

## UNIT- 2

### 1. List the requirements that be satisfied by materials used to manufacture optical fiber?

#### ANS: Fiber Materials

Most of the fibers are made up of glass consisting of either Silica ( $\text{SiO}_2$ ) or Silicate. High-loss glass fibers are used for short-transmission distances and low-loss glass fibers are used for long distance applications. Plastic fibers are less used because of their higher attenuation than glass fibers. Glass Fibers

The glass fibers are made from oxides. The most common oxide is silica whose refractive index is 1.458 at 850 nm. To get different index fibers, the dopants such as  $\text{GeO}_2$ ,  $\text{P}_2\text{O}_5$  are added to silica.  $\text{GeO}_2$  and  $\text{P}_2\text{O}_5$  increase the refractive index whereas fluorine or  $\text{B}_2\text{O}_3$  decreases the refractive index. Few fiber compositions are given below as follows,

- (i)  $\text{GeO}_2 - \text{SiO}_2$  Core:  $\text{SiO}_2$  Cladding
- (ii)  $\text{P}_2\text{O}_5 - \text{SiO}_2$ , Core;  $\text{SiO}_2$  Cladding

The principle raw material for silica is sand. The glass composed of pure silica is referred to as silica glass, nitrous silica or fused silica. Some desirable properties of silica are,

- (i) Resistance to deformation at temperature as high as  $1000^\circ\text{C}$ .
- (ii) High resistance to breakage from thermal shock.
- (iii) Good chemical durability.
- (iv) High transparency in both the visible and infrared regions.

#### Basic Requirements and Considerations in Fiber Fabrication

- (i) Optical fibers should have maximum reproducibility.
- (ii) Fibers should be fabricated with good stable transmission characteristics i.e., the fiber should have invariable transmission characteristics in long lengths.
- (iii) Different size, refractive index and refractive index profile, operating wavelengths material. Fiber must be available to meet different system applications.
- (iv) The fibers must be flexible to convert into practical cables without any degradation of their characteristics.
- (v) Fibers must be fabricated in such a way that a joining (splicing) of the fiber should not affect its transmission characteristics and the fibers may be terminated or connected together with less practical difficulties.

#### Fiber Fabrication in a Two Stage Process

- (i) Initially glass is produced and then converted into preform or rod.

### 2. Write in detail about glass fiber and detail about plastic optical fiber?

**Ans:** Glass fiber is a mixture of selenides, sulfides and metal oxides. It can be classified into,

1. Halide Glass Fibers
2. Active Glass Fibers
3. Chalcogenide Glass Fibers.

Glass is made of pure  $\text{SiO}_2$  which refractive index 1.458 at 850 nm. The refractive index of  $\text{SiO}_2$  can be increased (or) decreased by adding various oxides are known as dopant.

The oxides  $\text{GeO}_2$  or  $\text{P}_2\text{O}_3$  increases the refractive index and  $\text{B}_2\text{O}_3$  decreases the refractive index of  $\text{SiO}_2$ . The various combinations are,

- (i)  $\text{GeO}_2$   $\text{SiO}_2$  Core;  $\text{SiO}_2$  cladding
- (ii)  $\text{P}_2\text{O}_3$  -  $\text{SiO}_2$  Core;  $\text{SiO}_2$  cladding
- (iii)  $\text{SiO}_2$  Core;  $\text{B}_2\text{O}_3$ , -  $\text{SiO}_2$  cladding
- (iv)  $\text{GeO}_2$ -  $\text{B}_2\text{O}_3$ -  $\text{SiO}_2$ , Core;  $\text{B}_2\text{O}_3$  -  $\text{SiO}_2$  cladding.

From above, the refractive index of core is maximum compared to the cladding.

### (1) Halide Glass Fibers

A halide glass fiber contains fluorine, chlorine, bromine and iodine. The most common Halide glass fiber is heavy "metal fluoride glass". It uses  $\text{ZrF}_4$  as a major component. This fluoride glass is known by the name ZBLAN. since its constituents are  $\text{ZrF}_4$ ,  $\text{BaF}_2$ ,  $\text{LaF}_3$ ,  $\text{AlF}_3$ , and  $\text{NaF}$

The percentages of these elements to form ZBLAN fluoride glass is shown as follows,

Materials	Molecular percentage
$\text{ZrF}_4$	54%
$\text{BaF}_2$	20%
$\text{LaF}_3$	4.5%
$\text{AlF}_3$	3.5%
$\text{NaF}$	18%

These materials add up to make the core of a glass fiber. By replacing  $\text{ZrF}_4$  by  $\text{HfF}_4$ , the lower refractive index glass is obtained.

The intrinsic losses of these glasses is 0.01 to 0.001 dB/km

### (2) Active Glass Fibers

Active glass fibers are formed by adding erbium and neodymium to the glass fibers. The above material performs amplification and attenuation

### (3) Chalcogenide Glass Fibers

Chalcogenide glass fibers are discovered in order to make use of the nonlinear properties of glass fibers.

It contains either "S", "Se" or "Te", because they

are highly nonlinear and it also contains one element from "Cl", "Br", "Cd", "Ba" or "Si".

The mostly used chalcogenide glass is  $AS_2-S_3$ ,  $AS_{40}S_{58}Se_2$  is used to make the core and  $AS_2S_3$  is used to make the cladding material of the glass fiber. The insertion loss is around 1 dB/m.

### Plastic Optical Fibers

Plastic optical fibers are the fibers which are made up of plastic material. The core of this fiber is made up of Polymethylmethacrylate (PMMA) or Perflourmated Polymer (PFP).

Plastic optical fibers offer more attenuation than glass fiber and is used for short distance applications. These fibers are tough and durable due to the presence of plastic **material**. The modulus of this plastic material is two orders of magnitude lower than that of silica and even a 1 mm diameter graded index plastic optical fiber can be installed in conventional fiber cable routes. The diameter of the core of these fibers is 10-20 times larger than that of glass fiber which reduces the connector losses without sacrificing coupling efficiencies. So we can use inexpensive connectors, splices and transceivers made up of plastic injection-molding technology.

Graded index plastic optical fiber is in great demand in customer premises to deliver high-speed services due to its high bandwidth

### 3. What are the basic attenuation mechanisms in the optical fiber communication? Explain in brief on what factors this mechanism depends?

#### Ans: Attenuation

When a decrease in light power occurs during light propagation along an optical fiber then such a phenomenon is called attenuation. The major causes for attenuation in fiber optic communications are,

1. Bending loss
2. Scattering loss
3. Absorption loss

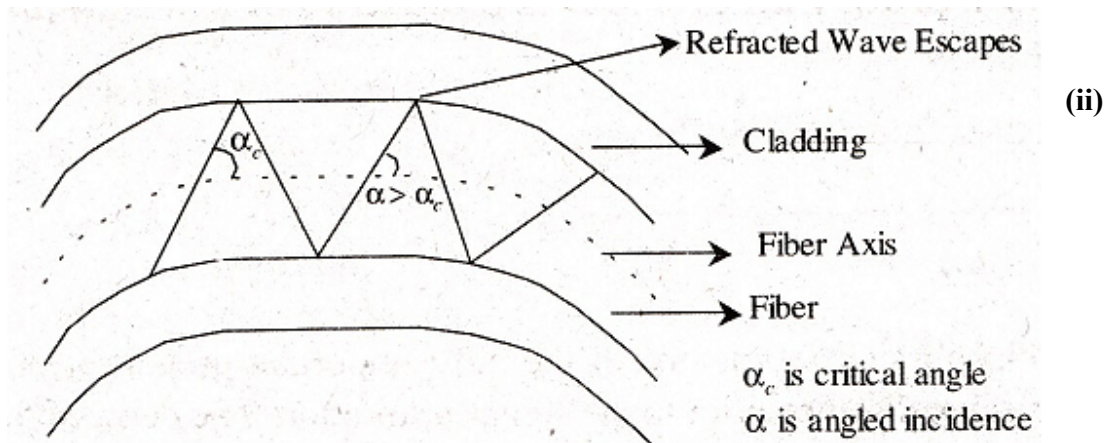
#### 1. Bending Loss

Bending loss is further classified into,

- (i) Macro bending loss-and
- (ii) Micro bending loss.

#### (i) Macro bending Loss

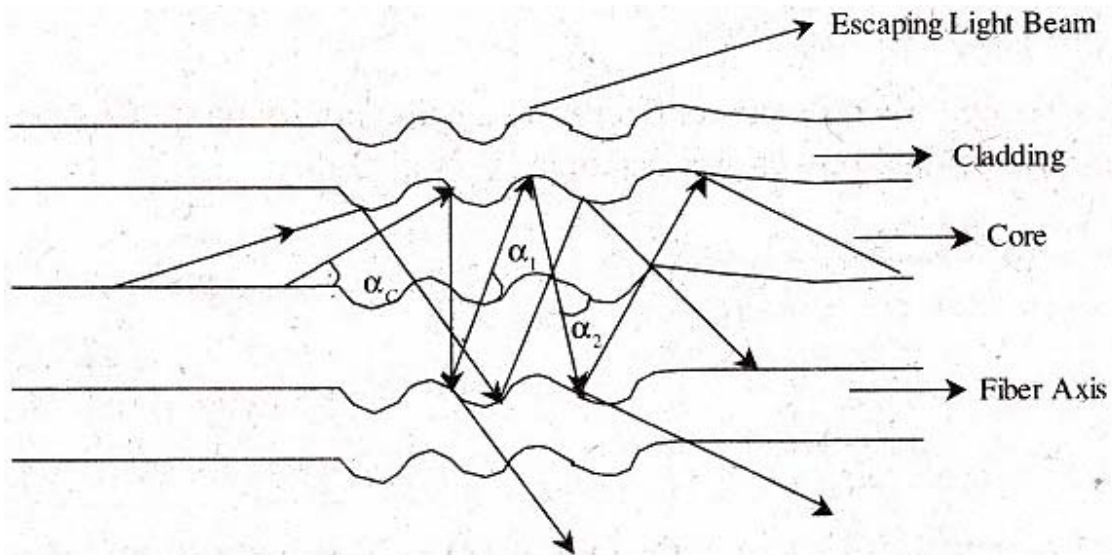
The light travels in fiber due to occurrence of total internal reflection inside the fiber at the interface of core and cladding. However the light beam forms a critical angle with the fiber's central axis at the fiber face. When the fiber is bend and the light beam travelling through fiber strikes at the boundary of core at an angle greater than critical angle then the beam fails to achieve total internal reflection. Hence this beam is lost through the cladding.



3.1 Macro Bending of optical Fiber

**Micro bending Loss**

Micro bending loss is caused by micro-deformations of the fiber axis. The beam which travels at the critical propagation angle before incident on micro-deformations will change the angle of propagation after being reflected by the imperfection of fiber and hence the condition for total internal reflection is lost and the beam escapes from the fiber through cladding.

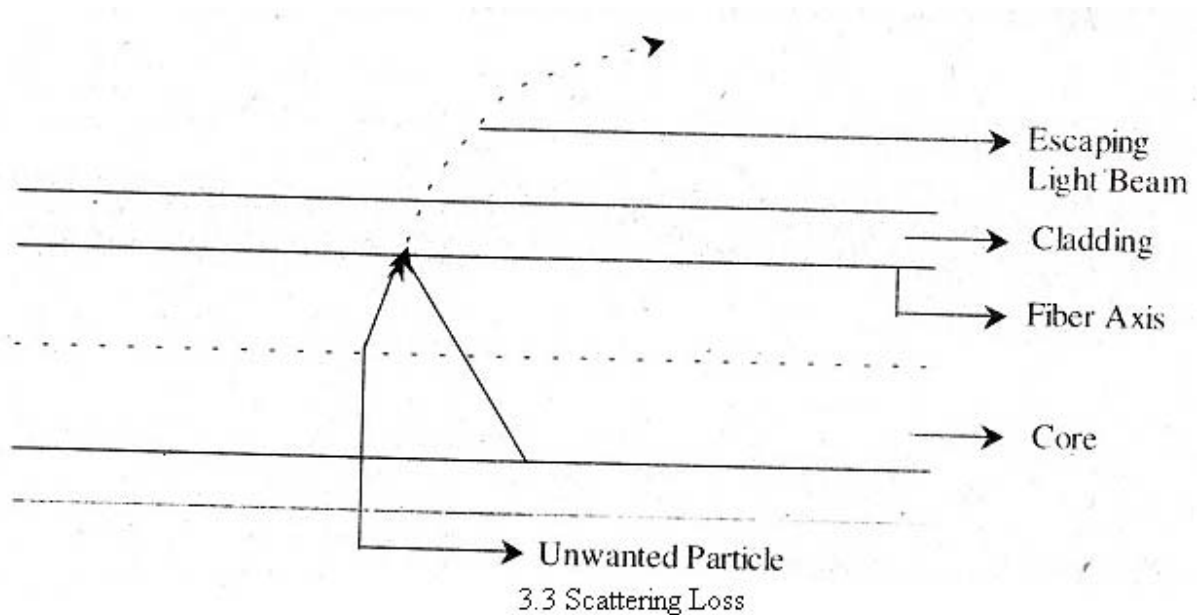


3.2  $\alpha_c$  is Critical Angle where  $\alpha_1 > \alpha_c$ ,  $\alpha_2 > \alpha_c$

**2. Scattering Loss**

A light beam propagating through the fiber core at critical angle or less will change its direction after hitting on an obstacle in the core region. The obstacle can be any particle in core that may have diffused inside the core at the time of manufacturing when the light beam hits the particle it

get scattered and due to this total internal reflection is not achieved hence, the beam is lost through the cladding.



### 3. Absorptions Loss

Whenever a beam of light photon having energy equal to energy band gap then the light photon is absorbed by the material resulting in absorption loss. Absorption loss occur due to presence of anions  $\text{OH}^-$  in silica fibers and due to metallic ions like Iron (Fe), Chromium (Cr) and Nickel (Ni). The absorption loss peak is observed in the region of 2700 nm and 4200 nm wavelength with low-loss at 7200 nm, 9500 nm and 13800 nm wavelength windows.

### 4. Explain in detail about ultra sonic absorption, infrared absorption and ion resonance absorption losses in the pure and doped $\text{SiO}_2$ at various levels?

**Ans:** An absolutely pure silicate glass has little intrinsic absorption due to its, basic material structure in the near infrared region. However it does have two major intrinsic absorption mechanisms at optical wavelengths as illustrated in the following figure which shows a possible optical attenuation against wavelength characteristic for absolutely pure glass (i.e.,  $\text{SiO}_2$ ). There is a fundamental absorption edge, the peaks of which are centered in the ultraviolet wavelength region. This is due to the stimulation of electrons transitions within the glass by higher energy excitation. The tail of this peak may extend into the window region at the shorter wavelengths. Also in the infrared and far-infrared, normally at wavelengths above  $7\mu\text{m}$ . Absorption bands from the interaction of photons with molecular variations within the glass occur. These give

absorption peaks which again extend into the window region. Hence, above  $1.5\mu\text{m}$ , the tails of these largely far-infrared absorption peaks tend to increase the pure glass losses.

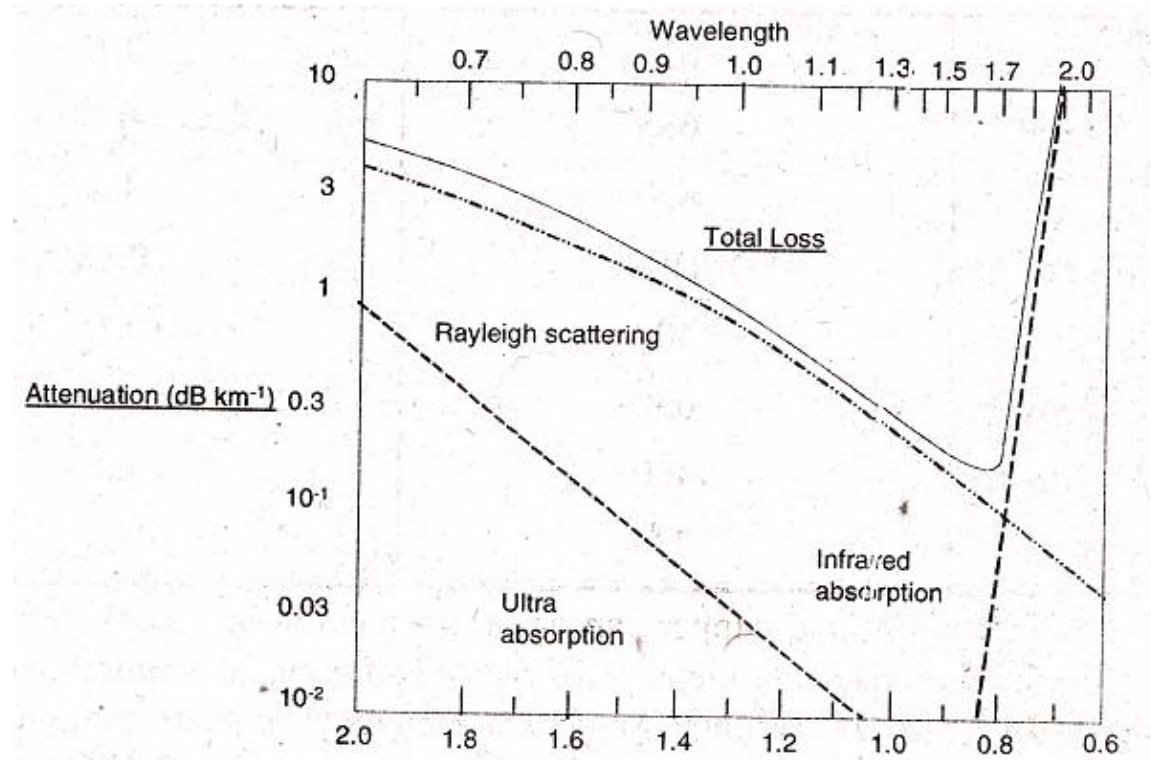


fig 4.1 The Attenuation Spectrum for intrinsic Loss mechanism in pure GeO<sub>2</sub>, SiO<sub>2</sub> Glass

In practical optical fibers prepared by conventional melting techniques, a major source of signal attenuation is extrinsic (doped) absorption from transition metal element impurities. Certain impurities, namely Chromium and Copper, in their worst valence state can cause attenuation in excess of 1 dB/km in the near infrared region. Transition element contamination may be reduced to acceptable levels i.e., one part in 10<sup>10</sup> by glass refining techniques such as vapor-phase oxidation. It may also be observed that the only significant absorption band in the region below a wavelength of 1 μm is the second overtone at 0.95 μm which causes attenuation of about 1 dB/km for one part per million (ppm) of hydroxyl. At longer wavelengths the first overtone at 1.38 μm and its side band at 1.24 μm are strong absorbers giving attenuation of about 2 dB/km ppm and 4

dB/km

respectively.

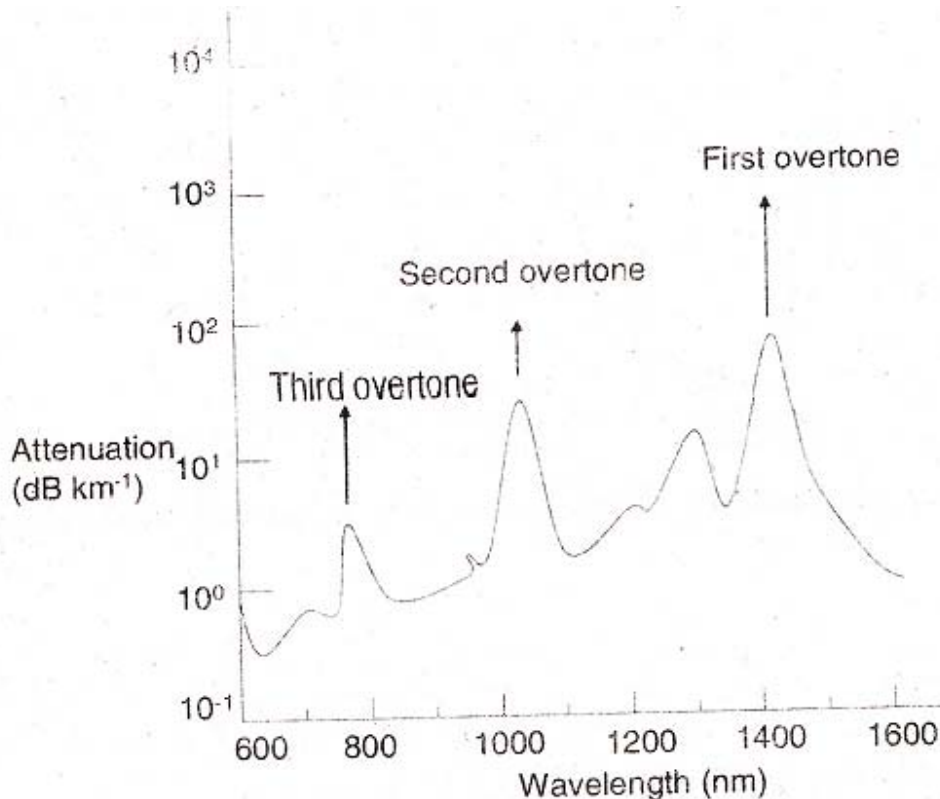


fig 4.2 The Absorption Spectrum for the Hydroxyl (OH) Group In silica

Since most resonances sharply peaked, narrow window exist in the longer wavelength region around 1.3 and 1.55 $\mu$ m which are essentially unaffected by OH absorption, once the impurity, level has been reduced below one part in 10<sup>7</sup>. This situation is illustrated in. figure (b) which shows the attenuation spectrum of an ultra-low-loss single mode fiber. It may be observed that the lowest attenuation for this fiber occurs at a wavelength of 1.55 $\mu$ m and is 0.2dB/km. This approaching is the minimum possible attenuation of around 0.18 dB/km at this wavelength.

### 5. Explain in detail about signal distortion and attenuation in optical fiber?

#### Ans: Signal Distortion in Optical Fibers

One of the important property of optical fiber is signal attenuation. It is also known as fiber loss or signal loss. The signal attenuation of fiber determines the maximum distance between transmitter and receiver. The attenuation also determines the number of repeaters required, maintaining repeater is a costly affair.

Another important property of optical fiber is distortion mechanism. As the signal pulse travels along the fiber length it becomes broader. After sufficient length the broad pulses starts

overlapping with adjacent pulses. This creates error in the receiver. Hence the distortion limits the information carrying capacity of fiber

### Attenuation

Attenuation is a measure of decay of signal strength or loss of light power that occurs as light pulses propagate through the length of the fiber.

In optical fibers the attenuation is mainly caused by two physical factors absorption and scattering losses. Absorption is because of fiber material and scattering due to structural imperfections within the fiber. Nearly 90% of total attenuation is caused by Rayleigh scattering only. Micro bending of optical fiber also contributes to the attenuation of signal.

**Attenuation Units** As attenuation leads to a loss of power along the fiber, the output power is significantly less than the coupled power. Let the coupled optical power is  $P(0)$  i.e. at origin ( $z = 0$ ) Then the power at distance  $z$  is given by

$$P(Z) = P(0)e^{-\alpha_p Z}$$

Therefore  $\alpha_p = \left(\frac{1}{Z}\right) \ln \left[\frac{P(0)}{P(Z)}\right]$

$$\alpha_{dB/Km} = 10 \cdot \left(\frac{1}{Z}\right) \ln \left[\frac{P(0)}{P(Z)}\right]$$

This parameter is known as fiber loss or fiber attenuation. Attenuation is also a function of wavelength. Optical fiber wavelength as a function of wavelength is shown in fig 5.1

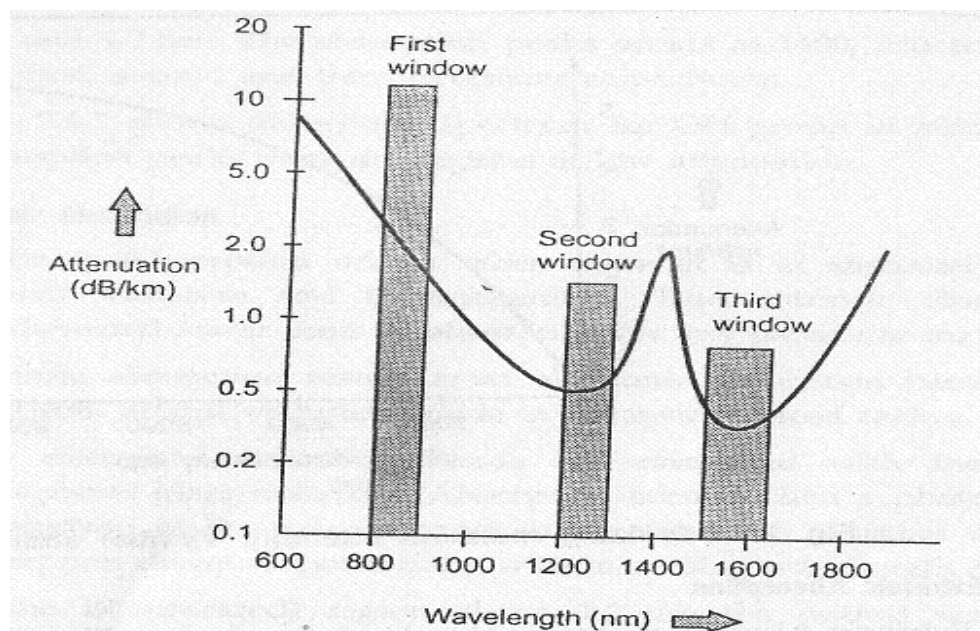


Fig 5.1 Fiber Attenuation As a function of Wave length



## 6. Explain the following

(i) Mode field diameter

(ii) Modal Birefringence

ans:

**Mode field diameter:**

Mode field diameter is a primary parameter of single-mode fibers. It is obtained from the mode field distribution of the fundamental mode.

The figure shows, the distribution of light in a single mode fiber.

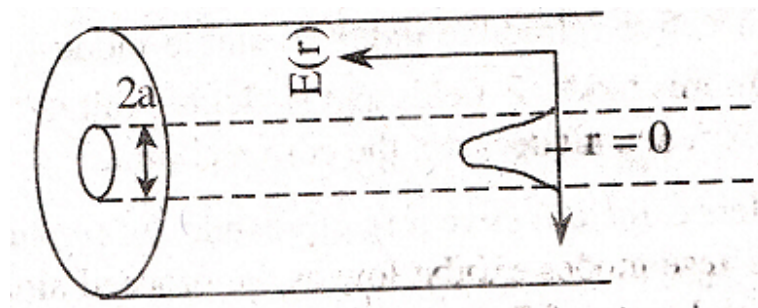


Fig 6.1 Mode Field Diameter

In order to find the MFD for field intensity  $E^2(r)$  must be calculated by using  $E^2(r)$  MFD can be calculated as,

$$\begin{aligned} \text{MFD} &= 2\omega_0 \\ &= 2 \sqrt{\frac{2 \int_0^\infty E^2(r) r^3 dr}{\int_0^\infty E^2(r) r dr}} \end{aligned}$$

Where

$$2\omega_0 = \text{spot size}$$

To avoid complexity,  $E(r)$  can be taken as,

$$E(r) = E(0) \exp(-r^2/\omega_0^2)$$

Where  $r$  = radius

$$E(0) = \text{field at } (r=0)$$

By using this relation, we can write

$$\text{MFD} = 1/e^2 \text{ width of optical power.}$$

### (ii) Modal Birefringence

The propagation of two approximately degenerate modes with orthogonal polarizations is allowed in single mode fibers with nominal circular symmetry about the core axis. Thus, these are referred as bimodal supported  $HE_{11}^x$  and  $HE_{11}^y$  modes. Here, the super scripts x and y denotes the principle axes and are calculated using the symmetry elements of the fiber cross section. The difference in the effective refractive indices and phase velocities for these orthogonally polarized modes makes the fiber to function as a birefringent medium. The independency of fiber cross section with the fiber length in the z-direction yields the expression for modal birefringence  $B_F$  as,

Where,

$$\beta_x = \text{Propagation constant for the mode 'x'}$$

$$\beta_y = \text{Propagation constant for the mode 'y'}$$

$$\lambda = \text{Optical wavelength.}$$

The difference in phase velocities is responsible for linear retardation  $\Phi(z)$  exhibited by the fiber. The expression for linear retardation is given by,

$$\Phi(z) = (\beta_x - \beta_y)L$$

Where,

$$L = \text{Length of the fiber.}$$

If the coherence time of the source is greater than the delay between the two transit times then only, the phase coherence of the two mode components is achieved. However, the expression for coherence time of the source is given by,

$$t_c = 1/\delta f$$

$$\text{Where, } \delta f = \text{Uncorrelated source frequency width}$$

Then, the length of fiber over which birefringent coherence is maintained is given by

$$\text{Where, } c = \text{Velocity of light in vacuum}$$

$$\delta\lambda = \text{Source line width}$$

Figure 6.1 illustrates the variations of polarization state periodically along the fiber

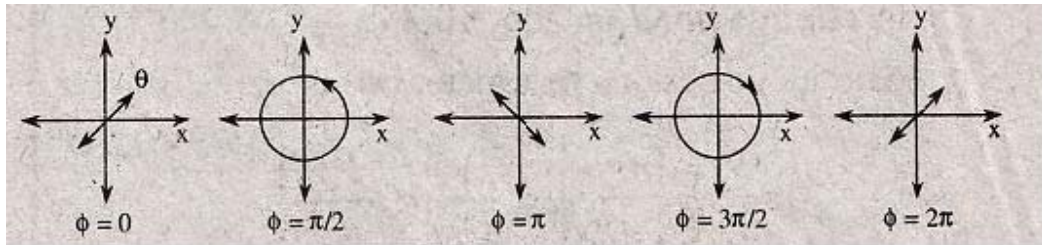


Fig 6.1 Polarization

The characteristic length  $L_B$  corresponding to the above process is referred as beat length and is given by,

$$L_B = \lambda/B_F \dots \dots \dots (5)$$

From equation (1), we have

$$L_B = \frac{2\pi}{(\beta_x - \beta_y)} \dots \dots \dots (6)$$

And expression 2 can be written as.

$$\begin{aligned} \Phi(L_B) &= (\beta_x - \beta_y)L_B \\ &= (\beta_x - \beta_y) \frac{2\pi}{(\beta_x - \beta_y)} = 2\pi \dots \dots \dots (7) \end{aligned}$$

Based on the above observation of beat length, we can determine the modal birefringence  $B_F$ .

**7. Commonly available single mode fiber have beat length in the range  $10\text{cm} < L_P < 2\text{m}$ . What rate of refractive index difference does this corresponds to for  $\lambda = 1300\text{nm}$ ?**

**Ans:**

Give that

For a single mode fiber,

Beat length  $L_P = 10\text{cm}$  to  $2\text{cm}$

Operating wavelength  $\lambda = 1300\text{nm}$

The refractive index difference is known as birefringence and is denoted by  $\beta_f$ .

$$\beta_f = 2\pi/L_p$$

Case 1

For  $L_p = 10\text{cm}$

$$\beta_f = 2\pi/10$$

$$\beta_f = 62.83 \text{ m}^{-1}$$

Case 2

For  $L_p = 2\text{cm}$

$$\beta_f = 2\pi/2$$

$$\beta_f = 3.14 \text{ m}^{-1}$$

Therefore, the range of refractive index differences is  $3.14\text{m}^{-1} < \beta_f < 62.83\text{m}^{-1}$

**8. A 10 km length of fiber is 100  $\mu\text{W}$  and the average output power is 25 (J.W. Calculate,**

- (i) The signal attenuation in dB through the fiber. It is assumed that there are no connectors or splices**
- (ii) Signal attenuation per km of the fiber**
- (iii) Overall signal attenuation for the 11 km optical link using the same fiber with 3 splices, each having an attenuation of 0.8 dB**
- (iv) Numerical value of the ratio between input and output power.**

**Ans:**

Given that

$$L = 10\text{Km}$$

$$P_{\text{input}} = 100\mu\text{m}$$

$$P_{\text{output}} = 25\mu\text{m}$$

(i) Attenuation

$$(\alpha_{dB}) = 10 \log_{10} (P_{input} / P_{output})$$

$$\alpha_{dB} = 10 \log_{10} \left[ \frac{100 * 10^{-6}}{25 * 10^{-6}} \right]$$

$$\alpha_{dB} = 6.02 \text{ dB}$$

(ii) The signal attenuation per Km of the fiber is,

$$\alpha_{dB} \cdot L = 6.02$$

$$\alpha_{dB} = 6.02 / 10$$

$$\alpha_{dB} = 0.602 \text{ dB km}^{-1}$$

**9. A 10 km length of fiber is 100  $\mu$ W and the average output power is 25 (J.W). Calculate,**

- (i) The signal attenuation in dB through the fiber. It is assumed that there are no connectors or splices**
- (ii) Signal attenuation per km of the fiber**
- (iii) Overall signal attenuation for the 11 km optical link using the same fiber with 3 splices, each having an attenuation of 0.8 dB**
- (iv) Numerical value of the ratio between input and output power.**

**Ans:**

Given L=10

P<sub>input</sub> = 100 $\mu$ m

P<sub>output</sub> = 25 $\mu$ m

**(i) Attenuation**

$$(\alpha) \text{ dB} = 10 \log_{10} (P_{input} / P_{output})$$

$$\alpha(\text{dB}) = 10 \log_{10}(100 * 10^{-6} / 25 * 10^{-6})$$

$$\alpha (\text{dB}) = 6.02 \text{ dB}$$

**(ii) The signal Attenuation per Km of the fiber is**

$$\alpha \text{ (dB) } \cdot L = 6.02$$

$$\begin{aligned}\alpha \text{ (dB)} &= 6.02/10 \text{ dBKm}^{-1} \\ &= 0.602 \text{ dBKm}^{-1}\end{aligned}$$

**(iii) Attenuation per unit length  $\alpha$  (dB)**

The loss produced along 11Km of the fiber is,

$$\begin{aligned}\alpha \text{ (dB) } \cdot L &= 0.602 \cdot 11 (\text{Km} \cdot \text{dBKm}^{-1}) \\ &= 6.622 \text{ dB}\end{aligned}$$

The number of splices are 3, each having attenuation of 0.8 dB

Therefore Total loss due to splices is  $0.8 \cdot 3 = 2.4$

Therefore Total signal attenuation =  $6.622 \text{ dB} + 2.4 \text{ dB}$

$$\alpha \text{ (dB)} = 9.022 \text{ dB}$$

(iv) Numerical values of the ratio between input and output power is,

$$\begin{aligned}P_{\text{input}}/P_{\text{output}} &= 10^{\left(\frac{\alpha \text{ dB}}{10}\right)} \\ &= 10^{\left(\frac{9.022}{10}\right)} = 7.98\end{aligned}$$

**10. A graded index fiber with a parabolic refractive index profile core has a refractive index at the core axis of 1.5 and a relative index difference of 1%. Estimate the maximum possible core diameter which allows single mode operation at a wave length of  $1.3 \mu\text{m}$ ?**

**Ans:** Given that,

For a graded index fiber with parabolic refractive index profile,

Refractive index of core is  $n_1 = 1.5$ .

Relative index difference,  $\Delta = 1\% = 0.01$

Operating wave length,  $\lambda = 1.3 \mu\text{m}$

Maximum possible core diameter =  $2a = ?$

## Optical Communications

## Unit II

For a graded index fiber, we have,

$$\Delta = \frac{n_1^2 - n_2^2}{2n_1^2}$$

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

$$n_2 = \sqrt{1.5^2 - 2 * 1.5^2 * 0.01}$$

$$n_2 = 1.485$$

we have,

$$V = \frac{2a\pi}{\lambda} (n_1^2 - n_2^2)^{\frac{1}{2}}$$

For a single mode operation  $V \leq 2.4$

$$2.4 \geq \frac{2a\pi}{\lambda} (n_1^2 - n_2^2)^{\frac{1}{2}}$$

$$a \leq \frac{2.4\lambda}{2\pi(1.5^2 - 1.485^2)^{\frac{1}{2}}}$$

$$a \leq 2.346\mu\text{m}$$

Where a is the radius of the core.

Therefore the maximum possible diameter of the of the core is given by,

$$2a_{\text{max}} = 4.692\mu\text{m}$$

