JAIPUR ENGINEERING COLLEGE AND RESEARCH CENTRE

- Year & Sem – Ist Year , Ist Sem
- Subject – Engineering Physics
- Unit – Coherence and Optical fiber
- Department- Applies Science (Physics)

VISION

To become a renowned institute of outcome based learning and work towards academic, professional, cultural and social enrichment of the lives of individuals and communities.

MISSION

- Focus on valuation of learning outcomes and motivate students to inculcate research aptitude by project based learning.
- Identify based on informed perception of Indian, regional and global needs, the areas of focus and provide platform to gain knowledge and solutions.
- Offer opportunities for interaction between academia and industry.
- Develop human potential to its fullest extent so that intellectually capable and imaginatively gifted leaders can emerge in a range of professions.

Syllabus & Course outcomes

- **Syllabus: Coherence and Optical Fibers:** Spatial and temporal coherence: Coherence length; Coherence time and 'Q' factor for light, Visibility as a measure of Coherence and spectral purity, Optical fiber as optical wave guide, Numerical aperture; Maximum angle of acceptance and applications of optical fiber.
- **Course outcomes:** After studying this topic students will be able to learn all basic concepts of Coherence and its types, visibility as a measure of coherence ,optical fiber and their applications in optical communication ,medical science ,industry and military etc.

CONTENTS

- Coherence
- Types of Coherence
- Relation between Coherence length, Coherence time and Quality factor
- Visibility as a measure of Coherence
- Optical Fiber and its construction
- Types of optical Fiber
- Acceptance Angle and Numerical Aperture of Optical fiber
- Applications of optical fiber
- Problems
- Lecture contents with a blend of NPTEL contents
- References/Bibliography

Lecture Plan

S. No	Topics	Lectures required	Lect. No.
1	Definition of Coherence, spatial & temporal coherence, Coherence length & Coherent time	1	1
2	Q - factor for light (spectral purity), Visibility as measures of Coherence	1	2
3	Optical fibers as optical wave guide, Types of fibers & working principle.	1	3
4	Numerical aperture of step index fiber, maximum angle of acceptance and it’s applications.	1	4
5	Problems	1	5

COHERENCE

Two wave sources are perfectly coherent if they have a constant phase difference and the same frequency. Coherence is an ideal property of waves that enables interference.

Coherent sources are those which emits light waves of same wave length or frequency and have a constant phase difference.

Coherent Laser Light

Ordinary light & Laser

Types of Coherence

Temporal Coherence

- It is measure of ability of a beam to interfere of another portion of it self

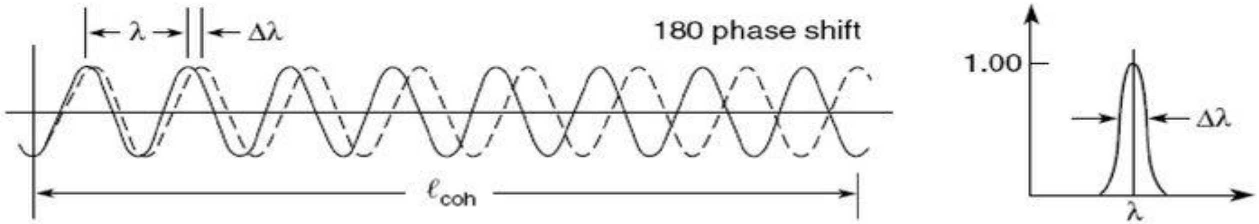
Spatial Coherence

- It refer to ability of two separate portion of wave to produce interference

Spatial and temporal coherence

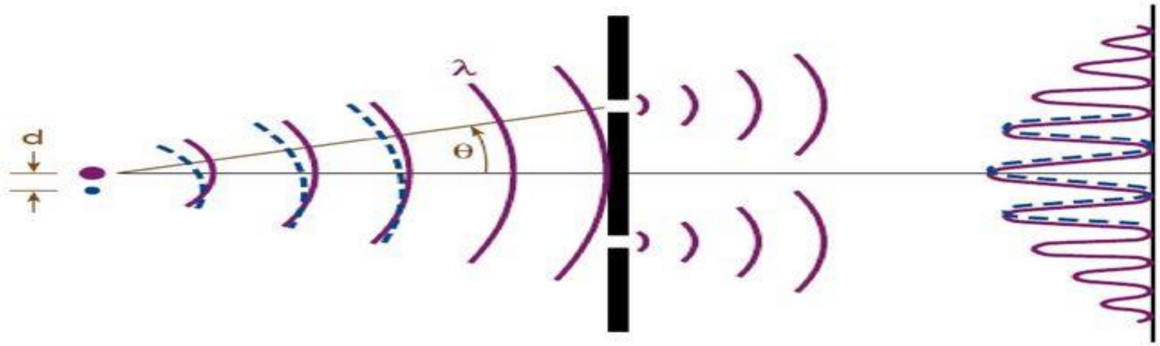
Temporal Coherence

Ability of a light beam to form fringes with a delayed version of itself



Spatial Coherence

Ability of spatially separated points in a wavefront to form fringes.



Difference between Temporal and Spatial coherence

Temporal coherence	Spatial Coherence
1. It is a measure of correlation between the phases of light wave at different points along the direction of wave propagation	1. It is a measure of correlation between the phases of light wave at different points along the direction of wave propagation
2. It is related directly to the wavelength of the source	2. It is related to the finite size of the source
3. This type of coherence is related with time	3. This type of coherence is related with position
4. It is also known as longitudinal coherence	4. It is also known as transverse coherence
5. eg. Michelson interferometer	5. eg. Young's Double slit experiment and Fresnel biprism

Coherence time, Coherence Length and Spectral Purity Factor

The average time interval for which definite phase relationship exists in knowledge is known as coherence time τ

The distance L for which the wave field remains sinusoidal is given by coherence Length L

$$L = c\tau \quad \text{---------------Eq 1}$$

Coherence Length In Terms of Frequency

$$L = c\tau$$

$$\tau = \Delta t = \frac{1}{\Delta \upsilon} \quad \text{---------------Eq 2}$$

$$\upsilon = \frac{c}{\lambda} \quad \text{---------------Eq 3}$$

By Differentiate equation 3 we got

$$\Delta \upsilon = -\frac{c}{\lambda^2}\Delta\lambda = \left|\frac{c}{\lambda^2}\Delta\lambda\right| \quad \text{--------Eq 4}$$

& Spectral Purity Factor is given by

$$Q = \frac{\lambda}{\Delta\lambda} \quad \text{--------Eq 5}$$

So

$$L = c\tau = \frac{c}{\Delta\upsilon} = \frac{\lambda^2}{\Delta\lambda} = \lambda Q \quad \text{--------Eq 6}$$

$$L = \lambda Q \quad \text{--------Eq 7}$$

$$\tau = \frac{L}{c} = \frac{\lambda Q}{c} \quad \text{--------Eq 8}$$

Interference Visibility

A quantitative measurement of the coherence of a light source is equal to the visibility V of the fringes.

The fringe visibility is defined as

$$V = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}} \qquad \text{---------- eq (1)}$$

A Value V ranging between 0 to 1 if V = 1 implies very high contrast fringes, the fringes are washed away when V=0

A value greater than 0.88 indicates that light is highly coherent.

Interference Visibility as a measure of Coherence

Let us consider two interfering waves, each of intensity I_0 . Both the waves consists of coherent part I_c and Incoherent part I_{inc} .

If C degree of coherence then.

$$I_c = CI_o \qquad \text{------------ eq . 1}$$

$$I_{inc} = (1-C)I_o \qquad \text{------------ eq . 2}$$

When superimposed. The coherence part shall interfere adding there by their amplitudes where as for the incoherent parts the intensities are simply added. Thus

$$I_{\max} = 4I_c + 2I_{inc} \qquad \text{------------ eq . 3}$$

$$I_{\min} = 0 + 2I_{inc} \qquad \text{------------ eq . 4}$$

Putting the values from eq 1 and 2 to eq 3 and 4

$$I_{\max} = 4CI_o + 2(1-C)I_o \qquad \text{------------ eq . 5}$$

$$I_{\min} = 0 + 2(1-C)I_o \qquad \text{------------ eq . 6}$$

As we know interference visibility given as

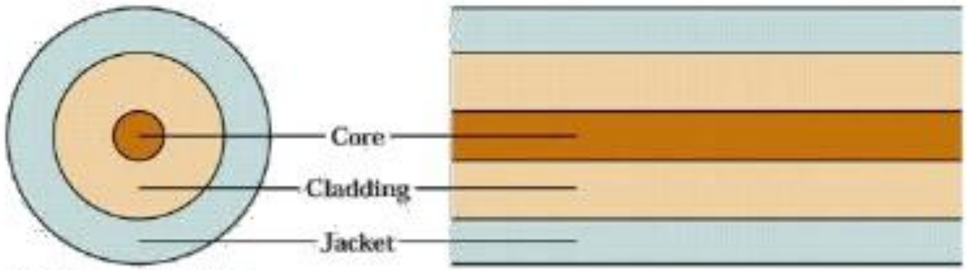
$$V = \frac{I_{\max} - I_{\min}}{I_{\max} + I_{\min}} = \frac{4CI_o + 2(1-C)I_o - 2(1-C)I_o}{4CI_o + 2(1-C)I + 2(1-C)I_o} = C$$

Therefore it is seen that degree of contrast is a measure of degree of coherence between waves of equal intensities000

Optical Fibre (Introduction)

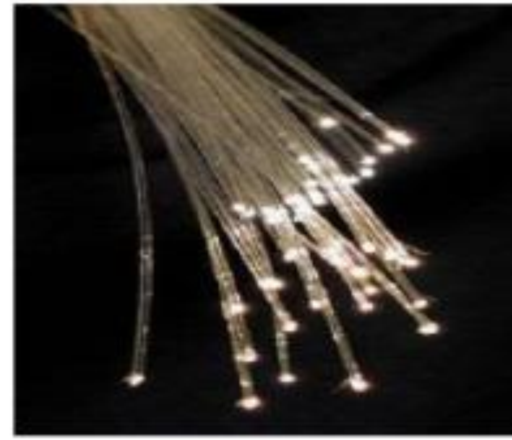
- An optical fiber is essentially a waveguide for light
- It consists of a **core** and **cladding** that surrounds the core
- The **index of refraction** of the cladding is less than that of the core, causing rays of light leaving the core to be refracted back into the core
- A light-emitting diode (LED) or **laser diode** (LD) can be used for the source
- Advantages of optical fiber include:
  - Greater bandwidth than copper
  - Lower loss
  - Immunity to **crosstalk**
  - No electrical hazard

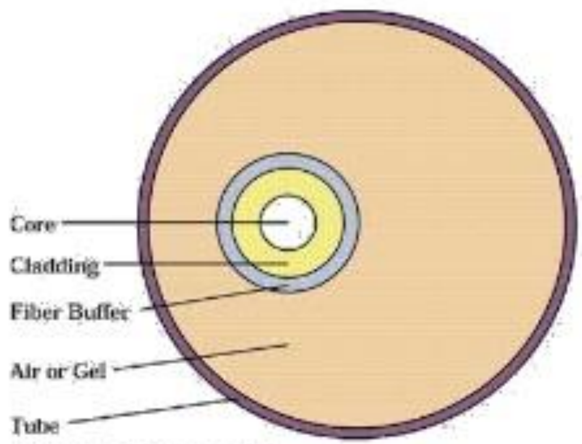
Optical Fiber Construction



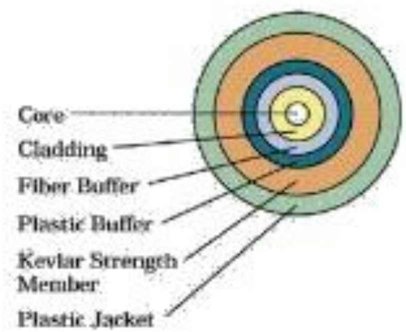
(a) Fiber cross section

(b) System





(a) Loose-tube construction



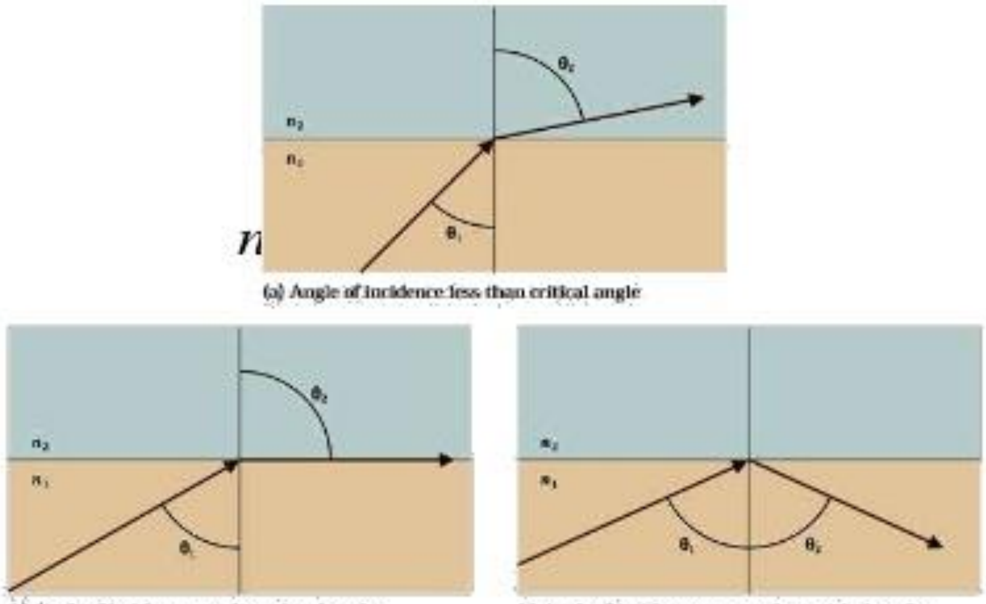
(b) Tight-buffer construction

Optical Fiber

- Optical fiber is made from thin strands of either glass or plastic
- It has little mechanical strength, so it must be enclosed in a protective jacket
- Often, two or more fibers are enclosed in the same cable for increased bandwidth and redundancy in case one of the fibers breaks
- It is also easier to build a full-duplex system using two fibers, one for transmission in each direction

Optical Fibre Working Principle

- Optical fibers work on the principle of **total internal reflection**
- With light, the refractive index is listed
- The **angle of refraction** at the interface between two media is governed by Snell's law:



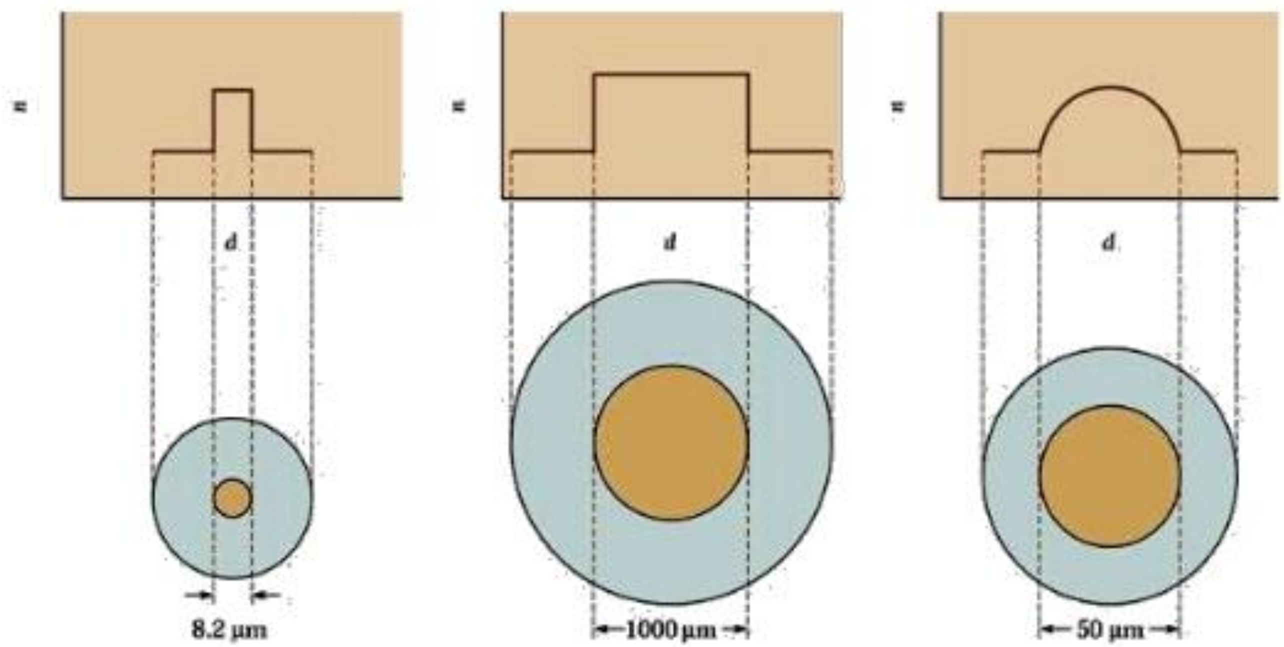
(a) Angle of incidence less than critical angle

(b) Angle of incidence equal to critical angle

(c) Angle of incidence greater than critical angle

Types of Fiber on the basis on Index

- In **step-index** fibers the index of refraction changes radically between the core and the cladding.
- **Graded-index** fiber is a compromise multimode fiber, but the index of refraction gradually decreases away from the center of the core
- Graded-index fiber has less dispersion than a multimode step-index fiber

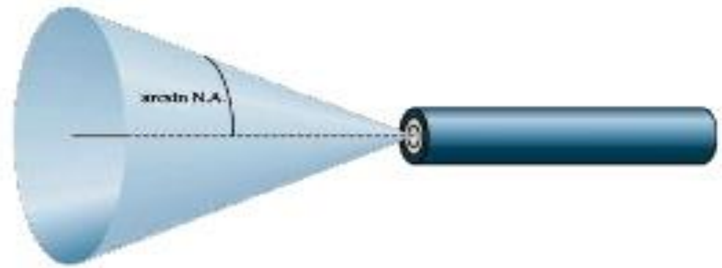


Numerical Aperture and Angle of Acceptance

- The **numerical aperture** of the fiber is closely related to the critical angle and is often used in the specification for optical fiber and the components that work with it
- The numerical aperture is given by the formula:

$$N.A. = \sin i_o = \sqrt{\mu_{core}^2 - \mu_{clad}^2}$$

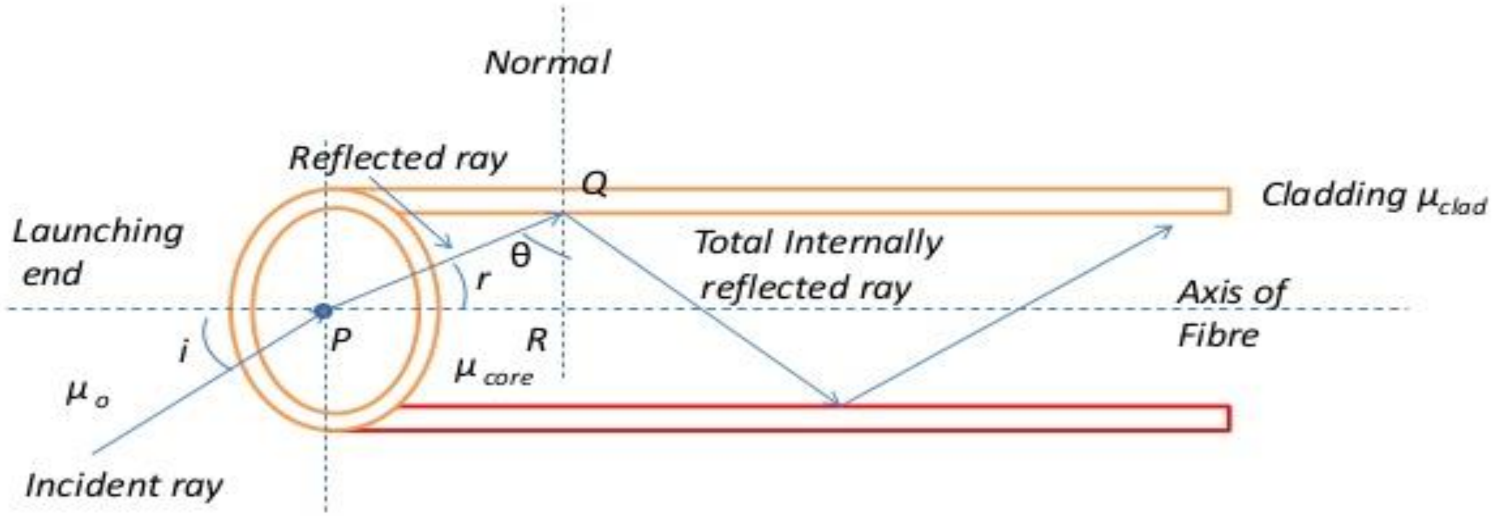
- The **angle of acceptance** is twice that given by the numerical aperture



Numerical Aperture and Angle of Acceptance

Consider a cylindrical fibre wire which consists of an inner core of refractive index μ_{core} and an outer cladding of refractive index $\mu_{clad.}$

Let $\mu_{o.}$ be the refractive index of the medium from which the light ray enters the fibre. This end is known as launching end. Let a ray of light enters the fibre at an incidence angle of i. to the axis of fibre as shown in figure. This ray refracted at an angle r and strikes the core-cladding interface at an angle θ. Let θ is greater than critical angle θ_c. As long as the angle θ is greater than critical angle θ_c, the light will stay within the optical fibre.



Now we shall calculate the angle of incidence i for which θ is greater than and equal to θ_c So that the light remains within the core.

Applying the snell's law of refraction at the point of entry P.

$$\mu_o \sin i = \mu_{core} \sin r \qquad \text{---------- eq 1}$$

From triangle PQR it is seen that

$$r + \theta = 90^o \; , \; r = 90^o - \theta$$

Or

$$\sin r = \sin(90^o - \theta) = \cos\theta \qquad \text{---------- eq 2}$$

Substituting the value of sin r from equation 2 to eq 1

$$\mu_o \sin i = \mu_{core} \cos\theta \qquad \text{---------- eq 3}$$

$$\sin i = \frac{\mu_{core}}{\mu_o} \cos\theta \qquad \text{---------- eq 4}$$

If Incidence angle i is increased beyond a limit , θ will drop below the critical value θc and the ray will escape from the side walls of the fibre. The largest value of i (i_{max}) occures when θ = θc.

So the eq 4 can be written as

$$\sin i_{max} = \frac{\mu_{core}}{\mu_o} \cos\theta_c \qquad \text{---------- eq 5}$$

Applying the snell's law of refraction at the core cladding interface

$$\mu_{core} \sin\theta_c = \mu_{clad} \sin 90^o \qquad \sin\theta_c = \frac{\mu_{clad}}{\mu_{core}}$$

$$\cos\theta_c = \sqrt{1 - \frac{\mu_{clad}^2}{\mu_{core}^2}} \qquad \text{---------- eq 6}$$

So the eq 5 can be written as

$$\sin i_{max} = \frac{\mu_{core}}{\mu_o} \sqrt{1 - \frac{\mu_{clad}^2}{\mu_{core}^2}} = \sqrt{\frac{\mu_{core}^2 - \mu_{clad}^2}{\mu_o^2}}$$

$$\sin i_{max} = \sqrt{\mu_{core}^2 - \mu_{clad}^2} = NA$$

$$i_{max} = \sin^{-1} \sqrt{\mu_{core}^2 - \mu_{clad}^2}$$

Here i_{max} is the angle of acceptance

So the angle of acceptance is defined as the maximum angle that a light ray can have relative to the axis of the fibre and propagate down the fibre.

Numerical Aperture:- It is also known as figure of merit for optical fibre. It is defined as sine of acceptance angle. NA= $i_o = i_{max}$

Propagation Condition

If i is the angle of incidence of an incident ray, then the ray will be able to propagate only if $i < i_o$ or $\sin i < \sin i_o$

or $\sin i \langle \sqrt{\mu_{core}^2 - \mu_{clad}^2}$

NA in terms of Fractional Refractive index Δ

The fractional refractive index change Δ is defined as the ratio of refractive index difference between core and cladding to the refractive index of core. It is expressed as

$$\Delta = \frac{\mu_{core} - \mu_{clad}}{\mu_{core}}$$

$$NA = \sqrt{\mu_{core}^2 - \mu_{clad}^2} = \sqrt{(\mu_{core} - \mu_{clad})(\mu_{core} + \mu_{clad})} = \sqrt{\frac{(\mu_{core} - \mu_{clad})}{\mu_{core}} \frac{(\mu_{core} + \mu_{clad})}{2} 2\mu_{core}}$$

$$NA = \sqrt{\Delta \frac{(\mu_{core} + \mu_{clad})}{2} 2\mu_{core}}$$ Or if $$\frac{(\mu_{core} + \mu_{clad})}{2} \approx \mu_{core}$$

than

$$NA = \sqrt{\Delta 2 \mu_{core}^2} = \mu_{core}\sqrt{2\Delta}$$

V- Number

This is an important parameter of optical fibre given by the relation

$$V = \frac{2\pi a}{\lambda}\sqrt{\mu_{core}^2 - \mu_{clad}^2}$$

Where a is the radius of the core and λ is free space wave length.

The maximum number of modes (N_m) supported by a single mode step index fibre is determined by.

$$N_m = \frac{1}{2}V^2$$

If V< 2.405, the fibre will support only one mode and known as single mode optical fibre
If V>2.405, the fibre will support many modes simultaneously. This is known as multi-mode fibre

The wavelength corresponding to the value V=2.0405 known as cutoff wavelength this is expressed as

$$\lambda_c = \frac{\lambda V}{2.405}$$

Applications

Communication :

- A large information can be sent through optical fiber with least attenuation.
- It has a capacity of transmitting thousands of Channels at a time.

Medicine :

- The instrument based on the optical fiber used for searching an ulcer in the stomach of a patient called the fiberscope.
- Such fiberscope's are widely used in endoscopic applications

Optical fiber sensing :

- In thermometer it is used as a heat sensing element.
- A smoke detector can be made using optical fiber.

Military Applications :

- An aircraft ,ship or a tank reduces much weight and maintains true communication silence to the enemies.
- Fiber guided missiles are used during the recent wars.

Problems & Solutions

Q.1. Light of wavelength 4800Å has a length of 25 waves. What is the coherence length and coherence time.

Sol:- Given Wavelength 4800Å so the coherence length $L = 25 \times 4800 \times 10^{-10}$ m

$= 12 \times 10^{-6}$m

So coherence Time $\tau = \frac{L}{C} = \frac{12\times10^{-6} m}{3\times10^{8} m/s} = 4.0\times10^{-14} s$

Problems and Solutions

Q.1. Calculate the refractive indices of the core and cladding material of a fibre from the following data NA=0.22 and Δ=0.012

Sol:- Given NA=0.22 and Δ=0.012

We know the relation

$$NA = \sqrt{\Delta 2\mu_{core}^{2}} = \mu_{core}\sqrt{2\Delta}$$

$$\mu_{core} = \frac{NA}{\sqrt{2\Delta}} = \frac{0.22}{\sqrt{2\times 0.012}} = 1.42$$

$$\Delta = \frac{\mu_{core} - \mu_{clad}}{\mu_{core}}$$

so

$$0.012 = \frac{1.42 - \mu_{clad}}{1.42}$$

$$\mu_{clad} = 1.40$$

Problems

- Show that the numerical aperture of step index optical fiber is given by $NA = n_{core}\sqrt{2\Delta}$.
- Light of wavelength 4800 Å has wave train length of 25 waves. What is the coherent length, coherent time and quality factor?
- The spectral spread of red cadmium light of wave length 6943 Å is 0.001 mm. Calculate purity factor, coherence length and coherence time.
- A LASER operates at wavelength of 6000 Å and its spectral line width is 10^2 Hz. For this LASER, calculate Quality factor, coherence length and coherence time.

- For a typical step index multimode fiber the core index is n_1=1.45 and the relative refractive index difference of core- cladding (n_1-n_2) is 0.01. Find the numerical aperture and the maximum acceptance angle?

- Calculate the refractive indices of core and cladding materials of an optical fiber having NA = .22 and relative refractive index change is .012. Also find the critical angle and maximum acceptance angle.

- Two wavetrain overlaps 40% of their length . If the maxima in the resulting interfernce pattern receives 20 units of light , how much do the minima receive ?

LECTURE CONTENTS WITH A BLEND OF NPTEL CONTENTS & OTHER PLATFORMS

- https://youtu.be/IoNyH3mmIsQ
  (Video lecture by Dr. R.K.Mangal)
- https://nptel.ac.in/courses/115/107/115107095/
  (Video lecture by Prof. Vipul Rastogi)
- https://www.youtube.com/watch?v=oIurmHsRFSc
  (Video lecture by Prof. R. K. Shevgaonkar)
- https://nptel.ac.in/courses/108/104/108104113/
  (Video lecture by Dr. Pradeep Kumar K)

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- Engineering Physics by Dr. Y.C.Bhatt , Ashirwad Publications.
- Engineering Physics by H K Malik and A K Singh, Tata McGraw Hill publications.
- Fundamental of Optics by Jetkins and White, Tata McGraw Hill publications.

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