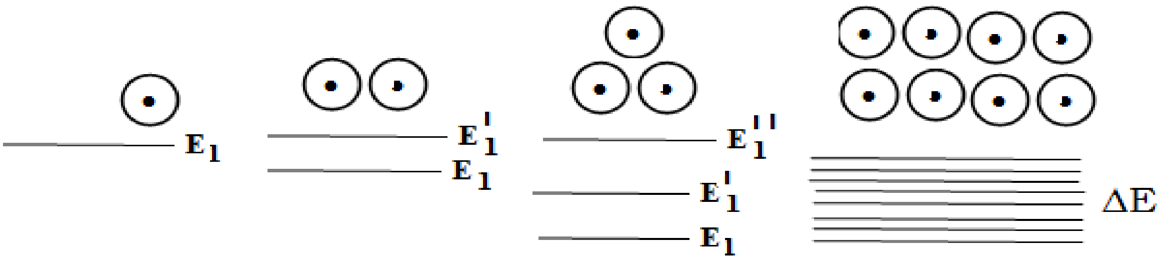
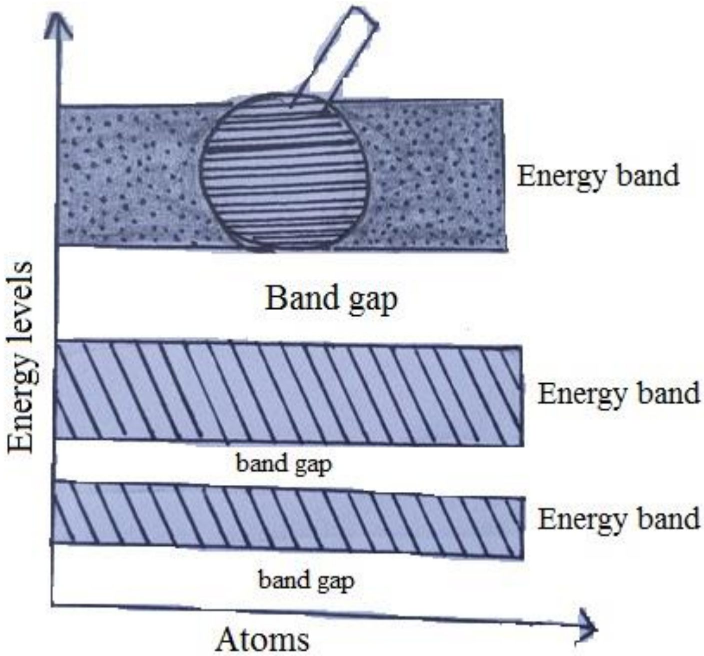
SEMICONDUCTORS

1. Origin of Energy Bands in Solids

It has to be noted that as long as the atoms are widely separated, they have identical energy levels. But once the atoms are brought together, inter atomic force of attraction between the atoms in the solid may modify the energy levels of a solid as energy bands.



If two atoms of equal energy levels are brought closer together, the original energy levels splits each into two energy levels. When 3 atoms are brought closer together the original energy levels splits each into three energy levels.



Energy bands:

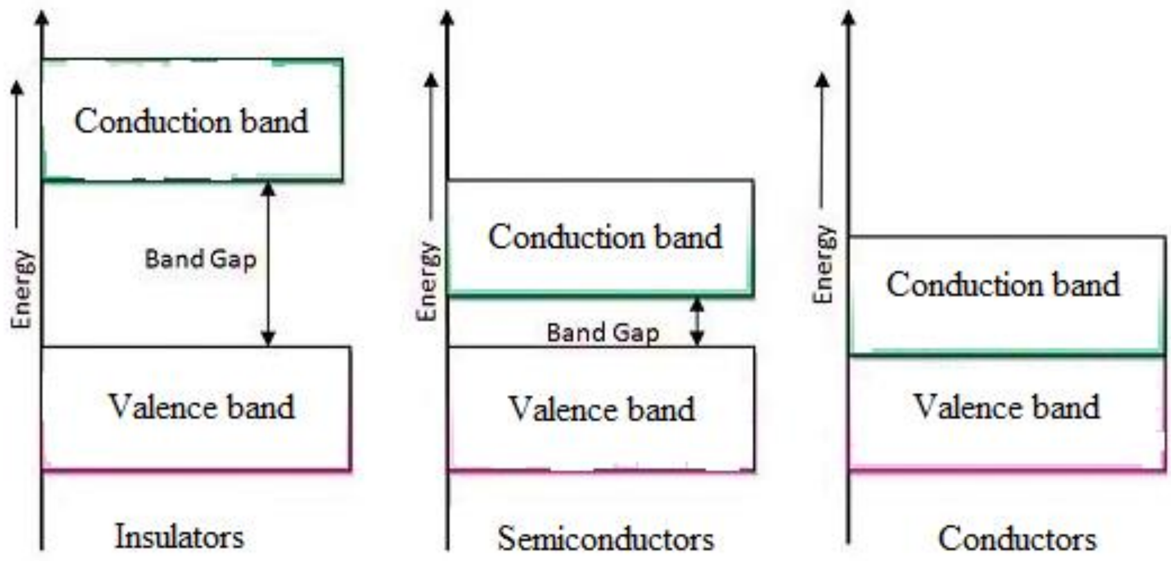
If N number of atoms of equal energy levels is brought closer to form a solid, then it forms closely spaced continuous energy levels, so they are called *energy bands*.

Hence an energy band can defined as the range of energies possessed by an electron in a solid. The modified view of the energy band which consists of a large number of very closely spaced energy levels is shown.

During the formation of energy bands, the inner filled energy levels form an energy band called *inner field bands.* Similarly the electrons in the outer most shells of atoms form an energy band called ***valence band.*** Valence band will be completely filled or partially filled with electrons is based on the material. If an electron comes out from valance band for conduction then they form an energy levels and corresponding energy band is called ***conduction band.***

While referring to energy bands they are separated by small regions which do not allow any energy levels. Such regions between the energy bands are called ***energy band gaps*** or ***forbidden energy gaps***. Valance electrons are responsible for electrical, thermal and optical properties of solids

2. Classification of solids based on energy bands



Depending on the nature of band occupation by electrons and on the width of the forbidden band, the solids can be classified as conductors, semi conductors and insulators.

Conductors

If there is no energy band gap between valence band and conduction band and two bands are overlapped with each other such solids are called as *conductors*. Metals are the best examples for conductors.

Semiconductors

If the energy band gap between valence band and conduction band lies between 0.5eV to 1.5eV such solids behaves as a semi conductors. Examples are Silicon and Germanium having band gap energies 1.1eV and 0.7eV respectively.

Insulators

If the energy band gap between valence band and conduction band is more than 5eV such solids behaves as insulators or resisters. The diamond is a perfect insulator having a band gap of 5.5 eV.

Introduction to Semiconductors

The band theory of solids introduced the concept of Conduction band, valence band and an energy band gap separating the two bands. In which solids band gap between conduction band and valence band is lies between 0.5 eV to 1.5 eV such solids acts as a semiconductor. Semiconductors are the material whose electric properties are intermediate between those of conductors and insulator.

At absolute zero temperature the valence band is completely filled and conduction band is empty such that the semiconductor is similar to an insulator. As the temperature increased, some of the electrons reach the conduction band, there by leaving vacant places in valence band. The semiconductor now starts exhibiting conducting properties. In semiconductors, resistivity decreases with increasing of temperature.

The unique and interesting feature of semiconductors is that they are bipolar and two charge carriers, namely electrons and holes. From last 25 years a number of semiconducting devices have in to use. Many modern electronic gadgets incorporate semiconducting materials.

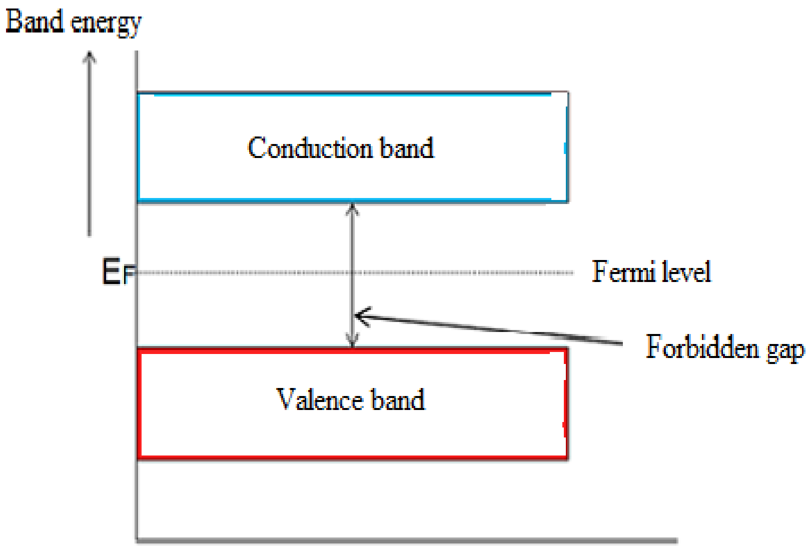
3. Types of semiconductors

Semiconductors can be classified as: i. Intrinsic Semiconductor. ii. Extrinsic Semiconductor. Extrinsic Semiconductors are further classified as: a) n-type Semiconductors. b) p-type Semiconductors.

i. Intrinsic Semiconductor

A perfect, pure Semiconducting crystal congaing no impurities or lattice defects is called ***Intrinsic*** Semiconductor. At 0 K temperature the valence band of Intrinsic Semiconductor filled with electrons and the conduction band is empty. Therefore it has no charge carriers at 0 K temperatures.

Examples: Germanium, silicon



Germanium and silicon both have four valance electrons in valence band. As temperature increased, valence band electrons acquire thermal energy and excited across the forbidden energy band gap and start moving to the conduction band, leaving behind holes. Thus electron hole pairs are created, on applying electric field, the holes moving in a direction opposite to that of the valence electrons.

In intrinsic Semiconductor the number of electrons and holes are equal and they are less. Hence the current produced in an Intrinsic Semiconductor is not sufficient for any useful work. The Fermi level E_F is at the middle of valence band and conduction band. E_v is energy level of valance band and E_c is energy level of Conduction band then the energy band gap $E_g = \frac{E_c + E_v}{2}$ and $E_g = E_c - E_v$

Limitations of Intrinsic semiconductors

a. Intrinsic semiconductors are not useful for device manufacture because of low conductivity
b. Strong dependence of conductivity on temperature.
c. Temperature increase conductivity can't be controlled.

ii. Extrinsic Semiconductor

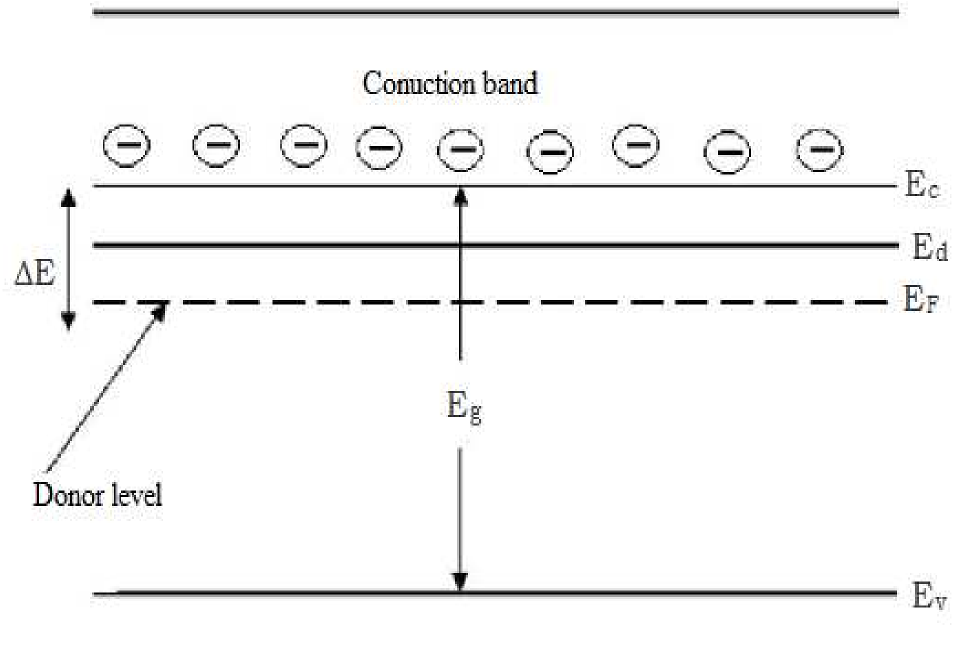
If a small amount of impurity is added to a pure semiconductor its conductivity significantly increases. The process of adding the impurities to a semiconductor is known as ***doping***. A semiconductor doped with impurities is called extrinsic Semiconductor.

Depending upon the type of impurity added to pure semiconductor's the extrinsic Semiconductors are further sub divide into two types.

a) n-type Semiconductors.

b) p-type Semiconductors.

n-type semiconductors:



A Pure Semiconductor doped with a pentavalent impurity is called n-***type*** Semic

~~When the impurities are added to pure crystal, four v~~alence electrons of impurit

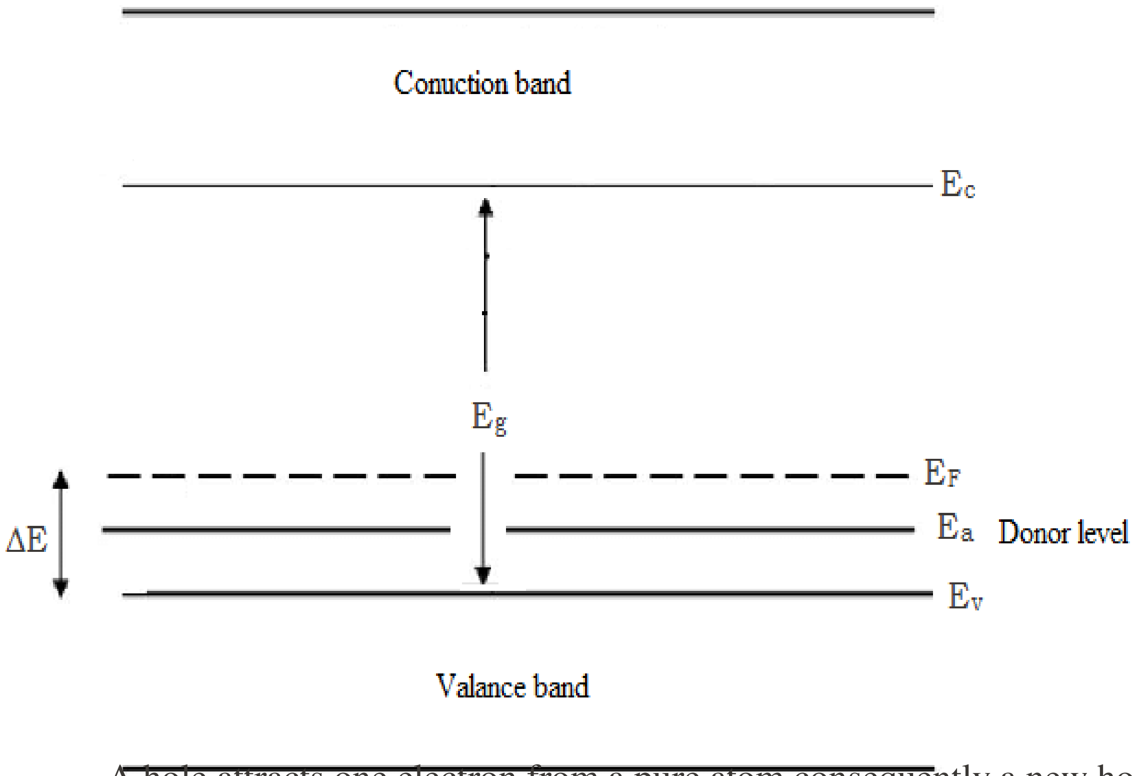
randomly in the crystal.

The each impurity atom donates a free electron to the semiconductor. Hence the impurity is called donor impurity. So n-type semiconductor has donor impurity. It has negative charge carrier. Here E_d represents the energy level corresponding to donor impurities and it lies just below the conduction band and Fermi energy level lies near to the conduction band. In n-type semiconductor majority charge carriers are electrons and holes are the minority charge carriers.

p-type semiconductors:

A Pure Semiconductor doped with a trivalent impurity is called ***p-type*** Semiconductors. Example is Gallium and Indium. Any trivalent impurity is consists of three valence electrons in its valence band.

When the impurities are added to intrinsic semiconductor, three valence electrons of impurity atom forms covalent bonds with three valence electrons of the pure semiconductor. There is a deficiency of one electron to complete fourth bond. This electron deficiency is called the hole and it behaves like positively charged particle.



A hole attracts one electron from a pure atom consequently a new hole is created

An impurity that produces hole inside a semiconductor is called acceptor, because it accepts electron from the pure atom, Hence the impurity is called acceptor impurity. So p-type semiconductor has acceptor impurity. It has positive charge carrier. Here E_a represents the energy level corresponding to acceptor impurities and it lies just above the valence band and Fermi energy level lies near to the valence band. In p-type semiconductor majority charge carriers are holes and electrons are the minority charge carriers.

Advantages of extrinsic semiconductors

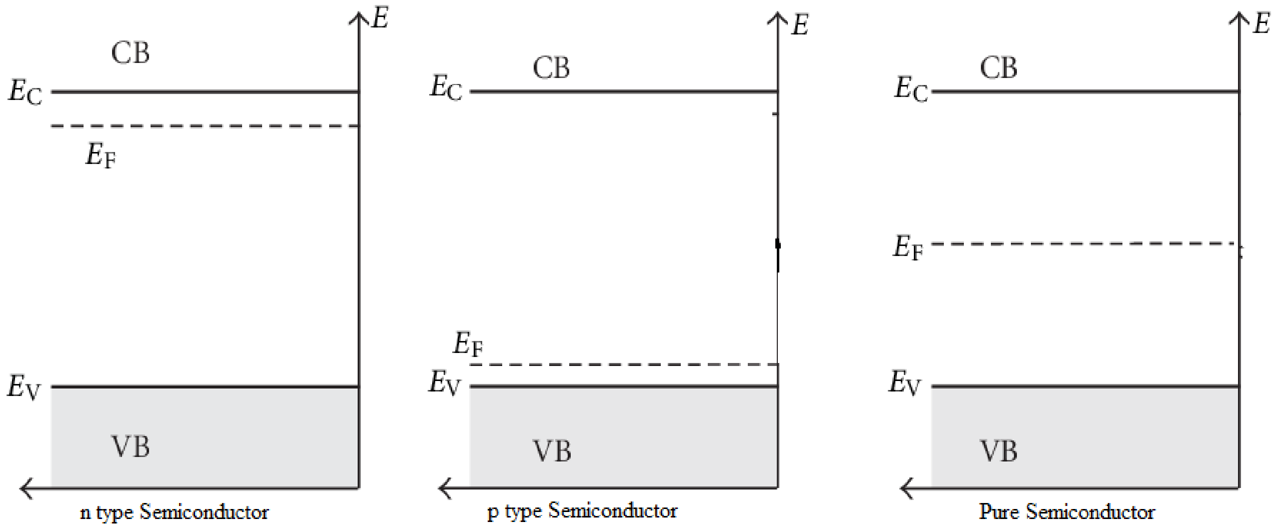
a. Conductivity is high

b. Conductivity can be tailored to the desired value through the control of doping concentration.

c. Conductivity is not function of a temperature.

7. Fermi Energy level with temperature In Semiconductors

Fermi energy level is used as reference energy level. In an intrinsic [pure] semiconductor the Fermi level lies at the centre of the forbidden energy gap and it is independent of the temperature.

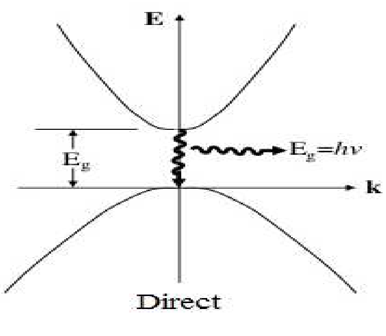
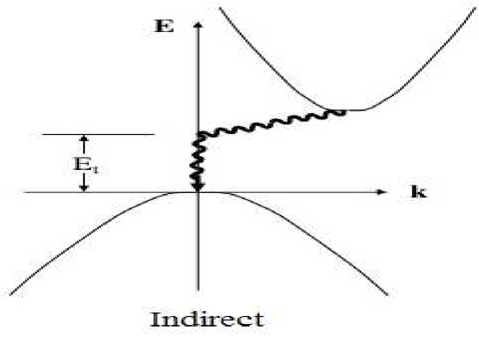


When we add a donor impurity like Arsenic to an intrinsic semiconductor the Fermi level rises above the mean level. When we add an acceptor impurity like Aluminum, Boron etc, the Fermi level lies falls below the mean level in the forbidden energy gap. Thus in a n- type semiconductor the Fermi energy level is nearer to the conduction band, while in a P- type semiconductor the Fermi energy level is nearer to the valance band.

E_F is independent of temperature in intrinsic semiconductor. But in extrinsic E_F moves closer to the middle. Thus the both n, p –type materials become more like an intrinsic material at high temperature. This places a limit on the operating temperature of extrinsic semiconductors devices.

8. Direct band gap and indirect band gap Semiconductors

According to band theory of solids the energy Spectrum of electrons consists a large number of energy bands and they are separated by forbidden regions. Based on the structure of energy bands the semiconductors classified into two types. i. Direct band gap semiconductors ii. Indirect band gap semiconductors

	Direct band gap Semiconductor	**Indirect band gap Semiconductor**
1	In energy versus position diagram the position of electron in conduction band is same as in position of hole in the valence band then the semiconductor is called direct band gap semiconductor	In energy versus position diagram the position of electron in conduction band does not always occur the same value of position of hole in the valence band then the semiconductor is called indirect band gap semiconductor
2	impure type of semiconductors comes under this category	Pure type of semiconductors comes under this category
3	Examples: Gallium, Indium, Arsenic, Antimony	Examples: Germanium, Silicon
4	 energy versus position diagram	 energy versus position diagram
5	Electron from conduction band can recombine with a hole in valence band directly by emitting light	Electron from conduction band can recombine with a hole in valence band indirectly through taps. Here no

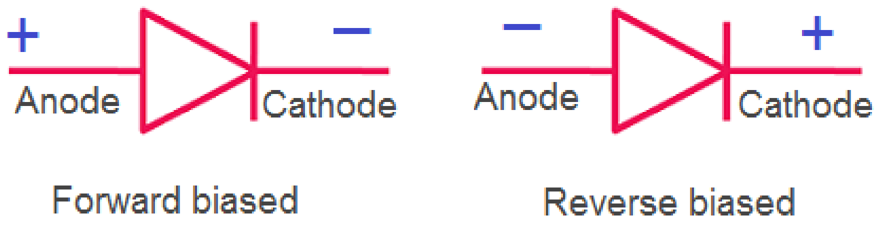
	photon	emission of light.
6	Light emission has energy equal to $E_g = h\upsilon$	No emission of light. It conducts only electricity and heat generated.
7	Life time of charge carriers is very less.	Life time of charge carriers is more.
8	They are used to fabricate LEDs, Laser diodes	They are used to amplify the signals in electronic devices like transistors amplifiers and to fabricate solar cells

12. P-N junction semiconductor diode:

A p-n junction diode is two-terminal or two-electrode semiconductor device, which allows the electric current in only one direction while blocks the electric current in opposite or reverse direction. 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. P-N junction semiconductor diode is also called as p-n junction semiconductor device.

When the n-type semiconductor is joined with the p-type semiconductor, a p-n junction is formed. The p-n junction diode is made from the semiconductor materials such as silicon, germanium, and gallium arsenide. For designing the diodes, silicon is more preferred over germanium. The p-n junction diodes made from silicon semiconductors works at higher temperature when compared with the p-n junction diodes made from germanium semiconductors.

The basic symbol of p-n junction diode under forward bias and reverse bias is shown in the below figure



In the above figure, arrowhead of a diode indicates the conventional direction of electric current when the diode is forward biased (from positive terminal to the negative terminal). The hole which moves from positive terminal (anode) to the negative terminal (cathode) is the conventional direction of current.

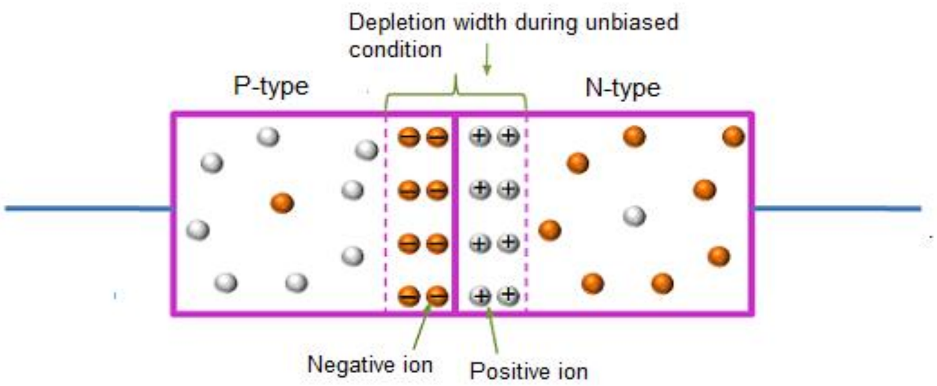
The free electrons moving from negative terminal (cathode) to the positive terminal (anode) actually carry the electric current. However, due to the convention we have to assume that the current direction is from positive terminal to the negative terminal.

Biasing of p-n junction semiconductor diode:

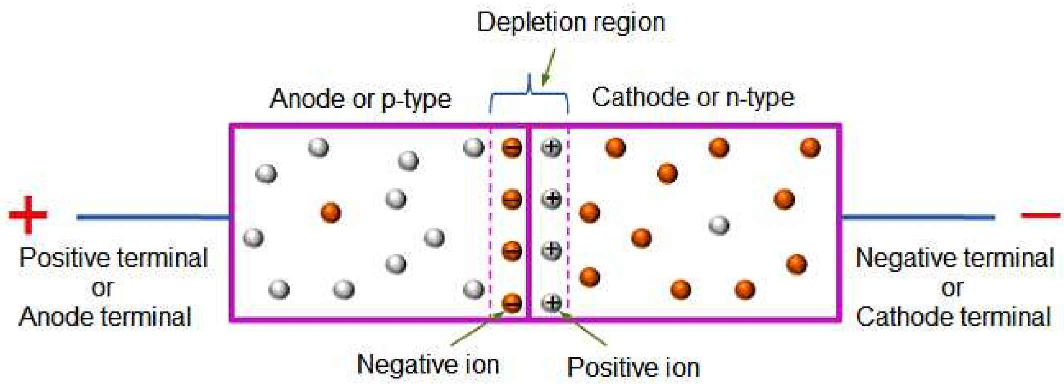
The process of applying the external voltage to a p-n junction semiconductor diode is called biasing. External voltage to the p-n junction diode is applied in any of the two methods: forward biasing or reverse biasing.

If the p-n junction diode is forward biased, it allows the electric current flow. Under forward biased condition, the p-type semiconductor is connected to the positive terminal of battery whereas; the n-type semiconductor is connected to the negative terminal of battery.

If the p-n junction diode is reverse biased, it blocks the electric current flow. Under reverse biased condition, the p-type semiconductor is connected to the negative terminal of battery whereas; the n-type semiconductor is connected to the positive terminal of battery.



Unbiased



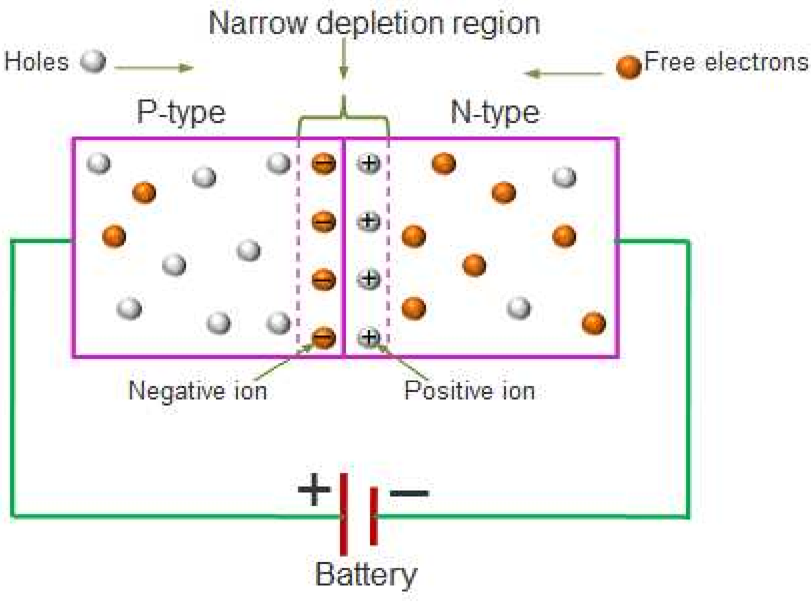
Forward biased

Terminals of pn junction diode:

pn junction diode consists of two terminals: positive and negative. At positive terminal, all the free electrons will ends and all the holes will begins whereas at negative terminal all the free electrons will begins and all the holes will ends.

Forward Biased pn junction Diode:

Theory: In forward biased p-n junction diode (p-type connected to positive terminal and n-type connected to negative terminal), anode terminal is a positive terminal whereas cathode terminal is negative terminal. Anode terminal is a positively charged electrode or conductor, which supplies holes to the p-n junction. In other words, anode or anode terminal or positive terminal is the source of positive charge carriers (holes), these holes begins their journey at anode terminal and travel through the diode and ends



Forward bias

at cathode terminal. Cathode is the negatively charged electrode or conductor, which supplies free electrons to the p-n junction. In other words, cathode terminal or negative terminal is the source of free electrons, the negative charge carriers (free electrons) begins their journey at cathode terminal and travel through the diode and ends at anode terminal.

Mechanism: In the depletion region due to the formation of positive and negative ions, electric field will be created which directs from positively charged ion to negatively charged ion. In this forward biased condition external electric field will be generated in opposite direction to built-in electric field. External electric field cancels the electric field in depletion region, resulting in potential barrier termination. Thus, current flows through the junction.

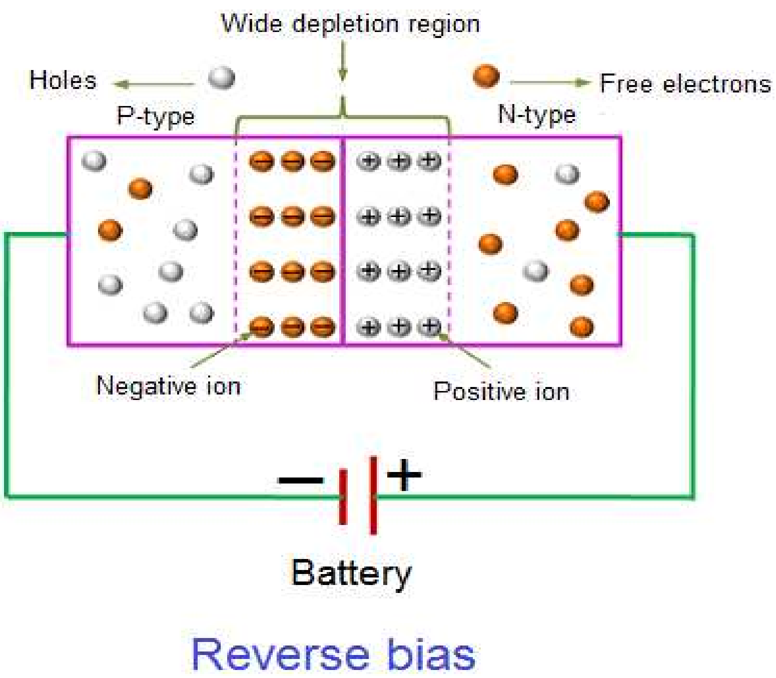
Working: The forward biased p-n junction diode is connected as shown in the above figure. The free electrons are attracted towards the anode terminal or positive terminal whereas the holes are attracted towards the cathode terminal or negative terminal. When an external voltage is applied to pn junction in such a direction that cancels the potential barrier and permits the current flow is called as forward bias. The applied forward potential establishes an electric field opposite to the potential barrier. Therefore, the potential barrier is reduced. As it is very small (Ge=0.3 eV and Si=0.7 eV) therefore, a small forward voltage is sufficient to completely eliminate the barrier. When potential barrier is eliminated by the forward voltage, junction resistance becomes almost zero.

In this, the holes from p type semiconductor and electrons from n type semiconductor are repelled by the positive terminal and negative terminal of the battery respectively. Here, the battery voltage should be high to overcome the potential barrier at the junction. The electron hole combination takes place near the junction, and a covalent bond near the positive terminal of battery breaks down with liberation of electron, which enters the positive terminal. This action creates a new hole which moves towards the junction. Thus, constant movement of electrons towards the positive terminal and the holes towards the negative terminal produces a high forward current.

Reverse Biased pn junction Diode:

When an external voltage is applied to pn junction in such a direction that it increases the potential barrier then it is called as reverse bias. For reverse bias, the positive terminal of the battery is connected to N-type semiconductor and negative terminal to P-type semiconductor as shown in figure. The applied reverse voltage establishes an electric filed which acts in the same direction of potential barrier. Therefore, the resultant filed at the junction is strengthened and the barrier height is increased. The potential barrier prevents the flow of charge carriers across the junction. In this way a high resistance path is established.

When the junction is reverse biased, the electrons in N-type semiconductor and holes in P-type semiconductor are attracted away from the junction. Since there is no recombination of electron hole pairs no current flows in the circuit. The positive charge carriers (holes) which cross the p-n junction are attracted towards the negative terminal of the battery. On the other hand, the negative charge carriers (free electrons) which cross the p-n junction are attracted towards the positive terminal of the battery. Thus, the minority charge carriers carry the electric current in reverse biased p-n junction diode.



"Thus, P-N junction diode is one-way device which offers a low resistance when forward biased and behaves like an insulator when reverse biased. Thus, it can be used as a rectifier, i.e., for converting alternating current into direct current".