B.Sc. I

SECTION – II (Active circuit Elements)

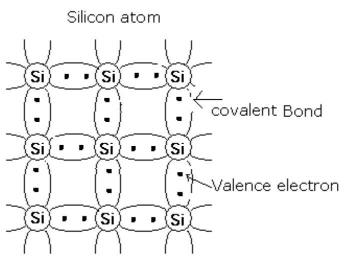
UNIT :5 Semiconductor diode: - 9

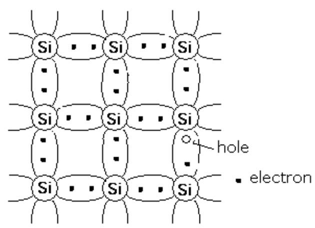
Definition of PN junction, unbiased junction, formation of depletion layer and internal potential barrier. Biased junction: - Forward and Reverse biased I-V characteristics of pn junction diode. [Both forward and reverse biasing] Junction resistance (i.e. diode resistance) Diode application, power and current rating of diode, effect of temperature on PN junction diode.

Zener diode: - Breakdown mechanism, Zener and Avalanche Break down,Zener Diode as voltage regulator. specification of Zener diode, point contact diode, applications, effect of temperature on Zener diode, photo diode, varactor diode, LED [Construction and applications only] ,Seven segment display, LCD.

Semiconductor: whose electrical properties lie between those of conductors & insulators e.g. ge, si, GaAs, CdS…

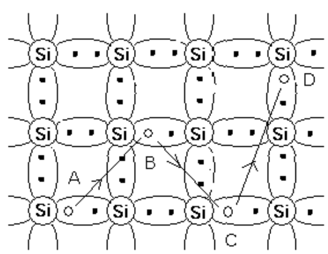
Types : Intrinsic Semiconductors





Generation of electrons & holes: At room temp. Some of covalent bonds get broken. The energy required to break such a covalent bond is equal to the band gap energy Eg. At room temp. Eg=0.7eV for Ge & Eg= 1.1eV for Si. The vacancy of an incomplete covalent is called hole.

Mechanism of holes contributing to conductivity:



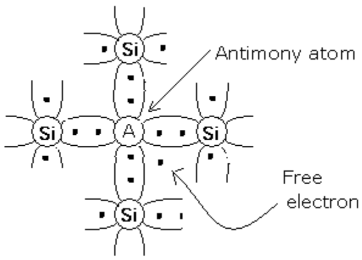
Suppose a hole is present at point A. due to the thermal agitation, in crystal lattice, an electron at B may find it more favorable to jump to the position A. this reestablishes the covalent bond at A. but this creates a new hole at B. similarly, the hole may continue to move from B to C, from C to D …. The net displacement of the hole from A to D constitutes the electric current. The motion of a hole in one direction means the transport of a negative charge by an equal distance in the opposite direction.

Free charge carriers in semiconductor: The conduction property of a semiconductor depend upon the number of valence electrons. When sufficient energy (thermal or electrical) is given to valence electrons, they break away from their parent atoms & take part in conduction through crystal. Such valence electrons are called conduction band electrons. These electrons leave behind the holes in the valence band. The electrons & holes generated in such a way are called free charge carriers. They are free to move anywhere within crystal.

Extrinsic semiconductors: The process of adding impurity atoms to the intrinsic semiconductor is called doping. Generally, the impurities are added at the rate of only one atom per 10^6 to 10^{10} semiconductor atoms. The impurity atoms enter the crystal by substituting for one Ge or Si atoms. The purpose of adding impurity is to increase either the number of free electrons or holes in a semiconductor.

N type semiconductor:

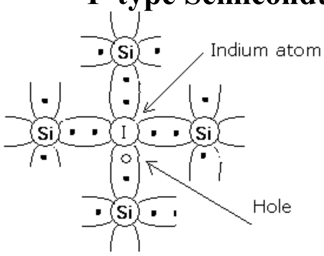
Obtained by introducing penta valent impurity atoms i. e. atoms containing five valence electrons are known as N-type semiconductors (e.g. phosphorus, antimony, arsenic, bismuth) figure shows the structure of a silicon crystal lattice containing an antimony atom at the central



position. Out of 5 valence electrons, 4 electrons will form covalent bonds by sharing one electron to the neighboring atoms. The fifth electron is an extra electron & is loosely bound with the antimony atom. This extra electron if detached from the antimony atom will be available as a carrier of the current. The energy required to detach this electron is of the order of 0.05eV for Si & 0.01 for Ge.

The addition of a penta valent impurity atoms give away or donate its fifth electron. After the donation, the impurity atom becomes a positively charged ion & is known as a donar ion. this ion is bounded by 4 covalent bonds in the crystal lattice& therefore cannot be made to move within the lattice. Thus in a N type semiconductor a major part of the current flows due to the movement of electrons & are called majority carriers & holes as minority carriers.

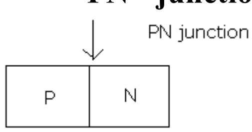
P-type Semiconductor:



Obtained by introducing a trivalent impurity atoms i. e. atoms containing 3 valence electrons, are known as p-type semiconductors. E.g. Gallium, Indium, Aluminum, Boron. These elements make available positive charge carriers, because they create holes, which can accept electrons. Therefore such electrons are known as acceptor p type impurities.

Figure shows the structure of a silicon crystal containing an indium atom at the central position. The 3 valence electrons of an indium atom form 3 covalent bonds by sharing one electron with the electros of neighboring atoms. However, the fourth covalent bond is incomplete. A vacancy which exists in the incomplete covalent bond constitutes a hole. Indium atom accepts one electron & becomes an immobile ion. The energy involved in capturing the electron to 0.05eV for Si & 0.01 eV for Ge. The immobile ion is bounded by 4 covalent bonds & cannot be made to move within the lattice. Thus, in P type semiconductor a major part of the current flows due to the movement of holes & are called majority carriers & electrons are called minority carriers.

PN- junction : If we join a piece of P type semiconductor to a piece of N type semiconductor such that the crystal structure remains continuous at the boundary as shown in figure, a PN junction is formed. Such a PN junction forms a very useful device & is called a semiconductor diode, PN junction diode.



Formation of depletion layer in a PN junction:

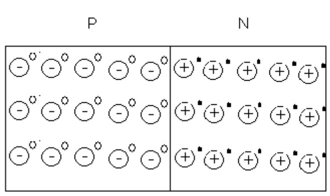
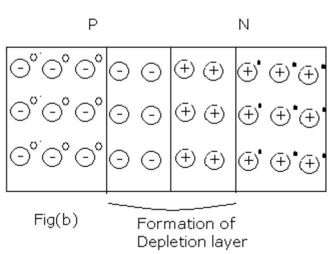


Fig (a)



Fig(b)

Figure shows a semiconductor consists of a PN junction, which has just formed. The P region has holes (as majority carriers) & negative charged impurity atoms called negative ions (or acceptor ions). The N region has free electrons (as majority carriers) & positively charged impurity atoms called positive ions (or donor ions). The minority carriers are not show.

Holes & electrons are mobile charges & take part in the conduction. Whereas positive 7 negative ions are immobile charges & do not take part in the conduction. The sample as a whole is electrically neutral. Thus in the P region, the total positive charge on the holes is equal to the total negative charge on free electrons & immobile ions. Similarly, in the N region, the total negative charge on free electrons is equal to the total positive charge on holes & immobile ions.

As soon as the junction formed the following processes takes place.

The holes from the P region diffuse to the N region, where they combine with free electrons.

The free electrons, from the N region diffuse to the P region, where they combine with holes.

The diffusion of holes (from p region to N region) & free electrons (from N region to P region) takes place due to the reason that there is a difference of concentration in the two regions.

After a few recombinations of holes & free electrons in the vicinity of junction, a restraining force is automatically set up. This force is produced due to depletion region, which exists on either side of the junction. As a result further diffusion of charges stops.

The depletion layer behaves like an insulator. The width of the depletion layer depends upon the doping of the impurity in N & P type semiconductor. The higher the doping level, the thinner will be the depletion layer & vice a versa.

Junction or barrier voltage:

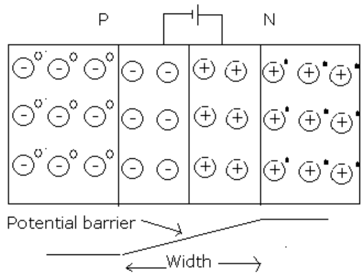


Fig Junction or barrier voltage

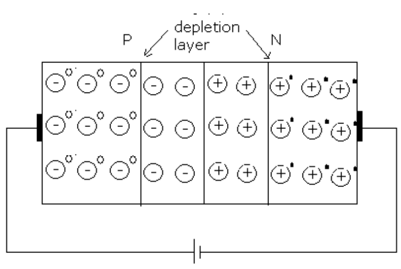
The depletion region of a PN junction has no mobile charge carriers. But it contains fixed rows of oppositely charged ions on its two sides. Because of this charge separation, an electric potential (V_B) is established across the junction, even when the junction is not connected to any external source. This electric potential is called junction or potential barrier. This potential barrier exerts a repelling force on the mobile charge carriers, trying to cross over the junction. At room temp the value of VB is 0.6 V for si & 0.2 V for Ge.

Currents in an unbiased PN junction: When junction is at room temp thermal energy is given to electrons & holes. As a result they get over the potential barrier & diffuse the junction. Since the diffusion of electrons & holes is opposite in direction, there is single current across the junction & is known as majority carrier current.

The current produced due to the diffusion of minority carriers, across the junction is called minority carrier current. The minority carrier current flows in a direction opposite to that of the majority carrier current. In an unbiased PN junction, the majority carrier current & minority carrier current are equal in magnitude & flow in opposite direction i. e. there is no net flow of current across the junction.

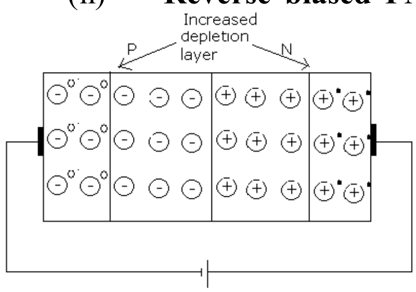
Biasing the PN junction:

A PN junction connected to an external voltage source is called a biased PN junction. By applying an external voltage across a PN junction we are able to control the width of the depletion layer, thereby we can control the resistance of the junction & also the amount of the current that can pass through the device.



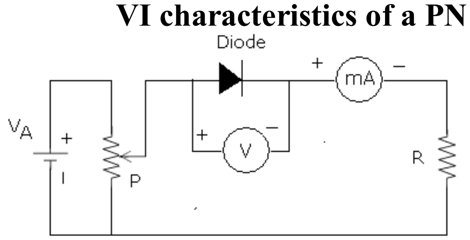
(i) **Forward biased PN junction:** In this case, positive terminal of the voltage source is connected to the P side & negative terminal to the N side as shown in figure. A large amount of current flows through the junction under this condition. When a PN junction is forward biased as shown the hoes are repelled by the positive terminal of the voltage source & electrons are repelled by the negative terminal of the source &are forced to move towards the junction. This reduces the width as well as height of the potential barrier. As a result, more majority carriers diffuse across the junction. Therefore it causes a large amount current to flow through the PN junction.

(ii) **Reverse biased PN junction:** When positive terminal of the voltage source is connected to the N region & negative to the P region then the PN junction is said to be reverse biased.



When a PN junction is reversed biased as shown in figure, the holes in the P region are attracted towards the negative terminal of the voltage source. And the electrons in the N region are attracted to wards the positive terminal of the voltage source. Thus the majority carriers are drawn away from the junction. This widens the depletion layer & increases the barrier potential. Therefore junction offers very high resistance under reverse biased condition, however a small amount of current due to minority carriers flow through the reverse biased junction. This current depends on temp & not on applied reverse voltage. It is also known as reverse saturation current.

VI characteristics of a PN junction diode:



Fig(a) Circuit arrangement

i) Forward characteristics: Figure (a) shows the circuit arrangements for obtaining the forward characteristics of a diode. Diode is connected to a D.C. source through a potentiometer & a resistor R. the potentiometer helps in varying the voltage applied across the diode. The resistor is included, so as to limit the current through the diode. A voltmeter & milliameter are connected to measure voltage & current respectively.

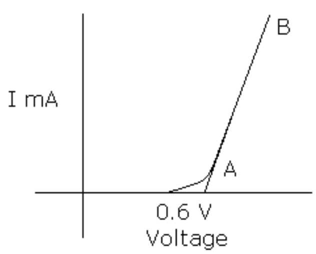
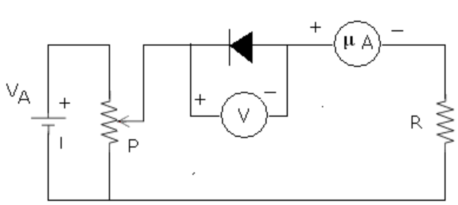


Fig Forward characteristics

Let us gradually increase the voltage in small steps about 0.1V & record the corresponding values of diode current & plot the graph as shown. From the graph it is seen that there is no current till the point A is reached & above A the diode current increases rapidly. It is because the external applied voltage is being opposed by the junction voltage whose value is 0.6V for Si & 0.2 V for Ge. The applied voltage should not be increased beyond a certain safe limit; otherwise the diode is likely to burn out.

The voltage, at which the diode starts conducting, is called knee voltage, cut-in voltage or threshold voltage. The knee voltage may be obtained from the forward characteristics by extending the curve AB backwards, till it meets the horizontal axis. The value on the horizontal axis is equal to the knee voltage.

ii) Reverse characteristics:



Fig(a) Circuit arrangement

The negative terminal of the voltage source is connected to the anode of a diode & the positive terminal of the cathode i. e. diode is reverse biased. The applied reverse voltage is gradually increased above zero in suitable steps & the values of the diode current are recorded at each step & graph is plotted as shown.

It is observed that when the applied reverse voltage

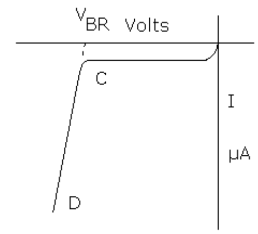
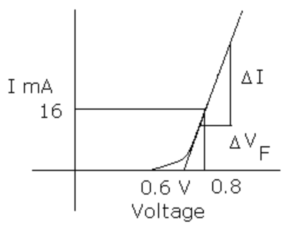


Fig Reverse characteristics

is below the break down voltage V_{BR}, the diode current is small & remains constant & above this the current increases rapidly as shown by CD curve. The constant current up to V_{BR} is called reverse saturation current (for Si it is 10 -9 & for Ge it is 10 -6 A). The voltage at which the current increases rapidly is called breakdown voltage.

Static& dynamic resistance of a diode: When diode is forward biased it has a definite value of resistance known as D.C. static or forward resistance of diode. It is given by the ratio of the Dc voltage across the diode to the DC current flowing through it. Mathematically $R_f = V_f/I_f$



The resistance offered by the diode to an AC signal is called its dynamic or AC resistance.

$$r_{ac} = \frac{\Delta VF}{\Delta IF} = \frac{\text{change in voltage}}{\text{Resulting change in current}}$$

When diode is reverse biased it offers very high value of resistance. It is in the range of several megaohms.

Diode applications: A PN junction diode has an important characteristic that it conducts well in forward direction & poorly in reverse direction. This characteristic makes a diode very useful in a number of applications given below.

1. As rectifiers or power diodes in DC power supplies.
2. As signal diodes in communication circuits.
3. As zener diode in voltage stabilizing circuits.
4. As Varactor diodes in radio & TV receivers.
5. As a switch in logic circuits used in computers.

Power & current ratings of a diode: Every diode carrying current dissipates some power, whose value is given by the product of voltage & current through it.

$P_D= V_F*I_F$ V_F forward voltage, IF forward current

$P_D= V_R*I_R$ VR reverse voltage, IR reverse current

The maximum value of power which a diode can dissipate without failure is called power rating. Thus the power dissipation should not exceed power rating. If it happens, the diode gets destroyed. The manufacturers specify power rating of a diode on a data sheet e.g. the diode 1N914 has a power rating of 250 mW. It means that the diode can dissipate a maximum power of 250 mW. In some cases current ratings are given.

The small signal diodes are those which have a power rating below 0.5W, whereas the rectifier diodes have a power rating above 0.5W.

Effect of temp on PN junction diode:

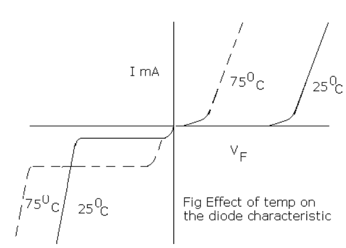


Fig Effect of temp on the diode characteristic

For both Si & Ge diode the value of barrier voltage decreases by 2 mV $/^0$c. With the increase in temp the forward current decreases. In the reverse bias region, the break down voltage increases with the increase with temp.

Zener diode: A zener diode is also called a voltage reference, voltage regulator or breakdown diode. This diode is operated in the reverse breakdown region. The breakdown voltage of a zener diode is set by carefully controlling the doping level during manufacture.

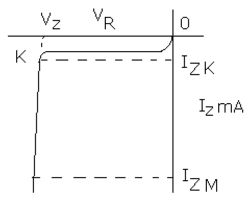
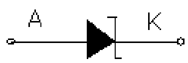


fig Reverse chracteristic of zener diode

Zener diode is operated only in the reverse bias region. Figure shows the reverse portion of the VI characteristics of the zener diode. As the reverse voltage is increased, the reverse current Iz remains negligibly small up to the knee of the curve (point K). At this point the effect of breakdown process begins. From the bottom of the knee, the break down voltage remains essentially constant. This ability of a diode is called regulating ability & is an important feature of a zener diode.



Symbol of Zener diode

There is a minimum value of zener current called break over current designated as Izk which must be maintained in order to keep the diode in break down region. When the current is reduced below the knee of the curve, the voltage changes drastically& the regulation is lost.

There is a maximum value of zener current designated as Izm above which the diode may be damaged. The value of this current is given by the maximum power dissipation of the zener diode.

Break down mechanism: When PN junction is reverse biased a very small amount of current due to the movement of minority carriers flows across junction & is independent of the applied reverse voltage. If the reverse bias is increased above break down voltage, the current through the junction increases abruptly. At this voltage, the crystal structure breaks down. The following two processes cause junction break down due to the increase in reverse voltage.

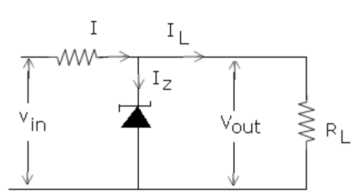
i) **Zener break down:** In this case the break down occurs in junctions, which are heavily doped. The heavily doped junctions have a narrow depletion layer. When the reverse voltage is increased, the electric field at the junction also increases. A strong electric field causes a covalent bond to break from the crystal structure. As a result of this, a large number of majority carriers are generated & a large current flows through the junction.

ii) **Avalanche break down:** In this case, the increased reverse voltage increases the amount of energy imparted to minority carriers, as they diffuse across the junction. As the reverse voltage is increased further, the minority carriers acquire a large amount of energy (or momentum). When these carriers collide with Si (or Ge) atoms, within the crystal structure, they impart sufficient energy to break a covalent bond & generate additional carriers (i.e. electron hole pairs). These additional carriers pick up energy from the applied voltage & generated still more carriers. As a result of this, the reverse current increases rapidly. This cumulative process of carrier generation (or multiplication) is known as avalanche break down or avalanche multiplication.

Zener diode specifications:

1. Zener voltage : Vz 1.8 V to 2000V
2. Maximum power dissipation : 150 mWto 50 W
3. Break over current : in mA
4. Zener resistance : ~25 Ω

Zener diode as voltage regulator: A zener diode, when working in the break down region, can serve as a voltage regulator. Figure shows a circuit for zener voltage regulator. Vin is the input DC voltage whose variations are to be regulated. The zener diode is reverse connected across Vin. When P.D. across the diode is greater than Vz, it conducts & draws relarively large current through the series resistance R. the load resistance R_L across which a



constant voltage Vout is required, is connected in parallel with the diode. The total current I passing through R equals the sum of diode current & load current i.e. $I = Iz + I_L$

Case i) Suppose R is kept fixed & supply voltage is increased slightly. It will increase I. This increase in I will be absorbed by the zener diode without affecting I_L. The increase in Vin will be dropped across R thereby keeping Vout constant. Conversely, if Vin falls, the diode takes a smaller current & voltage drop across R is reduced, thus again keeping Vout constant. Hence, when Vin changes I & IR drop change in such a way as to keep Vout constant.

Case ii) In this case, Vin is fixed but I_L is changed. When I_L increases diode current Iz decreases which keeps I & IR drop constant. When I_L decreases, Iz increases again I & hence IR drop remains constant i.e. Vout remain unchanged.

$Vout = Vin - IR = Vin - (Iz + I_L) R$

For proper operation, the input voltage must be greater than the zener voltage. This ensures that the zener diode operates in the reverse break down region.

Applications of zener diode:

1. As a voltage regulator
2. As a fixed voltage reference voltage in transistor biasing circuits
3. As peak clippers or limiters in wave shaping circuits
4. For meter protection against damage from accidental applications

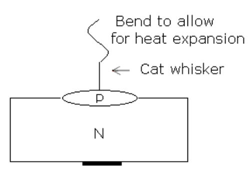


fig (a)

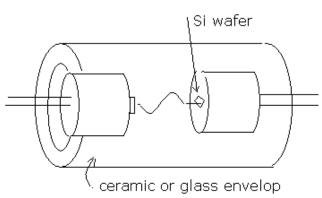


fig (b)

Point contact junction: It consists of an N type Ge or Si wafer about 1.25 mm square by 0.5 mm thick, one face of which is soldered to a metal base by radio frequency heating as shown in figure. The other face has a phosphor bronze (or tungsten) spring pressed against it. The PN junction is formed bypassing a large current for a second or two through the wire while the crystal face with wire point is kept positive. The heat is produced drives away some of the electrons from the atoms in the small region around the point of contact thereby leaving holes behind. This small region of the N type material is consequently converted in to P type material as shown in figure. The small area of the PN junction results in very low junction capacitance.

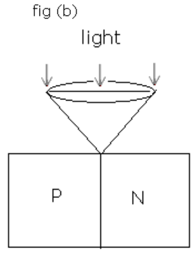
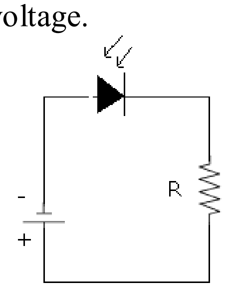


Photo diode: A photo diode is a two terminal PN junction device, which operates in a reverse bias. It has a small transparent window, which allows light to strike the PN junction. Figure a & b shows the structure & schematic symbol of a photo diode. The basic arrangement of a photo diode is as shown in fig. c. The reverse current in case of photo diode increases with the light intensity at the PN junction. When there is no incident light, the reverse current is almost negligible & is called the dark current. An increase in the amount of light energy produces an increase in the reverse current for a given value of reverse bias voltage.

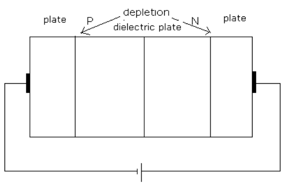


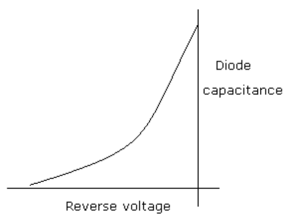
Applications:

1. Photo detection (both visible & invisible)
2. Demodulation
3. Logic circuits
4. Switching
5. Optical communication systems
6. Character recognition

7. Encoders

Varactor diode: A varactor diode basically a reverse biased PN junction which utilizes the inherent capacitance of the depletion layer. It is also known as varicap, voltcap or tuning diode. It is used as a voltage variable capacitor.





When the reverse bias voltage increases the depletion layer widens. This increases the dielectric thickness, which in turn, reduces the capacitance. When the reverse bias voltage decreases, the depletion layer narrows down. This decreases the dielectric thickness which in turn increases the capacitance. Figure b shows the variation of capacitance with the reverse voltage. This indicates that the variation of capacitance is maximum when the reverse voltage is equal to zero. It reduces in a non linear manner as the value of reverse voltage in increased. In a varactor diode, the capacitance parameters are controlled by the method of doping in the depletion layer or the size& geometry of the diode construction. Fig a shows the doping profile for an abrupt junction diode i.e. the normal PN junction. In this type the doping is uniform on both sides of the junction. The range of capacitance variation of an abrupt PN junction is 4: 1. It means that if its max. transition capacitance is 10 pF & the minimum is 25 pF then its tuning range is 4:1.

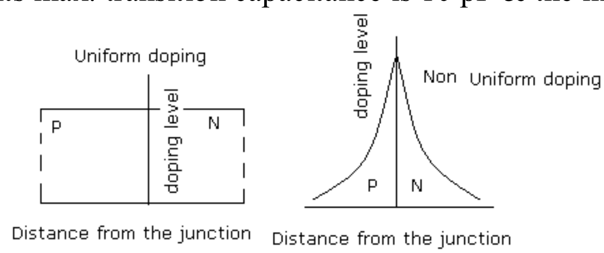
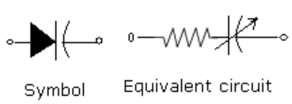


Fig (a) Abrupt doping profile Fig(b) Hyper abrupt profile

The hyper tuning range is obtained for varactors, which have hyper abrupt junction as shown in fig. b. In this type the doping level increases as we approach the junction. The heavy doing at the junction results in a narrower depletion layer & hence a large capacitance. A hyper abrupt varactor diode has a tuning range of 10:1. This range is enough to tune a broad cast receiver, over its frequency range of medium wave band (550 KHz to 1650 KHz). Fig a shows a schematic symbol for a varactor diode & fig b shows its equivalent circuit CT ranges typically from 2 pF to 100 pF.



Applications: In tuning circuits

LED: A PN junction diode which emits light when forward biased is known as light emitting diode (LED). The emitted light may be visible or invisible. The amount of light is directly proportional to the forward current. The symbol is shown in figure. The arrows pointing away from the diode symbol represent the light, which is being transmitted away from the junction.

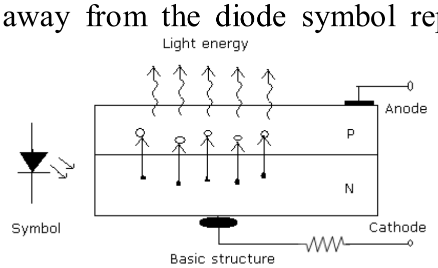
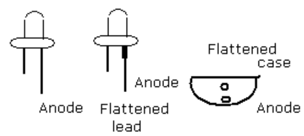


Figure b shows the basic structure of LED. Here an N type layer is grown on a P type substrate(not indicated in fig) by a diffusion process. Then a thin P type layer is grown on the N type layer. The metal connection to both the layers make anode & cathode terminals.

When LED is forward biased the electrons & holes move towards the junction & the recombination takes place. After recombination, the electrons lying in the conduction bands on N region fall into the holes lying in the valance band of a P region. The difference of energy between conduction band & valance band is radiated in the form of light energy. In ordinary diodes this energy is radiated in the form of heat.

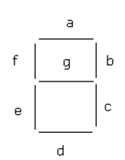
The colour of the emitted light depends upon the type of semiconductor used.

GaAs	Infrared radiations
Gallium arsenide phosphide	red, yellow
Gallium phosphide	red, yellow
Gallium nitrite	blue

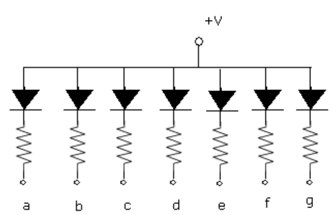


LED applications: The LED's operate at low voltage, from 1.5 V to 2.5 V. they have a long life of about 10,000 hrs & can be switched On & OFF at a very high speed (~ 1 nS).

1. In 7 segment, 16 segment & dot matrix displays.
2. For indicating power On/OFF conditions, power level indicators or stereo amplifiers.
3. In optical switching applications
4. For solid state video displays
5. In the field of optical communication, where LED's are used to transfer (or couple) energy from one circuit to another. They are also used to send light energy to fiber optical cable.
6. For image sensing circuits in picture phone
7. LED's are used in burglar alarm systems. In such applications, LED's radiating infrared light is preferred.
8. In automobile dash boards, backlighting of keypads on cellular phones & path marking lights
9. Widely used for traffic signal management



fig(a) 7 segment



Fig(b) Schematic diagram

Seven segment display: figure (a) shows a seven segment display. It is used to display alphanumeric characters. It consists of 7 rectangular LED's designated by the letters a, b, c, d, e, f & g. Each LED is called a segment, because it forms a part of the character being displayed.

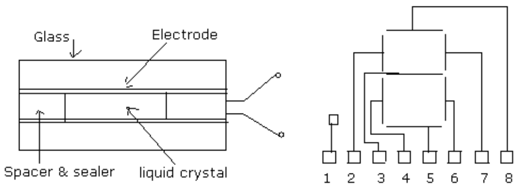
Figure b shows a schematic diagram of a seven segment display. In this circuit, the anodes of all the diodes are connected together to the positive terminal of the DC source. The cathodes are connected to the external resistors, which are necessary to limit the current. By grounding the external resistors, we can form decimal digits from 0 to 9 e.g. by grounding a, b, g, e, & d we can form the digit 2 & so on.

An average LED requires a current of about 20mA for its operation.

Applications

1. Used in digital clock, calculators
2. Microwave ovens
3. Stereo tuners
4. Digital multimeters
5. Microprocessor training kit

LCD (Liquid Crystal Displays): The molecules in ordinary liquids have random orientations but in a liquid crystal they are oriented in a definite crystal pattern. Normally, a thin layer of liquid crystal is transparent to incident light but when an electric field is applied across it, its molecular arrangement gets disturbed causing charges in falls on an activated layer of liquid crystal, it is either absorbed or else is scattered by the disoriented molecules.



a b

As shown in fig(a), a liquid crystal cell consists of a thin layer about 10mm of a liquid crystal sandwiched between two glass sheets with transparent electrons deposited on their inside faces. With both glass sheets transparent, the cell is known as transmitter type cell. When one glass is transparent & the other has a reflective coating the cell is called reflective type. The LCD does not produce any illumination of its own. It in fact depends entirely on illumination falling on it from an external source for its visual effect.

The two types of display available are known as i) field effect display ii) dynamic scattering display. When field effect display is energized areas of the LCD absorb the incident light & hence give localized black display. When dynamic scattering display is energized the molecules of energized area of the display become turbulent & scatter light in all directions. Consequently, the activated areas take on frosted glass appearance resulting in a silver display. Of course the un-energized areas remain translucent.

As shown in fig (b), a digit of an LCD has a seven segment appearance. The reflected type LCD molecules are suitable for use in sunlight & low light application. An LCD has the advantage of extremely low power requirement 10-15mW/7 segment display.

Applications

1. Field effect LCD's are normally used in watches & portable instruments such as digital thermometer, blood pressure, blood sugar, pressure monitoring where source of power is a prime consideration.
2. Desk top LCD monitors
3. Note book computer display
4. Cellular phone display
5. To display data on personal digital assistant such as palm & pocket PC's etc