layer and then enters into p-side. In simple words, the electrons can pass over the barrier (depletion layer) if the energy of the electrons is greater than the barrier height or barrier potential.

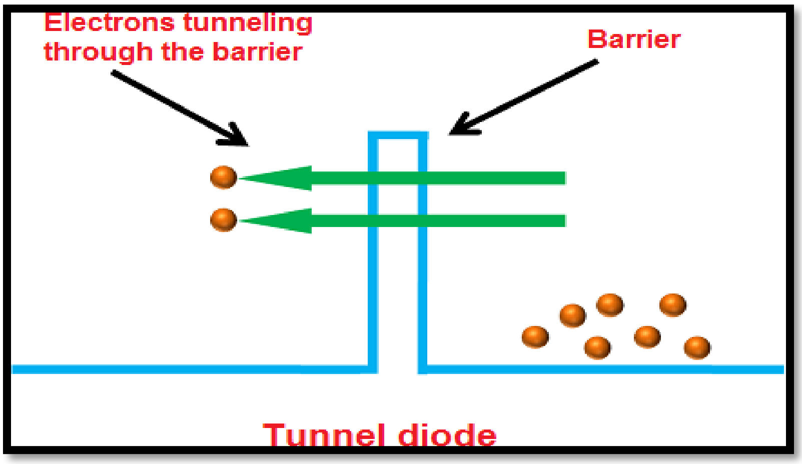



Therefore, an ordinary p-n junction diode produces electric current only if the applied voltage is greater than the built-in voltage of the depletion region.

## Electric current in tunnel diode

In tunnel diode, the valence band and conduction band energy levels in the n-type semiconductor are lower than the valence band and conduction band energy levels in the p-type semiconductor. Unlike the ordinary p-njunction diode,thedifferencein energylevelsisveryhighintunnel diode.Becauseof this high difference in energy levels, the conduction band of the n-type material overlaps with the valence band of the p-type material.

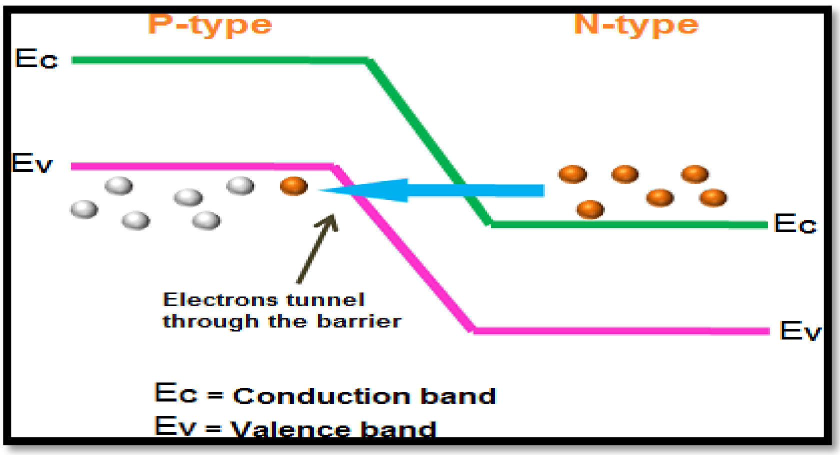



Quantum mechanics says that the electrons will directly penetrate through the depletion layer or barrier if the depletion width is very small.

The depletion layer of tunnel diode is very small. It is in nanometers. So the electrons can directly tunnel across the small depletion region from n-side conduction band into the p-side valence band.

In ordinary diodes, current is produced when the applied voltage is greater than the built-in voltage of the depletion region. But in tunnel diodes, a small voltage which is less than the built-in voltage of depletion region is enough to produce electric current.

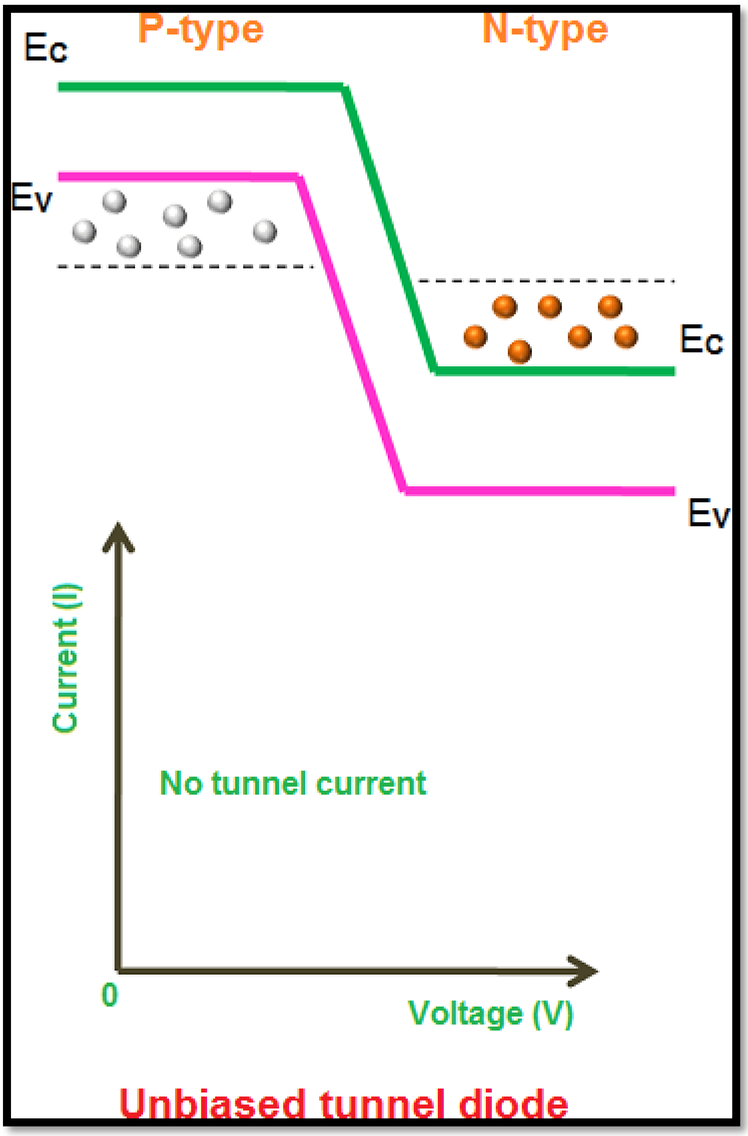
In tunnel diodes, the electrons need not overcome the opposing force from the depletion layer to produce electric current. The electrons can directly tunnel from the conduction band of n-region into the valence band of p-region. Thus, electric current is produced in tunnel diode.



## Working of Tunnel Diode

Step 1: Unbiased tunnel diode

When no voltage is applied to the tunnel diode, it is said to be an unbiased tunnel diode. In tunnel diode, the conduction band of the n-type material overlaps with the valence band of the p-type material because of the heavy doping.



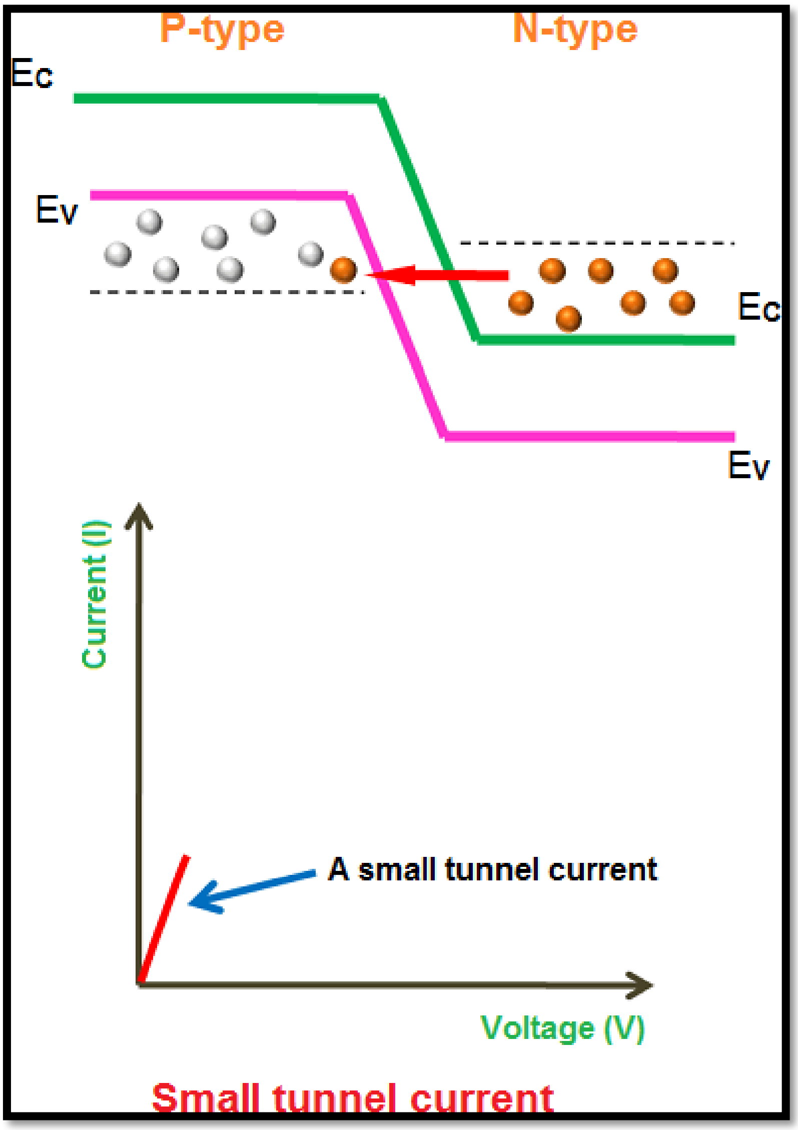

Because of this overlapping, the conduction band electrons at n-side and valence band holes at p-side arenearlyat thesameenergylevel.Sowhenthetemperatureincreases,someelectronstunnelfrom the conduction band of n-region to the valence band of p-region. In a similar way, holes tunnel from the valence band of p-region to the conduction band of n-region.

However, the net current flow will be zero because an equal number of charge carriers (free electrons and holes) flow in opposite directions.

Step 2: Small voltage applied to the tunnel diode

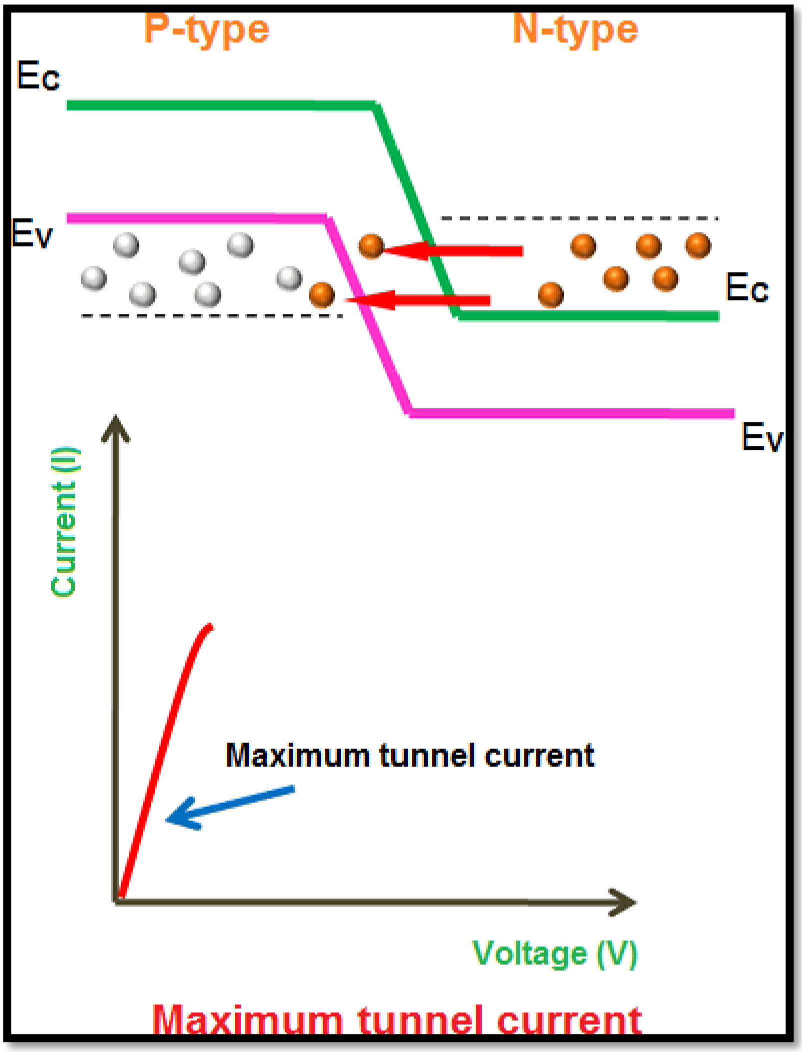
When a small voltage is applied to the tunnel diode which is less than the built-in voltage of the depletion layer, no forward current flows through the junction.

However, a small number of electrons in the conduction band of the n-region will tunnel to the empty states of the valence band in p-region. This will create a small forward bias tunnel current. Thus, tunnel current starts flowing with a small application of voltage.



Step 3: Applied voltage is slightly increased

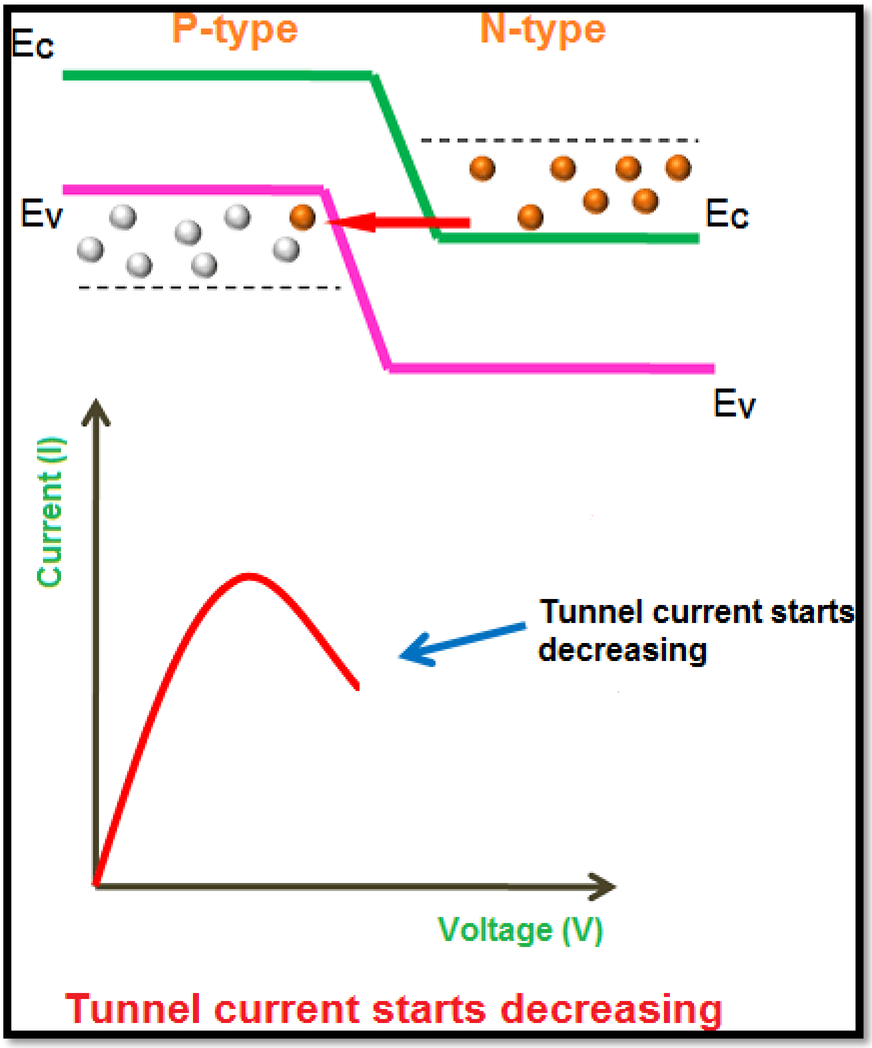
When the voltage applied to the tunnel diode is slightly increased, a large number of free electrons at n-side and holes at p-side are generated. Because of the increase in voltage, the overlapping of the conduction band and valence band is increased.




In simple words, the energy level of an n-side conduction band becomes exactly equal to the energy level of a p-side valence band. As a result, maximum tunnel current flows.

Step 4: Applied voltage is further increased

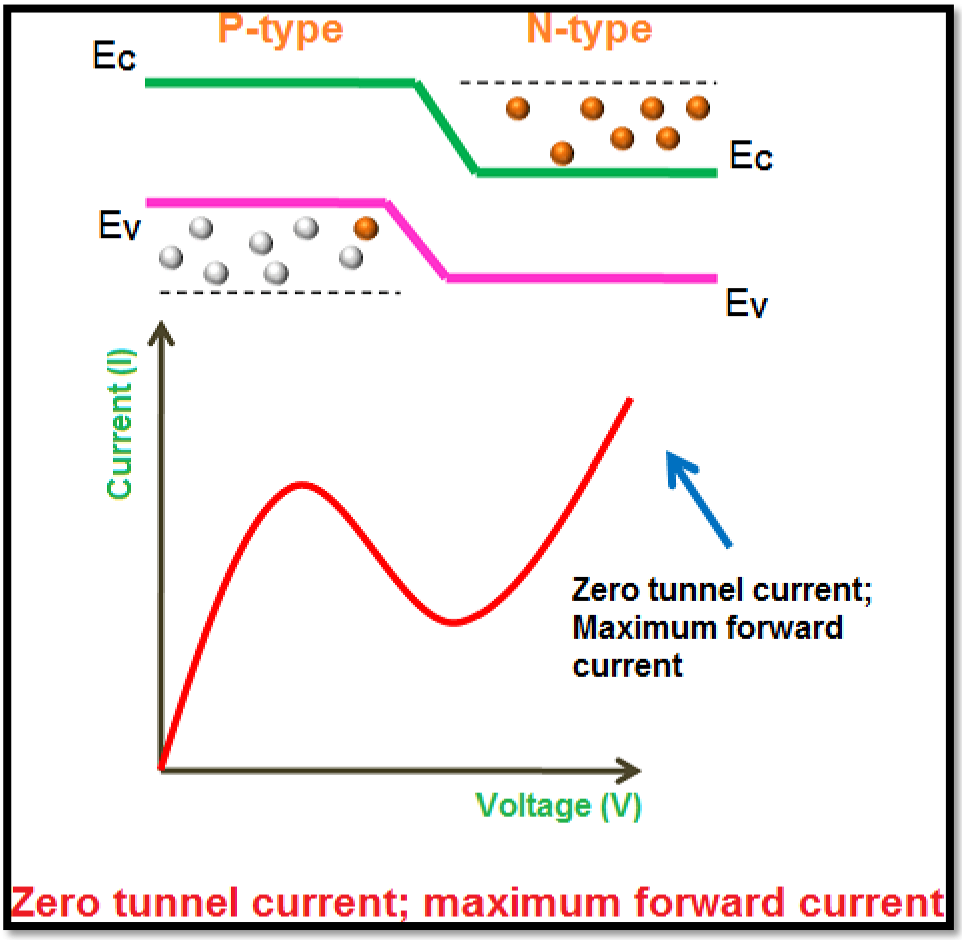
If the applied voltage is further increased, a slight misalign of the conduction band and valence band takes place.




Since the conduction band of the n-type material and the valence band of the p-type material sill overlap. The electrons tunnel from the conduction band of n-region to the valence band of p-region and cause a small current flow. Thus, the tunneling current starts decreasing.

Step 5: Applied voltage is largely increased

If the applied voltage is largely increased, the tunneling current drops to zero. At this point, the conductionbandandvalencebandnolongeroverlapandthetunneldiodeoperatesinthesamemanner as a normal p-n junction diode.




If this applied voltage is greater than the built-in potential of the depletion layer, the regular forward current starts flowing through the tunnel diode.

The portion of the curve in which current decreases as the voltage increases is the negative resistance region of the tunnel diode. The negative resistance region is the most important and most widely used characteristic of the tunnel diode.

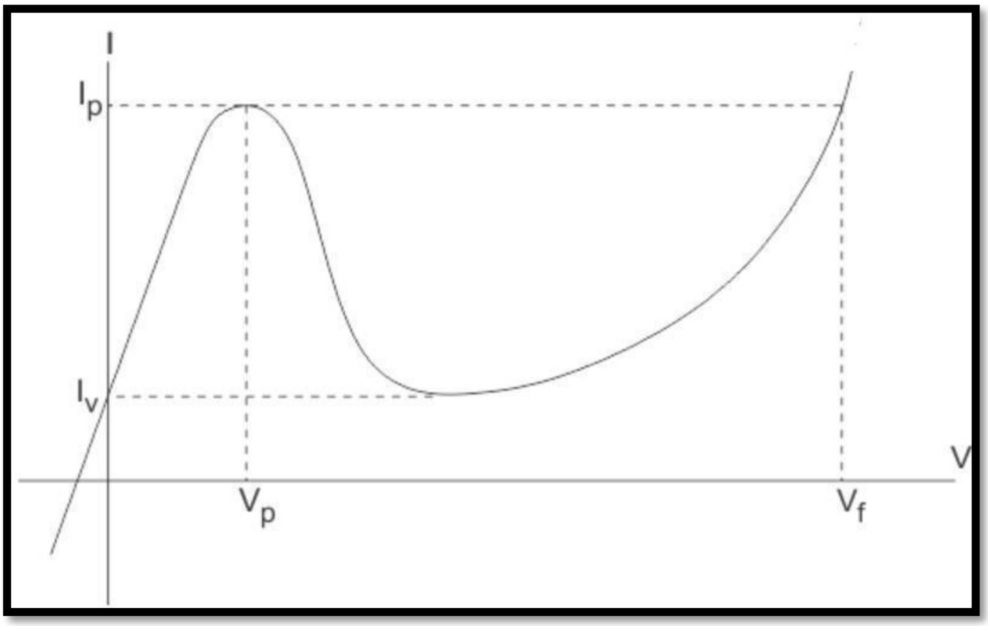
A tunnel diode operating in the negative resistance region can be used as an amplifier or an oscillator.

## Characteristics of Tunnel Diode

When reverse bias is applied the Fermi level of the p-side becomes higher than the Fermi level of n-side. Hence, the tunneling of electrons from the balance band of p-side to the conduction band of n-side takes place. With the interments of the reverse bias the tunnel current also increases.

When forward bias is applied the Fermi level of n-side becomes higher that the Fermi level of p-side, thus the tunneling of electrons from the n-side to p-side takes place. The amount of the tunnel current is very large than the normal junction current. When the forward bias is increased, the tunnel current is increased up to certain limit.

When the band edge of n-side is the same as the Fermi level in p-side, the tunnel current is maximum with the further increment in the forward bias the tunnel current decreases and we get the desired negative conduction region. When the forward bias is raised further, normal pn junction current is obtained which is exponentially proportional to the applied voltage. The V-I characteristics of the tunnel diode is given by




## Tunnel Diode Applications

**Tunnel diode** is a type of sc diode which is capable of very fast and in microwave frequency range. It was the quantum mechanical effect which is known as tunneling. It is ideal for fast oscillators and receivers for its negative slope characteristics. But it cannot be used in large integrated circuits – that's why it's an applications are limited.

When the voltage is first applied current stars flowing through it. The current increases with the increase of voltage. Once the voltage rises high enough suddenly the current again starts increasing and tunnel diode stars behaving like a normal diode. Because of this unusual behavior, it can be used in number of special applications started below.

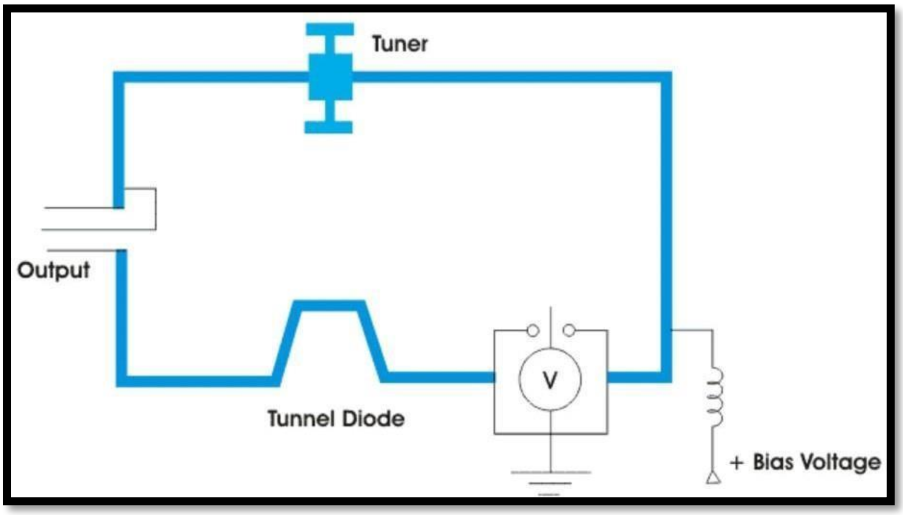
***Oscillator Circuits:***

***Tunnel diodes can be used as high frequency oscillators as the transition between the high electrical***

conductivity is very rapid. They can be used to create oscillation as high as 5Gz. Even they are capable of creativity oscillation up to 100 GHz in a appropriate digital circuits.

**Tunnel Diode Oscillator**

Tunnel diode can make a very stable oscillator circuit when they are coupled to a tuned circuit or cavity, biased at the centre point of negative resistance region. Here is an example of tunnel diode oscillatory circuit.




The tunnel diode is losing coupled to a tunable cavity. By using a short, antenna feed probe placed in the cavity off center loose coupling is achieved. To increase the stability of oscillation and achieve o/p power over wider bandwidth loose coupling is used. The range of the output power produced is few hundred micro-watts.

This is useful for many microwave application. The physical position of the tuner determining the frequency of operation. If the frequency of operation is changed by this method, that is called mechanical tuning. Tunnel diode oscillators can be tuned electronically also.

Tunnel diode oscillators which are meant to be operated at microwave frequencies, generally used some form of transmission lines as tunnel circuit. These oscillators are useful in application that requires a few millwatts of power, example- local oscillators for microwave super electrodyne receiver.

***Used in Microwave Circuits***:

Normal diode transistors do not perform well in microwave operation. So, for microwave generators and amplifiers tunnel diode are used. In microwave waves and satellite communication equipment they were used widely, but lately their usage is decreasing rapidly, as transistors which operate in this frequency range are becoming available.

***Used in Microwave Circuits***:

Tunnel diodes are resistant to the effects of magnetic fields, high temperature and radioactivity. That's why these can be used in modern military equipment. These are used in nuclear magnetic