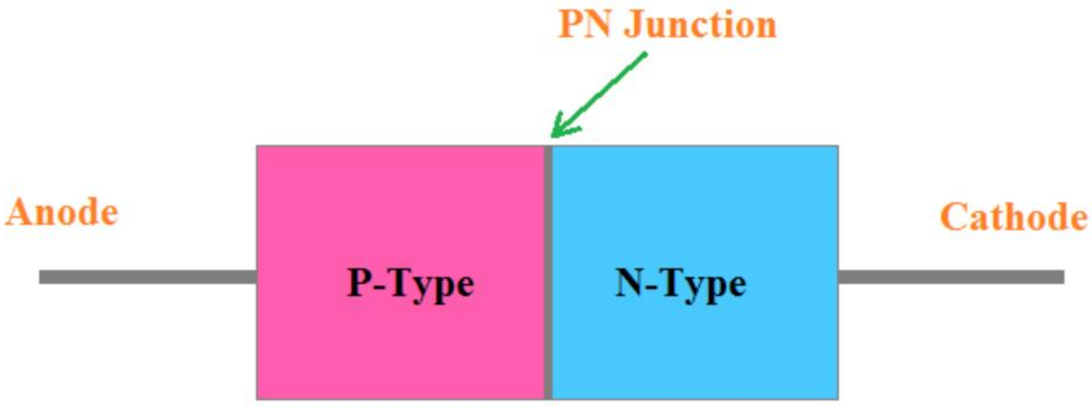
WEEK 3: SEMICONDUCTOR PN JUNCTION DIODE

What is p-n junction semiconductor diode?



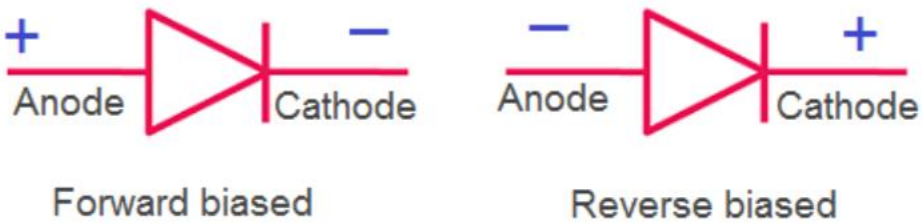
PN Junction Diode

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.

In n-type semiconductors, free electrons are the majority charge carriers whereas in p-type semiconductors, holes are the majority charge carriers. When the n-type semiconductor is joined with the p-type semiconductor, a p-n junction is formed. The p-n junction, which is formed when the p-type and n-type semiconductors are joined, is called as p-n junction diode.

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 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 holes 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.

Diode - a semiconductor device with two terminals, typically allowing the flow of current in one direction only.

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.

Terminals of PN Junction Diode

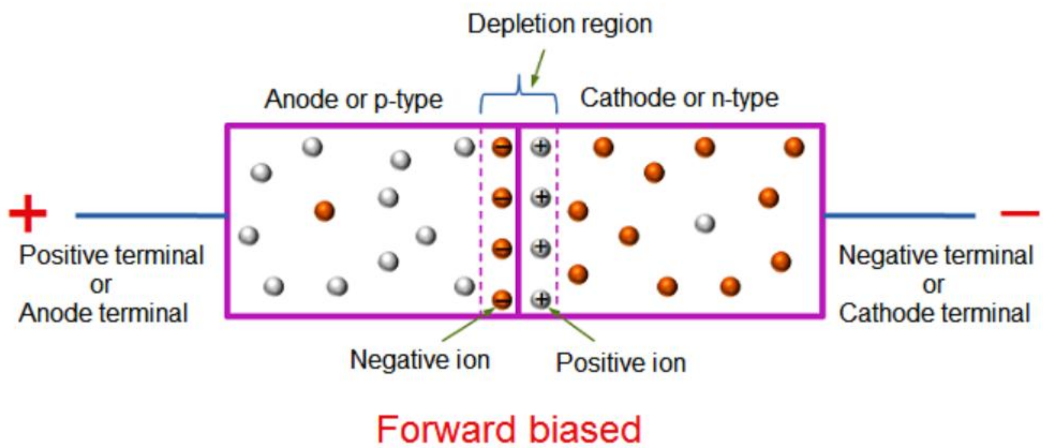
Generally, terminal refers to a point or place at which any object begins or ends. For example, bus terminal or terminus is a place at which all the buses begins or ends. Similarly, in a p-n junction diode, terminal refers a point at which charge carriers begins or ends.

P-n 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.

- **Terminals of diode under forward bias**

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), the positive charge carriers (holes) begins their journey at anode terminal and travel through the diode and ends at cathode terminal.



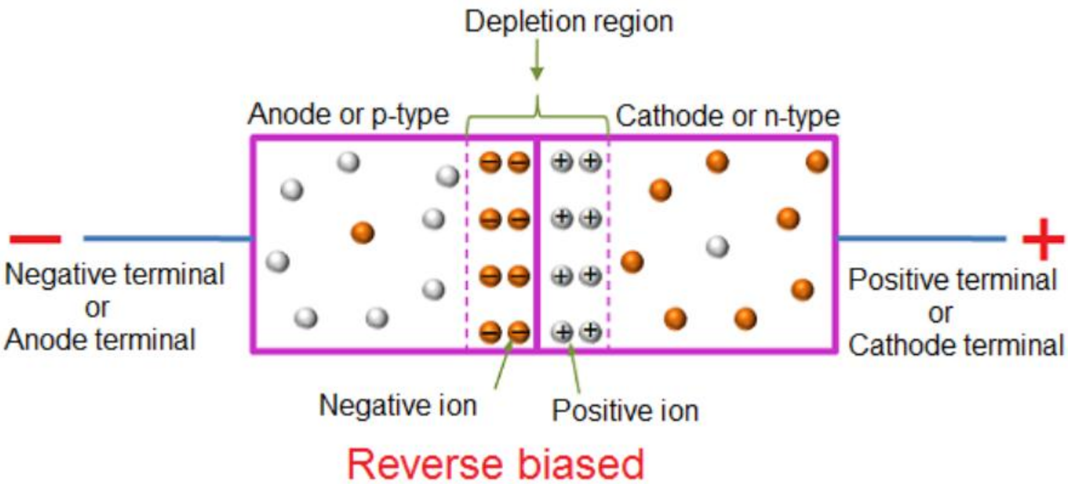
Cathode is the negatively charged electrode or conductor, which supplies free electrons to the p-n junction. In other words, cathode terminal or negative terminal is the source of free electrons, the negative charge carriers (free electrons) begins their journey at cathode terminal and travel through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

The free electrons are attracted towards the anode terminal or positive terminal whereas the holes are attracted towards the cathode terminal or negative terminal.

- **Terminals of diode under reverse bias**

If the diode is reverse biased (p-type connected to negative terminal and n-type connected to positive terminal), the anode terminal becomes a negative terminal whereas the cathode terminal becomes a positive terminal.

Anode terminal or negative terminal supplies free electrons to the p-n junction. In other words, anode terminal is the source of free electrons, the free electrons begins their journey at negative or anode terminal and fills the large number of holes in the p-type semiconductor. The holes in the p-type semiconductor get attracted towards the negative terminal. The free electrons from the negative terminal cannot move towards the positive terminal because the wide depletion region at the p-n junction resists or opposes the flow of free electrons.



Cathode terminal or positive terminal supplies holes to the p-n junction. In other words, cathode terminal is the source of holes, the holes begins their journey at positive or cathode terminal and occupies the electrons position in the n-type semiconductor. The free electrons in the n-type semiconductor gets attracted towards the positive terminal. The holes from the positive terminal cannot move towards the negative terminal because the wide depletion region at the p-n junction opposes the flow of holes.

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.

Advantages of P-N Junction Diode

P-n junction diode is the simplest form of all the semiconductor devices. However, diodes plays a major role in many electronic devices.

- A p-n junction diode can be used to convert the alternating current (AC) to the direct current (DC). These diodes are used in power supply devices.

- If the diode is forward biased, it allows the current flow. On the other hand, if it is reverse biased, it blocks the current flow. In other words, the p-n junction diode becomes on when it is forward biased whereas the p-n junction diode becomes off when it is reversed biased (I.e. it acts as switch). Thus, the p-n junction diode is used as electronic switch in digital logic circuits.

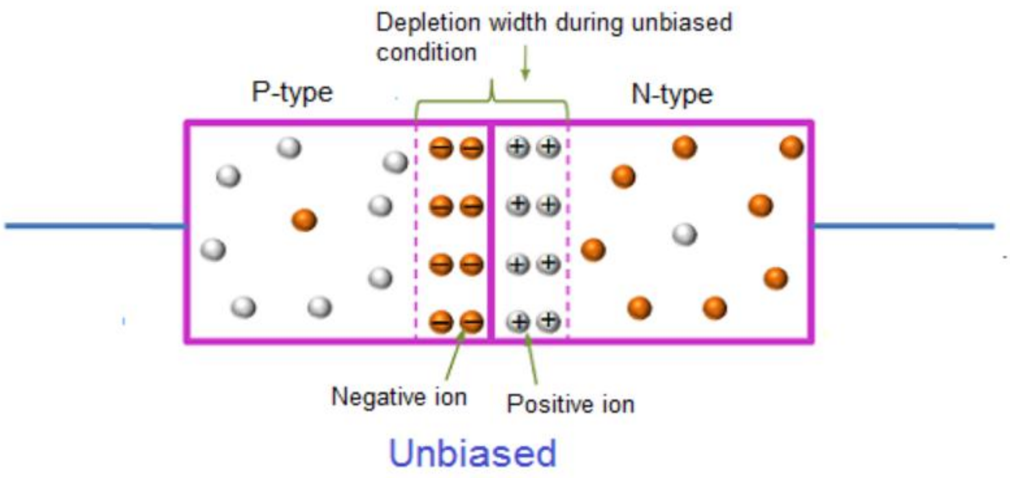
Forward Biased P-N Junction Diode

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.

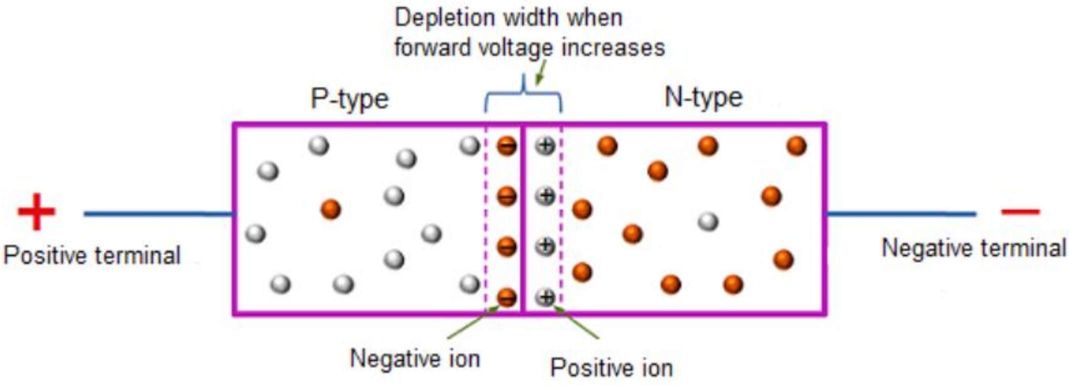
In forward biased p-n junction diode, the positive terminal of the battery is connected to the p-type semiconductor material and the negative terminal of the battery is connected to the n-type semiconductor material.

Unbiased diode and forward biased diode

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.



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.

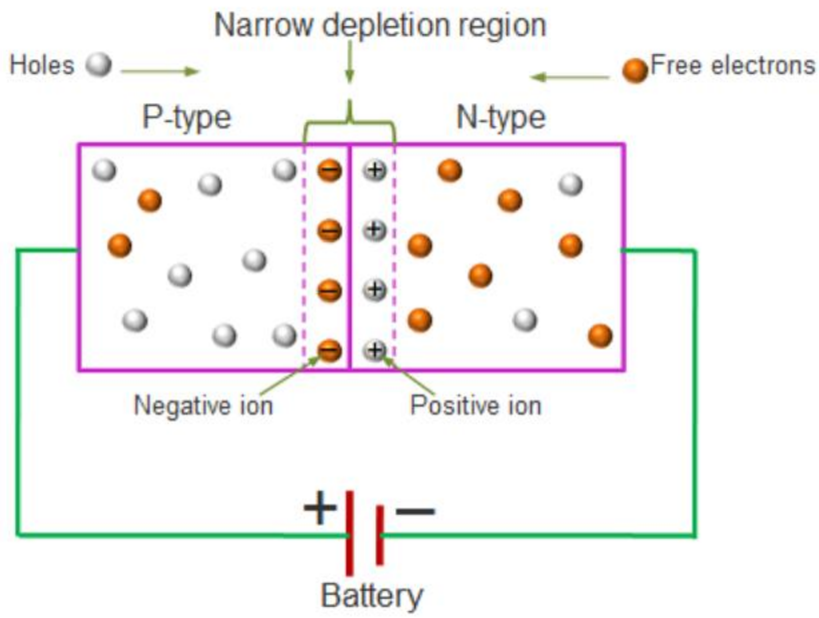


Forward biased

Electron and hole current

- **Electron current**

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.



Forward bias

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.

- **Hole current**

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.

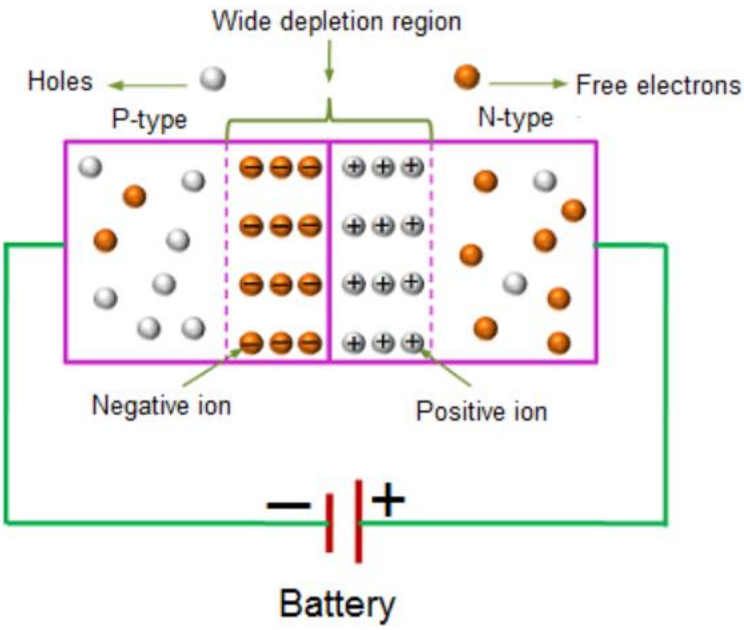
In reverse biased p-n junction diode, the positive terminal of the battery is connected to the n-type semiconductor material and the negative terminal of the battery is connected to the p-type semiconductor material.

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.

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.

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.



Reverse bias

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.

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.