



Circuit Essentials: Exploring P-N Junction Diode

Riya Sharma¹, Inamul Haq Wani²

Department of Physics Govt. Maulana Azad Memorial College Jammu, Jammu and Kashmir, India

ABSTRACT: A P-N junction diode is a semiconductor device formed by joining together a P-type semiconductor material (with excess positive charge carriers, or "holes") and an N-type semiconductor material (with excess negative charge carriers, or electrons). This junction creates a depletion region, devoid of mobile charge carriers, which acts as a barrier to current flow under reverse bias and allows current flow under forward bias.

KEYWORDS: Basic structure, Depletion region, Forward bias, reverse bias, current voltage characteristics, Applications.

INTRODUCTION:

Semiconductors are materials whose conductivity lies between conductors and insulators. Semiconductors are classified as extrinsic semiconductors and intrinsic semiconductors. Extrinsic semiconductors are further classified as N-type and P-type semiconductors. The P-N junction is formed between p-type and n-type semiconductors.

P-TYPE SEMICONDUCTORS:

When a trivalent impurity is added in a pure semiconductor, then semiconductor is so formed as P-type semiconductors.

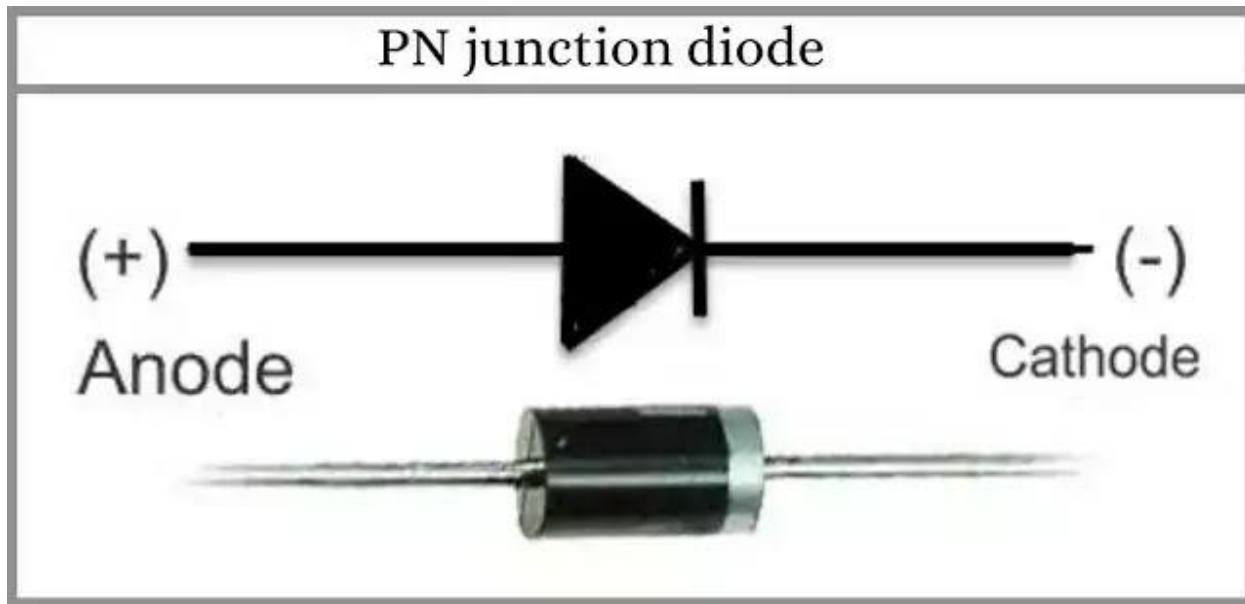
N-TYPE SEMICONDUCTOS:

When a pentavalent impurity is added to a pure semiconductors then semiconductor so formed is known as n-type semiconductors.

P-N JUNCTION

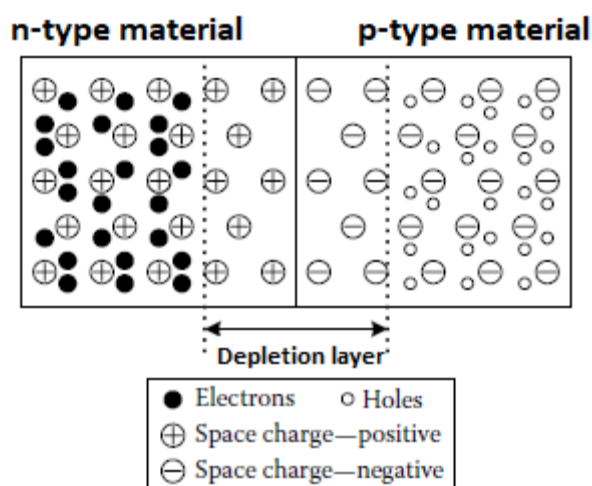
A P-N junction is an interface or a boundary between two semiconductors material types namely P-type and N-type inside a semiconductor.

In a semiconductor, the P-N junction is created by method of doping. The P side or the positive side of semiconductor has an excess of holes and the N side or negative side of semiconductor has excess of electrons.



DEPLETION REGION:

When the P-type and the N-type materials are kept in contact with each other, the junction between them behaves differently from either side of material alone. The electrons and holes are close to each other at the junction. According to coulomb's law, there is a force between the negative electrons and positive holes. When the p-n junction is formed a few electrons from the n-type diffuse through the junction and combine with the holes in the p-side to form negative ions and leaves behind positive ions in n-side. This results in the formation of depletion layer, which acts as the barrier and does not allow any further flow of electrons from the n region to the p region.



UNBIASED P-N JUNCTION:

An unbiased PN junction refers to a PN junction diode that is not subjected to any external voltage bias. In this state, no external voltage is applied across the diode, meaning there is no forward bias or reverse bias condition present.

Here's what happened in unbiased PN junction:

1. **Equilibrium State:** Without any external bias, the PN junction diode is in a state of equilibrium. This means that there is no net flow of charge carriers across the junction.
2. **Built-in Potential Barrier:** Even in the absence of external bias, there exists a built-in potential barrier at the PN junction. This barrier is due to the difference in the concentration of majority carriers (holes in the P-type region and electrons in the N-type region) near the junction.
3. **Depletion Region:** The built-in potential barrier creates a depletion region at the junction. This region is depleted of mobile charge carriers, resulting in a lack of conductivity.
4. **Potential Energy Difference:** The built-in potential barrier creates a potential energy difference across the junction, with the P-type region having a higher potential compared to the N-type region.
5. **Diffusion and Drift:** Despite the absence of external bias, some diffusion and drift processes still occur. However, these processes are in equilibrium, meaning that the net movement of charge carriers across the junction is zero.
6. **Zero Current Flow:** Since there is no external voltage to overcome the built-in potential barrier, no significant current flows through the diode in the unbiased state. Any small current that does flow is due to thermal generation of electron-hole pairs, resulting in a small leakage current known as the reverse saturation current.
7. **Electron-Hole Recombination:** Within the depletion region, electron-hole pairs may recombine, contributing to the reverse saturation current.

In summary, an unbiased PN junction diode is in a state of equilibrium, with no external voltage applied across it. Despite this, there is still a built-in potential barrier at the junction, resulting in a depletion region and a small reverse saturation current.

FORMATION OF P-N JUNCTION:

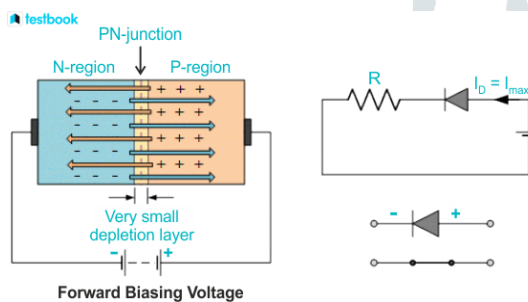
As we know if we use different semiconductor materials to make a P-N junction there will be a grain boundary that would inhibit the movement of electrons from one side to the other by scattering the electrons and holes and thus, we use the process of doping. We will understand the process of doping with the help of this example. Let us consider a thin p-type silicon semiconductor sheet. If we add a small amount of pentavalent impurity to this, a part of the p-type Si will get converted to n-type silicon. This sheet will now contain both the p-type region and the n-type region and a junction between these two regions. The processes that follow after forming a P-N junction are of two types – diffusion and drift. There is a difference in the concentration of holes and electrons at the two sides of a junction. The holes from the p-side diffuse to the n-side, and the electrons from the n-side diffuse to p-side. These give rise to a diffusion current across the junction. Also, when an electron diffuses from the n-side to p-side, an ionized donor is left behind on the n-side, which is immobile. As the process goes on, a layer of positive charge is developed on the n-side of junction. Similarly, when a hole goes from the p-side to n-side, an ionized acceptor is left behind on the p-side,

resulting in the formation of layer of negative charges in the p-side of the junction. This region of positive charge and negative charge on either side of the junction is termed as depletion layer. Due to this positive space charge region on either side of junction, an electric field with the direction from a positive charge toward the negative charge is developed. Due to this electric field, an electrons on the p-side of junction moves to the n-side of junction. This motion is termed as drift. Here, we see that direction of the drift current is opposite to that of diffusion current.

FORWARD BIASED P-N JUNCTION DIODE:

When the positive terminal of the battery is connected to P- side and negative terminal to the N- side, so that the potential difference acts in opposite direction to the barrier potential, then the P-N junction diode is said to be forward biased.

When the P-N junction is forward biased, the applied positive potential repels the holes in the P- region, and the applied negative potential repels the electrons in the N- region, so the charges move towards the junction. If the applied potential difference is more than the potential barrier, some holes and free electrons enter the depletion region.

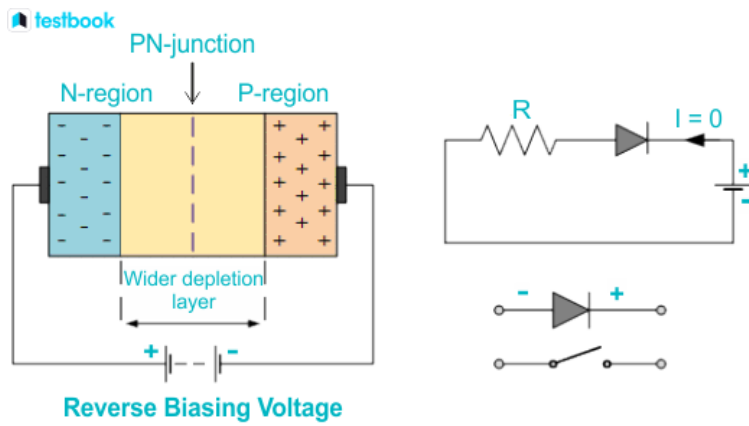


Hence, the potential barrier as well as the width of the depletion region are reduced. The positive donor ions and negative acceptor ions within the depletion region regain electrons and holes respectively. As a result of this, the depletion region disappears and the potential barrier also disappears. Hence, under the action of the forward potential difference, the majority charge carriers flow across the junction in opposite direction and constitute current flow in the forward direction.

REVERSE BIASED P-N JUNCTION DIODE:

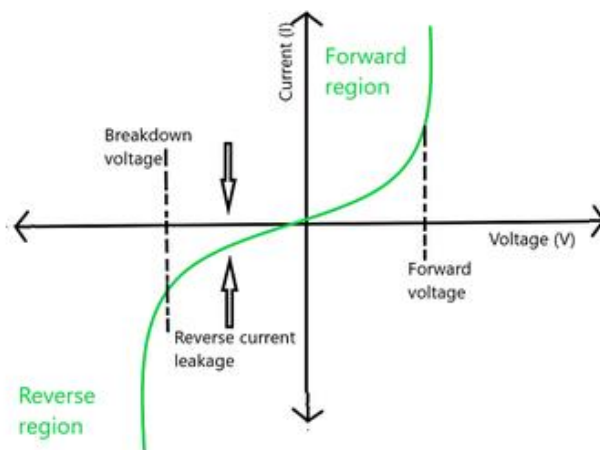
When the positive terminal of the battery is connected to the N- side and negative terminal to P- side, so that the applied potential difference is in the same direction as that of barrier potential, the junction is said to be reverse biased.

When the P-N junction is reverse biased, electrons in the N region and holes in P region are attracted away from junction. Because of this, the number of negative ions in the P- region and positive ions in the N- region increases. Hence the depletion region becomes wider and the potential barrier is increased.



Since the depletion region does not contain majority charge carriers, it acts like an insulator. Therefore, no current should flow in the external circuit. But, in practice, a very small current of the order of few microamperes flow in reverse direction. This is due to the minority carriers flowing in the opposite direction. This reverse current is small, because the number of minority carriers in both regions is very small. Since the major source of minority carriers is, thermally broken covalent bonds, the reverse current mainly depends on the junction temperature.

V-I CHARACTERISTICS OF P-N JUNCTION DIODE :



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

- Zero bias
- Forward bias
- Reverse bias

When the P-N junction diode is in zero bias condition, there is no external voltage applied and this means that the potential barrier at the junction does not allow the flow of current.

When the P-N junction diode is in forward bias condition, the p-type is connected to the positive terminal while the n-type is connected to negative terminal of external voltage. When the diode is arranged in this manner, there is a reduction in the potential barrier. For silicone

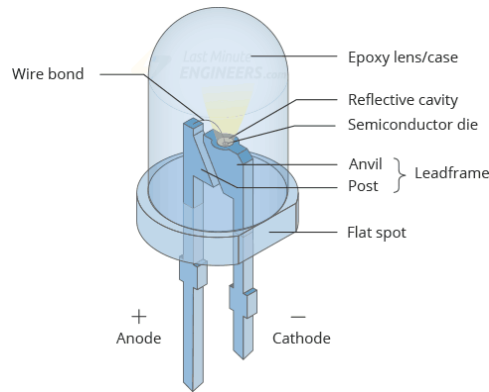
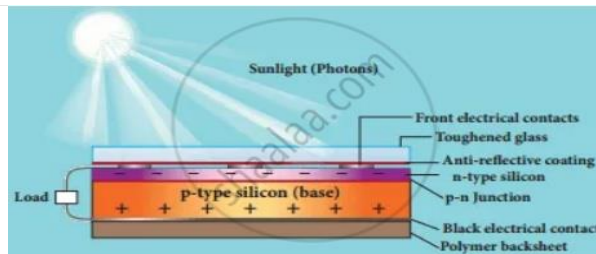
diodes, when voltage is 0.7V and for germanium diodes, when voltage is 0.3V, the potential barriers decreases, and there is a flow of current. When the diode is in forward bias, the current increases slowly, and the curve obtained is non - linear as the voltage applied to the diode overcomes the potential barrier. Once the diode overcomes the potential barrier, the diode behaves normally, and curve rises sharply as the external voltage increases, and the curve obtained is linear.

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

APPLICATION OF P-N JUNCTION DIODE :

- P-N junction diode can be used as a photodiode as the diode is sensitive to the light when the configuration of the diode is reverse biased.
- It can be used as a solar cell. Photovoltaic cells, which convert light energy into electrical energy, are essentially PN junction diodes. When photons strike the semiconductors materials of the solar cells, electron-hole -pair are generated, resulting in a flow of current.
- When the diode is forward biased, it can be used in LED lighting applications.
- It is used as rectifier in many electric circuits and as a voltage controlled oscillator in varactors.
- Diodes are used to recover original modulation signals from AM or FM modulated waveform.
- It is commonly used in rectifier circuits to convert AC to DC. Half –wave and Full wave rectifiers utilize diodes to allow current flow in only one direction, resulting in a pulsating DC output.
- Zener diode, operated in reverse breakdown region, provide stable voltage reference or regulate voltage in electronic circuits. They are often used in voltage regulator circuits to maintain a constant output voltage despite variation in input voltage or load conditions.
- Diodes play roles in the design of logic gates and digital circuits.
- Diodes are utilized in clipping circuits to limit the amplitude of input signals by clipping off portions of the waveform above or below a certain threshold voltage.
- Specialized PN junction diodes, known as LEDs, emit light when forward biased. LEDs are widely used in display, indicator light, automotive light and general illumination due to their efficiency, longevity and color variety.

These applications demonstrate the versatility and importance of PN junction diodes in modern electronics, spanning from basic rectification and signal processing to advanced functions like voltage regulation and optoelectronics.



CONCLUSION:

In conclusion, the PN junction diode stands as a foundational semiconductor device with multifaceted applications in electronics. Here's a summative overview:

2. **Fundamental Semiconductor Component:** The PN junction diode is a basic semiconductor component formed by joining P-type and N-type materials, creating a depletion region and a built-in potential barrier.
3. **Versatile Applications:** Its unique properties make it invaluable across a wide range of applications:
 - **Rectification:** Converting AC to DC in power supplies.
 - **Signal Demodulation:** Extracting modulating signals in communication systems.
 - **Voltage Regulation:** Utilizing Zener diodes for stable voltage references.
 - **Switching:** Employed in digital logic circuits for high-speed switching.
 - **Light Emission:** Serving as light-emitting diodes (LEDs) in displays and lighting systems.
 - **Photovoltaic Energy Conversion:** Forming the basis of solar cells for converting light energy into electricity.
4. **Operating Characteristics:**
 - Under forward bias, it allows current flow with an exponential relationship between current and voltage.
 - Under reverse bias, it blocks current until the breakdown voltage is reached, beyond which it may exhibit avalanche breakdown or Zener breakdown.
5. **Equilibrium State:** In an unbiased state, the PN junction diode is in equilibrium, with no net flow of charge carriers across the junction. However, a small reverse saturation current exists due to thermal generation of electron-hole pairs.

6. **Future Developments:** Ongoing advancements in semiconductor technology continue to refine and expand the capabilities of PN junction diodes, enabling innovations in fields ranging from renewable energy to telecommunications and beyond.

In essence, the PN junction diode stands as a cornerstone of modern electronics, underpinning countless devices and technologies that shape our daily lives. Its simplicity belies its significance, making it a vital component in the intricate tapestry of semiconductor technology.

REFERENCES:

References regarding PN junctions can be found in various textbooks, research papers, and online resources. Here are some commonly referred sources:

1. Books:
• "Semiconductor Physics and Devices" by Donald A. Neamen. • "Physics of Semiconductor Devices" by Simon M. Sze and Kwok K. Ng. • "Solid State Electronic Devices" by Ben G. Streetman and Sanjay Banerjee. • "Fundamentals of Semiconductor Devices" by Betty Lise Anderson and Richard L. Anderson.
2. Research Papers:
• Original research papers by scientists such as William Shockley, John Bardeen, and Walter Brattain, who were instrumental in the development of semiconductor physics and devices. • Recent research papers published in journals like IEEE Transactions on Electron Devices, Applied Physics Letters, and Journal of Applied Physics.
3. Online Resources:
• Websites of universities offering courses in semiconductor physics or electronics often provide lecture notes and resources on PN junctions. • Online educational platforms like Khan Academy, Coursera, and edX may offer courses or modules covering semiconductor physics and devices.
4. Datasheets and Application Notes:
• Semiconductor manufacturers often provide datasheets and application notes for specific semiconductor components, including diodes, which extensively use PN junctions. Manufacturers like Texas Instruments, Analog Devices, and Infineon offer comprehensive resources.
5. Semiconductor Industry Publications:
• Magazines and websites focused on the semiconductor industry, such as Semiconductor Today and Semiconductor Engineering, may have articles, interviews, or analysis related to PN junctions and their applications.