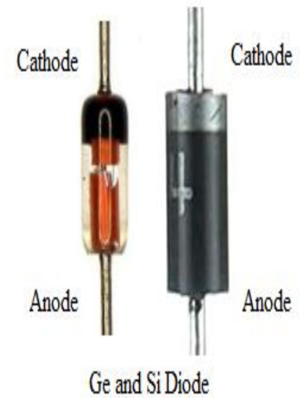
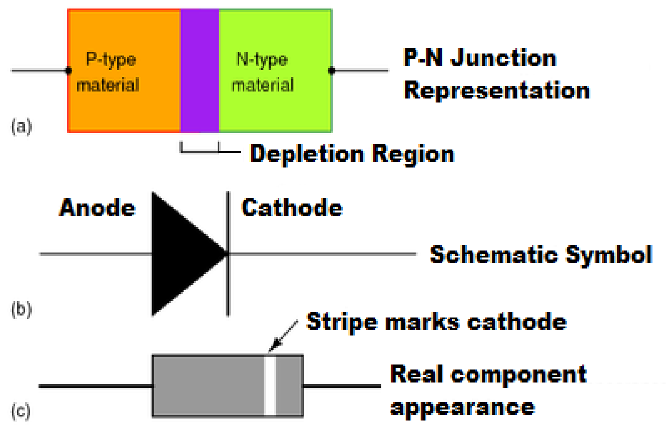
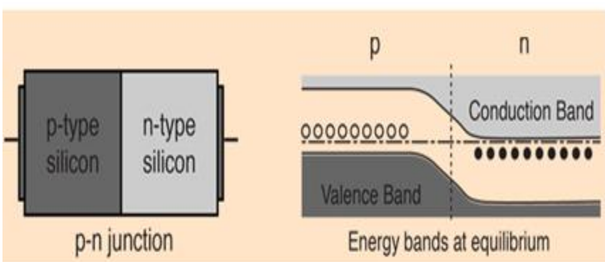
PN JUNCTION DIODE

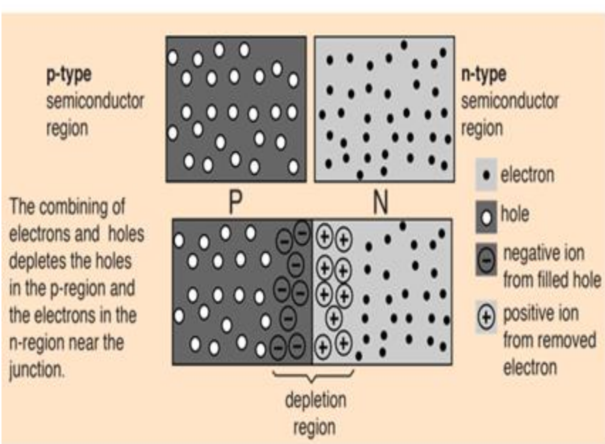
Diode is a semi conductor device formed by joining P-type and N-type semi conductor material together. It is a two terminal device with positive and negative regions.The positive and negative regions of the diode are the component's anode and cathode respectively. It permits the current to flow in forward direction(anode to cathode) and effectively blocks the current in the reverse direction(cathode to anode).The symbol of diode is shown below.

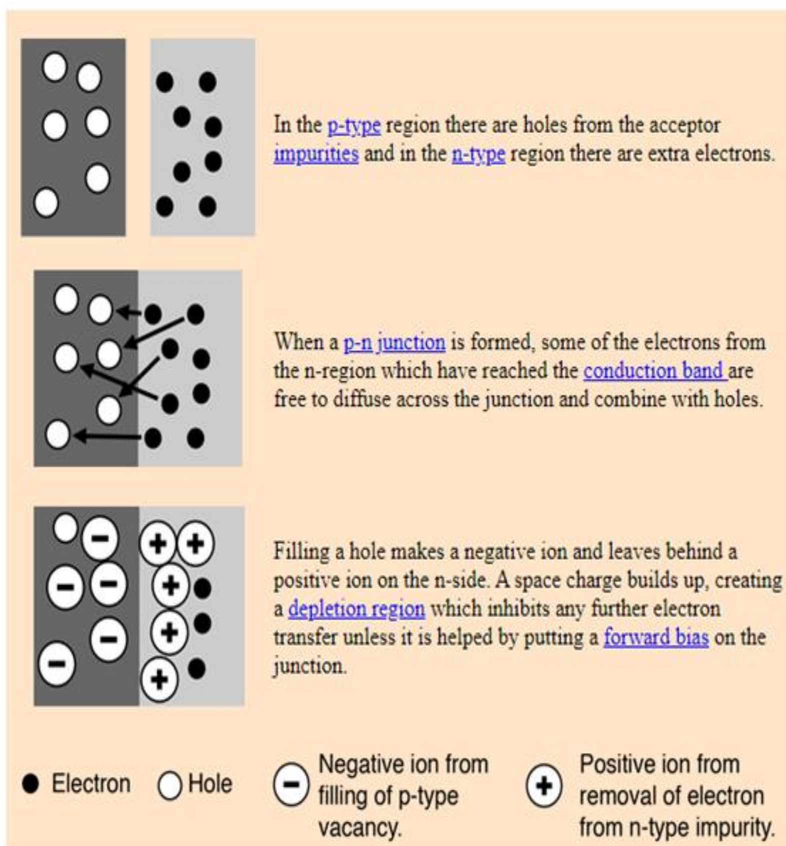




PN junction formation:-







When the two blocks ie p-type and n-type materials are placed nearer to each other, the electrons and holes diffuse towards the region of lower concentration from the region of higher concentration.

In the process of diffusion, electrons from N region diffuse towards the P region whereas holes from P region diffuse towards the N region. The electrons from N region recombine with the acceptor atoms in P region and become negatively charged immobile atoms near the junction. Similarly once holes enter the N region, they will recombine with donor atoms and become positively charged immobile atoms near the junction.

As a result, a large number of positively charged ions are produced at the junction on the N side and a large number of negatively charged ions are produced at the junction on P side i.e the region is depleted of charge carriers.So it is known as depletion region. This depletion region has positive and negative charges close to each other. This develops a potential of about 0.7V for silicon diodes across the depletion region. 0.3V in case of Germanium diodes.

The diffusion continues until the holes diffused into N-type region starts opposing further diffusion of holes from P-type region and the diffused electrons to P-type oppose further movement of electrons from N-type region.

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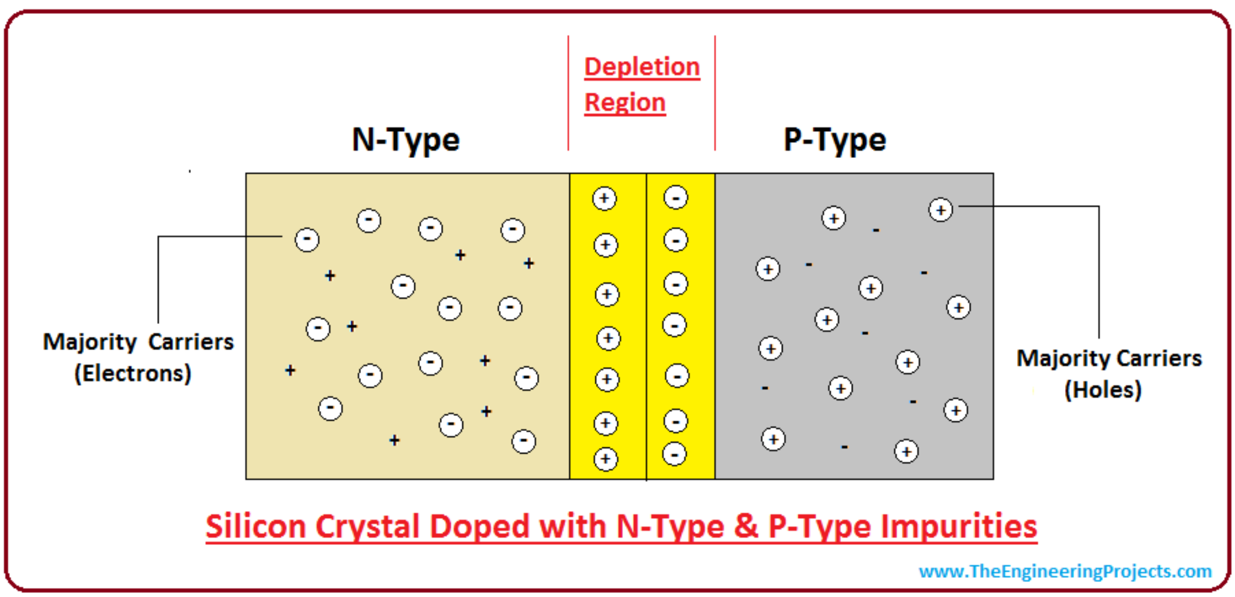
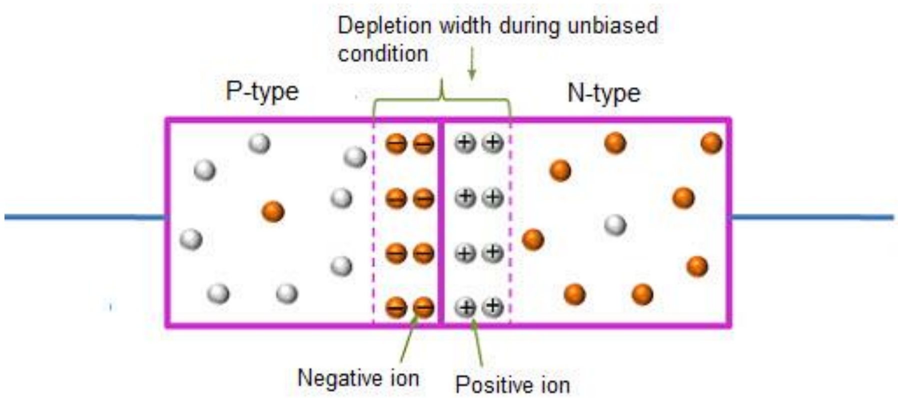


BIASING OF DIODE:-

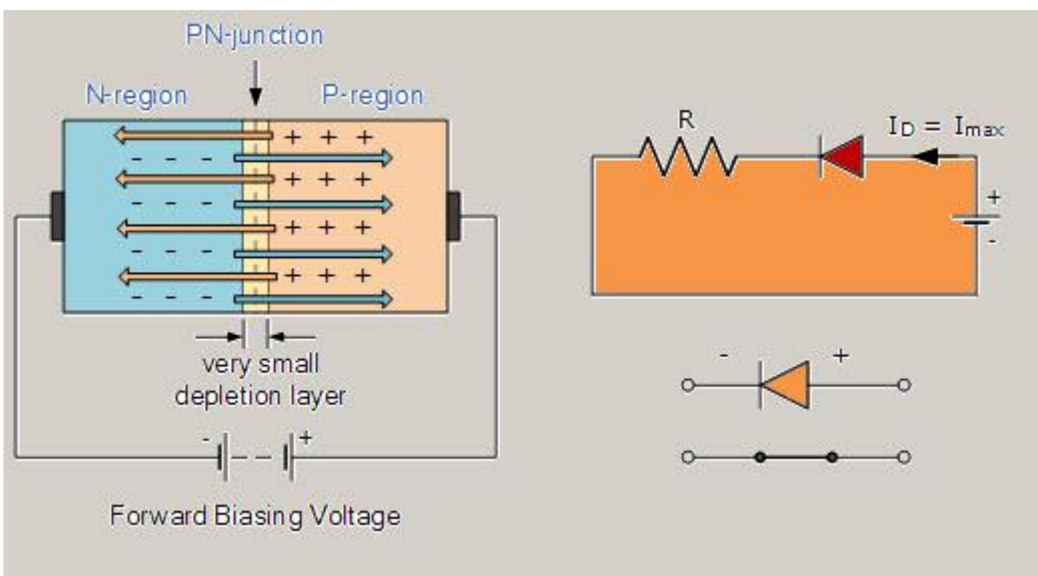
There are three possible “biasing” conditions for the P-N Junction Diode, which are as follows:

1.Zero Bias – No external voltage is applied to the PN junction diode.



2.Forward bias

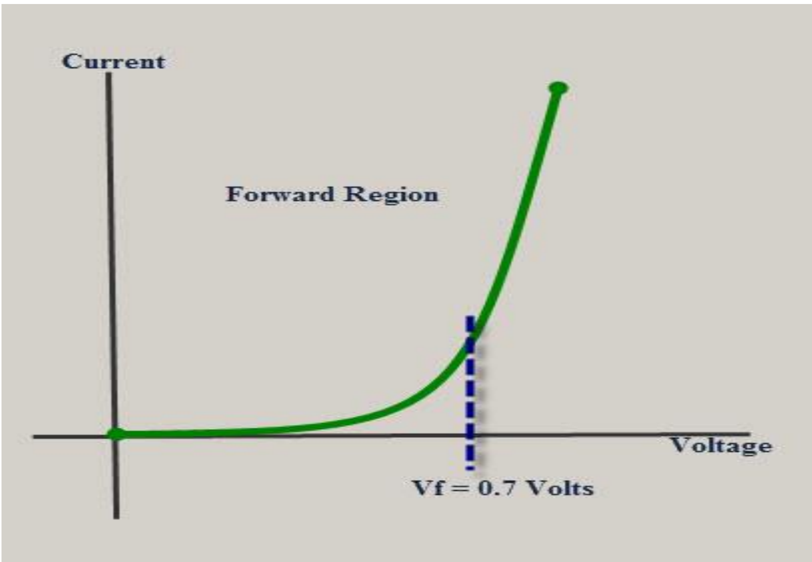
In the forward bias condition, the negative terminal of the battery is connected to the N-type material and the positive terminal of the battery is connected to the P-Type material. Electrons from the N-region cross the junction and enters the P-region. Due to the attractive force that is generated in the P-region the electrons are attracted and move towards the positive terminal. Simultaneously the holes are attracted to the negative terminal of the battery. By the movement of electrons and holes current flows in the diode. In this condition, the width of the depletion region decreases due to the reduction in the number of positive and negative ions.



Forward Bias Condition

V-I Characteristics

By supplying positive voltage, the electrons get enough energy to overcome the potential barrier (depletion layer) and cross the junction and the same thing happens with the holes as well. The amount of energy required by the electrons and holes for crossing the junction is equal to the barrier potential 0.3 V for Ge and 0.7 V for Si, 1.2V for GaAs. This is also known as **Voltage drop or cutin voltage or knee voltage**. The voltage drop across the diode occurs due to internal resistance. This can be observed in the below graph.



Forward bias V-I Characteristics

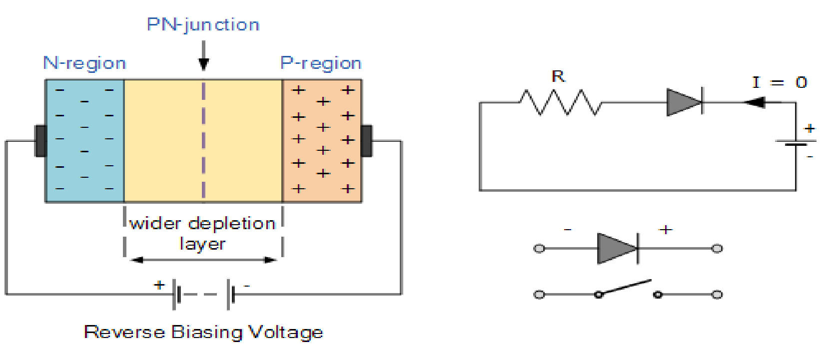
Reverse Bias

When a diode is connected in a **Reverse Bias** condition, a positive voltage is applied to the N-type material and a negative voltage is applied to the P-type material.

The positive voltage applied to the N-type material attracts electrons towards the positive electrode, while the holes in the P-type end are also attracted away from the junction towards the negative electrode.

The net result is that the depletion layer grows wider due to a lack of electrons and holes and presents a high impedance path, almost an insulator and a high potential barrier is created across the junction thus preventing current from flowing through the semiconductor material.

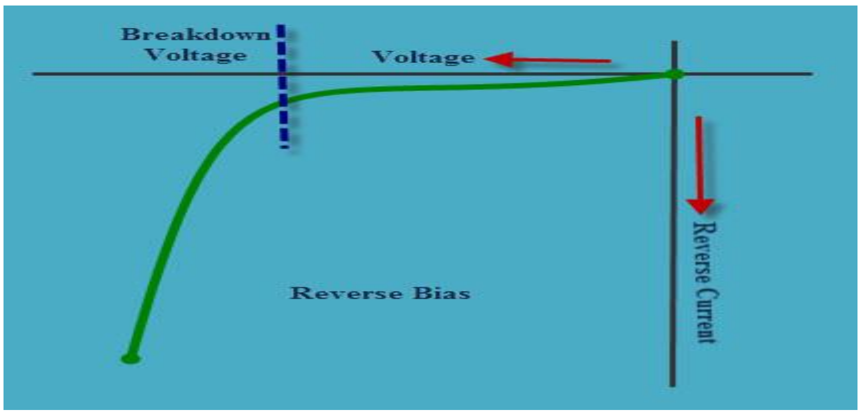
Increase in the Depletion Layer due to Reverse Bias



This condition represents a high resistance value to the PN junction and practically zero current flows through the junction diode with an increase in bias voltage. However, a very small **reverse leakage current or reverse saturation current** flow through the junction which can normally be measured in micro-amperes, (μA).

One final point, if the reverse bias voltage Vr applied to the diode is increased to a sufficiently high enough value, it will cause the diode's PN junction to overheat and fail due to the avalanche effect around the junction. This may cause the diode to become shorted and will result in the flow of maximum circuit current, and this shown as a step downward slope in the reverse static characteristics curve below.

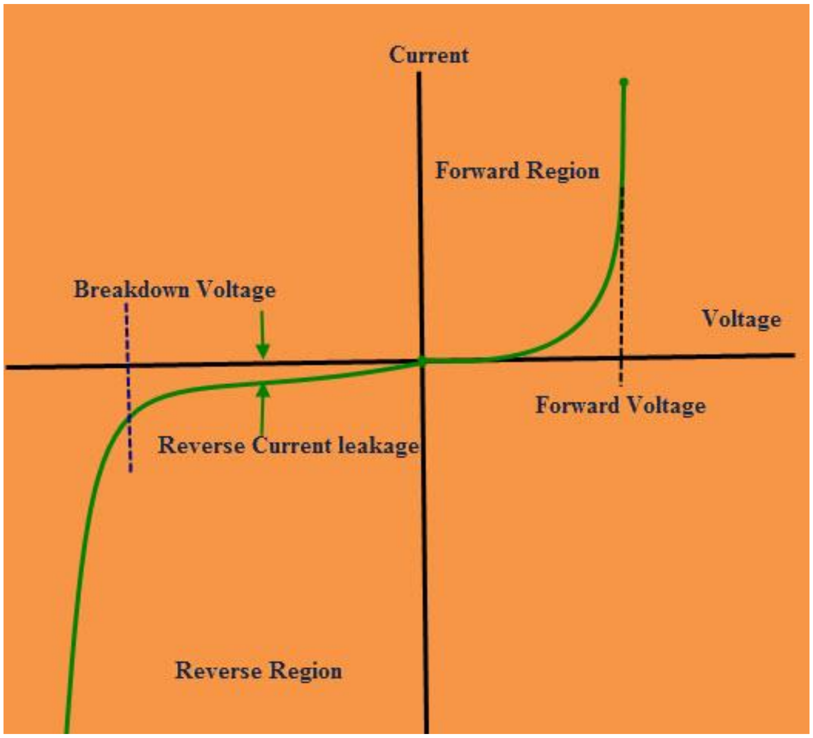
V-I Characteristics



Due to thermal energy,minority(a hole in N-type material and electrons in P-type material) carriers are produced in crystal. These minority carriers are pushed towards P-N junction by the negative terminal and positive terminal, respectively. Due to the movement of minority carriers, a very little current flows, which is in nano Ampere range (for silicon). This current is called as reverse saturation current. Saturation means, after reaching its maximum value, a steady state is reached wherein the current value remains same with increasing voltage.

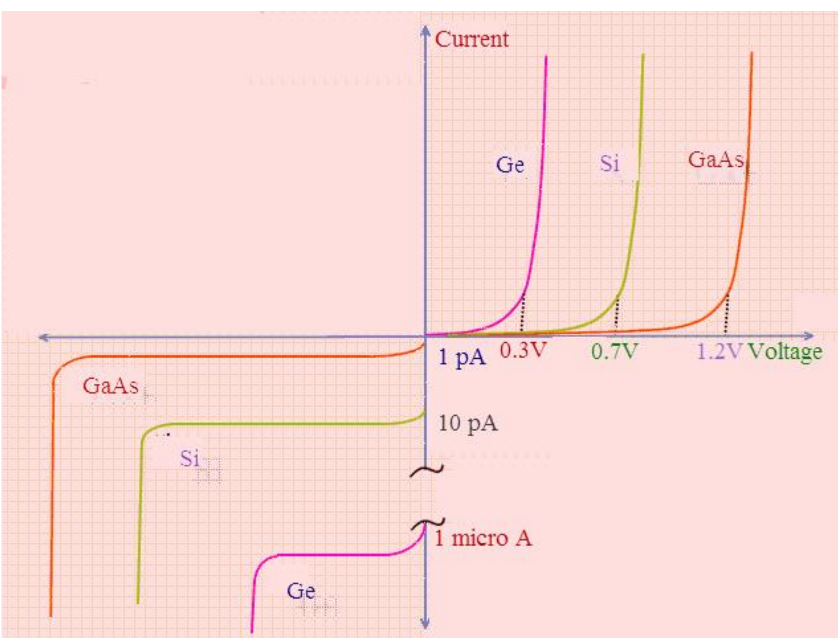
When the reverse voltage is increased beyond the limit, then the reverse current increases drastically. This particular voltage that causes the drastic change in reverse current is called reverse breakdown voltage. Diode breakdown occurs by two mechanisms: Avalanche breakdown and Zener breakdown.

V-I Characteristics of P-N junction Diode



V-I Characteristics of P-N junction Diode

The graph will be changed for different semiconductor materials used in the construction of a P-N junction diode. The below diagram depicts the changes.



Comparison with Silicon, Germanium, and Gallium Arsenide

DIODE EQUATION:-

$$I = I_0 \left(e^{\frac{qV}{\eta KT}} - 1 \right)$$

Where,
I is the current flowing through the diode,

I_0 is the dark saturation current

q is the charge on the electron

V is the voltage applied across the diode,

η is the (exponential) ideality factor. if the diode under consideration behaves exactly as that of an ideal diode, then η will be 1. Its value increases from 1 as the difference between the behaviors of the ideal diode and diode under consideration increases: greater is the deviation, greater is the value of η.
The value of η is typically considered to be 1 for germanium diodes and 2 for silicon diodes.

$K = 1.38 \times 10^{-23} JK^{-1}$is the Boltzmann constant

T is the absolute temperature in Kelvin.
(kT/q) At room temperature = 0.026V (Here η=1)
Therefore, it can be written as **I=I_S[exp(V/0.026)-1]**

AVALANCHE BREAKDOWN

The width of the depletion region vary depending on the bias voltage applied at the terminals of the p-n junction i.e. an increase in the applied voltage reduces the width of the depletion region in case of forward bias, while it increases the depletion region width for the case of reverse bias. Further the span of the depletion region is found to be more for a lightly doped material when compared to that of a heavily doped material.

Figure 1 shows the I-V characteristics of such a p-n junction both for the case of forward- as well as reverse-bias. From the figure, it is clear that when the p-n junction is forward biased the current through the semiconductor rises with an increase in the magnitude of the applied voltage. Also the minimum current reverse saturation current (I_S) due to the minority charge carriers flows through the p-n junction under the reverse bias condition.

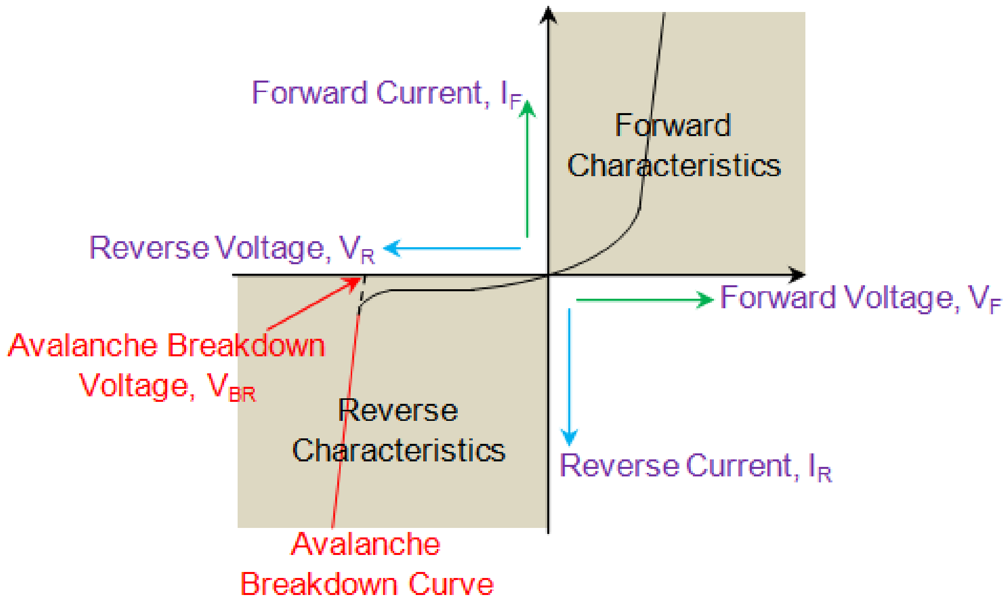


Figure 1 I-V Curve for a P-N Junction Depicting Avalanche Breakdown Phenomenon

The current I_S is independent of the applied voltage at its initial stage. However after reaching a particular point, the junction breaks-down leading to the heavy flow of reverse current through the device. This is because, as the magnitude of the reverse voltage increases, the kinetic energy of the minority charge carriers also increase. These fast moving electrons collide with the other atoms in the device to knock-off some more electrons from them.

The electrons so released further release much more electrons from the atoms by breaking the covalent bonds. This process is termed as carrier multiplication and leads to a considerable increase in the flow of current through the p-n junction. This phenomenon is called **Avalanche Breakdown** (shown in red color in the figure) and the corresponding voltage is Avalanche Breakdown Voltage (V_{BR}).This is the central phenomenon to the working principle of avalanche diodes.

Avalanche breakdown occurs in lightly doped p-n junctions when the reverse voltage increases beyond 5 V. Further, it is difficult to control this phenomenon as the number of charge carriers generated cannot be directly controlled. Moreover the Avalanche breakdown voltage has positive temperature coefficient meaning which the **Avalanche breakdown** voltage increases with the increase in the junction temperature.

Difference between avalanche and zener breakdown:-

Zener Breakdown	Avalanche Breakdown
The process in which the electrons move across the barrier from the valence band of p-type material to the conduction band of n-type material is known as Zener breakdown.	The process of applying high voltage and increasing the free electrons or electric current in semiconductors and insulating materials is called an avalanche breakdown.
This is observed in Zener diodes having a Zener breakdown voltage of 5 to 8 volts.	This is observed in Zener diode having a Zener breakdown voltage greater than 8 volts.
The valence electrons are pulled into conduction due to the high electric field in the narrow depletion region.	The valence electrons are pushed to conduction due to the energy imparted by accelerated electrons, which gain their velocity due to their collision with other atoms.
The increase in temperature decreases the breakdown voltage.	The increase in temperature increases the breakdown voltage.
The VI characteristics of a Zener breakdown has a sharp curve.	The VI characteristic curve of the avalanche breakdown is not as sharp as the Zener breakdown.
It occurs in diodes that are highly doped.	It occurs in diodes that are lightly doped.