Applied Physics

Ayesha Malik

TOPIC

1.P-N junction

2.Forward and Reverse Bias diode

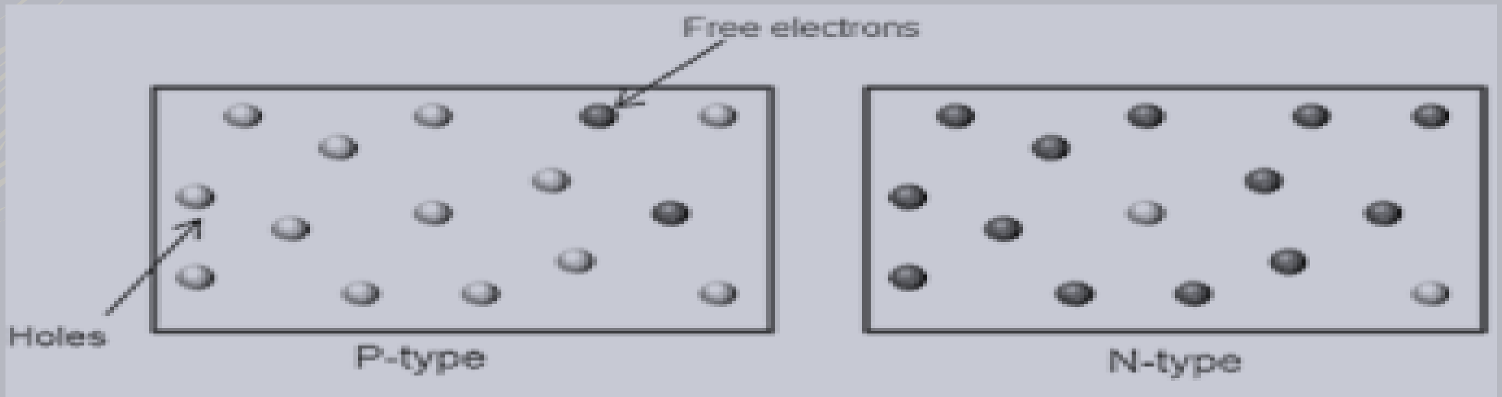
3.V-I characteristics curve

Table of Content

P and N type Materials

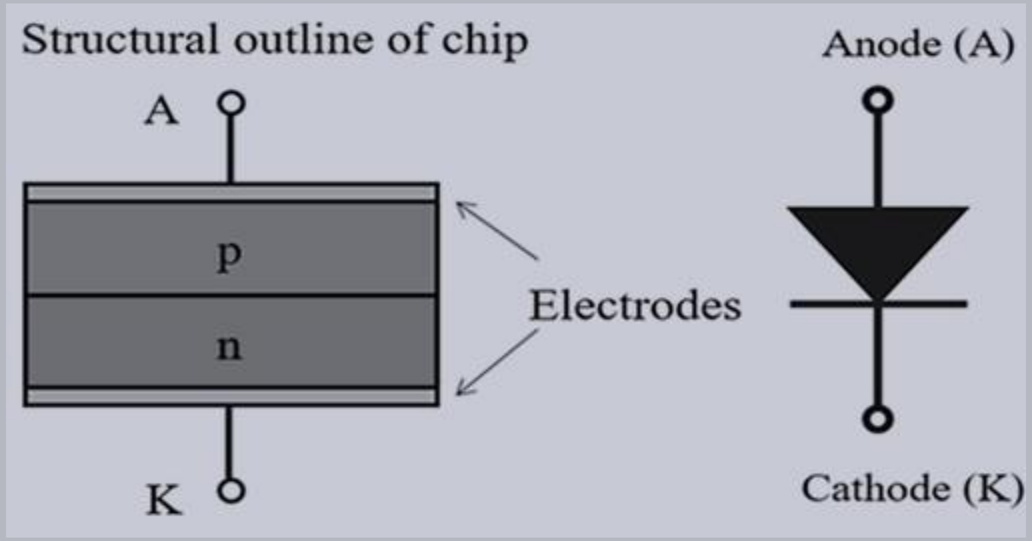
- A **p-type material** consists of silicon atoms and trivalent impurity atoms such as boron.
- The boron atom adds a hole when it bonds with the silicon atoms.
- However, since the number of protons and the number of electrons are equal throughout the material, there is no net charge in the material and so it is neutral.

- An **n-type** silicon material consists of silicon atoms and pentavalent impurity atoms such as antimony.
- As you have seen, an impurity atom releases an electron when it bonds with four silicon atoms.
- Since there is still an equal number of protons and electrons (including the free electrons) throughout the material, there is no net charge in the material and so it is neutral.



Semiconductor diode

- A semiconductor diode is a p-n junction diode. It is a two-terminal device (cathode and anode) that conducts current only in one direction.
- The figure below represents the symbol for the p-n junction diode, which symbolizes the direction of the current. By applying an external voltage V we can vary the potential barrier.



PN Junction

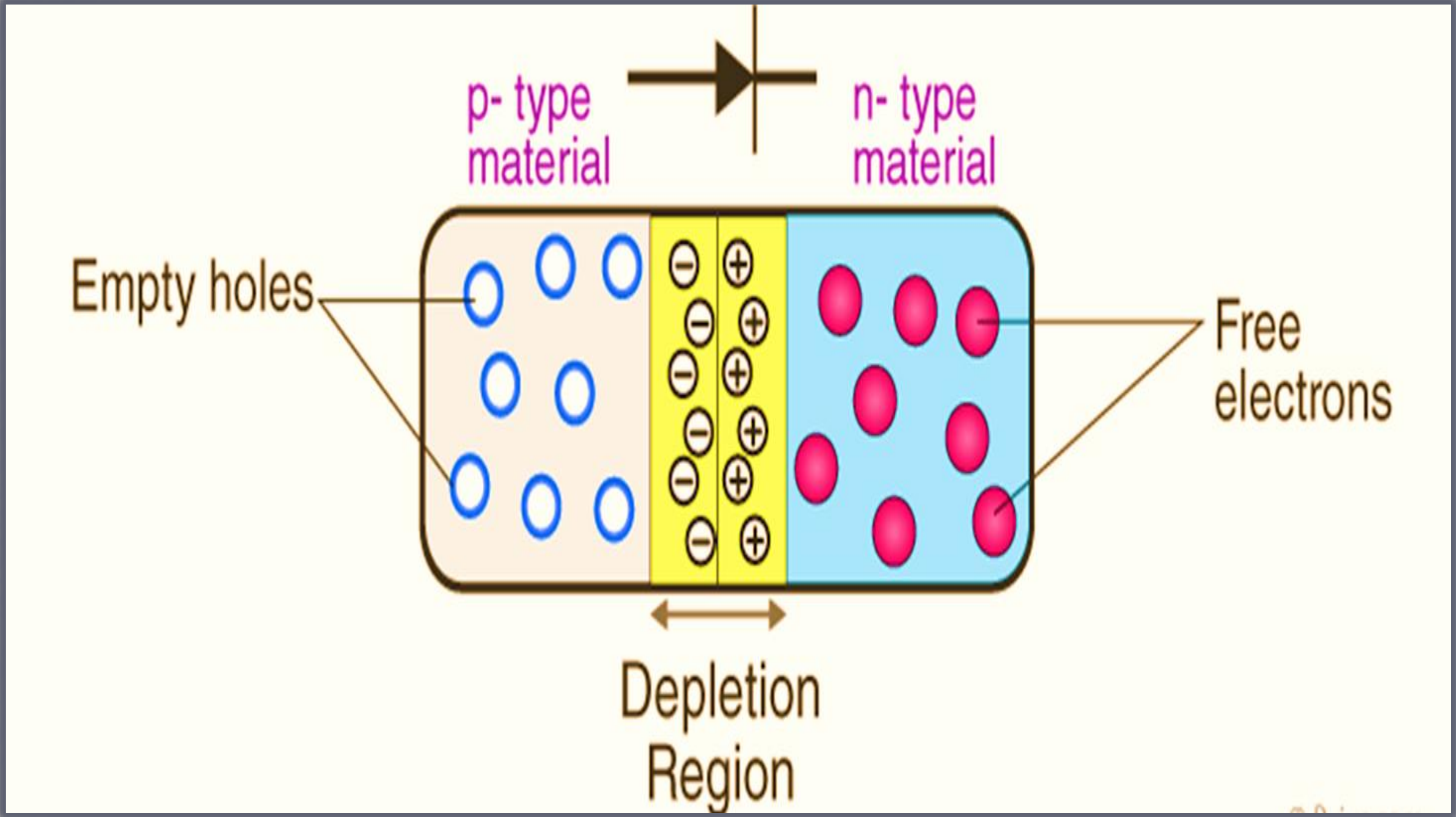
- A **<u>PN junction</u>** is a boundary or interface between two types of semiconductor materials, namely P-type (positive) and N-type (negative). The term "PN" junction comes from the combination of these two semiconductor types.
- **<u>PN Junction</u>** is formed at the interface or boundary between a p-type and the n-type semiconductor.
- The positive side of the semiconductor (p side) has an excess of holes.
- The negative side of the semiconductor (n side) has an excess of electrons.
- The PN junction is created by the process of doping. Doping is done to provide movement of electrons between the p side and n side of the semiconductor.

- When a P-type semiconductor is brought into contact with an N-type semiconductor, a PN junction is formed.
- At this junction, free electrons from the N-type material diffuse into the P-type material, and holes from the P-type material diffuse into the N-type material.
- This migration of charge carriers creates a region near the junction called the **depletion zone,** which has no free charge carriers.

Formation of P-N Junction

- Let us consider a thin p-type silicon semiconductor sheet. If we add a small amount of pentavalent (n type) impurity to this, a part of the p-type Si will get converted to n-type silicon. This sheet will now contain both the p-type region and the n-type region and a junction between these two regions.
- The processes that follow after forming a P-N junction are of two types – diffusion and drift.
- There is a difference in the concentration of holes and electrons at the two sides of a junction.
- The holes from the p-side diffuse to the n-side, and the electrons from the n-side diffuse to the p-side. These give rise to a diffusion current across the junction.

- Also, when an electron diffuses from the n-side to the p-side, an ionized donor is left behind on the n-side, which is immobile.
- As the process goes on, a layer of positive charge is developed on the n-side of the junction. Similarly, when a hole goes from the p-side to the n-side, an ionized acceptor is left behind on the p-side, resulting in the formation of a layer of negative charges in the p-side of the junction. This region of positive charge and negative charge on either side of the junction is termed as the depletion region.
- Due to this positive space charge region on either side of the junction, an electric field with the direction from a positive charge towards the negative charge is developed. Due to this electric field, an electron on the p-side of the junction moves to the n-side of the junction. This motion is termed the drift. Here, we see that the direction of the drift current is opposite to that of the diffusion current.


p- type
material
n- type
material
Empty holes
Free
electrons
Depletion
Region

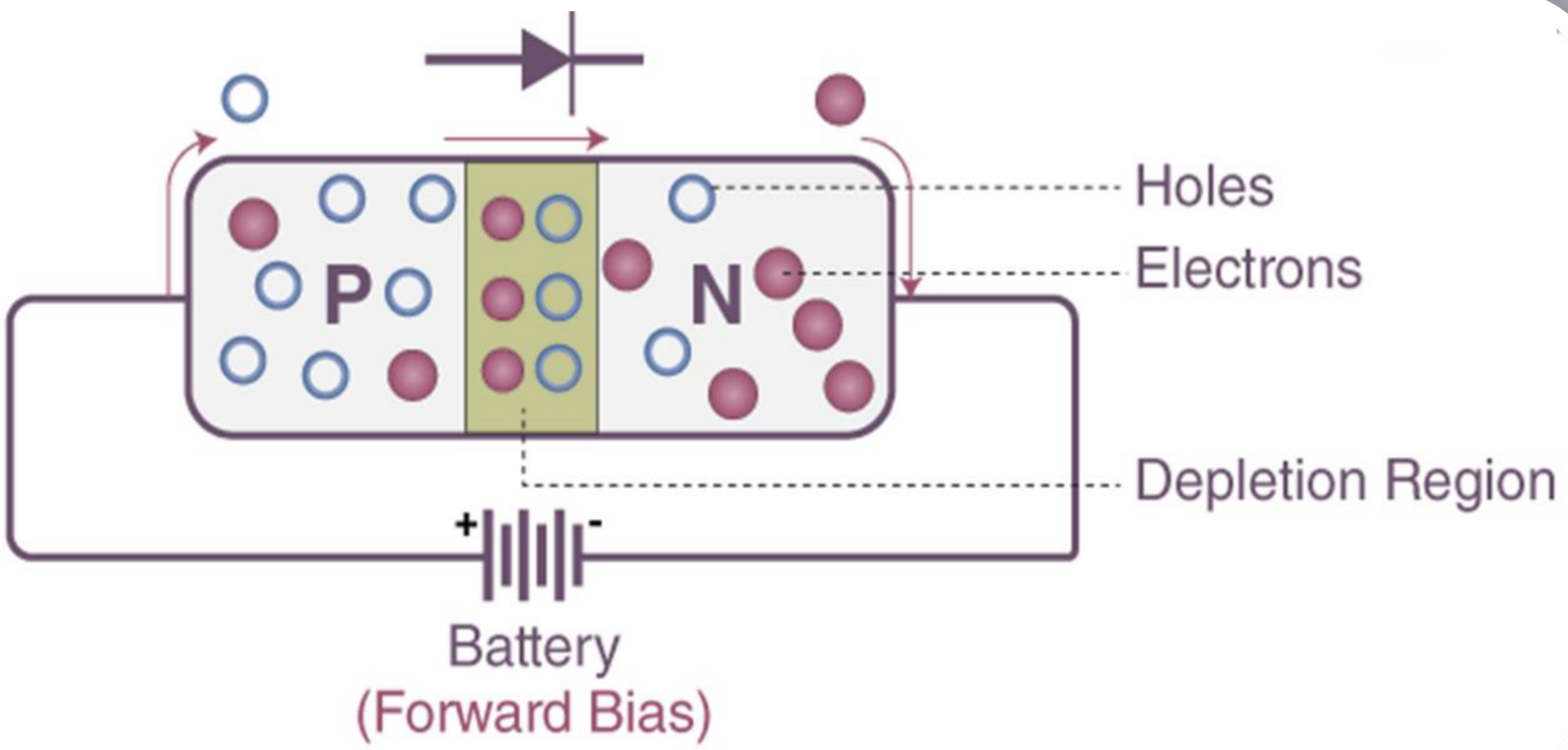
Biasing Conditions for the P-N Junction Diode

There are two operating regions in the P-N junction diode:

- P-type
- N-type
- There are three biasing conditions for the P-N junction diode, and this is based on the voltage applied:
- **Zero bias:** No external voltage is applied to the P-N junction diode.
- **Forward bias:** The positive terminal of the voltage potential is connected to the p-type while the negative terminal is connected to the n-type.
- **Reverse bias:** The negative terminal of the voltage potential is connected to the p-type and the positive is connected to the n-type.

P-N Junction Diode Under Forward Bias

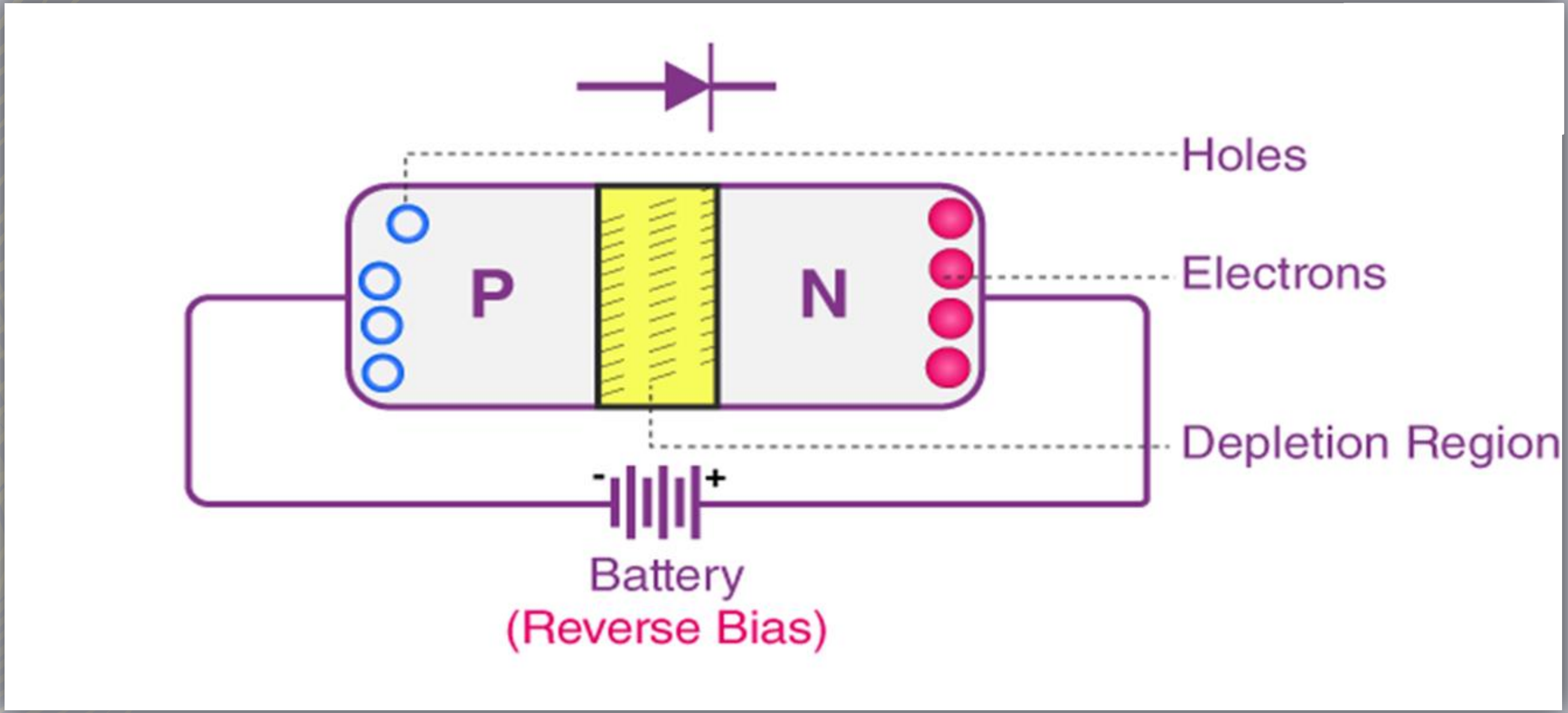
- When we apply the external voltage across the semiconductor diode in such a way that the p-side is connected to the positive terminal of the battery and the n-side is connected to the negative terminal, then the semiconductor diode is said to be forward-biased.
- When the P-N junction is forward biased, the built-in potential of the diode and width of the depletion region decreases, and the height of the barrier gets reduced.
- As we supply a small amount of voltage, the reduction in the barrier voltage is very less and thus only a small number of current carriers cross the junction in this case. Whereas, if the potential is increased by a significant value, the reduction in the barrier height will be more, thus allowing the passage of more number of carriers.
- The depletion region's resistance becomes negligible when the applied voltage is large. In silicon, at the voltage of 0.6 V, the resistance of the depletion region becomes completely negligible, and the current flows across it.



P
N
Holes
Electrons
Depletion Region
+
-
Battery
(Forward Bias)

P-N Junction Diode Under Reverse Bias

- When we apply the external voltage across the semiconductor diode in such a way that the positive terminal of the battery is connected to its n-side and the negative terminal of the battery is connected to the p-side of the diode, then it is said to be in the condition of reverse bias.
- When the p-type is connected to the battery's negative terminal and the n-type is connected to the positive side, the P-N junction is reverse biased. In this case, the built-in electric field and the applied electric field are in the same direction. When the two fields are added, the resultant electric field is in the same direction as the built-in electric field, creating a more resistive, thicker depletion region. The depletion region becomes more resistive and thicker if the applied voltage becomes larger.


Holes
P
N
Electrons
Depletion Region
-
+
Battery
(Reverse Bias)

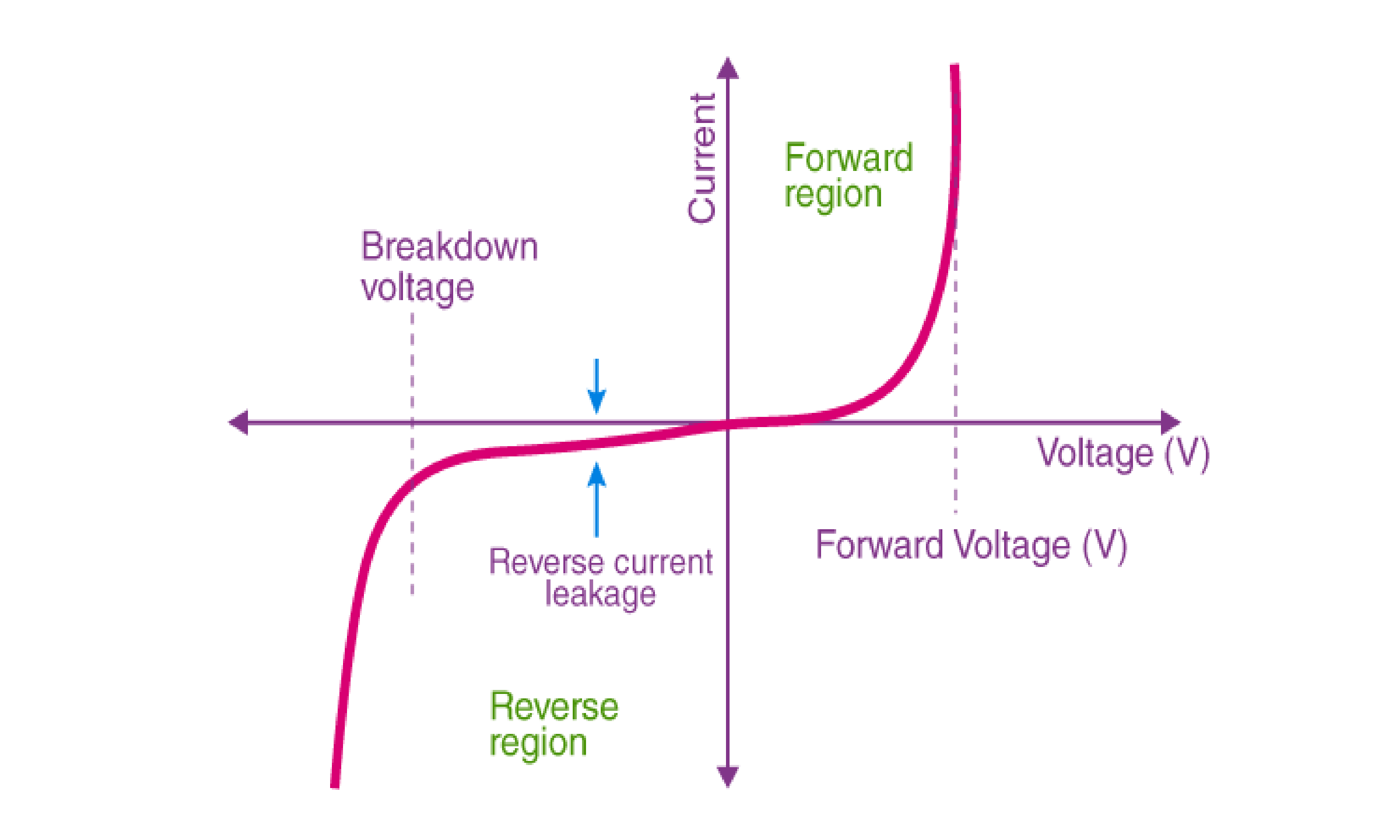
V-I Characteristics of P-N Junction Diode

- VI characteristics of P-N junction diodes is a curve between the voltage and current through the circuit. Voltage is taken along the x-axis while the current is taken along the y-axis. The below graph is the V-I characteristics curve of the P-N junction diode. With the help of the curve, we can understand that there are three regions in which the diode works, and they are:
- Zero bias
- Forward bias
- Reverse bias

- When the P-N junction diode is in **zero bias condition**, there is no external voltage applied and this means that the potential barrier at the junction does not allow the flow of current.
- When the P-N junction diode is in **forward bias condition**, the p-type is connected to the positive terminal while the n-type is connected to the negative terminal of the external voltage. When the diode is arranged in this manner, there is a reduction in the potential barrier. For silicone diodes, when the voltage is 0.7 V and for germanium diodes, when the voltage is 0.3 V, the potential barriers decrease, and there is a flow of current.

When the diode is in forward bias, the current increases slowly, and the curve obtained is non-linear as the voltage applied to the diode overcomes the potential barrier. Once the diode overcomes the potential barrier, the diode behaves normally, and the curve rises sharply as the external voltage increases, and the curve obtained is linear.

- When the P-N junction diode is in **negative bias condition,** the p-type is connected to the negative terminal while the n-type is connected to the positive terminal of the external voltage. This results in an increase in the potential barrier. Reverse saturation current flows in the beginning as minority carriers are present in the junction.
- When the applied voltage is increased, the minority charges will have increased kinetic energy which affects the majority charges. This is the stage when the diode breaks down. This may also destroy the diode.



Current
Forward region
Breakdown voltage
Voltage (V)
Reverse current leakage
Forward Voltage (V)
Reverse region

Significance of PN junction

- The process of creating a PN junction is essential in the construction of various semiconductor devices, including diodes and transistors. Diodes, for example, are simple semiconductor devices that allow current to flow in one direction only.
- The behavior of the PN junction plays a major role in the operation of these devices. The application of a voltage across the PN junction can control the flow of current, making it a fundamental building block in electronic circuits.

Applications of P-N Junction Diode

- P-N junction diode can be used as a photodiode as the diode is sensitive to the light when the configuration of the diode is reverse-biased.
- It can be used as a solar cell.
- When the diode is forward-biased, it can be used in LED lighting applications.
- It is used as rectifier in many electric circuits and as a voltage-controlled oscillator in varactors.

Summary of P-N Junction Diode

A pn junction is a boundary between two semiconductor regions, one doped with positive charge carriers (p-type) and the other with negative charge carriers (n-type).
The interaction between these materials creates a depletion region near the junction. The junction exhibits a built-in potential that results in a barrier to the flow of charge carriers. When a forward bias is applied, allowing current to flow easily, the junction becomes conductive. Conversely, a reverse bias increases the barrier, inhibiting current flow. This behavior is essential in the operation of diodes and other semiconductor devices, forming the basis for electronic components in various applications.


Thank you