2(b). LASER and FIBRE OPTICS

Part – A

1. **What is meant by stimulated emission?**

   The process of the forced emission of photons caused by the incident photons is called stimulated emission. This process is the key factor for the operation of laser.

2. **Write down the difference between spontaneous and stimulated emission?**

Sl.No	Spontaneous Emission	Stimulated emission
01.	Emission of light is not triggered by external influence	Forced emission of light radiation caused by incident radiation
02.	Emitted photon travel in random direction	Emitted photon can be made to travel in particular direction
03.	Emitted photon cannot be controlled	Emitted photon can be controlled
04.	This is not a key factor for the operation of laser	This is the key factor for the operation of laser

3. **What is meant by population inversion and how it is achieved?**

   The number of atoms in the excited state is greater than the ground state is called population inversion and it is achieved by the pumping action

4. **What are the characteristics of a LASER?**

   (i) It is highly coherent
   (ii) It is highly directional
   (iii) The beam is purely monochromatic
   (iv) It is highly intense
   (v) It can able to travel over long distance without energy loss

5. **What is pumping action?**

   The process of creating a population inversion in the atomic states is called pumping action.

6. **What are the methods commonly used for pumping action?**

   (i) Optical pumping
   (ii) Electrical Discharge method
   (iii) Direct conversion
   (iv) Inelastic collision between atoms

7. **What is meant by active material in laser?**

   A material in which the population inversion is achieved in LASER is called active material

8. **What are the three important components of any LASER device?**

   (i) Active medium

(ii) Pumping source

(iii) Optical resonator

9. What are the conditions required for laser action?

(i) Population inversion should be achieved

(ii) Stimulated emission should be predominant over spontaneous emission.

10. What is semiconductor Laser?

It is a specially fabricated PN junction diode which emits Laser light when it is forward biased during electron and hole recombination process

11. What are the applications of semiconductor Laser?

(i) It is used in fibre optic communication

(ii) It is used to heal the wounds by means of infrared radiation

(iii) It is used to write and read CD's and for printouts

12. Mention the applications of Laser in industries?

(i) It is used for drilling, cutting, welding, soldering of materials

(ii) It is used for heat treatment of metallic and non-metallic materials

(iii) It is used in NDT

13. Mention the medical applications of Laser in Medical field?

(i) It is used in the treatment of detached retina's

(ii) It is used to perform microsurgery which is a bloodless surgery

(iii) It is used in the treatment of cancer & skin tumor

14. Write the scientific & engineering applications of Laser?

(i) It is used to transmit hundred messages at a time on radio, television & telephone

(ii) Communication between the planets is possible with laser

(iii) Since the Laser doesn't absorb water, it is used under water communication between the submarines

15. What is meant by Homo junction & Hetero Junction Laser?

Homo – PN junction is formed by single crystalline material (Eg: GaAs)

Hetero – PN junction is formed by two or more crystalline materials (Eg: GaAs & GaAlAs)

16. What are coherent sources?

Coherent sources are the sources which have same wavelength and frequency. It has correlation with the amplitude and phase at any point with any other point.

17. Define Acceptance Angle?

The maximum angle with which a ray of light can enter through one end of the fiber so that the ray will have total internal reflection inside the fiber

18. Define Numerical aperture of a fiber?

It is a light gathering ability of a fiber. It is a measure of the amount of light that can be accepted by a fiber. i.e., the sine of the acceptance angle is called Numerical aperture

N.A = $\sqrt{n_1^2 - n_2^2}$ where n_1 & n_2 are refractive index of core & cladding

19. What is the basic principle of fiber optic communication?

"When light ray falls from denser to rarer medium at a particular angle of incidence called critical angle the ray emerges between the surface of separation. When the ray exceeds the critical angle, then it will be reflected in same medium and this phenomenon is called **total internal reflection**"

20. Mention the components involved in fiber optic system?

(a) Light source
(b) Optic fiber transmission line
(c) Photo detector

21. What are the advantages of the fiber optic communication system?

(a) Optical fiber are light in weight and small in size
(b) There is no possibility of internal noise and cross talk generation
(c) No hazards of short circuits as in metal wires
(d) Immunity to adverse temperature and moisture
(e) Less cost

22. Give the applications of fiber optical communication system?

(i) Due to larger bandwidth, the system is capable of handling a large number of channels.
(ii) It is used in defense services due to the maintenance of high privacy
(iii) It is used for signaling purpose
(iv) It is also used in cable television, space vehicles, ships & submarine cable.

23. What are the differences between the single and multimode fibers?

S.No	**Single mode Fiber**	**Multi-mode Fiber**
1.	Only one mode can propagate through fiber	It allows large number of modes for the light rays travelling through it
2.	It has smaller core dia and the difference between the refractive index of core & cladding is small	It has larger core dia and the refractive index of core & cladding is greater than single mode fiber
3.	There is no degradation of signal during propagation due to dispersion	There is degradation of signal during propagation due to dispersion
4.	Fabrication is difficult & costly	Fabrication is not difficult & less cost

24. What are the differences between step index & graded index fibers?

S.No	**Step Index Fiber**	**Graded Index Fiber**
1.	The refractive index of the core is uniform throughout and undergoes an step change at the cladding boundary	The refractive index of the core is made to vary gradually such that the maximum refractive index is present at the center of the core
2.	Core diameter is 50 – 200 μm in multimode fiber and 10μm for single mode fiber	Core diameter is 50μm in multimode fiber
3.	Attenuation is greater in multimode step index fiber and lesser in single mode step index fiber	Attenuation is less
4.	Numerical aperture is greater in multimode and less in single mode step index fiber	Numerical aperture is less

25. What is meant by attenuation?

It is ratio of the optical power output (P_{out}) from a fiber of length "L" to the power input (P_{in}). Attenuation (α) = $\frac{-10}{L}\log\frac{P_{out}}{P_{in}}$ dB / Km

26. Define dispersion?

Degradation of optical signal is called dispersion. i.e., during transmission the pulse width spreads due to external effect

27. What are the losses that occur during optical fiber communication?

During transmission of light losses occur due to attenuation, distortion and dispersion.

28. What is called mode of propagation in optical fibers?

In optical fiber, only certain ray directions are allowed to propagate inside the fiber. The rays travelling in these specific directions are said to be mode of propagation in optical fiber

29. What are the types of sensors used in fiber optics?

(i) Intrinsic sensors: Fiber itself acts as sensing element (Eg: Pressure sensor, phase & polarization sensor)

(ii) Extrinsic sensors: Separate sensing system collects the light from the fiber. Fiber act as Guiding medium (Eg: Displacement sensor , current measurement sensor)

30. Mention any four advantages of fiber optic sensors?

(i) It has no external interference
(ii) It is used in remote sensing
(iii) Safety of data transfer
(iv) It is small in size

31. How fibers are used as a sensor?

The fiber optic sensors are used to detect changes in frequency, intensity, temperature, current, polarization of light waves, etc., A fiber optic sensor modulates the light passing through it, when it is exposed to change in environment.

32. Write the Industrial application of optical fibers?

(i) It is used to detect minor cracks, pores, etc., in big machineries
(ii) It is used in coagulation in chemical industries and laborites
(iii) It is used to connect a monitoring state and a remote sensor in industries

33. List out conditions to be satisfied for total internal reflection?

- The refractive index of core should be higher than refractive index of cladding ($n_1 > n_2$)
- The angle of incidence (θ_1) at core – cladding interface must be greater than critical angle (θ_c)

Part – B

1. Derive the relation between the probabilities of spontaneous & stimulated emission in terms of Einstein's Coefficients?

If N_0 is the number of the atoms per unit volume in ground state, then the number of atoms per unit volume in the excited state of energy E is given by Maxwell – Boltzmann distribution law as $N = N_0\, e^{(-E/kT)}$ (1)

Consider two energy levels of an atomic systems E_1 & E_2 such that $E_2 > E_1$. Let N_1 & N_2 be the number of atoms per unit volume present at E_1 & E_2 respectively. Then by the Boltzmann's Distribution law, $N_1 = N_0\, e^{-E_1/kT}$ & $N_2 = N_0\, e^{-E_2/kT}$

$$\therefore \frac{N_1}{N_2} = e^{\frac{E_2 - E_1}{kT}} = e^{\frac{h\upsilon}{kT}} \quad (2)$$

Where K is the Boltzmann constant & $E_1 \sim E_2 = h\upsilon$

We know that when an assembly of atoms is exposed to light photon of energy

$E_1 \sim E_2 = h\upsilon$, then the following three transitions takes place:

Process 1 **Stimulated absorption**

Atoms in the ground state (E_1) are raised to excited state (E_2) after the absorbing a photon of energy $h\upsilon$, provided the photon energy is equal to the energy difference ($E_2 \sim E_1$). This is upward transition

Number of transition (N_{ab}) occurring per unit volume per unit time is given by

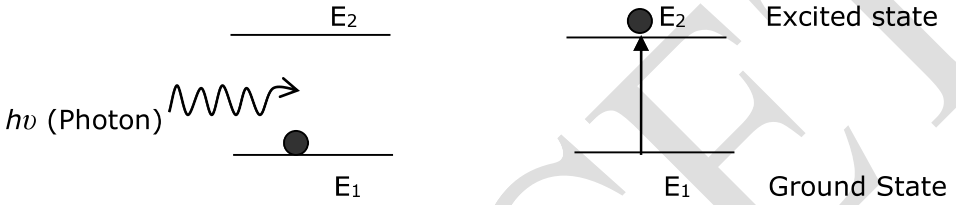
$$(N_{ab}) = B_{12}\, N_1\, Q \qquad (3)$$

Where

B_{12} - probability of absorption transition

N_1 – Number of atoms in state E_1

Q – Energy density of incident radiation



Fig(i)

Process 2 **Spontaneous emission**

The atoms in excited state E_2 make a spontaneous transition to the ground state E_1. This is a downward transition

Number of transitions occurring per unit volume per unit time $(N_{sp}) = A_{21}\, N_2$ (4)

A_{21} - Probability of spontaneous transition from E_2 to E_1

N_2 – Number of atoms lying in the energy state E_2

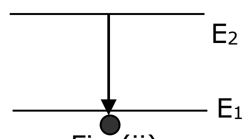


Fig (ii)

Process 3 **Stimulated Emissions**

The atoms in the excited state (E_2) may be forced to go to ground state (E_1) by striking the atom with a photon of energy $h\upsilon$, this is known as stimulated emission. It is downward transition

Number of transition per unit volume per unit time $(N_{st}) = B_{21}\, N_2\, Q$ (5)

B_{21} – Probability of stimulated transition

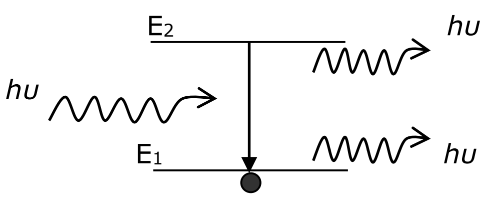


Fig (iii)

Einstein Coefficients A & B:

Under Equilibrium condition,

No. of upward transition per unit volume per unit time = No. of downward transition per unit volume per unit time

i.e., $\mathbf{A_{21} N_2 + B_{21} N_2 Q = B_{12} N_1 Q}$ (6)

(or) $B_{12} N_1 Q - B_{21} N_2 Q = A_{21} N_2$

(or) $Q (B_{12} N_1 - B_{21} N_2) = A_{21} N_2$

$$(\text{or})\, Q = \frac{A_{21}N_2}{B_{12}N_1 - B_{21}N_2}$$

Divide by $B_{21} N_2$ on L.H.S

$$Q = \frac{\frac{A_{21}N_2}{B_{21}N_2}}{\frac{B_{12}N_1}{B_{21}N_2} - \frac{B_{21}N_2}{B_{21}N_2}} \quad (\text{or}) \quad Q = \frac{\frac{A_{21}N_2}{B_{21}N_2}}{\frac{B_{12}N_1}{B_{21}N_2} - 1}$$

$$(\text{or})\; Q = \frac{A_{21}}{B_{21}} \times \frac{1}{\frac{B_{12}}{B_{21}}\left(e^{\frac{h\upsilon}{kT}}\right) - 1} \quad \text{from equation (2)} \qquad (7)$$

We know that Planck's radiation for energy distribution in terms of frequency is

$$Q = \frac{8\pi h\upsilon^3}{C^3} \times \frac{1}{\left(e^{h\upsilon/kT} - 1\right)} \qquad (8)$$

Comparing equation (7) & (8)

$\mathbf{B_{12} = B_{21}}$ (9)

$$\frac{A_{21}}{B_{21}} = \frac{8\pi h\upsilon^3}{C^3} \qquad (10)$$

Result

(i) Equation (9) states that stimulated emission rate per atom = stimulated absorption rate per atom

(ii) Equation (10) shows that $\frac{A_{21}}{B_{21}}$ is proportional to frequency υ. The probability of spontaneous emission rapidly increases with the energy difference between the two states.

(iii) To achieve laser action, the stimulated emission should be predominant that spontaneous emission. To achieve this population inversion is required.

3. Describe the construction and working of a semiconductor laser (homojunction & Heterojunction) with necessary diagrams. Also compute its advantages, disadvantages and applications?

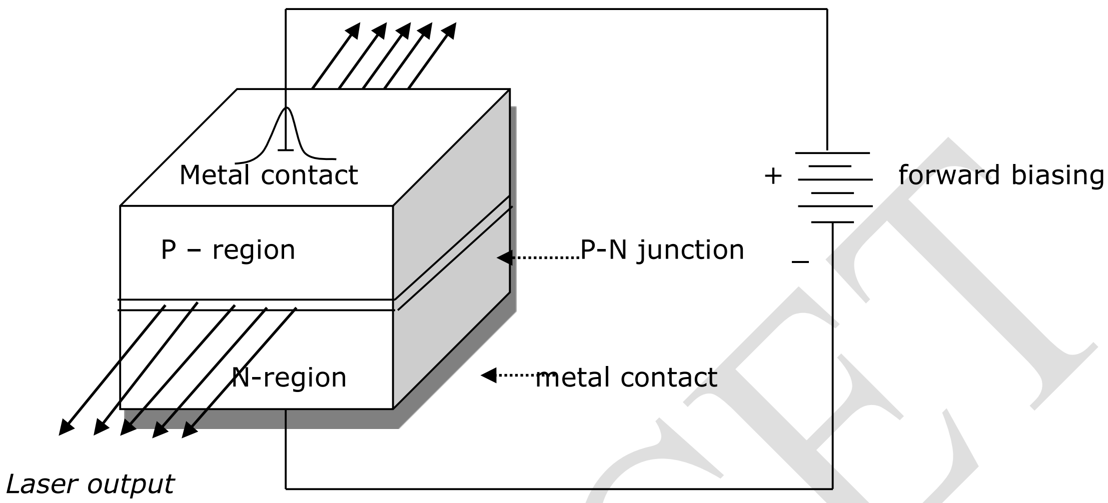
HOMOJUNCTION

Principle

When a P-N junction diode is forward biased the electrons from n – region and the holes from p – region cross the junction and recombine with each other. During the recombination process the photons (light radiation) is released from direct band gap semiconductor (Eg: GaAs) which stimulates other electrons and holes to recombine and hence the stimulated emission takes place which produces the laser

Construction

The basic construction of a semiconductor homojunction diode is shown in the figure

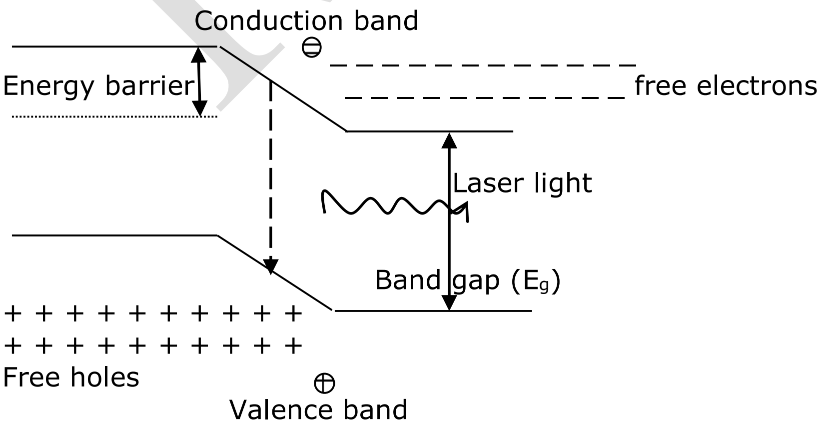


The active medium is a P-N junction diode made from a single crystal of GaAs. This crystal is cut in the form a platelet of thickness 0.5mm.this platelet has a electrical (n-type) and hole conductivities (p-type)

The photon emission is stimulated by a thin layer of PN junction. The potential difference is applied to the homojunction diode through the metal contact .the end faces of the junction are polished and made parallel to each other. They act as optical resonator (the diode has high refractive index) where the laser comes out.

Working

Figure shows the energy level diagram. When the diode is forward biased using the applied potential difference, the electron and holes are injected in to the junction where the concentration of holes in p – region and electrons in N – region strengthens. After the population inversion condition is achieved, the electrons and holes are recombined to produce a radiation in the form of light



When the forward biased voltage is increases, the emitted photon multiplies and triggers these recombining photons in phase. These photons moving at the plane of junction travels back and forth by reflection between two sides of the junction and grows in strength. After gaining enough strength it emits a laser beam of wavelength 8400A°. The wavelength of emitted radiation depends on (i) band gap & (ii) the concentration of donor & acceptor atoms. The wavelength of laser light is given by $E_g = h\upsilon$ (or) $\lambda = \frac{hc}{E_g}$ where E_g – band gap energy & $\upsilon = c / \lambda$

Characteristics

01.	Type	Solid state homojunction semiconductor laser
02.	Active Medium	PN junction GaAs diode
03.	Pumping Method	Direct conversion method
04.	Power output	1mW
05.	Nature of Output	Continuous (or) Pulsed
06.	Wavelength	8400 A°

Advantages

(i) It is small in dimension and compact
(ii) It exhibits high efficiency
(iii) The laser output can be increased easily by controlling junction current
(iv) It requires little auxiliary equipment

Disadvantages

(i) It is difficult to control mode pattern and structure of laser
(ii) Output beam has large divergence
(iii) Monochromacity is poorer than other type of laser
(iv) Threshold current density is large

Applications

(i) It is used in optical communication
(ii) It is used to heal the wounds by infrared radiation
(iii) It is used in CD writing and reading

2. HETEROJUNCTION

Principle

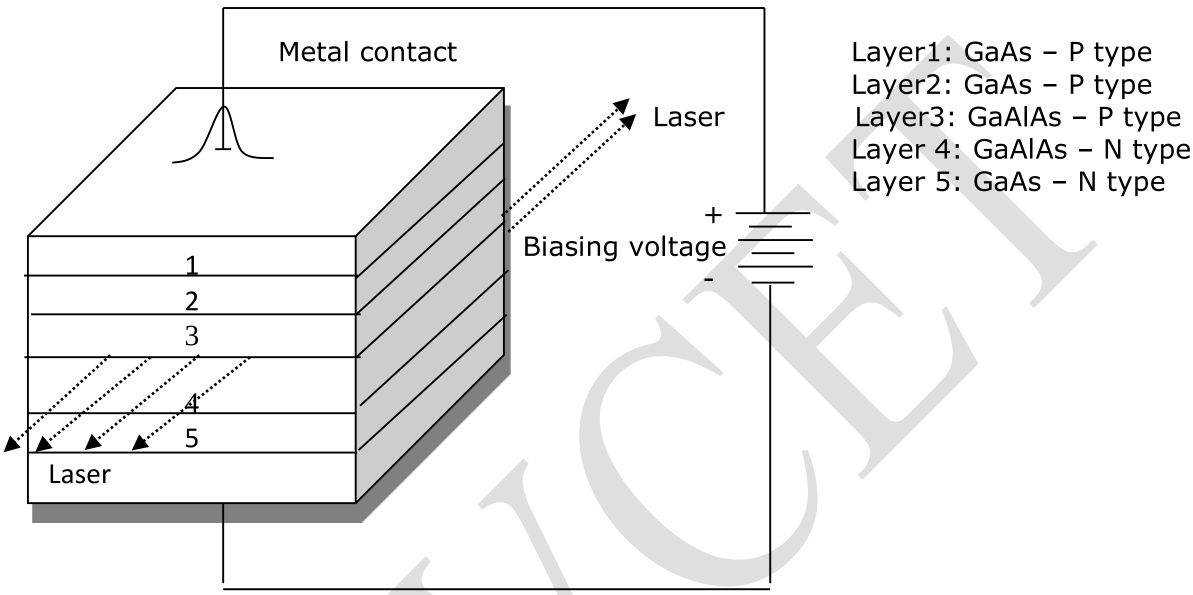
When a PN junction diode is forward biased, the electrons from n- region and holes from p – region recombines with each other at junction and emits photons in the form of light at certain direct band gap semiconductor

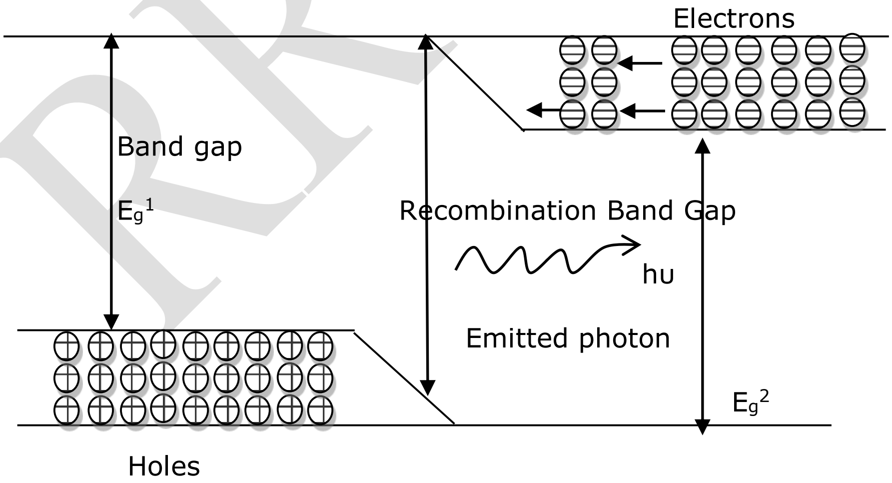
Construction

This laser consists of five layers as shown in figure. A layer of GaAs – P type act as active medium (3rd layer).This layer is sandwiched between two layer of GaAlAs – P type & GaAlAs N type with wide band gap. The electrical voltage is applied at the extreme layers (1 & 5th layer) and the 3rd & 4th layers are polished and made parallel to each other. They behave as optical resonator

Working

When the PN junction is forward biased, the electrons and holes are injected into junction. The region around junction has large no of electrons in conduction and large no of holes in valence band. Hence the population inversion is achieved. As a result recombination electrons and holes produce photons as light radiation. When the forward biasing voltages increases, the stimulated recombination increases the intensity of photons and they are in phase. This photon travels back and forth at junction due to reflection and grows in strength. A coherent laser beam of wavelength 8000 A° is emitted at the junction.





Characteristics

01.	Type	Solid state Heterojunction semiconductor laser
02.	Active Medium	PN junction made from different layers
03.	Pumping Method	Direct conversion method
04.	Power output	1mW
05.	Nature of Output	Continuous

06.	Wavelength	8000 A°

Advantages

(i) It produces continuous wave output
(ii) The power output is high

Disadvantages

(i) It is difficult to grow different layers of a PN junction
(ii) The cost is high

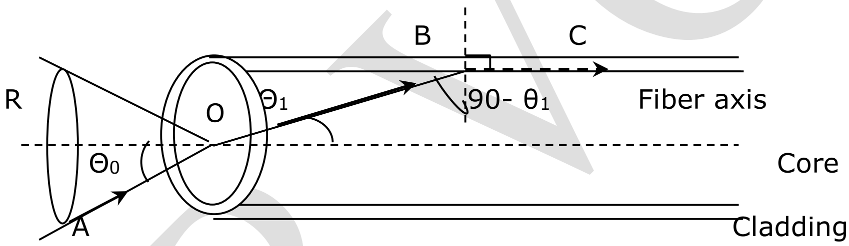
3. Derive an expression for numerical aperture and acceptance angle in optical fibers?

Let us consider the propagation of light in an optical fiber. The incident ray AO enters in to the core at θ_o to the fiber axis. This incident ray is refracted along OB at an angle θ_1 in the core. The refracted ray falls on the interface of core & cladding at the critical angle of incidence (90 – θ_1) and it moves along BC

Any light ray that enters into core at an angle of incidence less than θ_0 has refraction angle less than θ_1.i.e. Angle of incidence is (90 - θ_1) is more than the critical angle and hence the light is totally reflected back in to core

The light ray enters into core at an angle of incidence greater then θ_0 at O incident at B at an angle less than critical angle. Hence it is reflected in to cladding region and absorbed.

Let n_o be refractive index of the surroundings, n_1 be refractive index of the core & n_2 be refractive index of cladding.



By Snell's law of reflection on ray RO, we have

$n_o \sin\theta_0 = n_1 \sin\theta_1$ (1)

$\sin\theta_0 = \frac{n_1}{n_2}\sin\theta_1$ (2)

$\sin\theta_0 = \frac{n_1}{n_0}\sqrt{1-\cos^2\theta_1} \because [sin^2\theta + cos^2\theta = 1]; \left[sin\theta_1 = \sqrt{1-cos^2\theta_1}\right]$ (3)

At point B on the interface of core & cladding, Angle of incidence θ_c = 90- θ_1

By Snell's law of refraction, $n_1\sin(90-\theta_1) = n_2\sin 90°$

(or) $n_1\cos\theta_1 = n_2$ $\because [\sin(90-\theta_1) = \cos\theta_1, \sin 90° = 1]$

(or) $\cos\theta_1 = \frac{n_2}{n_1}$ (4)

Sub the value of (4) in (3) ,we get

$\sin\theta_0 = \frac{n_1}{n_0}\sqrt{1-\frac{n_2^2}{n_1^2}}$

$$\sin\theta_0 = \frac{n_1}{n_0}\sqrt{\frac{n_1^2-n_2^2}{n_1^2}}$$

$$\sin\theta_0 = \frac{\sqrt{n_1^2-n_2^2}}{n_0} \qquad (5)$$

$$\boxed{\theta_0 = \sin^{-1}\left(\frac{\sqrt{n_1^2-n_2^2}}{n_0}\right)} \qquad (6)$$

Where θ_0 is called acceptance angle.

If the fiber is surrounded in air, then θ_0 = 1, eqn. (6) becomes

$$\boxed{\theta_0 = \sin^{-1}\left(\sqrt{n_1^2-n_2^2}\right)} \qquad (7)$$

Thus *"the maximum angle (θ_0) at which a ray of light can suffers total internally reflection "is* called acceptance angle

Numerical Aperture

"The light gathering capability of an optical fiber or the sine of the acceptance angle is called Numerical aperture"

i.e., NA = $\sin\theta_0 = \sqrt{n_1^2 - n_2^2}$ (8)

Fractional Index Change

"it is the ratio of refractive index difference in core and cladding to the refractive index of core

i.e., $\Delta = \frac{(n_1-n_2)}{n_1}$ (9)

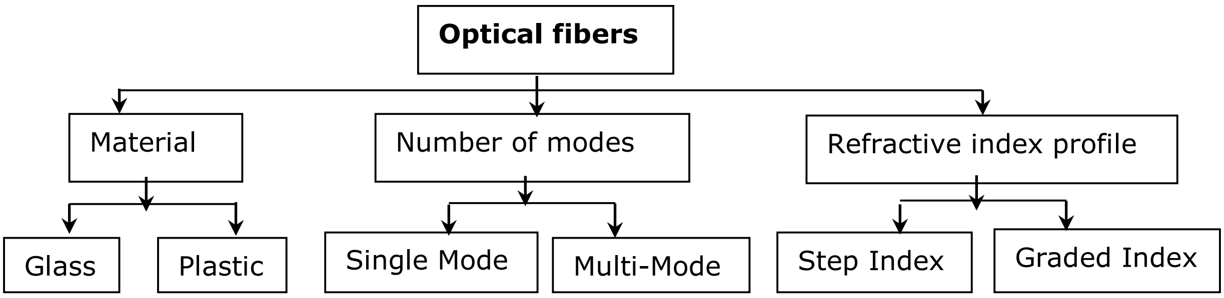
(or) $n_1\Delta = n_1 - n_2$ (10)

Eqn. (8) can be rewritten as NA = $\sqrt{(n_1+n_2)\,(n_1-n_2)}$

(or) NA = $\sqrt{(n_1+n_2)(n_1\Delta)}$

If $n_1 \approx n_2$ then, $\boxed{NA = \sqrt{2n_1^2\Delta}}$ (11)

4. Discuss the various types of optical fibers?



Based on materials

Glass fibers

If the fibers are made up of mixture of metal oxides and silica glasses, then it is called glass fibers.

Eg: **Core**: SiO_2 **Cladding**: P_2O_5 - SiO_2

Plastic Fibers

If the fibers are made up of plastics which can be handled without any care due to its toughness and durability it is called Plastic Fibers.

Eg: **Core:** Polymethyl methacrylate **Cladding:** Co – Polymer

The light ray consists of large number finite rays which will produce constructive interference during their motion and these rays are called modes which will propagate inside the fiber. Based on modes

Single Mode Fibers

It has very small core diameter so that it can allow only one mode of propagation and hence called single mode fibers. The cladding diameter must be very large compare to the core diameter. Hence the optical loss is minimum.

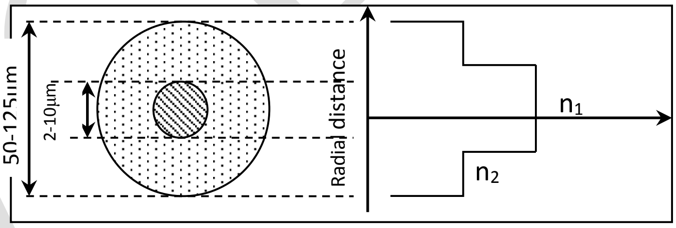
Core Diameter : 5 – 10 μm

Cladding Diameter : ≈125μm

Protective layer : 250 - 1000μn

Numerical Aperture : 0.08 – 0.10

Band Width : > 50 MHz



Applications: because of high bandwidth, they are used in haul communication syste

Multimode Fiber

Here the core diameter is very large compared to single mode fibers, so that it can allow many modes to propagate through it and hence called as multi-mode fibers. The cladding diameter is also larger than single mode fiber. These multimode fibers are useful in manufacturing both step index and graded index fiber.

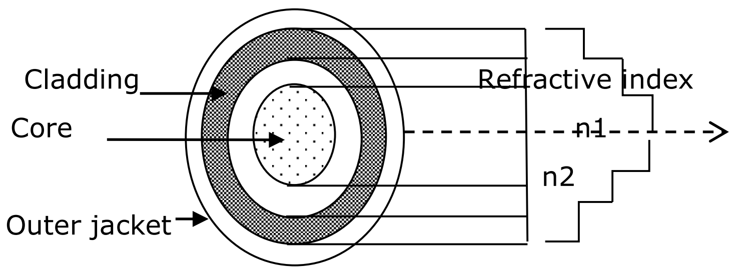
Core Diameter : 50 -350μm

Cladding Diameter :125-500μm

Protective layer :250-1100μm

Numerical Aperture : 0.12 – 0.5

Band width : < 50 MHz



Applications: because of low bandwidth, they are used in short haul communication systems.

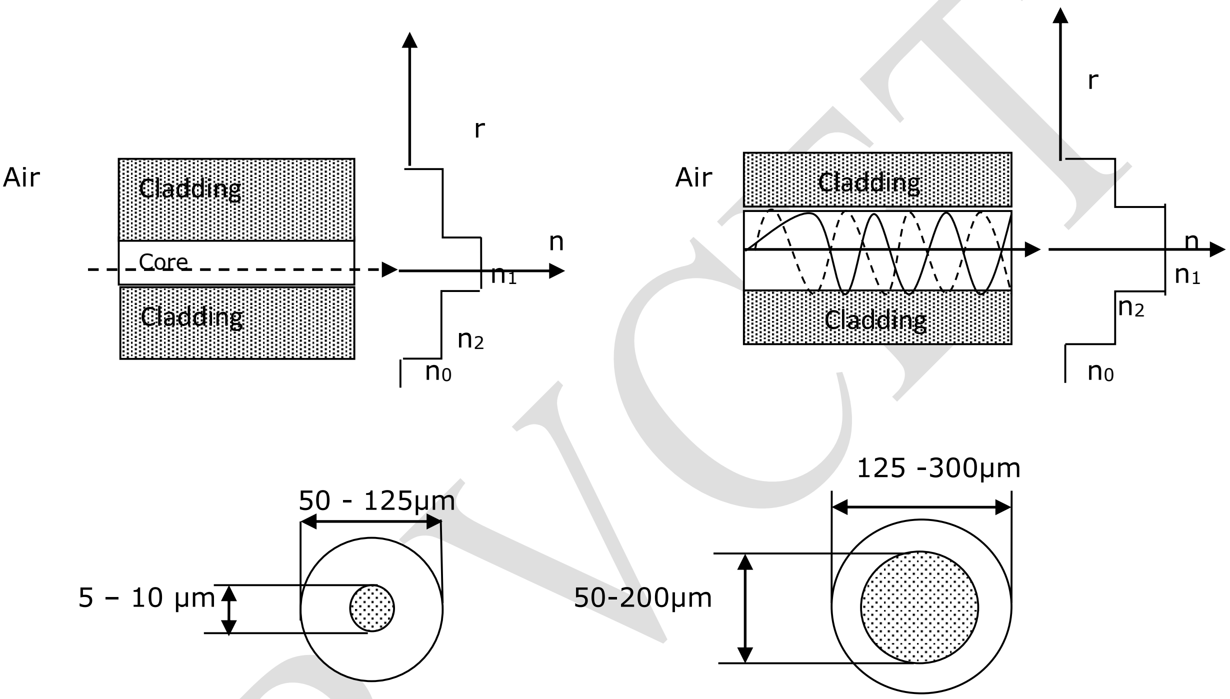
Refractive Index Profile

In any optical fiber, cladding has a uniform refractive index. However, the refractive index of core either remains constant or vary in a particular way. The curve which denotes the variation of refractive index with respect to the radial distance from the axis of the fiber is called *refractive index profile*. This profile is further classified as *step index fiber* and *graded index fiber*

Step Index Fiber

Here the refractive index of air, cladding and core varies by step by step and hence it is called as step index fiber. Based on the refractive index and number of modes it is further classified as single step index and multimode step index.

In this type we have both single and multimode fibers and their corresponding refractive index varies step by step. Due to less dispersion, single mode step index fiber has low intermodal dispersion than multimode step index fiber.



(i)Step index - Single mode   (ii) Step index – Multi mode

Advantages

- (i) Here LED is used as light source
- (ii) It has large core diameter, low bandwidth and high numerical aperture
- (iii) It has high attenuation

Application: They are widely used in data links

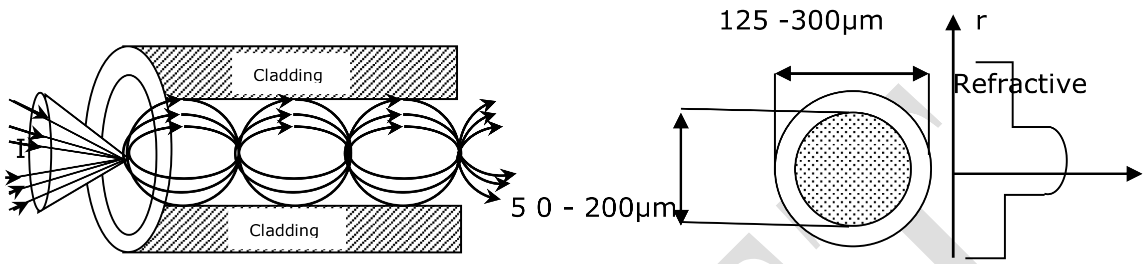
Graded Index Multi mode fiber (GRIN)

In this mode of fiber, the light rays (skew rays) which travel in the helical path without crossing the fiber axis and the refractive index of the core varies radially from the axis of the fiber. The refractive index of the core is maximum along the fiber axis and it gradually decreases towards cladding. Thus it is called as graded index fiber. Here the refractive index is minimum at core cladding interface. It has a core diameter of 50 - 200μm and cladding of 100 – 250 μm. If the diameter of the core is high, the intermodal dispersion loss must be high. But, because of the gradual decrease in the refractive index of the core, the intermodal dispersion is minimized.

Advantages

(i) It has intermediate band width
(ii) It has small numerical aperture
(iii) Laser (or)LED is used as light source
(iv) Low attenuation

Application: it is used in medium distance applications



5. Explain the different types of losses resulting in the propagation of light through optical fiber?

When light propagates through an optical fiber. a small percentage of light is lost through different mechanisms. The loss of optical power is measured in terms of decibels per kilometer for attenuation losses

"Attenuation is defined as the ratio of the optical power output (P_{out}) from a fiber of length 'L' to the power input (P_{in}) $\boldsymbol{Attenuation\ (\alpha) = \frac{-10}{L}\ log\ \frac{P_{out}}{P_{in}}}$ ***dB/km.***

The losses in optic fiber occurs due to (i) Material Absorption (ii) Scattering Loss (iii) Radiative Loss

(i) Material Absorption Losses

It mainly depends on fiber material composition and the wavelength of light used. Generally there are three types of absorption namely:

(a) **Extrinsic (or) Ultraviolet absorption**
In pure fused silica glass fiber, absorption of UV radiation (around 0.14μm) results in ionization of valence electron in conduction band. Also due to doping of pure silca, there is change in UV absorption band towards longer wavelength. As a result there is a loss of light due to this ionization

(b) **Intrinsic (or) Infrared absorption** even in the pure silica fiber, there is a small amount of absorption of light which results in heating due to random vibration

(c) **Absorption due to atomic defects** usually atomic defects such as imperfection, vacancy of atomic structure will produce a small absorption loss

(ii) Scattering Loss

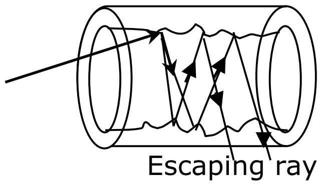
It is also a wavelength dependent loss, which occurs inside the fibers. Since the glass is used in fabrication of fibers, the disordered structure of glass will make some variations in the refractive index inside the fiber, a portion of the light is scattered. This type of scattering is called Rayleigh's Scattering

Rayleigh's scattering $\propto \frac{1}{\lambda^4}$

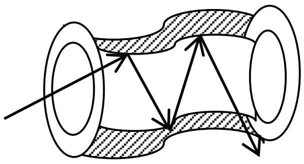
(iii) **Radiative Loss (Geometric effect)**

It is due to bending of finite radius of curvature in optical fibers. There are two types:

(a) Micro Bending: it is due to non-uniform (or) micro bends inside the fiber due to non-uniform pressures created during cabling of the fiber. This lead to loss of light by leakage through the fiber

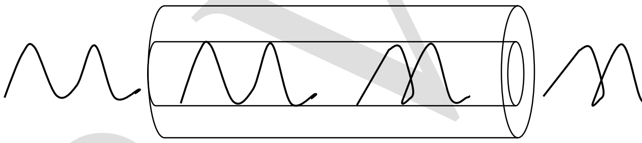


Macroscopic Bending: if the radius of the core is large compared to fiber diameter, then large curvature is formed when the fiber cable turns at the corner. At these corners the light will not satisfy the total internal reflection condition and hence it escapes out from the fiber.



Dispersion

"when an optical signal (or) pulse is sent into the fiber the pulse spreads / broaden as it propagates through the fiber. This phenomenon is called dispersion. It is found that the pulse received at output is wider than input pulse. There are four types:

Input pulse  over lapping output pulse

(i) **Inter modal dispersion**

When more than one mode is propagating through the fiber, then the inter modal dispersion will occur. Since, many modes are propagating; they will have different wavelengths and will take different time to propagate through the fiber, which leads to inter modal dispersion This dispersion is absent in single mode fiber

(ii) **Material Dispersion (Chromatic dispersion)**

The dispersion occurs due to variation of refractive index from different wavelength of light travelling at different speed inside the fiber. Also the narrow pulse passes inside the fiber broaden& hence pulses with different wavelengths travel with different velocities

Characteristics

- This dispersion is proportional to frequency bandwidth of transmitted pulse
- It is very low in single mode fiber

(iii) **Wave Guide Dispersion**

It arises due to the guiding property of the fiber and due to their different angles at which they incident at the core – cladding interface of the fiber

(iv) Intramodal Dispersion

The dispersion occurs in single mode due to group velocity as a function of wavelength of an optical source, which will broaden as a band of frequencies and delay the spectral components of the transmitted pulse.

6. **What are the different types of fiber optic sensors? Explain the principle, construction and working of pressure and displacement sensor using optical fibers?**

A sensor is a transducer which converts any form of signal in to optical signal in the measurable form. Here optical fibers are used as wave guides. There are two types of sensors: (i) Intrinsic sensors (Active sensor) (ii) Extrinsic sensor (Passive sensor).

(i) Intrinsic Sensor: The physical parameter to be sensed directly acts on the fiber itself to produce the changes in the transmission characteristics. Eg: Pressure & Liquid level sensors.

(ii) Extrinsic Sensor: Separate sensing element is used and the fiber acts as a guiding media to the sensors.. Eg: Displacement & Laser Doppler Velocity meter sensors.

Pressure Sensor

When a single optical fiber is subjected to pressure variations, then its length and refractive index changes. This causes change in phase of light at the end of fiber.

The change in phase of light is proportional to magnitude of the change in pressure. The phase changes can be measured by an interferometer method as shown in figure

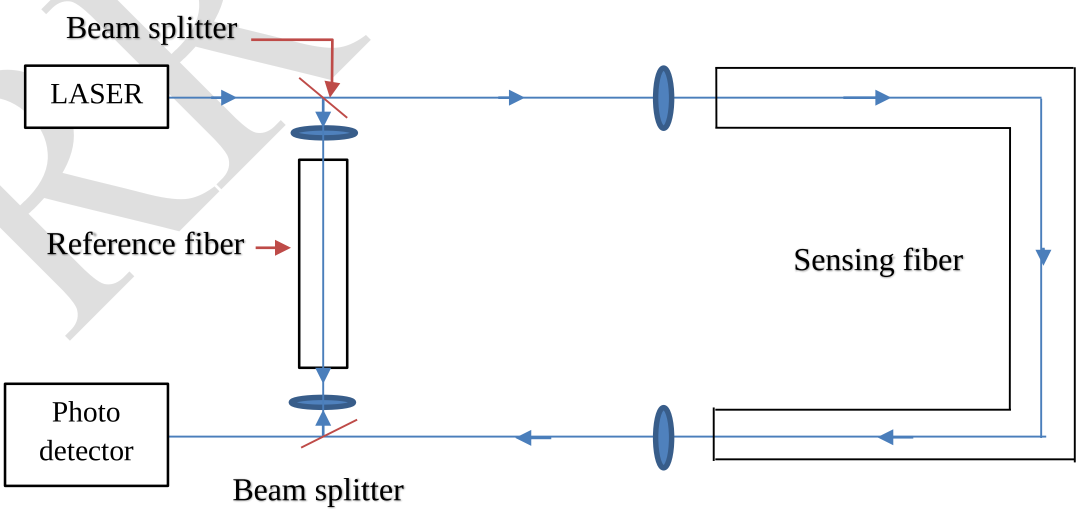
(i) Here the light from a laser source is split into two beams of approximately equal amplitude by a 50% beam splitter. One beam is passed through sensing fiber, which is subjected to pressure variations. The other beam through reference fiber which is not subject to any changes and it is used for comparison.

(ii) Light from these two fibers is superimposed using another beam splitter. Interference of these two waves gives fringes.

(iii) The intensity of the fringe depends on the phase relation between two waves. If the waves are in phase, then the intensity is maximum. This happens when the sensing fiber is not disturbed.

(iv) The intensity is minimum if the waves are out of phase due to $\lambda/2$ change in length of sensing fiber

(v) The intensity of interference fringes can be measured with a photo detector and pressure changes can be measured.



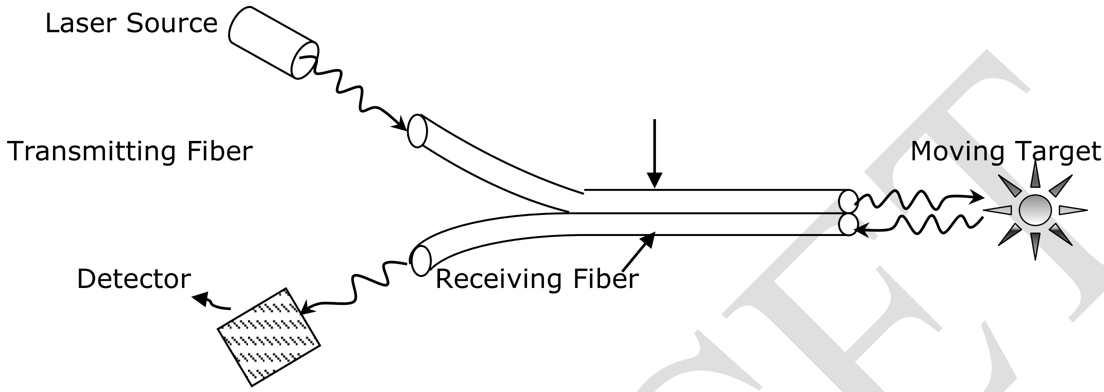
Displacement Sensor

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 from it 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 as shown in figure. 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 reflected beam 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 the sensor.

7. **Describe the Fiber optic communication system and its advantages with neat block diagram?**

Principle

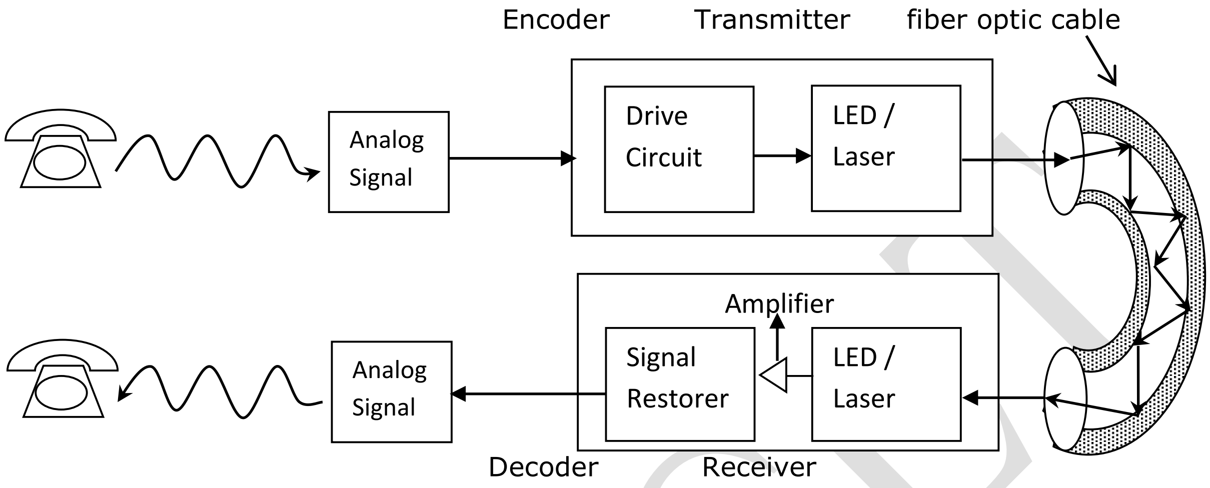
The transmission of information over the required distance by the propagation of optical signal through optical fibers.

Description it consists of

- **(i) Information Signal Source:** it may voice, music, digital or analog signal. Here it is considered as analog information
- **(ii) Transmitter:** it consists of drive circuit to transfer the electric input signals in to digital pulses and a light source
- **(iii) Light Source:** the light source such as LED (or) laser used to convert the digital pulses in to optical pulses
- **(iv) Propagation Medium:** the optical fiber is the propagation medium. This acts as waveguide and suffers total internal reflection inside the fibers.
- **(v) Receiver:** it consists of a photo detector, an amplifier and a signal restoring circuit.

Working

Analog information produces an electrical signal in analog form and converted in to digital signals using transmitter which is in form of the electrical pulses. This pulses modulates the LED by an optical source and fed in to fiber. Here the light suffers total internal reflection and received as an optical signal at photo detector. The photo detector converts the optical signal in to digital signal further it is converted in to analog signal using a demodulator. Hence the received signal contains information as in the transmitted end.



Applications

Extremely wide bandwidth

Optical frequencies are very large (~10^{15} Hz) as compared to radio frequencies (~ 10^{6} Hz) and microwave frequencies (10^{10} Hz). The rate at which information can be transmitted is directly related to carrier frequency.

No cross talk between parallel fibers

There is no signal leakage from fibers. Hence, cross – talks between neighbouring fibers are almost absent. This is quite frequent in conventional metallic systems.

Absence of inductive interference

Since optical fibers are not metallic, they do not pick up electromagnetic waves. In fiber optic cables, there is no interference caused by lightning or other nearby electromagnetic equipment.

Smaller diameter, lighter weight and cheap cables

Optical fibers are light weight and flexible to be handled more easily than copper cables. These fibers are made from silica (SiO_2) which is one of the most abundant materials on earth

Signal security

The transmitted signal through the fibers does not radiate. Further the signal cannot easily be tapped from a fiber.

Low loss per unit length

The transmission loss per unit length of an optical fiber is low (~4 dB / km).