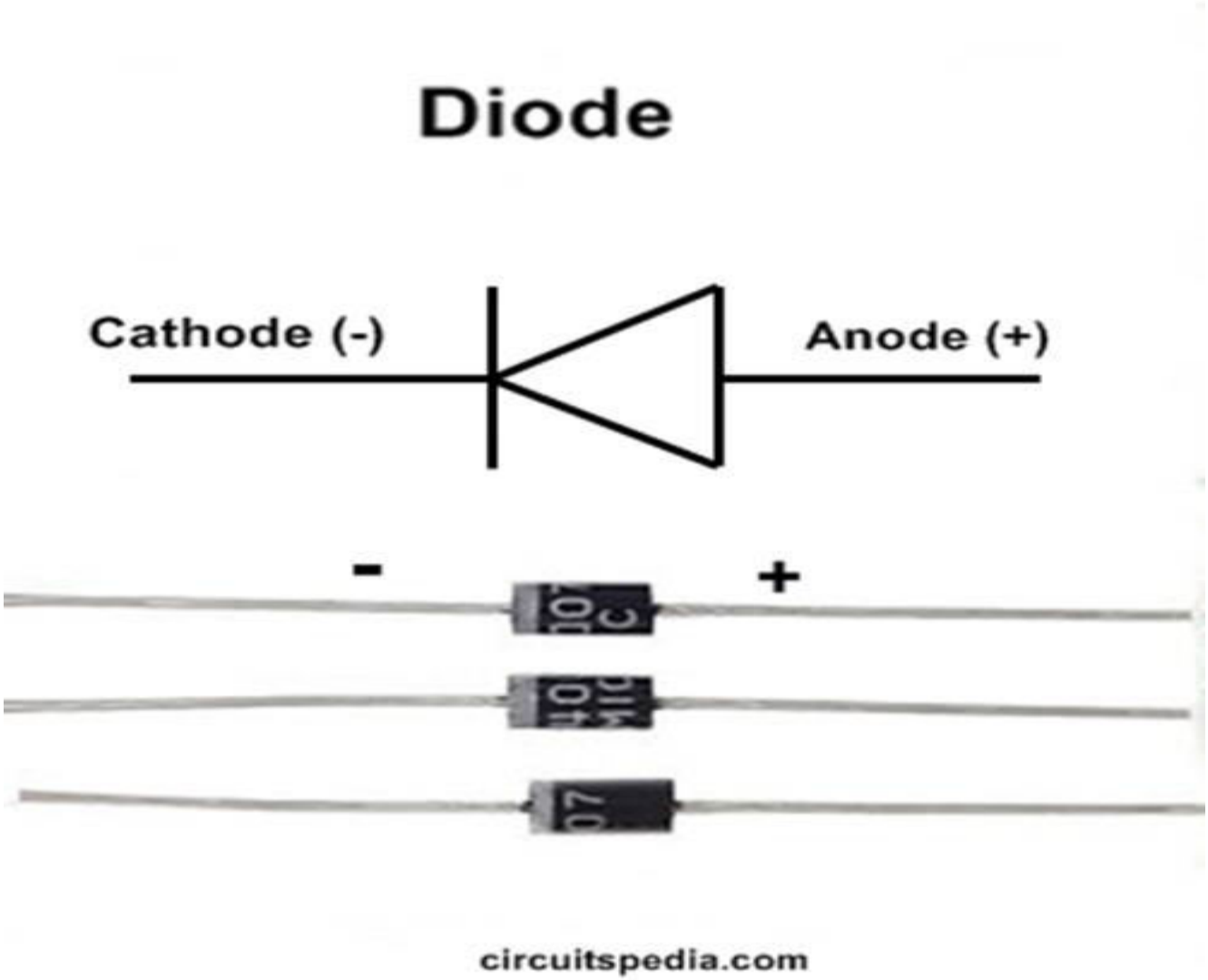
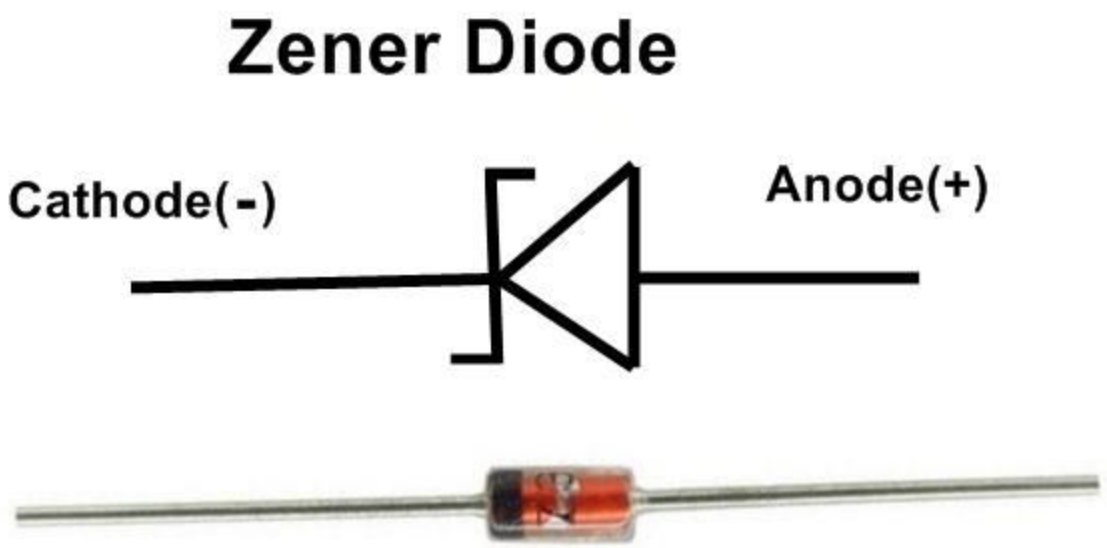
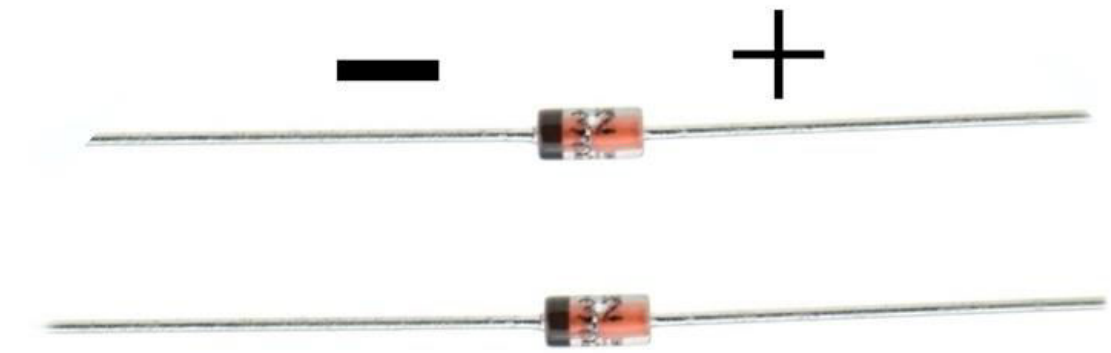
Semiconductor P-N Junction Diode Working Principle http://www.circuitspedia.com/

Diode is the two terminal polarised electronic semiconductor device . One terminal is Anode(-) and other is Cathode(+). The cathode is marked with the silver colour or colour band. This is the simplest semiconductor device but this is very important and most useful in electronic circuits.





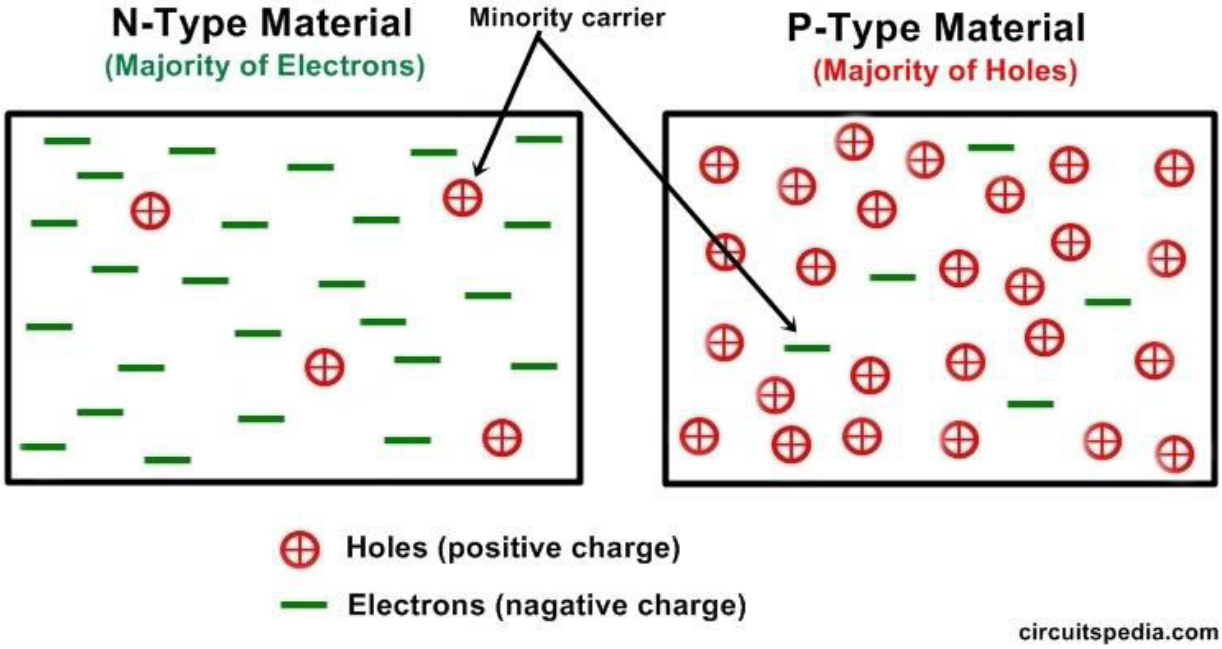


Diode Function

The main function of the semiconductor diode is the flow of electrons to totally in **only one direction** across it . It means Diode conducts current in **only one direction**. If change the polarity of diode then no any cuurent passes through it. So we can say that diode is act as a switch which allow to coduction of current in only one direction. This is property of an Ideal Diode.

An **Ideal diode** acts like short circuit with same polarity with supply, But in Reverse connection it acts like Open circuit means no any current flows in reverse polarity.

The semiconductor Diode is formed by adding and apply a burning force or crystalization on together of P-type and n-Type materials (p-n junction). Joining of Both materials should of the same base - Ge or Si. The PN-junction is the basic root for semiconductor diodes .



PN junction

PN junction is made from a single piece of semiconductor of two different properties . One side is made to be P-type material and the other side is made with N-type. Both ends of the PN-junction have different properties. One end has an excess/majority of electrons and the other end has an excess/majority of holes.

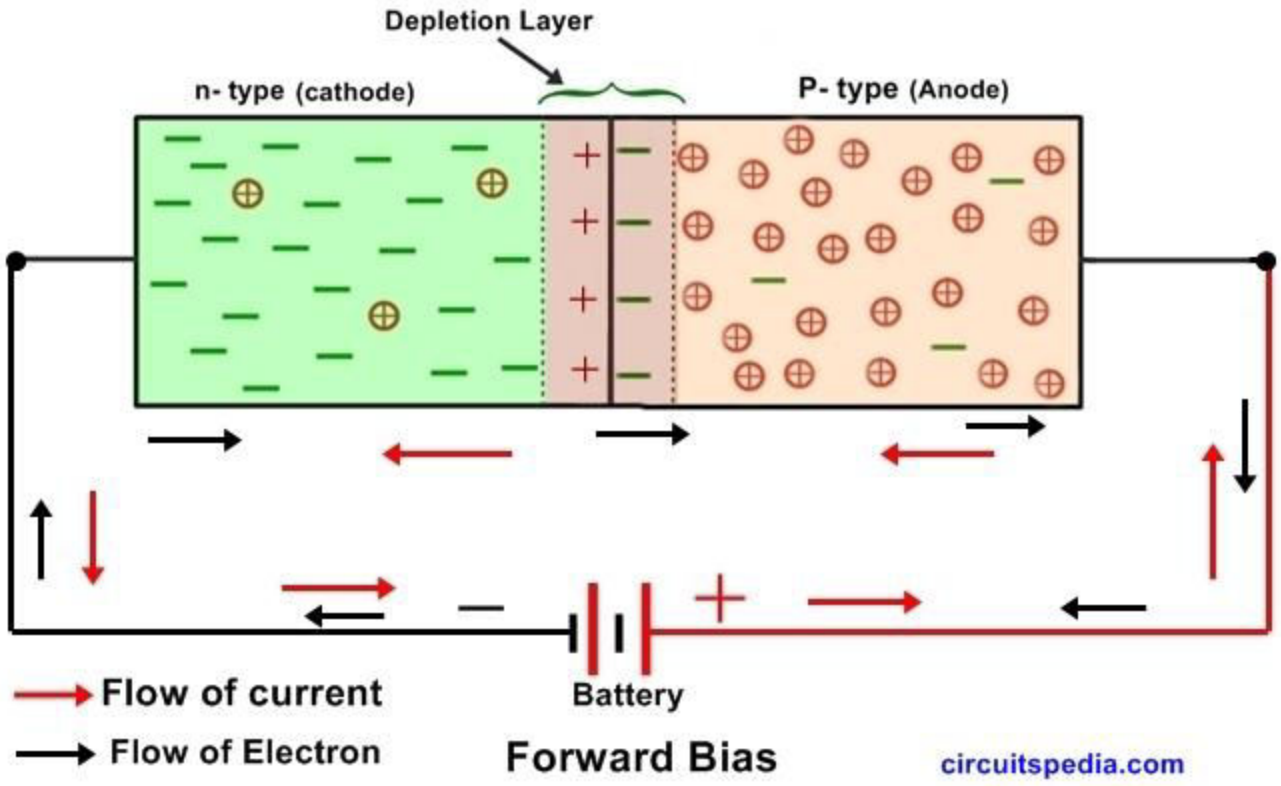
The p-type semiconductor is formed by adding trivalent impurities in pure or intrinsic semiconductor and n-type semiconductor is formed by adding pentavalent impurities in pure or intrinsic semiconductor.

P-type materials have **majority charge carriers** of **holes**, and **minority charge carriers of electrons**. But in **N-type** materials have **majority charge carriers of electrons** and minority charge carriers of holes .

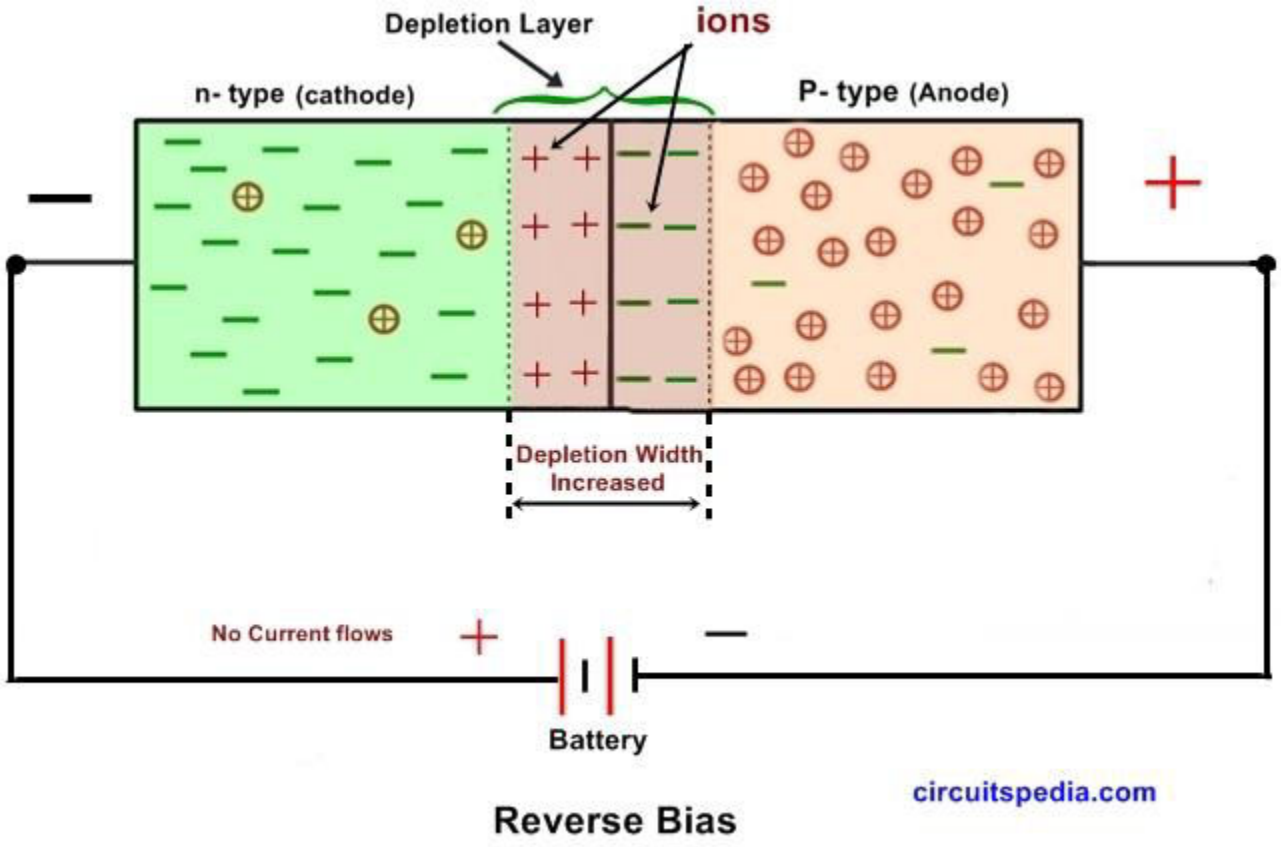
Half part of a Si crystal is doped with **trivalent impurity** and half with **pentavalent impurity**, we get P-N junction diode. The border where p-type and n-region meets called the junction .

The free electrons move from negative terminal (cathode) to the positive terminal (anode) . But the current flow direction is from positive terminal to the negative terminal.

Forward bias- If p-terminal of diode is connected with positive supply and n-terminal is connected with negative supply then it is called forward bias. If the diode is forward biased, it allows the electric current flow. On the other hand, if the diode is reverse biased, it **blocks** the electric current flow.



Reverse bias- When p- terminal of diode is connected with n-terminal of supply and n- terminal is connected with p, this connection is called Reverse bias connection. In this connection no Electrons flow and no current flows.



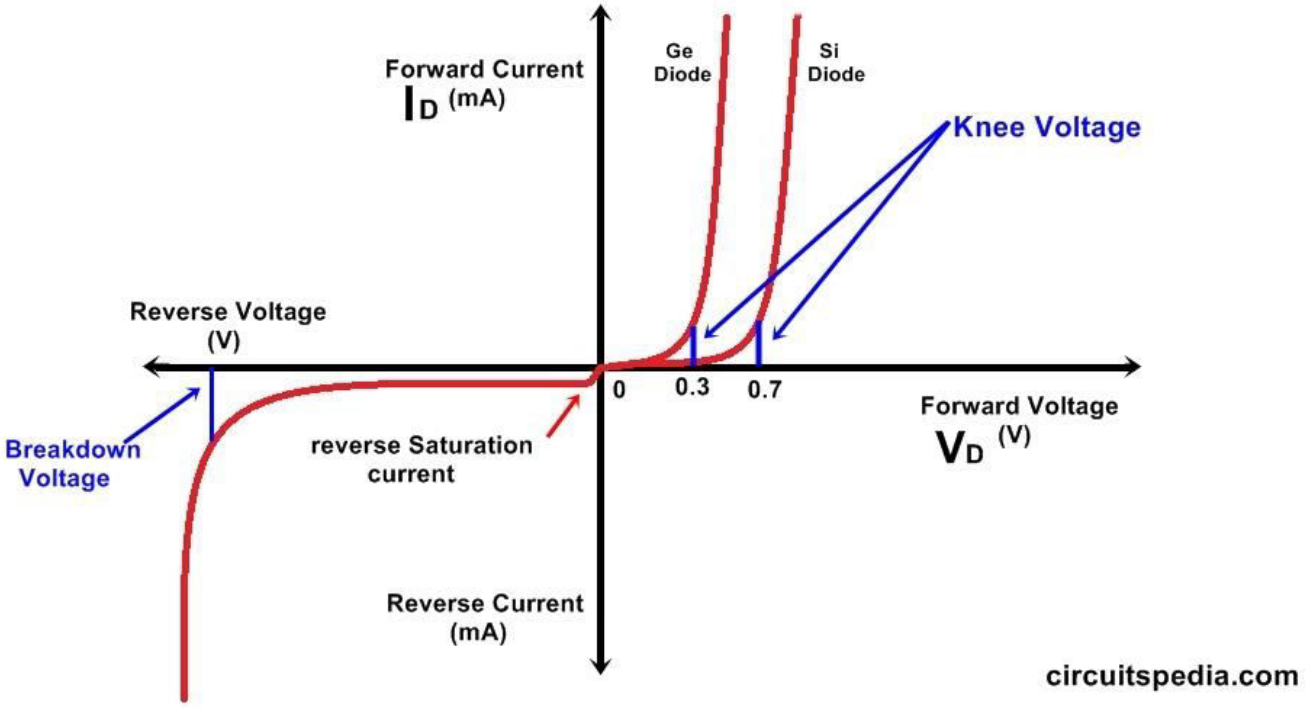
• Depletion layer-

Depletion layer created by the initial movement of majority carrier across the junction. Holes concentration on p- type and electron concentration on n-type are very high . Due to formation of p-n junction by diffusion electron moves from n-type to p-type and holes move from p-type to n-type. By the combination of electrons and holes at the junction creates ions, and there are presents only ions at the junction . Ions are non- movable.

Therefore when holes passes to electrons through these ions, then **+ve ions** repels the holes and oppose it passing to electron, And created a resistance wall of very small width . This is called Depletion layer. Width of depletion increases in reverse bias connection. An electric field intensity is created with depletion layer. and the sign of this electric field is negative because the direction of electric fiels is +ve to -ve.

- *Depletion layer consists +ve charge and –ve charge on either sides of junction.*
- *Depletion layer opposes only the the majority carrier not minority carrier.*
- *Depletion layer is also called **Space charge region or transition region**.*
- *Depletion layer consists **immobile charge particles**.*

V-I Characteristics of Semiconductor P-N diode



P-N Junction Diode V-I Characteristics

• Knee voltage-

This is the minimum required voltage to start the conduction of current through diode. This is also known as cut-in voltage. This is the forward voltage at which the diode current starts increasing rapidaly.

The knee voltage of si diode is 0.7 voltage and 0.3v of Ge diode.

• Breakdown voltage-

This is the minimum amount of voltage of any insulator that makes it electrically conductor.

In **Reverse bias connection** of pn diode. no any current flows through diode, but when we increase the reverse voltage level continuously Then diode get internally damage (breakdown) and start conduction at a fix level. Breakdown voltage is the minimum Amount of reverse bias voltage at which diode starts conduction in reverse bias connection. This breakdown characteristics of diode uses in **Zener Diode** which is always used in reverse bias and Limits the circuit voltage.

• Doping-

A material in pure form acts like insulator. So making it more conductive in nature we need to add some impurity to it. The process of adding impurities in pure (intrinsic material) is called doping to change their electrical properties.Generally **trivalent and pentavalent** elements are used to doping to semiconductor .When a semiconductor is doped with trivalent impurity(Boron,Aluminium) ,it becomes P-type semiconductor material. When dope any intrinsic material with Pentavalent impurity (phosphorus, arsenic,bismuth,antimony) then it becomes N-type semiconductor.

• Reverse Saturation Current

Both sides of p-n junction a very small amount of minority charge carrier present. P type minority charge carrier in n-type side and n-type minority charge carrier on p-type side.It also allows to flow a minority charge current. The current which is flowing by the minority carriers is called Reverse current.

When a voltage applied on junction then further external reverse voltage flows due to minority charge carriers and this increases external voltage does not increases reverse current. At a voltage level where current goes on a fix maximum level and after Only voltage increases and curren does not increases . This is called **reverse saturation current.**

Reverse saturation current remain constant with the increase of voltage, But when voltage will increase contineously then at a Level of voltage when junction will get breakdown and high reverse current will flow.

Reverse saturation current depends on temperature. If temperature of junction increases , the minority charge carriers also increases.

• <u>The Width of Depletion Layer</u>

Practically The value of Depletion width vary from 0.1μm to 0.5μm

Typical value of Depletion width is -0.5μm

By increasing doping concentration Depletion layer width can Reduced

electrons moves across the PN junction from the N-type to the P-type , they leave behind positively charged donor ions on the negative side. Holes from the acceptor impurity moves across the junction in the opposite direction into the region where there are large numbers of free electrons.

As a result, the charge density of the P-type through the junction is filled with negatively charged acceptor ions , and the charge density of the N-type along with the junction becomes positive. This charge transfer of electrons and holes across the PN junction is known as **diffusion .**

• Barrier potential/built in potential

Simply Voltage form across the depletion layer is called the **contact potential**. The **built-in potential** in a semiconductor equals the potential across the depletion region in thermal equilibrium.This is also called built-in potential or **barriar voltage/potential or potential hill or diffusion voltage**.

Contact potential always appear with in depletion layer It is noted as **V0 or vbi.**

Contact potential of any diode can not measure by any instrument.

V0 for Ge diode = 0.1v to 0.5v typically we use V0=0.2v

V0 for Si diode = 0.6v to 0.9v typically V0= 0.7v

The Width of Depletion Layer

$$W \propto \frac{1}{\sqrt{Doping\ concentration}}$$

Equation for width of depletion layer in open circuit (no any voltage applied)

$$W = \sqrt{\frac{2\epsilon}{q}\left(\frac{1}{NA}+\frac{1}{ND}\right)vbi}$$

NA= Doping Concentration on Doner(n side)
ND= Doping Concentration on Acceptor Side

ϵ = Permittivity in F/M (farad per meter)

$\epsilon = \epsilon_0 . \epsilon r$

$\epsilon 0$ = Absolute permittivity of free space

$\epsilon 0 = 8.85\times10^{-12}$F/M or 8.85×10^{-14}F/CM

ϵr = Relative permittivity of medium or Dielectric constant of material.

ϵr = 11.7 for Si

ϵr = 16 for Ge

Application of p-n junction diode

- As Rectifier to convert AC to DC signal
- Clipper circuit for clipping the signal (changing the wave shape)
- To supply (for protection from reverse supply)
- Clamper circuit to restore the dc signal wave
- As Voltage multiplier
- In digital logic design
- In Demodulation Circuits

Other types of diode

Photodiode, Zener Diode, Gunn Diode, Tunnel Diode. PIN Diode, Varactor Diode. Light Emitting Diode (LED), Schottky Diode, Laser Diode, Switching Diode.

Also read

[4017 Decade counter]

[What is NOT Gate Inverter]