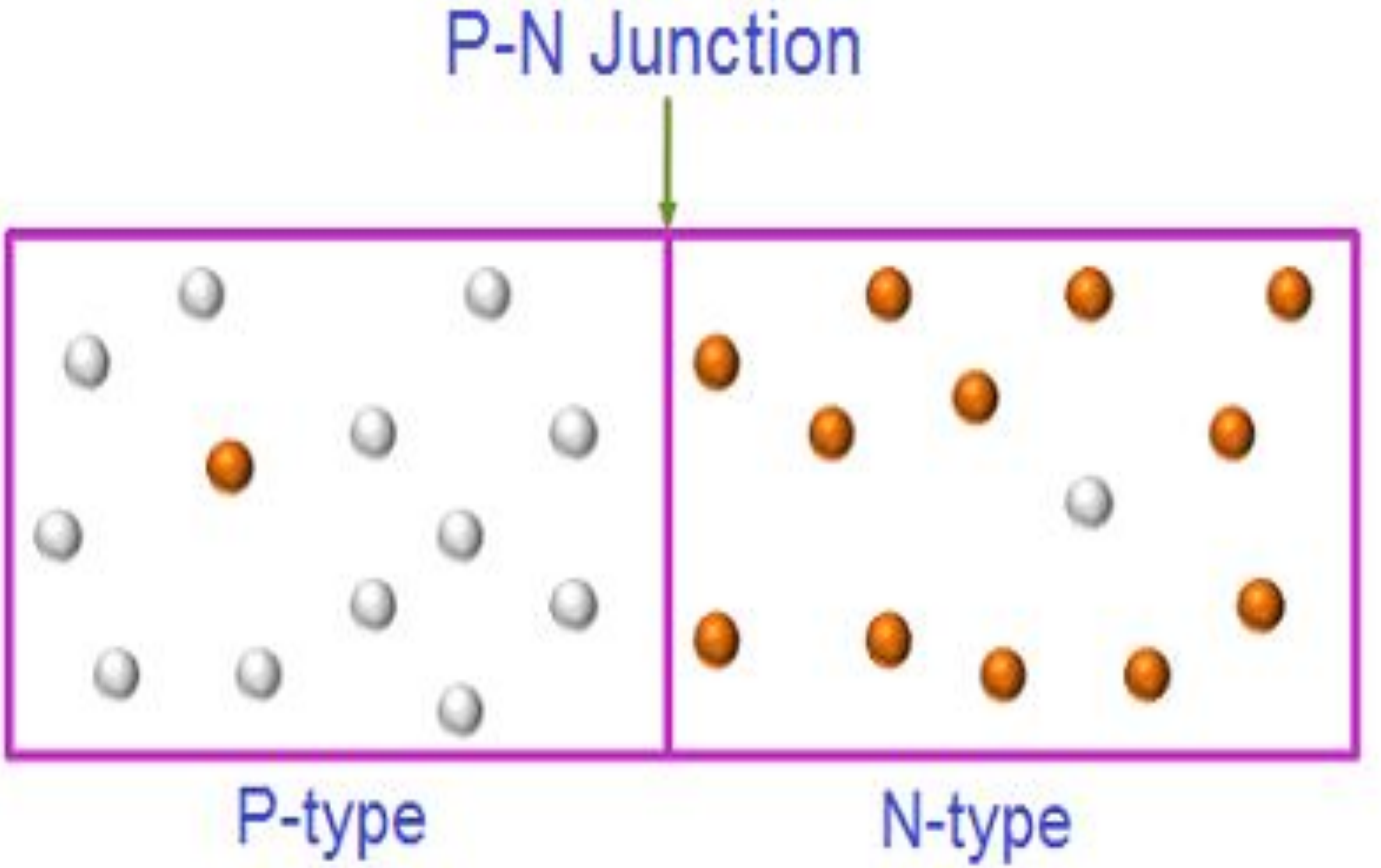
PN JUNCTION DIODE

Formation of p-n junction

Generally junction refers to a point where two or more things are joined. For example, when one or more railway tracks are joined a railway junction is formed. The region where the tracks meet or joined is called railway junction.

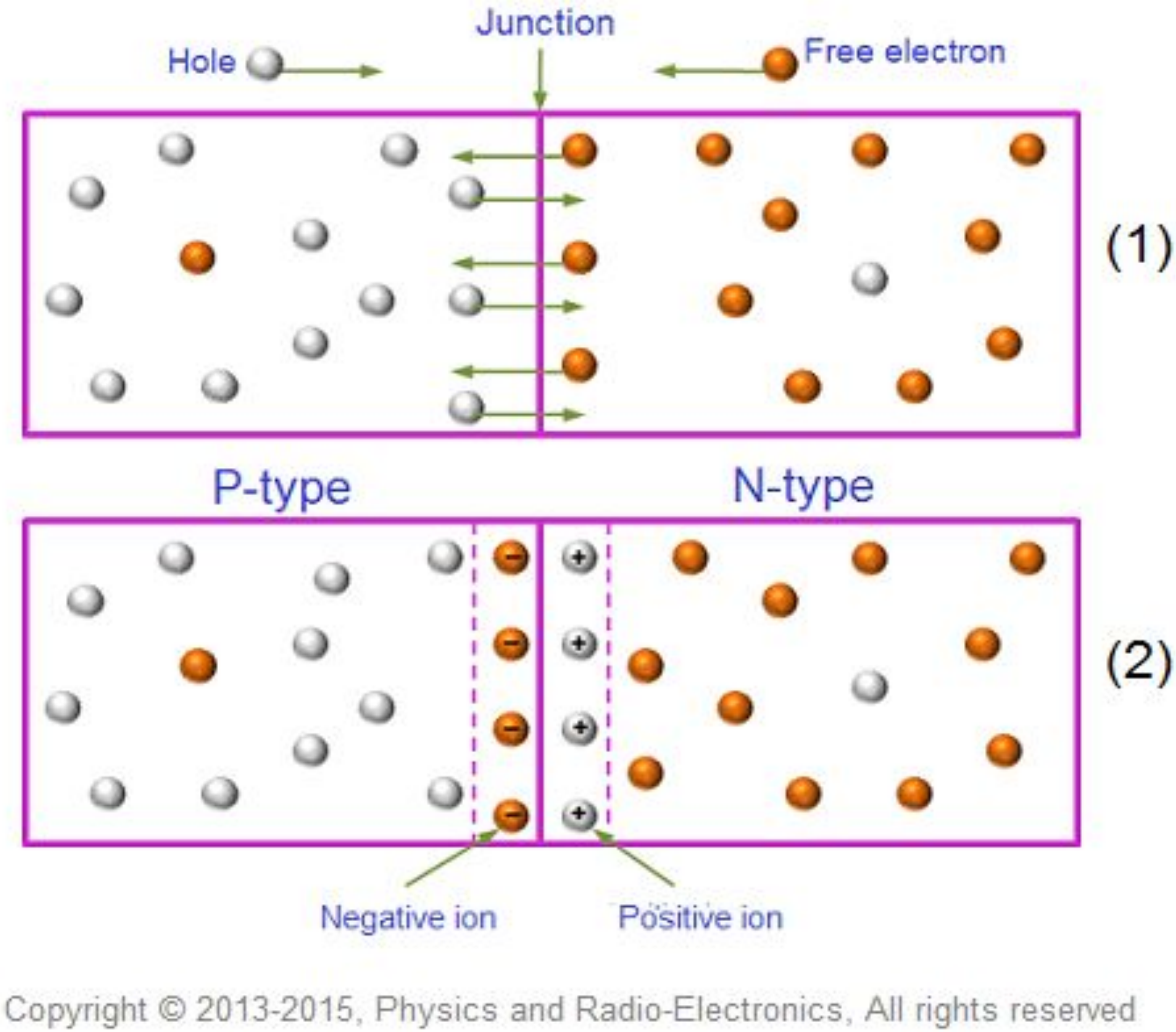
In the similar way, when an n-type semiconductor is joined with the p-type semiconductor, a p-n junction is formed. The region where the p-type and n-type semiconductors are joined is called **p-n junction**. It is also defined as the boundary between p-type and n-type semiconductor. This p-n junction forms a most popular semiconductor device known as **diode.**


P-N Junction
P-type
N-type

P-N Junction

- The credit of discovery of the p-n junction goes to American physicist Russel Ohi of Bell Laboratories.
- p-n junction is also a fundamental building block of many other semiconductor electronic devices such as transistors, solar cells, light emitting diodes, and integrated circuits

Zero bias P-N junction



Zero bias P-N junction

- The p-n Junction in which no external voltage is applied is called zero bias p-n junction. Zero bias p-n Junction is also called as unbiased p-n junction.
- In n-type semiconductor large number of free electrons is present while at p-type semiconductor small number of free electrons is present. Hence, the concentration of electrons at n-type semiconductor is high while the concentration of electrons at p-type semiconductor is low.
- Due to this high concentration of electrons at n-side, they get repelled from each other. Hence they try to move towards the low concentration region.

Zero bias P-N junction

- According to coulomb’s law there exist an electrostatic force of attraction between the opposite charges.
- Hence, the free electrons from the n-side are attracted towards the holes at the p-side. Thus, the free electrons move from n-region (high concentration region) to p-region (low concentration region).
- Similarly the concentration of holes at p-type semiconductor is high while the concentration of holes at n-type semiconductor is low.
- Hence, the holes from the p-side are attracted towards the free electrons at the n-side. Thus, the holes move from p-region (high concentration region) to n-region (low concentration region).

Formation of positive and negative ion

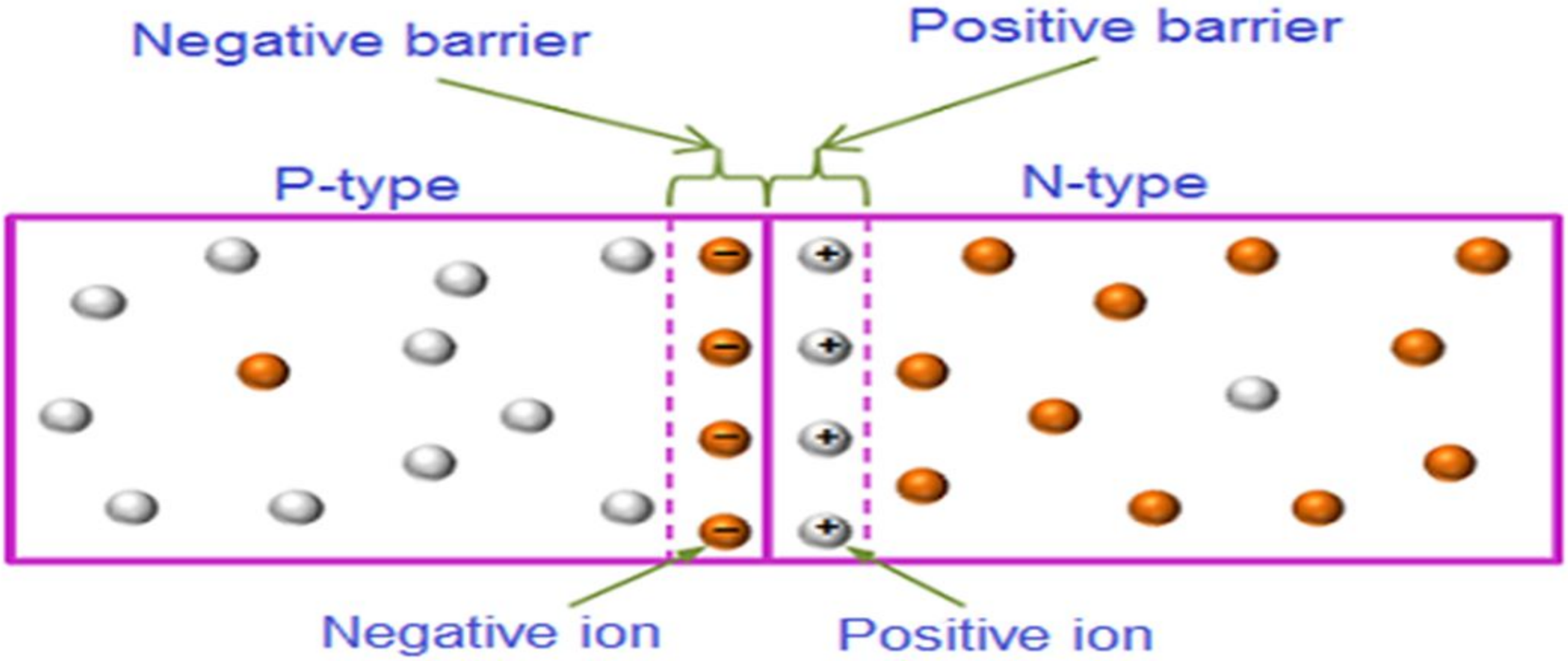
- Each free electron that crosses the junction to fill the holes in the p-side creates negative ions on the p-side. Negative ions are also called as acceptors because they accept extra electrons from outside atoms.
- Each free electron that left the n-side parent atom and crosses the junction to fill the holes in the p-side atom creates positive ion at n-side. Positive ions are also called as donors because they donate extra electrons to the outside atoms.

Barrier voltage

- Thus, a net positive charge is built at the n-side of the p-n junction due to the positive ions at the n-side; similarly a net negative charge is built at the p-side of the p-n junction due to the negative ions at the p-side after diffusion.
- This net negative charge at the p-side of the p-n junction prevents the further flow of free electrons crossing from n-side to p-side because the negative charge present at the p-side of p-n junction repels the free electrons.
- Similarly, the net positive charge at n-side of the p-n junction prevents the further flow of holes crossing from p-side to n-side. Hence, positive charge present at n-side and negative charge present at p-side of p-n junction acts as barrier between p-type and n-type semiconductor.

Barrier voltage

- Thus, a barrier is build near the junction which prevents the further movement of electrons and holes.

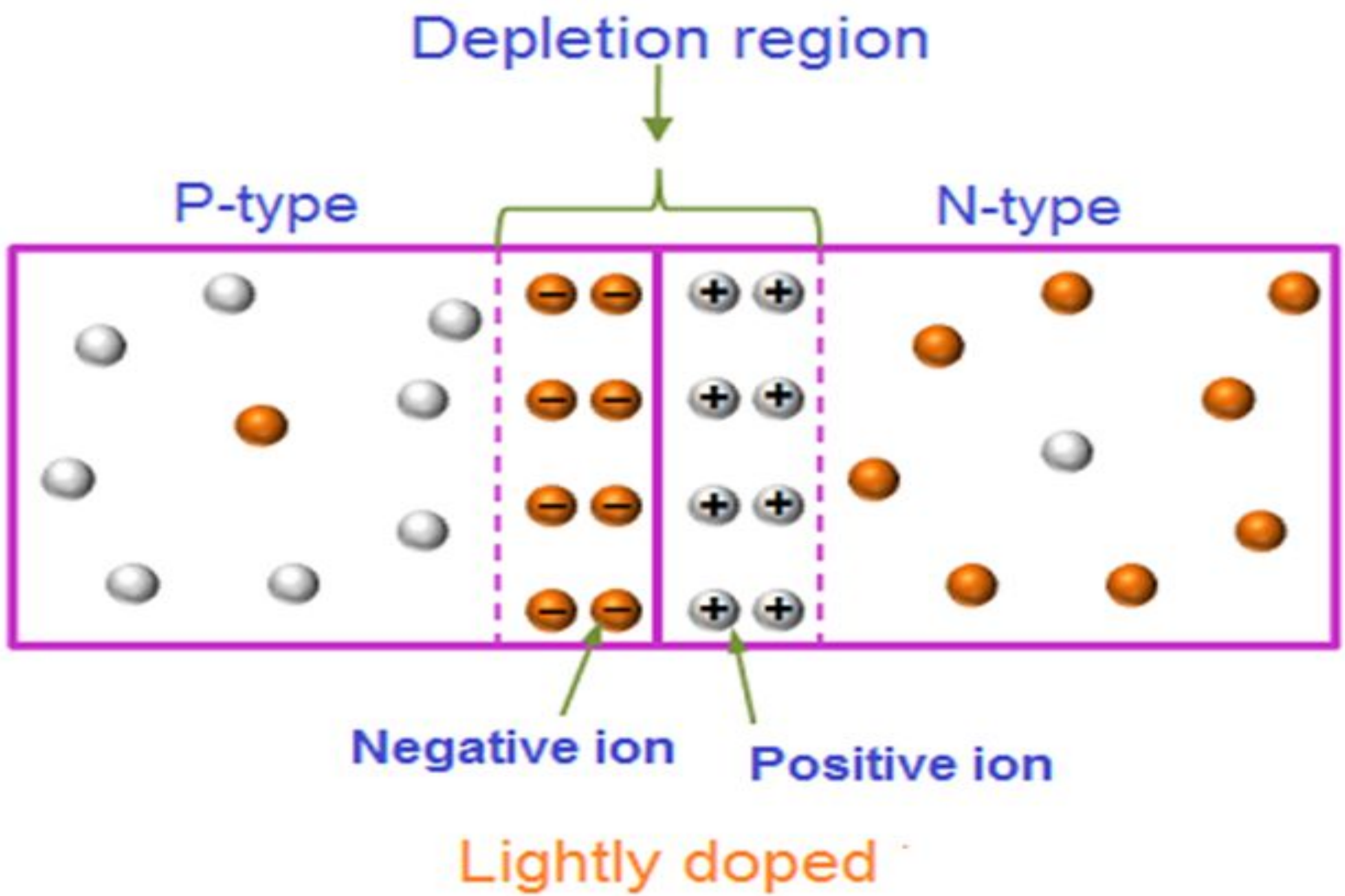


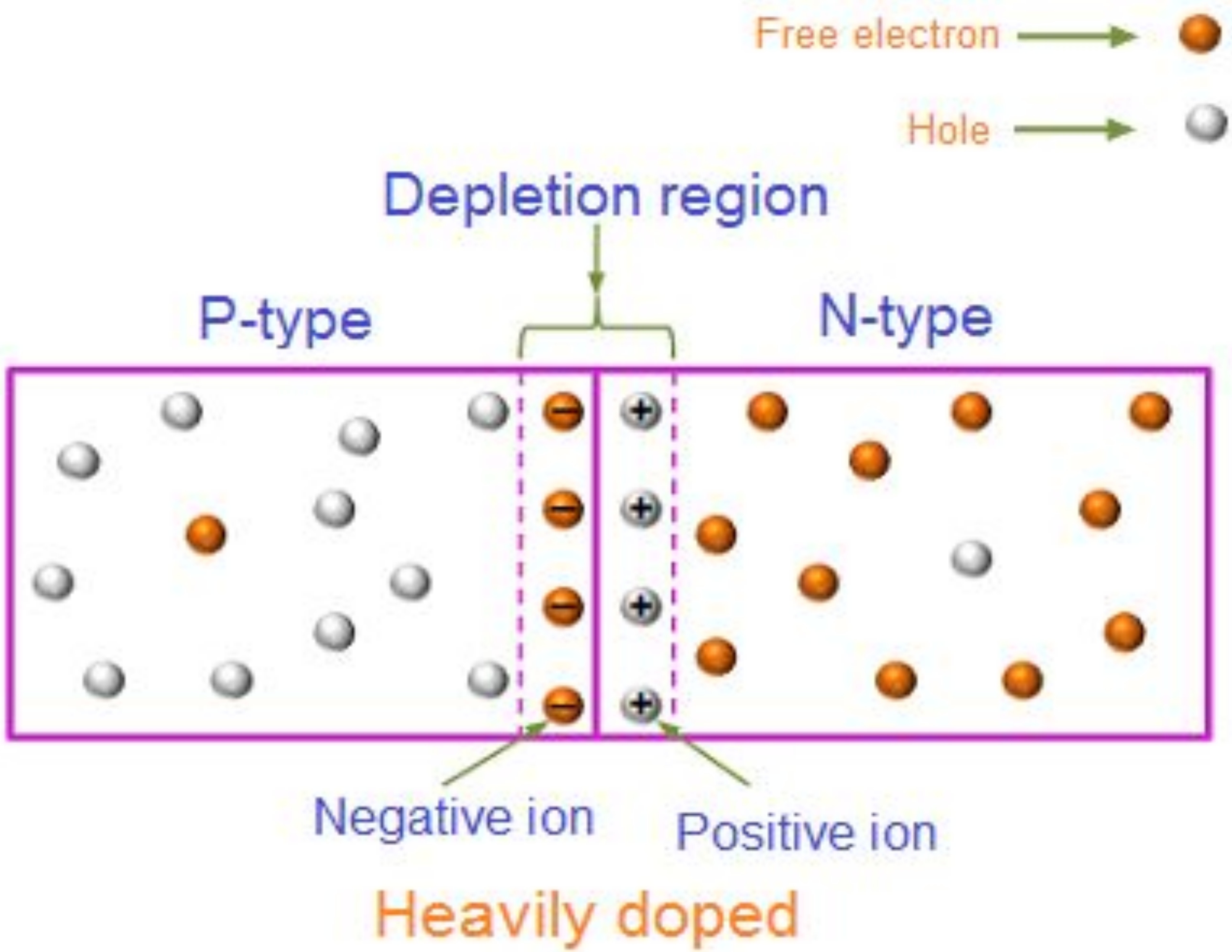
Barrier voltage

- The negative charge formed at the p-side of the p-n junction is called negative barrier voltage while the positive charge formed at the n-side of the p-n junction is called positive barrier voltage. The total charge formed at the p-n junction is called barrier voltage, **barrier potential or junction barrier.**
- The size of the barrier voltage at the p-n junction depends on, the amount of doping, junction temperature and type of material used. The barrier voltage for **silicon diode is 0.7 volts and for germanium is 0.3 volts.**
- The barrier voltage at the p-n junction opposes only the flow of majority charge carriers but allows the flow of minority carriers (.I.e. free electrons at p-side and holes at n-side) to cross the junction.

What is depletion region?

- Generally, depletion refers to reduction or decrease or deficiency in quantity of something.
- The region near the junction where flow of charges carriers are decreased over a given time and finally results in empty charge carriers or full of immobile charge carriers is called **depletion region.**
- The depletion region is also called as depletion zone, depletion layer, space charge region, or space charge layer. The depletion region acts like a wall between p-type and n-type semiconductor and prevents further flow of free electrons and holes.
- The width of depletion region depends on the amount of impurities added to the semiconductor. , the width of depletion region is more in the lightly doped semiconductors and is less in the heavily doped semiconductor


Depletion region
P-type
N-type
Negative ion
Positive ion
Lightly doped


Free electron
Hole
Depletion region
P-type
N-type
Negative ion
Positive ion
Heavily doped

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.
- 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.

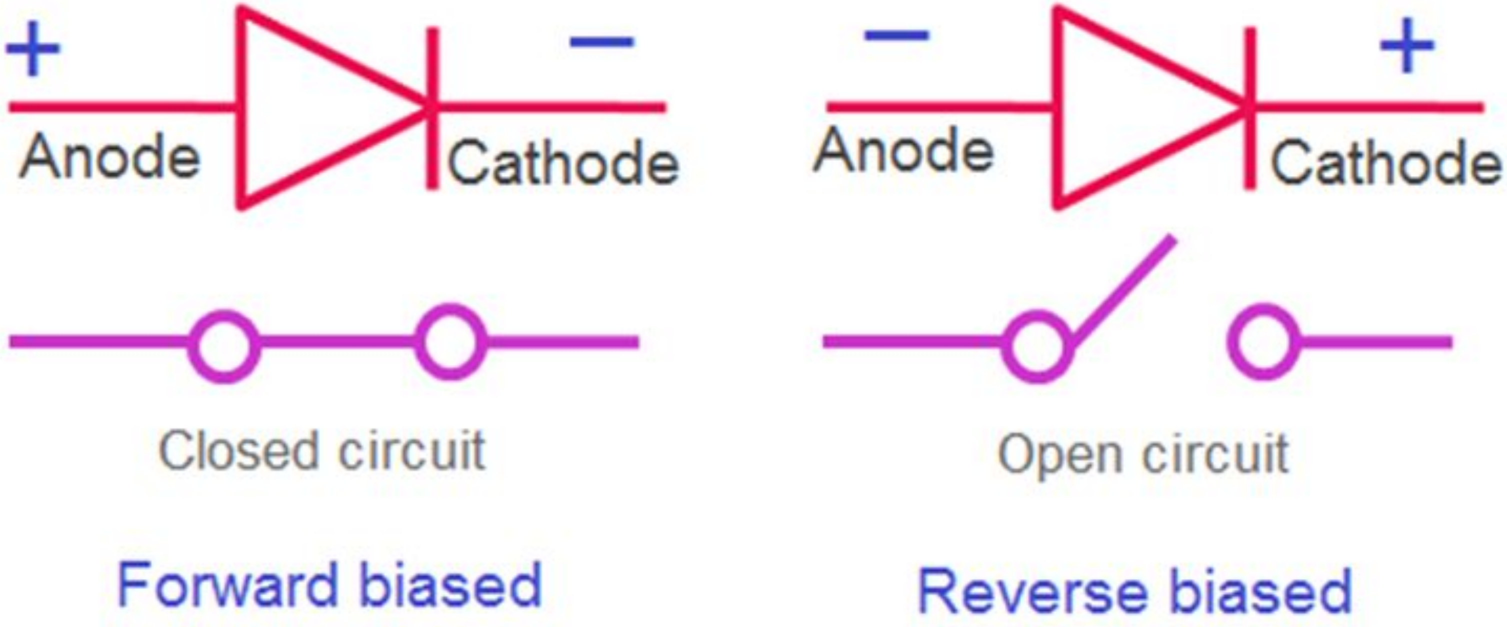
P-N junction semiconductor diode

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

Ideal diode

- The ideal diode or perfect diode is a two terminal device, which completely allows the electric current without any loss under forward bias and completely blocks the electric current with infinite loss under reverse bias.
- Ideal diodes actually do not exist. However, the V-I characteristics of ideal diodes is used to study the diode circuits. In other words, it is used to study the quality of a real diode by comparing it with the ideal diode.
- Under forward biased condition, ideal diode acts as a perfect conductor with zero resistance whereas under reverse biased condition, it acts as a perfect insulator with infinite resistance. In other words, ideal diodes acts as closed circuit or short circuit under forward biased condition and acts as an open circuit or open switch under reverse biased condition.

Ideal diode symbol



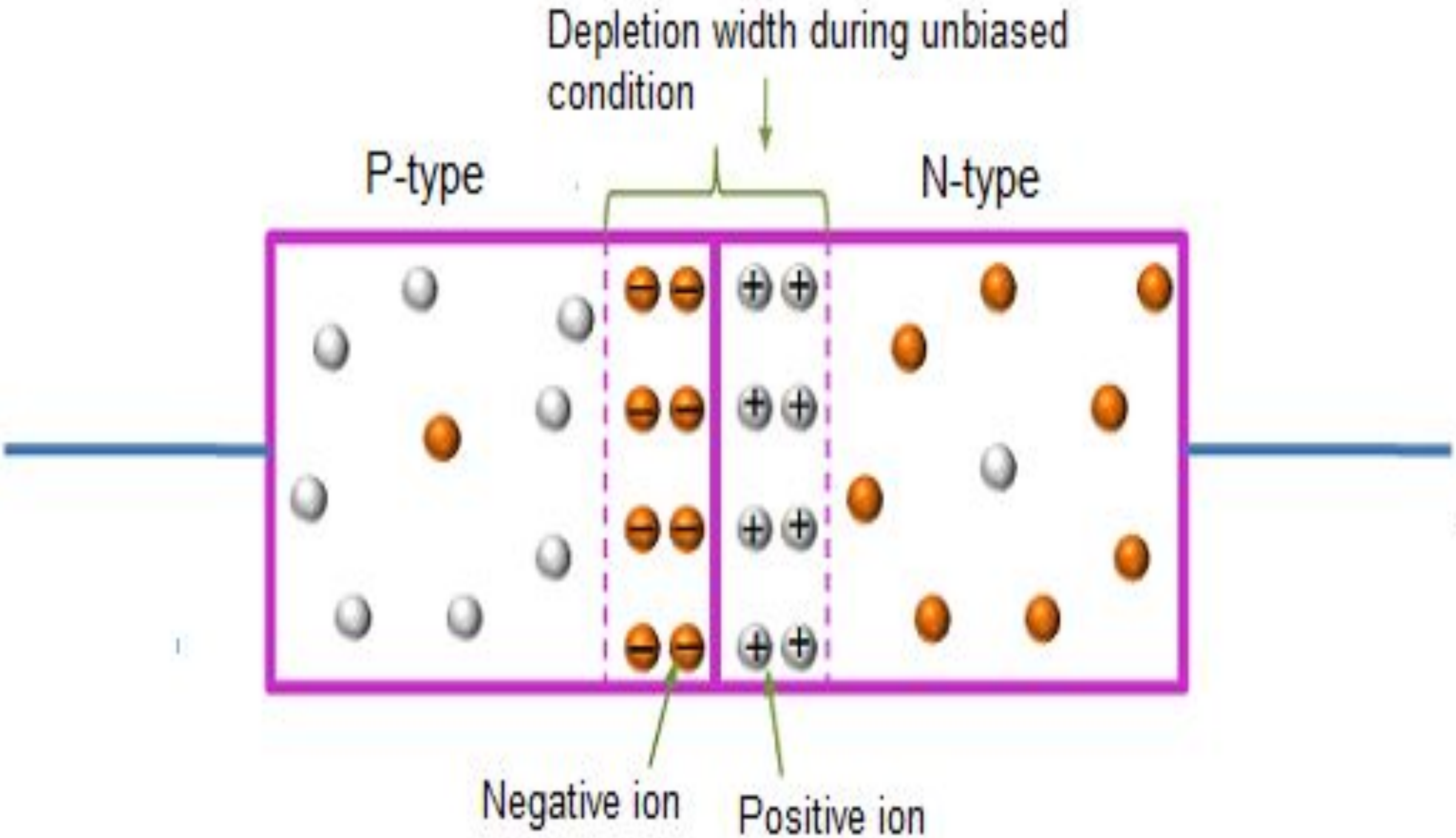
Biasing of p-n junction semiconductor diode

- 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.

Forward biased p-n junction diode

- The process by which, a p-n junction diode allows the electric current in the presence of applied voltage is called forward biased p-n junction diode.
- In forward biased p-n junction diode, the positive terminal of the battery is connected to the p-type semiconductor material and the negative terminal of the battery is connected to the n-type semiconductor material.

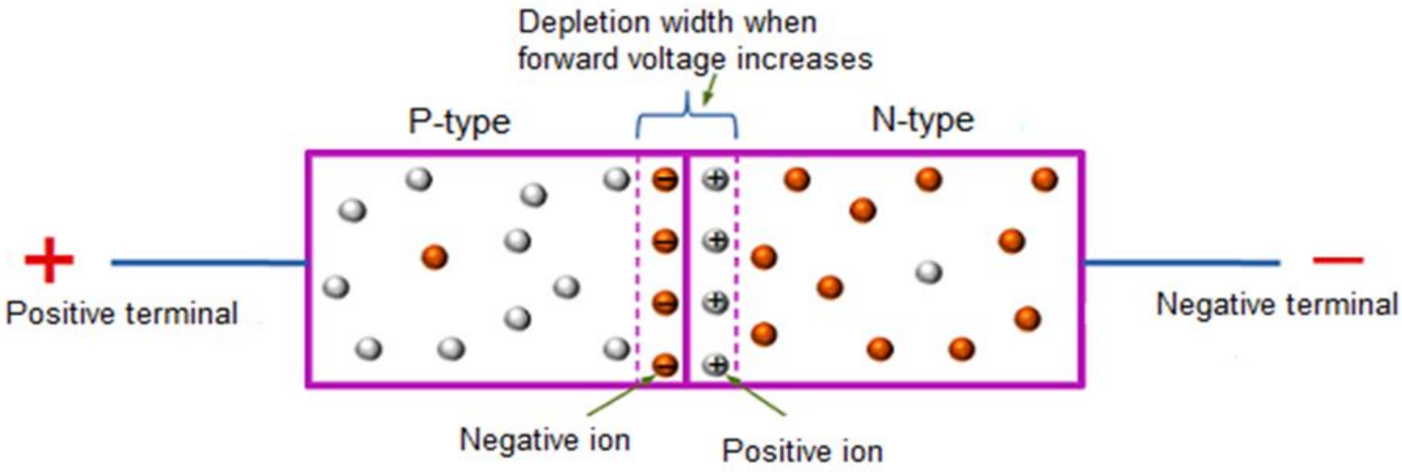
- Under no voltage or unbiased condition, the p-n junction diode does not allow the electric current. If the external forward voltage applied on the p-n junction diode is increased from zero to 0.1 volts, the depletion region slightly decreases. Hence, very small electric current flows in the p-n junction diode. However, this small electric current in the p-n junction diode is considered as negligible. Hence, they not used for any practical applications


Depletion width during unbiased condition
P-type
N-type
Negative ion
Positive ion

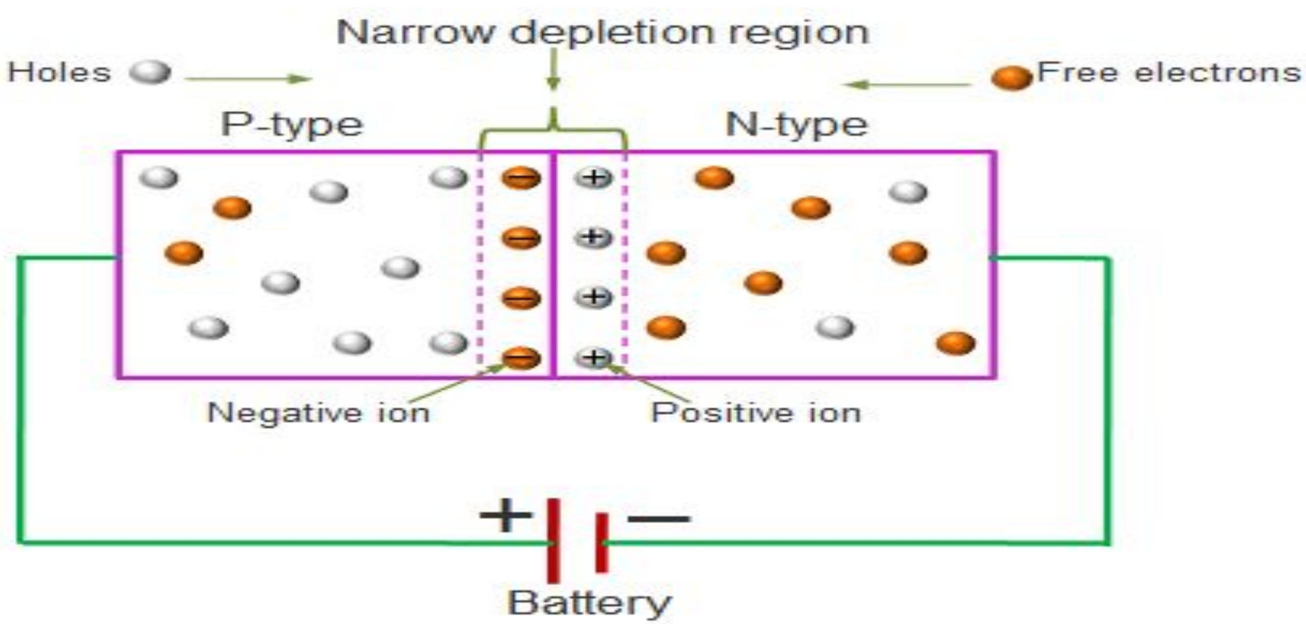
Unbiased

Forward biased p-n junction diode

- If the voltage applied on the p-n junction diode is further increased, then even more number of free electrons and holes are generated in the p-n junction diode. This large number of free electrons and holes further reduces the depletion region (positive and negative ions). Hence, the electric current in the p-n junction diode increases. Thus, the depletion region of a p-n junction diode decreases with increase in voltage. In other words, the electric current in the p-n junction diode increases with the increase in voltage.



Forward biased



Forward bias

- If the p-n junction diode is forward biased with approximately 0.7 volts for silicon diode or 0.3 volts for germanium diode, the p-n junction diode starts allowing the electric current. Under this condition, the negative terminal of the battery supplies large number of free electrons to the n-type semiconductor and attracts or accepts large number of holes from the p-type semiconductor. In other words, the large number of free electrons begins their journey at the negative terminal whereas the large number of holes finishes their journey at the negative terminal.

- The free electrons, which begin their journey from the negative terminal, produce a large negative electric field. The direction of this negative electric field is apposite to the direction of positive electric field of depletion region (positive ions) near the p-n junction.
- Due to the large number of free electrons at n-type semiconductor, they get repelled from each other and try to move from higher concentration region (n-type semiconductor) to a lower concentration region (p-type semiconductor). However, before crossing the depletion region, free electrons finds the positive ions and fills the holes. The free electrons, which fills the holes in positive ions becomes valence electrons. Thus, the free electrons are disappeared.
- The positive ions, which gain the electrons, become neutral atoms. Thus, the depletion region (positive electric field) at n-type semiconductor near the p-n junction decreases until it disappears.
- The remaining free electrons will cross the depletion region and then enters into the p-semiconductor. The free electrons, which cross the depletion region finds the large number of holes or vacancies in the p-type semiconductor and fills them with electrons. The free electrons which occupy the holes or vacancies will becomes valence electrons and then these electrons get attracted towards the positive terminal of battery or terminates at the positive terminal of battery. Thus, the negative charge carriers (free electrons) that are crossing the depletion region carry the electric current from one point to another point in the p-n junction diode.

- The positive terminal of the battery supplies large number of holes to the p-type semiconductor and attracts or accepts large number of free electrons from the n-type semiconductor. In other words, the large number of holes begins their journey at the positive terminal whereas the large number of free electrons finishes their journey at the positive terminal.

- The holes, which begin their journey from the positive terminal, produce a large positive electric field at p-type semiconductor. The direction this positive electric field is opposite to the direction of negative electric field of depletion region (negative ions) near the p-n junction.

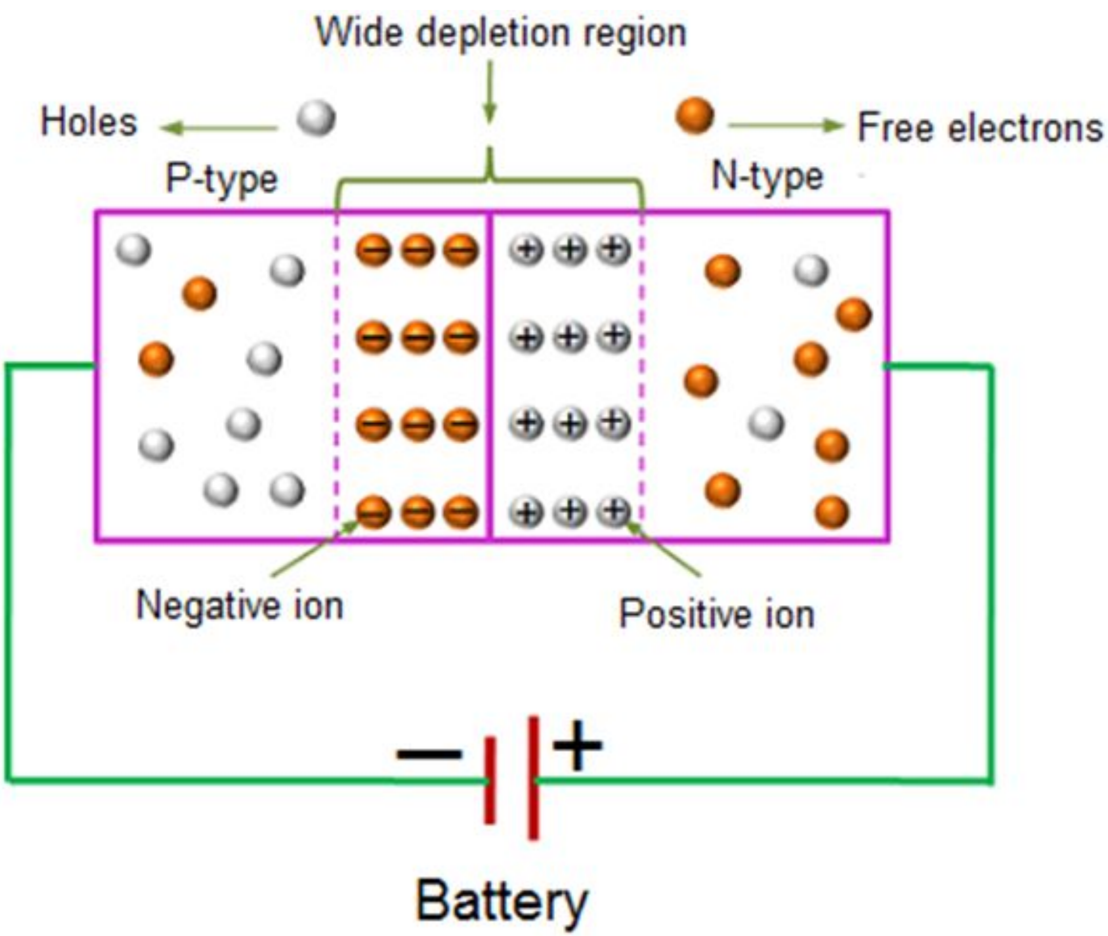
- Due to the large number of positive charge carriers (holes) at p-type semiconductor, they get repelled from each other and try to move from higher concentration region (p-type semiconductor) to a lower concentration region (n-type semiconductor). However, before crossing the depletion region, some of the holes finds the negative ions and replaces the electrons position with holes. Thus, the holes are disappeared.

- The negative ions, which lose the electrons, become neutral atoms. Thus, the depletion region or negative ions (negative electric field) at p-type semiconductor near the p-n junction decreases until it disappears.
- The remaining holes will cross the depletion region and attracted to the negative terminal of battery or terminate at the negative terminal of battery. Thus, the positive charge carriers (holes) that are crossing the depletion region carry the electric current from one point to another point in the p-n junction diode.

Reverse biased p-n junction diode

- The process by which, a p-n junction diode blocks the electric current in the presence of applied voltage is called reverse biased p-n junction diode.
- In reverse biased p-n junction diode, the positive terminal of the battery is connected to the n-type semiconductor material and the negative terminal of the battery is connected to the p-type semiconductor material.
- When the external voltage is applied to the p-n junction diode in such a way that, negative terminal is connected to the p-type semiconductor and positive terminal is connected to the n-type semiconductor, holes from the p-side are attracted towards the negative terminal whereas free electrons from the n-side are attracted towards the positive terminal.

Reverse biased p-n junction diode



Reverse bias

Reverse biased p-n junction diode

- In reverse biased p-n junction diode, the free electrons begin their journey at the negative terminal whereas holes begin their journey at the positive terminal. Free electrons, which begin their journey at the negative terminal, find large number of holes at the p-type semiconductor and fill them with electrons. The atom, which gains an extra electron, becomes a charged atom or negative ion or motionless charge. These negative ions at p-n junction (p-side) oppose the flow of free electrons from n-side.
- On the other hand, holes or positive charges, which begin their journey at the positive terminal, find large of free electrons at the n-type semiconductor and replace the electrons position with holes. The atom, which loses an electron, becomes a charged atom or positive ion. These positive ions at p-n junction (n-side) oppose the flow of positive charge carriers (holes) from p-side.

Reverse biased p-n junction diode

- If the reverse biased voltage applied on the p-n junction diode is further increased, then even more number of free electrons and holes are pulled away from the p-n junction. This increases the width of depletion region. Hence, the width of the depletion region increases with increase in voltage. The wide depletion region of the p-n junction diode completely blocks the majority charge carriers. Hence, majority charge carriers cannot carry the electric current.
- However, p-n junction diode allows the minority charge carriers. The positive terminal of the battery pushes the holes (minority carriers) towards the p-type semiconductor. In the similar way, negative terminal of the battery pushes the free electrons (minority carriers) towards the n-type semiconductor.

Reverse biased p-n junction diode

- 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.
- The electric current carried by the minority charge carriers is very small. Hence, minority carrier current is considered as negligible.

V-I characteristics of p-n junction diode

$$I_D = I_S\left(e^{\frac{qV_D}{nkT}} - 1\right)$$

Ideal Diode Equation

Where

I_D and V_D are the diode current and voltage, respectively

q is the charge on the electron

n is the ideality factor: n = 1 for indirect semiconductors (Si, Ge, etc.)
n = 2 for direct semiconductors (GaAs, InP, etc.)

k is Boltzmann's constant

T is temperature in Kelvin

kT/q is also known as V_{th}, the thermal voltage. At 300K (room temperature), kT/q = 25.9mV

V-I characteristics of p-n junction diode

- The V-I characteristics or voltage-current characteristics of the p-n junction diode is shown in the figure. The horizontal line in the figure represents the amount of voltage applied across the p-n junction diode whereas the vertical line represents the amount of current flows in the p-n junction diode.

Forward V-I characteristics of silicon diode

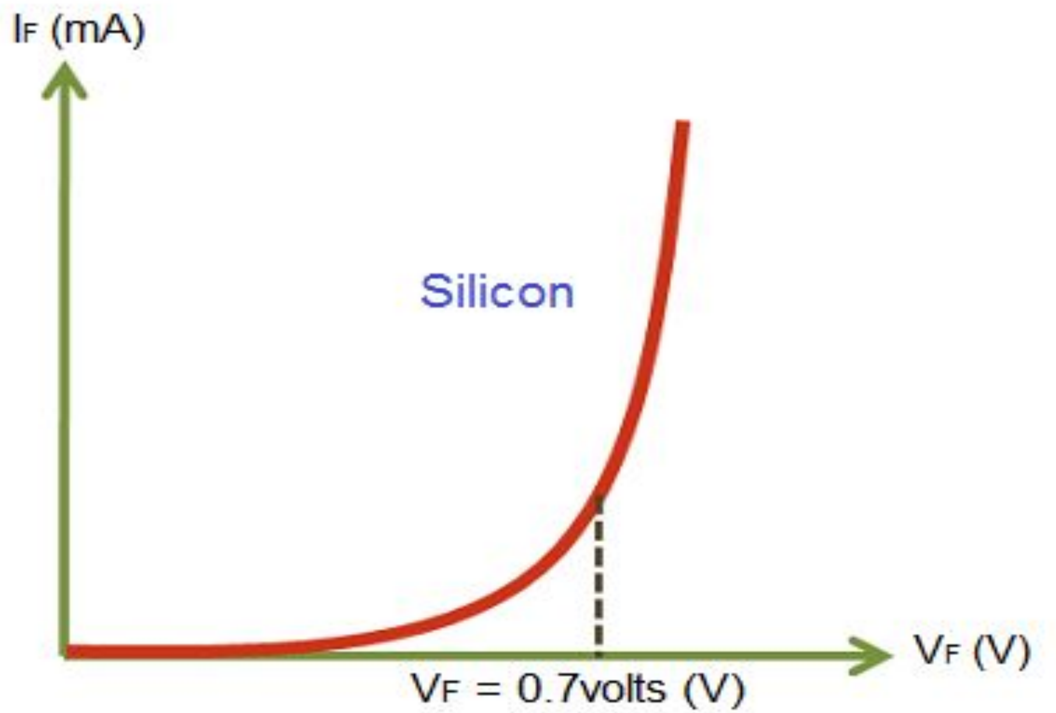


Fig: Forward characteristics of silicon diode

V_F represents the forward voltage whereas I_F represents the forward current.

Forward V-I characteristics of silicon diode

- If the external voltage applied on the silicon diode is less than 0.7 volts, the silicon diode allows only a small electric current. However, this small electric current is considered as negligible.
- When the external voltage applied on the silicon diode reaches 0.7 volts, the p-n junction diode starts allowing large electric current through it. At this point, a small increase in voltage increases the electric current rapidly. The forward voltage at which the silicon diode starts allowing large electric current is called cut-in voltage. The **cut-in voltage** for silicon diode is approximately 0.7 volts.

Forward V-I characteristics of germanium diode

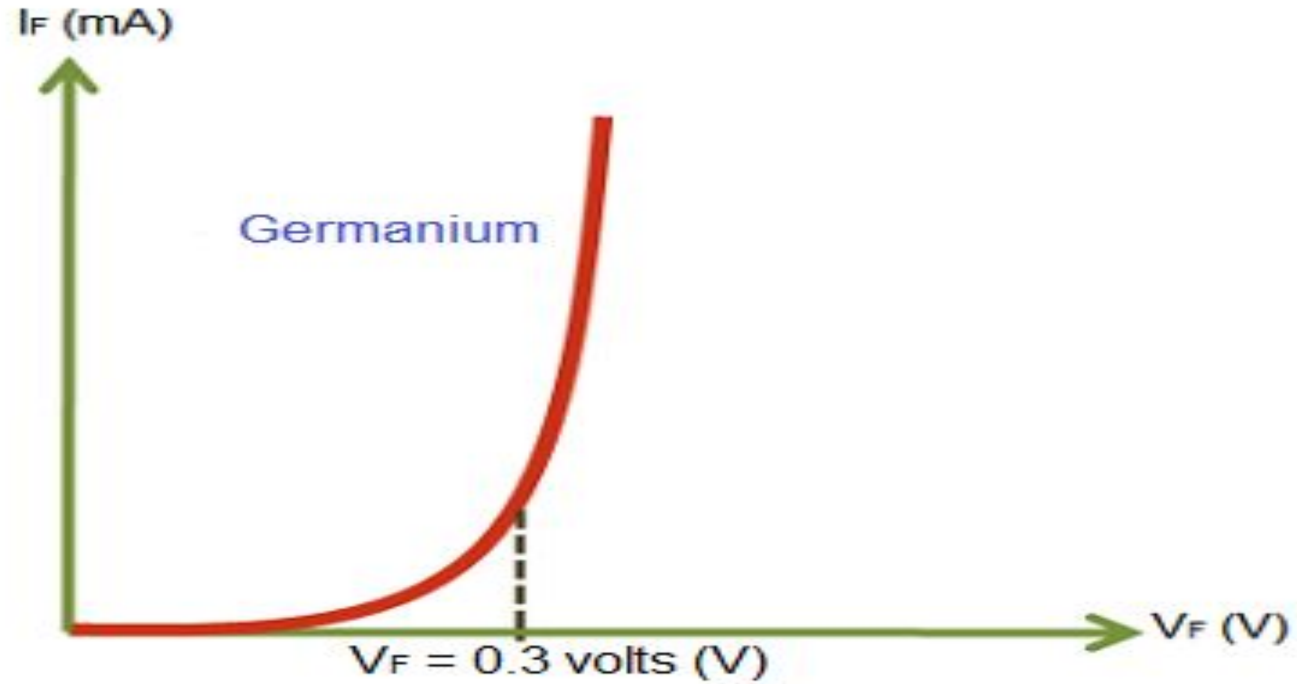


Fig: Forward characteristics of germanium diode

Reverse V-I characteristics of p-n junction diode

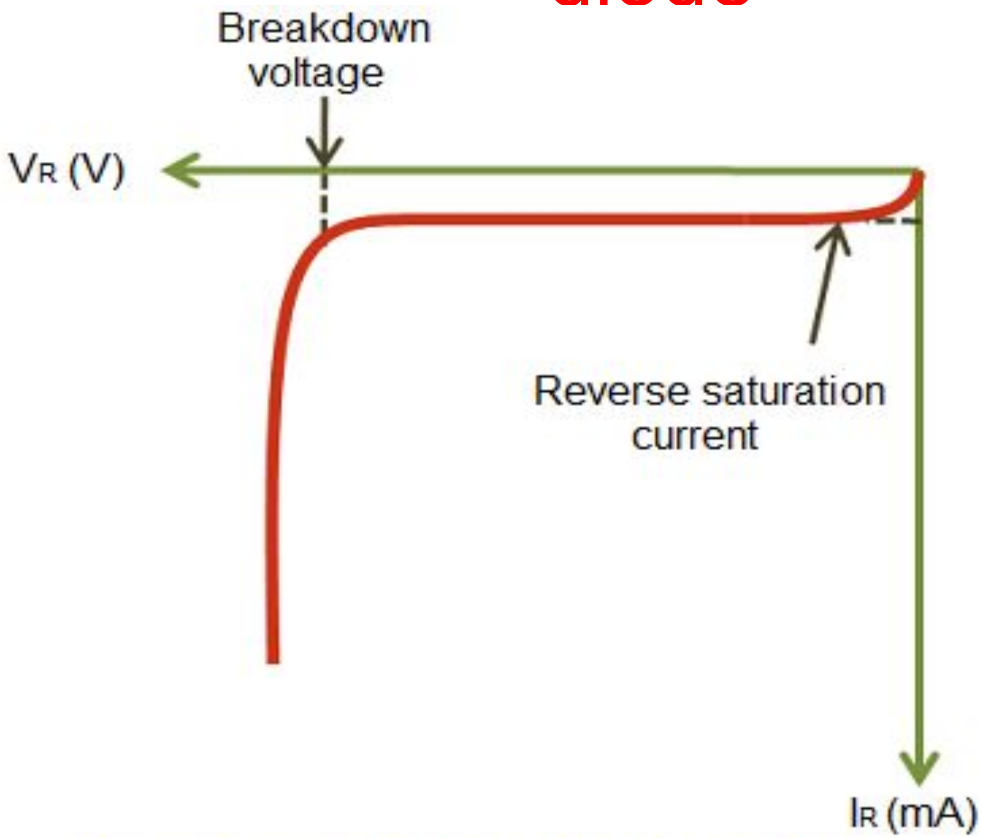


Fig: Reverse characteristics of diode

V_R represents the reverse voltage whereas I_R represents the reverse current.

Reverse V-I characteristics of p-n junction diode

- The reverse saturation current is depends on the temperature. If temperature increases the generation of minority charge carriers increases. Hence, the reverse current increases with the increase in temperature. However, the reverse saturation current is independent of the external reverse voltage. Hence, the reverse saturation current remains constant with the increase in voltage. However, if the voltage applied on the diode is increased continuously, the p-n junction diode reaches to a state where junction breakdown occurs and reverse current increases rapidly.
- In germanium diodes, a small increase in temperature generates large number of minority charge carriers. The number of minority charge carriers generated in the germanium diodes is greater than the silicon diodes. Hence, the reverse saturation current in the germanium diodes is greater than the silicon diodes.

V-I Characteristics of Ideal diode

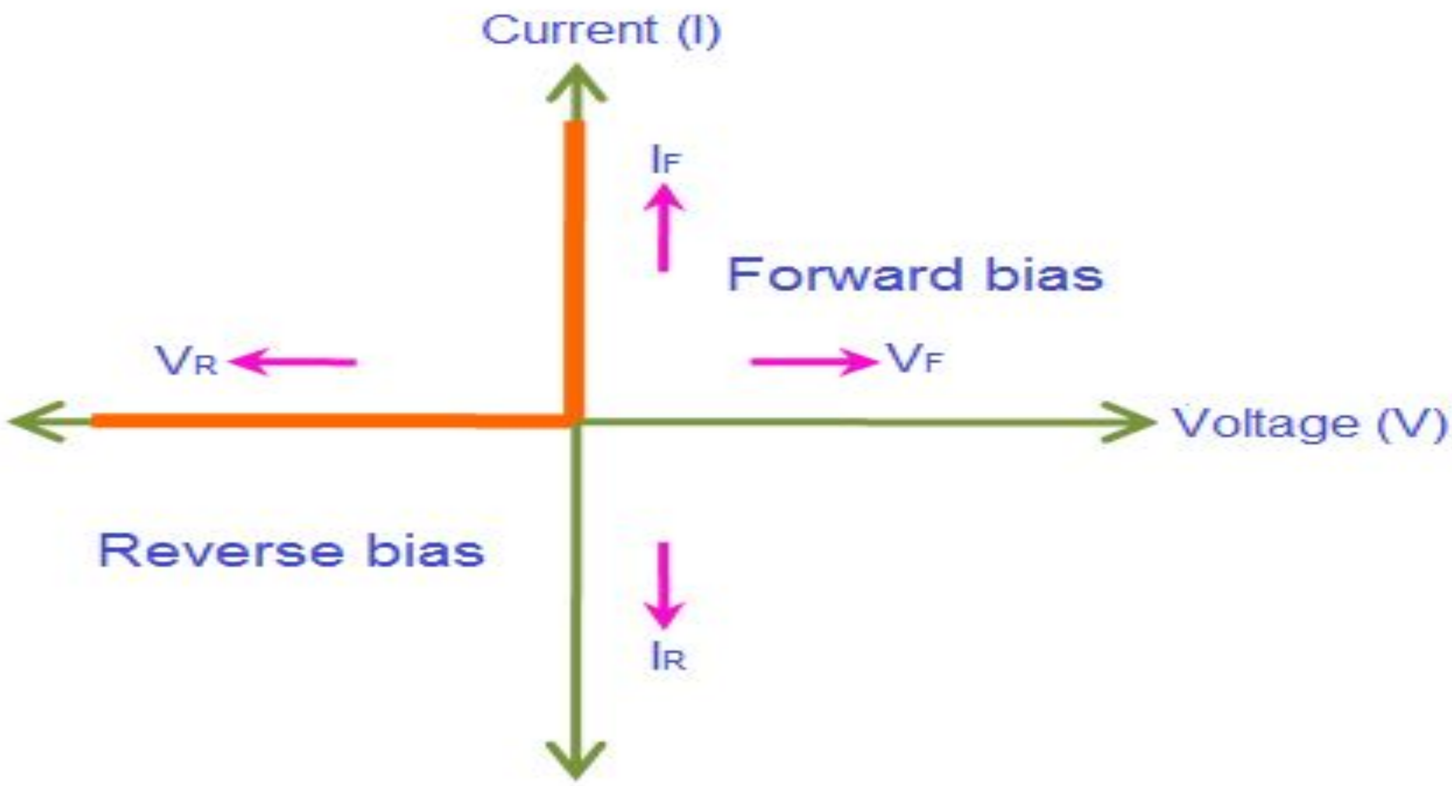


Fig: V-I characteristics of ideal diode

Diode resistance

- The two types of resistance found in forward biased diode are

A)Static resistance or DC resistance

B)Dynamic resistance or AC resistance

Static resistance or DC resistance

- The resistance offered by a p-n junction diode when it is connected to a DC circuit is called static resistance.
- Static resistance is also defined as the ratio of DC voltage applied across diode to the DC current or direct current flowing through the diode.
- The resistance offered by the p-n junction diode under forward biased condition is denoted as R_f.

$$R_f = \frac{\text{DC voltage}}{\text{DC current}}$$

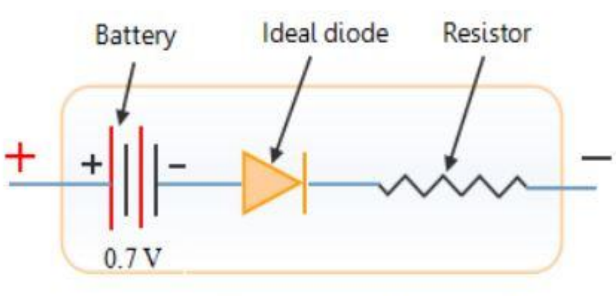
Dynamic resistance or AC resistance

- The dynamic resistance is the resistance offered by the p-n junction diode when AC voltage is applied.
- When forward biased voltage is applied to a diode that is connected to AC circuit, an AC or alternating current flows though the diode.
- Dynamic resistance is also defined as the ratio of change in voltage to the change in current. It is denoted as r_f.

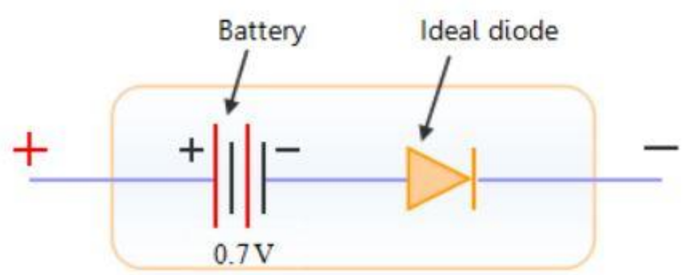
$$r_f = \frac{\text{Change in voltage}}{\text{Change in current}}$$

Diode equivalent circuit

- An equivalent circuit is nothing but a combination of elements that best represents the actual terminal characteristics of the device. In simple language, it simply means the diode in the circuit can be replaced by other elements without severely affecting the behavior of circuit.
- The diodequivalent circuits are classified as
- Piece-wise linear model
- Simplified model



Piecewise-linear equivalent model



Simplified model

Silicon vs Germanium diode

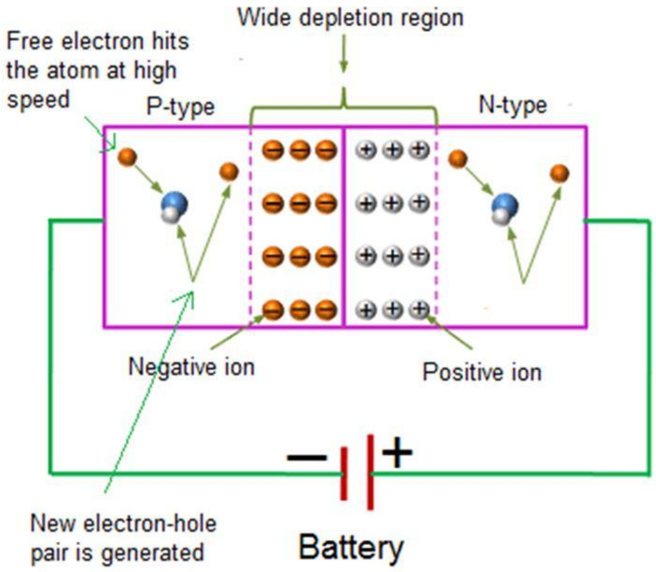
- Silicon and germanium semiconductor diodes
- For designing the diodes, silicon is more preferred over germanium.
- The p-n junction diodes made from silicon semiconductors works at high temperature than the germanium semiconductor diodes.
- Forward bias voltage for silicon semiconductor diode is approximately 0.7 volts whereas for germanium semiconductor diode is approximately 0.3 volts.
- Silicon semiconductor diodes do not allow the electric current flow, if the voltage applied on the silicon diode is less than 0.7 volts.
- Silicon semiconductor diodes start allowing the current flow, if the voltage applied on the diode reaches 0.7 volts.
- Germanium semiconductor diodes do not allow the electric current flow, if the voltage applied on the germanium diode is less than 0.3 volts.
- Germanium semiconductor diodes start allowing the current flow, if the voltage applied on the germanium diode reaches 0.3 volts.
- The cost of silicon semiconductors is low when compared with the germanium semiconductors

Breakdown in diode

- There are two types of reverse breakdown regions in a diode: avalanche breakdown and zener breakdown.

Avalanche breakdown

- The avalanche breakdown occurs in both normal diodes and zener diodes at high reverse voltage. When high reverse voltage is applied to the p-n junction diode, the free electrons (minority carriers) gains large amount of energy and accelerated to greater velocities.



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- The free electrons moving at high speed will collides with the atoms and knock off more electrons. These electrons are again accelerated and collide with other atoms. Because of this continuous collision with the atoms, a large number of free electrons are generated. As a result, electric current in the diode increases rapidly. This sudden increase in electric current may permanently destroys the normal diode.

Zener breakdown

- The zener breakdown occurs in heavily doped p-n junction diodes because of their narrow depletion region. When reverse biased voltage applied to the diode is increased, the narrow depletion region generates strong electric field.
- When reverse biased voltage applied to the diode reaches close to zener voltage, the electric field in the depletion region is strong enough to pull electrons from their valence band. The valence electrons which gains sufficient energy from the strong electric field of depletion region will breaks bonding with the parent atom. The valance electrons which break bonding with parent atom will become free electrons. This free electrons carry electric current from one place to another place. At zener breakdown region, a small increase in voltage will rapidly increases the electric current.

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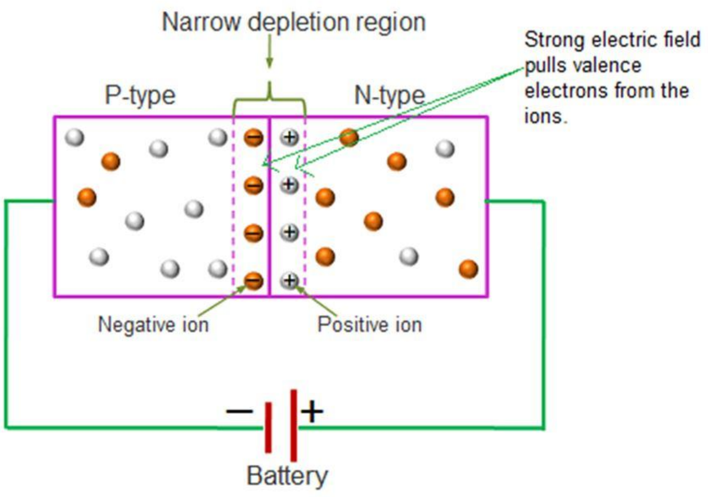
- Zener breakdown occurs at low reverse voltage whereas avalanche breakdown occurs at high reverse voltage.
- Zener breakdown occurs in zener diodes because they have very thin depletion region.
- Breakdown region is the normal operating region for a zener diode.
- Zener breakdown occurs in zener diodes with zener voltage (Vz) less than 6V.



Difference between Zener and Avalanche Breakdown

- The depletion region of the Zener is thin whereas the avalanche is thick.
- The connection of the Zener is not-destroy whereas the avalanche is destroyed.
- The electric field of the Zener is strong whereas the avalanche is weak.
- The Zener breakdown generates electrons whereas the avalanche generates holes as well as electrons.
- The doping of the Zener is heavy whereas the avalanche is low.
- The reverse potential of the Zener is low whereas the avalanche is high.
- The temperature coefficient of the Zener is negative whereas the avalanche is positive.
- The Ionization of the Zener is due to Electric field whereas the avalanche is the collision.

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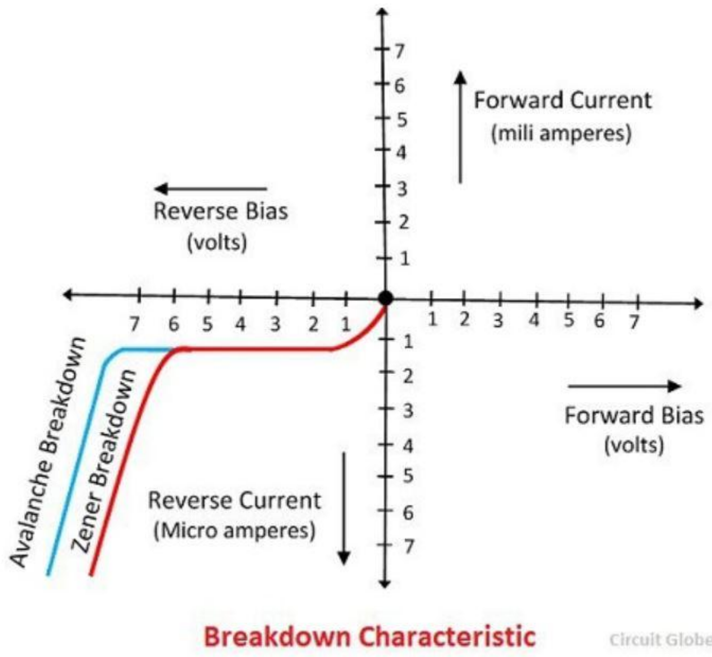
- The temperature coefficient of the Zener is negative whereas the avalanche is positive.
- The breakdown voltage (Vz) of the Zener is inversely proportional to temperature (ranges from 5v to 8v) whereas the avalanche is directly proportional to temperature (Vz > 8V).
- After the breakdown of the Zener is voltage remains constant whereas the avalanche is voltage vary.



What is zener diode?

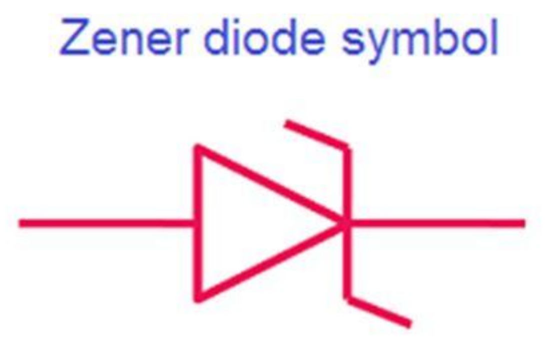
- A zener diode is a special type of device designed to operate in the zener breakdown region. Zener diodes acts like normal p-n junction diodes under forward biased condition. When forward biased voltage is applied to the zener diode it allows large amount of electric current and blocks only a small amount of electric current.
- Zener diode is heavily doped than the normal p-n junction diode. Hence, it has very thin depletion region. Therefore, zener diodes allow more electric current than the normal p-n junction diodes.
- Zener diode allows electric current in forward direction like a normal diode but also allows electric current in the reverse direction if the applied reverse voltage is greater than the zener voltage. Zener diode is always connected in reverse direction because it is specifically designed to work in reverse direction.

Zener diode definition

- A zener diode is a p-n junction semiconductor device designed to operate in the reverse breakdown region. The breakdown voltage of a zener diode is carefully set by controlling the doping level during manufacture.
- The name zener diode was named after the American physicist Clarance Melvin Zener who discovered the zener effect. Zener diodes are the basic building blocks of electronic circuits. They are widely used in all kinds of electronic equipments. Zener diodes are mainly used to protect electronic circuits from over voltage.

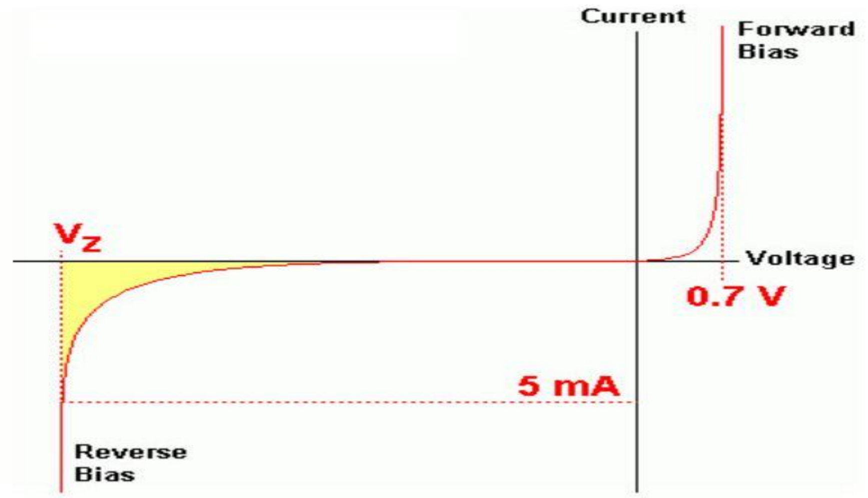
Symbol of zener diode

- The symbol of zener diode is shown in figure. Zener diode consists of two terminals: cathode and anode.
- In zener diode, electric current flows from both anode to cathode and cathode to anode.
- The symbol of zener diode is similar to the normal p-n junction diode, but with bend edges on the vertical bar.



VI characteristics of zener diode

- The VI characteristics of a zener diode is shown in the below figure. When forward biased voltage is applied to the zener diode, it works like a normal diode. However, when reverse biased voltage is applied to the zener diode, it works in different manner.



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- When reverse biased voltage is applied to a zener diode, it allows only a small amount of leakage current until the voltage is less than zener voltage. When reverse biased voltage applied to the zener diode reaches zener voltage, it starts allowing large amount of electric current. At this point, a small increase in reverse voltage will rapidly increases the electric current. Because of this sudden rise in electric current, breakdown occurs called zener breakdown. However, zener diode exhibits a controlled breakdown that does damage the device.
- The zener breakdown voltage of the zener diode is depends on the amount of doping applied. If the diode is heavily doped, zener breakdown occurs at low reverse voltages. On the other hand, if the diode is lightly doped, the zener breakdown occurs at high reverse voltages. Zener diodes are available with zener voltages in the range of 1.8V to 400V.

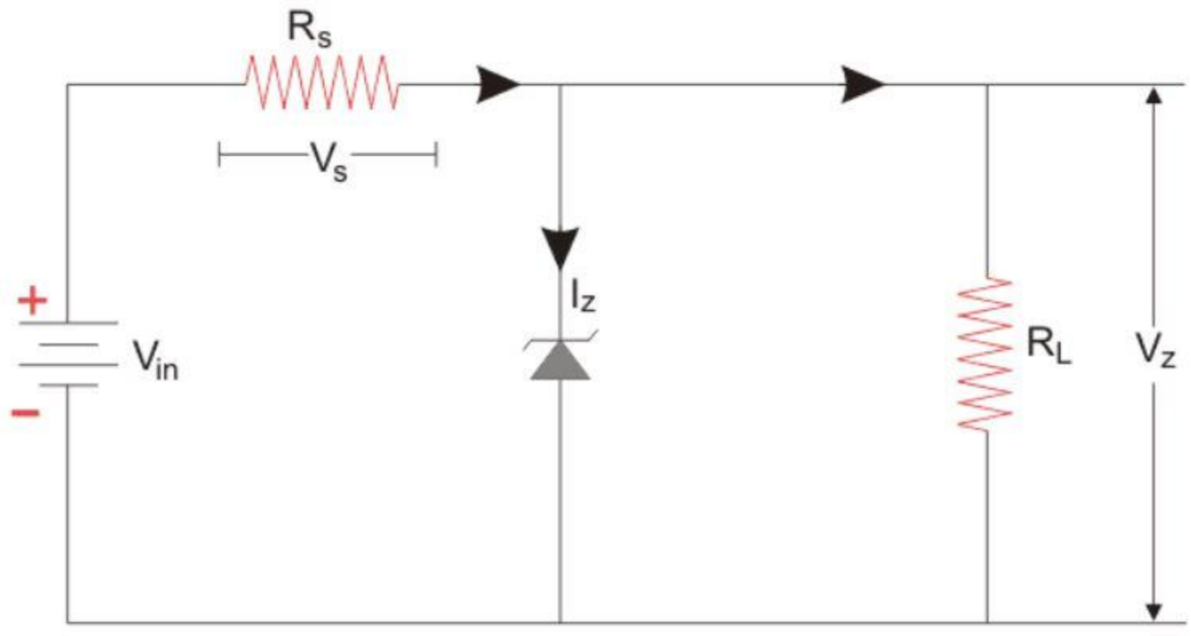
Advantages of zener diode

- Power dissipation capacity is very high
- High accuracy
- Small size
- Low cost

Applications of zener diode

- It is normally used as voltage reference
- Zener diodes are used in voltage stabilizers or shunt regulators.
- Zener diodes are used in switching operations
- Zener diodes are used in various protection circuits

Zenerdiode as voltage regulator.



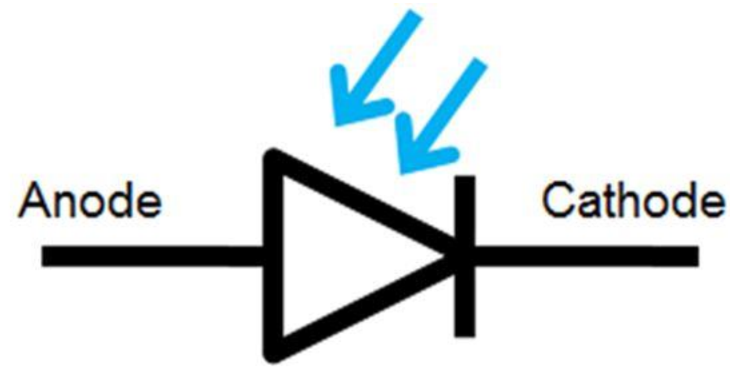
Photodiode

- A photodiode is a p-n junction or pin semiconductor device that consumes light energy to generate electric current. It is also sometimes referred as photo-detector, photo-sensor, or light detector.
- Photodiodes are specially designed to operate in reverse bias condition. Reverse bias means that the p-side of the photodiode is connected to the negative terminal of the battery and n-side is connected to the positive terminal of the battery.
- Photodiode is very sensitive to light so when light or photons falls on the photodiode it easily converts light into electric current. Solar cell is also known as large area photodiode because it converts solar energy or light energy into electric energy. However, solar cell works only at bright light.

- The construction and working of photodiode is almost similar to the normal p-n junction diode. PIN (p-type, intrinsic and n-type) structure is mostly used for constructing the photodiode instead of p-n (p-type and n-type) junction structure because PIN structure provide fast response time. PIN photodiodes are mostly used in high-speed applications.
- In a normal p-n junction diode, voltage is used as the energy source to generate electric current whereas in photodiodes, both voltage and light are used as energy source to generate electric current.

Photodiode symbol

- The symbol of photodiode is similar to the normal p-n junction diode except that it contains arrows striking the diode. The arrows striking the diode represent light or photons.
- A photodiode has two terminals: a cathode and an anode.



Photodiode symbol

Objectives of photodiode

1.Photodiode should be always operated in reverse bias condition.

2.Applied reverse bias voltage should be low.

3.Generate low noise

4.High gain

5.High response speed

6.High sensitivity to light

7.Low sensitivity to temperature

8.Low cost

9.Small size

10.Long lifetime

How photodiode works?

- A normal p-n junction diode allows a small amount of electric current under reverse bias condition. To increase the electric current under reverse bias condition, we need to generate more minority carriers.
- The external reverse voltage applied to the p-n junction diode will supply energy to the minority carriers but not increase the population of minority carriers.
- However, a small number of minority carriers are generated due to external reverse bias voltage. The minority carriers generated at n-side or p-side will recombine in the same material before they cross the junction. As a result, no electric current flows due to these charge carriers. For example, the minority carriers generated in the p-type material experience a repulsive force from the external voltage and try to move towards n-side. However, before crossing the junction, the free electrons recombine with the holes within the same material. As a result, no electric current flows.

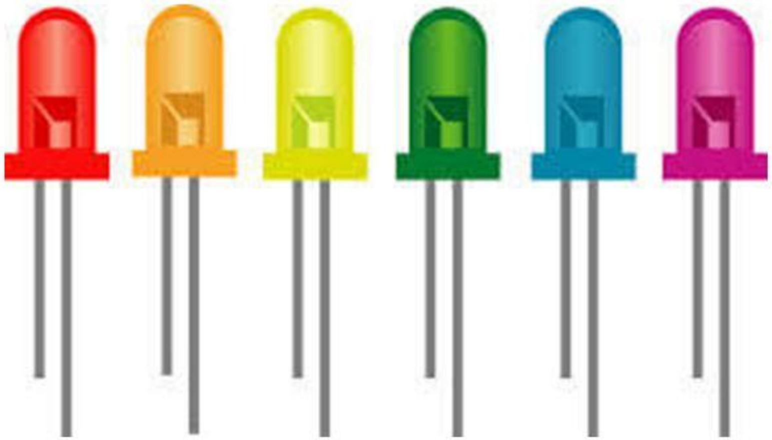
CONTD..

- To overcome this problem, we need to apply external energy directly to the depletion region to generate more charge carriers.
- A special type of diode called photodiode is designed to generate more number of charge carriers in depletion region. In photodiodes, we use light or photons as the external energy to generate charge carriers in depletion region.

Light Emitting Diodes

- Light Emitting Diodes (LEDs) are the most widely used semiconductor diodes among all the different types of semiconductor diodes available today. Light emitting diodes emit either visible light or invisible infrared light when forward biased. The LEDs which emit invisible infrared light are used for remote controls.
- A light Emitting Diode (LED) is an optical semiconductor device that emits light when voltage is applied. In other words, LED is an optical semiconductor device that converts electrical energy into light energy.
- When Light Emitting Diode (LED) is forward biased, free electrons in the conduction band recombines with the holes in the valence band and releases energy in the form of light.
- The process of emitting light in response to the strong electric field or flow of electric current is called electroluminescence.

- Like the normal p-n junction diodes, LEDs also operates only in forward bias condition. To create an LED, the n-type material should be connected to the negative terminal of the battery and p-type material should be connected to the positive terminal of the battery. In other words, the n-type material should be negatively charged and the p-type material should be positively charged.
- The construction of LED is similar to the normal p-n junction diode except that gallium, phosphorus and arsenic materials are used for construction instead of silicon or germanium materials.



How Light Emitting Diode (LED) works?

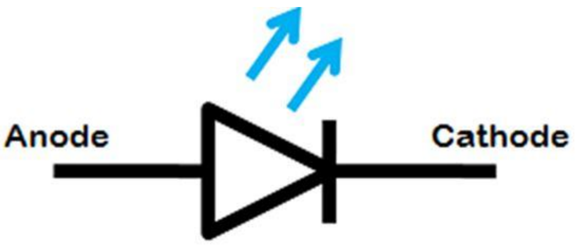
- Light Emitting Diode (LED) works only in forward bias condition. When Light Emitting Diode (LED) is forward biased, the free electrons from n-side and the holes from p-side are pushed towards the junction.
- When free electrons reach the junction or depletion region, some of the free electrons recombine with the holes in the positive ions. We know that positive ions have less number of electrons than protons. Therefore, they are ready to accept electrons. Thus, free electrons recombine with holes in the depletion region. In the similar way, holes from p-side recombine with electrons in the depletion region.
- Because of the recombination of free electrons and holes in the depletion region, the width of depletion region decreases. As a result, more charge carriers will cross the p-n junction

CONTD..

- Some of the charge carriers from p-side and n-side will cross the p-n junction before they recombine in the depletion region. For example, some free electrons from n-type semiconductor cross the p-n junction and recombines with holes in p-type semiconductor. In the similar way, holes from p-type semiconductor cross the p-n junction and recombines with free electrons in the n-type semiconductor.
- Thus, recombination takes place in depletion region as well as in p-type and n-type semiconductor.
- The free electrons in the conduction band releases energy in the form of light before they recombine with holes in the valence band.

Light emitting diode (LED) symbol

- The symbol of LED is similar to the normal p-n junction diode except that it contains arrows pointing away from the diode indicating that light is being emitted by the diode.LEDs are available in different colors. The most common colors of LEDs are orange, yellow, green and red.
- The schematic symbol of LED does not represent the color of light. The schematic symbol is same for all colors of LEDs. Hence, it is not possible to identify the color of LED by seeing its symbol.



What determines the color of an LED?

- The material used for constructing LED determines its color. In other words, the wavelength or color of the emitted light depends on the forbidden gap or energy gap of the material.
- Different materials emit different colors of light.
- Gallium arsenide LEDs emit red and infrared light.
- Gallium nitride LEDs emit bright blue light.
- Yttrium aluminium garnet LEDs emit white light.
- Gallium phosphide LEDs emit red, yellow and green light.
- Aluminium gallium nitride LEDs emit ultraviolet light.
- Aluminum gallium phosphide LEDs emit green light.

Advantages of LED

1. The brightness of light emitted by LED is depends on the current flowing through the LED. Hence, the brightness of LED can be easily controlled by varying the current. This makes possible to operate LED displays under different ambient lighting conditions.
2. Light emitting diodes consume low energy.
3. LEDs are very cheap and readily available.
4. LEDs are light in weight.
5. Smaller size.
6. LEDs have longer lifetime.
7. LEDs operates very fast. They can be turned on and off in very less time.
8. LEDs do not contain toxic material like mercury which is used in fluorescent lamps.
9. LEDs can emit different colors of light.

Disadvantages of LED

1. LEDs need more power to operate than normal p-n junction diodes.
2. Luminous efficiency of LEDs is low.

Applications of LED

1. Burglar alarms systems
2. Calculators
3. Picture phones
4. Traffic signals
5. Digital computers
6. Multimeters
7. Microprocessors
8. Digital watches
9. Automotive heat lamps
10. Camera flashes
11. Aviation lighting

APPLICATION OF P-N JUNCTION DIODE

- RECTIFIER
- CLIPPER
- CLAMPER

Rectifier

- In a large number of electronic circuits, we require DC voltage for operation. We can easily convert the AC voltage or AC current into DC voltage or DC current by using a device called P-N junction diode.
- One of the most important applications of a P-N junction diode is the rectification of Alternating Current (AC) into Direct Current (DC). A P-N junction diode allows electric current in only forward bias condition and blocks electric current in reverse bias condition. In simple words, a diode allows electric current in one direction. This unique property of the diode allows it to acts like a rectifier.

Rectifier definition

- A rectifier is an electrical device that converts an Alternating Current (AC) into a Direct Current (DC) by using one or more P-N junction diodes.

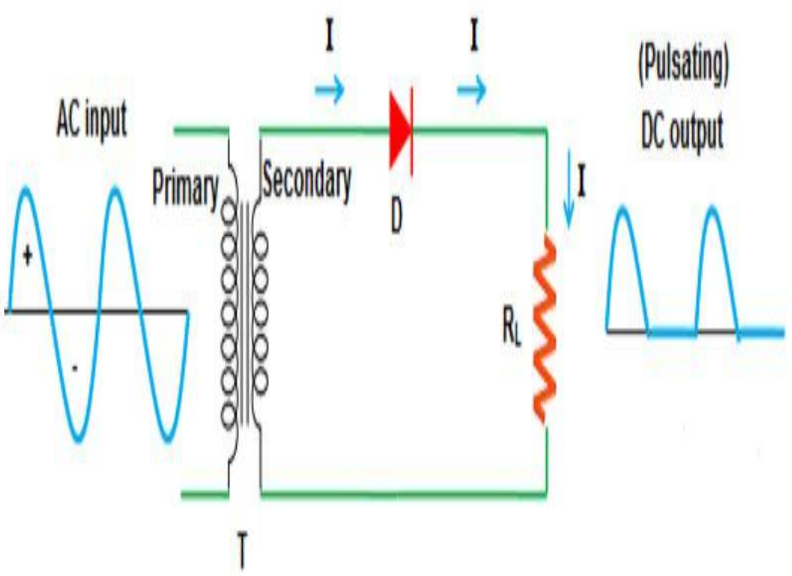
Types of rectifiers

The rectifiers are mainly classified into two types:

1. Half wave rectifier
2. Full wave rectifier

Half wave rectifier definition

- A half wave rectifier is a type of rectifier which allows only half cycle (either positive half cycle or negative half cycle) of the input AC signal while the another half cycle is blocked.
- The half wave rectifier is made up of an AC source, transformer (step-down), diode, and resistor (load). The diode is placed between the transformer and resistor (load).



- Advantages of half wave rectifier
- We use very few components to construct the half wave rectifier. So the cost is very low.
- Easy to construct
- Disadvantages of half wave rectifier
- Power loss
- The half wave rectifier either allows the positive half cycle or negative half cycle. So the remaining half cycle is wasted. Approximately half of the applied voltage is wasted in half wave rectifier.

- Pulsating direct current
- The direct current produced by the half wave rectifier is not a pure direct current; it is a pulsating direct current which is not much useful.

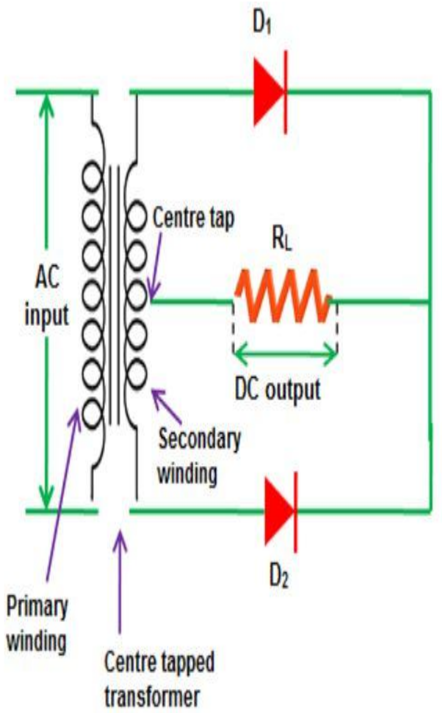
- Produces low output voltage.

Full wave rectifier definition

- **A full wave rectifier is a type of rectifier which converts both half cycles of the AC signal into pulsating DC signal.**
- The full wave rectifier is further classified into two types: **center tapped full wave rectifier and full wave bridge rectifier.**

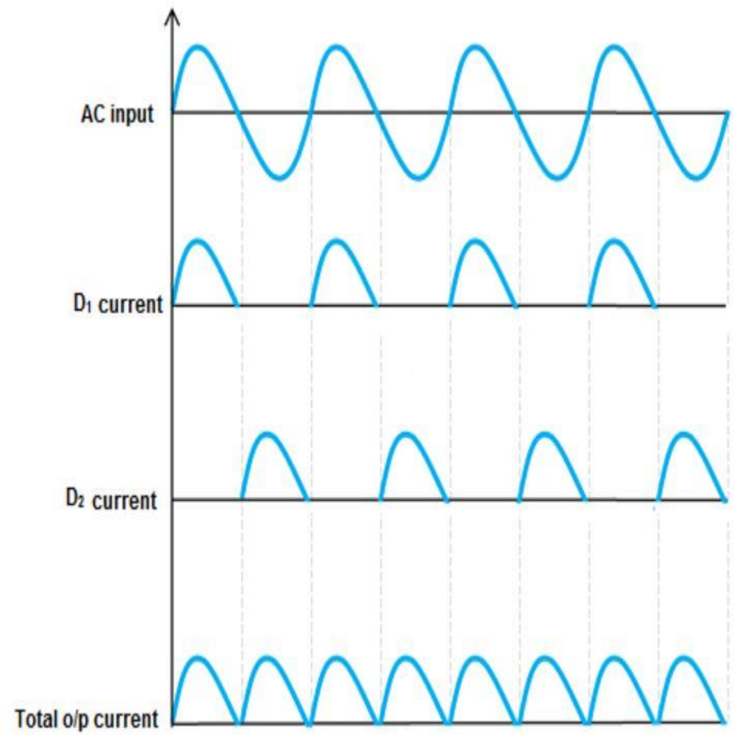
Center tapped full wave rectifier

- A center tapped full wave rectifier is a type of rectifier which uses a center tapped transformer and two diodes to convert the complete AC signal into DC signal.
- The center tapped full wave rectifier is made up of an AC source, a center tapped transformer, two diodes, and a load resistor.



Output waveforms of full wave rectifier

- The first waveform represents an input AC signal. The second waveform and third waveform represents the DC signals or DC current produced by diode D1 and diode D2. The last waveform represents the total output DC current produced by diodes D1and D2. From the above waveforms, we can conclude that the output current produced at the load resistor is not a pure DC but a pulsating DC.



Advantages of full wave rectifier with center tapped transformer

- High rectifier efficiency

- Full wave rectifier has high rectifier efficiency than the half wave rectifier. That means the full wave rectifier converts AC to DC more efficiently than the half wave rectifier.

- Low power loss

- In a half wave rectifier, only half cycle (positive or negative half cycle) is allowed and the remaining half cycle is blocked. As a result, more than half of the voltage is wasted. But in full wave rectifier, both half cycles (positive and negative half cycles) are allowed at the same time. So no signal is wasted in a full wave rectifier.

- Low ripples

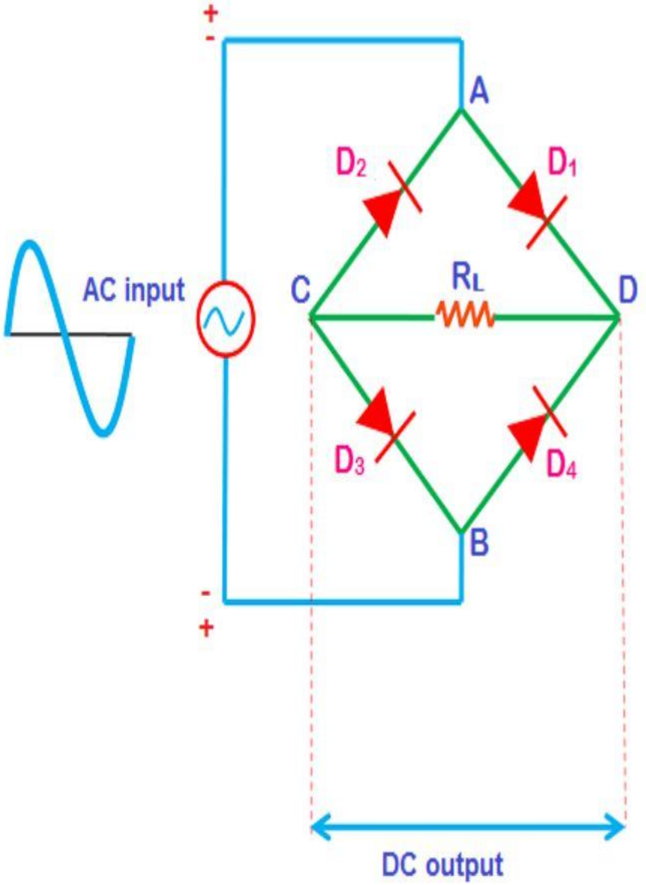
- The output DC signal in full wave rectifier has fewer ripples than the half wave rectifier.

Disadvantages of full wave rectifier with center tapped transformer

- High cost

Bridge rectifier

- A bridge rectifier is a type of full wave rectifier which uses four or more diodes in a bridge circuit configuration to efficiently convert the Alternating Current (AC) into Direct Current (DC).
- The construction diagram of a bridge rectifier is shown in the below figure. The bridge rectifier is made up of four diodes namely D1, D2, D3, D4 and load resistor RL. The four diodes are connected in a closed loop (Bridge) configuration to efficiently convert the Alternating Current (AC) into Direct Current (DC). The main advantage of this bridge circuit configuration is that we do not require an expensive center tapped transformer, thereby reducing its cost and size.

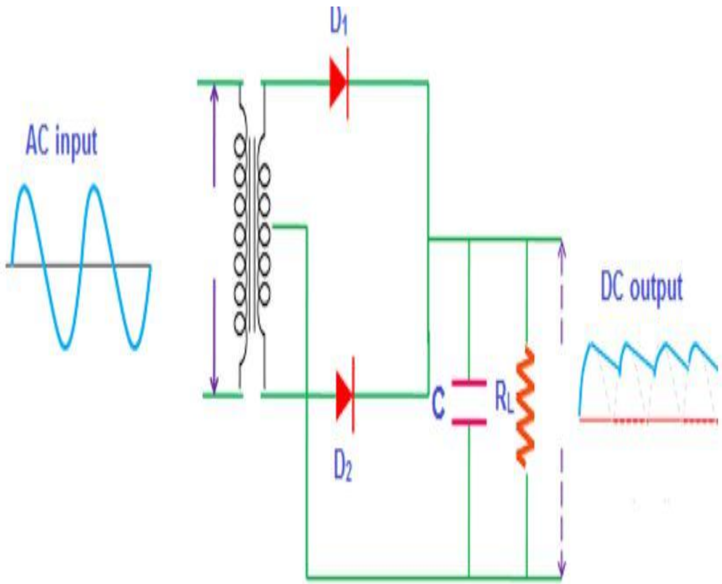


- Advantages of bridge rectifier
- Low ripples in the output DC signal
- The DC output signal of the bridge rectifier is smoother than the half wave rectifier. In other words, the bridge rectifier has fewer ripples as compared to the half wave rectifier. However, the ripple factor of the bridge rectifier is same as the center tapped full wave rectifier.
- High rectifier efficiency
- The rectifier efficiency of the bridge rectifier is very high as compared to the half wave rectifier. However, the rectifier efficiency of bridge rectifier and center tapped full wave rectifier is same.
- Low power loss
- In half wave rectifier only one half cycle of the input AC signal is allowed and the remaining half cycle of the input AC signal is blocked. As a result, nearly half of the applied input power is wasted.
- However, in the bridge rectifier, the electric current is allowed during both positive and negative half cycles of the input AC signal. So the output DC power is almost equal to the input AC power.

- Disadvantages of bridge rectifier
- Bridge rectifier circuit looks very complex
- More power loss as compared to the Center tapped full wave rectifier

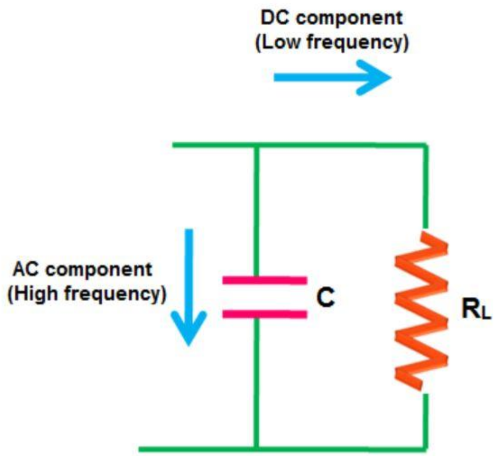
Full wave rectifier with filter

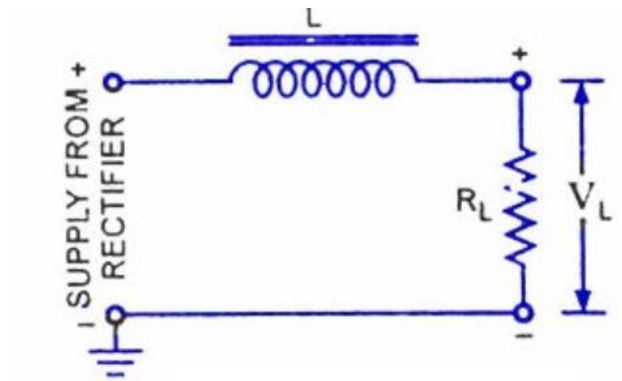
- The filter is an electronic device that converts the pulsating Direct Current into pure Direct Current.
- The filter is made up of a combination of electronic components such as resistors, capacitors, and inductors. The property of inductor is that it allows the DC components and blocks the AC components. The property of a capacitor is that it allows the AC components and blocks the DC components.
- Here, a center tapped full wave rectifier with a filter made up of capacitor and resistor is explained. The filter made up of capacitor and resistor is known as capacitor filter.
- In the circuit diagram, the capacitor C is placed across the load resistor RL.

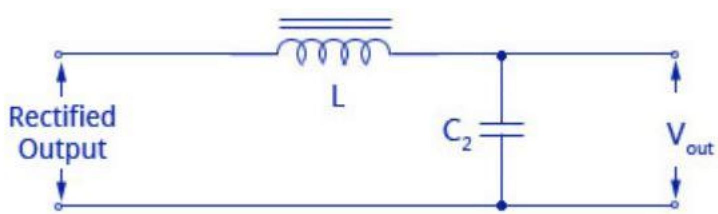


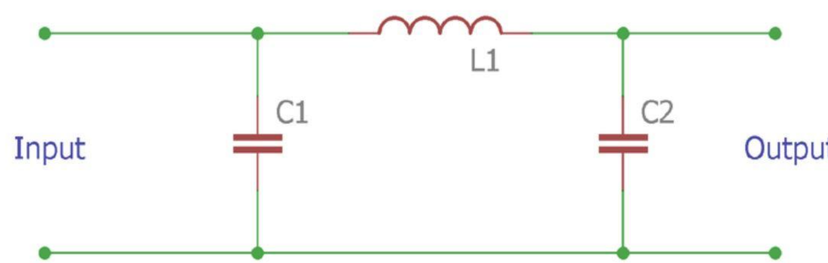
Full wave rectifier with capacitor filter

DIFFERENT TYPES OF FILTER CIRCUIT









Clipper Circuits

- Electronic devices are very sensitive to voltage. If a large amplitude voltage is applied, it may permanently destroy the device. So, it is essential to protect the electronics devices.
- The protection of the electronic devices can be achieved by using the clipper circuits.
- A clipper is a device that removes either the positive half (top half) or negative half (bottom half). In other words, a clipper is a device that limits the positive amplitude or negative amplitude of the input AC signal
- The clipper circuit does not contain energy storage elements such as capacitor but contains both linear and no-linear elements. The linear elements used in the clippers include resistors and the non-linear elements used in the clippers include diodes.
- The clipping (removal) of the input AC signal is done in such a way that the remaining part of the input AC signal will not be distorted.

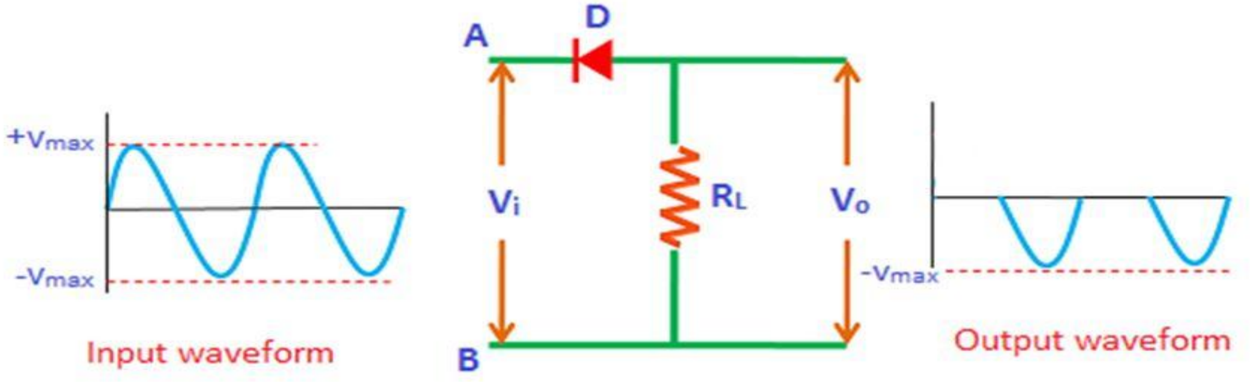
Types and Application

Clippers are often referred to as voltage limiters, current limiters, slicers, or amplitude selectors. Clipper circuits are extensively used in digital computers, radars, television receivers, radio receivers and other electronic systems for removing unwanted portion of the input AC signal.

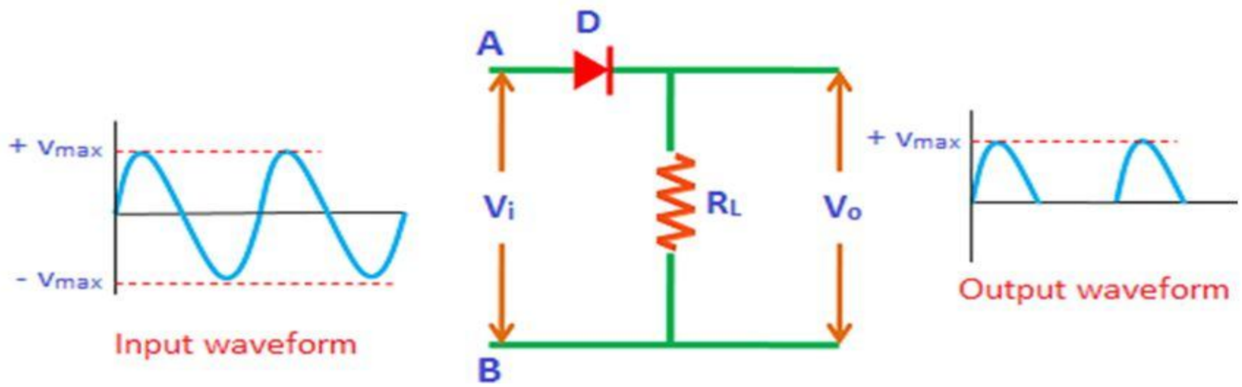
The various types of clippers are as follows:

- Series positive clipper
- Series positive clipper with bias
- Series negative clipper
- Series negative clipper with bias
- Shunt positive clipper
- Shunt positive clipper with bias
- Shunt negative clipper
- Shunt negative clipper with bias

Circuit



+Vmax
-Vmax
Input waveform
A
D
B
Vi
RL
Vo
-Vmax
Output waveform



+ vmax
- vmax
Input waveform
A
D
B
Vi
RL
Vo
+ vmax
Output waveform

Clamper Circuits

- A clamper is an electronic circuit that changes the DC level of a signal to the desired level without changing the shape of the applied signal. In other words, the clamper circuit moves the whole signal up or down to set either the positive peak or negative peak of the signal at the desired level.

Types of clamper and construction

The construction of the clamper circuit is almost similar to the clipper circuit. The only difference is the clamper circuit contains an extra element called capacitor. A capacitor is used to provide a dc offset (dc level) from the stored charge.

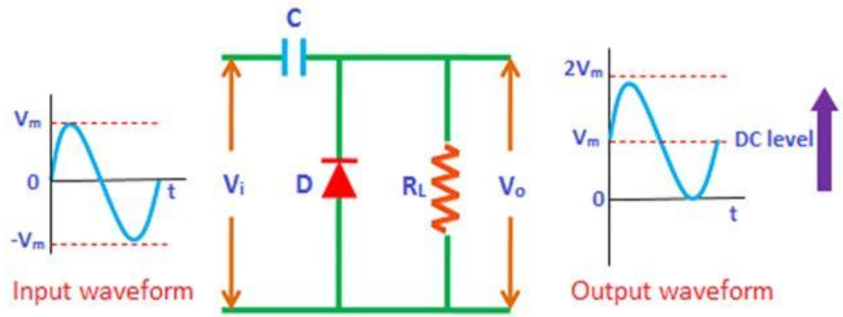
A typical clamper is made up of a capacitor, diode, and resistor. Some clampers contain an extra element called DC battery. The resistors and capacitors are used in the clamper circuit to maintain an altered DC level at the clamper output. The clamper is also referred to as a DC restorer, clamped capacitors, or AC signal level shifter.

Types of clampers

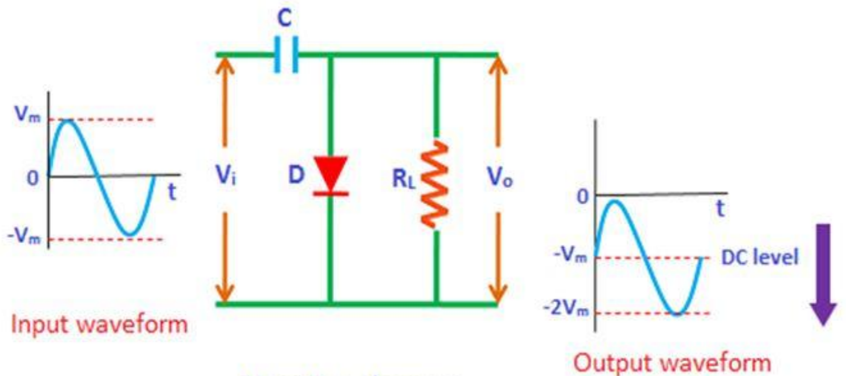
Clamper circuits are of three types:

- Positive clampers
- Negative clampers
- Biased clampers

Circuit



Positive clamper



Negative clamper

APPLICATIONS

- ….as rectifiers to convert AC into DC.
- As an switch in computer circuits.
- As detectors in radios to detect audio signals
- As LED to emit different colours.

- The load resistance of a center tapped full-wave rectifier is 1450Ω and the necessary end to end voltage is 100 sin(100πt). Calculate the (i)peak, rms and average value of current (ii) Efficiency of rectifier. Assume that each diode has an idealized V-I characteristics having slope corresponding to a resistance of 50Ω.