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# Characteristics of Semiconductor Diode and Its Application

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**Abstract:** In this paper, we have explained the characteristics of semiconductors diodes and its application have influenced the universe beyond anything before they might have thought. While the communications and processing records have been nonetheless essential via the humans, thanks to the semiconductors all vital duties have been conveniently accomplished and infinitely less time has been needed than, for example, during vacuum tubes. The Semiconductor diode that is made from a small piece of semiconductor material, usually silicon, in which half is doped as a p region and half is doped as an n region with a p-n junction and depletion region in between. In order to review the semiconductor diode, we used unbiased, forward-biased and reverse biased methods. In unbiased condition the external voltage does not apply on the p-n Junction, In forward bias the P-region of the diode is connected with the positive terminal of the battery and N-region is connected with the negative region. While in the reverse bias, the P-type region is connected to negative voltage and N-type is connected to the positive terminal The building blocks of the entire electronics and computing sectors are semi-conductive substances. Without included circuits (chips) which consist of semiconductor substances, compact, lightweight, excessive velocity and coffee-energy gadgets might no longer be possible. This essay explores the general records, description and impact of semiconductors on semiconductors. Statistics on the effects of temperature on mosfet band difference, carrier density, mobility, provider diffusion and speed saturation, contemporary density, threshold voltage, leakage cutting-edge and interconnection resistance are given below. We also provide the applications of semiconductor materials in different sectors of modern electronics and communications.

**Keywords:** Light Emitting Diode, Semiconductor Diode, Traffic Light Signals, Semiconductor Application and Remote Control

## 1. Introduction

### *1.1. Background of the Study*

The first electronic device to be introduced is called the diode. It is the simplest of semiconductor devices but plays a very vital role in electronic systems [1]. It's a two-terminal electronic component that conducts current primarily in one direction; it has low (ideally zero) resistance in one direction, and high (ideally infinite) resistance in the other. A diode vacuum tube or thermionic diode is a vacuum tube with two electrodes, a heated cathode and a plate, in which electrons can flow in only one direction, from cathode to plate. A semiconductor diode, the most commonly used type today, is a crystalline piece of semiconductor material with a p–n junction connected to two electrical terminals. The discovery of asymmetric electrical conduction across the contact between a crystalline mineral and a metal was made by German physicist Ferdinand Braun in 1874. Today, most diodes are made of silicon, but other semiconducting materials such as gallium arsenide and germanium are also used [2]. The word diode can be explained as "Di" means two and "ode" is obtained from an electrode. A diode has two terminals or electrodes (one connected to P-type and the other to the N-type) [3].

The most common function of a diode is to allow an electric current to pass in one direction (called the diode's forward direction), while blocking it in the opposite direction (the reverse direction). As such, the diode can be viewed as an electronic version of a check valve. This unidirectional behavior is called rectification, and is used to convert alternating current (ac) to direct current (dc). Forms of rectifiers, diodes can be used for such tasks as extracting modulation from radio signals in radio receivers [2, 4].

However, diodes can have more complicated behavior than this simple on-off action, because of their nonlinear current-voltage characteristics. Semiconductor diodes begin conducting electricity only if a certain threshold voltage or cut-in voltage is present in the forward direction (a state in which the diode is said to be forward-biased). The voltage drop across a forward- biased diode varies only a little with the current, and is a function of temperature; this effect can be used as a temperature sensor or as a voltage reference. Also, diodes' high resistance to current flowing in the reverse direction suddenly drops to a low resistance when the reverse voltage across the diode reaches a value called the breakdown voltage [2].

Generally, Diodes are used in a wide variety of applications in communication systems (limiters, gates, clippers, mixers), computers (clamps, clippers, logic gates), radar circuits (phase detectors, gain-control circuits, power detectors, parameter amplifiers), radios (mixers, automatic gain control circuits, message detectors), and television (clamps, limiters, phase detectors, etc.).

The ability of diodes to allow the flow of current in only one direction is commonly exploited in these applications. In this project we have focused on the fundamental and new concept of semiconductor diodes and their application in photodiodes and light emitting diodes (LED). We would like to study about semiconductor diodes and its application. In the future we want to learn more about it. Therefore, we are interested in studying this title.

### *1.2. Statement of the Problem*

Due to the fact that science is new and much beyond what we have known before, some people See's the idea of semiconductor diodes and its applications not to be understood. So, to make a clear understanding of the science truth it is necessary to have a series of publications to people around us. Therefore, the study is aimed to solve this problem and to have a clear understanding more about Diode and its applications in their related course matter. In this project work we have answered the following questions:

### *1.3. Research Question*

1) What is unbiased (not biased) of semiconductor diodes?
2) What is forward biased of semiconductor diodes?
3) What is reverse biased of semiconductor diodes?
4) What are applications of semiconductor diodes?

### *1.4. Objective of Study*

#### *1.4.1. General Objective*

The General objective of this project was to describe semiconductor diodes and its application.

#### *1.4.2. Specific Objective*

1) To describe unbiased of semiconductor diode
2) To describe forward bias of semiconductor diode
3) To describe reverse bias of semiconductor diode
4) To study application of semiconductor diode

### *1.5. Significance of the Study*

Every scientific study is not designed without the significance and benefits. This study is expected to give the significance listed below;

1) Motivating other researchers to involve semiconductor diodes.
2) It is helpful for students in physics to use as a base for further study.
3) To share experience and knowledge about newly emerging and promising semiconductor diodes.
4) We researchers are requested to perform this study to fulfill our graduation requirements.

### *1.6. Limitation of the Study*

When we study this project work, we have the following limitations:

1) Difficulty to get relevant information on the related topic.
2) Lack of Internet accessibility.
3) Lack of more time to do this project work.

## 2. Literature Review

### *2.1. Semiconductor*

Semiconductors are a group of materials having conductivities between those of metals and insulators. Two general classifications of semiconductors are the elemental semiconductor materials, found in group IV of the periodic table, and the compound semiconductor materials, most of which are formed from special combinations of group III and group V elements. The elemental materials, those that are composed of single species of atoms, are silicon and germanium. Silicon is by far the most common semiconductor used in integrated circuits and will be emphasized to a great extent [5].

The two-element, or binary, compounds such as gallium arsenide or gallium phosphide are formed by combining one group III and one group V element. Gallium arsenide is one of the more common of the compound semiconductors. Its good optical properties make it useful in optical devices. GaAs is also used in specialized applications in which, for example, high speed is required. We can also form a three-element, or ternary, compound semiconductor. An example is $Al_xGa1_xAs$, in which the subscript x indicates the fraction of the lower atomic number element component. More complex semiconductors can also be formed that provide flexibility when choosing material properties [6].

Semiconductor devices are ubiquitous, controlling our computers, smart phones, dishwashers, cars, and even children’s toys. Because the electrical properties of a semiconductor material can be easily modified by controlled addition of impurities (doping), semiconductor devices can be used for switching, amplification, and energy conversion, making them the foundation of modern electronics [7].

### *2.2. Type of Semiconductor*

#### *2.2.1. Intrinsic Semiconductor*

Robert Boylestad and Louis Nashelsky, defines intrinsic semiconductor as Semiconductor which is pure and contains no impurity. In an intrinsic semiconductor, the number of free electrons and holes are equal. Common examples of intrinsic semiconductors are pure germanium and silicon [1]. The impurity content in intrinsic semiconductor is very small, of the order of one part in 100 million parts of semiconductor. For achieving such a pure form, the semiconductor materials are carefully refined. To understand the conduction in an intrinsic semiconductor. Let us study the crystalline structure of an intrinsic semiconductor [8].

#### *(i). Crystal Structure of Intrinsic Semiconductor*

Consider the atomic structure of an intrinsic semiconductor material like silicon. An outermost shell of an atom is capable of holding eight electrons. It is said to be completely filled and stable, if it contains eight electrons. But the outermost shell of an intrinsic semiconductor like Silicon has only four electrons. Each of these four electrons forms a bond with another valence electron of the neighboring atoms. The atoms align themselves to form a three-dimensional uniform pattern called a crystal [8].

The crystal structure of Germanium and Silicon material consists of repetitive occurrences in three dimensions of a tetrahedron with an atom at each vertex but such a three-dimensional structure is very difficult to represent pictorially. Hence symbolic two-dimensional structures are used to represent a three-dimensional crystal form. The covalent bond is represented by a pair of dotted lines encircling the two-electron forming the covalent bond. The clearer understanding of the covalent bonds can be obtained from figure 1 shows the sharing of valence electrons. Both the electrons are shared by the two atoms. Hence the outermost shell of all the atoms is completely filled; the valence electrons are tightly bound to the parent atoms. No free electrons are available at absolute zero temperature. Hence such an intrinsic semiconductor behaves as a perfect insulator at absolute zero temperature [8, 6].

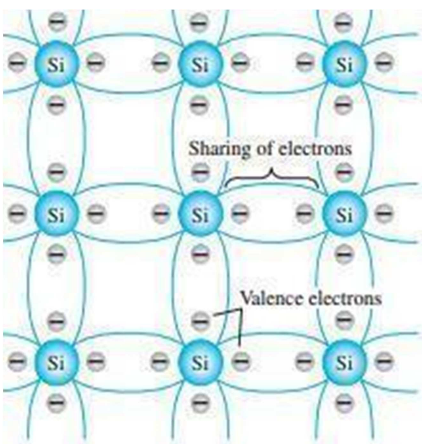


***Figure 1.*** *Semiconductor diode.*

#### *(ii). Charge Carriers in Intrinsic Semiconductor*

Intrinsic semiconductor behaves as a perfect insulator at absolute zero temperature. Let us see what happens at room temperature. At room temperature, the numbers of valence electrons absorb the thermal energy, due to which they break the covalent bond and drift to the conduction band. Such an electron becomes free to move in the crystal [9].

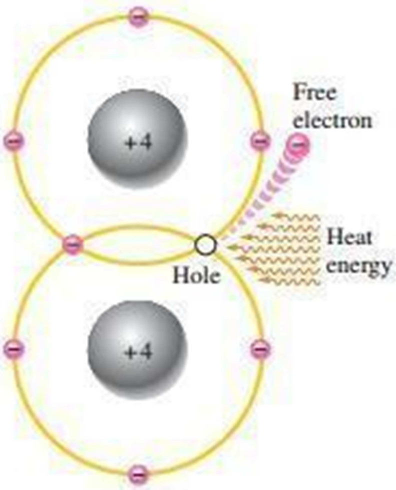


***Figure 2.*** *Breaking of covalent bond [9].*

Once the electron is dislodged from the covalent bonds then they become free, such electrons wander in a random fashion in a crystal.

When a valence electron drifts from valence to conduction band breaking a covalent bond, a vacancy is created in the broken covalent bond. Such a vacancy is called a hole. Whenever an electron becomes free, the corresponding hole gets generated. So, free electrons and holes get generated in pairs. Such a generation of electron hole pairs due to thermal energy is called thermal generation. The concentration of free electrons and holes is always equal in an intrinsic semiconductor. The holes also serve as a carrier of electricity similar to that of free electrons. An electron is a negatively charged particle. Thus a hole getting created due to electron drift is said to be positively charged. Thus in an intrinsic semiconductor both holes as well as free electrons are the charge carriers [8].

#### *(iii). Conduction in Intrinsic Semiconductor*

Let us now consider that the battery is connected across an intrinsic semiconductor. The free electrons as negatively charged experience a force toward the positive terminal of the battery while the hole as positively charged experiences a force towards the negative terminal of the battery; this is shown in figure 2. Electron flow from negative to positive is known as the direction of electron flow [8].

#### *2.2.2. Extrinsic Semiconductor*

Intrinsic or pure semiconductor has negligible conductivity at room temperature. Therefore, it is not of any practical significance. In order to make the intrinsic semiconductor useful, their characteristics have to be changed. In order to change the characteristics of intrinsic semiconductor, a small amount of some other material is added to it. The process of adding other material to the Crystal of intrinsic semiconductor to improve its conductivity is called doping. The impurity added is called dopant. Doped semiconductor is called extrinsic semiconductor. The doping increases the conductivity of the basic intrinsic semiconductors hence the extrinsic semiconductors are used in practice for manufacturing of various electronic devices such as diodes, transistors etc. [5, 8].

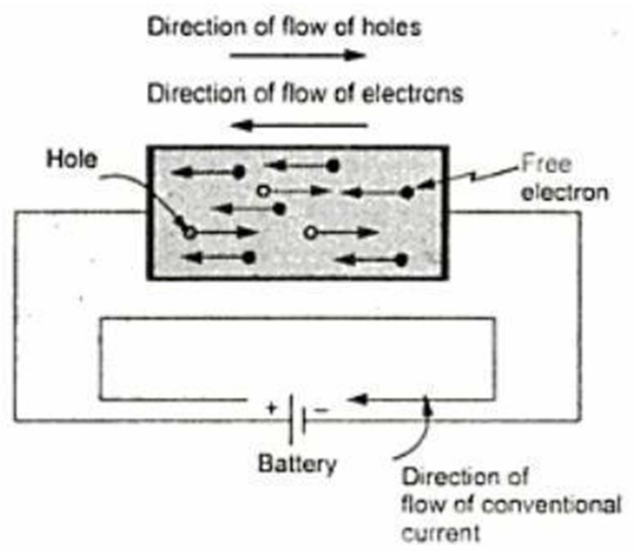


***Figure 3.*** *Conduction in intrinsic semiconductor [8].*

***(i). Types of Impurity***

When this is added to an intrinsic semiconductor called donor doping, each impurity atom donates one free electron to an intrinsic material. Such an impurity is called donor impurity. The example of such impurity is arsenic, bismuth, phosphorus etc. This creates an extrinsic semiconductor with a large number of free electrons, called N- type of Semiconductor [8].

Another type of impurity used is trivalent atom which has only three valence electrons such an impurity is called acceptor impurity Then this is added to an intrinsic semiconductor it creates more holes and ready to accept an electron hence the doping is called acceptor doping the example of such impurity are gallium, indium and Boron. The resulting extrinsic semiconductor with a large number of holes is called p- type semiconductor [8].

Generally, the purpose of adding impurity is to increase either the number of electrons or holes in a semiconductor. Depending on the type of impurity atoms added to the semiconductor, the resulting semiconductor (i.e., extrinsic semiconductor) may be of the following two types [5].
1. N- type and 2. P-type.

***(ii). N-Type Semiconductor***

When a small amount of pentavalent impurity is added to a pure semiconductor, it is called N- type semiconductor. The pentavalent impurity has five valence electrons. Consider the formation of electron material by adding antimony into Silicon. The antimony atom has five valence electrons. Each pentavalent atom (antimony, in this case) forms covalent bonds with four adjacent silicon atoms. Four of the antimony atom’s valence electrons are used to form the covalent bonds with silicon atoms, leaving one extra electron. This extra electron becomes a conduction electron because it is not involved in bonding. Because the pentavalent atom gives up an electron, it is often called a donor atom [9].

The number of conduction electrons can be carefully controlled by the number of impurity atoms added to the silicon. A conduction electron created by this doping process does not leave a hole in the valence band because it is in excess of the number required to fill the valence band. Since the free electrons have negative charges, the material is known as N-Type material and an impurity donates free electrons [8, 9].

***(iii). Conduction in N-Type Semiconductor***

When the voltage is applied to N-type semiconductor, the free electrons which are readily available due to added impurity move in a direction of positive terminal of voltage applied. This constitutes a current. Thus, conduction is predominantly by free electrons. The holes are less in number hence electron current is dominant over the hole current. Hence in N-Type semiconductor free electrons are called majority carriers while the holes which are small in number are called minority carriers. The conduction in N-Type material is shown in figure 4. [8].

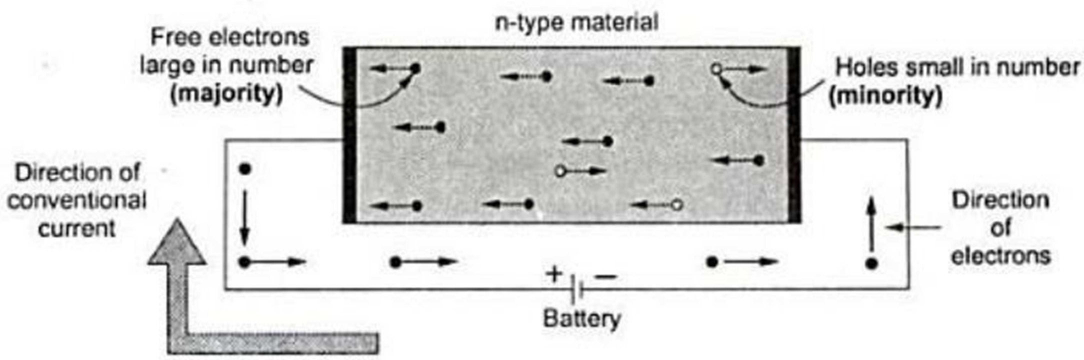


***Figure 4.*** *Conduction in N-type material [8].*

***(iv). P-Type Semiconductor***

When a small amount of trivalent impurity is added to a pure semiconductor, it is called p- type semiconductor. The trivalent impurity has three valence electrons. These elements are such as gallium, boron or indiums such an impurity is called acceptor impurity [10].

Consider the formation of p-type by adding gallium into silicon. The gallium atom has three valence electrons. So gallium atoms fit in the silicon Crystal in such a way that it's three valence electrons form covalent bonds with the three adjacent silicon atoms being short of one electron, the fourth covalent bond in the valence shell is incomplete. The resulting vacancy is called a hole. This means that each gallium atom added into the silicon atom gives one hole. The number of such holes can be controlled by the amount of impurity added to silicon. As the holes are treated as positively charged, the material is known as p-type material [8, 11].

At room temperature, the thermal energy is sufficient to extract an electron from the neighboring atom which fills the vacancy in the incomplete bond around the impurity atom. But this creates a vacancy in the adjacent bond from where the electron had jumped, which is nothing but a hole. This indicates that a hole created due to added impurity is ready to accept an electron and hence is called acceptor impurity. Thus, even for a small amount of impurity added, a large number of holes gets created in the p-type material [8].

***(v). Conduction in P-Type***

If now such p-type material is subjected to an electric field by applying a voltage then the holes move in a valence band and are mainly responsible for the conduction so the current conduction in p-type material is predominantly due to the holes. The free electrons are also present in the conduction band but are very less in number. Hence holes are the majority carrier while electrons are minority carriers in p-type material. The conduction in p-type material is shown in figure 5. [8, 9].

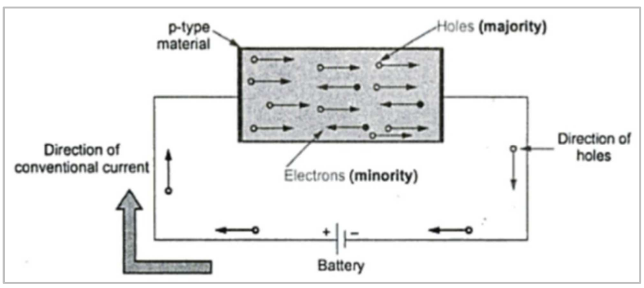


***Figure 5.*** *Conduction in p-type material [8].*

***(vi). P-N Junction***

A p–n junction is a boundary between two types of semiconductor materials, p-type and n-type, inside a single crystal of semiconductor. The "p" (positive) side contains an excess of holes, while the "n" (negative) side contains an excess of electrons in the outer shells of the electrically neutral atoms there. This allows electrical current to pass through the junction only in one direction. The p-n junction is created by doping. If two separate pieces of material were used, this would introduce a grain boundary between the semiconductors that would severely inhibit its utility by scattering the electrons and holes [1]. When P and N type semiconductors are brought together during manufacture, a junction is created where the P type and N type materials meet, and holes close to the junction in the P type semiconductor are attracted into negatively charged N type material at the other side of the junction. Also, electrons close to the junction in the N type semiconductor are attracted into the positively charged P type semiconductor [10].

***2.2.3. Formation of the Depletion Region***

The free electrons in the n region are randomly drifting in all directions. At the instant of the p-n junction formation, the free electrons near the junction in the n-region begin to diffuse across the junction into the p region where they combine with holes near the junction, as shown in Figure 6. Before the p-n junction is formed, recall that there are as many electrons as protons in the n- type material, making the material neutral in terms of net charge. The same is true for the p-type material [1].

When the p-n junction is formed, the n-region loses free electrons as they diffuse across the junction. This creates a layer of positive charges (pentavalent ions) near the junction as the electrons move across the junction; the p region loses holes as the electrons and holes combine. This creates a layer of negative charges (trivalent ions) near the junction. These two layers of positive and negative charges form the depletion region [13]. The term depletion refers to the fact that the region near the p-n junction is depleted of charge carriers (electrons and holes) due to diffusion across the junction. Keep in mind that the depletion region is formed very quickly and is very thin compared to the n region and p region [9].

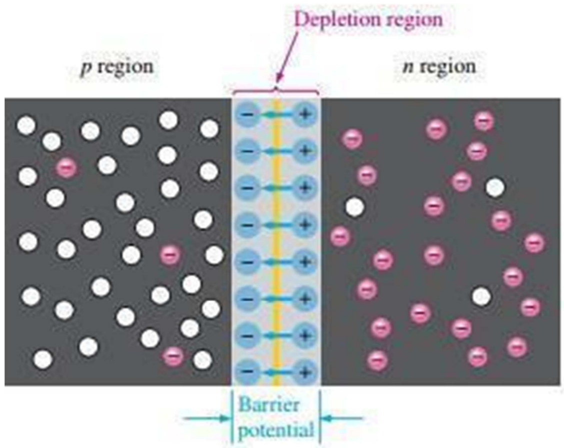


***Figure 6.*** *Formation of the Depletion Region [9].*

After the initial surge of free electrons across the p-n junction, the depletion region has expanded to a point where equilibrium is established and there is no further diffusion of electrons across the junction. This occurs as follows. As electrons continue to diffuse across the junction, more and more positive and negative charges are created near the junction as the depletion region is formed. A point is reached where the total negative charge in the depletion region repels any further diffusion of electrons (negatively charged particles) into the p region (like charges repel) and the diffusion stops. In other words, the depletion region acts as a barrier to the further movement of electrons across the junction [9].

The potential difference of the electric field across the depletion region is the amount of voltage required to move electrons through the electric field. This potential difference is called the barrier potential and is expressed in volts. Stated another way, a certain amount of voltage equal to the barrier potential and with the proper polarity must be applied across a p-n junction before electrons will begin to flow across the junction. The barrier potential of a p-n junction depends on several factors, including the type of semiconductor material, the amount of doping, and the temperature [9].

# 3. Materials and Methods

## 3.1. Experimental Description

Experiments were performed in five eyes of three dwarf Netherlands rabbits, each weighing an average of 1 kg. The animals were anesthetized intramuscularly by using ketamine hydro- chloride (50 mg/kg) and xylazine (2 mg/kg) and with topical proparacaine. The eyes were dilated 30 minutes preoperatively with 1% tropicamide hydrochloride and 2.5% phenylephrine hydrochlo- ride. Photocoagulation was performed by using an Oculight SL diode laser endophotocoagulation (Iris Medical Instruments, Inc., Mountain view, California). This device utilizes high-power diode laser to deliver 1.0 W of CW power at the 810-nm wavelength. The probe size is 20 gauge (200 pm).

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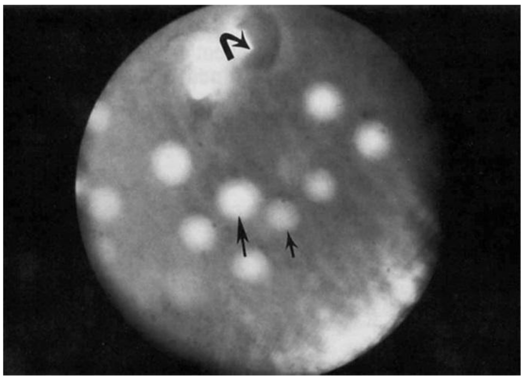

*Figure 7. Fundus photograph demonstrating acute (white) lesions after application of diode laser.*

## 3.2. Experimental Treatment

Small arrow indicates a 200 MW lesion, and large arrow a 500 MW lesion. Bent arrow indicates an explosive choroidal hemorrhage when the power setting approached 700 MW.

Fiber optic by 35 mm. Exposure duration is user-selected from 100 to 5,000 msec. Tran's scleral photocoagulation of the retina and ciliary body was performed by using different output powers (200 MW to 700 MW). Exposure duration of 0.5 sec was kept constant for all burns applied to the retina and ciliary body. Fundus and anterior segment photographs were obtained (using Topcon fundus camera TRC- FET). Two rabbits were sacrificed 30 minutes after laser application by using an overdose intra- venous injection of pentobarbital sodium. Eyes were enucleated and fixed in a mixture of 2% paraformaldehyde and 3% glutaraldehyde, dehydrated in graded series of ethyl alcohol (70- 80% and 95%), embedded in glycol methacrylate (GMA), sectioned at 1 pm, and stained with toluidine blue. One rabbit was followed for 21 days. After obtaining fundus pictures, the animal was killed and eyes were enucleated for histology as de- scribed.

# 4. Result and Discussion

## 4.1. Unbiased (No Biased) of Semiconductor Diode

If a given material, the doping is not uniform then at one place a large number of charge carriers exist while at other places a small number of charge carrier's exist. In a high charge carrier concentration area, all charge carriers are of similar type, either electrons or holes and hence start repelling each other. Due to this charge carriers start moving from high concentration areas towards low concentration areas, to achieve uniform concentration all over the material. In a case of p-n junction, on the n-side there is a large number of electrons while on p-side electrons are minority in number. Therefore, there is high concentration of electrons on the n-side while low concentration of electrons on p-side. Hence diffusion starts and electrons start moving from n-Side toward p-side. Similarly, the holes from p-side diffuse across the junction into the n-region [8].

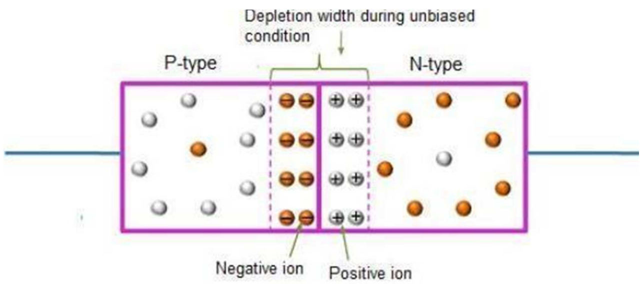


*Figure 8. Unbiased semiconductor diode [3].*

As holes enter the n-region, they find the number of donor atoms. The holes recombine with the donor atoms. as donor atoms accept additional holes, they become positively charged immobile ions. This happens immediately when holes across the junction. Hence positively charged immobile ions get formed near the junction on the n-side. Atoms on the p side are acceptor atoms. The electrons diffusing from n side to p-side are combined with the acceptor atoms on p side. as acceptor atoms accept additional electrons; they become negatively charged immobile ions. Such large numbers of negatively charged immobile ions get formed near the junction on p-Side [8].

When it comes to thermal equilibrium, in the region near the junction there exists a wall of negative immobile charges on p-side and a wall of positive immobile charges on n side. In this region there are no charge carriers. Such a region is depleted of the free mobile charge carriers and hence called depletion region or depletion layer. Due to immobile positive charge on n side and negative charge on p-side there exists an electric field across the junction [8]. The direction of the induced electric field will cause the resulting force to repel the diffusion of holes from the p- region and the diffusion of electrons from the n-region. Thermal equilibrium occurs when the force produced by the electric field and the "force" produced by the density gradient exactly balance. The positively charged region and the negatively charged region comprise the space- charge region, or depletion region, of the p-n junction, in which there are essentially no mobile electrons or holes. Because of the electric field in the space charge region, there is a potential difference across that region. This potential difference is called barrier potential, it is given by [10].

$$Vb=VT \ln (Na/Nd)$$

Where $V_b$=barrier potential, $V_1 \equiv kT/e$, k = Boltzmann's constant, T=absolute temperature, e=the magnitude of the electronic charge, and Na and Nd are the net acceptor and donor concentrations in the p- and n-regions, respectively. The parameter $V_T$ is called the thermal voltage and is approximately $V_T$=0.026 V at room temperature, T=300K.

Generally, in the absence of an applied bias voltage (unbiased), the net flow of charge in any one direction for a semiconductor diode is zero.

### *4.2. Forward Biased of Semiconductor Diode*

If an external potential of V volts is connected in such a way that the p-region terminal is connected to the positive of the external voltage and the n-region connected to the negative of the external voltage, the biasing condition is called forward biasing. The p-n junction is said to be forward biased [1]. When the p-n junction is forward biased, the applied voltage is greater than the barrier potential. At this time the negative terminal of the battery pushes the free electrons against barrier potential from n-region to p-region. Similarly, the positive terminal pushes the holes from p-region to n-region. Thus, holes get repelled by a positive terminal and cross the junction against the barrier potential. Thus, applied voltage overcomes the barrier potential. This reduces the width of the depletion region [8].

As forward voltage increases, at a particular value the depletion region becomes very much narrow such that a large number of majority charge carriers can cross the junction. The large number of majority carriers constitutes the current called forward current. Once the conduction electrons enter the p-region, they become valence electrons. Then they move from hole to hole towards the positive terminal of the battery. The movement of valence electrons is nothing but movement of holes in opposite direction to that of electrons, in the p-region. So current in the p- region is the movements of holes which are majority carriers. This is the hole current. While a current in the n-region is the movement of free electrons; which are majority carriers. This is the electron current. Hence the overall forward current is due to majority charge carriers. These majority carriers can travel around the closed circuit and a relatively large current flow. The direction of flow of electrons is from negative to positive of the battery. The direction of the conventional current is from positive to negative of the battery [8].

Under the influence of applied forward bias voltage, the free electrons get the energy equivalent to the barrier potential so that they can easily overcome the barrier, which is a sort of hill, and cross the junction. While crossing the junction, the electrons give up the amount of energy equivalent to the barrier potential. This loss of energy produces a voltage drop across the p-n junction which is almost equal to the barrier potential [8-12].

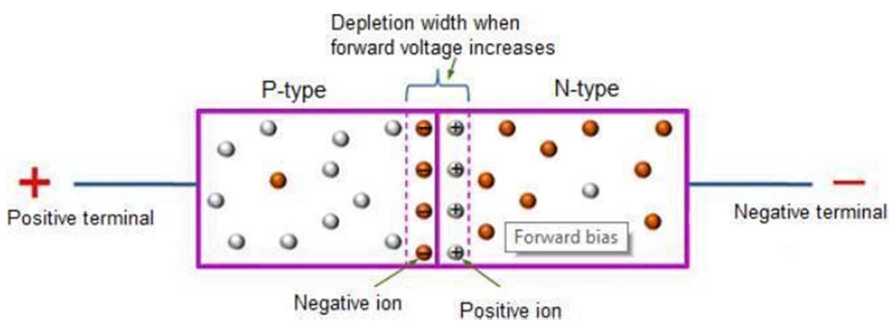


***Figure 9.*** *Forward biased of semiconductor diode [3].*

If a positive voltage $V_D$ is applied to the p-region, the potential barrier decreases. The electric fields in the space-charge region are very large compared to those in the remainder of the p- and n-regions, so essentially all of the applied voltage exists across the p-n junction region. The applied electric field, $E_A$, induced by the applied voltage is in the opposite direction from that of the thermal equilibrium space-charge Electric field. However, the net electric field is always from the n- to the p-region. The net result is that the electric field in the space-charge region is lower than the equilibrium value. This upsets the delicate balance between diffusion and the Electric field force. Majority carrier electrons from the n-region diffuse into the p-region, and majority carrier holes from the p-region diffuse into the n-region. The process continues as long as the voltage $V_D$ is applied, thus creating a current in the p-n junction [13].

### *4.3. Reverse bias of Semiconductor Diode*

If an external potential of V volts is applied across the p-n junction such that the positive terminal is connected to the n - type material and the negative terminal is connected to the p - type material. The biasing condition is called reverse biasing. The p-n junction is said to be reverse biased [1].

When the p-n junction is biased the negative terminal attracts the holes in the p-region, away from the junction. The positive terminal attracts the free electrons in the n-region away from the junction. No charge carrier cross to the junction. Electrons and holes both move away from the junction, the depletion region widens. This creates more positive ions and hence more positive charge in the n-region and more negative ions and hence more negative charge in the p-region. This is because applied voltage helps the barrier potential [8]. As the depletion region widens, barrier potential across the junction also increases. However, this process cannot continue for a long time. In the steady state, majority current ceases as holes and electrons stop moving away from the junction. Due to increased barrier potential, the positive side drags the electron from p-region towards the positive battery. The electron on the p-side and holes on the n-side are minority charge carriers, which constitute the current in reverse biased condition. Thus, the reverse condition takes place [1].

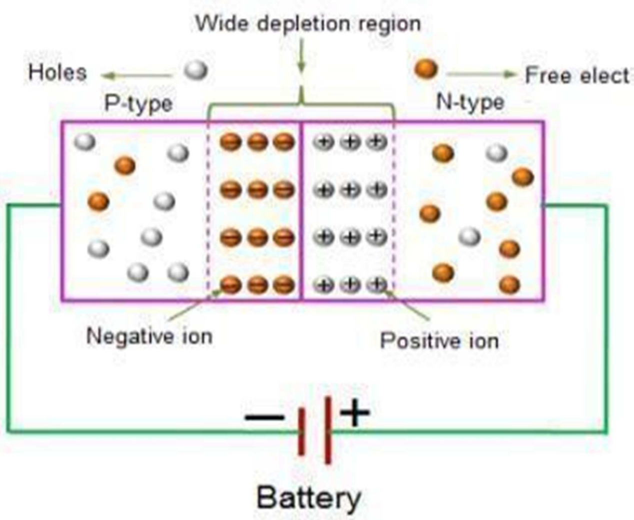


***Figure 10.*** *Reverse biased of semiconductor diode [3].*

The reverse current flows due to minority charge carriers which are small in number. Hence reverse current is always very small. The generation of minority charge carriers depends on the temperature and not on the applied reverse bias voltage and not on the reverse voltage applied. For a constant temperature, the current is almost constant though reverse voltage increases up to a certain limit. Hence it is called reverse saturation current [8].

If the positive voltage is applied to the n-region of a p-n junction, the applied voltage $V_D$ induces an applied electric field, $E_A$, in the semiconductor. The direction of this applied field is the same as that of the Electric field in the space-charge region. The magnitude of the electric field in the space-charge region increases above the thermal equilibrium value. This increased electric field holds back the holes in the p-region and the electrons in the n-region, so there is essentially no current across the p-n junction [13].

### *4.4. Application of Semiconductor Diode*

#### *4.4.1. Photodiode*

The photo diode is a semiconductor p-n junction device whose region of operation is limited to the reverse biased region. The figure below shows the symbol of photodiode [13].


***Figure 11.*** *Symbol for photodiode [13].*

A photodiode is a type of photo detector capable of converting light into either current or voltage, depending upon the mode of operation. The common, traditional solar cell used to generate electric solar power is a large area photodiode. A photodiode is designed to operate in reverse bias. The depletion region width is large. Under normal conditions it carries small reverse current due to minority charge carriers. When light is incident through a glass window on the p-n junction, photons in the light bombard the p-n junction and some energy is imparted to the valence electrons, so, valence electrons break covalent bonds and become free electrons. Thus, more electron-hole pairs are generated. Thus, the total number of minority charge carriers increases and hence reverse current increases. This is the basic principle of operation of photodiodes [13].

When the P-N junction is reverse-biased, a reverse saturation current flows due to thermally generated holes and electrons being swept across the junction as the minority carriers. With the increase in temperature of the junction more and more hole-electron pairs are created and so the reverse saturation current Io increases. The same effect can be had by illuminating the junction. When light energy bombards a P-N junction, it dislodges valence electrons.

The more light striking the junction the larger the reverse current in a diode. It is due to generation of more and more charge carriers with the increase in level of illumination. The dark current is the current that exists when no light is incident. It is to be noted here that current becomes zero only with a positive applied bias equal to VQ. The almost equal spacing between the curves for the same increment in luminous flux reveals that their verse saturation current Io increases linearly with the luminous flux. Increase in reverse voltage does not increase the reverse current significantly, because all available charge carriers are already being swept across the junction. For reducing the reverse saturation current Io to zero, it is necessary to forward bias the junction by an amount equal to barrier potential. Thus, the photodiode can be used as a photoconductive device [13].

On removal of reverse bias applied across the photodiode, minority charge carriers continue to be swept across the junction while the diode is illuminated. This has the effect of increasing the concentration of holes in the P-side and that of electrons in the N-side but the barrier potential is negative on the P-side and positive on the N-side, and was created by holes flowing from P to N- side and electrons from N to P-side during fabrication of junction. Thus, the flow of minority carriers tends to reduce the barrier potential [13].

When an external circuit is connected across the diode terminals, the minority carrier; return to the original side via the external circuit. The electrons which crossed the junction from P to N- side now flow out through the N-terminal and into the P-terminal This means that the device is behaving as a voltage cell with the N-side being the negative terminal and the P-side the positive terminal. Thus, the photodiode is & photovoltaic device as well as a photoconductive device [13].

#### *4.4.2. Light Emitting Diode*

The increasing use of digital displays in calculators, watches, and all forms of instrumentation has contributed to an extensive interest in structures that emit light when properly biased. The two types in common use to perform this function are the light-emitting diode (LED) and the liquid-crystal display (LCD) [1]. Since the LED falls within the family of p – n junction devices, we have to see in this study.

A light-emitting diode (LED) is the inverse of a photodiode; that is, a current is converted into an optical signal. If the diode is forward biased, electrons and holes are injected across the space charge region, where they become excess minority carriers. These excess minority carriers diffuse into the neutral n- and p-regions, where they recombine with majority carriers, and the recombination can result in the emission of a photon [1].

LEDs are fabricated from compound semiconductor materials, such as gallium arsenide or gallium arsenide phosphate. These materials are direct-band gap semiconductors. Because these materials have higher band gap energies than silicon, the forward-bias junction voltage is larger than that in silicon-based diodes [13]. In Si and Ge diodes the greater percentage of the energy converted during recombination at the junction is dissipated in the form of heat within the structure, and the emitted light is insignificant. For this reason, silicon and germanium are not used in the construction of LED devices [1].

The basic construction of an LED appears in Figure 3. with the standard symbol used for the device. The external metallic conducting surface connected to the p-type material is smaller to permit the emergence of the maximum number of photons of light energy when the device is forward-biased. Note in the figure that the recombination of the injected carriers due to the forward-biased junction results in emitted light at the site of the recombination [12].

Even though the light is not visible, infrared (invisible) LEDs have numerous applications where visible light is not a desirable effect. These include security systems, industrial processing, optical coupling, safety controls such as on garage door openers, and in-home entertainment centers, where the infrared light of the remote control is the controlling element [13].

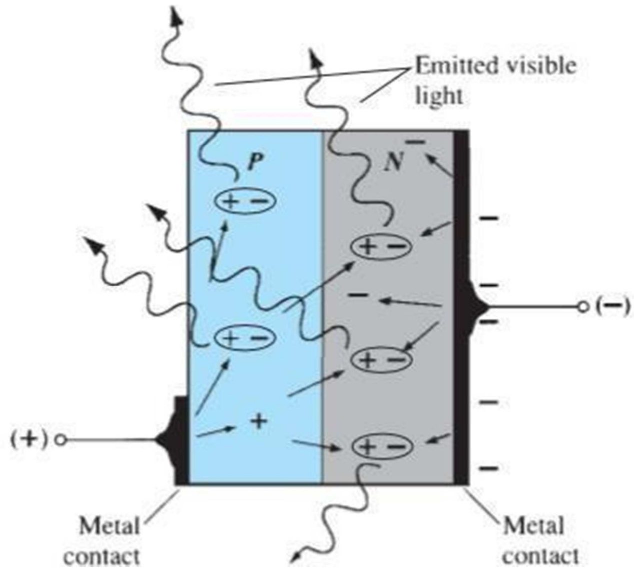


***Figure 12.*** *Process of electroluminescence in the LED [1].*

## 5. Conclusion and Recommendation

### *5.1. Conclusions*

This paper study makes a contribution to the literature on conceptual understanding of important concepts in physics. Specifically, it focuses on electronics. Based on our discussion, the following conclusions can be made; Semiconductor diodes are active devices which are extremely important for various electrical and electronic circuits. In the absence of a bias voltage (unbiased voltage) across the diode, the net flow of charge in one direction is zero. When an external potential of V volts is applied across the p-n junction such that the positive terminal is connected to the n- type material and the negative terminal is connected to the p-type, then we say that the P-N junction is reverse-biased and the following happens: The external voltage creates an electric field which enhances the barrier potential and the depletion region becomes wider since the majority carriers are pulled away from the junction. When an external potential of V volts is applied across the p-n junction such that the positive terminal is connected to the p- type material and the negative terminal is connected to the n-type, then we say that the P-N junction is forward-biased and the following happens: The external voltage creates an electric field which opposes the barrier potential and the depletion region becomes smaller provided it is larger than the voltage barrier of the depletion region. The simplest semiconductor component, the diode, has an astonishing number of applications that are enabled by a number of practical and unique types of diodes that are vital in modern electronics. One of the applications of the diode are photodiodes. Photodiodes are used in consumer electronics devices such as compact disc players, smoke detectors, and the receivers for remote controls in televisions. The second one is LED (light emitting diode) that has many applications, used in the homes and industries, used in motorcycles and cars, used in mobile phones to display the message, used for projector Light Sources and used at the traffic light signals.

### *5.2. Recommendations*

Semiconductor diode is the current useful finding for research in order to compute with modernization. For better and more valuable study, we would like to recommend students who want to study about semiconductor diodes and its applications and our department.

1) For students who want to study semiconductor diodes and its application, they can use this study as an initial study. This research is just an introduction which needs more explanation and new researchers must have done their best to come up with something new and more simplified.
2) Studying a semiconductor diode is not a simple process rather it needs deep intention. For this case sufficient time should be given for the researchers on this topic.

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