KUNTHAVAI NAACHIYAAR GOVERMENT ARTS COLLEGE FOR WOMEN (A),THANJAVUR-7

DEPARTMENT OF PHYSICS

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Unit-1 Semiconductor physics

1) Theory of energy bands in crystals

All the atoms are found to have discrete energy levels around their central nucleus. Now two or more such atoms are placed nearer to one another. In this case, the structure of their discrete energy levels gets transformed into energy band structure. That is, in the place of discrete energy levels, one can find discrete energy bands. The cause behind the formation of such ***energy bands in crystals*** is the mutual interaction between the atoms which is a result of electromagnetic forces acting between them.

Energy bands in a crystal can be of various types. A few of them would be completely empty due to which they are called empty energy bands while a few more would be completely filled and are thus named as filled energy bands. Usually, the filled energy bands will be the lower energy levels which lie nearer to the atom's nucleus and possess no free electron, meaning which they cannot afford for conduction. There also exist yet another set of energy bands may be a combination of empty and filled energy bands called the mixed energy bands. Nevertheless in the field of electronics one is particularly interested in conduction mechanism. As a result, here, two of the energy bands gain extreme importance. These are

Valence Band

This energy band comprises of valence electrons (electrons in the outer most orbit of an atom) and can either be completely or partially filled. At room temperature, this is the highest energy band which comprises of electrons.

Conduction Band

The lowest **energy band** which is usually unoccupied by the electrons at the room temperature is called conduction band. This energy band comprises of electrons which are free from the attractive force of the atom's nucleus.

In general, valence band is a band with lower energy in comparison with the conduction band and is thus found below the conduction band in the energy band diagram (Figure 2). The electrons in the valence band are loosely bound to the atom's nucleus and jump into conduction band when the material is excited.

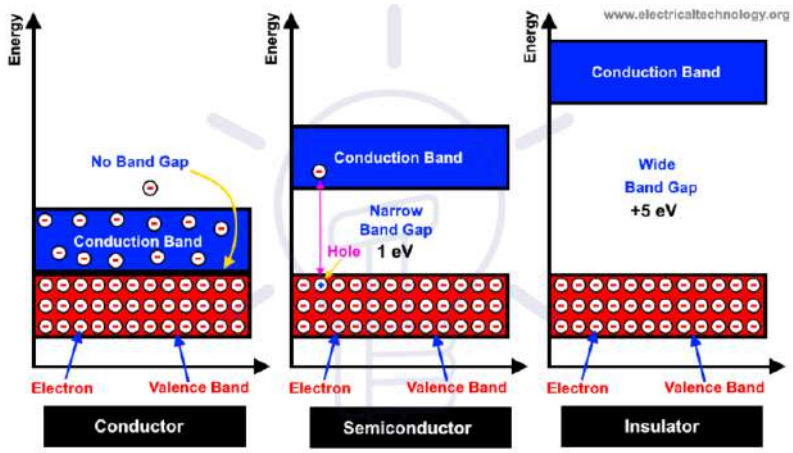
For example, say, the energy band diagram shows a considerable overlapping between the valence and the conduction bands, Then, it means that the material has abundant free electrons in it, due to which it can be considered to be a good conductor of electricity i.e. a metal.

On the other hand if we have an **energy band** diagram in which there is a huge gap between the valence and the conduction bands, this means that one needs to provide the material with large amount of energy so as to obtain the filled conduction band. At times, this may be tough or sometimes even practically impossible. This would leave the conduction band void of electrons due to which the material will fail to conduct. Thus, these kind of materials would insulators.

Now, let us say that we have a material which shows a slight separation between the valence and the conduction bands as shown by Figure 3c. In this case, one can make the electrons in

the valence band occupy the conduction band by providing slight amount of energy. This means that although such materials are usually insulators, they can be converted to act as conductors by exciting them externally. Hence these materials will be called semiconductors.

2) Difference between conductors, insulators and semiconductors



Characteristics	Conductor	Semiconductor	Insulator
Definition	A conductor is a material that allows the flow of charge when applied with a voltage.	A semiconductor is a material whose conductivity lies between conductor & insulator	An insulator is a material that does not allow the flow of current.
Temperature Dependence	The resistance of a conductor increases with an increase in temperature.	The resistance of a semiconductor decrease with increases in temperature. Thus it acts as an insulator at absolute zero.	Insulator has very high resistance but it still decreases with temperature.
Conductivity	The conductors have very **high conductivity** (**10^{-7} ℧ /m**), thus they can conduct electrical current easily.	They have **intermediate conductivity** (**(10^{-7} ℧ /m** to **10^{-13} ℧ /m**), thus they can acts as insulator & conductor at different conditions.	They have very **low conductivity** (**10^{-13} ℧ /m**), thus they do not allow current flow.

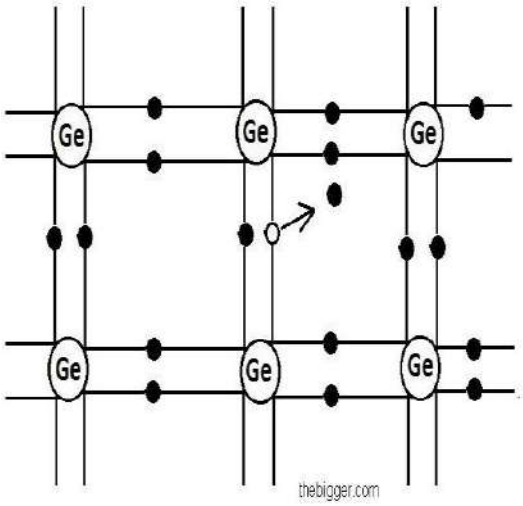
Conduction	The conduction in conductors is due to the free electrons in metal bonding.	The conduction in semiconductor is due to the movement of electron & holes.	There are no free electrons or holes thus, there is no conduction.
Band gap	There is **no or low energy gap** between the conduction & valance band of a conductor. It does not need extra energy for the conduction state.	The band gap of semiconductor is greater than the conductor but smaller than an insulator i.e. **1 eV**. Their electrons need a little energy for conduction state.	The band gap in insulator is huge (**+5 eV**), which need an enormous amount of energy like lightning to push electrons into the conduction band.
Resistivity	Low (**10^{-5} Ω/m**)	Normal (**10^{-5}Ω/m** to **10^{5} Ω/m**)	Very High (**10^{5} Ω/m**)
Coefficient of Resistivity	It has **positive coefficient** of resistivity i.e. its resistance increase with temperature	It has **negative coefficient** of resistivity.	The coefficient of resistivity of an insulator is also **negative** but it has very huge resistance.
Absolute Zero	Some special conductors turn into superconductors when supercooled down to absolute zero while other have finite resistance.	The semiconductors turn into insulator at absolute zero.	The insulator's resistance increase when cooled down to absolute zero.
Valence Electron in Outer Shell	1 Valence electron in outer shell.	4 Valence electron in outer shell.	8 Valence electron in outer shell.
Examples	Gold, Copper, Silver, Aluminum etc	Silicon, Germanium, Selenium, Antimony**,** Gallium Arsenide (known as semi insulator),Boron etc.	Rubber, Glass, Wood, Air, Mica, Plastic, Paper etc.

Application	The metals like iron & copper etc. that can conduct electricity are made into wires and cable for carrying electric current.	Semiconductors are used every day electronic devices such as cellphone, computer, solar panel etc as switches, energy converter, amplifiers, etc.	The insulators are used for protection against high voltages & prevention of electrical short between cables in circuits.

3) Intrinsic semiconductors

The semiconductor is divided into two types. One is **Intrinsic Semiconductor** and other is an **Extrinsic semiconductor**. The pure form of the semiconductor is known as the intrinsic semiconductor and the semiconductor in which intentionally impurities is added for making it conductive is known as the extrinsic semiconductor.

An extremely pure semiconductor is called Intrinsic Semiconductor. Germanium and Silicon are the two important semiconductors. These substances belong to the IV group of the periodic table and have four electrons in the outermost shell.

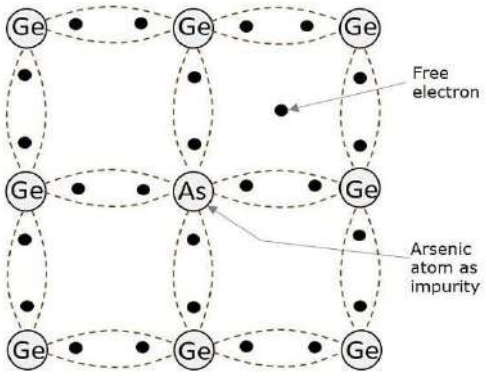


Each of the four outer electrons forms a bond with one electron of the nearest neighbouring atoms. At absolute zero temperature intrinsic semiconductor behaves as a perfect insulator because at this temperature there is no free electrons, to act as a charge carrier.

4) Extrinsic Semiconductor

A semiconductor to which an impurity at a controlled rate is added to make it conductive is known as an extrinsic semiconductor. An intrinsic semiconductor is capable to conduct a little current even at room temperature, but it is not useful for the preparation of various electronic devices. Thus, to make it conducive a small amount of suitable impurity is added to the material. The process by which an impurity is added to a semiconductor is known as **Doping**. The amount and type of impurity which is to be added to the material have to be closely controlled during the preparation of extrinsic semiconductor. Generally, one impurity atom is added to 10^8 atoms of a semiconductor.

The purpose of adding impurity in the semiconductor crystal is to increase the number of free electrons or holes to make it conductive. If a Pentavalent impurity, having five valence electrons is added to a pure semiconductor a large number of free electrons will exist. If a trivalent impurity having three valence electrons is added, a large number of holes will exist in the semiconductor. Depending upon the type of impurity added the extrinsic semiconductor may be classified as **n type semiconductor** and **p type semiconductor**.

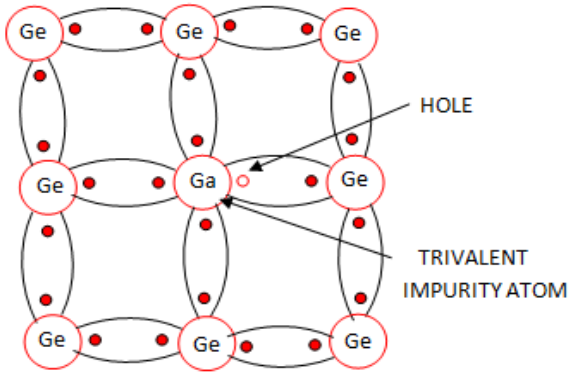


An **N-type semiconductor** is a **type** of material used in electronics. It is made by adding an impurity to a pure **semiconductor** such as silicon or germanium. The impurities used may be phosphorus, arsenic, antimony, bismuth or some other chemical element. They are called donor impurities. The impurities used may be phosphorus, arsenic, antimony, bismuth or some other chemical element. They are called donor impurities. The impurity is called a *donor* because it gives a free electron to a semiconductor. The purpose of doing this is to make more charge carriers, or electron wires available in the material for conduction.

Semiconductor materials like silicon and germanium have four electrons in their outer shell. The outer shell of electrons is called the valence shell. The four electrons are used by the semiconductor atom in forming bonds with its neighbouring atoms. This leaves a low number of electrons available for conduction. Pentavalent elements are those elements which have five electrons in their outer shell. To make the n-type semiconductor, pentavalent impurities like phosphorus or arsenic are added. Four of the impurities' electrons form bonds with the

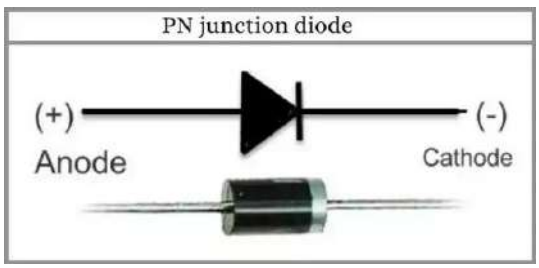
surrounding silicon atoms. This leaves one electron free. The resulting material has a large number of free electrons. Since electrons are negative charge carriers, the resultant material is called an n-type (or negative type) semiconductor. The pentavalent impurity that is added is called a 'dopant' and the process of addition is called 'doping'.

A **p-type semiconductor** is a **type** of **semiconductor**. When the trivalent impurity is added to an intrinsic or pure **semiconductor** (silicon or germanium), it is said to be a **p-type semiconductor**. Trivalent impurities such as boron (B), gallium (Ga), indium (In), aluminium (Al) etc. are called acceptor impurity. Ordinary semiconductors are made of materials that do not conduct (or carry) an electric current very well but are not highly resistant to doing so. They fall half way between conductors and insulators. An electric current occurs when electrons move through a material. In order to move, there must be an electron 'hole' in the material for the electron to move into. A p-type semiconductor has more holes than electrons. This allows the current to flow along the material from hole to hole but only in one direction.

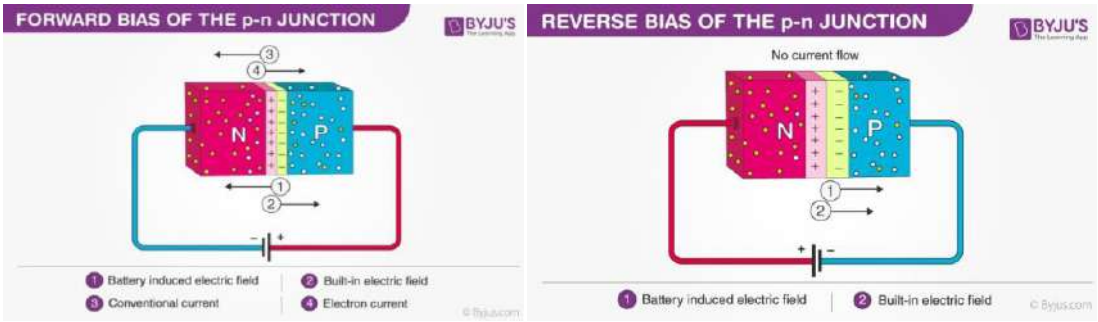


Semiconductors are most often made from silicon. Germanium is an element with four electrons in its outer shell. To make a p-type semiconductor extra materials like Galium, boron or aluminium are added to the silicon. These materials have only three electrons in their outer shell. When the extra material replaces some of the Germanium it leaves a 'hole' where the fourth electron would have been if the semiconductor was pure Germanium

5) Junction diode



A p-n **junction diode** is two-terminal or two-electrode semiconductor device, which allows the electric current in only one direction while blocks the electric current in opposite or reverse direction. If the **diode** is forward biased, it allows the electric current flow.



When the p-type is connected to the positive terminal of the battery and the n-type to the negative terminal then the p-n junction is said to be forward-biased. When the p-n junction is forward biased, the built-in electric field at the p-n junction and the applied electric field are in opposite directions. When both the electric fields add up, the resultant electric field has a magnitude lesser than the built-in electric field. This results in a less resistive and thinner depletion region. The depletion region's resistance becomes negligible when the applied voltage is large. In silicon, at the voltage of 0.6 V, the resistance of the depletion region becomes completely negligible and the current flows across it unimpeded.

When the p-type is connected to the negative terminal of the battery and the n-type is connected to the positive side then the p-n junction is said to be reverse biased. In this case, the built-in electric field and the applied electric field are in the same direction. When the two fields are added, the resultant electric field is in the same direction as the built-in electric field creating a more resistive, thicker depletion region. The depletion region becomes more resistive and thicker if the applied voltage becomes larger.

6) Zener diode

A Zener diode is a heavily doped semiconductor device that is designed to operate in the reverse direction. A Zener diode is a silicon semiconductor device that permits current to flow in either a forward or reverse direction. The diode consists of a special, heavily doped p-n junction, designed to conduct in the reverse direction when a certain specified voltage is reached. The Zener diode has a well-defined reverse-breakdown voltage, at which it starts conducting current, and continues operating continuously in the reverse-bias mode without getting damaged. Additionally, the voltage drop across the diode remains constant over a wide range of voltages, a feature that makes Zener diodes suitable for use in voltage regulation.

Zener diode operation

The Zener diode operates just like the normal diode when in the forward-bias mode, and has a turn-on voltage of between 0.3 and 0.7 V. However, when connected in the reverse mode, which is usual in most of its applications, a small leakage current may flow. As the reverse voltage increases to the predetermined breakdown voltage (Vz), a current starts flowing through the diode. The current increases to a maximum, which is determined by the series resistor, after which it stabilizes and remains constant over a wide range of applied voltage.

Zener breakdown

The breakdown is either due to the Zener breakdown effect that occurs below 5.5 V, or impact ionization that occurs above 5.5 V. Both mechanisms result in the same behavior and do not require different circuitry; however, each mechanism has a different temperature coefficient. The Zener effect has a negative temperature coefficient while the impact effect experiences a positive coefficient. The two temperature effects are almost equal at 5.5 V and cancel out each other to make the Zener diodes rated at around 5.5 V the most stable over a wide range of temperature conditions.

7) Transistor

A **transistor** is a semiconductor device used to amplify or switch electronic signals and electrical power. **Transistors** are one of the basic building blocks of modern electronics. It is composed of semiconductor material usually with at least three terminals for connection to an external circuit.

Types of Transistors

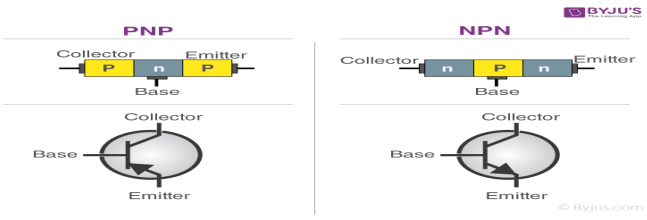
Based on how they are used in a circuit there are mainly two types of transistors.

Bipolar Junction Transistor (BJT)

The three terminals of BJT are base, emitter and collector. A very small current flowing between base and emitter can control a larger flow of current between the collector and emitter terminal. Furthermore, there are two types of BJT. These include;

- P-N-P Transistor: It is a type of BJT where one n-type material is introduced or placed between two p-type materials. In such a configuration, the device will control the flow of current. PNP transistor consists of 2 crystal diodes which are connected in series. The right side and left side of the diodes are known as the collector-base diode and emitter-base diode respectively.

- N-P-N Transistor: In this transistor, we will find one p-type material that is present between two n-type materials. N-P-N transistor is basically used to amplify weak signals to strong signals. In NPN transistor, the electrons move from the emitter to collector region resulting in the formation of current in the transistor. This transistor is widely used in the circuit.

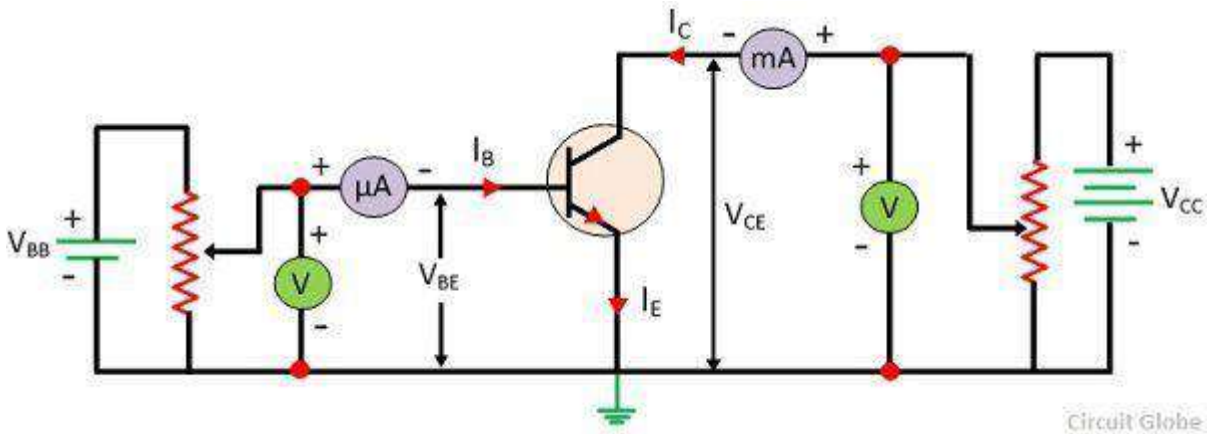


There are three types of configuration as a common base (CB), common collector (CC) and common emitter (CE).

In Common Base (CB) configuration the base terminal of the transistor is common between input and output terminals.

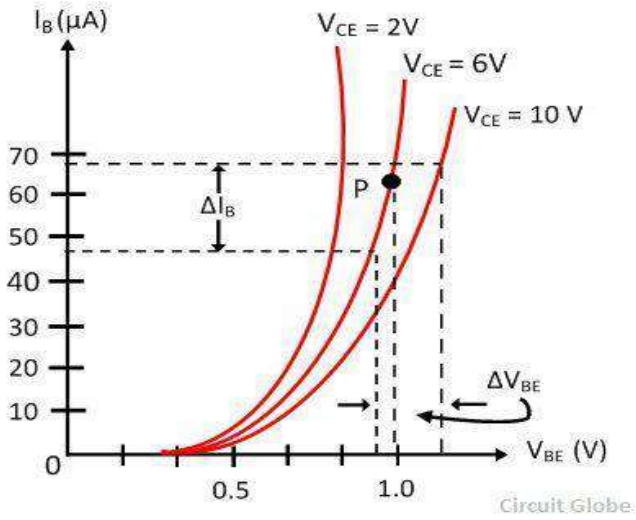
Characteristics of Common emitter (CE) Configuration

The characteristic of the common emitter transistor circuit is shown in the figure below. The base to emitter voltage varies by adjusting the potentiometer R_1. And the collector to emitter voltage varied by adjusting the potentiometer R_2. For the various setting, the current and voltage are taken from the milliammeters and voltmeter. On the basis of these readings, the input and output curve plotted on the curve.



Input Characteristic Curve

The curve plotted between base current I_B and the base-emitter voltage V_{EB} is called Input characteristics curve. For drawing the input characteristic the reading of base currents is taken through the ammeter on emitter voltage V_{BE} at constant collector-emitter current. The curve for different value of collector-base current is shown in the figure below.



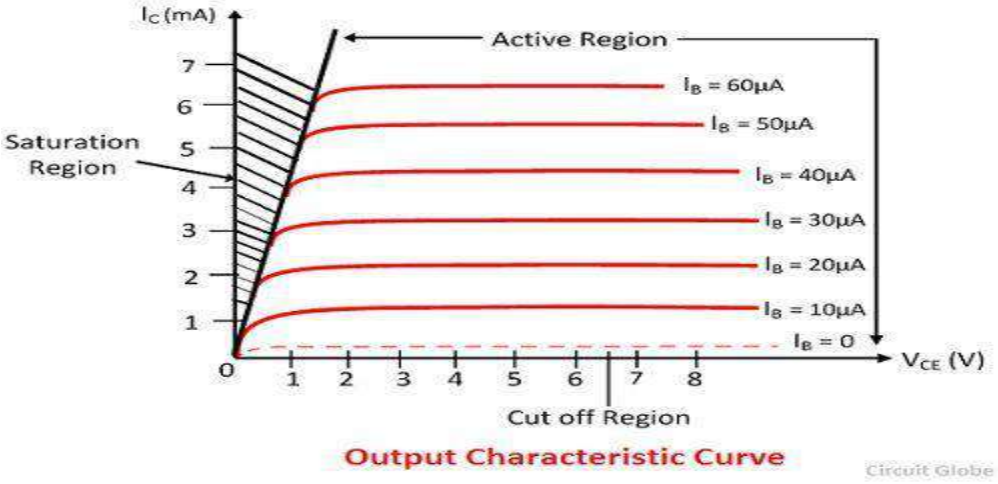
The curve for common base configuration is similar to a forward diode characteristic. The base current I_B increases with the increases in the emitter-base voltage V_{BE}. Thus the input resistance of the CE configuration is comparatively higher that of CB configuration. The effect of CE does not cause large deviation on the curves, and hence the effect of a change in V_{CE} on the input characteristic is ignored.

Input Resistance: The ratio of change in base-emitter voltage V_{BE} to the change in base current ΔI_B at constant collector-emitter voltage V_{CE} is known as input resistance, i.e.,

$$r_i = \frac{\Delta V_{BE}}{\Delta I_B} \text{ at constant } V_{CE}$$

Output Characteristic

In CE configuration the curve draws between collector current I_C and collector-emitter voltage V_{CE} at a constant base current I_B is called output characteristic. The characteristic curve for the typical NPN transistor in CE configuration is shown in the figure below.



In the active region, the collector current increases slightly as collector-emitter V_{CE} current increases. The slope of the curve is quite more than the output characteristic of CB configuration. The output resistance of the common base connection is more than that of CE connection. The value of the collector current I_C increases with the increase in V_{CE} at constant voltage I_B, the value β of also increases. When the V_{CE} falls, the I_C also decreases rapidly. The collector-base junction of the transistor always in forward bias and work saturate. In the saturation region, the collector current becomes independent and free from the input current I_B In the active region $I_C = \beta I_B$, a small current I_C is not zero, and it is equal to reverse leakage current I_{CEO}.

Output Resistance: The ratio of the variation in collector-emitter voltage to the collector-emitter current is known at collector currents at a constant base current I_B is called output

resistance r_o.

$$r_o = \frac{\Delta V_{CE}}{\Delta I_C} \text{ at constant } I_B$$

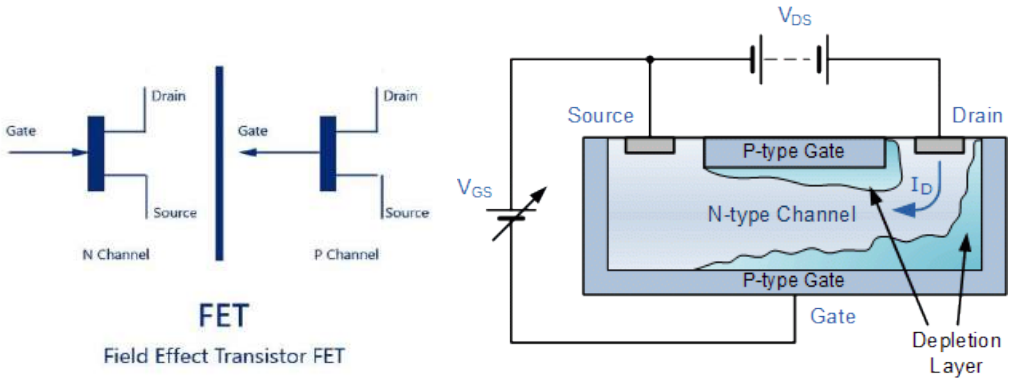
Base Current Amplification Factor (β)

The base current amplification factor is defined as the ratio of the output and input current in a common emitter configuration. In common emitter amplification, the output current is the collector current I_C, and the input current is the base current I_B. In other words, the ratio of change in collector current with respect to base current is known as the base amplification factor. It is represented by β (beta). $\beta = \frac{\Delta I_c}{\Delta I_B}$

8) Field effect transistor

The **field-effect transistor** (**FET**) is a type of transistor that uses an electric field to control the flow of current. FETs are devices with three terminals: *source*, *gate*, and *drain*. FETs control the flow of current by the application of a voltage to the gate, which in turn alters the conductivity between the drain and source.

FETs are also known as **unipolar transistors** since they involve single-carrier-type operation. That is, FETs use either electrons or holes as charge carriers in their operation, but not both. Many different types of field effect transistors exist. Field effect transistors generally display very high input impedance at low frequencies. The most widely used field-effect transistor is the MOSFET (metal-oxide-semiconductor field-effect transistor).



Source

The Source (S) is the electrode of the transistor, which the charge carriers enter the channel, then it acts as the source of carriers for the device, current flowing through the source to the channel is chosen by IS.

Drain

The Drain (D) is the electrode of the transistor, through which the majority charge carriers leave the channel, i.e. they are exhausted from the channel. Conventional current entering the channel at the drain is chosen by ID. Also Drain to Source voltage is frequently chosen by the VDS

Gate

The Gate terminal (G) controls the conductivity of the channel. By applying voltage to gate terminal one can control the ID

The cross sectional diagram above shows an N-type semiconductor channel with a P-type region called the Gate diffused into the N-type channel forming a reverse biased PN-junction and it is this junction which forms the *depletion region* around the Gate area when no external voltages are applied. JFETs are therefore known as depletion mode devices.

This depletion region produces a potential gradient which is of varying thickness around the PN-junction and restrict the current flow through the channel by reducing its effective width and thus increasing the overall resistance of the channel itself.

Then we can see that the most-depleted portion of the depletion region is in between the Gate and the Drain, while the least-depleted area is between the Gate and the Source. Then the JFET's channel conducts with zero bias voltage applied (ie, the depletion region has near zero width).

With no external Gate voltage ($V_G = 0$), and a small voltage (V_{DS}) applied between the Drain and the Source, maximum saturation current (I_{DSS}) will flow through the channel from the Drain to the Source restricted only by the small depletion region around the junctions.

If a small negative voltage ($-V_{GS}$) is now applied to the Gate the size of the depletion region begins to increase reducing the overall effective area of the channel and thus reducing the current flowing through it, a sort of "squeezing" effect takes place. So by applying a reverse bias voltage increases the width of the depletion region which in turn reduces the conduction of the channel.

Since the PN-junction is reverse biased, little current will flow into the gate connection. As the Gate voltage ($-V_{GS}$) is made more negative, the width of the channel decreases until no more current flows between the Drain and the Source and the FET is said to be "pinched-off" (similar to the cut-off region for a BJT). The voltage at which the channel closes is called the "pinch-off voltage", (V_P).

The voltage V_{GS} applied to the Gate controls the current flowing between the Drain and the Source terminals. V_{GS} refers to the voltage applied between the Gate and the Source while V_{DS} refers to the voltage applied between the Drain and the Source.

Because a **Junction Field Effect Transistor** is a voltage controlled device, "NO current flows into the gate!" then the Source current (I_S) flowing out of the device equals the Drain current flowing into it and therefore ($I_D = I_S$).

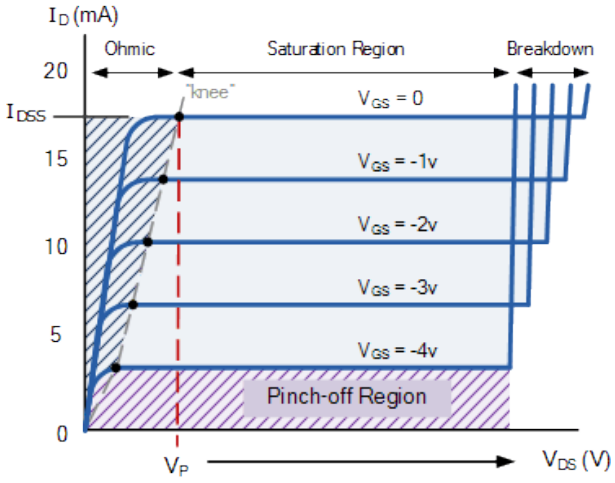
The characteristics curves example shown above, shows the four different regions of operation for a JFET and these are given as:

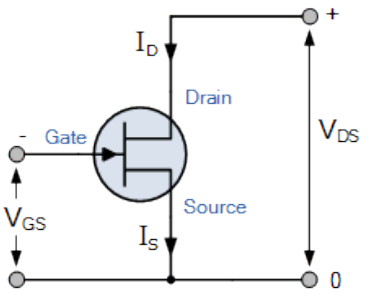
- Ohmic Region – When V_{GS} = 0 the depletion layer of the channel is very small and the JFET acts like a voltage controlled resistor.
- Cut-off Region – This is also known as the pinch-off region were the Gate voltage, V_{GS} is sufficient to cause the JFET to act as an open circuit as the channel resistance is at maximum.
- Saturation or Active Region – The JFET becomes a good conductor and is controlled by the Gate-Source voltage, (V_{GS}) while the Drain-Source voltage, (V_{DS}) has little or no effect.
- Breakdown Region – The voltage between the Drain and the Source, (V_{DS}) is high enough to causes the JFET's resistive channel to break down and pass uncontrolled maximum current.

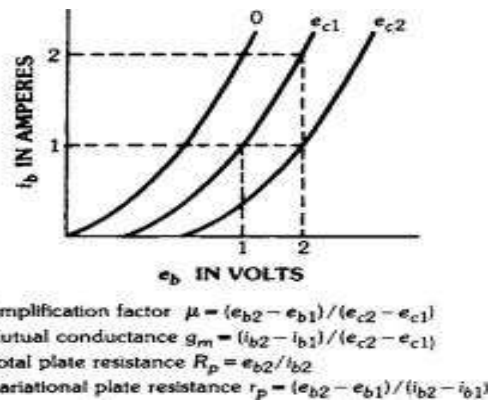
Drain-Source Channel Resistance.

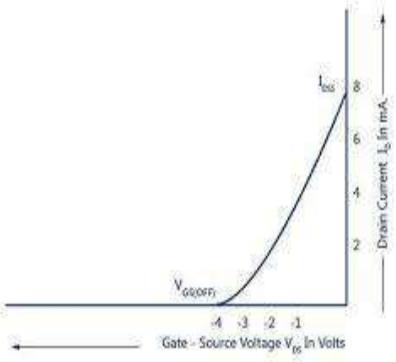
$$R_{DS}=\frac{\Delta V_{DS}}{\Delta I_D}$$

Where: g_m is the "transconductance gain" since the JFET is a voltage controlled device and which represents the rate of change of the Drain current with respect to the change in Gate-Source voltage.









Transfer Characteristics of JFET

$$\mu = \frac{\Delta V_{DS}}{\Delta V_{GS}}$$

$$\mu = \frac{\Delta V_{DS}}{\Delta V_{GS}} = \frac{\Delta V_{DS}}{\Delta I_D} \times \frac{\Delta I_D}{\Delta V_{GS}} = r_d \cdot g_m$$

UNIT IV : IC FABRICATION

An **integrated circuit** or **monolithic integrated circuit** (also referred to as an **IC**, a **chip**, or a **microchip**) is a set of electronic circuits on one small flat piece (or "chip") of semiconductor material that is normally silicon.

Scale of integration:

Name	Signification	Year	Transistor count	Logic gates number
SSI	*small-scale integration*	1964	1 to 10	1 to 12
MSI	*medium-scale integration*	1968	10 to 500	13 to 99
LSI	*large-scale integration*	1971	500 to 20 000	100 to 9999
VLSI	*very large-scale integration*	1980	20 000 to 1 000 000	10 000 to 99 999
ULSI	*ultra-large-scale integration*	1984	1 000 000 and more	100 000 and more

Merits of IC

1. The entire physical size of IC is extremely small than that of discrete circuit.
2. The weight of an IC is very less as compared entire discrete circuits.
3. It’s more reliable.
4. Because of their smaller size it has lower power consumption.
5. It can easily replace but it can hardly repair, in case of failure.
6. Because of an absence of parasitic and capacitance effect it has increased operating speed.

7. Temperature differences between components of a circuit are small.
8. It has suitable for small signal operation.
9. The reduction in power consumption is achieved due to extremely small size of IC.

Demerits of IC

1. Coils or indicators cannot be fabricated.
2. It can be handled only limited amount of power.
3. High grade P-N-P assembly is not possible.
4. It is difficult to be achieved low temperature coefficient.
5. The power dissipation is limited to 10 watts.
6. Low noise and high voltage operation are not easily obtained.
7. Inductors and transformers are needed connecting to exterior to the semiconductor chip as it is not possible to fabricate inductor and transformers on the semiconductor chip surface.
8. Inductors cannot be fabricated directly.
9. Low noise and high voltage operation are not easily obtained.

Monolithic IC Manufacturing Process

For the manufacture and production of the monolithic IC, all circuit components and their interconnections are to be formed in a single thin wafer. The different processes carried out for achieving this are explained below.

1. P-layer Substrate Manufacture

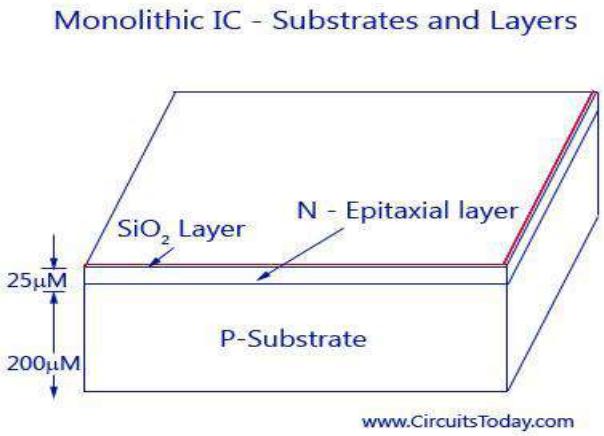
Being the base layer of the IC, the P-type is silicon is first built for the IC. A silicon crystal of P-type is grown in dimensions of 250mm length and 25mm diameter. The silicon is then cut into thin slices with high precision using a diamond saw. Each wafer will precisely have a thickness of 200 micrometer and a diameter of 25 mm. These thin slices are termed wafers. These wafers may be circular or rectangular in shape with respect to the shape of the IC. After cutting hundreds of them each wafer is polished and cleaned to form a P-type substrate layer.

2. N-type Epitaxial Growth

The epitaxial groth process of a low resistive N-type over a high resistive P-type is to be carried out. This is done by placing the n-type layer on top of the P-type and heating then inside a diffusionfurnace at very high temperature (nearly 1200C). After heating, a gas mixture f Silicon atoms and pentavalent atoms are also passed over the layer. This forms the epitaxial layer on the substrate. All the components required for the circuit are built on top of this layer. The layer is then cooled down, polished and cleaned.

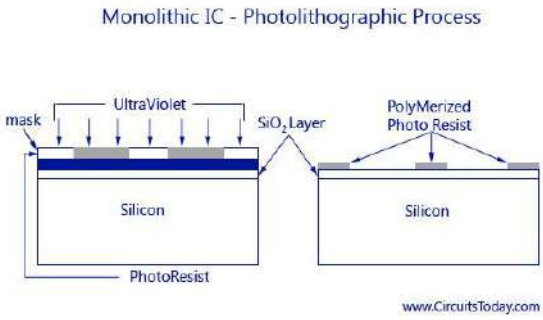
3. The Silicon Dioxide Insulation Layer As explained above, this layer is required contamination of the N-layer epitaxy. This layer is only 1 micrometer thin and is grown by exposing the epitaxial

layer to oxygen atmosphere at 1000C. A detailed image showing the P-type, N-type epitaxial layer and SiO2 layer is given below.



4. Photolithographic Process for SiO2

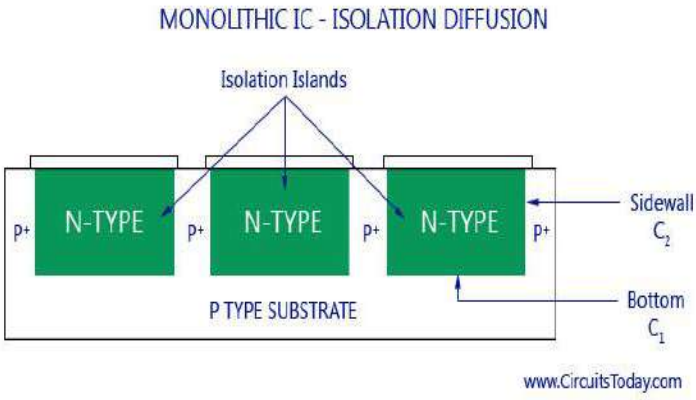
To diffuse the impurities with the N-type epitaxial region, the silicon dioxide layer has to be etched in selected areas. Thus openings must be brought at these areas through photolithographic process. In this process, the SiO2 layer is coated with a thin layer of a photosensitive material called photoresist. A large black and white pattern is made in the desired patter, where the black pattern represents the area of opening and white represents the area that is left idle. This pattern is reduced in size and fit to the layer, above the photoresist. The whole layer is then exposed to ultraviolet light. Due to the exposure, the photoresist right below the white pattern becomes polymerized.



5. Isolation Diffusion

After photolithographic process the remaining SiO2 layer serves as a mask for the diffusion of acceptor impurities. To get a proper time period for allowing a P-type impurity to penetrate into the N-type epitaxial layer, isolation diffusion is to be carried out. By this process, the P-type impurity will travel through the openings in SiO2 layer, and the N-type layer and thus reach the P-type substrate, Isolation junctions are used to isolate between various components of the IC. The temperature and time period of isolation diffusion should be carefully monitored and controlled.

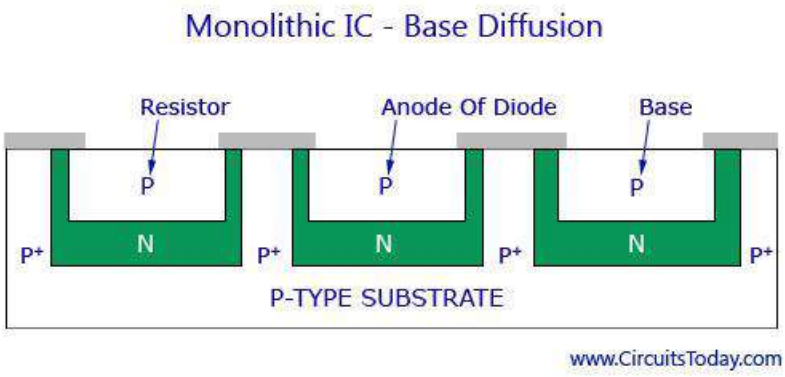
As a result of isolation diffusion, the formation of N-type region called Isolation Island occurs. Each isolated island is then chosen to grow each electrical component. From the figure below you can see that the isolation islands look like back-to-back P-N junctions. The main use if this is to allow electrical isolation between the different components inside the IC. Each electrical element is later on formed in a separate isolation island. The bottom of the N-type isolation island ultimately forms the collector of an N-P-N transistor. The P-type substrate is always kept negative with respect to the isolation islands and provided with reverse bias at P-N junctions. The isolation will disappear if the P-N junctions are forward biased.



Monolithic IC - Isolation Diffusion

An effect of capacitance is produced in the region where the two adjoining isolation islands are connected to the P-type substrate. This is basically a parasitic capacitance that will affect the performance of the IC. This kind of capacitance is divided into two. As shown in the figure C1 is one kind of capacitance that forms from the bottom of the N-type region to the substrate and capacitance C2 from the sidewalls of the isolation islands to the P-region. The bottom component C1 is essentially due to step junction formed by epitaxial growth and, therefore, varies as the square root of the voltage V between the isolation region and substrate. The sidewall capacitance C2 is associated with a diffused graded junction and so varies as (-1/2) exponential of V. The total capacitance is of the order of a few picoFarads.

6. Base Diffusion The working of base diffusion process is shown in the figure below. This process is done to create a new layer of SiO2 over the wafer. P-regions are formed under regulated environments by diffusing P-type impurities like boron. This forms the base region of an N-P-N transistor or as well as resistors, the anode of diode, and junction capacitor. In this case, the diffusion time is so controlled that the P-type impurities do not reach the substrate. The resistivity of the base layer is usually much higher than that of the isolation regions.

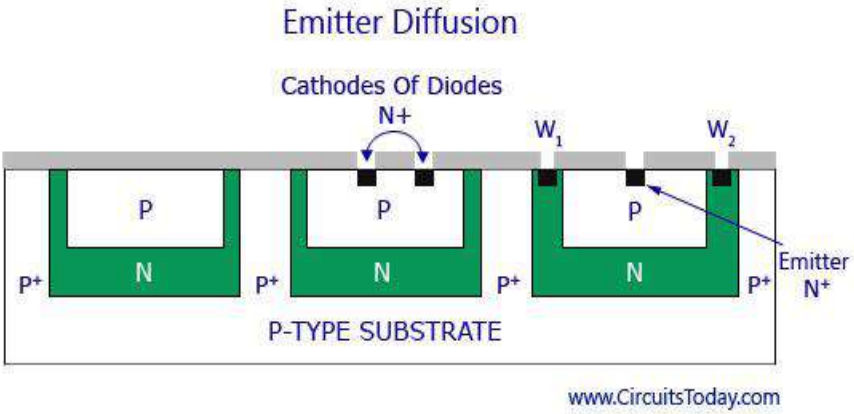


Monolithic IC - Base Diffusion

The isolation regions will have a lot lesser resistivity than that of the base layer.

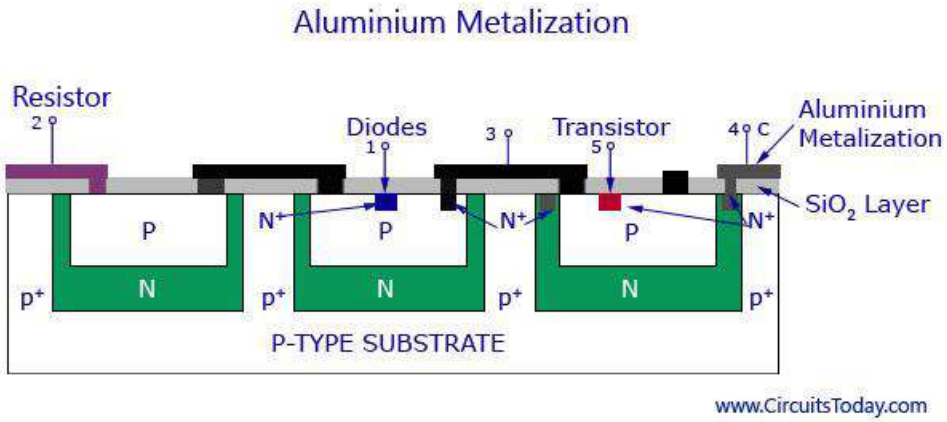
7. Emitter Diffusion

Masking and etching process is again carried out to form a layer of silicon dioxide over the entire surface and opening of the P-type region. The transistor emitters, the cathode regions for diodes, and junction capacitors are grown by diffusion using N-type impurities like phosphorus through the windows created through the process under controlled environmental process. As shown in the figure below there are two additional windows: W1 and W2. These windows are made in the N-region to carry an aluminium metallization process.



8. Aluminium Metallization

The windows made in the N-region after creating a silicon dioxide layer are then deposited with aluminium on the top surface. The same photoresist technique that was used in photolithographic process is also used here to etch away the unwanted aluminium areas. The structure then provides the connected strips to which the leads are attached. The process can be better understood by going through the figure below.



9. Scribing and Mounting

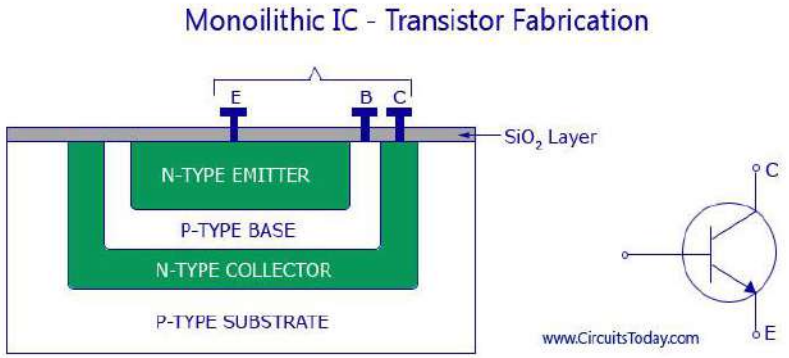
This is the final stage of the IC manufacturing process. After the metallization process, the silicon wafer is then scribed with a diamond tipped tool and separated into individual chips. Each chip is then mounted on a ceramic wafer and is attached to a suitable header. Next the package leads are connected to the IC chip by bonding of aluminium or gold wire from the terminal pad on the IC chip to the package lead. Thus the manufacturing process is complete. Thu, hundreds of IC's is manufactured simultaneously on a single silicon wafer.

Monolithic IC – Component Fabrication

Now we shall discuss in detail how different circuit elements like capacitors, transistors, diodes, and resistors are fabricated into an IC. Please note that it is practically impossible to fabricate an inductor into an IC. It is thus added externally by connecting it to the corresponding IC pin as designed by the manufacturer.

Transistors

The fabrication process of a transistor is shown in the figure below. A P-type substrate is first grown and then the collector, emitter, and base regions are diffused on top of it as shown in the figure. The surface terminals for these regions are also provided for connection.

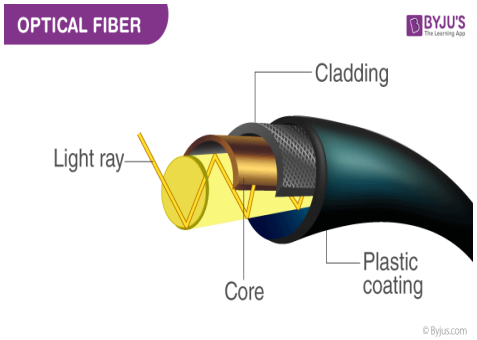


Both transistors and diodes are fabricated by using the epitaxial planar diffusion process that is explained earlier. In case of discrete transistors, the P-type substrate is considered as the collector. `But this is not possible in monolithic IC's, as all the transistors connected on one P-type substrate would have their collectors connected together. This is why separate collector regions are diffused into the substrate.

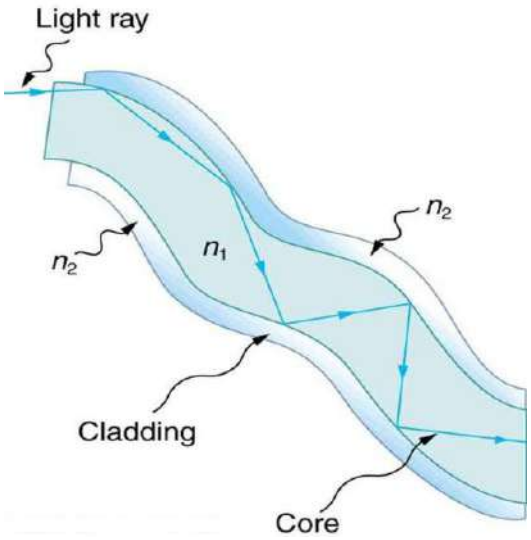
Unit-5 Fibre optics

1) Optical fibre

It is made up of transparent dielectrics. An optical fibre consists of a central core glass surrounded by a cladding which is slightly lower refractive index than core.



The cladding is enclosed by strength members and polyurethane jacket, which acts as a protective skin for core and cladding. The protective layer is used to so has to make the optical cable to withstand for hard pulling, bending, sketching and rolling. The layer also traps the escaping light from core.

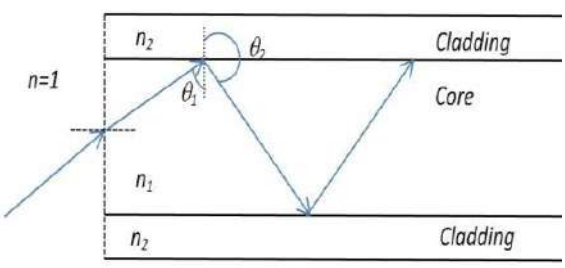


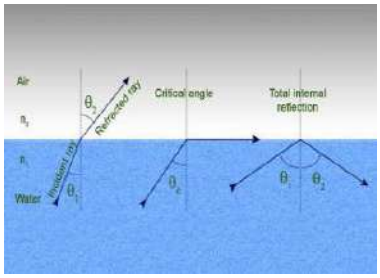
Total internal reflection is a powerful tool since it can be used to confine light. One of the most common applications of total internal reflection is in fibre optics. An optical fibre is a thin, transparent fibre, usually made of glass or plastic, for transmitting light. The construction of a single optical fibre is shown in the figure. The basic functional structure of an optical fiber consists of an outer protective cladding and an inner core through which light pulses travel. The overall diameter of the fiber is about 125μm and that of the core is just about 50μm. The difference in refractive index of the cladding and the core allows total internal reflection in the same way as happens at an air-water surface show in the figure . If light is incident on a cable end with an angle of incidence greater than the critical angle then the light will remain trapped inside the glass strand. In this way, light travels very quickly down the length of the cable over a very long distance (tens of kilometers). Optical fibers are commonly used in telecommunications, because information can be transported

over long distances, with minimal loss of data. Another common use can be found in medicine in endoscopes. The field of applied science and engineering concerned with the design and application of optical fibers are called fiber optics.

2) PROCESS OF TOTAL INTERNAL REFLECTION IN OPTICAL FIBRES – DIAGRAM

The phenomenon which occurs when the light rays travel from a more optically denser medium to a less optically denser medium.





We can say that the refracted angle θ_2 is dependent on the ratio of the indices of the two materials n2 n1 as well as the incident angle θ_1. As a result, by controlling the ratio of the indices, one can control the refracted angle such that all of the light is reflected back from the interface. This is known as total internal reflection and is the method that allows for light to be contained and guided inside of a fiber optic.

Formula of Total Internal Reflection

Total internal reflection	n1/n2=sinr/sini
Critical angle, Θ	sinΘ=n2/n1

What are the conditions of Total Internal Reflection?

Following are the two conditions of total internal reflection:

- The light ray moves from a more dense medium to less dense medium.
- The angle of incidence must be greater than the critical angle.

3) Acceptance angle:

The **acceptance angle** of an **optical fiber** is defined based on a purely geometrical consideration (ray **optics**): it is the maximum **angle** of a ray (against the **fiber** axis) hitting the **fiber** core which allows the incident light to be guided by the core.

Numerical Aperture of Optical Fiber:

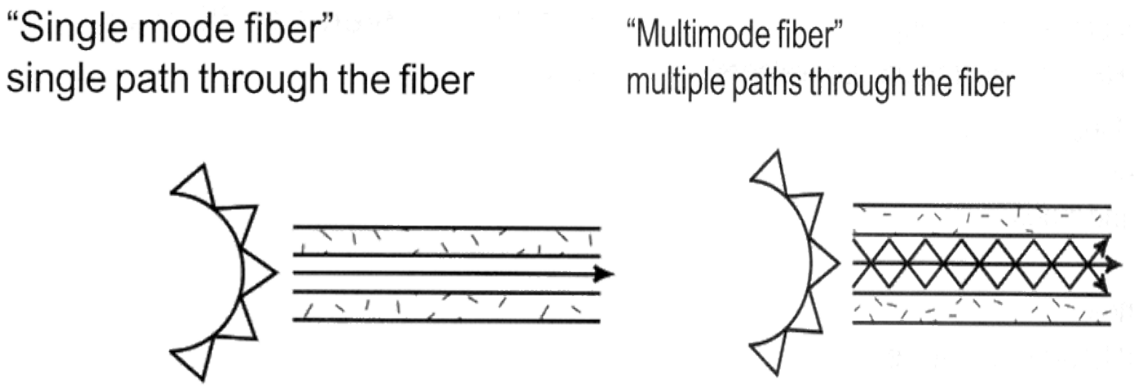
Definition: Numerical Aperture is the measure of the ability of an optical fiber to collect or confine the incident light ray inside it. It is among the most basic property of optical fiber.

4) Types of optical fibre

Single Mode cable is a single stand (most applications use 2 fibers) of glass fiber with a diameter of 8.3 to 10 microns that has one mode of transmission. Single Mode Fiber with a relatively narrow diameter, through which only one mode will propagate typically 1310 or 1550nm. Carries higher bandwidth than multimode fiber, but requires a light source with a narrow spectral width. Synonyms mono-mode optical fiber, single-mode fiber, single-mode optical waveguide, uni-mode fiber. Single Modem fiber is used in many applications where data is sent at multi-frequency (WDM Wave-Division-Multiplexing) so only one cable is needed - (single-mode on one single fiber). Single-mode fiber gives you a higher transmission rate and up to 50 times more distance than multimode, but it also costs more. Single-mode fiber has a much smaller core than multimode. The small core and single light-wave virtually eliminate any distortion that could result from overlapping light pulses, providing the least signal attenuation and the highest transmission speeds of any fiber cable type. Single-mode optical fiber is an optical fiber in which only the lowest order bound mode can propagate at the wavelength of interest typically 1300 to 1320nm.

Multi-Mode cable has a little bit bigger diameter, with a common diameters in the 50-to-100 micron range for the light carry component (in the US the most common size is 62.5um). Most applications in which Multi-mode fiber is used, 2 fibers are used. POF is a newer plastic-based cable which promises performance similar to glass cable on very short runs, but at a lower cost.

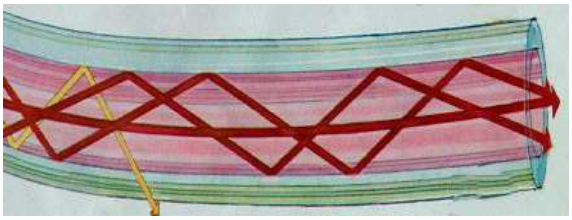
Single mode fibre:



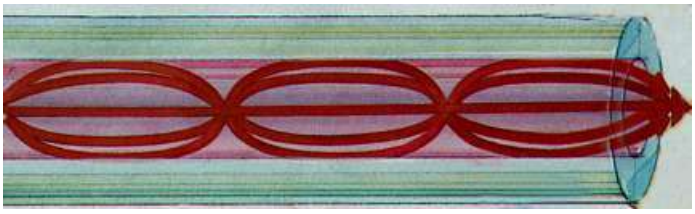
Multimode fiber gives you high bandwidth at high speeds (10 to 100MBS - Gigabit to 275m to 2km) over medium distances. Light waves are dispersed into numerous paths, or modes, as they travel through the cable's core typically 850 or 1300nm. Typical multimode fiber core diameters are 50, 62.5, and 100 micrometers. However, in long cable runs (greater than 3000 feet [914.4 meters), multiple paths of light can cause signal distortion at the receiving end, resulting in an unclear and incomplete data transmission so designers now call for single mode fiber in new applications using Gigabit and beyond.

Multimode fibre:

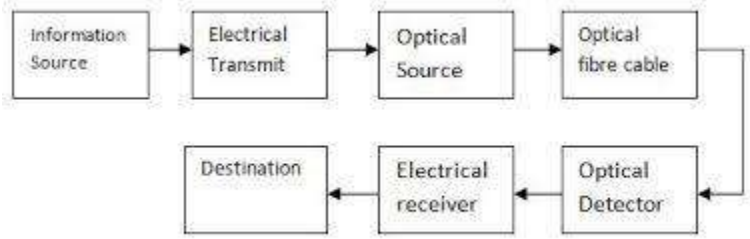
STEP-INDEX MULTIMODE FIBER has a large core, up to 100 microns in diameter. As a result, some of the light rays that make up the digital pulse may travel a direct route, whereas others zigzag as they bounce off the cladding. These alternative pathways cause the different groupings of light rays, referred to as modes, to arrive separately at a receiving point. The pulse, an aggregate of different modes, begins to spread out, losing its well-defined shape. The need to leave spacing between pulses to prevent overlapping limits bandwidth that is, the amount of information that can be sent. Consequently, this type of fiber is best suited for transmission over short distances, in an endoscope, for instance.



GRADED-INDEX MULTIMODE FIBER contains a core in which the refractive index diminishes gradually from the center axis out toward the cladding. The higher refractive index at the center makes the light rays moving down the axis advance more slowly than those near the cladding. Also, rather than zigzagging off the cladding, light in the core curves helically because of the graded index, reducing its travel distance. The shortened path and the higher speed allow light at the periphery to arrive at a receiver at about the same time as the slow but straight rays in the core axis. The result: a digital pulse suffers less dispersion.



Block diagram of fibre optics:



1 .**Transmitter**: An electric signal is applied to the optical transmitter. The optical transmitter consists of driver circuit, light source and fiber flylead.

- Driver circuit drives the light source.
- Light source converts electrical signal to optical signal.
- Fiber flylead is used to connect optical signal to optical fiber.

2. Transmission channel: It consists of a cable that provides mechanical and environmental protection to the optical fibers contained inside. Each optical fiber acts as an individual channel.

- Optical splice is used to permanently join two individual optical fibers.
- Optical connector is for temporary non-fixed joints between two individual optical fibers.
- Optical coupler or splitter provides signal to other devices.
- Repeater converts the optical signal into electrical signal using optical receiver and passes it to electronic circuit where it is reshaped and amplified as it gets attenuated
- and distorted with increasing distance because of scattering, absorption and dispersion in waveguides, and this signal is then again converted into optical signal by the optical transmitter.

3. **Receiver**: Optical signal is applied to the optical receiver. It consists of photo detector, amplifier and signal restorer.

- Photo detector converts the optical signal to electrical signal.
- Signal restorers and amplifiers are used to improve signal to noise ratio of the signal as there are chances of noise to be introduced in the signal due to the use of photo detectors.
- For short distance communication only main elements are required.

Source- LED

Fiber- Multimode step index fiber

Detector- PIN detector

- For long distance communication along with the main elements there is need for couplers, beam splitters, repeaters, optical amplifiers.

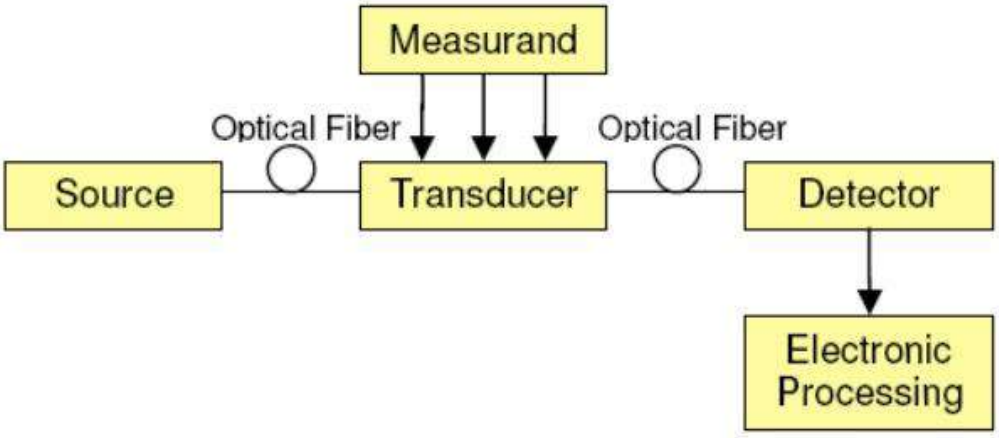
Source- LASER diode

Fiber- single mode fiber

Detector- Avalanche photo diode (APD)

Fiber-optic sensor

Optical sensor is a transducer which converts any form of a signal into optical signal in the measurale form. Here optical fibres are used as a guidding media and hence called as a wave guide.



Typesof Sensors

1. Intrinsic sensors (or) Active sensors
2. Extrinsic sensors (or) Passive sensors

Intinsic sensor

In intrinsic sensors the physical parameter to be sensed directly acts on the fibre itself to produce the changes in the transmissioncharacteristics.

Example:Liquid level sensors.

Extrinsic sensors

In extrinsic sensors separate sensing elements will be used and the fibre will act as a guiding media to the sensors.

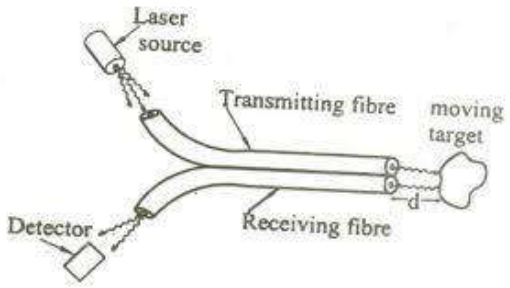
Example: Displacement sensor.

Displacement sensors:

Principle: Light is sent through a transmitting fiber and is made to fall on a moving target. The reflected light from the target is sensed by a detector with respect to intensity of light reflected and the displacement of the target is measured..

Description: It consists of a bundle of transmitting fibers coupled to the laser source and a bundle of receiving fibers coupled to the detector.

The axis of the transmitting fiber and the receiving fiber with respect to the moving target can be adjusted to increase the sensitivity of the sensor.



Working:

Light from the source is transmitted through the transmitting fiber and is made to fall on the moving target. The light reflected from the target is made to pass through the receiving fiber and the same is detected by the detector.

Based on the intensity of light received, the displacement of the target can be measured, (i.e.) If the received intensity is more, then we can say that the target is moving towards the sensor and if the intensity is less, we can say that the target is moving away from the sensor.

BOOKS FOR REFERENCE:

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2. Principles of Electronics- V.K.Metha (S.Chand & Co.2010)
3. Engineering physics -I , Dr. G. Senthil kumar (VRB Hitech Pub.Pri.Ltd. 2014-15)