Physics of Semiconductor Devices

Introduction

Diodes are made from a single pieced of Semiconductor material which has a positive P-region at one end and a negative N- region at the other, and has a resistivity somewhere between that of a conductor and an insulator. Firstly let's look at what makes something either a Conductor or an insulator.

The electrical resistance of an electrical or electronic component or device is generally defined as being the ratio of the voltage difference across it to the current following through it, as per Ohm's law. The problem with using resistance as a measurement is that it depends very much on the physical size of the material being measured as well as the material out of which it is made. For example, of we were to increase the length of the material (making it longer) its resistance would also increase. Likewise, if we increased its diameter (making it fatter) its resistance would then decrease. So we want to be able to define the material in such a way as to indicate its ability to either conduct or oppose the flow of electrical current through it no matter what its size or shape happens to be. The quantity that is used to indicate this is called resistivity and is generally given the Greek symbol of ρ, (Rho) and is measured in Ohms per metre, (Ω' s/m).

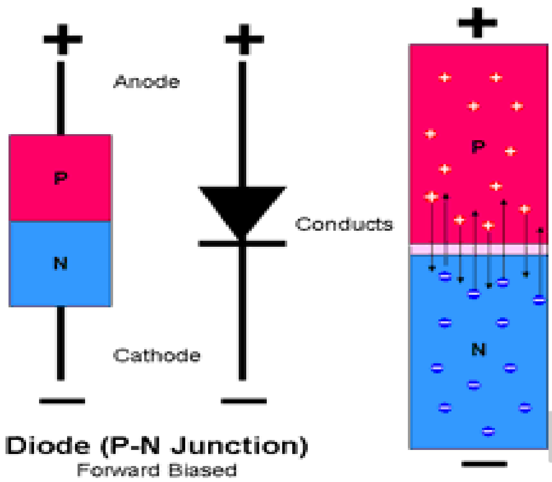
If the resistivity of various materials is compared, they can be classified into three main groups, Conductors, insulators and semi-conductors which we have already discussed in Band theory of solids.

1. Describe about the PN – Junction with the help of suitable figure and how it is useful as diode?

In the previous chapter, semiconductor physics we saw how to make an N-type Semiconductor material by doping it with Antomony and also how to make a P-type Semiconductor material by doping that with Boron. This is all well and good, but these semiconductor N and P –type materials do very little on their own as they are electrically neutral, but when we join (or fuse) together these two materials they behave in a very different way producing what is generally known as a PN-Junction.

When the N and P –type semiconductor materials are first brought together some of the free electrons move across the junction to fill up the holes in the P-type material producing negative ions, but because the electrons have moved they leave behind positive ions on the negative N-side and the holes move across the junction in the opposite direction into the region where there are large numbers of free electrons. This movement of electrons and holes across the junction is known as diffusion. This process continuous until the number of electrons which have crossed the junction have a large enough electrical charge to repel or prevent any more carries from crossing the junction. Eventually a state of equilibrium (electrically neutral situation) will occur producing a potential barrier zone around the area of the junction as the donor atoms repel the holes and the accepter atoms repel the electrons. Since no free charge carries can rest in a position where there is a potential barrier it is therefore depleted of any free mobile carriers, and this area around the junction is now called the depletion layer.

The PN-Junction Diode:



A PN-Junction Diode

As the N-type material has lost electrons and the P – type has lost holes, the N-type material has become positive with respect to the P-type. The external voltage required to overcome this barrier potential that now exist and allow electrons to move freely across the junction is very much dependent upon the type of semiconductor material used and its actual temperature, and for silicon this is about 0.6 – 0.7 volts and for germanium it is about 0.3- 0.35 volts. This potential barrier will always exist even if the device is not connected to any external power surface.

The significance of this built- in potential is that it opposes both the flow of holes and electrons across the junction and is why it is called the potential barrier. In practice, a PN –Junction is formed with in a single crystal of material rather than just simply joining or fusing together two separate pieces. Electrical contents are also fused onto either side of the crystal to enable an electrical connection to be made to an external circuit.

Then the resulting device that has been made is called a PN-Junction diode or rectifier diode. The effect described in the previous topic is achieved with out any external voltage potential being applied to the actual PN-Junction. However, if we were to make electrical connections at the ends of both the N-type and P-type materials and then connect them to a battery in the appropriate direction, depletion layer around the junction can be increased or decreased there by increasing or decreasing the effective resistance of the junction itself. The behavior of the PN-Junction with regards to the potential barrier size produces an asymmetrical conducting device, better known as the junction diode.

2. Define and discuss about zero bias, forward bias and reverse bias I – V Characteristics of p-n junction?

But before we can use the PN-Junction as a practical device or as a rectifying device we need to firstly bias the junction, ie connect a voltage potential across it. On the voltage axis above reverse bias refers to an external voltage potential which increases the potential barrier. An external voltage which decreases the potential barrier is said to act in the forward bias direction.

There are three possible biasing conditions for the standard junction diode and these are:

i. **Zero bias:** No external voltage potential is applied to the PN-junction.

ii. **Reverse bias:** The voltage potential is connected negative,(-ve) to the P-type material and positive, (+ve) to the N-type material across the diode which has effect of increasing the PN-junction width.

iii. **Forward bias:** The voltage connection is connected positive, (+ve) to the P-type material and negative, (-ve) to the N-type material across the diode which has effect of decreasing the PN-junction width.

Zero Bias:

When a diode is connected in a zero bias condition, no external potential energy is applied to the PN-junction. However if the diodes terminals are shorted together, a few holes (majority carriers) in the P-type material with enough energy to overcome the potential barrier will move across the junction against this barrier potential. This is known as the forward current and is referenced as I_F.

Likewise, holes generated in the N-type material (minority carriers), find this situation favorable and move across the junction in the opposite direction. This is known as the reverse current and is referenced as I_R as shown in Fig. 1.

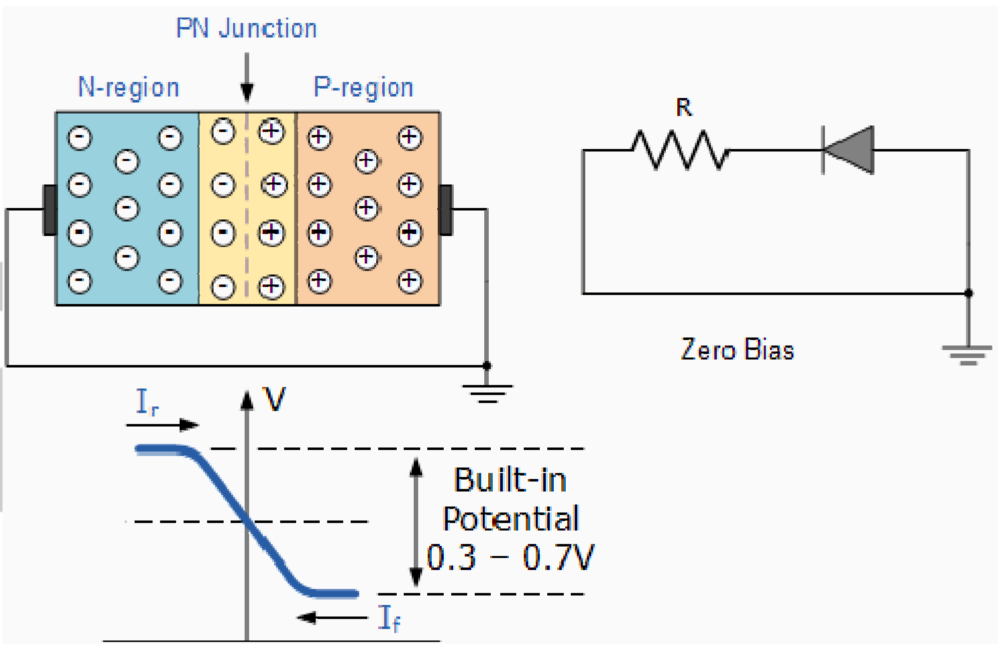


Fig: 1 Zero biased diode.

An equilibrium or balance will be established when the two currents are equal and both moving in opposite directions, so that the net result is zero current following in the circuit. When this occurs the junction is said to be in a state of dynamic equilibrium.

This state of equilibrium can be broken by raising the temperature of the PN-junction causing an increase in the generation of minority carriers, there by resulting in an increase in leakage current.

Reverse Bias:

When a diode is a connected in a reverse bias condition, a positive voltage is applied to the N-type material and a negative voltage is applied to the P-type material. The positive voltage applied to the N- type material attracts electrons towards the positive electrode and away from the junction, while the holes in the p-type end are also attracted away from the junction towards the negative electrode. The net result is that the depletion layer grows wider due to a lack of electrons and holes and presents a high impedance path, almost an insulator. The result is that a high potential barrier is created thus preventing current from flowing through the semiconductor material. (Fig: 2)

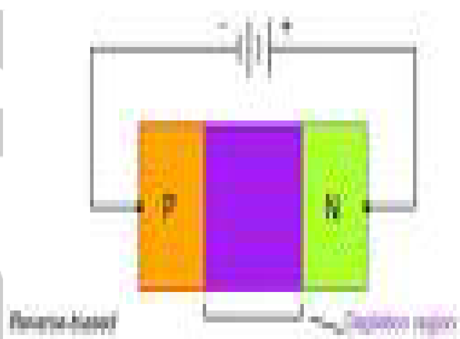


Fig: 2 A Reverse biased junction showing the increase in the depletion layer.

This condition represents the high resistance direction of a PN-junction and practically zero current flows through the diode with an increase in bias voltage. However, a very small leakage current does flow through the junction which can be measured in microamperes, (μA). One final point, if the reverse bias voltage V, applied to the junction is increased to a sufficiently high enough value, it will cause the PN-junction to overhead and fail due to the avalanche effect around the junction. This may cause the diode to become shorted and will result in maximum circuit current to flow, Ohm's law and this shown in Fig. 3 (a) and (b).

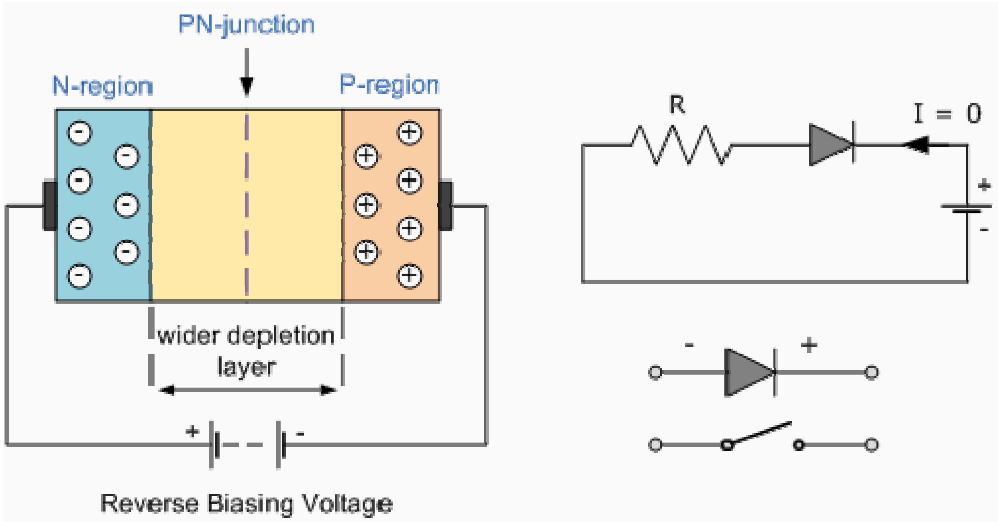


Fig. 3(a). reverse biased p-n junction

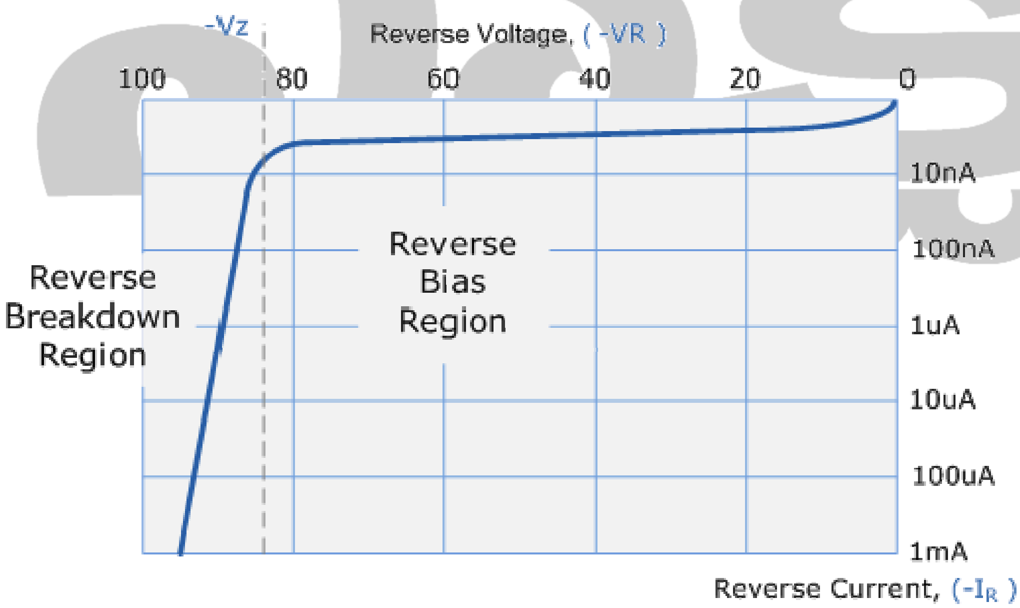


Fig: 3 (b) Reverse characteristics curve for a diode.

Sometimes this avalanche effect has practical applications in voltage stabilizing circuits where a serious limiting resistor is used with the diode to limit this reverse breakdown current to a present maximum value thereby producing a fixed voltage output across the diode. These types of diodes are commonly known as zener diodes.

Forward Bias:

When a diode is connected in a forward bias condition, a negative voltage is applied to the N-type material and a positive voltage is applied to the P-type material. If this external voltage becomes greater than the value of the potential barrier, 0.7 volts for silicon and 0.3 volts for Germanium, the potential barriers opposition will be overcome and current will start to flow as the negative voltage pushes or repels electrons towards the junction giving them the energy to cross over and combine with the holes being pushed in the opposite direction towards the junction by the positive voltages. This results in a characteristics curve if zero current flowing up to this knee voltage and high current flow through the diode with little increase in the external voltage as shown in Fig.4 (a)

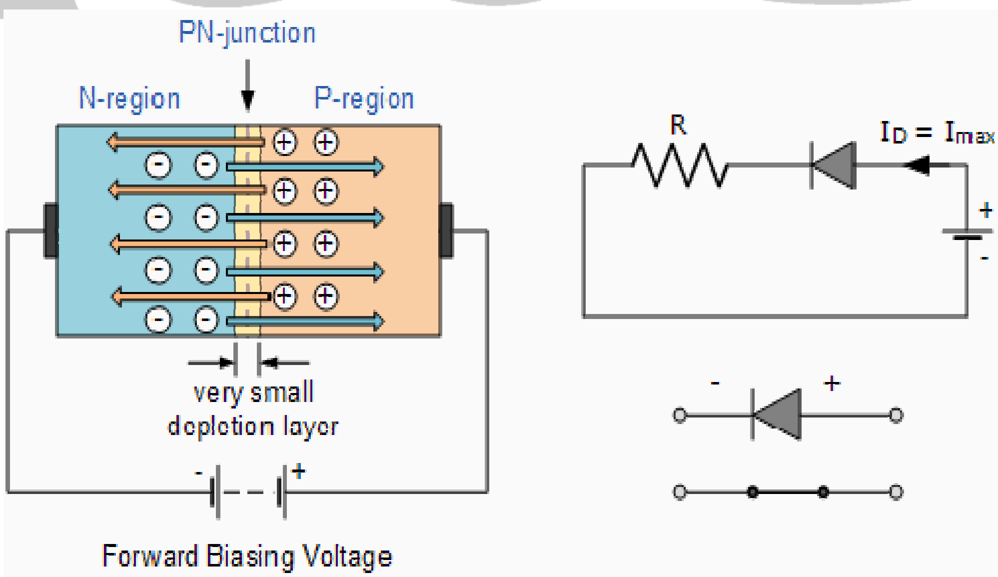


Fig. 4 (a): Forward biased p-n junction

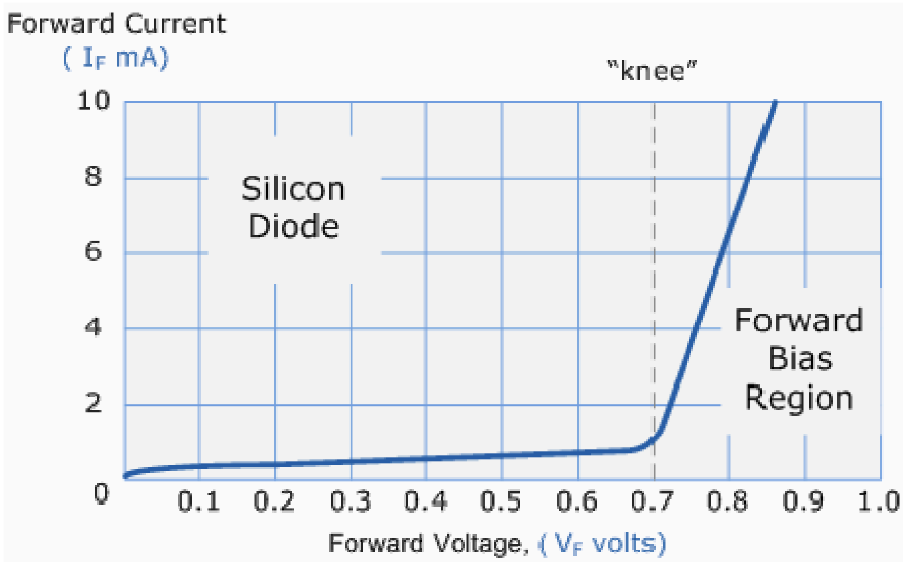


Fig. 4 (b) Forward characteristics curve for a diode.

This results in the depletion layer becoming very thin and narrow and which now represents a low impedance path thereby producing a very small potential barrier and allowing high currents to flow. The point at which this take place is represented on the static I-V characteristics curve above as the knee point.

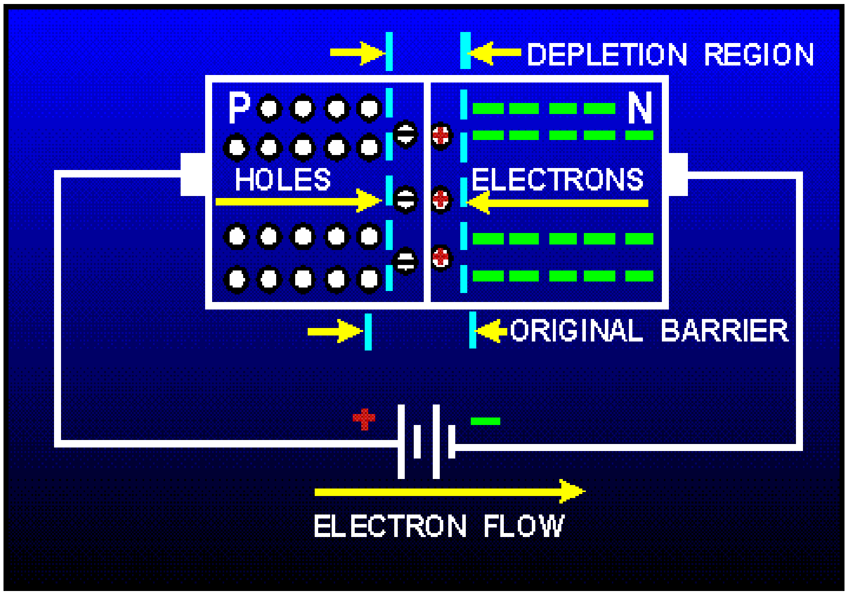


Fig: 5 Forward biased junction diode showing a reduction in the depletion layer.

This condition represents the low resistance direction in a PN-junction allowing very large curries to flow through the diode with only a small increase in bias voltage. The actual potential difference across the junction or diode is kept constant by the action of the depletion layer at about 0.3 v for Germanium and about 0.7v for silicon diodes. Since the diode can conduct infinite current above this knee point as it effectivity becomes a short circuit, resistors are used in series with the device to limit its current flow. Exceeding its maximum forward current specification causes the device to dissipate more power in the form of heat than it was designed for resulting in failure of the device.

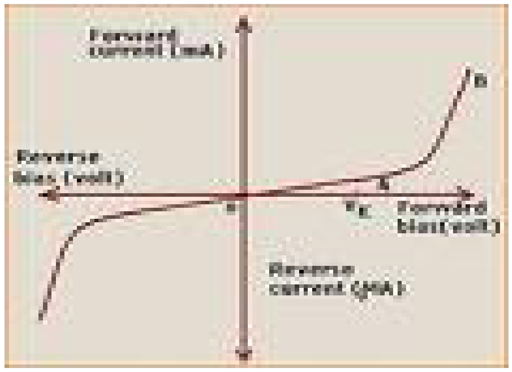


Fig. 6 I-V characteristics of PN junction diode.

Summary:

- Semiconductors contain two types of mobile charge carries, holes and electrons.
- The holes are positively charged while the electrons negatively charged.
- A semiconductor may be doped with donor impurities such as antimony (N-type doping), so that it contains mobile charges which are primary electrons.
- A semiconductor may be doped with a acceptor impurities such as boron (P-type doping), so that it contains mobile charges which are many holes.
- When a diode is zero biased no external energy source is applied and a natural potential barrier is developed across a PN-junction which is about 0.7v for silicon diode and about 0.3v for germanium diodes.
- When a diode is forward biased the PN-junction is reduced and current flows through the diode.
- When a diode is reverse biased the PN-junction is increased and zero current flows. (only a very small leakage current)

3. Describe the action of P-n junction as half wave rectifier?

Half – Wave Rectification:

A rectifier is a circuit which converts alternating current (AC) into a direct current (DC) form and the simplest of all the rectifier circuits is that of the half-wave rectifier. A half-wave rectifier circuit uses just one half of each complete sine wave or cycle of the AC supply in order to convert it to a DC supply. Then this type of circuit is called a half-wave rectifier because it passes only half of the incoming AC power signal as shown in Fig. 12.10.

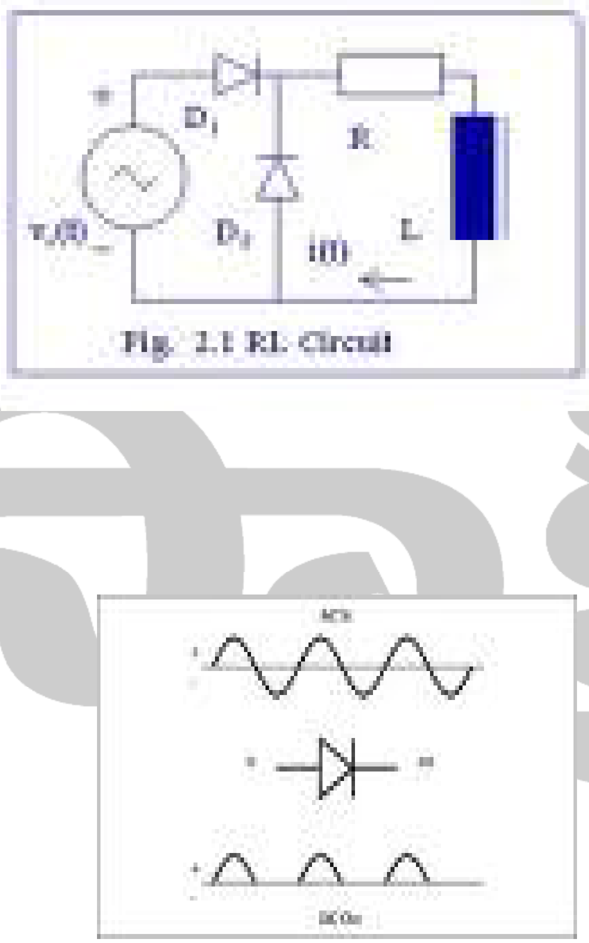


Fig: 1 half-wave rectifier circuit and corresponding wave form

During each positive half cycle of the AC sine wave, the diode is forward biased (Anode is positive with respect to the cathode) and current flows through it. Since the DC load is resistive (resistor R), the current flowing in the load resistor is therefore proportional to the voltage (Ohm's law), and the voltage across the load resistor is the same as the supply voltage, V_s (minus V_f), that is the DC voltage across the load is sinusoidal. For the forst half cycle only. Then $V_{out} = V_s$.

During each negative half cycle of the AC sine wave, the diode is reverse biased (Anode is negative with respect to the cathode) and No current flows though it. Therefore, in the negative half cycle of the supply, no current flows in the load resistor as no voltage appears across it. Then $V_{out} = 0$.

The current on the DC side of the current flows in one direction only making the circuit unidirectional and the value of the DC voltage V_{DC} across the load resistor is calculated as follows.

$$V_{dc} = V_{max} / \prod = 0.318V_{max} = 0.45V_s$$

Where V_{max} is the maximum voltage value of the AC supply, and V_s is the r.m.s value of the supply.

Example No.1:

Calculate the current (I_{DC}) flowing through a 100Ω resistor connected to a 240V single phase half-wave rectifier as shown above, and also the power consumed by the load.

$V_{dc} = 0.45V_s = 0.45 \text{ x } 240 = 108V$

$I_{dx} = V_{dx}/R = 108/100 = 1.08\text{amps}.$

$\text{Power} = I^2R = 1.08^2 \text{ x } 100 = 116 \text{ watts}$

As the voltage across the load resistor is only present during the positive of the cycle, the resultant voltage is ON and OFF during every cycle resulting is a low average DC value. This variation on the rectified waveform is called ripple has a frequency that is equal to that of the AC supply frequency. Very often when rectifying an alternating voltage we wish to produce a steady direct voltage free form any voltage variations or ripple. One way of doing this is to connect a capacitor across the output voltage terminals in parallel with the load resistor as shown below. This type of capacitor is known commonly as a reservoir or smoothing capacitor.

When rectification is used to provide a direct voltage power supply form an alternating source, the amount of ripple can be reduced by using larger value capacitors but there are limits both on cost and size. For a given capacitor value, a greater load current (smaller load resistor) will discharge the capacitor more quickly (RC time constant) and so increase the ripple obtained. Then for single phase, half-wave rectifier circuits it is not very practical to try and reduce the ripple voltage by capacitor smoothing alone so it is more practical to use full-wave rectification.

4. Describe p-n junction as full wave rectifier?

The Full-Wave Rectifier:

In the previous power diodes tutorial we discussed ways of reducing the ripple or voltage variations in a direct DC voltage by connecting capacitors across the load resistance. While this method may be suitable for low power applications it is unsuitable to applications which need a steady and smooth DC supply voltage. One method to improve on this is to use every half-cycle of the input voltage instead of every other half – cycle. The circuit which allows us to do this is called a full – wave rectifier.

In a full-wave rectifier circuit two diodes are now used, together with a transformer whose secondary winding is spilt equally into two and has a common centre tapped connection (C). Now each diode conducts in turn when its anode terminal is positive with respect to the centre point C as shown in Fig. 1.

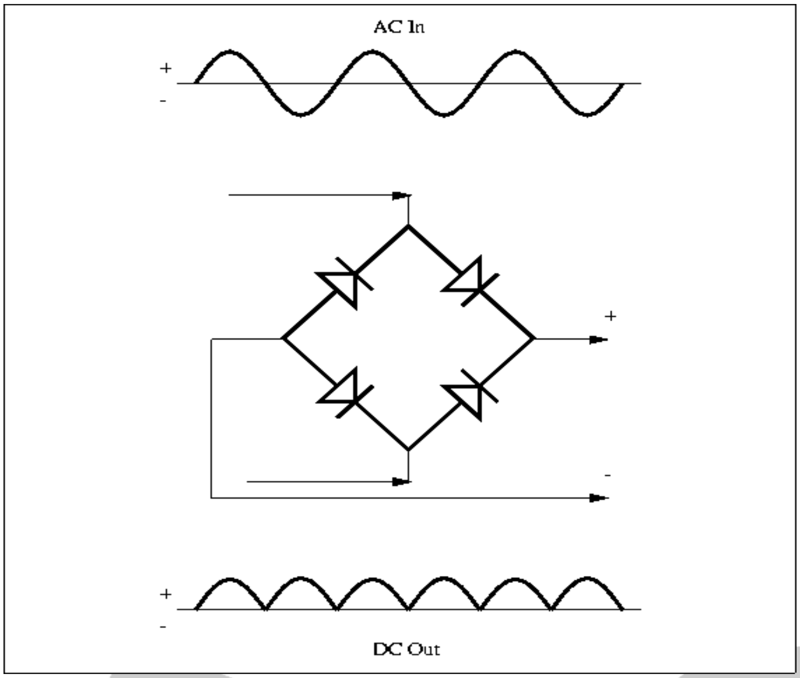


Fig: 1 Full-wave rectifier circuit and corresponding wave forms.

The circuit consists of two h rectifiers connected to a single load resistance with each diode taking it in turn to supply current to the load. When point A is positive with respect to point B, diode D_1 conducts in the forward direction as indicated by the arrows. When point B is positive (in the negative half of the cycle) with respect to point A, diode D_2 conducts in the forward direction and the current flowing through resistor R is in the same direction for both circuits. As the output voltage across the resistor R is the sum of the two waveforms, this type of circuit is also known as a bi-phase circuit.

As the spaces between each half-wave developed by each diode is now being filled in by the other diode the average DC output voltage across the load resistor is now double that of the single half-wave rectifier circuit and is about 0.637 V_{max} of the peak voltage, assuming no losses.

$$V_{dc} = 2V_{max} / \prod = 0.637V_{max} = 0.9V_s$$

The peak voltage of the output waveform is the same as before for the half- wave rectifier provided each half of the transformer windings has the same rms voltage value. To obtain a different d.c. voltage output different transformer ratios can be used, but one main disadvantage of this type of rectifier is that having a larger transformer for a given power output with two separate windings makes this type of circuit costly compared to a bridge rectifier circuit equivalent.

5. Describe the action of p-n junction as the bridge rectifier?

The Bridge Rectifier:

Another type of circuit that produces the same output as a full – wave rectifier is that of the bridge rectifier. This type of single phase rectifier uses 4 individual rectifying diodes connected in a bridged configuration to produce the desired output does not required special centre tapped transformer, thereby reducing its size and cost. The single secondary winding is connected to one side of the diode bridge network and the load to the other side as shown in Fig. 1.

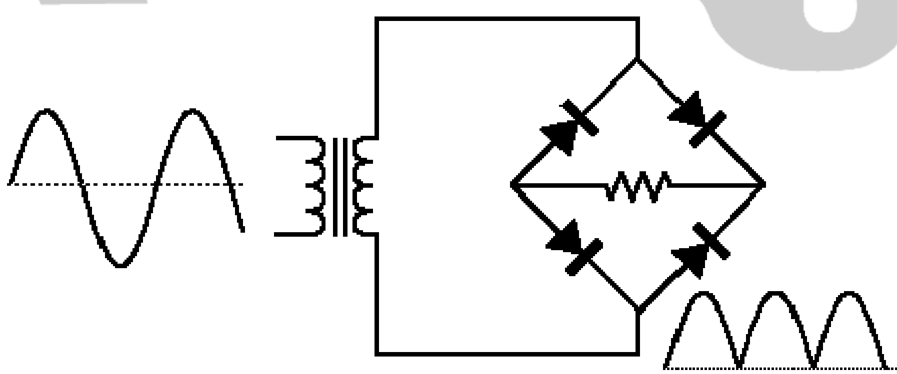
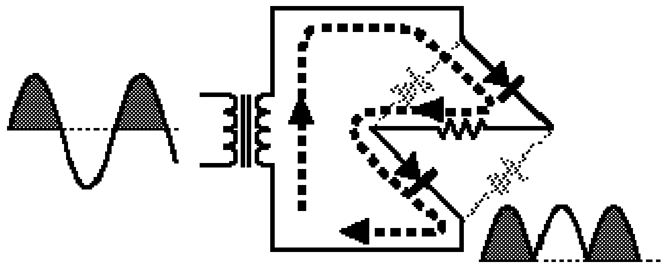
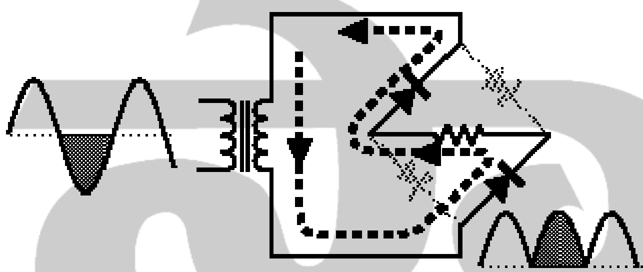


Fig. 1 bridge rectifier and its corresponding input and out put wave form.

Current Flow in the Bridge Rectifier

For both positive and negative swings of the transformer, there is a forward path through the diode bridge. Both conduction paths cause current to flow in the same direction through the load resistor, accomplishing full-wave rectification.





While one set of diodes is forward biased, the other set is reverse biased and effectively eliminated from the circuit

The 4 diodes labeled D_1 and D_4 are arranged in series pairs with only two diodes conducting current during each half cycle. During the positive half cycle of the supply, diodes D_1 and D_2 conduct in series while diodes D_3 and D_4 are reverse biased and the current flows through flow through the load as shown in Fig.1 .

During the negative half cycle of the supply, diodes D_3 and D_4 conduct in series, but diodes D_1 and D_2 switch of as they are now reverse biased. The current flowing through the load is the same direction as before.

As the current flowing through the load is unidirectional, so the voltage developed across the load is also unidirectional the same as for previous two diode full-wave rectifier, therefore the average DC voltage across the load is 0.637 V_{max} and ripple frequency is now twice the supply frequency (e.g. 100Hz for a 50Hz supply).

6. Describe working of light emitting diodes with the help of figures?

Light Emitting Diodes:

Light emitting diodes or LED's are among the most widely used of all the types of diodes available. They are the most visible type of diode, that emits a fairly narrow bandwidth of either visible coloured light, invisible infra –red or laser type light when a forward current is passed through them. A light emitting diode or LED as it is more commonly called, is basically just a specialized type of PN-junction diode, made from a very thin layer of fairly heavily doped semiconductor material. When the diode is Forward Biased, electrons from the semiconductors conduction band combine with holes from the valence band, releasing sufficient energy to produce photons of light. Because of this thin layer a reasonable number of these photons can leave the junction and radiate away producing a problem light output.

Unlike normal diodes which are made for direction or power rectification, and which are generally made from either Germanium of Silicon semiconductors material, light emitting diodes are made from compound type semiconductor materials such as Gallium Arsenide (GaAs), Gallium Phosphide (GAP), Gallium arsenide Phosphide (GaAsP), silicon Carbide (SiC) or Gallium Indian Nitride (GalnN). The exact choice of the semiconductor material used will determine the overall wavelength of the photon light emissions and therefore the resulting colour of the light emitted, as in the case of the visible light coloured LEDs, (RED, AMBER, GREEN etc.).

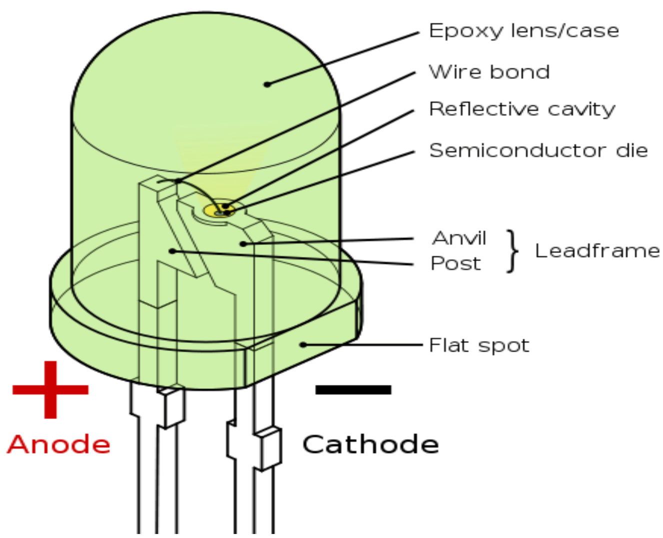


Fig. 1 Diagrams of light emitting diodes

From the above table we can see that the main P-type dopant used in the manufacture of light emitting diodes is gallium (Ga, atomic number 31) and the main N-type dopant used is arsenic (as, atomic number 33) giving the resulting gallium arsenide (GaAs) crystal structure, which has the characteristics of radiating significant amounts of infrared radiation from its junction when a forward current is flowing through it. By also adding phosphorus (P, atomic number 15), as a third dopant the overall wavelength of the emitted radiation is reduced to give visible red light to the human eye. Further refinements in the doping process of the PN-junction have resulted in a range of colours available from red, orange and amber through to yellow, and the recently developed blue LED which is achieved by injecting nitrogen atoms into the crystal structure during the doping process.

Light Emitting Diodes I-V Characteristics:

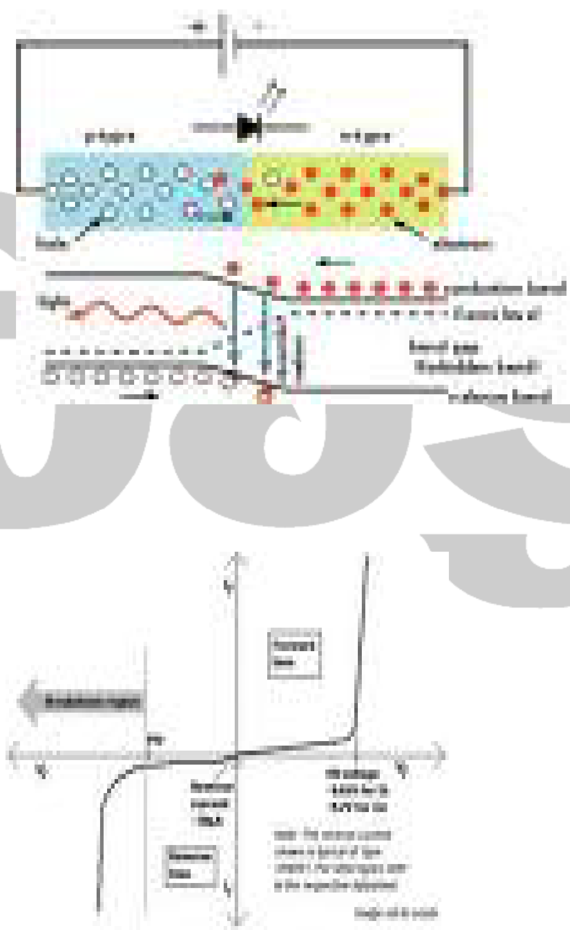


Fig:1 Light Emitting Diode (LED) I-V characteristics curves and corresponding circuit diagram

Before a light emitting diode can “emit” any from of light it needs a current to flow through it, as it is a current dependent device. As the LED is to be connected in a forward bias condition across a power supply it should be current limited using a series resistor to protect it from excessive current flow. From the table above we can see that each LED has its own forward voltage drop across the PN-junction and this parameter which is determined by the semiconductor material used is the forward voltage drop for a given amount of forward conduction current, typically for a forward current of 20mA. In most cases LEDs are operated from a low voltage DC supply, with a series resistor to limit the forward current to a suitable value from say 5mA for a simple Led indicator to 30mA or more where a high brightness light output is needed.

7. Explain the principle and wording of light emitting diodes?

As well as individual colour or multi colour LEDs, light emitting diodes can be combined together in a single package to produce displays such as bargraphs, strips, arrays and 7-segment displays. A 7-segment Led display provides a very convenient way of displaying information or digital data in the form of numbers, letters or even alpha-numerical characters and as their name suggests, they sonsists of 7 individual LEDs (the segments), with in one single display package. In order to produce the required numbers or characters from 0 to 9 and A to F respectively, on the display the corrent combination of LED segments need to be illuminated. A standard 7- segment LED display generally has 8 input connections, one for each LED segment and one that acts as a common terminal or connection for all the internal segments.

There are two important types of 7 – segment LED digital display.(Fig. 1)

The common cathode display (CCD)

In the common cathode display, all the cathode connections of the LEDs are joined together and the individual segments are illuminated by application of a HIGH, logic “1” signal.

The Common Anode Disply (CAD)

In the common anode display, all the anode connections of the LEDs are joined together and the individual segments are illuminated by connecting the terminals to a LOW, logic “0” signal.

Fig: 1 Typical display of LEDs

8. Describe the working of photodiodes?

A photodiode is a optimized to produce an electron current flow in response to irradiation by ultraviolet, visible, or infrared light. Silicon is most often used to fabricate photodiodes; through, germanium and gallium arsenide can be used. The junction through which light centers the semiconductor must be thin enough to pass most of the light on to the active region (depletion region) where light is converted to electron hole pairs.

Fig.1. shows cross section of photodiode. The P-type layer needs to be thin to pass as much light as possible. A heavy N+ diffusion on the back of the wafer makes contact with metallization. The top metallization may be a fine grid of metallic fingers in the top of the wafer for large cells. In small photodiodes, the top contact might be a bond wire contacting the bare P-type silicon top.

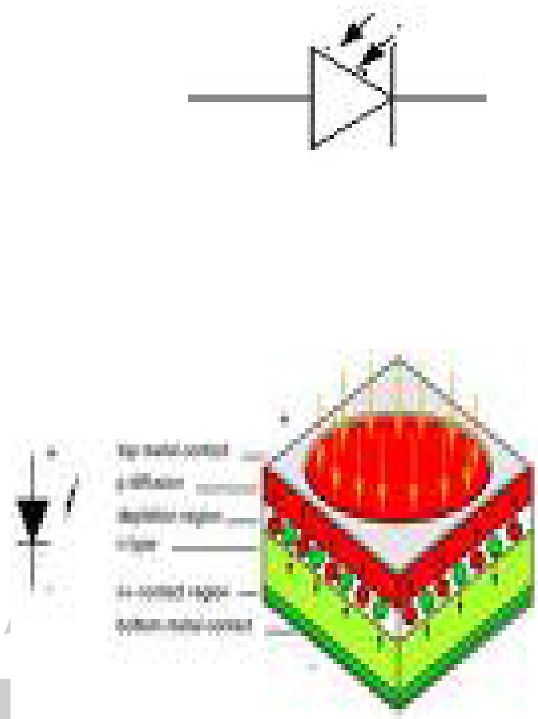


Fig: 1 Photodiode: schematic symbol and cross section

Light entering the top of the photo diode stack fall of exponentially in with depth the silicon. A thin top P-type layer allows most photons to pass into the depletion region where electron – hole pairs are formed. The electric field across the depletion region due to the built in diode potential causes electrons to the swept in to the N-layer, holes into the P-layer. Actually electron holes pairs may be formed in any of the semiconductor region however those formed in the depletion region are most likely to be separated in to the respective N and P- regions. Many of the electron – hole pairs formed in the P and N-region recombine. Only a few do so in the depletion region. Thus, a few electron- hole pair in the N and P-regions, and most in the depletion region contribute to photo current, that current resulting from light falling on the photo diode.

The voltage out of a photo diode may be observed. Operation in this photovoltaic (PV) mode is linear over a large dynamic range, though it is sensitive and has low noise at frequencies less than 100khz. The preddered mode of operation is often photo current (PC) mode because the current is linearly proportional to light flux over several decades of intensity, and higher frequency response can be achieved. PC mode is achieved with reverse bias or zero bias on the photo diode. A current amplifier (trnasimpedance amplifier) should be sued with a photo diode in PC mode. Linearity and PC mode are achieved as long as the diode does not become forward biased.

High speed operation is often required of photodiodes, as opposed to solar cells. Speed is a function of diode capacitance, which can be minimized by decreasing cell area . Thus, sensor for a high speed fiber optic link will use an area no larger than necessary, say 1 mm Capacitance may also be decreased by increasing the thickness of the depletion region, in the manufacturing process or by increasing the reverse bias on the diode.

9. Discuss about PIN and avalanche diodes in detail with the help of diagrams?

The p-i-n diode or PIN diode is a photodiode with an intrinsic layer between the P and N-regions as in Fig. 1 The p-Intrinsic-N structure increases the distance between the P and N conductive layers, decreasing capacitance, increasing speed. The volume of the photo sensitive region also increases, enhancing conversion efficiency. The bandwidth can extend to 10's of gHz. PIN photodiodes are the preferred for high sensitivity and high speed at moderate cost.

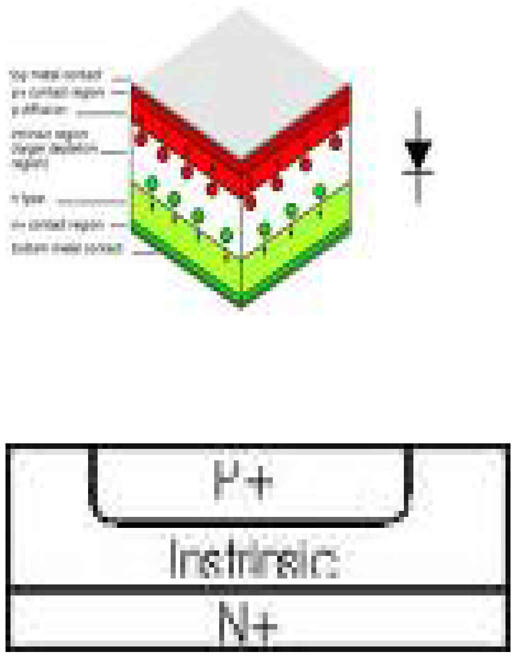
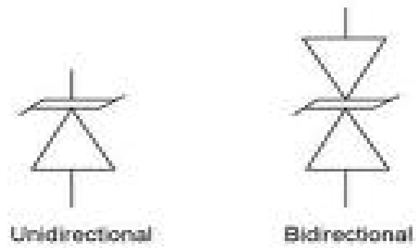
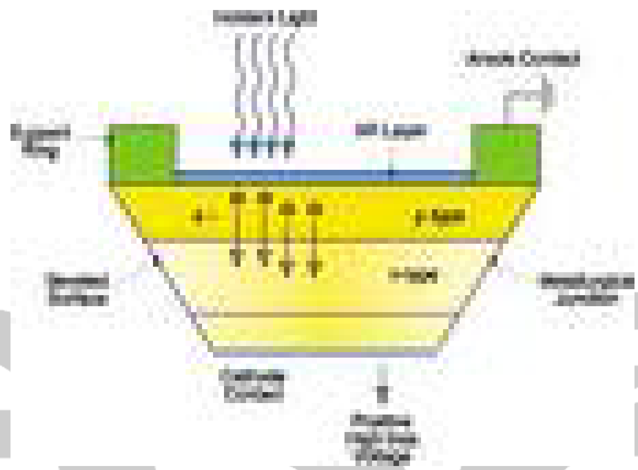


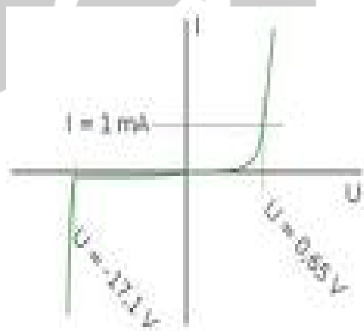
Fig. 1 PIN photodiode: The intrinsic region increases the thickness of the depletion region.

Avalanche photo diode

An avalanche photodiode (APD) designed to operate at high reverse bias exhibits an electron multiplier effect analogous to a photomultiplier tube. The reverse bias can run from 10’s of volts nearly 2000V. the high level of reverse bias accelerates photon created electron-hole pairs in the intrinsic region to a high enough velocity to free additional carries from collisions with the crystal lactic. Thus many electrons for photon result. The motivation for the APD is to achieve amplification within the photo diode to overcome noise to external amplifiers. This works to some extent. However, the APD creates noise of its own. At high speed the APD is superior PIN diode amplifier combination, though not for low speed amplifications. APD’s are expensive, roughly the price of a photomultiplier tube. So, they are only competitive with PIN photodiodes for niche applications. One such application is single photon counting as applied to nuclear physics. Fig 1 shows the symbol, cross section and I-V characteristic of avalanche diode


Unidirectional
Bidirectional


Incident Light
Anode Contact
Cathode Contact


I
I = 1 mA
U
U = 0.55 V
U = -17.1 V

10. Write short notes about Liquid crystal displays?

Liquid Crystal Display

An LCD or Liquid Crystal Display is a flat, thin display device consisting of any number of pixels aligned in front of a reflector or source of light. The LCD has been widely hail as a prized invention as it is relatively cheap and it consumes less power to function the competing technologies, making it almost indispensable in battery powered electron devices. Fig. 1 shows typical liquid crystal display.

i. Types of LCDs

LCDs are broadly classified as either Transmissive or reflective, depending upon the positive of their source of light. A transmissive LCD is illuminated by a light source from the base and is viewed from the front. Such LCDs are used in applications where high luminal levels are required, such as computer displays, personal digital assistance televisions, and mobile phones.

On the other hand, reflective LCDs, usually found in digital displays of watches and calculators, are illuminated by an external light, which in turn is reflected back by a diffusing reflector located behind the display. As the light has to pass twice through the liquid crystal layer, it is attenuated twice and hence reflective LCDs produce darker blacks than its transmissive counterparts. But, since the same attenuating phenomenon, to an extent, happens in the translucent part of the liquid crystal layer as well, the contrast of the display image will be less than a transmissive LCD.

In terms of power consumption, reflective LCDs, due to the absence of an artificial light source, are more power efficient than their transmissive counterparts.

There are now LCDs, which combine the basic features of both transmissive and reflective LCDs. They are called transflective LCDs and they operate transmissively or reflectively depending upon the ambient light conditions.

ii. Principle of LCD displays

This is the basic architecture of a pixel in a LCD: A pixel is made up of a column of liquid crystal molecules, hung between two electrodes (transparent ones) and two polarizing filers, the axes of polarity of which are at 90 degrees to each other. The arrangement of these polarization filters is such that without any liquid crystal existing between them, the light traveling through one would be stopped by the other. The presence of liquid crystals changes the polarization of light entering one crystal, enabling it to pass through the other. This is the basic principle of the working of LCDs.

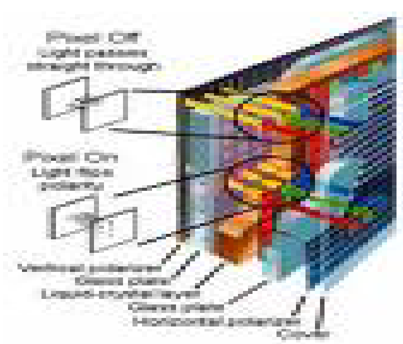
What makes the liquid crystal polarize the light rays passing through it? It all happens at a molecular level. The liquid crystal molecules are electrically charged, and on application of an electric field to each transparent electrode over each pixel/sub pixel, the molecules are twisted on their axes by the electrostatic force. This changes the polarization of the light passing through the crystal, allowing only certain degrees of light to make its way through the polarization filters.

When an electric field is applied to the transparent electrodes attached to a pixel, the liquid crystal molecules will align themselves parallel to the applied field, thus limiting the polarization of the entering light. If the liquid crystal molecules are completely untwisted, the light making its way through them will be polarized at 90 degrees to the second filter, thereby completely blocking it from escaping. In other words, the LCD will appear unlit. Therefore, by controlling the alignment of liquid crystal molecules in a pixel, it is possible to vary the amount of light passing through it, thereby illuminating it accordingly.

iii. Colours in LCDs:

In colour liquid crystals, each pixel is further classified into in to a number of sub pixels representing the primary colors. They are lit by means of additional filters such that each subpixel can be produce millions of possible colors.

In color LCDs, color components can be grouped into separate pixel geometries, depending upon the usage of the monitor. If the software controlling the display understands the type of geometry being used by a particular LCD monitor, the information can be used to improve the resolution of the display through a process called sub pixel rendering. Subpixel rendering is used primarily to anti-alias text. Fig 2 shows the colors display of liquid crystal display.



iV. LCD quality control:

LCD panels may have a few unlit pixels, caused by a defective transistor or some missing connection. But, unlike ICs, and LCD with a few dead pixels is still usable. The number of defective pixels permissible is determined by the manufacture. Samsung offers its customers something called the zero defective pixel guarantee, which ensures a complete replacement of the product of there is even a single defective pixel on the monitor.

V. LCD drawbacks:

Before we end, here are some disadvantages of LCD displays, as opposed to other display technologies such as CRT and plasma.

- As opposed to CRTs, LCDs cannot from multiple resolution images. LCDs can only produce clear images in their native resolution or a small fraction of it.
- The contrast ratio for LCD images is less than its CRT and plasma conteraprts.
- Due to their longer response time, LCDs may show ghosting and mixing when images change rapidly.
- The viewing angle of an LCD is narrower than a CRT or plasma display, thereby restricting the number of people who can conveniently view the image on the screen at one time.
- Image persistence is a common phenomenon with LCDs. This is something comparable to screen burn-in on CRTs.

Review Questions:

1. Define the diffusion process that takes place at the junction of a semiconductor diode and explain the presence of a depletion region.
2. What is the diffusion current as it relates to a semiconductor diode, and how is it functionality related to the applied forward biased voltage of the diode.
3. What is the potential energy barrier of a pn junction? How does it arise and what is its order of magnitude?
4. Sketch the V-I characteristic of the pn junction diode for forward bias voltages distinguish between the incremental resistances the apparent resistance of the diode.
5. What is the diffusion capacitance of a semiconductor diode? Explain how it arises.
6. Draw the energy band diagram of a pn diode.
7. Derive an expression for continuity equation.
8. Explain the working of pn diode in forward and reverse bias conditions.
9. Explain in detail about the current components in a pn junction diode.
10. What are the applications of a diode?

Problems

1. If the radiative and non-radiative time periods of LEDs are 2.75 ns and 55.5 ns respectively. Calculate the internal quantum efficiency?

Solution:

$$\eta = \frac{non-radiativetimeperiode}{radiative+non-radiativetimeperiod} x100$$

= 95.28%

1. A photo-diode is placed at a distance of 2.5 cm from GaAs LED having a peak wavelength of 650 nm. The output power of LED is 0.45 mW and divergence angle is 0.5radian. Calculate the number of photons falling on photodiode, neglecting the reflection loss and transmission loss.

Solutions:

The irradiance at diode, $H = \frac{4P_{out}}{\pi d^2\theta^2}$

$$H = \frac{4x(0.45x10^{-3})}{3.14x(2.5)^2x(0.5)^2} = 0.367x10^{-3}W/cm^2$$

The number of photons falling on the photodiode is $P = \frac{\lambda H}{hc}$ = 1.2 x 10^{15}

Here $\lambda = 650x10^{-9}m$

h = 6.665 x 10^{-34} J.s

c = 3x10^8 m/s

2. If a light from a LED having normal efficiency of 0.915% is allowed to fall on a detector kept at 3.048 cm from the LED, calculate the irradiance at the detector for divergence angle 0.215 radians. Given that forward voltage and forward current for LED is 1.18 volt and 79/5 mA respectively?

Solution:

Normal efficiency of LED = $\left(\frac{P_{out}}{P_{in}}\right)x100$

Where $P_{in} = V_F$ x I_F = 1.18 x79.5x10^{-3}

P_{in} = 0.094 watt

Hence 0.915% = $\frac{P_{out}}{0.094}x100$

P_{out} = $\frac{0.915xx0.094}{100}x100$ = 0.086 Watt

The irradiance $H = \frac{4P_{out}}{\pi d^2\theta^2}$

Here d = 3.048 cm

θ= 0.215 radians

P_{out} = 0.086 watt

$$H = \frac{4x0.086}{\pi x(3.048)^2 x(0.215)^2} = 0.25 watt / cm^2$$