Diode as a Rectifier

Objectives

After going through this module, the learners will be able to:

- Understand the meaning, construction and working of a rectifier
- Distinguish between half wave and full wave rectifier
- Know about special diodes, their construction, working and application
    - Photo Diode
    - Solar Cells
    - Light Emitting Diode

Content Outline

- Unit Syllabus
- Module Wise Distribution of Unit Syllabus
- Words you must know
- Introduction
- *p-n* Junction Diodes as a Rectifier
- Rectifier in Our Daily Life
- Special Diode
- Solar Energy the Future
- Summary

Unit Syllabus

Unit-09: Electronic Devices

Chapter-14: Semiconductor electronic material, devices and simple circuits

- Energy bands in conductors, semiconductors and insulators (qualitative only)
- Semiconductors: intrinsic and extrinsic
- Semiconductor diode - IV characteristics in forward and reverse bias, application of diode as a rectifier
- Special purpose *p-n* diodes LED, photodiode, solar cell and Zener diode and their characteristics, Zener diode as a voltage regulator
- Junction transistor, transistor action, characteristics of a transistor and transistor as amplifier common emitter configuration

- Basic idea of Analog and digital signal, logic gates OR, AND, NOR, NOT, NAND

Keeping the needs of state boards in mind we have not changed the content

Module Wise Distribution of Unit Syllabus - 10 Modules

Module 1	• Energy bands in solids • Forbidden gap • Fermi level • Energy bands in conductors, semiconductors and insulators
Module 2	• Uniqueness of semiconductors • Charge carriers in semiconductors electrons and holes • Intrinsic semiconductors • Extrinsic semiconductors *p* and *n* type • Why are *p* and *n* type semiconductors neutral?
Module 3	• *p-n* junction diode • Potential barrier • Depletion layer • Characteristics of p-n junction diode • Forward and reverse bias, knee voltage, magnitude of bias voltages • To draw the IV characteristics curve for a p-n junction in forward bias and reverse bias
Module 4	• Application of diode • Rectifier meaning and need of such a devise • Half wave and full wave rectifier • Rectifier in our homes • Special purpose diode ○ LED ○ Photodiode ○ Solar cells • Solar panels and future of energy

Module 5	• To identify a diode, an LED, a resistor and a capacitor
	• Use a multimeter to
	  ○ See the unidirectional flow of current in case of a diode and an LED
	  ○ Check whether a given diode is in working order

Module 6	• Zener diode • Characteristics of Zener diode • To draw the characteristic curve of a Zener diode and to determine its reverse breakdown voltage • How is a Zener diode different from other diodes? • Zener diode as a voltage regulator • Working of a Zener diode • Zener diodes in our homes

Module 7	• Junction transistor
	• design of the transistor
	• *n-p-n* and *p-n-p*
	• Use a multimeter to
	  ○ Identify base of transistor
	  ○ Distinguish between *n-p-n* and *p-n-p* type transistor
	  ○ Check whether a given electronic component (e.g. diode, transistor or IC) is in working order
	• Transistor action
	• Characteristics of a transistor, *n-p-n* -common emitter

Module 8	• Understanding transistor characteristics and its applications • To study the characteristics of a common emitter *n-p-n* and *p-n-p* transistor and to find the values of current and voltage gains. • Transistor as switch • Transistor as amplifier

Module 9	• Transistor as an amplifier • Circuit diagram and understanding bias • Input and output waveforms • Phase change
Module 10	• Analog signals • Logic gates • Truth tables • OR gate • AND gate • NOT gate • NAND gate • NOR gate

Module 4

Words You Must Know

- **Conductors:** These are the materials which conduct electricity easily. They have a very large number of free electrons.
- **Insulators:** These are the materials which do not conduct electricity because they do not have free electrons.
- **Semiconductors:** These are the materials for which electrical conductivity value is less than conductors but more than insulators. The conductivities of semiconductors are highly temperature sensitive.
- **Energy Level:** As per Bohr's theory electrons revolve around the nucleus only in some specific orbits called stationary orbits. Energy of electrons in these orbits is constant. These orbits are termed as energy levels.
- **Valence Bands:** This band comprises energy of valence electrons. Electrons of this band do not contribute to conduction of electric current.
- **Conduction Band:** This band corresponds to energy of free electrons. Electrons of this band are responsible for conduction of electric current.
- **Forbidden Energy Gap (E_g):** It is the minimum energy required to take an electron from valence band to conduction band. Insulators have highest E_g and conductors have least E_g.

- **Intrinsic Semiconductors:** These are pure semiconductors without any impurity. They show very small electrical conductivity at room temperature.
- **Doping:** It is the deliberate and controlled addition of impurities in intrinsic semiconductors to enhance their electrical conductivity in a controlled manner.
- **Extrinsic Semiconductors:** Semiconductors to which impurities are added to increase conductivity are known as extrinsic semiconductors or impurity semiconductors.
- **Dopant:** Two types of dopants used in doping the tetravalent Si or Ge element:
  - Pentavalent dopants (valency 5); like Arsenic (As), Antimony (Sb), Phosphorous (P), etc.
  - Trivalent dopants (valency 3); like Indium (In), Boron (B), Aluminium (Al), etc.
- ***p*-Type Semiconductors:** These are formed by doping elements like Si and Ge with trivalent atoms.
- ***n*-Type Semiconductors:** These are formed by doping elements like Si and Ge with pentavalent atoms.
- ***p-n* Junction:** A p-n junction is a boundary, or interface between the two types of semiconductors, (*p*-type and *n*-type), inside a single crystal.
- **Diffusion Current:** Holes diffuse from p-side to n-side ($p \to n$) and electrons diffuse from *n*-side to *p*-side ($n \to p$).
- **Potential Barrier:** Initially both the sides were electrically neutral. Now, because of diffusion of electrons and the holes, there are immobilised additional ions on both the sides.

  From the *n*-side, electrons have diffused to p-side, so there are positive immobile ions on the *n*-side, from the p-side, holes have diffused to the n-side, so there are negative immobile ions on the p side. These immobile ions near the junction create a potential difference across the junction.
- **Drift Current:** Due to the positive space-charge region on the *n*-side of the junction, and negative space charge region on the *p*-side of the junction, an electric field, directed from positive charge towards negative charge develops.
  - Due to this field, an electron on the *p*-side of the junction moves to the *n*-side and a hole on the *n*-side of the junction moves to p-side.
  - The motion of charge carriers due to the electric field is called drift.

A drift current, which is opposite in direction to the diffusion current, is set up.

- **Forward Bias:** When an external voltage V is applied across a semiconductor diode such that p-side is connected to the positive terminal of the battery and n-side to the negative terminal it is said to be forward biased.
- **Reverse Bias:** The positive terminal of the battery is connected to the n-side of the semiconductor and negative terminal is connected to the p-side. This way of connecting a diode with a battery is called **Reverse Biasing**.

Characteristics of a *p-n* Junction Diode

When a bias is placed across a conductor, its characteristic curves show the dependence of current on voltage placed across the conductor.

Knee Voltage: The special value of forward voltage beyond which the current increases with increase in the voltage is known as the knee Voltage.

Dynamic Resistance of a Junction Diode: The I-V characteristics of a *p-n* junction diode during forward /reverse biasing) is not a straight line. We therefore cannot have a unique (constant) value for the resistance of the diode. We can, however use the basic definition of resistance

$$resistance = \frac{change\ in\ potential\ difference}{corresponding\ change\ in\ current}$$

We can use it to define

Dynamic resistance of a junction diode (for a particular value of the applied /current flowing) is defined as the ratio of small change in the applied potential across the diode to the corresponding small change in the junction current.

$$dynamic\ resistance = \frac{\Delta V}{\Delta I}$$

Introduction

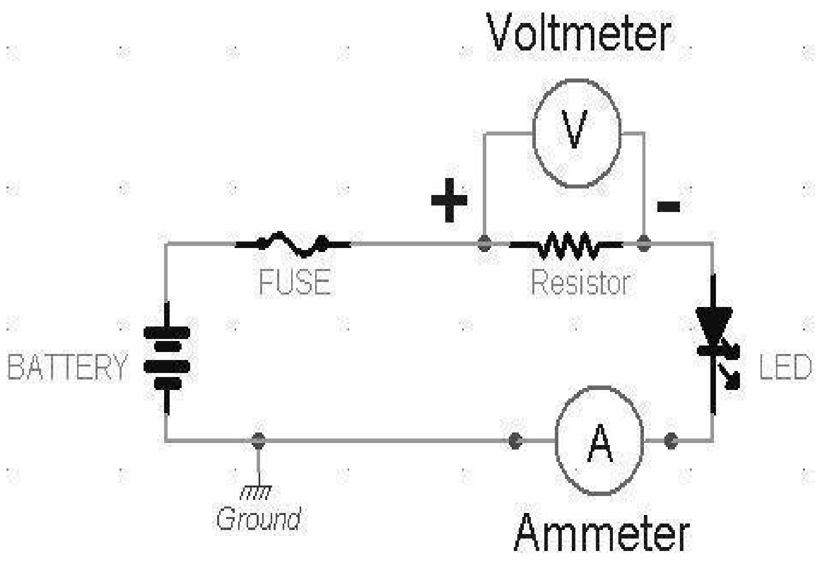
We know that the current in a circuit, connected to a (dc) battery flows in one direction only. However, when an AC source is used the current changes in magnitude and direction of flow in a regular and periodic way.

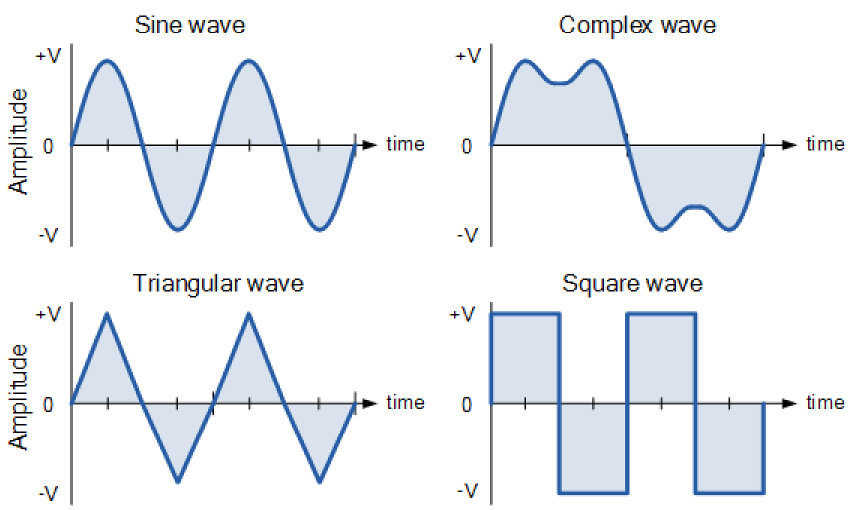
Suppose we have a device that can ensure that the current in a circuit flows in one direction only even when an AC voltage source is being used in the circuit.

From **the V-I characteristic of a junction diode** we see that it allows current to pass only when it is forward biased. So if an alternating voltage is applied across a diode the current flows only in that part of the cycle when the diode is forward biased. The current in the circuit therefore flows in one direction only. The diode can ensure that even with an AC voltage source, the current in the circuit flows in one direction. The p-n junction diode can act as a rectifier.This property is used to rectify alternating voltages and the circuit used for this purpose is called a rectifier.

Alternating Voltage Varies Sinusoidally With Time

Some of the ac voltage signals are shown for specific ac voltages. You must observe the periodicity, the variation in magnitude and direction for each of the waves shown.





A semiconductor device like the diode finds multiple uses in modern electronic systems. Diode allows the current to flow through only in one direction; hence it can act as a one-way switch. A diode can be connected to an external source, either in forward bias or in reverse bias mode. When connected in forward bias the diode conducts and in reverse bias it acts as an open switch. The application areas of a diode are in communication systems where they are used in modulators, gates, and in power supplies as rectifiers and inverters. You will learn about these in subsequent modules of this unit

They also find applications in **solar cells, as photodiodes, as indicator LED** etc. Here we are going to discuss these various types of diodes and their uses.

p-n Junction Diode as a Rectifier

A rectifier as we have said earlier is a device which converts an alternating current (AC) into a direct current (DC).

We can use a p-n junction diode as a rectifier in two ways:

- **A half wave rectifier**
- **A full wave rectifier**

Half Wave Rectifier

The figure below shows a half wave rectifier.A single diode is used.

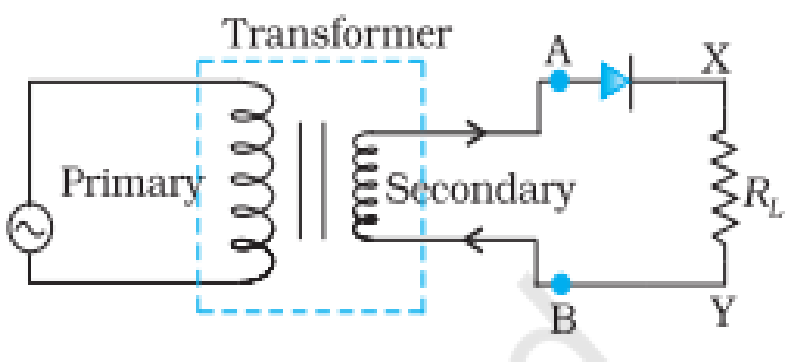
Observe The Circuit

It uses

- **A step-down transformer**
- **A single diode**
- **A load resistance R_L.**

The primary coil of the transformer is connected to the ac voltage to be rectified.

Working



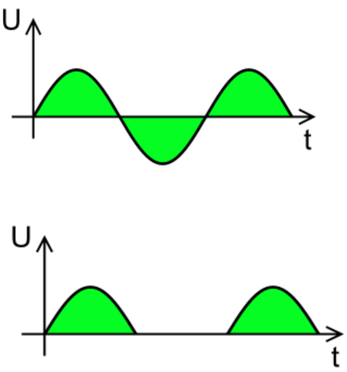
Circuit for Half-Wave Rectifier

As seen in the circuit, an AC potential is applied at the primary coil of the step down transformer and at the secondary coil the diode is connected as shown in the circuit. The n-side of the diode is connected to the load resistance, across which the output is taken.

For the input AC, point A may be taken as the reference point of zero potential and point B a variable AC potential is there. During **one half cycle of the input AC would be forward biased and the current will flow through the load resistance**. Hence there would be a varying voltage across the load resistance.

During the negative half cycle, **the potential at B becomes less than potential at A, so the diode is reverse biased and it offers high resistance to the flow of current and thus there is no output across the load resistance**. The input and output voltage is plotted as shown in the diagram.

Input means what is fed to the rectifier, here in the primary of the transformer.Output is the voltage across the load resistance



As the output just has the wave in one half of the cycle, this type of rectifier is called half wave rectifier.

The secondary coil of a transformer supplies the desired ac voltage across terminals A and B. When the voltage at A is positive, the diode is forward biased and it conducts. When A is negative, the diode is reverse-biased and it does not conduct.

In the next positive half-cycle, again we get the output voltage. Thus, the output voltage, though still varying, is restricted to only one direction and is said to be rectified. Since the rectified output of this circuit is only for half of the input ac wave it is called as **half-wave rectifier**

Important to Note That

- Why do we use the transformer?

  This is to keep the voltages across the diode low enough according to its specifications

- Can we convert 220 V AC into 220-volt DC with the help of a diode?

  No, it would burn at such high voltages considering the characteristic curves of a p-n junction diode from module 3 of this unit.
- **What about the reverse saturation current?**

  The reverse saturation current of a diode is negligible and can be considered equal to zero for practical purposes.
- **What precaution must be taken to save the diode from reverse breakdown?**

  The reverse breakdown voltage of the diode must be sufficiently higher than the peak ac voltage at the secondary of the transformer to protect the diode from reverse breakdown.
- **How is the output taken from the circuit?**

  In the positive half-cycle of ac there is a current through the load resistor R_L and a potential difference develops across it. This potential difference is the output voltage. Whereas there is no current in the negative half cycle. And there is no output voltage.

- **What is R_L?**

  The output voltage in actual practice will be used to operate some device.

  The general name given to this device operating through the output voltage is the load

  Hence, we talk of the output voltage as the voltage across a load resistance (impedance)

  Its value is selected as per the circuit requirement.

Full Wave Rectifier

Basics Circuit Components

- **A step-down centre tapped transformer**
- **A single diode**
- **A load resistance R_L.**

Principle

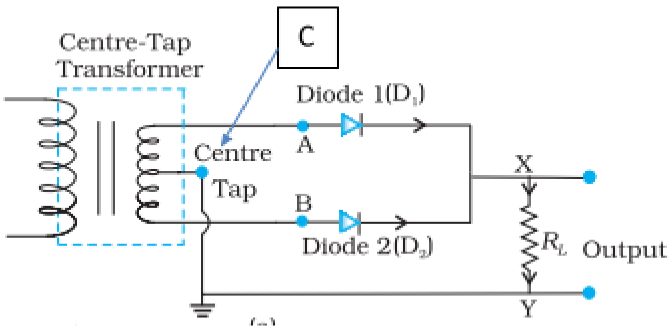
The two diodes can give output rectified voltage corresponding to both the positive as well as negative half of the ac cycle. Hence, this circuit is known as a **full-wave rectifier.**

Here the p-side of the two diodes is connected to the two ends of the secondary of a specially designed transformer. The transformer has two terminals at the two ends of its secondary coil and a spaced third terminal at the centre (or mid-point) of its secondary coil. It is therefore known as a **center tapped transformer.**

The n-side of the diodes is connected together, and the output is taken between this common point of diodes and the midpoint of the secondary of the transformer.

So for a full-wave rectifier the secondary of the transformer is provided with a centre tapping and so it is called **centre-tapped transformer**.

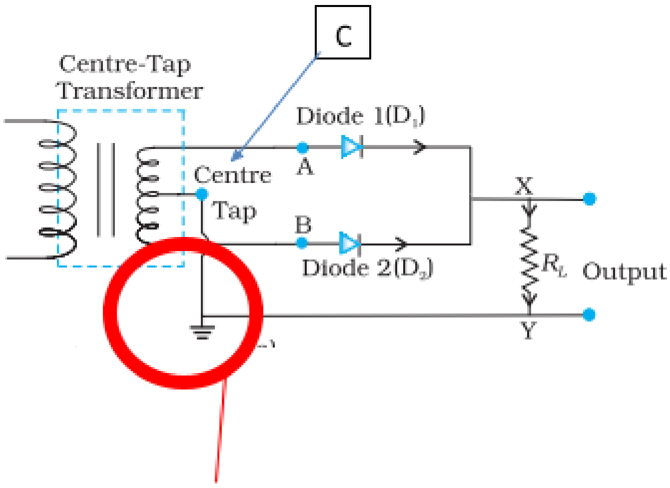
A full wave rectification can be achieved by using two diodes in an arrangement as shown in the circuit diagram:

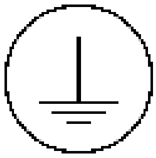


Circuit for full-wave rectifier

Working

The potential at the secondary of the transformer, in the positive half cycle, is such that potential at A is greater than that at C, which in turn is greater than the potential at B. Thus the diode D_1 is forward biased and the diode D_2 is reversed biased. The forward current flows through the diode and through the load resistance in the direction shown.





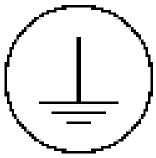
What is this sign?

We know that potential by itself is not a well-defined unique quantity. It is the potential difference that is uniquely defined and we can assign definite values to it. We therefore need a reference point (level), to which the potential value is arbitrarily assigned the value zero. This may be the point at infinity or the earth itself.

In electronic circuits, it is not always necessary to use earth itself as the reference level or zero level for potential. We can, as per our convenience, select any suitable point as the reference (or zero potential) level.

For a given circuit, it is conventional to call that reference or zero potential level as the earth point for that circuit.

The sign



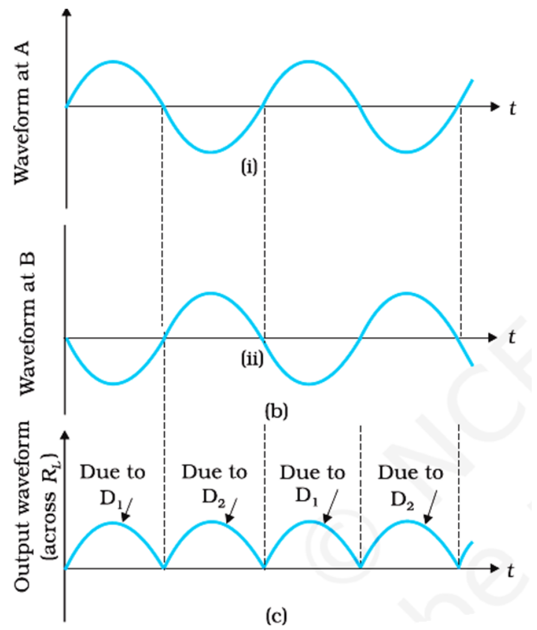
is to say that the point is connected to the least potential or the earth for the given circuit.

During the negative half cycle potential at C is greater than B which in turn is greater than that at A. Thus the diode D_2 becomes forward biased and diode D_1 gets reverse biased.

D_2 conducts and a forward current flows through it and also through the load resistance in the same direction as in the positive half cycle of the input.

The current therefore flows through the load resistance during both the positive as well as the negative half cycles of the input AC voltage. Further it flows in the same direction throughout.

An output waveform obtained is as shown.



- **A Full-wave rectifier circuit;**
- **Input waveforms given to the diode D_1 at A and to the diode D_2 at B;**
- **Output waveform across the load R_L connected in the full-wave rectifier circuit.**

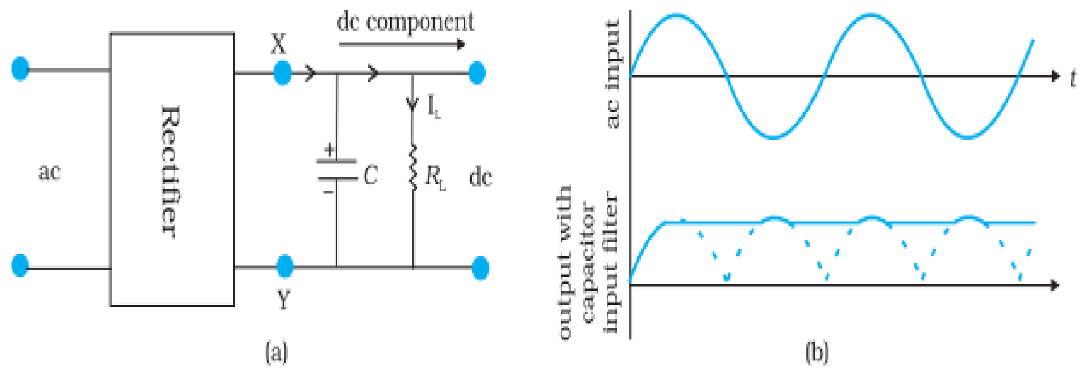
The output voltage is a **unidirectional rippled DC**.

Filter Circuit The ripples in the DC can be reduced by allowing the output to pass through a filter circuit.

The simplest of the **filter circuit** is a capacitor connected across the output of a rectifier but before the load resistance. A capacitor offers negligible reactance to the flow of AC components, which is therefore bypassed through it.

The remaining or the filtered DC components then drop across the load resistance and appear as almost DC output.

The RC filter is shown in the schematic diagram below



The efficiency of a rectifier is given by:

$$\eta = \frac{output\ power}{input\ power} \times 100\%$$

The output wave of a full wave rectifier has twice the frequency as that of the input wave. This is so because the output repeats itself in half the time period of the input wave.

Rectifier in Our Daily Life

A rectifier is a device that converts a periodically reversing AC into DC which flows in one direction. The AC switches back and forth, but its biggest advantage is that it can be transmitted over a long distance without much loss.

The following list gives examples of some of the situations in which we use full wave rectifier circuits to obtain a DC through a given load

- A key advantage of DC is that it is easy to store in batteries, hence the portable devices electronics like flashlights, cell phones, laptops uses DC power. The black box that we see connected to a cord as in laptop charger or phone charger is actually a rectifier!!

- DC is better suited for devices that need little power available all the time.
- Motion sensing outdoor lights use DC hence use a rectifier.
- Cordless phones have a charging station that use a rectifier as the phone would need a DC source to charge.
- Phone message machines use rectifiers.
- Remote control doorbells use rectifiers as they also work on DC.
- Rechargeable Shaver chargers uses rectifiers for charging.
- Flashlight battery recharger uses 12V DC, again it's a rectifier which is at work to convert AC into DC.

Special Diode

In the section, we shall discuss some devices which are basically junction diodes but are developed for different applications.

We have seen so far, how a semiconductor diode behaves under applied electrical inputs.

To create an e-h(electron and hole) pair, we spend some energy (photo-excitation, thermal excitation, etc.). Therefore, when an electron and hole recombine the energy is released in the form of light (radiative recombination) or heat (non-radiative recombination). It depends on the type of semiconductor and the method of fabrication of the p-n junction. For the fabrication of LEDs, semiconductors like GaAs, GaAsP are used in which radiative recombination dominates.

Now, we learn about semiconductor diodes in which carriers are generated by photons (photo-excitation).

All such devices are called **optoelectronic devices**. We shall study the functioning of the following optoelectronic devices:

- **Photodiodes used for detecting optical signals (photodetectors).**
- **Light emitting diodes (LED) which convert electrical energy into light.**
- **Photovoltaic devices which convert optical radiation into electricity (solar cells)**

p-n **junction diode as a photodiode**

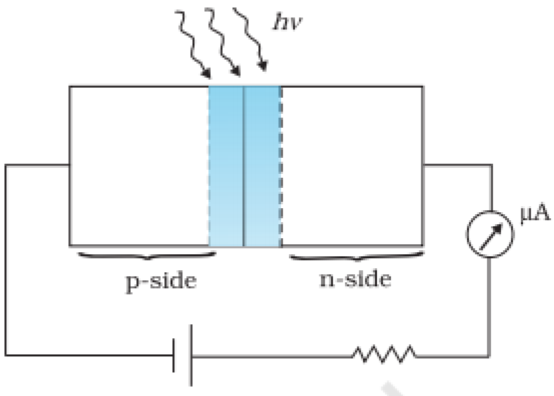
A photodiode is a diode which can convert light energy into electrical energy.It is also referred to as a photodetector, photo sensor or light detector. Photodiodes are specially designed diodes which are normally used under reverse bias conditions.

A reverse potential increases the depletion layer of the diodes also there is a small reverse current that flows. The external reverse voltage will supply energy to the minority charge carriers but doesn't increase their numbers significantly.

To increase the number of charge carriers, in a photodiode, external light energy is directly supplied to the junction of the diode.

If the light photon energy of the incident light is greater than the band gap of the semiconductor, the valence electrons gain energy and break free from their atoms, creating electron-hole pairs.

The electrons thus generated move quickly towards the n side because of the barrier potential and the external field. Due to the same reason the hole moves towards the p type semiconductor. As a result of the strong field the minority carriers generated in the depletion region will gain higher drift velocity and will cross the junction before they recombine with atoms.



Thus the minority current increases. When no light falls on the photodiode, small reverse current flows through the diode due to the external reverse potential being applied, this small reverse current is known as **the dark current.**

The electric current generated due to the application of light is known as the **photo current.**

- **Why is the photocurrent independent of reverse bias potential?**

The photo current is almost independent of the reverse potential (because the electrons-holes pair generated due to the reverse potential recombine quickly in the n and p sides)and it mainly depend upon the light intensity.

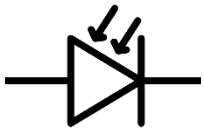
- **What would happen if we increase the light intensity?**

Increase in light intensity increases the number of photons incident on the junction. Hence the number of charge carriers generated increases, this in turn increases the photo current.

- **Why is the photo diode used in reverse bias?**

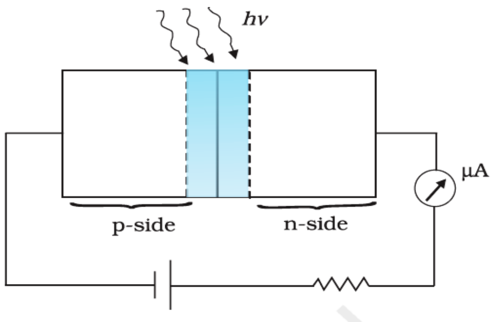
The photodiode is used in reverse bias because in reverse bias the change in reverse current can be easily measured in terms of change in light intensity, this is so because they are almost proportional and the dark current is very small. The total current through the diode is the sum total of the photo current and the dark current. To increase the sensitivity of the diode, dark current must be reduced.

The symbol, circuit and the graph related to the photodiodes is given below:



symbol

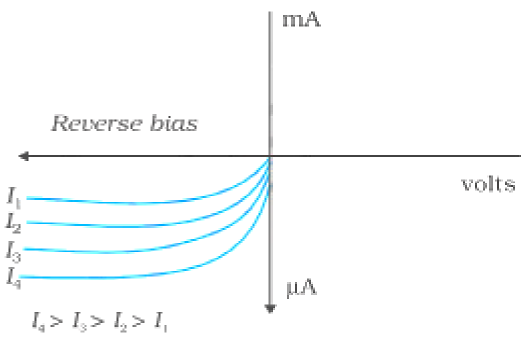
https://upload.wikimedia.org/wikipedia/commons/thumb/2/2b/Photodiode_symbol.svg/2000px-Photodiode_symbol.svg.png



Circuit diagram

I-V characteristics

The increase in reverse saturation current as the intensity of incident light increases.



I-V Characteristics of Photo Diode

The uses of a photodiode are as follows:

- Photodiodes are used in consumer electronics devices such as CD players, smoke detectors, and receivers for infrared remote control devices used to control TV or air conditioners etc.
- Photodiodes are used in switching the lights on or off in street lighting after dark.
- Photodiodes are used in optical communications circuits which couple a photodiode and a LED as a sensor system.
- Photodiodes are used in demodulation of optical signals.
- Photodiodes are used in reading punched cards and tapes.

Example

The current in the forward bias is known to be more (~mA) than the current in the reverse bias (~μA). Then what is the reason to operate the photodiodes in reverse bias?

Solution

Consider the case of an n-type semiconductor. Obviously, the majority carrier density (n) is considerably larger than the minority hole density p (i.e., n >> p). On illumination, let the excess electrons and holes generated be Δn and Δp, respectively: n′ = n + Δn p′ = p + Δp Here n′ and p′ are the electron and hole concentrations at any particular illumination and n and p are carriers concentration values when there is no illumination.

Remember Δn = Δp and n >> p. Hence, the fractional change in the majority carriers (i.e., $\frac{\Delta n}{n}$) would be much less than that in the minority carriers(i.e., $\frac{\Delta p}{p}$).

In general, we can state that the fractional change, due to the photo-effects on the **minority carrier dominated** reverse bias current is more easily measurable than the fractional change in the **majority carrier dominated** forward bias current.

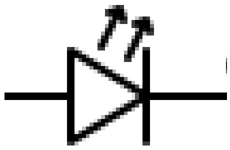
Hence, photodiodes are preferably used in the reverse bias condition for observing variations in light intensity

p-n junction diode as a LED

LED (light emitting diode)

An LED is a **heavily doped p-n junction** diode which emits light radiation under forward bias conditions. Hence**, a Light Emitting Diode is a photo electronic device which converts electrical energy into light energy under forward bias.**

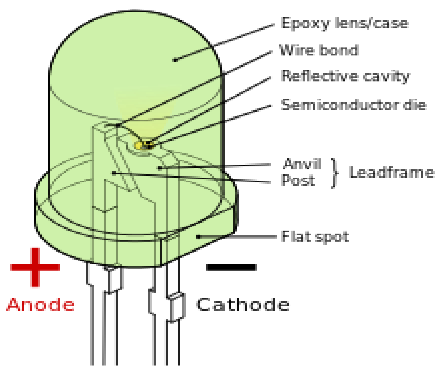
When suitable forward voltage is applied, electrons recombine with holes and release energy in the form of photons. This effect is known as **electroluminescence.** The colour of the light depends upon the band gap of the semiconductor. The symbol for a LED is given below.



https://commons.m.wikimedia.org/wiki/File:LED_symbol.svg#mw-jump-to-license

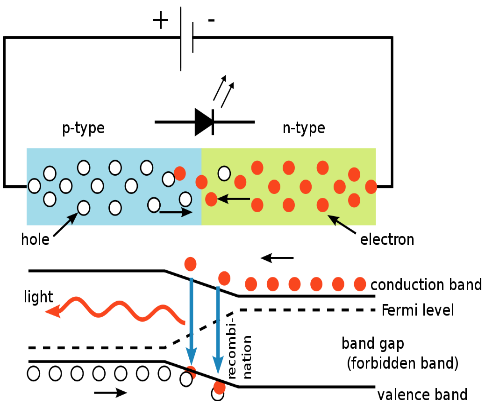
Construction of Led

In a LED, a p type layer is fabricated on top of the n type layer. The p-n junction is enclosed in a transparent, hard, plastic resin, hemispherical shell. The domed shaped shell acts like a lens and concentrates the light being emitted. There are two electrodes, anode wire is kept longer than the cathode, at times there is a notch to identify the anode from a cathode. The schematic diagram of the LED is shown:



https://en.m.wikipedia.org/wiki/Light-emitting_diode

Working Principle



When a LED is Forward Biased

The majority charge carriers, electrons on the n side or holes on the p side start crossing over the junction and the depletion layer decreases.

When the diode is forward biased, electrons are sent from n to p (where they are minority carriers) and holes are sent from p → n (where they are minority carriers). At the junction boundary the concentration of minority carriers increases compared to the equilibrium concentration (i.e., when there is no bias). Thus at the junction boundary on either side of the junction, excess minority carriers are there which recombine with majority carriers near the junction.

On recombination, the energy is released in the form of photons. Photons with energy equal to or slightly less than the band gap are emitted. When the forward current of the diode is small, the intensity of light emitted is small.

As the forward current increases, intensity of light increases and reaches a maximum. Further increase of the forward current results in decrease in the light intensity. Why? LEDs are biased such that the light emitting efficiency is maximum.

V-I Characteristics of LED

The *V-I* characteristics of a LED is similar to that of a Si junction diode. But the threshold voltages are much higher and slightly different for each colour. The reverse breakdown voltages of LEDs are very low, typically around 5V, so care should be taken that the high reverse voltages do not appear across them.

Colour Of Light from a LED

- The electrons crossing over to p-side tend to recombine with the majority holes of the p side and vice-versa for holes crossing over to n side. This recombination is shown in the diagram. As shown in the diagram, the electrons have higher energy levels than the holes, thus every recombination results in energy being released in the form of heat and light.
- This phenomenon of release of light energy in the presence of an electric field is known as **electroluminescence**.
- Another point to remember is that the majority of light produced is near the p junction, so the diode is designed in such a way that this side is kept as close as possible to the surface of the device to ensure maximum amount of light being emitted.
- The photon released has energy nearly equal to the band gap of the semiconductor. $E = hc/\lambda$ or $\lambda = hc/E$
- **LEDs that can emit red, yellow, orange, green and blue light are commercially available**.
- **The semiconductor used for fabrication of visible LEDs must at least have a band gap of 1.8 eV (spectral range of visible light is from about 0.4 µm to 0.7 µm, i.e., from about 3 eV to 1.8 eV).**

The compound semiconductor Gallium Arsenide – Phosphide ($GaAs_{1-x}P_x$) is used for making LEDs of different colours.$GaAs_{0.6}P_{0.4}$ ($E_g \sim 1.9$ eV) is used for red LED. GaAs ($E_g \sim 1.4$ eV) is used for making infrared LED.

These LEDs find extensive use in **remote controls, burglar alarm systems, optical communication**, etc. Extensive research is being done for developing white LEDs which can replace incandescent lamps for household use.

The electrons dissipate energy in different forms depending upon the nature of the semiconductor used. In silicon or germanium diodes the energy dissipates in the form of heat but in materials like gallium phosphide (GaP), gallium arsenide phosphide (GaAsP) or gallium arsenide (GaAs) dissipation of energy takes place in the form of light.

The following is the list of different materials emitting different colours of light

Semiconductor materials	Symbols	Colour
Gallium Arsenide	**GaAs**	**Infra-red**
Gallium Arsenide Phosphide	**GaAsP**	**Red**
Aluminum Gallium Phosphide	**AlGaP**	**Green**
Gallium Indium Nitride	**GaInN**	**Bluish-green and blue**
Indium Gallium Nitride	**InGaN**	**Violet**
Aluminum Gallium Indium Phosphide	**AlGaInP**	**Yellow**

Why should the band gap for the semiconductor used in an LED be at least or nearly 1.8 eV ?

The semiconductor used for fabrication of visible LEDs must at least have a band gap of 1.8 eV (spectral range of visible light is from about 0.4 μm to 0.7 μm, i.e., from about 3 eV to 1.8eV).

Extensive research has been done for developing white LEDs which can replace incandescent lamps. LEDs have the following advantages over conventional incandescent low power lamps:

- **Low operational voltage and less power.**
- **Fast action and no warm-up time required.**
- **The bandwidth of emitted light is 100 Å to 500 Å. In other words, it is nearly (but not exactly) monochromatic.**
- **Long life and ruggedness.**
- **Fast on-off switching capability**

Uses of Light Emitting Diodes

The low energy consumption, low maintenance, small size and low cost of LEDs, makes them highly useful in the following fields:

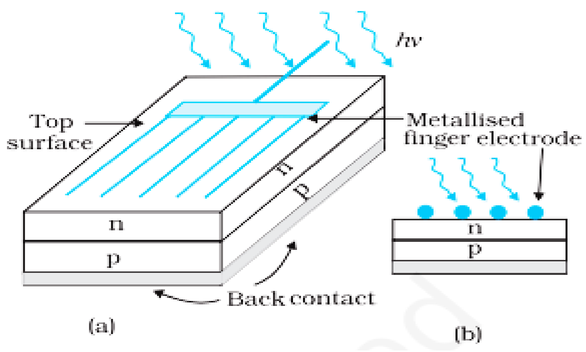
- **In alarm signals, infrared LEDs are used.**
- **In calculators, display sign boards, digital watches, LEDs are used as seven segment display.**
- **In optical communications, the high radiating LEDs are used to give signals through optical fibres.**
- **In optical mouse setups use LEDs as a light source and a light detector like photodiodes to detect the movement relative to a surface.**
- **In traffic lights to illuminate them.**
- **In remote controls to transmit information.**
- ***p-n* Junction Diode as a Solar Cell.**

A Solar Cell

A solar cell is a p-n junction that converts solar energy to electrical energy.

Structure

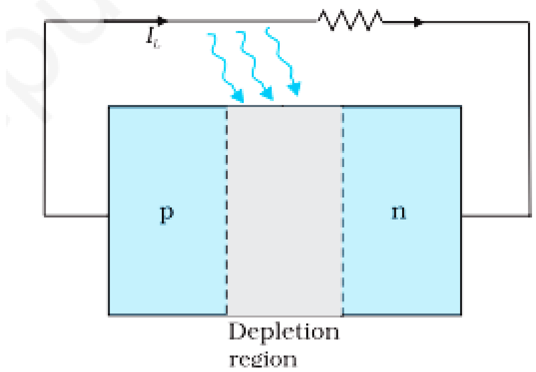
- A solar cell is a p-n junction diode with a large surface area.
- The diode is so fabricated that the p type semiconductor is very thin as compared to the n type semiconductor.
- The whole arrangement is kept in a transparent casing so as to allow the light to fall on the diode.
- The p side forms the top layer of the solar cell and has metal electrodes attached to it, the lower end of the n type layer is also connected to metal contact.



Typical p-n junction solar cell; (b) Cross-sectional view

Working

When the light of energy greater than the energy gap of the diode (that is sunlight) falls on the window, the photons are absorbed by the solar cell and they are able to reach the depletion layer, passing comfortably through the thin *p* layer.



A typical illuminated p-n junction solar cell

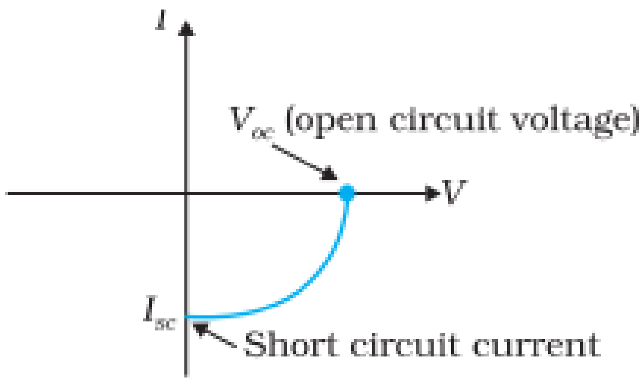
The photons have sufficient energy to dislodge electrons, thus creating electron holes pairs. Due to the electric field across the junction, the electrons are pushed to the n side of the semiconductor and the holes move towards the p side of the semiconductor.

The upper metal contact thus becomes positively charged and the lower metal contact becomes negatively charged.

Thus, when a load is connected across the metal contacts, a current flows through the load.

I-V Characteristics

The I-V graph is shown in the figure.



I-V characteristics of a solar cell

The curve is in the fourth quadrant because current is being drawn from the cell as V is increasing, I also increases, but in the reverse direction.

Solar Cells are Used:

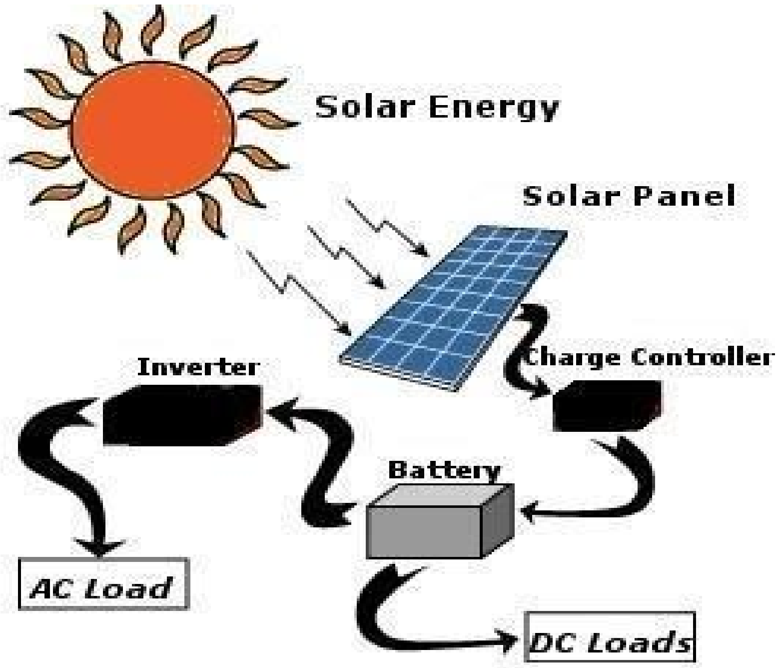
- For charging storage batteries during the day, these can then be used to light up lamps at night. Such arrangements are prevalent in remote areas where the grid cannot supply power.
- For generating electricity, which can operate electric appliances, cook food, pump water, heat water in geysers etc.
- In calculators, wrist watches, traffic lights, etc.
- In satellites as sunlight is in abundance in space.

Solar Energy the Future

Solar energy is light and heat from the Sun that is harnessed using a range of ever-evolving technologies such as solar heating, photovoltaic, solar thermal energy, solar architecture,.
It is an important source of renewable energy and its technologies are broadly characterized on how they capture and distribute solar energy or convert it into solar power. The techniques include the use of photovoltaic systems, concentrated solar power and solar water heating to harness the energy.
https://en.wikipedia.org/wiki/Solar_energy

Read
http://www.seci.gov.in/content/innerpage/statewise-solar-parks.php
see the solar energy parks distributed across India, and learn about the upcoming projects

Solar Panels



http://www.crestchd.org.in/images/PG1.jpg

http://images.indianexpress.com/2015/12/solarpanel-759.jpg

Summary

- *p-n* junction is the 'key' to all semiconductor devices.
- When such a junction is made, a 'depletion layer' is formed consisting of immobile ion-cores devoid of their electrons or holes. This is responsible for a junction potential barrier.
- By changing the external applied voltage, junction barriers can be changed. In forward bias (n-side is connected to the negative terminal of the battery and p-side is connected to the positive), the barrier is decreased while the barrier increases in reverse bias. Hence, forward bias current is more (mA) while it is very small (μA) in a reversed biased p-n junction diode.

- Diodes can be used for rectifying an AC voltage (restricting the ac voltage to one direction). With the help of a capacitor or a suitable filter, a dc voltage can be obtained.
- *p-n* junctions have also been used to obtain many photonic or optoelectronic devices where one of the participating entity is 'photon':
    a. Photodiodes in which photon excitation results in a change of reverse saturation current which helps us to measure light intensity;
    b. Solar cells which convert photon energy into electricity;
    c. Light Emitting Diode and Diode Laser in which electron excitation by a bias voltage results in the generation of light.