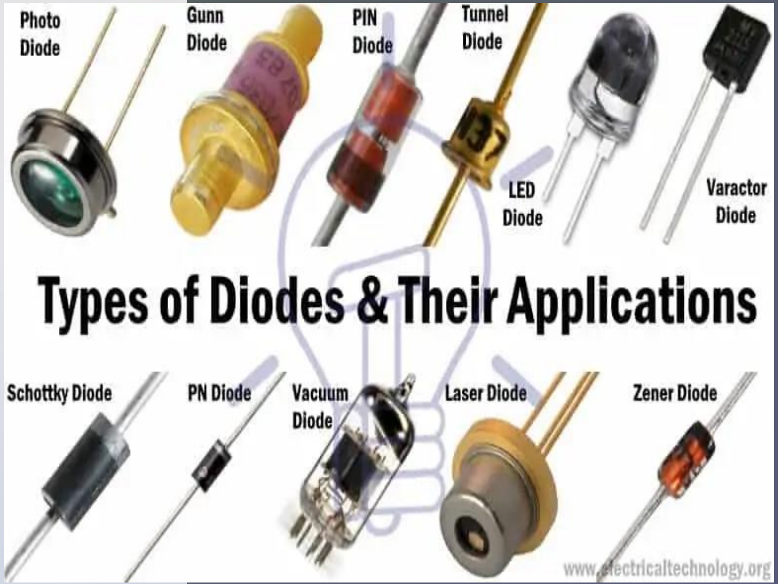
Junction Diodes and Their Applications



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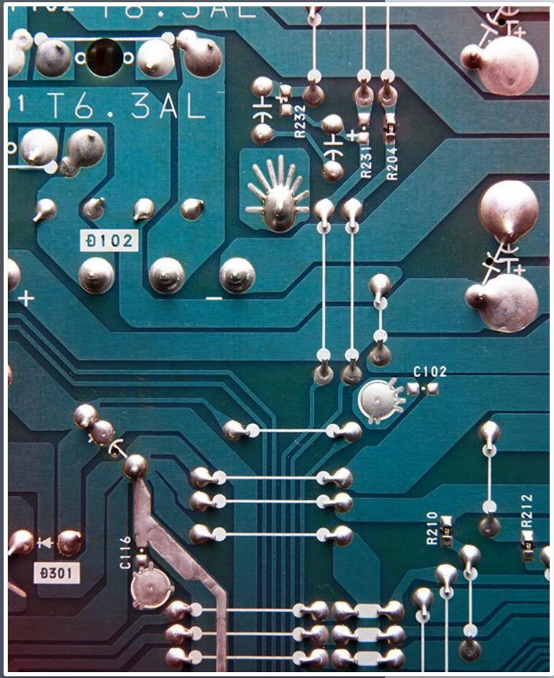
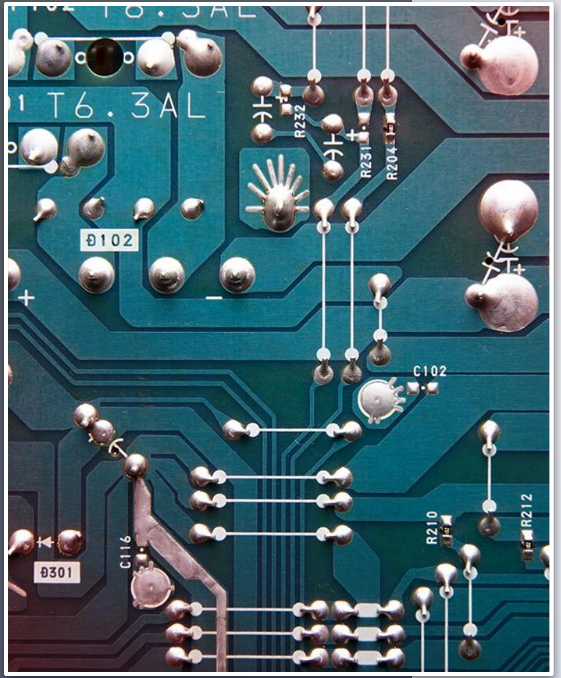


01

Introduction

Introduction

The diode is the most used semiconductor device in electronics circuits. **It is a two-terminal electrical check valve that allows the flow of current in one direction**. They are mostly made up of silicon but germanium is also used. Usually, they are used for rectification. But there are different properties & characteristics of diodes which can be used for different application. These characteristics are modified to form different types of diodes. Nowadays, several different types of diodes having different properties are available.



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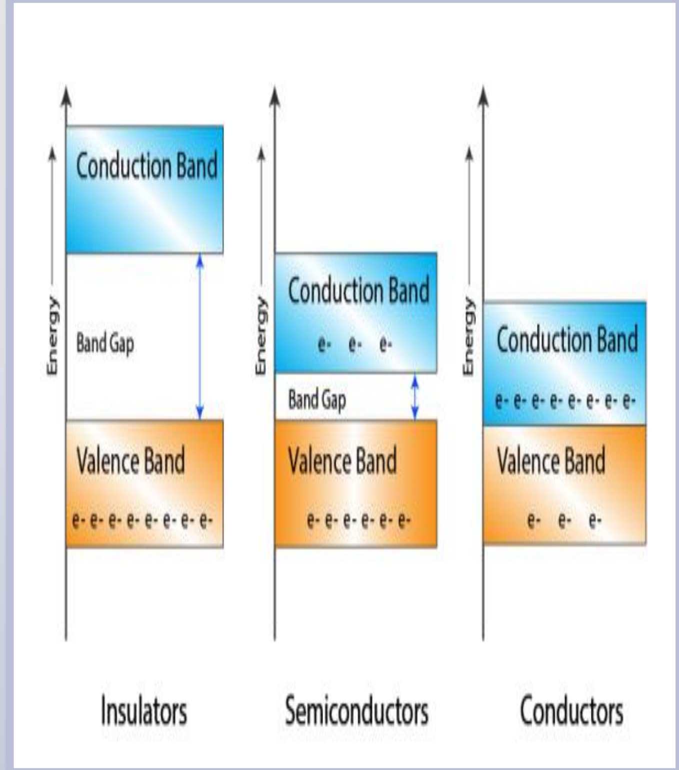
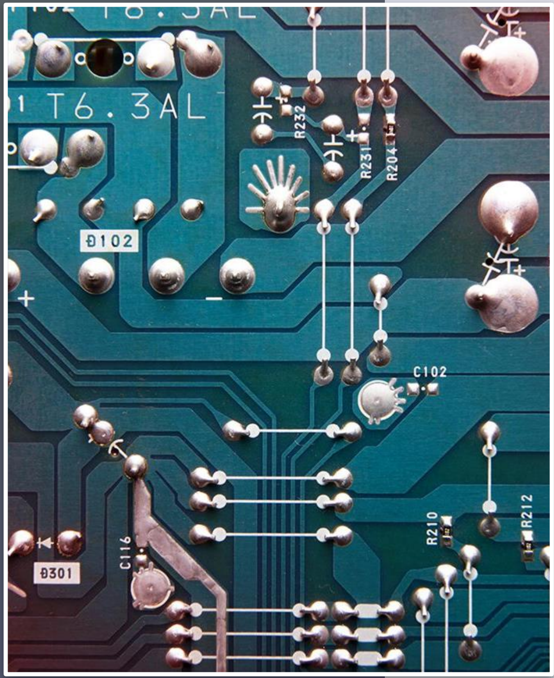
Semiconductor

What Are Semiconductor?

- A material with the electrical characteristics of an insulator, but has a small chance of allowing electrons to flow and contribute to an electric current.
- In other words, the electrical conductivity of a semiconductor is intermediate between that of metals and insulators.
- The electrical behavior of semiconductors is explained by band theory, which states that semiconductors have a small bandgap that allows electrons to move from the valence band to the conduction band. When an electric potential is applied, a small current flows, caused by the movement of both electrons and holes. Silicon is the most widely used semiconductor due to its good properties and natural abundance, although other semiconductors like germanium, gallium arsenide, and silicon carbide are also used.





03

Types of Semiconductor

Semiconductors are divided into two categories: intrinsic semiconductors and extrinsic semiconductors.

an Intrinsic Semiconductor

is a pure semiconductor without any impurities. Its electrical properties are determined by the material itself, such as temperature. At low temperatures, it behaves like an insulator, but as the temperature increases, some electrons gain enough energy to move from the valence band to the conduction band, creating charge carriers (electrons and holes).

Extrinsic Semiconductor

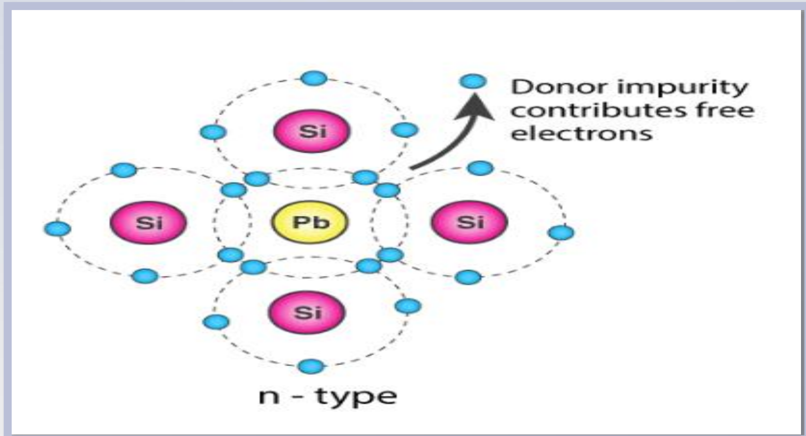
is a semiconductor material that has been doped with impurities to increase its electrical conductivity. These impurities introduce extra charge carriers (electrons or holes) into the material, enhancing its ability to conduct electricity. There are two types of extrinsic semiconductors: n-type (with extra electrons) and p-type (with extra holes).

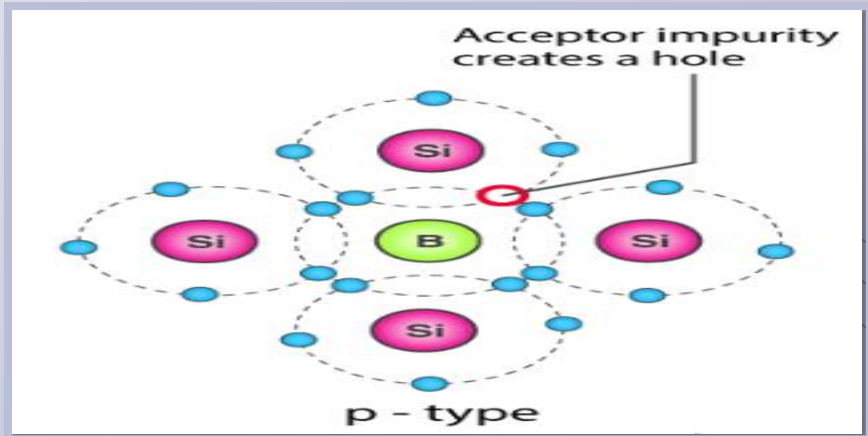
types of extrinsic semiconductors

Extrinsic semiconductors are semiconductors that are doped with specific impurities. The impurity modifies the electrical properties of the semiconductor and makes it more suitable for electronic devices such as diodes

N-type Semiconductor:
Doped with impurities that provide extra electrons, typically from elements with five valence electrons (e.g., phosphorus or arsenic). These extra electrons increase the material's electrical conductivity by contributing negatively charged carriers (electrons) to the conduction band.

P-type Semiconductor:
Doped with impurities that create "holes" or positive charge carriers, typically from elements with three valence electrons (e.g., boron or gallium). These holes allow electrical current to flow as electrons from the valence band move to fill the holes, effectively creating a positive charge flow.





p-n junction

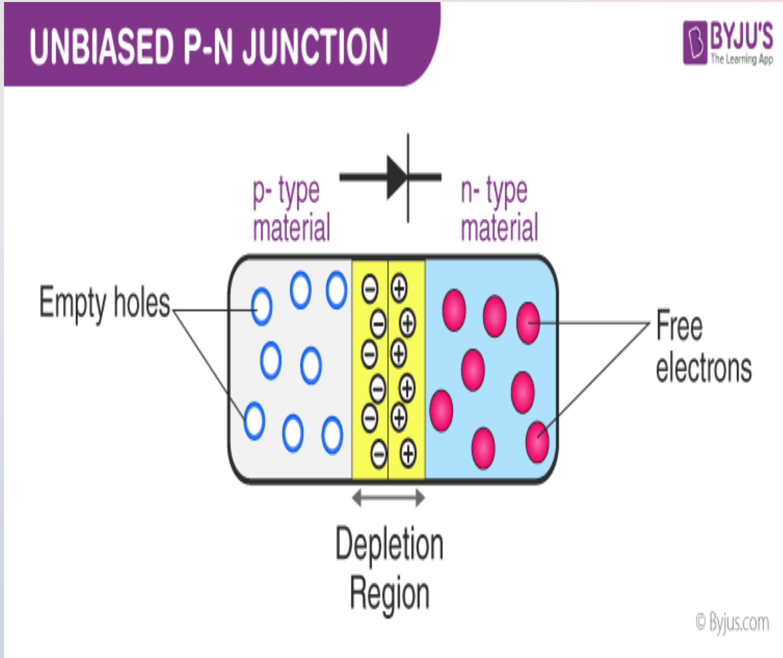
A **p-n junction** is the boundary formed between two types of semiconductor materials: **p-type** (positive) and **n-type** (negative). When these two materials are joined, an electric field is created at the junction, known as the **depletion region**, where electrons from the n-type region combine with holes from the p-type region.

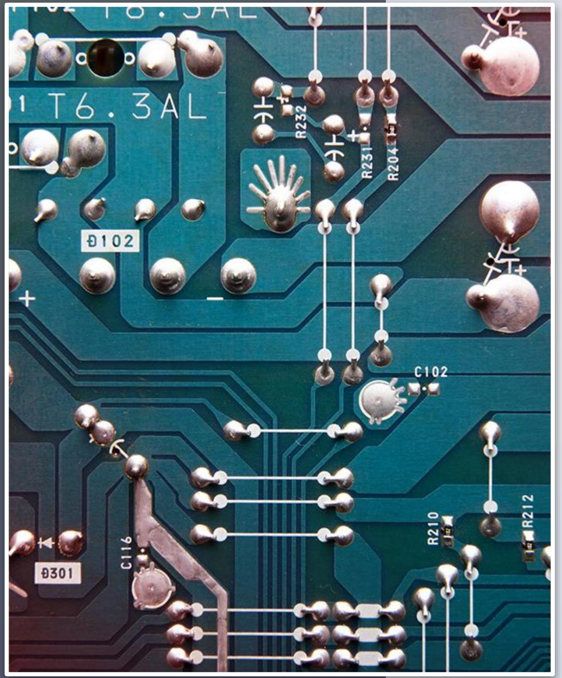
This junction has unique electrical properties:

Forward Bias: When a positive voltage is applied to the p-type side and a negative voltage to the n-type side, the junction allows current to flow easily.

Reverse Bias: When the voltage is reversed, the junction blocks current, making it act as an insulator.

The p-n junction is the core of many semiconductor devices, such as diodes, transistors, and solar cells.





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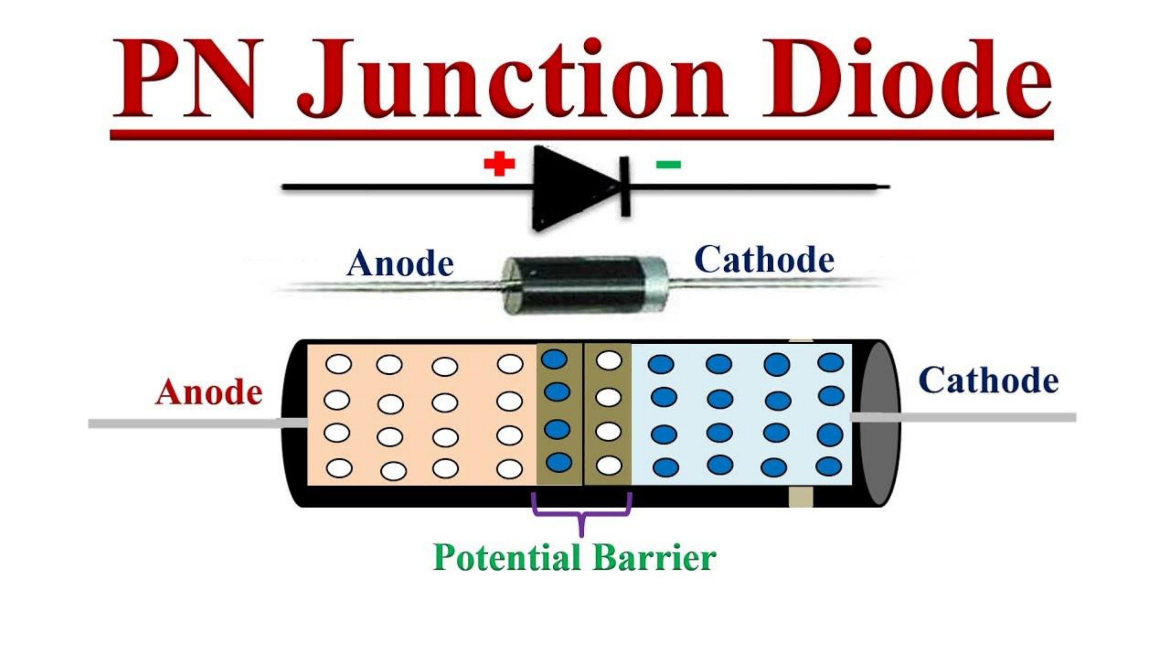
The Junction Diode

Constitution

The junction diode is made by a **PN junction**. It is the basic component of semiconductor devices and is formed by creating a simple **PN junction**. Figure illustrates the semiconductor structure of a diode and its symbol in electronic circuits.



Characteristics of a Diode

The characteristic of a diode refers to the relationship between the voltage applied across it and the current flowing through it. This is typically represented by a **current-voltage (I-V) curve**, which shows the diode's behavior under different conditions:

Forward Bias:
•When a positive voltage is applied to the p-type side and a negative voltage to the n-type side, the diode conducts electricity.
•Initially, in small voltage ranges, the current remains very low. Once the forward voltage exceeds a threshold (typically around 0.7V for silicon diodes), the current increases sharply.

Reverse Bias:
•When the polarity is reversed (positive voltage applied to the n-type side), the diode does not conduct current, except for a very small leakage current.
•If the reverse voltage exceeds a critical value (known as the **reverse breakdown voltage**), the diode may undergo **reverse breakdown**, allowing current to flow in the reverse direction and potentially damaging the diode.

Threshold Voltage:
•This is the minimum voltage required to turn the diode "on" in the forward bias condition. For a silicon diode, it is typically around 0.7V, and for a germanium diode, around 0.3V.

Reverse Leakage Current:
•A small amount of current flows even in reverse bias, which is called the **leakage current**. This current is negligible under normal operating conditions but increases significantly if the reverse voltage exceeds the breakdown voltage.

Diode Resistance

Resistance opposes the flow of current through a device. **Diode resistance** is the effective opposition a diode offers to current flow. Ideally, a diode offers zero resistance when forward biased and infinite resistance when reverse biased. However, no device is perfect. Practically, every diode has small resistance when forward biased and significant resistance when reverse biased. We can characterize a diode by its forward and reverse resistances.

Forward Resistance

Even with forward biasing, a diode won't conduct until it reaches a minimum threshold voltage. Once the applied voltage exceeds this threshold, the diode starts to conduct. The resistance offered by the diode in this condition is called forward resistance. In other words, forward resistance is the resistance a diode shows when it is forward biased.

Forward resistance is classified into two types , static or dynamic depending on whether the current flowing through the device is DC (Direct Current) or AC (Alternating Current), respectively.

Static or DC Resistance

It is the resistance offered by the diode to the flow of DC through it when we apply a DC voltage to it. Mathematically the static resistance is expressed as the ratio of DC voltage applied across the diode terminals to the DC flowing through it

$$R_{dc} = \frac{V_{dc}}{I_{dc}}$$

Dynamic or AC Resistance

Dynamic resistance is the resistance a diode offers to AC current when connected to a circuit with an AC voltage source. It is calculated as the ratio of the change in voltage across the diode to the change in current through it.

$$r_{ac} = \frac{v_{ac}}{i_{ac}}$$

Reverse Resistance

When we connect the diode in reverse biased condition, there will be a small current flowing through it which is called the reverse leakage current. We can attribute the cause behind this to the fact that when the diode functions in its reverse mode, it will not be completely free of charge carriers. That is, even in this state, one can experience the flow of minority carriers through the device.

Due to this current flow, the diode exhibits reverse resistance characteristic. The mathematical expression for the same is similar to that for the forward resistance and is given by

$$R_r = \frac{V_r}{I_r}$$

Where, V_r and I_r are the reverse voltage and the reverse current respectively.

Zener Diode

A Zener diode is a type of semiconductor diode that allows current to flow in the reverse direction when the applied voltage reaches or exceeds its Zener breakdown voltage. Unlike regular diodes, which block reverse current, Zener diodes are designed to operate reliably in this breakdown region without damage, making them ideal for voltage regulation, overvoltage protection, and reference voltage generation in electronic circuits.

Principle of Voltage Regulation Using a Zener Diode

1. Reverse-Bias Operation:
   - The Zener diode blocks current until the input voltage (V_{in}) reaches its **Zener breakdown voltage** (V_z).
   - At V_z, the diode conducts in the breakdown region, maintaining a constant voltage across its terminals.
2. Circuit Setup:
   - The Zener diode is connected in reverse bias, in parallel with the load.
   - A series resistor limits the current flowing through the circuit.
3. Voltage Regulation:
   - If $V_{in} < V_z$: The diode remains off, and the output voltage equals V_{in}.
   - If $V_{in} \geq V_z$: The diode conducts, clamping the output voltage at V_z.

Some Special Diodes

1. **Zener Diode:**
   Used for voltage regulation by maintaining a constant voltage in reverse bias.
2. **Schottky Diode:**
   Features a low forward voltage drop and fast switching speed, commonly used in high-frequency applications and power supplies.
3. **Light Emitting Diode (LED):**
   Emits light when forward-biased, widely used in display and lighting systems.
4. **Photodiode:**
   Converts light into electrical current, used in sensors and solar cells.
5. **Tunnel Diode:**
   Operates based on quantum tunneling, used in high-frequency and microwave applications due to its negative resistance property.