MODULE 5

SUPER CONDUCTIVITY

In 1911, the physicist Kammerlingh Onnes discovered the phenomenon of superconductivity. He found that the resistivity of mercury suddenly dropped to zero at 4.2K .

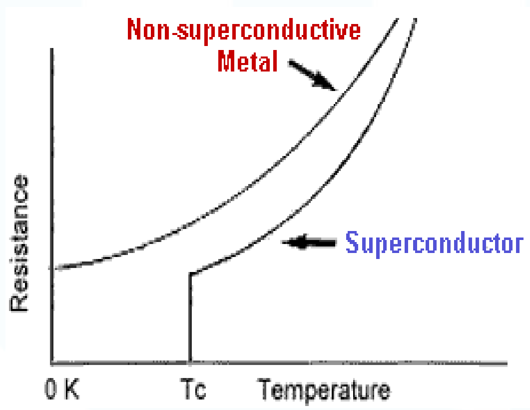
The property by which the resistivity of many metals and alloys suddenly falls to zero when they are cooled at a particular temperature is called superconductivity.

A number of elements and alloys exhibit superconductivity. The materials which exhibit the property of superconductivity and which are in the superconducting state are called superconductors.

Transition temperature(Tc) is that temperature at which the material changes from its normal conducting state to superconducting state.

It is found that superconducting transition is reversible. Above the transition temperature, the material is in the normal state and below the transition temperature, it is in the superconducting state

The relation between temperature and resistivity for a conductor and a superconductor is as in fig.

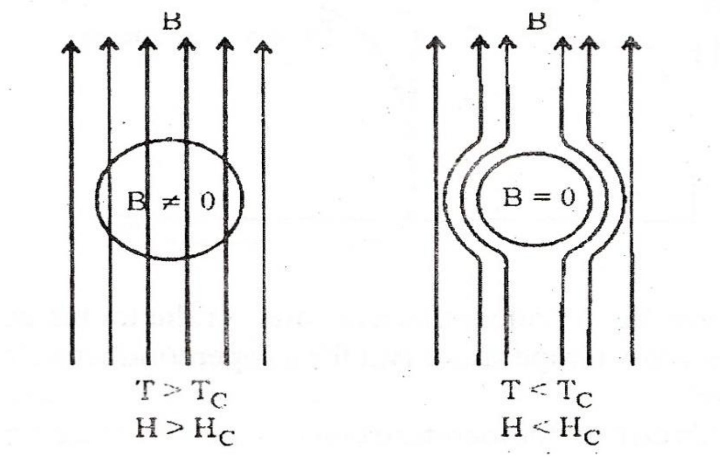


From the fig. it is clear that a normal conductor has some resistivity at very low temperature. But for a superconductor, it suddenly falls to zero.

MEISSNER EFFECT- PERFECT DIAMAGNET

In 1933 Meissner and Ochenfeld studied the properties of materials in the presence of magnetic field. It is found that all the magnetic lines have been expelled from the interior of the specimen when it is cooled below the transition temperature in the magnetic field.

The property of expulsion of magnetic flux density from the interior of a superconducting material during the transition from normal state to superconducting state is called Meissner effect.



When a specimen is placed in a magnetic field H, magnetic lines are passing through it.

$$B = \mu_0 (H + M)$$

Where,

B = flux density inside the specimen

μ_0 = Permeability

M = magnetization

When the specimen is cooled below the transition temperature, all magnetic lines are cancelled from the specimen.

Since B=0 , $\mu_0(H + M) = 0$

H = -M

Magnetic susceptibility χ = M/H = -1

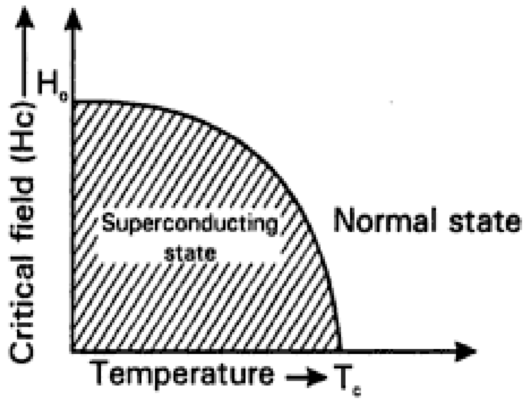
Hence the superconductor becomes a perfect diamagnet at the transition temperature.

PROPERTIES OF SUPERCONDUCTORS

1. Effect of magnetic field - Critical field (Hc)

Superconductivity vanishes if a sufficiently strong magnetic field is applied. The minimum strength ofa magnetic field required to destroy the superconducting nature of a metal at a particular temperature is called **critical field Hc**.

When the applied field is below Hc material will be in superconducting state and if it exceeds Hc, it gets converted into its normal state. The variation of critical field Hc with temperature is represented by a parabolic curve as in fig.Hc is 0 at Tc and increases when the temperature decreases .



$$H_c = H_0\left[1-\left(\frac{T}{T_c}\right)^2\right]$$

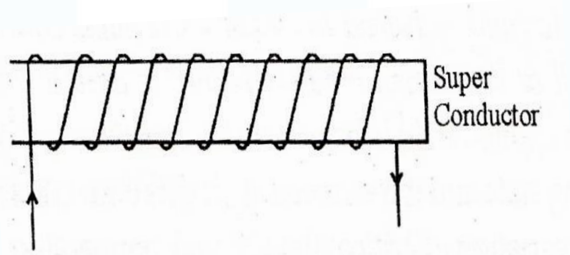
.
Where,

H_0 is the maximum critical field at Absolute zero (0K)
Hc is the maximum critical field at a temperature T
Tc is transition temperature

2. Effect of current density - Critical current(Ic) – Silsbee effect

Consider a coil of wire wound on a superconductor. When a current is passed through a conductor, it produced a magnetic field which changes it from superconducting state to normal state.

The minimum current that can be passed through a superconducting material without destroying its superconducting property is called critical current Ic.



The critical current Ic is given by

$I_c = 2 \Pi r H_c$

Where,

r is the radius of the superconductor
Hc is the critical field

Critical currentdensity Jcis the the minimum current density in a superconducting material below which the material remains in a superconducting state. If it exceeds this critical value, the material converts into its normal state. This was discovered by Silsbee and it is called Silsbee effect.

$J_c = I_c / A$ where A is the area.

3. Isotope effect

It is found that transition temperature varies with isotopic mass. This variation of transition temperature with isotopic mass is called isotopic effect.

$$T_C \alpha \frac{1}{M^{\alpha}}$$

$$\alpha = \frac{1}{2}$$

$$T_C M^{\frac{1}{2}} = constant$$

Where M is the mass of isotope. Larger the isotopic mass, smaller the transition temperature.

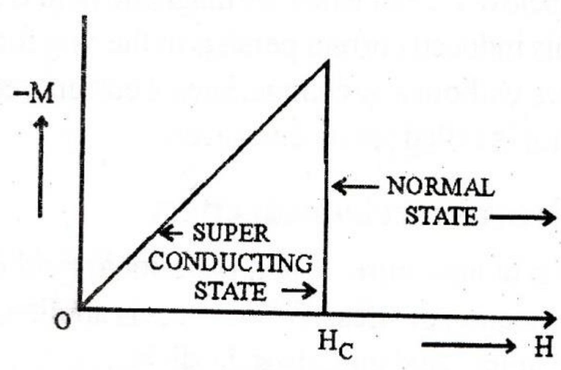
TYPES OFSUPERCONDUCTORS

Superconductors are divided into 2 types depending on the magnetic properties. They are

1. **Type I or Soft superconductor**
2. **Type II or Hard superconductor**

Type I or soft superconductors

When a superconductor is placed in a magnetic field H,the intensity of magnetization M is induced in it. When H increases, M also increases. The variation of M with H is shown in fig.

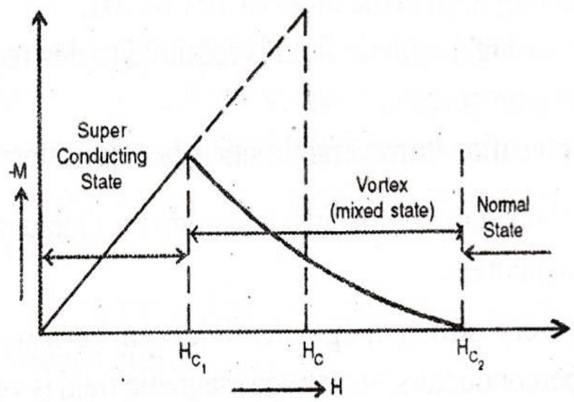


Up to the critical field Hc, magnetization increases proportional to the applied field and it abruptly drops to zero at the critical field. Above Hc it behaves as normal conductor. Below Hc, it is in the superconducting state. Up to Hc, it behaves like a diamagnet and strictly obeys Meissner effect.

Type of superconductors for which M becomes zero abruptly when H=Hc are called Type 1 superconductors. The transition from superconducting state to normal state is very abrupt. The critical field Hc is very small in the order of 0 .1 or 0.2 Tesla. Therefore it is easy to change type I superconductor in to a normal conductor. Hence they are also known as soft superconductors. The transition is reversible.

Eg: Al, Pb,Indium and almost all pure metals.

Type 2 superconductors



In this type there are two critical field,Lower critical field $Hc_1$and upper critical fields Hc_2. Up to Hc_1 magnetism is proportional to the applied field and it behaves like Type 1 superconductors. It strictly obeys Meissner effect up to Hc_1. In between Hc_1 and Hc_2 magnetization decreases gradually. At Hc_2, the magnetisation vanishes completely and external field penetrates, completely destroying the superconductivity .Above Hc_2 material behaves as normal conductor. Between Hc_1 and Hc_2 material is in a mixed state (it behaves partially conducting as well as partially superconducting) known as vortex state. It does not strictly obey meissner effect in this region.

Transition from superconducting state to normal state is very slow and gradual. The field Hc_2 value is very high in the order of 10T to 20T. A strong magnetic field is required to convert it into a normal conductor. They are known as hard superconductors. The transition is irreversible. Very strong magnetic field can be produced using type II superconductors.

Eg: Niobium, Germanium and all alloys

HIGH TEMPERATURES SUPERCONDUCTORS –HTSC

The discovery of a new type of superconductors is one of the most important scientific events in our century. Scientists made a lot of research works to produce superconductor with high Tc. In 1977 a high transition temperature 23 K was achieved using metallic compound of niobium and Germanium .But in 1986 Bedddnorz and Muller discovered La – Ba-CuO system of ceramic super conductors with a Tc of 34 K. Such superconductors with high critical temperature are called High Temperature Superconductors

High Temperature Super conductors are ceramic super conductors with a high transition temperature greater than 40 K.

In low temperature superconductors it is very difficult and expensive to maintain low temperature for a very long period .It is very difficult to maintain the liquid helium temperature (4.2K). nowadays it is possible to replace the expensive liquid He with cheaper and more efficient coolant liquid nitrogen. The temperature Tc can be raised using microwaves or laser radiations.

In ceramic superconductors , the cell contains 1 atom of rare earth metal, 2 Barium atoms,3 copper atoms and 7 Oxygen atoms. Since no. of atoms of metal are in the ratio 1:2:3 , such ceramic super conductors are called 1-2-3 super conductors and it is working at Tc of 90K. Copper oxide superconductors belongs to another group of HTSC working at Tc of 120K . The Resonating Valence Bond State Theory explained HTSC.

ADVANTAGES OF HTSC OVER LOW TEMPERATURE SUPERCONDUCTORS

1. In low temperature superconductors it is very difficult and expensive to maintain low temperature for a very long period . But in HTSC ,it is very easy to maintain the temperature. The temperature Tc can be raised using microwaves or laser radiations.
2. Smaller isotopic effect and smaller coherence length.
3. Here pressure raises the Tc of HTSC but lowers Tc of low temperature superconductors.

APPLICATIONS OF SUPERCONDUCTIVITY

It has a wide range of applications

1. Superconductors are used to produce a very strong and powerful magnetic field in the order of 20T at a low cost.

a) To bend and guide the charged particles in particle accelerators , cyclotrons etc.

b) Used for controlling and focusing high temperature plasma for the controlled nuclear fusion .

c) Used in magnetic levitation –Maglev.

d) Superconducting magnets are used to produce very efficient ore separating machines.

2) Medical field

a) MRI: The most important medical application of superconductivity is MRI. MRI is free from harmful effects of other radiations like X-rays.

b) Superconducting magnetic field is used to remove tumour cells from the healthy cells

c) A group of squids is used for the diagnosis of epilepsy

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d) Using superconducting susceptometer the iron content in the body can be estimated .

e) Squids are used to measure minute magnetic fields produced from heart and brain very accurately and used for pathological analysis of their functions.

3) Electric energy and power transmission

Another important application of superconductors is in the manufacture of electrical motors ,generators and other machines using superconducting windings . The efficiency of such machines is higher . They are smaller, lighter ,more efficient and they provide higher out put . The electric power can be transmitted through superconducting cables without any transmission losses.

4) Electronics and small devices

a) Squid : squid is used as a magnetometer to measure even a very feeble changing magnetic field . It is used to explore the oil and minerals deposits from earth, to separate ores, to study gravitons ,to detect submarines and in the study neuro physics .

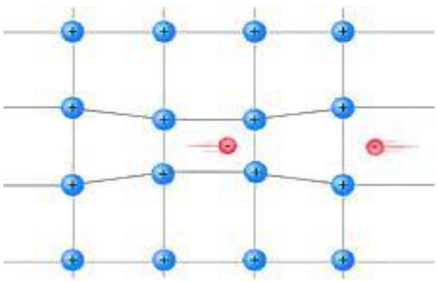
b) Josephson effect :Frictionless bearings , magnetically controlled superconducting switches ,superconductor fuses and breakers,superconducting transformers etc . are very sensitive and more efficient devices.

5) Computers and information processing

If superconducting wires are used ,a large number of components and circuits can be setup within a very smaller area . This reduces size of components. superconducting materials are used as efficient storage devices in computers .

BCS THEORY

Bardeen ,Cooper and Schrieffer developed a new theory to explain superconductivity of materials and this is known as BCS theory. According to this theory, superconductivity is mainly due to the interaction of phonons and electrons.



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When an electron is advancing through a path in between 2 sets of positive ions in the lattice, electron attracts nearby positive ions and lattice gets distorted. This distortion produces a region of increased positive charge density and is called phonon. If a second electron approaches this region, this electron also attracted by the positive region. Thus these 2 electrons are held together by force of attraction by phonon. Thus 2 electrons are coupled together at low temperature and this pair is called cooper pair. Cooper pair behaves like single particle. Cooper pair has zero spin and zero linear momentum. At absolute zero almost all electrons are coupled together as cooper pairs.

Superconducting energy gap

The net energy of electrons in a cooper pair is less than the total energy of these individual electrons. There is an energy gap in the energy spectrum of electrons. All the Cooper pairs are occupying lower energy states and energy gap prevents them from unpairing. The minimum energy required to break up cooper pairs is called superconducting energy gap. When temperature increases ,energy gap decreases. At Tc energy gap becomes zero and cooper pairs are broken up and thus electrons are separated.

PHOTONICS

Photonics is the science of light generation, detection, and manipulation.

BASICS OF SOLID STATE LIGHTING

Solid state lighting is a technology (SSL) in which the conventional light sources are replaced by semiconductor diodes, organic light emitting diodes etc. SSL creates visible light with reduced heat generation and less energy dissipation. For SSL efficiency is high comparing to conventional light sources.

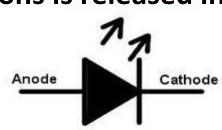
This technology has advantages over conventional lamps. SSL devices has long life span over conventional lamps. They do not emit ultraviolet radiations. It can work at lower temperature. Solid state lamps do not contain hazardous substance as in CFL.

The photovoltaic effect

The photovoltaic effect is the creation of voltage and electric current in a material upon exposure to light

LIGHT EMITTING DIODE (LED)

LED is a PN junction diode that gives off visible light when forward biased. When a LED is forward biased, the electrons from n-region and holes from p-region combine to produce energy and that will be emitted as light radiation. The electrons are in the conduction band(C.B 0 of n-type and at a higher state.The holes in the valence band (V.B) of p-type which are at a lower energy state.When forward biased electrons and holes recombine and the excess energy of electrons is released in the form of light.



Depending on the band gap light emitted will be in the IR region or visible region.LED band gap -1.8 eV to 2.8 eV. By doping we can modify the band gap.

The frequency of the emitted light is governed by the band gap of the semiconductor.

Frequency = Eg /h , where Eg is the band gap energy

They are made from elements like Gallium, Phosphorus and Arsenic. Different coloured LED can be made by making suitable compounds of these elements. Using Galium Arsenide red light is produced. Multi coloured LEDs are made by combining two LEDs.

PROPERTIES OF LED

- **It radiates very little heat**

- Fast on-off switching ability
- Low operational voltage and less power
- They do not contain mercury as in CFL.
- Small size and long life
- Available in all colours

APPLICATIONS OF LED

- Due to lack of heat radiations LEDs are enormously used in stage decorations
- Eco-friendly . The amount of CO_2 produced is comparatively much smaller than incandescent light
- Used for backlighting LCD televisions and laptops
- In cameras and mobile phones as flash lamps
- Indicator lamps and read out displays on devices
- In optical communication systems
- Seven segment display

PHOTO DETECTORS

The functions of a photo detector is to detect the optical signal and are based on semiconductor pn junction devices . The device can be operated either in photo voltaic mode or photo conductive mode. In photo voltaic mode the junction is treated as an open circuit to measure the voltage across the junction. In photoconductive mode the pn junction is connected in the reverse bias and the current is made to flow externally to complete the circuit between the junction.

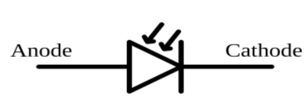
When the pn junction is connected in reverse bias a large depletion region is created. When the light with energy $h\upsilon >> E_g$ falls on the depletion layer of junction electrons are excited to the conduction band leaving a hole in valence band. Thus electron- hole pairs are produced and hence electric current. The number of electron-hole pairs depends on the amount of incident light.

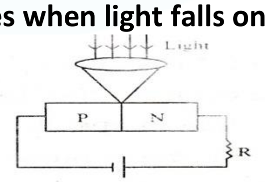
Commonly used photo detectors are,

- Photodiode
- PIN photodiode

PHOTO DIODE

Photo diode is a silicon or germanium p-n junction working under reverse biased condition. Reverse current increases when light falls on the junction.





CONSTRUCTION

Photodiode consist of a p-n junction mounded on an insulating substrate and sealed inside a metal case.A glass window is provided at the top for allowing light to strike at the junction.Two terminals acts as anode and cathode.

When a small reverse voltage is applied a very small current flows through the diode. This is due to minority charge carriers.At the same time majority charge carriers are prevented from crossing the junction.The current flowing through the reverse biased photodiode when no light is incident on the junction is called ‘ dark current ‘ .The corresponding resistance is called ‘dark resistance’

Dark resistance=V_R/I_d

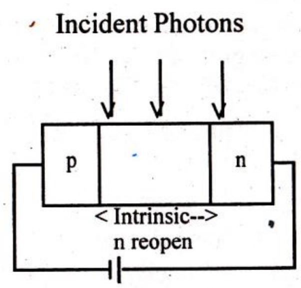
where V_R is reverse voltage and I_d the dark current.

When light falls on the junction the energy of the photons produce more electron-hole pairs.The number of new electron-hole pairs is proportional to the number of incident photons.

APPLICATIONS

- Used in CAT scanner
- Climate control-sunlight detector
- Widely used in optical communication
- For brightness control and barcode scanning
- In security systems

PIN PHOTO DIODE



PIN Photodiode

Pin photo diode is also a kind of photo detector. Pin photodiode convert optical signal into electrical signals. It consists of three regions, P region, intrinsic region (undoped) and N region. P and n regions are heavily doped. The width of intrinsic region should be larger .

PIN photo diode is operated in reverse bias. Under reverse bias majority charge carriers in n region and p region moves away from the junction.so width of depletion region is very wide. i.e majority charge carriers will not carry electric current under reverse bias. But the minority carriers will carry electric current

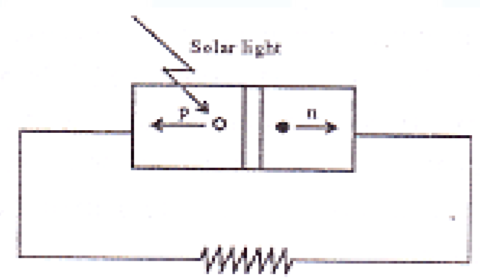
When light is incident on the pin diode,most part of light energy absorbed in intrinsic region and a large number of electron –hole pairs are generated.Free electron generated in the intrinsic region move towards n-side where as holes generated in the intrinsic region move towards p side. When free electrons and holes reaches the n and p regions they are attracted towards the terminals of the battery

ADVANTAGES

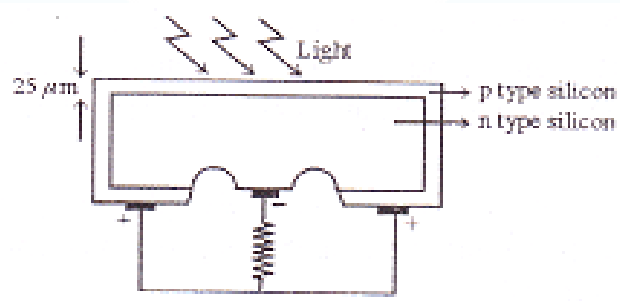
- Wide bandwidth
- High efficiency
- High response speed
- They generate more electric current than PN junction photodiode with the same amount of light energy.

SOLAR CELL

A solar cell is an LED operating in the reverse method. Also called photovoltaic cell. Solar cell produces electrical energy from light energy. Sunlight is absorbed at the p-n interface. It excites electrons from the valence band of p-type to the conduction band of n-type .This leaves a hole in the valence band. Sun light produces electron-hole pairs. The electric field at the junction pulls the electrons towards the n-region and holes towards the p-region. As a result a current flows from p-terminal to the n-terminal throughan external circuit.



The e.m.f of a silicon solar cell is 0.6V. Usually solar cells are grouped into modules and panels, like grouping of cells, so that any desired voltage can be made available .Storage batteries arranged together with these solar cells store up the excess electrical energy during daytime and it can be used at night.



Usually a solar cell is made by depositing a thin layer of p-type silicon on a wafer of n-type silicon.The semiconducting material must be very thin so that it is transparent to sunlight. Each photon caries an energy E=hv joules. If this photon energy is greater than the gap energy, the photons entering the region can break the covalent bonds and produce electron hole pairs.The resulting carriers produce a photocurrent

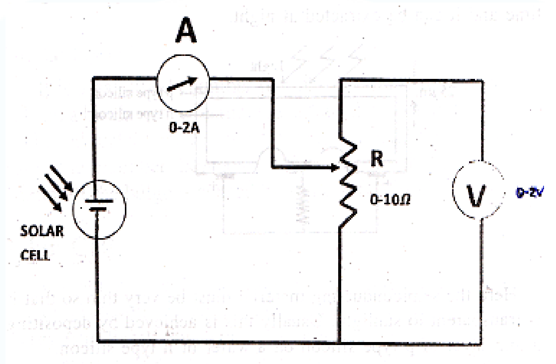
$$h\nu = eE_g \qquad \therefore \nu_{\min} = \left(\frac{eE_g}{h}\right)$$

$$h\left(\frac{C}{\lambda}\right) = eE_g \qquad \therefore \lambda_{\max} = \left(\frac{hC}{eE_g}\right)$$

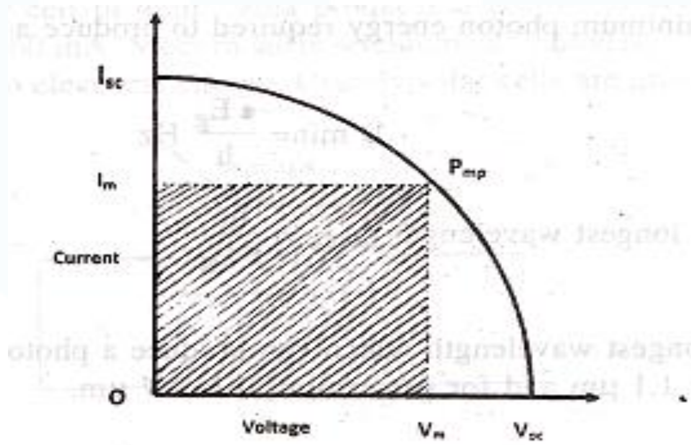
Solar cells are added together into a unit called a module.Modules are linked together in units called arrays or panels .

THE V-I CHARACTERISTICS

The V-I characteristics of a solar cell can be determined by connecting a resistance box, a voltmeter and an ammeter.



A source of light from a halogen lamp is made to fall on a solar cell .The resistance of the circuit is varied by using a resistance box and the corresponding values of voltage and current are measured.A graph is drawn between voltage and current and the V-I characteristic is as shown.



The open circuit voltage V_{oc} and the short circuit current I_{sc} is noted. Their product gives the ideal power of the solar cell. From Fig, the max.useful power is given by the largest rectangle that can be formed inside the V-I curve.

The *fill factor* is defined as the ratio of the actual maximum obtainable power, to the product of the open circuit voltage and short circuit current. The fill factor of a solar cell is found in the range 0.3 to 0.7.

Fill factor= Max. power output/ open circuit voltage x short circuit current

F.F =P_{mp}/(V_{oc} X I_{sc})

Efficiency of a solar cell is the ratio of the electrical power output of the solar cell to the incident sunlight energy.This is calculated by dividing a cell's power output at it's maximum power by input light intensity and surface area of solar cell.

$$Efficiency\ \eta = \frac{P_{mp}}{Light\ \text{int}\ ensity \times area\ of\ \ solar\ \ cell} \times 100$$

The efficiency of solar cell various from 10 to 20%.

USES OF SOLAR CELLS

- **Source of power in space crafts and satellites.**
- **Widely used in applications like watches calculators etc.**
- **Used as electric power generators**
- **In remote villages solar panels are used for street lighting, solar water pumps and solar cookers**
- **In remote areas houses can be electrified with solar cells**
- **Solar cells are used for providing electricity for light houses in sea and offshore drilling platforms.**

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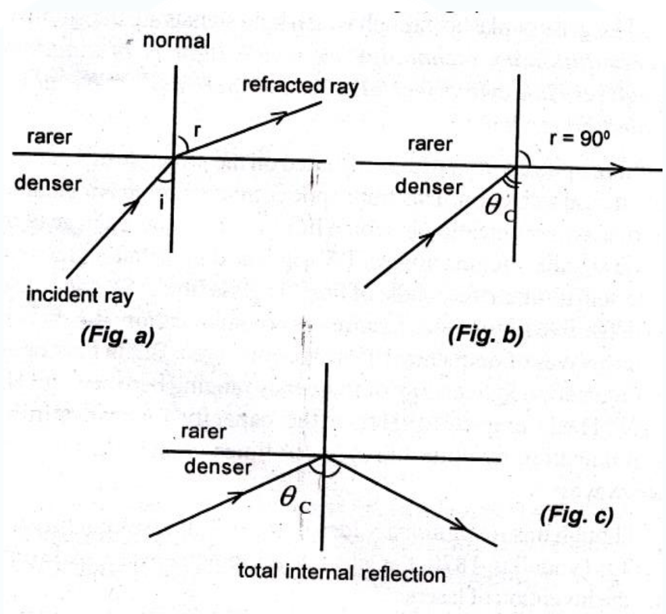
FIBRE OPTICS

The revolutionary technology by which light is propagated through very fine cylindrical hair like transparent fibres like glass is called Fibre optics.

Optical fibres are very fine narrow long and cylindrical transparent fibres like glass or plastic through which light signals are transmitted. The idea of fibre optics was put forward by John Tyndall in 1870.

BASIC PRINCIPLE

Basic principle of fibre optics is the MULTIPLE TOTAL INTERNAL REFLECTION



When a ray of light travels from denser to rarer medium it is bent away from the normal .For a particular angle of incidence in the denser medium refracted ray is grazing along the surface of separation of media. This angle of incidence in the denser medium for which the the refracted ray is grazing along the surface of separation of the media is called critical angle.

When the ray incidents at an angle of incidence greater than critical angle, the ray isreflected into the same denser medium. This is called **total internal reflection.**

Conditions for total internal reflection:

1. Ray must travel from denser to rarer medium.
2. Angle of incidence in the denser medium should greater than that of critical angle.

STRUCTURE OF OPTIC FIBER

1. CORE

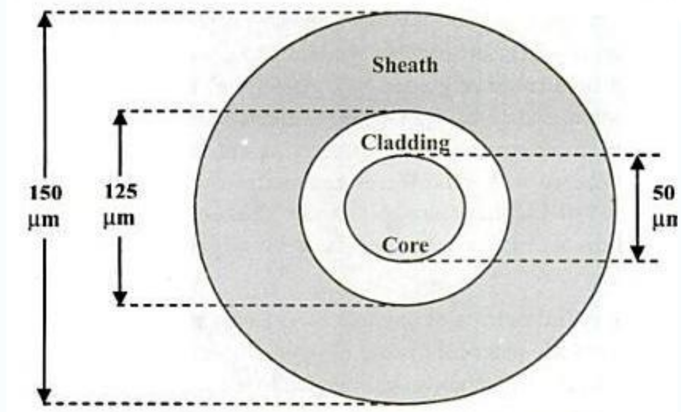
The innermost cylindrical region is called core. It is made of glass or plastic. Refractive index of core ismade higher and it act as denser medium. Light waves are propagated through the core and it act as wave guide.

2. CLADDING

The core is surrounded by cladding. This is also made up of glass or plastic.The refractive index of cladding is made smaller and it act as rarer medium. At core cladding interface total internal reflection takes place. Cladding is mainly responsible for propagation of light through the fibre.

3. SHEATH

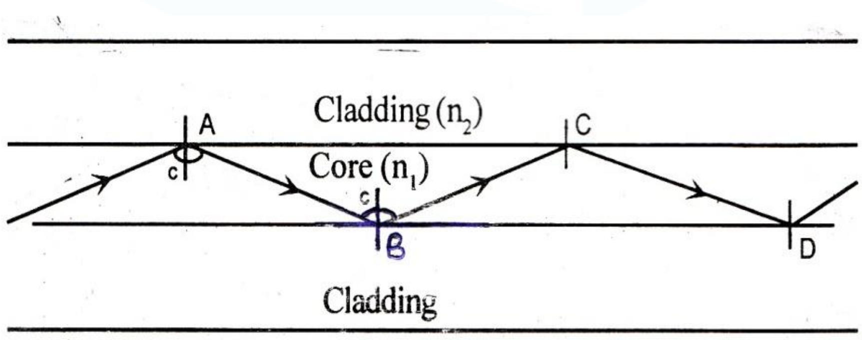
The outermost cylindrical jacket is called sheath.It is made up of opaque and coloured plastic. It provides mechanical strength to the core. It also protects core and cladding from scratches, crushing ,pulling..etc.



DIMENSION

The diameter of the core is usually 50m, the cladding has a diameter of 125m while the sheath has 150m. Usually optic fibre is of 1 km in length. Such fibres are connected end to end using suitable connectors.

PROPAGATION OF LIGHT WAVES THROUGH AN OPTIC FIBRE

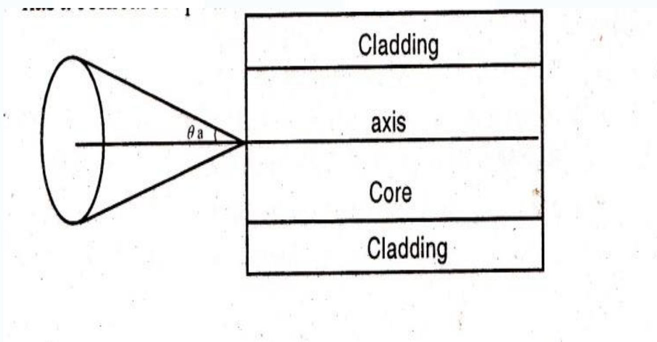


When a ray of light is incident from core tothe cladding at an angle of incidence i greater than the critical angle at A,it undergoes total internal reflection at the core - cladding interface. So the ray rebounds along AB. It is again incident at B at an angle greater than the critical angle on the core - cladding interface. So it again undergoes total internal reflection and the ray is travelling along BC. The ray is undergoing successive total internal reflections at points on the core- cladding interface. Thus the wave is propagated through the optical fibre in a zig-zag manner by the multiple total internal reflection principle without any loss of energy.

ACCEPTANCE ANGLE AND ACCEPTANCE CONE

The light rays which are incident within a particular angle with the axis of core alone are allowed to propagate through the fibre by multiple total internal reflections. The maximum of this particular angle is called acceptance angle θa .

The acceptance angle θa of an optic fibre is that maximum angle with the axis of core so that all the rays which are incident within this angle will be accepted and propagated through the fibre by multiple total internal reflections.



A cone at the end of the fibre with the acceptance angle as semi-vertex angle with the axis of the core is called acceptance cone. All the light rays which incident within this cone will be accepted and transmitted.If the ray incident at angle greater than acceptance angle ,it gets refracted out through the cladding and that light energy is lost.

Larger the diameter of the core, higher the acceptance angle and more the propagation of the light waves.

$$\sin \theta_a = \sqrt{n_1^2 - n_2^2}$$

Where, θa = Acceptance angle

n_1= Refractive index of core

n_2 = Refractive index of cladding

NUMERICAL APERTURE (NA)

Numerical aperture NA of an optic fibre is the sine of acceptance angle θa.

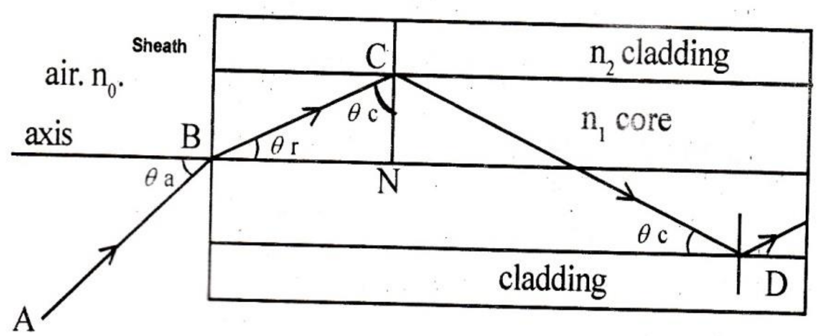
NA = Sin θa

NA depends on the acceptance angle. If θa is larger, NA will also be higher. Numerical aperture is also the light gathering power of the fibre and it measures the amount of light accepted by the fibre. NA is between 0.13 and 0.5. If NA is larger, fibre can accept more light from the source. NA depends on the refractive indices of core and cladding.

NA = $\sqrt{n_1^2 - n_2^2}$

PROOF

Consider a light ray AB incident at B at the edge of the core of an optic fibre from air. It is incident at an angle θa with the axis of the core. This maximum angle is known as acceptance angle. Since it travels from air to core, it is refracted along BC at an angle θr. This refracted ray is now incident at C at the core-cladding interface with an angle slightly greater than the critical angle θc. Hence the ray is undergoing total internal reflection and it is travelling along CD. Thus the ray is propagated through the fibre by multiple total internal reflections.



At C , CN is drawn normal to the axis. The angle at C is taken as the limiting angle θc , the critical angle. Let n_0 be the refractive index of air,n_1 that of core and $n_2$that of cladding.

By Snell's law at B, $\frac{\text{Sin } \theta a}{\text{Sin } \theta r} = \frac{n_1}{n_0}$

n_0Sinθa = n_1 Sin θr

n_0 for air = 1 and NA = Sin θa

NA = n_1Sin θr ……….(1)

At the critical angle, $\frac{\text{Sin } \theta c}{\text{Sin } 90} = \frac{n_2}{n_1}$

$$\text{Sin}\theta c = \frac{n_2}{n_1} \text{.............(2)}$$

But Sin θc = Cos (90 – θc) $\theta c + \theta r = 90^0$

Sin θc =Cos θr

$$\text{From (2) Cos}\theta r = \frac{n_2}{n_1}$$

But $\text{Cos}^2\theta r + \text{Sin}^2\theta r = 1$

$$\text{Sin}^2\theta r = 1 - \text{Cos}^2\theta r$$

$$\text{Sin}^2\theta r = 1 - \frac{n_2^2}{n_1^2}$$

$$Sin^2\theta r = \frac{n_1^2 - n_2^2}{n_1^2}$$

$$Sin\,\theta r = \sqrt{\frac{n_1^2 - n_2^2}{n_1^2}}$$

Substituting for Sin θr ineqn (1)

$$\text{NA} = n_1\sqrt{\frac{n_1^2 - n_2^2}{n_1^2}}$$

Numerical Aperture , NA = $\sqrt{n_1^2 - n_2^2}$

Where,

n_1= Refractive index of core
n_2 = Refractive index of cladding

FRACTIONAL REFRACTIVE INDEX CHANGE (Relative refractive index difference)

TheFractional refractive index change is the fractional difference between the refractive indices of core and cladding.

It is the ratio of change of refractive indices to the refractive index of core. It is always positive.

$$\Delta = \frac{n_1 - n_2}{n_1}$$

RELATION BETWEEN N.A , n_1 and Δ

$$\text{NA} = n_1\sqrt{2\Delta}$$

V- NUMBER OR NORMALIZED FREQUENCY

V- number is an important parameter of optic fibre. It is also called normalized frequency. V number is given by,

$$V = \frac{2\pi a}{\lambda} NA$$

where a= radius of core

λ = wavelength of light propagating through the fibre.

If V≤ 2.405, the fibre can support only one mode. If V> 2.405 , the fibre can support many modes.

MODES OF PROPAGATION

The light rays which are incident in the particulardirections within the acceptance angle alone are allowed to propagate through the fibre by multiple total internal reflections. These directionsthrough which the light rays are propagated through the optic fibre are called modes of propagation. Thus modes represent the number of paths of light rays in an optic fibre along which they are travelling in same phase.

CLASSIFICATION OF OPTIC FIBRE

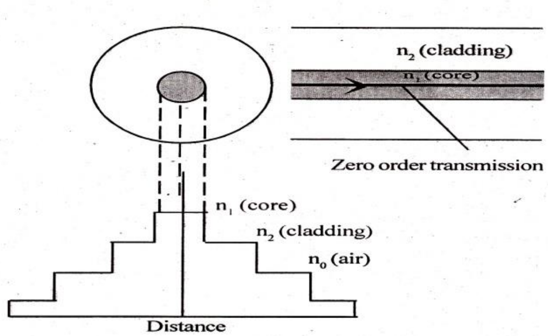
Optic fibre are generally classified into two groups depending on the refractive indices of core . They are

1. **Step index fibre**
2. **Graded index fibre**

STEP INDEX SINGLE MODE FIBER

The refractive index of core and cladding (n_1&n_2) are constants. n_1> n_2. There is a sudden decrease of refractive index at the core- cladding interface.

INDEX PROFILE: A graph drawn with refractive index on y axis & the distance from the axis of the core on x axis.



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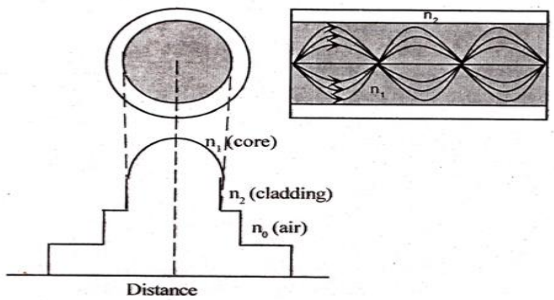
The refractive index profile is in the shape of a step and hence it is called step index fibre. This is reflective type fibre. Since the core is thin it supports only one mode for propagation. So this is called single mode fibre. The light is propagated almost along the axis of the core. This is called zero order mode of transmission.

STEP INDEX SINGLE MODE FIBER

Refractive index of core (n_1) is not constant. But n_2 is a constant. $n_1 > n_2$ .n_1 is varying. It is maximum along the axis of the core, it decreases radially outwards with the distance from the axis and it is minimum at the core boundary. Ie refractive index is graded. Index profile is in the shape of a parabolic curve



Graded index fibre has a very thick core. Since the core is thick, it permits a large number of modes and hence it is a multi mode fibre. This is refractive type fibre.

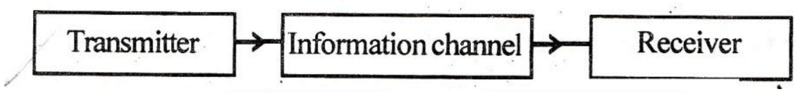
STEP INDEX SINGLE MODE FIBER	STEP INDEX SINGLE MODE FIBER
Refractive index of core and cladding(n_1&n_2)are constants.	Refractive index of core (n1) is not constant. But n2 is a constant
The refractive index profile is in the shape of a step	Index profile is in the shape of a parabolic curve
The core is thin. The light is propagated almost along the axis of the core	The core is thick. A large no. of rays are travelling along smooth parabolic curves.
It permit only one mode	Maximum number of modes that can be propagated is $V^2/4$
There is no pulse broadening effect and no intermodal dispersion.	No pulse broadening effect
This is reflective type	This is refractive type
The rays are travelling in a zig-zag manner	Rays are travelling along smooth paraboliccurves
Less expensive	Highly expensive
Band width is high and used for large distance communication	Band width is high and used for large distance communication

OPTIC FIBRE COMMUNICATION

One of the important application of optic fiber is in the field of communication system.

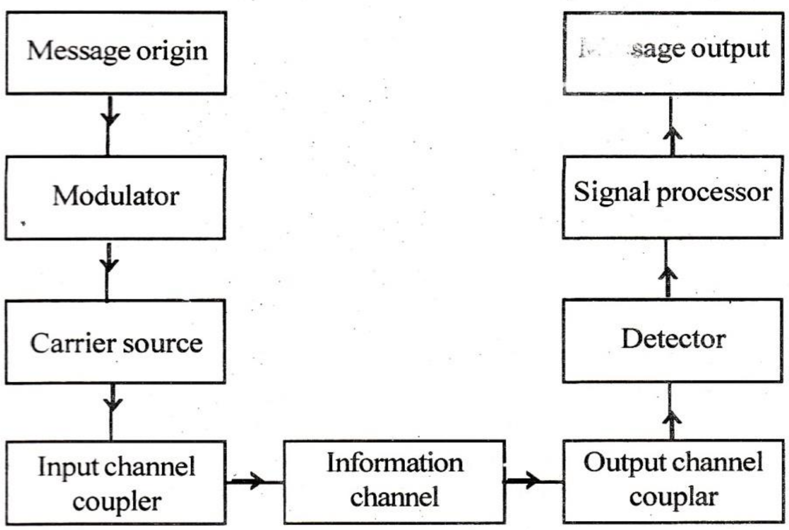
It is basically consists of 3 sections

1. **Transmitter: Converts electrical signal into optical signal**
2. **Information channel: Provides a path or passage to transmit the optical signals from transmitter to receiver**
3. **Receiver: Receives optical signals and converts back into electrical signals**



BLOCK DIAGRAM AND FUNCTION OF EACH COMPONENT

The message origin, modulator, carrier source, input channel coupler together constitute transmitter. Optic fibres are used as the information channel. Output channel coupler, detector, signal processor and message output constitute receiver.



1. MESSAGE ORIGIN

Converts all non electrical messages to electrical signals using transducer.

Eg; microphone converts sound energy to electrical energy

2. MODULATOR

Imposing a message on a carrier wave for propagations is called modulation

I. **At first it converts electrical message into proper format.**
II. **Secondly it imposes this format on a carrier wave for propagation.**

There are 2 types of modulation. Analog and digital modulation. In analogue modulation message is transmitted in a continuous manner and in digital modulation message is transmitted in discrete manner with the help of binary digits.

Digital modulation is preferred for long distance communication.

3. CARRIER SOURCE

Carrier source produces carrier waves on which the messages are transmitted. In fiber communication system light waves are the carrier waves.LED or Laser diodes are used to generate stable and monochromatic waves . The information is imposed on light waves.

4. INPUT CHANNEL COUPLER

This directs modulated light waves into the information channels.

In the case of radio or television broadcasting systems antenna delivers radio frequency waves into atmosphere for propagation. Here antenna behaves as input channel coupler

5. INFORMATION CHANNEL

This is a path to transmit the information from transmitter to receiver .Here very fine and long optic fibres are used as information channel. Modulated light signals are transmitted through optic fibre by principle of total internal reflection.

6. OUTPUT CHANNEL COUPLER

This directs the modulated light signals from the information channel to the detector .Eg. Antenna in radio and television broadcasting systems.

7. DETECTOR

This detects and separates the messages from the modulated signals. ie, demodulation takes place. Here light signals are converted into electric current using photo detector.

8. SIGNAL PROCESSOR

This filters and selects the required frequency from waves. The selected frequency is amplified. The unwanted frequency is filtered out.

9. MESSAGE OUTPUT

Here the original message is reproduced from the signals. The electrical pulses are converted into sound waves in the case of audio systems. Cathode ray tubes and proper transducers are used for this.

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ADVANTAGES OF COMMUNICATION WITH OPTIC FIBRES

- **Extremely wide Bandwidth**
  (Very high information carrying capacity)
- **Smaller diameter, lighter weight cable**
- **Lack of cross talk between the parallel fibers.**
- **Immunity to electromagnetic interference**
- **Electric isolation**
- **Low cost**
- **Much safer than copper cables**
- **Low transmission loss**
- **Signal security**
- **Longer life span**
- **Temperature resistant**
- **Easy maintenance**
- **Flexible and strong**

OPTIC FIBER SENSORS

Optic fiber sensors are very sensitive devices used to measure physical quantities like temperature ,pressure, displacement ..etc very accurately with the help of optic fibers.

Sensor has 3 components:

1. **A source of light**
2. **A fiber coil**
3. **Detector**

This is based on the based on the principle that the modulation of light takes place when light is transmitted through the fiber when subjected to the physical quantity.

There are 2 type of sensors :Active sensors and passive sensors.

In passive sensors (extrinsic sensor) modulation takes place outside the fiber.

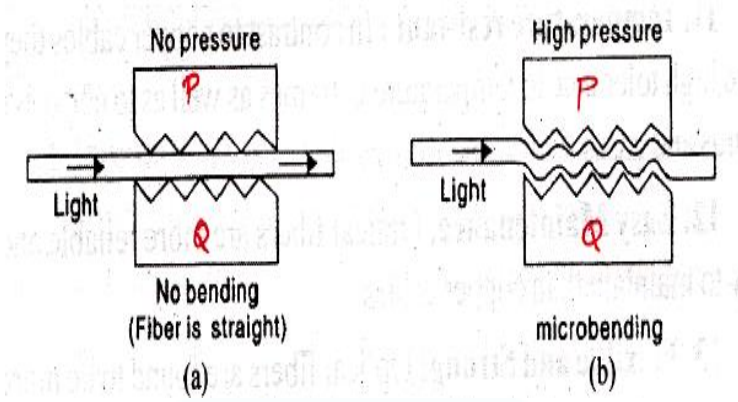
In active sensors (intrinsic sensor) modulation takes place inside the fiber.

This modulation based on the variation of intensity, phase, polarization, wavelength etc. Depending on that we can classify into different types.

INTENSITY MODULATED SENSORS

These are based on the variation of intensity of light either inside or outside the fibre.

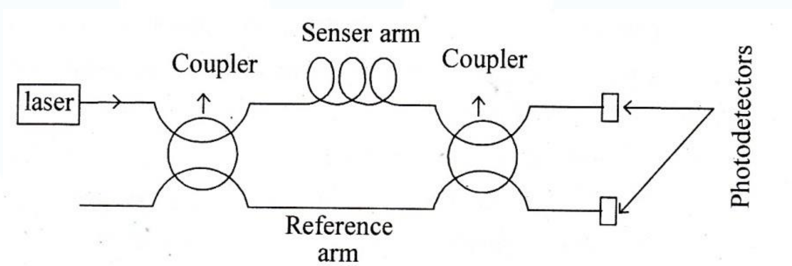
A) PRESSURE SENSOR



An optic fiber is mounted between a pair of plates P and Q containing a parallel groove .In the absence of pressure the fiber will be straight and all the light is transmitted through the fiber producing maximum output intensity in the detector. But when pressure is applied on the plates, they are pushed closer to each other and fiber is bent with large number of microbendings . A part of light is leaked out from these bendings and output intensity gets decreased .Noting the reduction of output intensity from the detector the pressure applied can be exactly estimated.

PHASE MODULATED SENSORS

The most sensitive fibre optic sensing method is based on the optical phase modulation. The phase of the light along an optical fibre depends on the properties like the length, geometrical dimension and refractive index of the fibre. The physical length and refractive index of an optic fibre varies with temperature, pressure and longitudinal strain.



Light from a laser is divided equally by a couplerand sent through the sensor arm and the reference arm.The output from the fibres are recombined at the second coupler.The sensor arm is in direct contact with the measure (temp,pressure) and the reference arm is isolated from externalperturbations. The external perturbations produce change in length or ref. index. in the sensor arm. This will change the phase of light passing through the sensor arm.No change in the refrence arm.Thus a phase difference occurs b/w the two light waves. Since the intensity varies with the phase difference, the external perturbations like temperature, pressure can be studied.

APPLICATIONS OF OPTIC FIBRES

1.MEDICAL FIELD

- Fiber endoscopy
- To stop the intestinal bleeding
- For bloodless surgery
- To examine heart-chambers, lungs and intestine
- To treat lung disorders
- Used in the treatment of cancer.
- In ophthalmology
- To remove the blocks in veins

2. COMMUNICATION FIELD

- Optic fibres are preferred in communication system due to its unlimited advantages
- Smaller size , light weight, low cost , non conducting nature etc make fibre optic supreme to others
- Local communication purposes(10Kms)
- Telephone & Telecommunications
- Local area network

3. INDUSTRY

- Used for signaling
- Fiberoscope(direct inspection is not needed)
- Inspection of various parts of huge machines
- Electric railway system
- For security and alarm system
- To Enlarge the pictures in a TV screen
- In computer in connection with CPU &memory
- To measure temperature and pressure without direct contact with the body.

4. MILITARY AND DEFENCE

- Used for secret communication(difficult to tap)
- Optic sensors mounted on the missiles are used for video picture transmission ,for monitoring and correct destination of the target.
- Used in aircrafts ,ships and submarines
- Used for tactical communication
- Fibre guided missiles are employed in modern wars

5. FIBRE OPTIC SENSORS

- To measure quantities like pressure,temperature etc

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- **Smoke detectors –presence of smoke ,dust,fog**
- **Liquid level sensors –measuring level in oil tank**
- **Safety sensors – detect dangerous situations in mines and oil rings**
- **Optic sensors mounted on missiles are used for picture transmission &correct destination**
- **Gyroscopes – used for correct measurement of even a very minute rotation.**