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PHYSICS FOR ELECTRONICS ENGINEERING

22PH102

UNIT I

LASER AND FIBRE OPTICS

Department : FIRST SEMESTER – ECE & EEE

Batch/Year : 2022-2023 / I

Created by : DEPARTMENT OF PHYSICS, RMKEC

Date : 06-11-2022

TABLE OF CONTENTS

COURSE OBJECTIVES

This course will enable the learners to

- **Educate the fundamental important concepts in Physics and apply the knowledge in solving scientific and engineering problems**
- **Impart the basic concepts of light propagation in waveguides, conducting materials, semiconducting materials, opto and nanoelectronic devices and photovoltaic technology**

SYLLABUS

L	T	P	C
3	0	2	4

UNIT 1 LASER AND FIBRE OPTICS 15

Population of energy levels – Einstein's A and B coefficients derivation - Resonant cavity - Optical amplification (qualitative) - Semiconductor lasers: homojunction and heterojunction - Engineering applications of lasers in data storage (qualitative)

Fibre optics: Principle and propagation of light through optical fibre - V-number - Types of optical fibres (Material, refractive index and mode) - Losses in optical fibre - Fibre optic communication - Fibre optic sensors (pressure and displacement)

Theory: 9 hrs

1. Determination of divergence of laser beam
2. Determination of acceptance angle and numerical aperture of an optical fibre

Practical: 6 hrs

COURSE OUTCOMES

On successful completion of this course, the students will be able to

CO1: Discuss the basic principles of working of laser and their applications in fibre optic communication

C02: Summarize the classical and quantum electron theories and energy band structures

C03: Describe the conductivity in intrinsic and extrinsic semiconductors and importance of Hall effect measurements

C04: Associate the properties of nanoscale materials and their applications in quantum computing

C05: Explain the concepts of photovoltaic technology and its applications.

CO – PO/PSO MAPPING

COs	PO 1	PO 2	PO 3	PO 4	PO 5	PO 6	PO 7	PO 8	PO 9	PO 10	PO 11	PO 12
CO1	3	2	3	2	-	-	-	-	-	-	-	-
CO2	3	2	3	2	-	-	-	-	-	-	-	-
CO3	3	2	3	2	-	-	-	-	-	-	-	-
CO4	3	2	3	2	-	-	-	-	-	-	-	-
CO5	3	2	3	2	-	-	-	-	-	-	-	-
CO6	3	2	3	2	-	-	-	-	-	-	-	-

LECTURE PLAN

S.No.	Topics to be Covered	No. of Periods	Pertaining CO	Taxonomy Level	Mode of Delivery
1	Introduction to laser Characteristics of laser population of energy levels	1	CO1	K1	PPT, Chalk & Talk
2	Einstein's A and B coefficients	1	CO1	K2	PPT, Chalk & Talk
3	Components of laser Resonant cavity Optical amplification	1	CO1	K1	PPT, Chalk & Talk
4	Semiconductor laser – Homojunction and heterojunction Laser	1	CO1	K2	PPT, Chalk & Talk
5	Engineering applications of laser	1	CO1	K3	PPT, Chalk & Talk
6	Introduction to optical fibres – Principle, Numerical aperture, acceptance angle and V number	1	CO1	K1, K2	PPT, Chalk & Talk
7	Types of optical fibre	1	CO1	K1	PPT, Chalk & Talk
8	Losses in fibre optic cable	1	CO1	K1, K2	PPT, Chalk & Talk
9	Fibre optic communication and fibre optic sensors	1	CO1	K3	PPT, Chalk & Talk

ACTIVITY

Watch the following videos and analyse the questions at the end

1. LASER in communication
https://www.nasa.gov/feature/goddard/2021/laser-communications-relay-demonstration-6-things-you-need-to-know
https://www.nasa.gov/feature/goddard/2021/exploring-together-nasa-and-industry-embrace-laser-communications

2. Laser in smart phone
https://us.hanslaser.net/application/phone-repair.html

3. Eye surgery
https://www.youtube.com/watch?v=f-YkzgfgN2k

4. Fiber optics in communication
https://www.youtube.com/watch?v=yd1JhZzoS6A

Questions for discussion

a. What are all the Physics concepts that you are able to recollect from this Unit which play a keyrole in all the above applications that you have seen in the videos?

b. The basic frame work for engineering and medical application is Physics - Justify

For the subject handling staff

In the activity period,

1. Students should be grouped
2. Each group should give one point for each question mentioned
3. It may be repeated till you get the required number of points
4. All the points may be noted by the staff on the board
5. Subject handling staff may summarise and conclude at the end

5. https://astroedu.iau.org/en/activities/1411/the-fibre-optic-cable-class/

   Activity 1:

   What is light and what are some of its uses?

   How can light be used in technology?

   How can light be used in Astronomy?

   What is a total internal reflection and what are its uses in the real world and in astronomy?

   Activity 2:

   What is a spectrograph and how does it work (i.e. where do fibre optics fit in)?

   Give an example of where a spectrograph is being used and what is its function?

1.1 INTRODUCTION

Einstein first predicted the existence of two different kinds of processes in which an atom can emit radiations in the year 1917. Later in 1958, A. L. Schawlow and C. H. Townes explained theoretically about the possibility of getting coherent light from stimulated emission process. Finally in 1960, Dr. Theodore Maiman demonstrated the first laser namely, the pulsed Ruby laser.

The term 'LASER' is an acronym of 'Light Amplification by Stimulated Emission of Radiation'. It is a device which produces a powerful, monochromatic (single colour) and coherent beam of light. It can travel over long distances without much loss of intensity. It amplifies light waves. There are solid state, liquid state, gaseous state and semiconductor lasers. They are used in many fields such as telecommunication, medicine, biology and computers.

1.2 CHARACTERISTICS OF LASER

The following characteristics distinguish a laser beam from an ordinary light.

- High directionality
- High intensity
- High monochromaticity
- High degree of coherence

High Directionality: An ordinary light source emits light in all possible directions. Since laser travels as a parallel beam, it can travel over a long distance with a small angular divergence or spread. The angular spread of a laser beam is less than 1 mm for every metre. But in the case of ordinary light beam, the spread is about 1 metre for every one metre that light traverses.

High Intensity: Since ordinary light spreads in all directions, the intensity reaching the target is very less. But, due to high directionality and coherent nature of laser, it has the ability to focus over a small area of 10^{-6} cm^2 with high intensity. Even a 1 watt laser beam is more intense than 100 watt ordinary incandescent lamp.

For example, 1 milli watt power of He–Ne laser appears to be brighter than the sunlight.

High Monochromaticity: Laser beam is highly monochromatic; the wavelength is single, whereas in ordinary light like mercury vapour lamp, many wavelengths of light are emitted. The light from a normal monochromatic source spreads over a range of wavelength of the order 100 nm. But the spread is of the order of 1 nm for laser.

High Degree of Coherence: It is an important characteristic of laser beam. In lasers, the wave trains of same frequency are in phase. The radiation given out is in mutual agreement not only in phase but also in the direction of emission and polarization. Since all the constituent photons of laser beam possess the same energy, momentum and propagate in the same direction, the laser beam is said to be highly coherent which leads to its high power.

1.3 DIFFERENCES BETWEEN ORDINARY LIGHT AND LASER LIGHT

Laser light is distinguished from ordinary light due to the following reasons.

Table 1.1 Differences between ordinary and laser light

S. No.	ORDINARY LIGHT	LASER
1	It is not coherent.	It is highly coherent.
2	It is not directional.	It is highly directional.
3	It is less intense.	It is highly intense,
4	Its angular spread is more.	Its angular spread is less.
5	Examples: Sunlight, Mercury vapour lamp, etc	Examples: He-Ne Laser, Carbon-di-oxide Laser, etc.

1.4 INTERACTION OF LIGHT WITH MATERIALS

In order to understand the working principle of laser, let us study the quantum processes that take place in a material, when it is exposed to light radiation. Let us consider an assembly of atoms exposed to light radiation. According to quantum theory, light radiation consists of photons with energy $h\nu$.

(i) Stimulated absorption: An atom residing in the lower energy state E_1 can absorb a photon and go to the higher energy level E_2 (excited state) provided the photon energy equals to the energy difference $E_2 - E_1$. This process is known as stimulated or induced absorption or simply absorption. Stimulated absorption process is shown in Fig. 1.1.

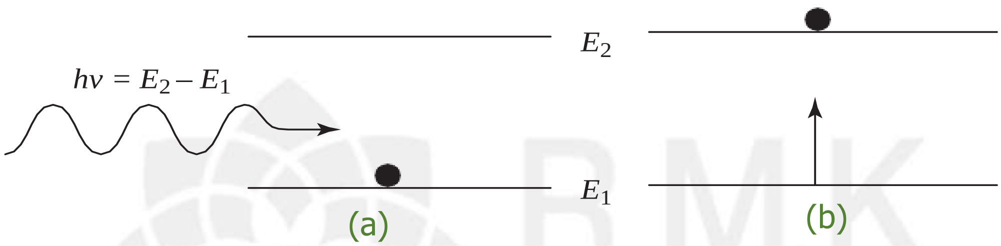


Fig. 1.1 Stimulated absorption (a) atom before absorption of photon energy (b) atom after absorption of photon energy

After absorption of photon, the atom returns to ground state by emitting photon of energy $h\nu$. The emission process can take one of the following forms.

1. Spontaneous emission
2. Stimulated emission

(ii) Spontaneous Emission: In the case of spontaneous emission, the atom passes from higher energy state E_2 (excited state) to lower energy state E_1 (ground state) spontaneously by emitting a photon of energy $h\nu$. This is a downward transition.

The spontaneous emission is random in character as shown in Fig. 1.2. The radiation emitted spontaneously by each atom has a random direction and phase. Thus radiation in this case is a random mixture of quanta having various wavelengths.

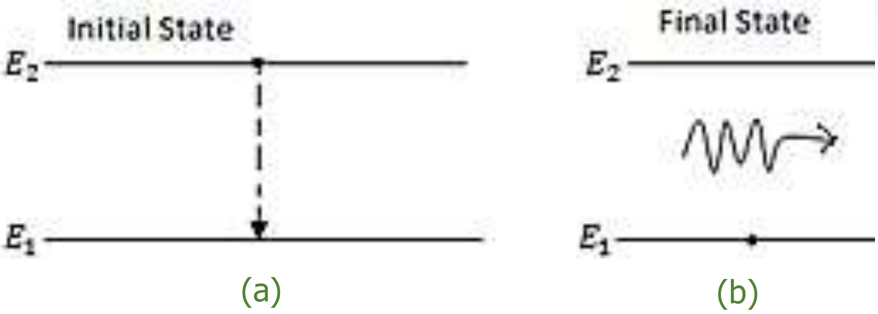


Fig. 1.2 Spontaneous emission (a) atoms before spontaneous emission (b) atoms after spontaneous emission

Moreover, they are not in phase. Thus the radiation is incoherent and has a broad spectrum. It is the process of spontaneous emission that dominates in conventional light sources.

(iii) Stimulated Emission: In the case of stimulated emission**,** the presence of incident photon will trigger excited atom to make a transition to the ground state. This is also another downward transition as shown in Fig. 1.3.

According to Einstein, an interaction between the excited atom and a photon can trigger the excited atom to make a transition to the ground state. The transition produces a second photon which would be identical to the triggering photon in respect of frequency, phase and propagation direction. This process of induced emission of photons caused by the incident photon is called stimulated emission.

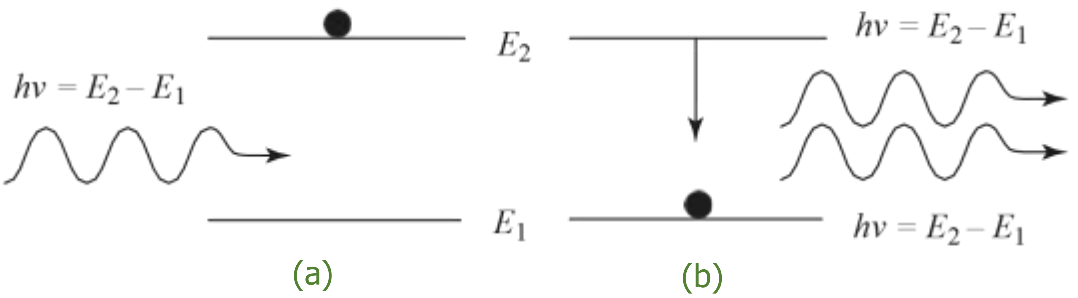


Fig. 1.3 Stimulated emission (a) atom before stimulation (b) atom after stimulated by photon energy

1.5 EINSTEIN'S A AND B COEFFICIENTS - DERIVATION

Einstein derived an expression that relates the rate of absorption, spontaneous emission and stimulated emission. Consider two energy levels E_1 and E_2 with population N_1 and N_2 in an atomic system. At thermal equilibrium, E_2 is greater than E_1 and N_2 is smaller than N_1.

Stimulated absorption: The atom in the ground state E_1 absorbs energy density of incident radiation ρ(ν) and goes to the excited state E_2 as shown in Fig. 1.1. For an easy follow up of the discussion, Fig. 1.1 has been shown here at the bottom. The number of induced absorption transition per unit time

$$R_{12(\text{abs})} = N_1\, B_{12}\, \rho(\nu) \qquad \text{...(1.1)}$$

where B_{12} is the probability of absorption transition per unit time

N_2 is the number of atoms with energy E_1 per unit volume of the medium

$\rho(\nu)$ is the energy density of incident radiation at frequency ν

Spontaneous emission: The atom passes from higher energy state E_2 to lower energy state E_1 spontaneously by emitting a photon of energy $h\nu$. This is a downward transition as shown in Fig. 1.4.

The average number of atoms undergoing spontaneous transition to state E_1 per unit time is given by

$$R_{21(\text{sp})} = N_2\, A_{21} \qquad \text{...(1.2)}$$

where A_{21} is the probability of spontaneous emission transition per unit time

N_2 is the number of atoms with energy E_2 per unit volume of the medium

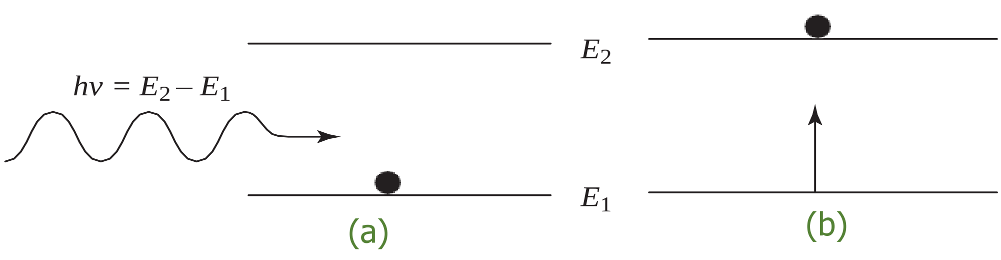


Fig. 1.1 Stimulated absorption (a) atom before absorption of photon energy (b) atom after absorption of photon energy

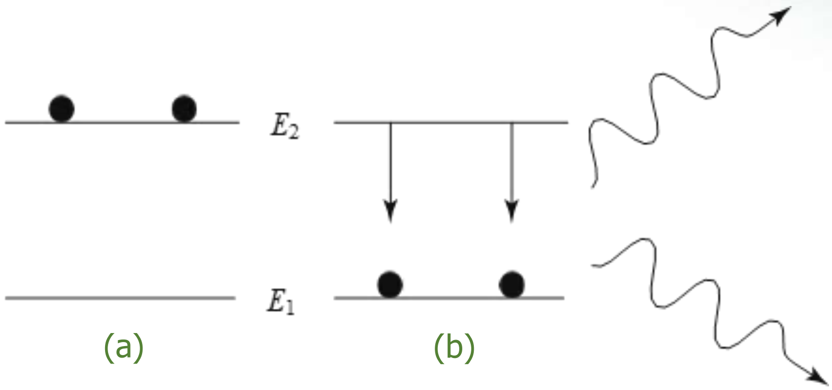


Fig. 1.4 Spontaneous emission (a) atoms before spontaneous emission (b) atoms after spontaneous emission

Stimulated Emission: In stimulated emission, a photon having energy $E=E_2-E_1$ stimulates an atom in the higher excited state E_2 to make a transition to the lower energy state E_1 with the emission of two coherent photons as shown in Fig. 1.3. Here also, for the discussion purpose, Fig. 1.3 has been shown here at the bottom. The rate of stimulated emission is

$$R_{21(\mathrm{st})} = N_2\, B_{21}\, \rho(\nu) \qquad \ldots(1.3)$$

where B_{21} is the probability of stimulated emission transition per unit time

N_2 is the number of atoms with energy E_2 per unit volume of the medium

At thermal equilibrium, the rate of upward transitions is equal to the rate of downward transition.

$$R_{12(\mathrm{abs})} = R_{21(\mathrm{sp})} + R_{21(\mathrm{st})}$$

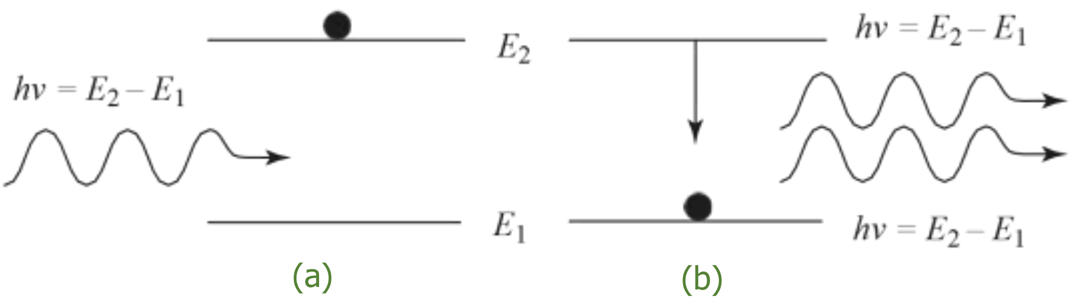


Fig. 1.3 Stimulated emission (a) atom before stimulation (b) atom after stimulated by photon energy of energy $h\nu$

At thermal equilibrium, the rate of upward transitions is equal to the rate of downward transition.

$$R_{12}(\mathrm{abs}) = R_{21}(\mathrm{sp}) + R_{21}(\mathrm{st})$$

$$N_1\, B_{12}\, \rho(\nu) = N_2\, A_{21} + N_2\, B_{21}\, \rho(\nu)$$

$$N_1\, B_{12}\, \rho(\nu) - N_2\, B_{21}\, \rho(\nu) = N_2\, A_{21}$$

$$\rho(\nu)\, (N_1\, B_{12} - N_2\, B_{21}) = N_2\, A_{21}$$

$$\rho(\nu) = \frac{N_2\, A_{21}}{(N_1\, B_{12} - N_2\, B_{21})} \qquad \text{...(1.4)}$$

Dividing both the numerator and denominator of right hand side of eqn. (1.4) by $N_2\, B_{21}$ we get

$$\rho(\nu) = \frac{A_{21} / B_{21}}{\left(\frac{N_1 B_{12}}{N_2 B_{21}} - 1\right)} \qquad \text{...(1.5)}$$

From Boltzmann's distribution law, the number of atoms in the excited state N at temperature T is given by

$$N_n = N_0 \exp\left(-\frac{E_n}{k_B T}\right)$$

where N_0 is the number of atoms in the ground state

k_B is the Boltzmann constant

Number of atoms in the first and second excited states can be written as,

$$N_1 = N_0 \exp\left(-\frac{E_1}{k_B T}\right) \qquad N_2 = N_0 \exp\left(-\frac{E_2}{k_B T}\right)$$

On dividing N_1 by N_2 we get

$$\frac{N_1}{N_2} = \exp\left(\frac{E_2 - E_1}{k_B T}\right)$$

$$\frac{N_1}{N_2} = \exp\left(\frac{h\nu}{k_B T}\right) \qquad \text{...(1.6)}$$

On substituting eqn. (1.6) in (1.5) we get

$$\rho(\nu) = \frac{A_{21} / B_{21}}{\left(\frac{B_{12}}{B_{21}} \exp\left(\frac{h\nu}{k_B T}\right) - 1\right)} \qquad \text{...(1.7)}$$

Equation (1.7) is in good agreement with Planck's radiation law, i.e.,

$$\rho(\nu) = \frac{8\pi h\nu^3/c^3}{\left(\exp\left(\frac{h\nu}{k_B T}\right) - 1\right)} \qquad ...(1.8)$$

On comparing eqns. (1.7) and (1.8), we get

$$\frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3} \qquad \text{and} \qquad \frac{B_{12}}{B_{21}} = 1 \qquad \text{or} \qquad B_{12} = B_{21}$$

RESULTS

- Einstein's coefficient relating absorption and stimulated emission rates are same ($B_{12} = B_{21}$).
- Since the ratio $\frac{A_{21}}{B_{21}}$ is proportional to ν^3, the spontaneous emission increases rapidly with energy difference between two states.
- If $\frac{A_{21}}{B_{21}} << 1$, then the stimulated emission will be predominant in producing the laser beam.

1.5.1 RATIO OF MAGNITUDES OF STIMULATED TO SPONTANEOUS EMISSION RATES

From eqns. (1.2) and (1.3) we have $R_{21(\mathrm{sp})} = N_2\, A_{21}$ and $R_{21(\mathrm{st})} = N_2\, B_{21}\, \rho(\nu)$, respectively.

Dividing eqn. (1.3) by eqn. (1.2) we obtain

$$\frac{R_{21(\mathrm{st})}}{R_{21(\mathrm{sp})}} = \frac{B_{21}}{A_{21}}\, \rho(\nu) \qquad ...(1.9)$$

On rearranging eqn. (1.7), we get

$$\frac{B_{21}}{A_{21}}\, \rho(\nu) = \frac{1}{\left(\frac{B_{12}}{B_{21}} \exp\left(\frac{h\nu}{k_B T}\right) - 1\right)}$$

On substituting the above rearranged equation of eqn. (1.7) in eqn. (1.9) and using $B_{12} = B_{21}$, then eqn. (1.9) is written as

$$\frac{R_{21(\mathrm{st})}}{R_{21(\mathrm{sp})}} = \frac{1}{\left(\exp\left(\frac{h\nu}{k_B T}\right) - 1\right)} \qquad ...(1.10)$$

On comparing eqns. (1.9) and (1.10), we get

$$\frac{R_{21(\mathrm{st})}}{R_{21(\mathrm{sp})}} = \frac{1}{\left(\exp\left(\frac{h\nu}{k_B T}\right) - 1\right)}$$

To increase the number of coherent photons, stimulated emission should dominate over spontaneous emission. An artificial condition called population inversion is necessary. To achieve this, there should be more atoms present in the higher energy level than in the lower energy level.

1.6 COMPONENTS OF LASER

The essential components of a laser are

- An active medium
- A pumping source
- An optical resonator

Active medium: The active medium is the material in which laser action takes place. It may be a solid or liquid or gas.

Pumping source: Pumping source is a device by which population inversion is achieved in the active medium. Population is a condition wherein more number of atoms is in the higher excited state than the lower excited state or the ground state.

Optical Resonator or Resonant cavity: An optical resonator consists of a pair of reflecting surfaces in which one is fully reflecting M_1 and the other is partially reflecting M_2 as shown in Fig. 1.7. Optical resonator helps to further intensify and amplify the radiations. For sustained and amplified output radiation, a part of the output energy should be fed back into the system. This is achieved by keeping the active material in the resonating cavity which can be as simple as a pair of mirrors.

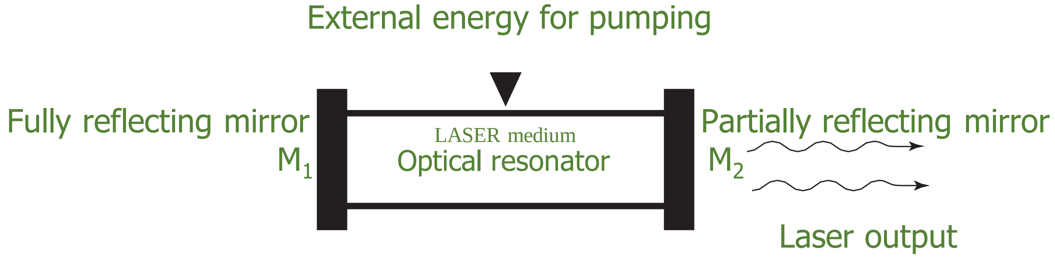


Fig. 1.7 Optical resonator

The photons generated due to laser transitions between the energy states of active material are bounced back and forth between two reflecting surfaces. This will induce more and more stimulated transition leading to laser action.

1.7 PUMPING

The process of creating a population inversion is called Pumping. The commonly used methods for pumping action are:

- Optical pumping
- Electrical discharge method
- Direct conversion
- Inelastic atom–atom collision
- Chemical reaction

i. Optical pumping (by photons)

In this type, the atoms are excited with the help of photons emitted by an external optical source. The atoms absorb energy from the photons and reach the excited state. This method is called optical pumping.

Example: Ruby-laser and Nd-YAG laser (Solid state laser)

ii. Electrical discharge method (by electrons)

Here, the electrons are accelerated to very high velocities due to strong electrical field. These accelerated electrons collide with gas atoms and the gas atoms are raised to excited states. This method is called electrical discharge method.

Example: Argon laser and CO_2 laser (Gas lasers)

iii. Direct conversion

The combination of electrons and holes takes place in semiconductors due to supply of electrical energy. The electrical energy is directly converted into light energy. This method is called direct conversion.

Example: Gallium arsenide [GaAs] (Semiconductor laser).

iv. Inelastic atom–atom collisions

In this type of pumping, a combination of two types of gases say A and B are used. Both are having same or nearly excited states. During the first step, A-atoms get excited due to collision with accelerated electrons. This excited A^* atoms now collide with B-atoms. Now B-atoms reach excited B^* due to gain of energy. This method is called inelastic atom-atom collision.

$$e^* + A \longrightarrow A^*$$

$$A^* + B \longrightarrow B^* + A$$

Examples: He–Ne laser and CO_2 laser.

v. Chemical reactions

Due to chemical reactions, the atoms in the ground state move to the excited state. **Example:** Dye laser.

1.8 PRINCIPLE OF LASER

Let us consider an assembly with more number of excited atoms. When the first excited atom undergoes stimulated emission due to an incident photon, a coherent photon is emitted. Both the incident photon and emitted photon move in the same direction with same frequency, phase and energy. These two coherent photons

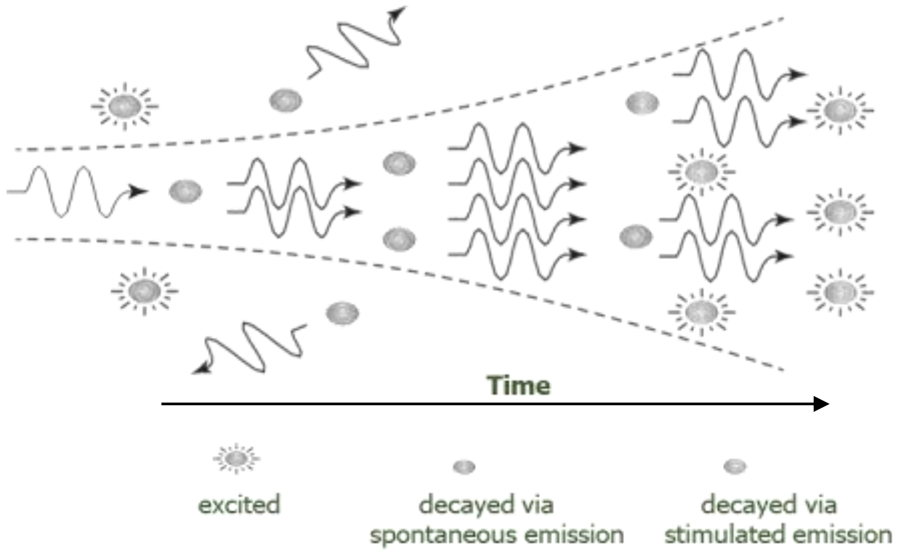


Fig. 1.8 Optical amplification

induce two excited atoms to produce four coherent photons and the four coherent photons produce eight coherent photons due to stimulated emission of four excited atoms. This process continues as a chain reaction for the emission of more and more number of coherent photons to produce a powerful laser beam as shown in Fig. 1.8. Hence, a laser beam is a powerful one due to production of large number of coherent photons by stimulated emission of excited atoms.

1.9 TYPES OF LASERS

Lasers are classified into five major categories based on the type of active medium. They are:

Gas laser	: He–Ne laser, CO_2 laser
Solid state laser	: Ruby laser, Nd-YAG laser
Liquid laser	: Europium Chelate laser
Semiconductor laser	: GaAs laser, InP laser
Dye and chemical laser	: Rhodamine 6G laser

1.10 DIRECT AND INDIRECT BAND GAP SEMICONDUCTORS

In some semiconductors like germanium and silicon, most of the energy is released in the form of heat during the recombination process. They are called **indirect band gap semiconductors**.

But in the case of other semiconductors such as Gallium Arsenide (GaAs) the energy is released in the form of light during the recombination process. They are called **direct band gap semiconductors.**

1.11 SEMICONDUCTOR LASERS

Semiconductors can also be used to generate laser beam. It is a most compact laser. When a forward bias is applied to a *p*–*n* junction of a semiconductor, holes are injected from *p*-region into *n*-region and electrons from n-region to p-region. The electrons and holes recombine and release of energy takes place near the junction region. Semiconductor lasers are classified into

i. Homojunction laser
ii. Heterojunction laser

Homojunction laser: When a pn junction is formed by a single crystalline material, it is known as **Homojunction laser**.

Example: Gallium Arsenide (GaAs).

Heterojunction laser: When a pn junction has one material on one side and a different material on the other side, it is called **Heterojunction laser**.

Example: Heterojunction laser is formed between GaAs and Ga-Al-As.

1.12 HOMOJUNCTION SEMICONDUCTOR LASER

It is a specially fabricated pn junction device which emits coherent light under forward biased condition.

1.12.1 Principle

The electron in conduction band combines with hole in the valence band and produces energy in the form of a light. This photon induces another electron from conduction band to move to the valence band and stimulate the emission of coherent photons.

1.12.2 Construction

A narrow *p–n* junction made from single crystalline Gallium Arsenide is the active medium. The ends of the junction diode are well-polished and made parallel to each other. It acts as an optical resonator. As the refractive index of Gallium Arsenide is high, external mirrors are not needed. The remaining two faces are roughened to eliminate lasing action in these directions. The *p–n* junction is forward-biased as shown in Fig. 1.9.

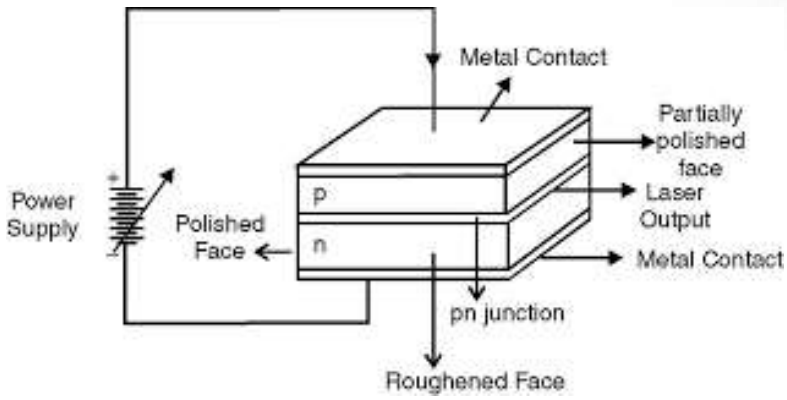


Fig. 1.9 Homojunction semiconductor laser

1.12.3 Working

Population inversion is achieved by heavily doped p and n regions. Before biasing, Fermi level lies within valence band of the p region and within the conduction band of the n region as shown in Fig. 1.10. When the junction is forward biased with the voltage nearly equal to the band gap voltage, electrons are injected from n region and holes are injected from p region get accumulate on either side of p–n junction and hence an active region is developed.

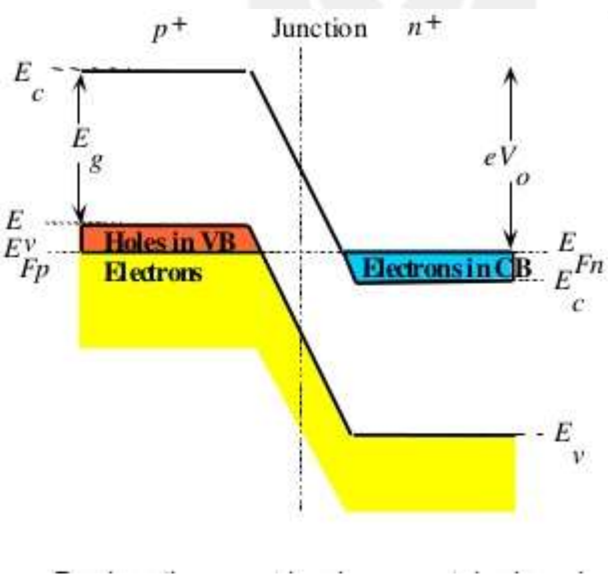


Fig. 1.10 Homojunction semiconductor laser without biasing

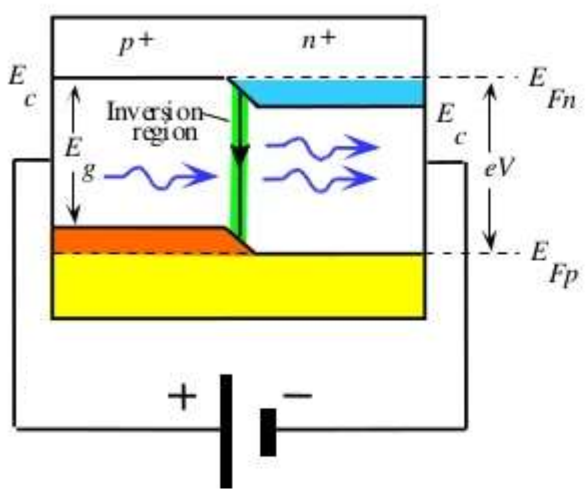


Fig. 1.11 Homojunction semiconductor laser with forward biasing

When a radiation having frequency ν is incident at this region, recombination of an electron and hole is started and hence a photon of energy $E = h\nu$ is released. This photon induces the injected charge carriers to emit photons. These photons are reflected back and forth at the junction and hence more recombination process takes place. As a result, large numbers of photons are produced due to increase in the rate of recombination process as shown in Fig. 1.11. Here the emitted photons have the same phase and frequency of the inducing photon. Hence, an intense, coherent beam of laser emerges out from the partially reflecting face of the pn junction.

Wavelength of the emitted radiation depends on the band gap of the GaAs semiconductor material and the concentration of donor and acceptor atoms in the semiconductor. The wavelength of the emitted laser is in near IR region.

$$E_g = h\nu = \frac{hc}{\lambda} = 1.44 \text{ eV}$$

$$\lambda = \frac{hc}{E_g} = 8626 \text{ x } 10^{-10} \text{ m}$$

1.12.4 CHARACTERISTICS

Type : Homojunction semiconductor laser

Active medium : *pn* junction

Active centre : Recombination of electrons and holes

Pumping method : Direct conversion method

Optical resonator : Polished *p–n* junction

Power outpu :1 mW

Nature of output : Pulsed or continuous

Output Wavelength : 8626 Å

1.12.5 ADVANTAGES

- Low cost.
- It is easy to manufacture the diode.
- High efficiency, powerful and coherent than LED.
- Simple arrangement and compact.

- Less power requirement for operation.
- Output can be easily modulated by controlling the junction current.

1.12.6 DISADVANTAGES

- Large threshold current density.
- Pulsed mode output only.
- Larger beam has large divergence.
- Poor coherence and stability.
- Poor electromagnetic field confinement.
- Low power output.

1.12.7 APPLICATIONS

It is used

- in fibre optic communication.
- in laser diodes (Laser diodes are more powerful and coherent than LED).
- in laser printers.
- in recording and reading data in CDs and DVDs.
- in bar code reading.
- as a pain killer.
- to heal wounds due to infra-red radiation.

1.13 HETEROJUNCTION SEMICONDUCTOR LASER

1.13.1 PRINCIPLE

The electron in conduction band combines with a hole in the valence band and produces energy in the form of light. This photon induces another electron from conduction band to move to the valence band and stimulate the emission of coherent photons.

1.13.2 Construction

The construction of GaAs heterojunction semiconductor laser is shown in Fig. 1.12.

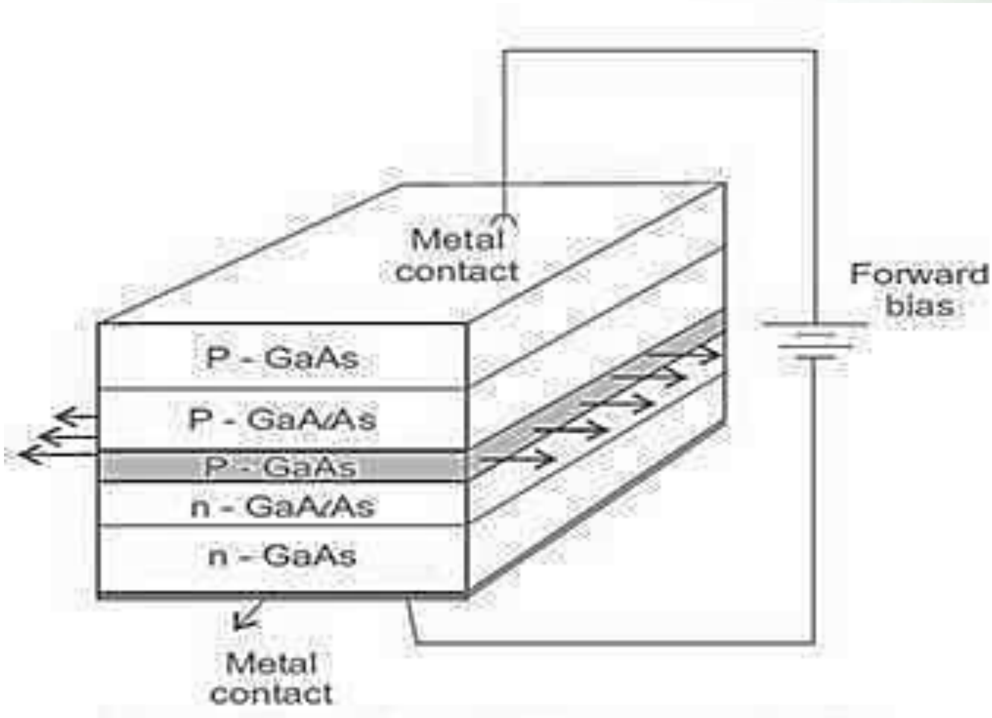


Fig. 1.12 Heterojunction semiconductor laser

There are five layers in the heterojunction semiconductor laser as shown in Fig. 1.12. A layer of narrow band gap p–type GaAs (third layer) is sandwiched between the layers of p–type GaAlAs (second layer) and n–type GaAlAs (fourth layer) which have a wider energy gap and a lower refractive index than GaAs. The active region is p-GaAs where the laser emission takes place. The first layer is the contact layer made of p–type GaAs and the fifth layer is the substrate made of n–type GaAs. Forward-biasing is given using the upper and lower electrodes.

1.13.3 Working

The principle of working of heterojunction laser is the same as that of homojunction laser. When the diode is suitably forward biased, electrons from fourth layer and holes from second layer are injected into the third layer, thereby creating an active region. Now population inversion is achieved. Some of the injected charge carriers recombine and produce spontaneously emitted photons. These photons stimulate the injected charge carriers to emit photons. The emitted photons are subjected to recombine and produce spontaneously emitted photons. These photons stimulate the injected charge carriers to emit photons. The emitted photons are subjected to reflect back and forth at the junction and hence coherent photon density is amplified inside the active medium. Finally, an intense, coherent beam of LASER emerges out from the p-GaAs of active region as shown in Fig. 1.13.

The band gap difference prevents the diffusion of injected charge carriers. Thus, the active region is very narrow. The change in refractive index of the layers is responsible for the confinement of injected charge carriers in the active region (between the layers 2 and 4). Since the active region is few microns wide, the threshold current density is drastically reduced. In this type of laser high power output, narrow spectral width, higher efficiency and high coherence can be achieved. It is highly stable and has longer life. The wavelength emitted is 8014 Å.

$$E_g = h\nu = \frac{hc}{\lambda} = 1.55 \text{ eV}$$

$$\lambda = \frac{hc}{E_g} = 8014 \times 10^{-10} \text{ m}$$

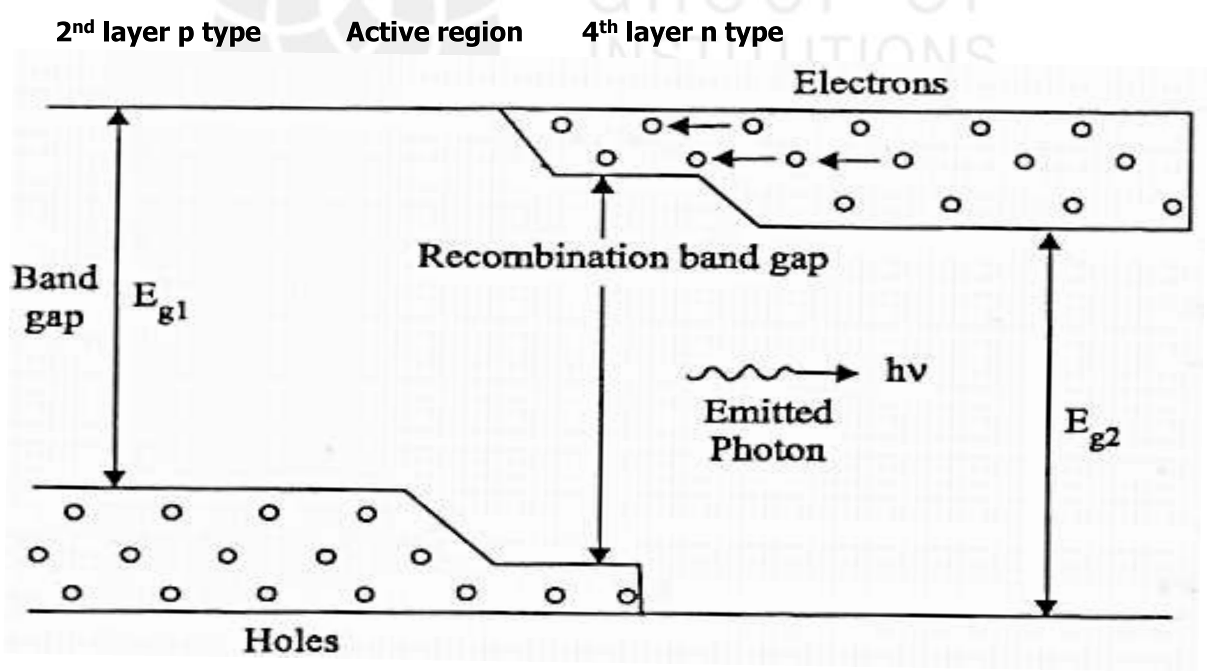


Fig. 1.12 Energy band diagram of GaAs heterojunction semiconductor laser

1.13.4 CHARACTERISTICS

Type	: Heterojunction semiconductor laser
Active medium	: p-GaAs
Active centre	: Recombination of electrons and holes
Pumping method	: Direct conversion method
Optical resonator	: Polished p-GaAs
Power output	: 10 mW
Nature of output	: Continuous wave
Output Wavelength	: 8014 Å

1.13.5 ADVANTAGES

- Very narrow beam with high coherence and monochromaticity is achieved.
- Continuous wave operation is possible.
- Carrier and optical confinement can be achieved simultaneously.
- High output power can be achieved even with low operating current.
- Threshold current density is very low at room temperature.
- These are highly stable with longer life.

1.13.6 DISADVANTAGES

- Cost is higher than homojunction laser.
- Growing different layers of semiconductors is difficult.

1.13.7 APPLICATIONS

- It is used as optical source in fibre optic communication.
- It is used in CD reading or writing data and in laser printers.
- It is used in holography.

1.14 ENGINEERING APPLICATIONS OF LASERS

Laser is an optical device that generates intense beam of coherent monochromatic light by stimulated emission of radiation. It has various unique properties such as coherence, monochromacity, directionality, and high intensity. Because of these unique properties, lasers are used in various applications like medicine, communications, industries, science and technology, and military. Some engineering applications are:

- Lasers are used in computers to retrieve stored information from a Compact Disc (CD).
- Lasers are used to store large amount of information or data in CD-ROM.
- Lasers are used to measure the pollutant gases and other contaminants of the atmosphere.
- Lasers helps in determining the rate of rotation of the earth accurately.
- Lasers are used in computer printers.
- Lasers are used for producing three-dimensional pictures in space without the use of lens.
- Lasers are used for detecting earthquakes and underwater nuclear blasts.
- A gallium arsenide diode laser can be used to setup an invisible fence to protect an area.

1.14.1 DATA STORAGE COMPACT DISC

CD stores the data in digital form represented by a series of 1s and 0s. The 0s are represented by tiny bumps and the 1s as flat areas. Such millions of bumps and flats areas are present in a standard size CD.

A CD is made from 1.2 mm thick, pure plastic and weighs 15–20 grams. From the center outward components are at the center (spindle) hole, the first-transition area (clamping ring), the clamping area (stacking ring), the second-transition area (mirror band), the information (data) area, and the rim.

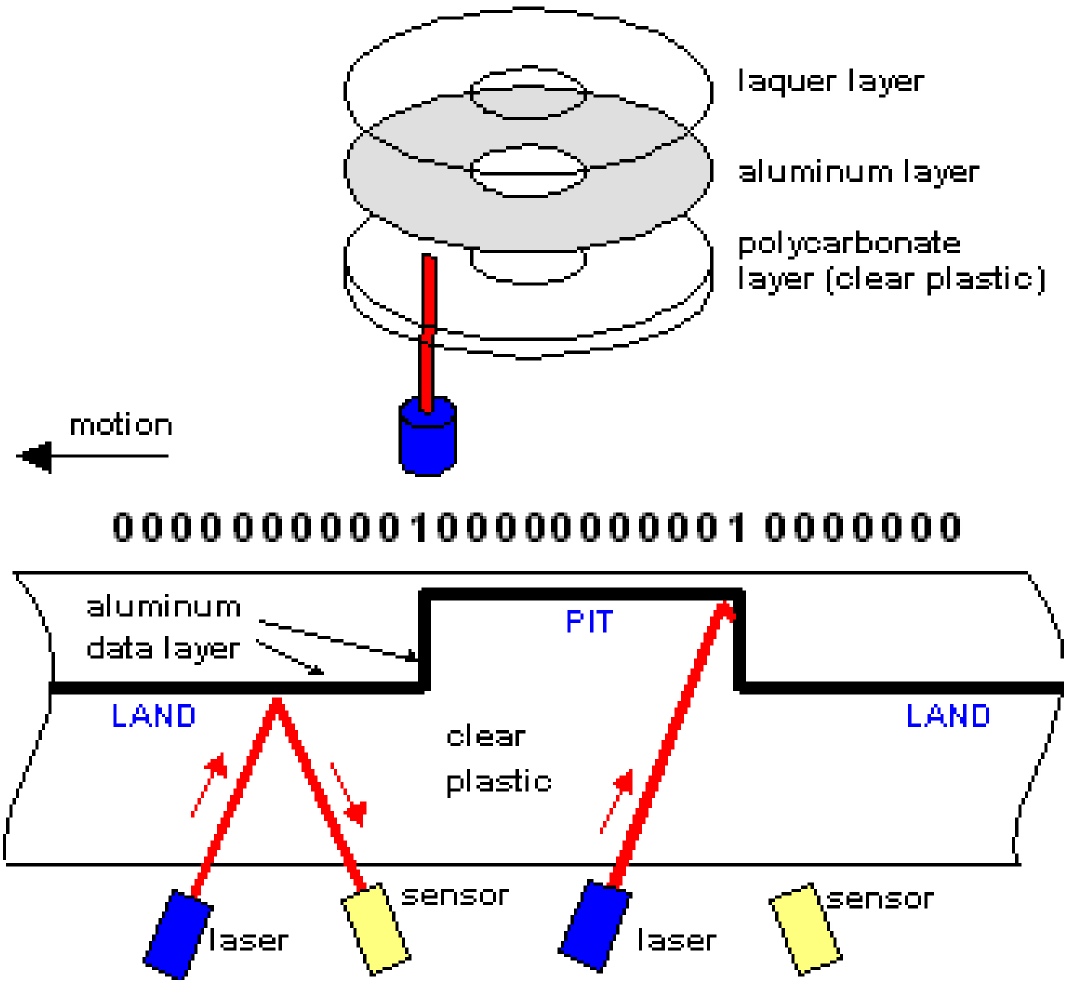


Fig 1.14 CD burning process using a laser beam

A CD is made up of a polycarbonate plastic known as Polymethyl Meta acrylic. The surface of the CD is coated with a thin layer of Aluminum to make it reflective, and is protected by a film of lacquer that is normally spin coated directly on top of the reflective layer, upon which the label print is applied.

CD Burning: CD writer is used to burn the CD to record the data in the digital format. The CD burner darkens microscopic areas in the reflective side of the 'Blank CD'. During burning, both reflective and non reflective areas are created in the CD that can be interpreted as 1 and 0 by the CD player. The CD burner has a laser assembly similar to the CD reader. But the laser is 'Write Laser' with high power around 40 mW. The write laser interacts with the CD and alters its surface.

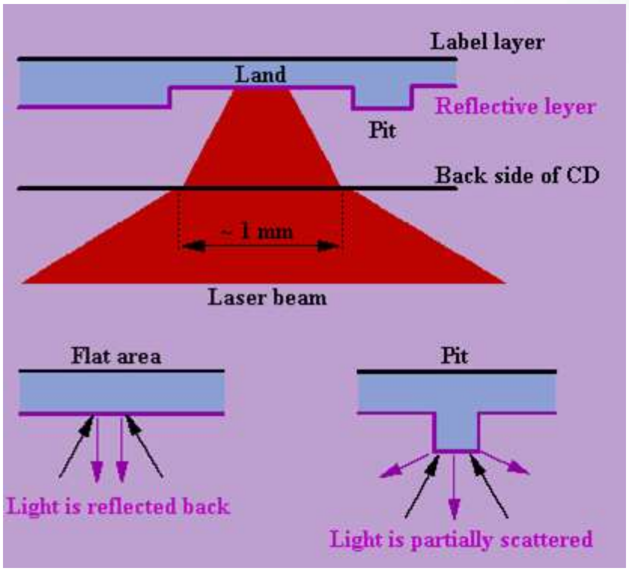


Fig 1.15 CD reading process using a laser beam

CD Reading: The bumps and flat areas are present on the reflective side of the CD which is arranged in continuous tracks. These tracks measures about 0.5 microns and can stretch about 5 km. During CD reading, a 'Read laser beam' passes over the flat area in the track. The laser beam will reflect back which will be passed onto a photo sensor assembly. The Photo sensor interprets the reflected laser light as 1. When the laser light bounce back from the bumps, the photo sensor will not get it and the CD player recognize it as 0.

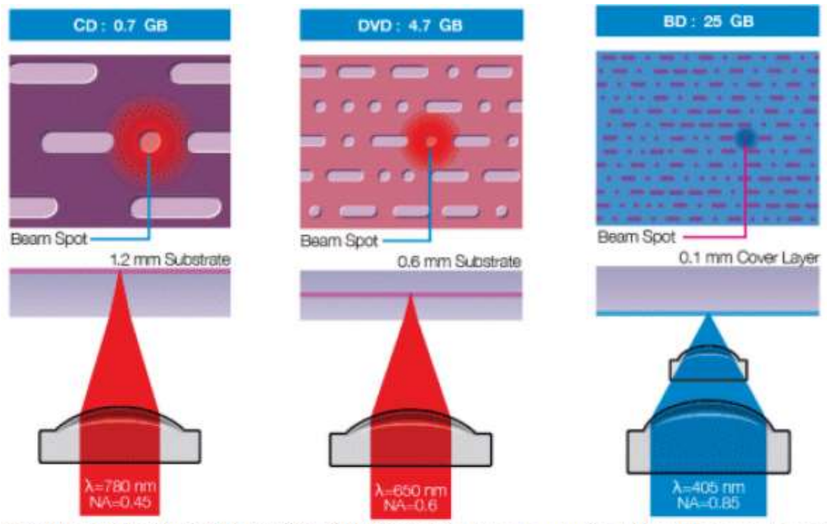
The bumps are arranged spirally starting from the centre of the CD to the periphery. The motor in CD player spins the CD in a steady speed. The laser assembly of the CD player moves from the center to the periphery of the CD at a steady speed to retrieve the data. The CD player shows a slow spinning speed as the laser assembly move outwards to keep the bumps moving past the laser at a constant rate. The digital information retrieved by the photo sensor will be then converted into audio or video by the amplifier circuit.

Rewritable CD: It is designed for 'Write and Erase' functions so that it is easy to erase the old data and record new data over it. Unlike the readable CD, the Rewritable CD has a' Phase change compound 'coated in its reflective surface. This phase change substance is the compound of silver, antimony, tellurium and indium.

This compound changes its physical state on heating depending on the temperature applied. When the temperature rises above its melting point, around 600 °C, it changes to liquid form and in below its crystallization point, around 200 °C, it becomes solid. Unlike the ordinary CD, in Rewritable CD, the bumps are represented by the phase changes in the compound. When it is in the 'Crystalline form', it remains translucent so that laser light can reflect back. When the compound becomes 'Amorphous' due to melting, it becomes non translucent and laser light will not reflect back. These changes during melting can 'lock' the phase change in place.

The erasing process changes the crystalline and amorphous states of the compound through melting. The high temperature from the Laser beam will change the states of the compound so that the data in the form of translucent and non translucent areas in the reflective layer will be erased. During writing, the high power laser beam melts points corresponding to the bumps of the conventional CD. They block the read laser so that it will not reflect. These non reflective melted points remain as opaque and represent 0s and the crystalline reflective areas represent 1s.

DVDs (digital video, or versatile, discs) work similarly, but they use a shorter-wavelength, red laser, to read smaller spots, so the discs can hold enough information to play a digitized motion picture. A newer generation of discs called Blu-ray uses blue-light lasers to read and store data at an even higher density



Comparison between the CD, DVD and Blue-Ray disk for data storage using different laser wavelengths

Fig 1.16 Comparisons of CD, DVD and Blu-ray discs

1.15 INTRODUCTION TO OPTICAL FIBRES

Fibre optics is a branch of physics deals with the propagation (transmission and reception) of data, voice, and images by the passage of light through thin, transparent fibre. In telecommunications, fibre optic technology has virtually replaced copper wire in long-distance telephone lines, and it is used to link computers within local area networks. fibre optics is also the basis of the fibrescopes used in examining internal parts of the body (endoscopy) or inspecting the interiors of manufactured structural products.

We know, as the light wave frequency is 10^{15} Hz, they cannot be used for communications in open atmosphere like radio and microwaves. A suitable medium is required to send information carrying light wave which led to the invention of a new medium called optical fibre. The optical fibres act as a guiding medium to the light wave. The light is propagated through the fibres by the principle of total internal reflection.

Optical fibres have more advantages than the conventional copper cables such as no leakage of energy from one channel to the other, more number of channels for propagation, very thin in size and more flexibility. They are used for transmitting voice, images and other data at close to the velocity of light. After the invention of optical fibres, there is a fast development in the medical and engineering and technology fields.

1.16 STRUCTURE OF OPTICAL FIBRE

An optical fibre is a cylindrical dielectric waveguide made of low-loss materials such as silica glass. It has a central core in which the light is guided, embedded in an outer cladding of slightly lower refractive index (Fig. 1.17). The cladding is enclosed by a thick polyurethane jacket which acts as a protective layer to protect the fibre from moisture and abrasion. Light rays incident on the core-cladding boundary at angles greater than the critical angle undergo total internal reflection and are guided through the core without refraction. Rays of greater inclination to the fibre axis lose part of their power into the cladding at each reflection and are not guided.

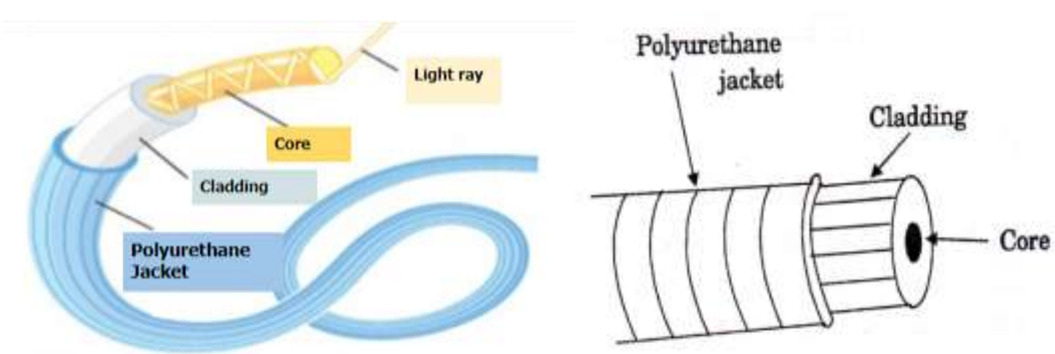


Fig. 1.17 Optical fibre cross section

1.17 PRINCIPLE OF PROPAGATION OF LIGHT THROUGH OPTICAL FIBRE

The principle of propagation of light through optical fibre is Total Internal Reflection. In Fig. 1.18, two rays entering the core reaches out the other end of the fibre after multiple reflections by the principle of total internal reflection.

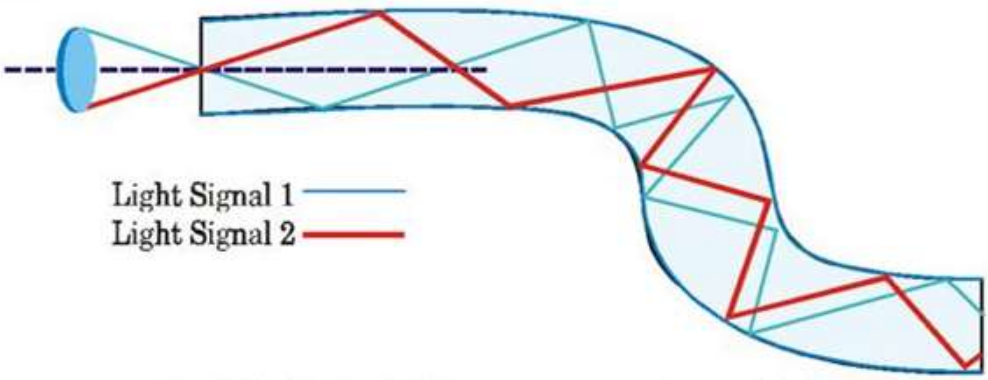


Fig. 1.18 Optical fibre – Propagation of light

1.18 TOTAL INTERNAL REFLECTION

The required conditions for Total Internal Reflection to take place are:

- The light ray should travel from denser medium to rarer medium.
  $n_1 > n_2$, where n_1 and n_2 are refractive indices of denser and rarer medium
- The angle of incidence at the core must be greater than the critical angle

1.18.1 PROPAGATION THEORY

- In Fig. 1.19, a ray of light travels from denser medium (n_1) to rarer medium (n_2). The angle of incidence of the light ray is less than the critical angle (θ_c) and hence the ray is refracted away from the normal in rarer medium. Now imagine what happens as the incident angle is increased. This causes θ_2 to increase.
- When the angle of refraction of the ray is 90°, the corresponding angle of incidence is called critical angle (θ_c). The refracted ray is along the core-cladding interface.
- When the angle of incidence is greater than the critical angle, the incident ray is totally internally reflected in the denser medium itself as shown in Fig. 1.21. This is called total internal reflection which is the principle of the propagation of light through the core of the optical fibre.

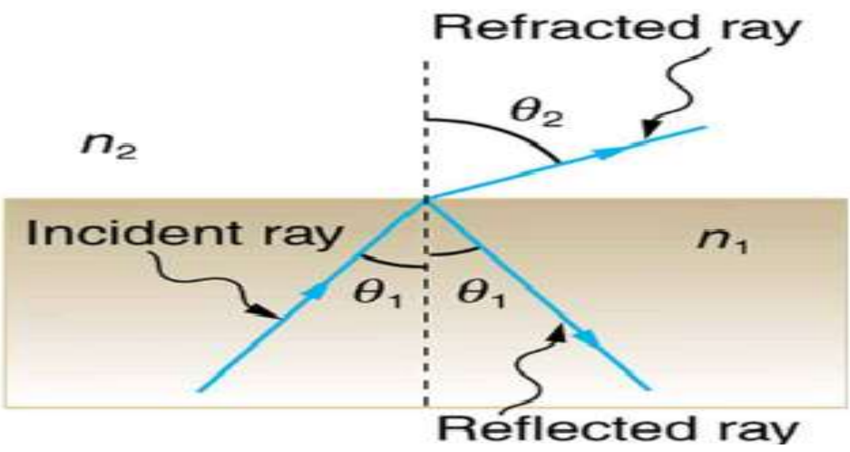


Fig. 1.19 Incident ray refracted into rarer medium

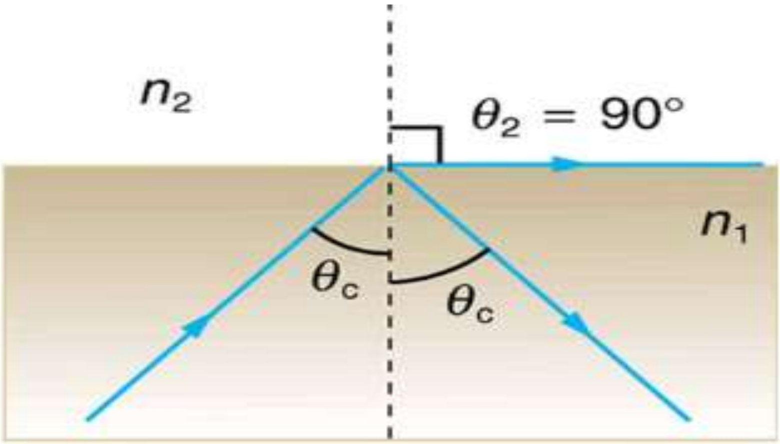


Fig. 1.20 Ray travels along the interface

1.18.2 CRITICAL ANGLE

The incident angle θ_1 that produces an angle of refraction of 90º is called the critical angle, θ_c. $\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$

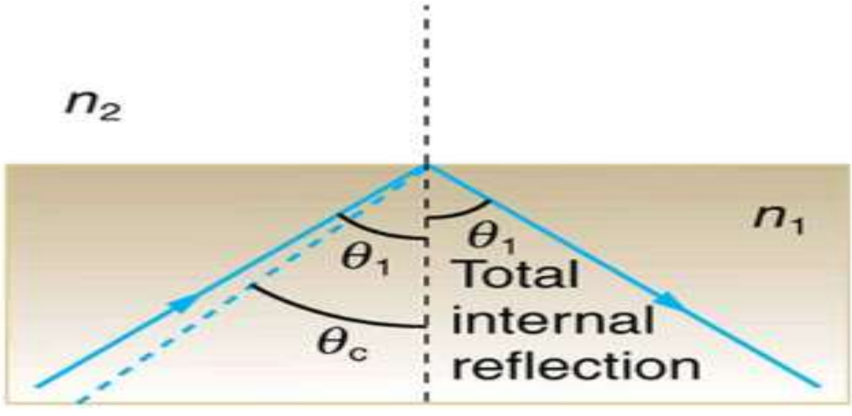


Fig. 1.21 Ray is totally internally reflected

Snell's law states the relationship between angles and indices of refraction. It is given by

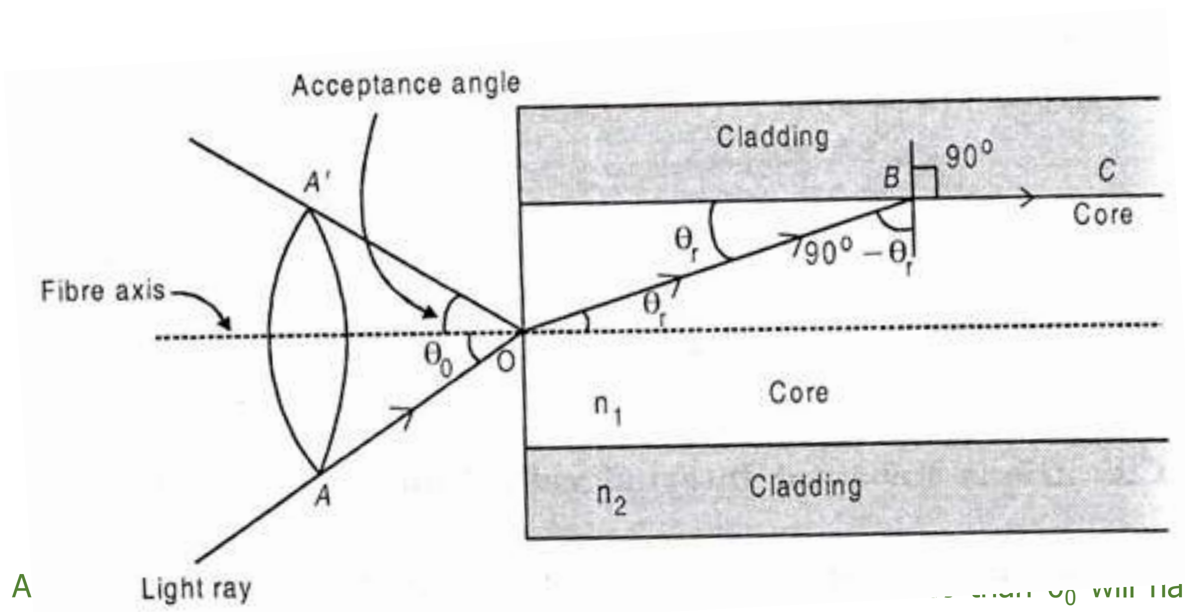
$$n_1 \sin \theta_1 = n_2 \sin \theta_2.$$

When the incident angle equals the critical angle ($\theta_1 = \theta_c$), the angle of refraction is 90° (θ_2 = 90°). Since sin 90° = 1, Snell's law in this case becomes $n_1 \sin \theta_1 = n_2$.

The critical angle (θ_c) is given by $\boldsymbol{\theta_c} = \sin^{-1}\left(\frac{n_2}{n_1}\right)$

1.19 NUMERICAL APERTURE AND ACCEPTANCE ANGLE

Consider a cylindrical fibre having core of refractive index n_1, cladding of refractive index n_2 and n_0 be the refractive index of the surrounding medium (air) as shown in Fig. 1.22. Incident ray AO enters the core at an angle θ_0. Then the ray gets refracted along OB at an angle θ_r, which then falls at critical angle of incidence θ_c = 90 – θ_r on the interface between core and cladding. The ray then moves along BC.



A ... than θ_0 will have re... less than θ_c.

Fig. 1.22 Propagation of light

Applying Snell's law at the point O

$$n_0 sin\,\theta_0 = n_1 \sin \theta_r$$

$$sin\theta_0 = \frac{n_1}{n_0} sin\theta_r$$

(1.11)

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

Applying Snell's law at the point B

$$n_1 \sin(90 - \theta_r) = n_2 sin90°$$

$$n_1 cos\theta_r = n_2$$

Since, sin 90^0 = 1,

$$\cos\theta_r = \frac{n_2}{n_1} \tag{1.12}$$

Substituting equation (1.12) in (1.11) we get

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

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

$$\sin\theta_0 = \frac{\sqrt{n_1^2 - n_2^2}}{n_0} \tag{1.13}$$

If the surrounding medium is air, n_0 = 1.

$$sin\theta_0 = \sqrt{n_1^2 - n_2^2} \tag{1.14}$$

$$\theta_0 = \sin^{-1}\left(\sqrt{n_1^2 - n_2^2}\right) \tag{1.15}$$

$\theta_0$is the acceptance angle of the fibre.

1.19.1 ACCEPTANCE ANGLE

The maximum angle at which the light suffers Total Internal Reflection is known as acceptance angle.

Rays enter through the cone, shown in Fig. 1.22, is subjected to the total internal reflection in the core and hence reach the other end of the fibre. Hence this cone is called as acceptance cone.

1.20.2 NUMERICAL APERTURE

It is defined as the sine of the acceptance angle of the fibre. It gives the light gathering capability of the fibre.

$$NA = sin\theta_0 \tag{1.16}$$

Substituting equation (1.13) in (1.16), we get

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

If the surrounding medium is air, then $n_0 = 1$,

$$NA = \sqrt{n_1^2 - n_2^2} \tag{1.17}$$

1.19.3 FRACTIONAL INDEX CHANGE (FIC) (Δ)

It is defined as ratio of the difference of refractive indices of core and cladding to the refractive index of core.

$$\Delta = \frac{n_1 - n_2}{n_1} \tag{1.18}$$

$$n_1\,\Delta = n_1 - n_2 \tag{1.19}$$

We know that

$$NA = \sqrt{n_1^2 - n_2^2} \tag{1.20}$$

$$NA = \sqrt{(n_1 + n_2)(n_1 - n_2)} \tag{1.21}$$

Substituting equation (1.19) in (1.21), we have

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

If $n_1 \cong n_2$,

$$NA = \sqrt{2{n_1}^2\Delta} \tag{1.22}$$

1.20 TYPES OF OPTICAL FIBRES

Optical fibres are classified on the basis of three major categories

i. The type of material used for fabrication

ii. The number of modes of propagation

iii. The refractive index profile

1.20.1 BASED ON THE MATERIAL

Based on the type of material used for making the fibres, they are classified into two types

1.20.1.1 GLASS FIBRE

It is made up of mixture of metal oxides and SiO_2 glasses.

(e.g) (i) **Core :** SiO_2; **Cladding :** $P_2O_3 - SiO_2$

(ii) **Core :** $GeO_2 - SiO_2$; **Cladding :** SiO_2

(iii) **Core :** $P_2O_5 - SiO_2$; **Cladding :** SiO_2

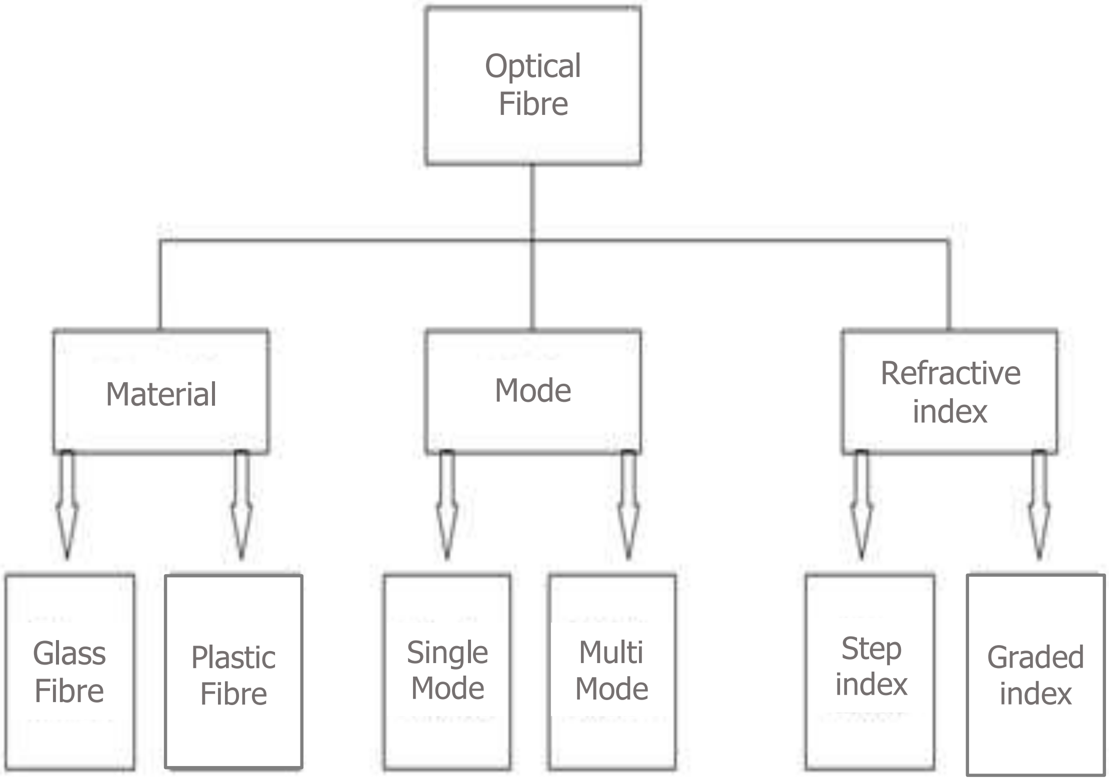


Fig. 1.23 Classification of optical fibre

1.20.1.2 PLASTIC FIBRE

It is made up of tough and durable plastic material..

(e.g) (i) **Core :** Poly methyl methacrylate **Cladding :** Co-polymer

(ii) **Core :** Polystyrene **Cladding :** Methyl methacrylate

1.20.2 BASED ON THE MODES OF PROPAGATION

Based on modes of propagation, optical fibres are classified as

1. Single mode fibre
2. Multimode fibre

Mode: It is the mathematical concept describing the nature of propagation of an electromagnetic wave.

❖ **Modes of propagation:** Light propagates as electromagnetic waves through an optical fibre. All waves, having ray directions above the critical angle will be trapped within the fibre due to total internal reflection. However, all such waves do not propagate through the fibre. Only certain ray directions are allowed to propagate. The allowed directions correspond to the modes of the fibre.

❖ In simple terms, modes can be visualized as the possible number of paths of light in an optical fibre. The paths are all zig-zag paths excepting the axial direction. Accordingly, light rays travelling through a fibre are classified as axial rays or zig-zag rays. As a ray gets repeatedly reflected at the walls of the fibre, phase shift occurs. Waves travelling along the certain zig-zag paths will be in phase and intensified. Waves travelling along certain other paths will be out of phase and diminish due to destructive interference. The light ray's path along which the waves are in phase inside the fibre are called modes. The number of modes that a fibre will support depends upon the ratio of d/λ where d is the diameter of the core and λ is the wavelength of the wave being transmitted.

❖ Modes are designated by an 'order' number 'm'. In a fibre of fixed thickness, the higher order modes propagate at smaller angles than the lower order modes.

1.20.2.1 SINGLE MODE FIBRE

In general, the single mode fibres are step - index fibres. These types of fibres are made of doped Silica. It has a very small core diameter that it can allow only one mode of propagation and hence called single mode fibre.

The cladding diameter is very large compared to its core diameter. Thus, the optical loss is very much reduced in case of single mode fibre. The structure of a single mode fibre is shown in Fig 4.8a below.

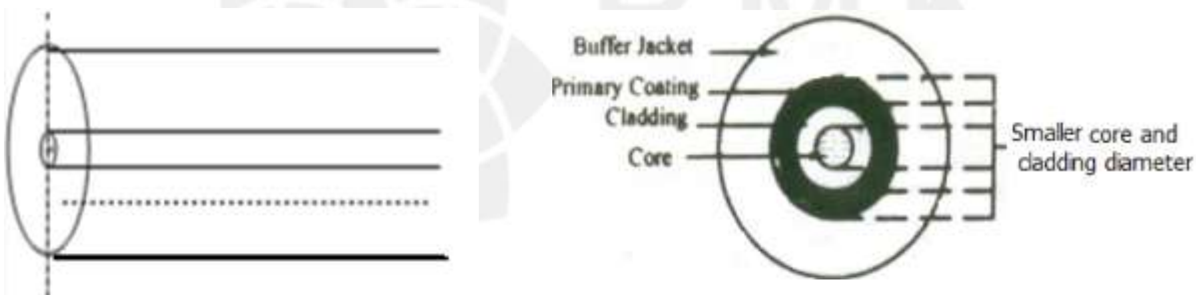


Fig. 1.24a Single mode fibre

Application: Due to high bandwidth, they are used in long haul communication systems.

1.20.2.2 MULTIMODE FIBRE

The multimode fibre can be manufactured as both step index and graded index fibres.

The multimode fibre is made up of multi-component glass compounds such as

Glass - Clad Glass, Silica - Clad - Silica, doped Silica, etc. The core diameter is large compared to single mode fibre that it can allow many modes to propagate through it and hence called as multimode fibres. The cladding diameter is also larger than that of the single mode fibre. The structure of the multimode fibre is shown in the Fig 1.24b.

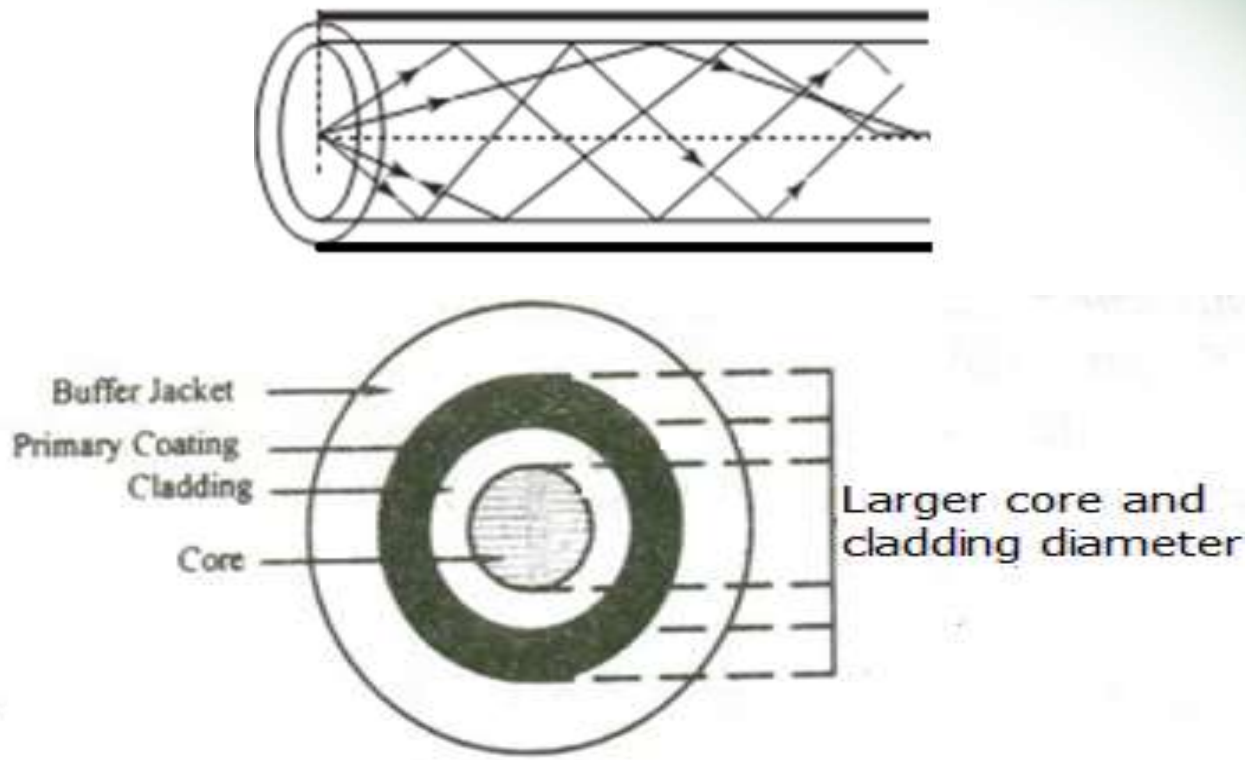


Fig. 1.24b Multimode fibre

Application: Because of its less band width, it is very useful in short haul communication systems

Sl. No	Single Mode Fibre	Multimode Fibre
1	It allows only one mode at a time	It allows two or more modes.
2	It is made up of doped SiO_2 material	It is made up of multi component glass compounds (i) core – glass; cladding – glass (ii) core – SiO_2; cladding – SiO_2 (iii) doped SiO_2 material in core & cladding
3	Core diameter is small (5 - 10 μm) Cladding diameter is around 125 μm	Core diameter is large (50 - 350 μm) Cladding diameter is around (125 - 500 μm)

Sl. No	Single Mode Fibre	Multimode Fibre
4	Protective layer diameter is 250 -1000 µm	Protective layer diameter is 250 – 1100 µm
5	Optical loss is low	Optical loss is high
6	Numerical Aperture is low (0.08 – 0.10)	Numerical Aperture is high (0.12 – 0.5)
7	Bandwidth of the spectrum is greater than 50 MHz km	Bandwidth of the spectrum is less than 50 MHz km
8	Degradation of the signal is due to chromatic or material dispersion only.	Degradation of the signal is due to modal, chromatic or material and waveguide dispersions.
9	Launching of light into fibres, connecting two fibres, fabrication of fibres are difficult due to its small size	Launching of light into fibres, connecting two fibres, fabrication of fibres are easier due its large size
10	Cost of fibre is high	Cost of fibre is low
11	**Application** Long haul communication	**Application** Short distance communication (LAN)

1.20.3 BASED ON REFRACTIVE INDEX PROFILE

Optical fibres are classified on the basis of refractive index profiles of core and cladding materials. They are,

a) step index fibre and

b) graded index fibre.

1.20.3.1 STEP INDEX FIBRE

If the variation of refractive index of the core from optical fibre axis to core-cladding interface is in the form of single step, then it is called step index fibre.

The step index fibre is further classified as step index single mode and step index multimode fibres.

- A **single mode step index fibre** consists of a very thin core of uniform refractive index surrounded by a cladding of refractive index lower than that of core. The refractive index abruptly changes at the core cladding boundary. Light travels along the axis only. So zero order mode is only supported by single mode fibre.

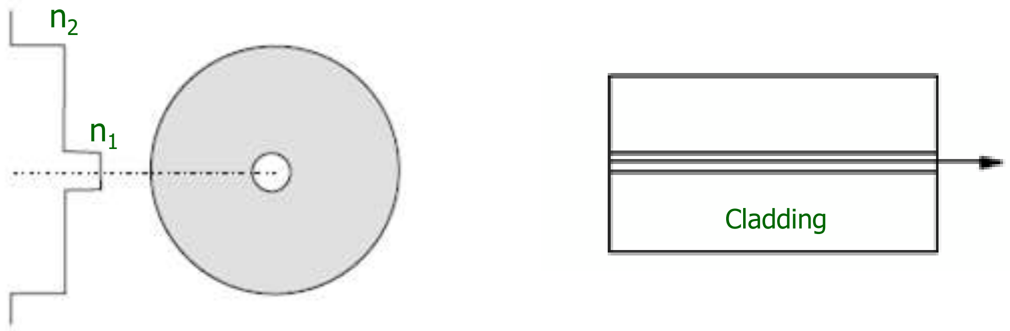


Fig. 1.25a Single mode step index fibre

- A **multimode step index fibre** consists of a core of uniform refractive index surrounded by cladding of refractive index lower than that of the core. The refractive index abruptly changes at the core-cladding boundary. The core is of large diameter. Light follows zig-zag paths inside the fibre. Many such zig-zag paths of propagation are permitted in multimode fibre. The numerical aperture of a multimode fibre is tend to be large so as to support many different modes of propagation.

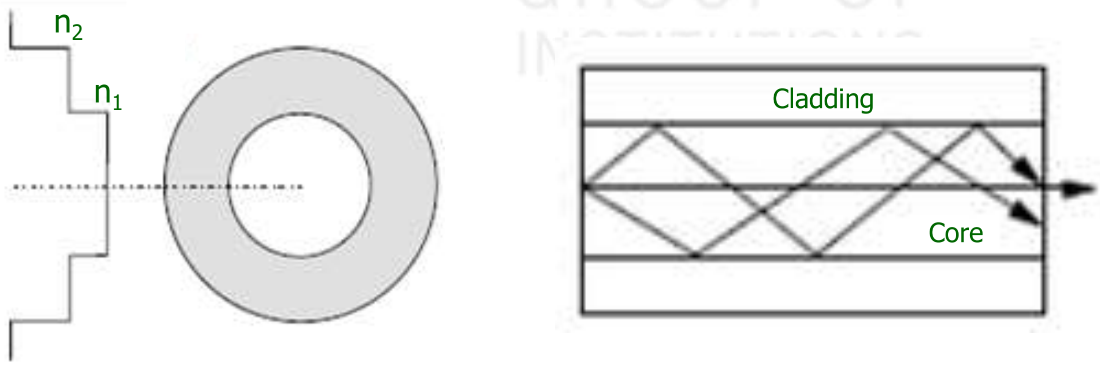


Fig. 1.25b Multimode step index fibre

1.21.3.2 GRADED INDEX FIBRE (GRIN FIBRE)

In GRIN fibre the refractive index varies radially. It decreases continuously in a parabolic manner from the maximum value of n_1 , at the center of the core to a value of n_2 at the core cladding interface.

Because of this variation in refractive index, light rays travel at different speeds in different parts of the fibre. Due to the lower refractive index near the outer edge, light rays near the outer edge travel faster than the rays at the center of the core..

Hence rays arrive at the end of the fibre approximately at the same time. This leads to small or no pulse dispersion. (The pulse dispersion gets reduced by a factor of about 200 in graded index fibre compared to step index fibre.)

1.20.3.2.1 Propagation of Light in GRIN Fibre.

Let n_a, n_b, n_c, n_d etc be the refractive index of different layers in graded index fibre with $n_a > n_b > n_c > n_d$ etc. then the propagation of light through the graded index fibre is as shown in the figure.

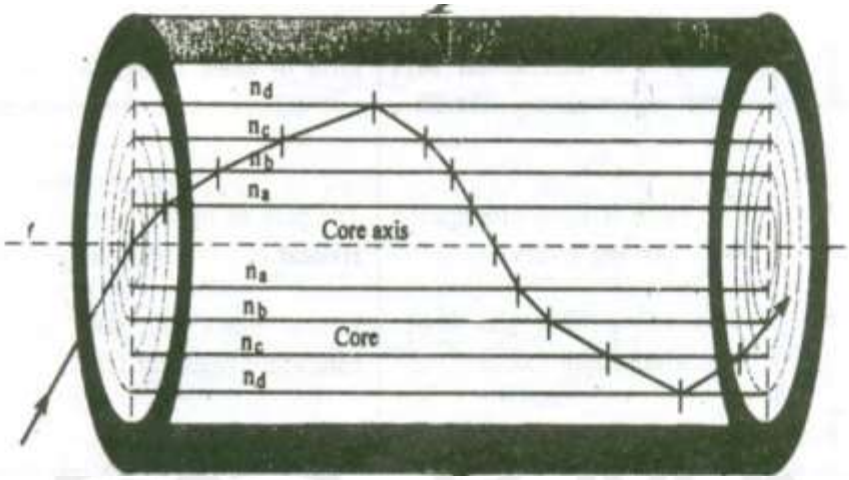


Fig. 1.25c Graded index fibre

1.21 V-NUMBER

In an optical fibre, the V number (normalized frequency) is an important specification. Many fiber parameters can be expressed in terms of V, such as: the number of modes at a given wavelength, mode cut off conditions, and propagation constants. The V number of a fibre is given as

$$V = \frac{2\pi a}{\lambda}\sqrt{n_1^2 - n_2^2}$$

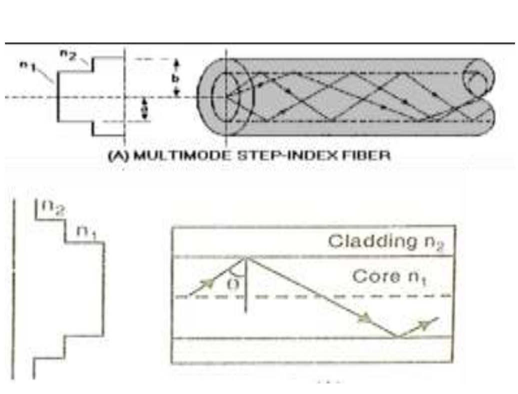
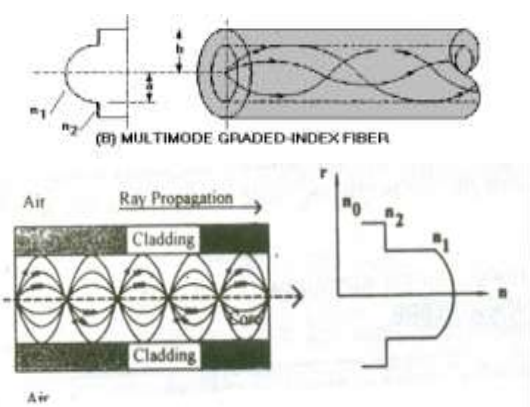
where a is the core radius, n_1 and n_2 are the refractive indices of core and cladding, respectively.

V-number determines the number modes a fiber can support. The number of modes supported by multimode step index fibre is given by

$$N_{Step} = \frac{V^2}{2}$$

The number of modes supported by multimode graded index fibre is given by

$$N_{Graded} = \frac{V^2}{4}$$

Sl. No	Step Index Fibre	Graded Index Fibre
1	If the variation of refractive index of the core from optical fibre axis to core-cladding interface is in the form of step. Then it is called step index fibre.	If the variation of refractive index of core is represented by a gradual decrease from core axis to core – cladding interface. Then it is called graded index fibre.
2	It has single mode and multimode fibres	It has only multimode fibre
3	Meridional ray Propagation (ray passes through fibre axis)	Skew ray Propagation (ray does not pass through fibre axis)
4	The light ray travels in a zig-zag path	It travels in a helical path
5	Allowed bandwidth is less	Allowed bandwidth is more
6	Distortion is less in single mode fibre and more in case of multimode fibre	Distortion is less or no distortion
7	Core diameter is small (10 -50 μm)	Core diameter is more (50 μm)
8	**Advantages** (i) Cost is less (ii) Life time of fibre is more	**Advantage** Intermodal dispersion is less
9	**Disadvantage** Intermodal dispersion is more	**Disadvantages** (i) Cost is more (ii) Splicing is difficult
10		

1.22 LOSSES IN OPTICAL FIBRES

When light signal propagates through optical fibre, a small part of light is lost through different mechanisms. This loss in optical energy when light is transmitted through a fibre is known as attenuation. Losses affect the transmission characteristics of light waves and the signal density of light waves that can be propagated through the fibre. The amount of loss decides the quality of transmission. The types of losses are:

(i) Attenuation loss

(ii) Dispersion loss

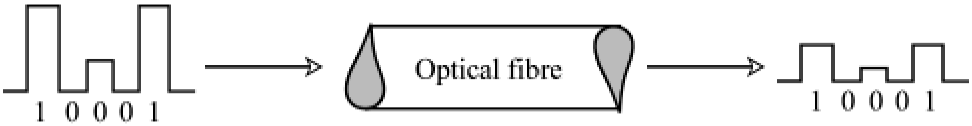


Fig. 1.26a Attenuation: Reduces power

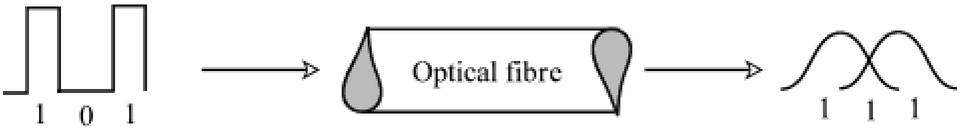


Fig. 1.26b Dispersion: Spreads power

1.22.1 ATTENUATION LOSS

It is the intensity loss during transmission. Attenuation can be defined as ratio of optical input power (P_{in}) to the output power (P_{out}) from a fibre of length L.

$$\text{Attenuation, } \alpha = \frac{10}{L}\log_{10}\left(\frac{P_{in}}{P_{out}}\right) \text{ dB / km}$$

Types of attenuation losses are

(a) Scattering loss

(b) Absorption loss

(c) Bending loss

(a) Scattering loss

This type of loss occurs due to density changes. It can be divided into

(i) Linear scattering

(ii) Non-linear scattering

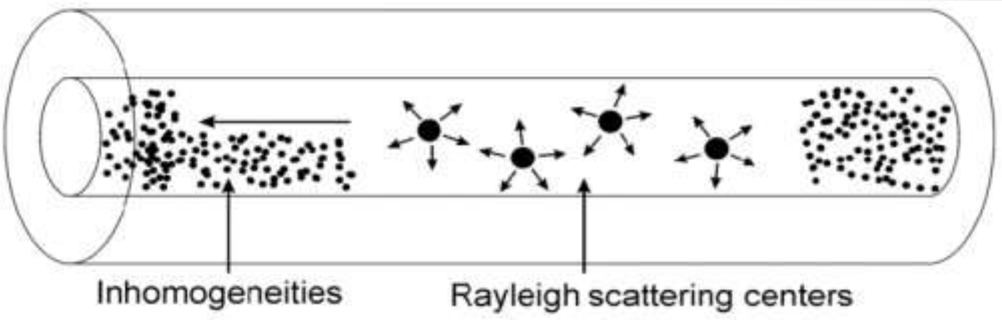


Fig. 1.27a Scattering process

(i) Linear scattering

(1) **Rayleigh scattering** occurs due to microscopic inhomogeneities like changes in density and composition. Loss is inversely proportional to λ^4.

(2) **Mie scattering** occurs due to macroscopic inhomogeneities of size 1/10 th of the wavelength of light used.

(ii) Non-linear scattering

This occurs when a source of very high output power is used. The types are:

(1) Stimulated Raman Scattering

(2) Stimulated Brillouin Scattering

(b) Absorption loss

(i) Intrinsic Absorption

It is the absorption of light by imperfections like vacancy, clusters of atoms, etc. It is the loss associated with silica itself. Absorption occurs in two regions:

(1) **Ultraviolet absorption loss**: Due to electrons absorbing energy and going to higher levels.

(2) **Infrared absorption loss**: Due to interaction of Si-O bonds with light, causing lattice vibrations.

(ii) Extrinsic Absorption

It is energy loss due to impurities like iron, chromium, copper, nickel and OH^- ions. Presence of water in silica causes Si-OH bonds, where light energy is absorbed by OH^- ions.

Absorption of light depends on imperfections, such as missing molecules, hydroxyl ions, high-density atoms, etc., which absorbs light. Absorption also depends on the wavelength of light used for transmission. The right selection of optical fibre and wavelength is required for minimizing the loss. Maximum absorption is observed at three bands of wavelengths: 950 nm, 1250 nm and 1380 nm.

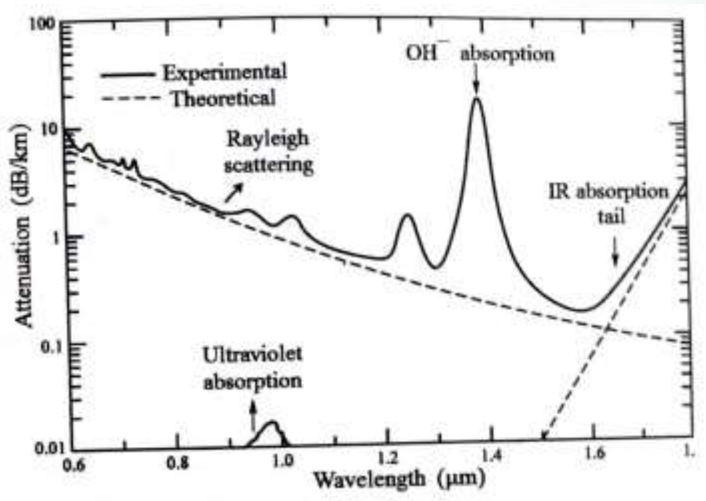


Fig. 1.27b Loss in optical fibre in the operating region of wavelength of light

There are three different "windows" at

(1) 850 nm: emitters and detectors are cheaper

(2) 1300 nm: minimal dispersion. Single mode fibres are used up to 30 km length.

(3) 1550 nm: minimal fibre attenuation (0.25 dB/km).

Attenuation reaches the lowest value centered on 1550 nm. For longer wavelength, infrared absorption occurs, causing attenuation to increase. Hence, in modern long haul communication, links are operated at this wavelength using single mode fibres up to 150 km length.

(c) Bending loss

Loss occurs whenever a fibre is bent. The types of bending are

(i) **Macro bending loss** occurs when fibre is bent around a corner and radius of curvature is greater than diameter of fibre.

(ii) **Micro bending loss** is caused by imperfections in axis of fibre and also due to external pressure.

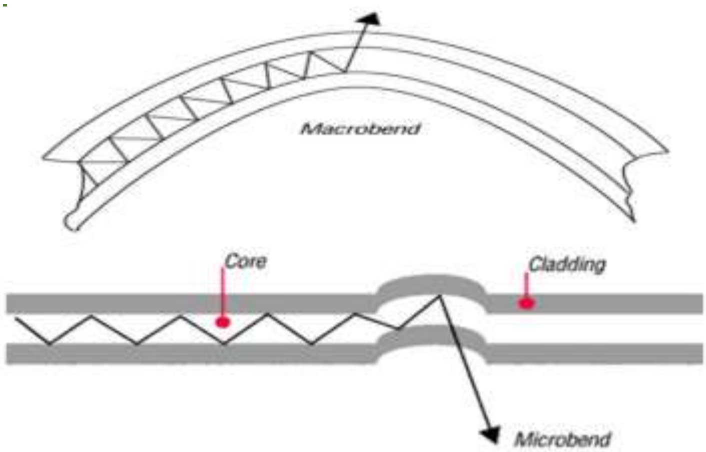


Fig. 1.27c Macro and Micro bending losses

1.22.2 DISPERSION LOSS

The two types of dispersion mechanisms are (a) Intermodal dispersion and (b) Intramodal dispersion.

(a) Intermodal dispersion

This loss occurs because each mode travels different distances in the same time. This causes the light pulse to spread, causing dispersion. It occurs only in multimode fibres.

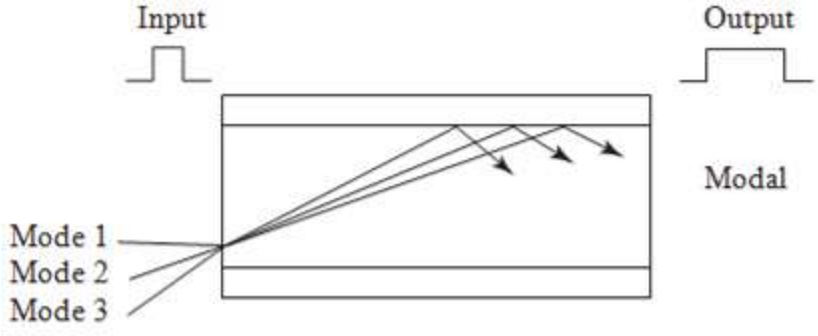


Fig. 1.28a Intermodal dispersion

(b) Intramodal dispersion

The spreading of a pulse within a single mode is intramodal dispersion. Intramodal dispersion can be further classified into:

(i) Material dispersion (ii) Waveguide dispersion

(i) Material dispersion or Chromatic dispersion: Different wavelengths travel at different speeds in the fibre and exit at different times. It is less at longer wavelengths.

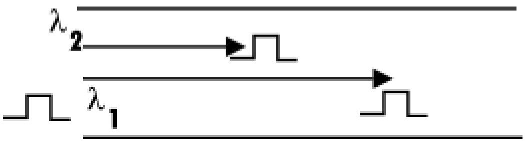


Fig. 1.28b Material dispersion

(ii) Waveguide dispersion: Loss occurs because mode propagation constant depends on size of fibre core and wavelength of propagation.

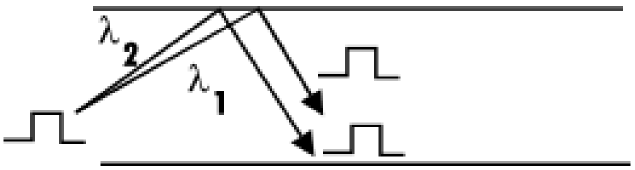


Fig. 1.28c Waveguide dispersion

1.23 FIBRE OPTIC COMMUNICATION

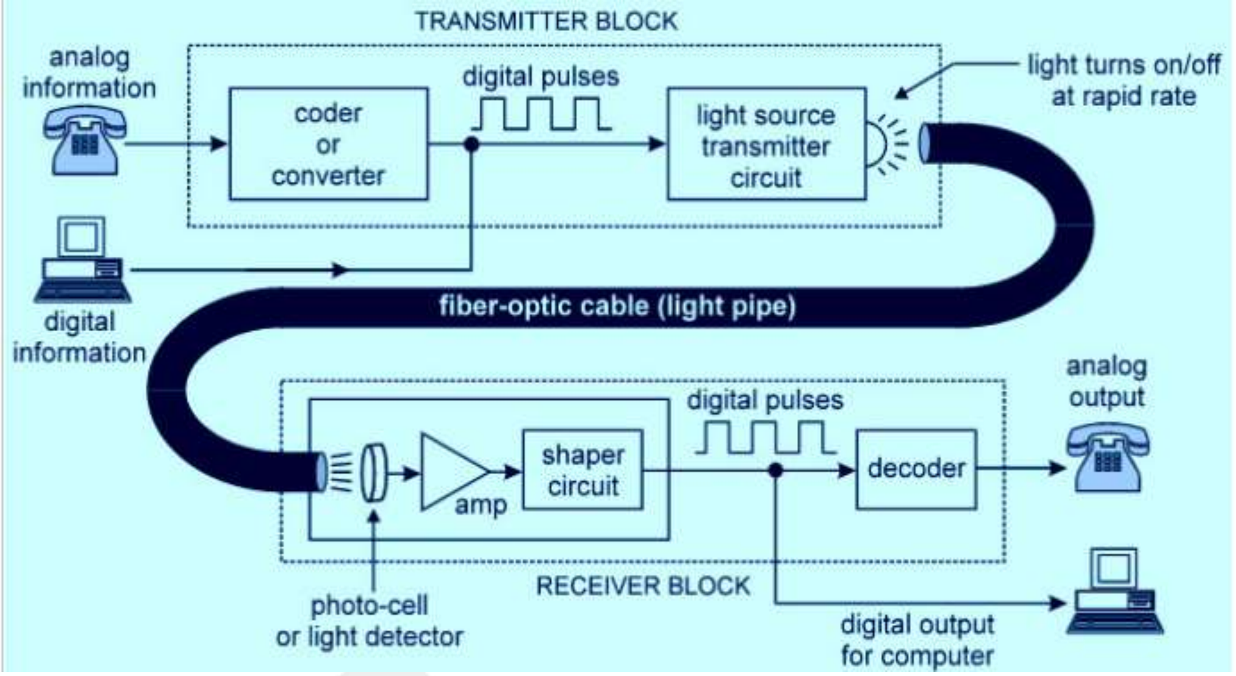


Fig. 1.29 Fibre optic communication system

1. One of the main advantage of optical fibre is communication. Like all other communication system, the primary objective of optical communication system also is to transfer the signal containing information (voice, data, and video) from the source to the destination.

1. The general block diagram of optical communication system is shown in the Fig. 1.29.

1. The source provides information in the form of electrical signal to the transmitter.
2. The electrical stage of the transmitter drives an optical source to produce modulated light wave carrier.

1. Semiconductor LASERs or LEDs are usually used as optical source here.

1. The information carrying light wave then passes through the transmission medium i.e. optical cables in this system.

1. Now it reaches to the receiver stage where the optical detector demodulates the optical carrier and gives an electrical output signal to the electrical stage.

1. The common types of optical detectors used are photodiodes (p-i-n, avalanche), phototransistors, photoconductors etc.

1. Finally the electrical stage gets the real information back and gives it to the concerned destination.

1.24 FIBRE OPTIC SENSOR

Fibre optic sensor is a transducer which converts any form of signal into optical signal in a measureable form. It is used to measure parameters like displacement, pressure, temperature, phase etc.

Types of Fibre Optic Sensors

The two types of fibre optic sensors are:

(a) Intrinsic sensors (or) Active sensors.

(b) Extrinsic sensors (or) Passive sensors.

(a) Intrinsic Sensor (or) Active Sensor

If the measuring parameter directly acts on the fibre, then produces the change in the amount of optical signal passing through it, then the sensor is known as Intrinsic sensor (or) Active sensor.

Example: Temperature Sensor, Pressure Sensor, Liquid Level Sensor, Intensity Sensor, Phase Sensor, Polarization Sensor and Wavelength sensor.

(b) Extrinsic Sensor (or) Passive Sensor

If the measuring parameter does not directly act on the fibre, but it just transmits the optical signal and the fibre acts as a guiding medium, then the sensor is known as Extrinsic sensor (or) Passive sensor.

Example: Displacement Sensor, Laser Doppler Velocimeter Sensor, Liquid level sensor

1.24.1 INTRINSIC SENSOR OR ACTIVE SENSOR (TEMPERATURE OR PRESSURE SENSOR)

Light from a laser source passes through a beam splitter which is a partially silvered mirror inclined exactly at 45° as shown in Fig. 1.30. The beam is made to fall on a glass plate inclined at an angle of 45° with respect to the direction of the laser beam.

The light is split into two equal beams of equal intensity after passing through the partially silvered mirror. One of the beam after condensing through lens L1 is passed through reference fibre, whereas the other beam after condensing through lens L3 is passed through the test fibre which is subjected to the environment for which the parameter is to be measured (temperature, pressure). Separate lens system L2 is provided to collect the light beam..

The reference fibre and the test fibre should be symmetrical in dimension and material. The path travelled by the two beams should be of the same distance before the test fibre is subjected to temperature or pressure i.e., the parameter which is to be measured.

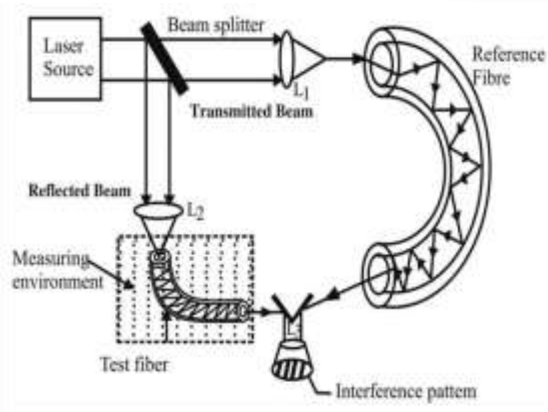


Fig. 1.30 Active sensor (Temperature / Pressure) sensor

The two beams after passing through the reference and test fibres produce a path difference, when the test fibre is subjected to temperature or pressure. Thus change in temperature/pressure can be accurately measured with the help of interference pattern formed by the two beams due to path difference.

1.24.2 EXTRINSIC SENSOR OR PASSIVE SENSOR (DISPLACEMENT SENSOR)

In Extrinsic sensor, two separate fibres of same dimension and materials are used. One of the fibre is used for transmitting the light to the moving object and the other one to receive the reflected light from the object as shown in Fig. 1.31. i.e., transmitting fibre is coupled to the laser source and receiving fibre is coupled to the detector.

The light from the source is incident on the object after passing through the transmitting fibre. After reflection from the object it undergoes a change in its intensity and reaches the receiving fibre, where its intensity is detected by a detector.

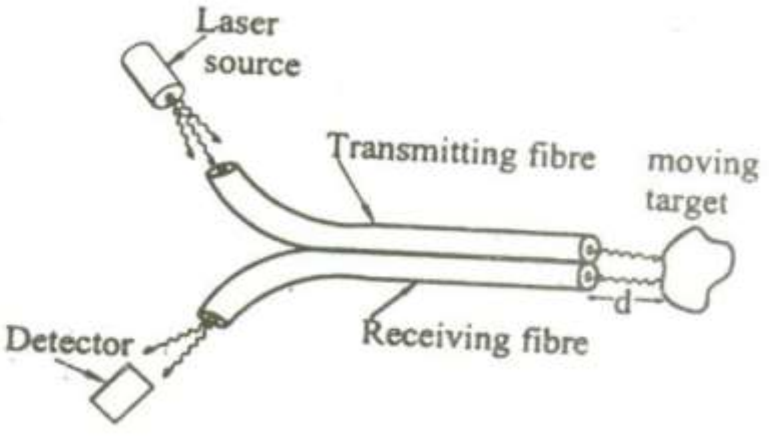


Fig. 1.31 Displacement sensor

Based on the intensity of light received, the displacement of the object can be measured. If the intensity received is more, then the object moves towards the sensor and if the intensity is less, then the object moves away from sensor. If the intensity remains constant, then the object is immobile. Thus from the intensity of light received, the displacement of the object can be measured.

SOLVED PROBLEMS

1. A semiconductor diode laser has a peak emission wavelength of 1.55 μm. Find its band gap in eV.

Solution:

Given data:	Laser wavelength, λ	=	1.55 μm
Other useful data:	Planck's constant, h	=	6.626×10^{-34} J s
	Speed of light, c	=	3×10^{8} m s^{-1}
	Charge of an electron, e	=	1.602×10^{-19} C

Bandgap of the semiconductor is the same as that of the energy of the emitted photon, therefore, the bandgap of the semiconductor in eV is obtained as follows

$$E_g = \frac{hc}{\lambda e}$$

$$= \frac{6.626 \times 10^{-34} \times 3 \times 10^{8}}{1.55 \times 10^{-6} \times 1.602 \times 10^{-19}}$$

$$= 0.801 \ \text{eV}$$

2. A solid state laser emits a photon of wavelength 7800×10^{-10} m of power 20 mW. Calculate the number of photons emitted in 10 ns.

Solution:

Given data:	Laser wavelength, λ	=	7800×10^{-10} m
	Laser power, P	=	20 mW = 20×10^{-3} W
	Time, t	=	10 ns = 10×10^{-9} s
Other useful data:	Planck's constant, h	=	6.626×10^{-34} J s
	Speed of light, c	=	3×10^{8} m s^{-1}

Number of photons emitted per unit time is obtained by dividing the power of the laser beam by the energy of any single photon in the laser beam, i.e.,

$$N = \frac{P}{hc/\lambda} = \frac{P\lambda}{hc}$$

$$= \frac{20 \times 10^{-3} \times 7800 \times 10^{-10}}{6.626 \times 10^{-34} \times 3 \times 10^{8}}$$

$$= 7.85 \times 10^{16} \ \text{photons per sec}$$

Then, the number of photons emitted in 10 ns is given by

$$n = N\,t$$

$$= 7.85 \times 10^{8} \quad \text{photons}$$

3. What is the ratio of the stimulated emission to spontaneous emission at temperature of 250 °C for the sodium D line? (λ = 590 nm)

Solution:

Given data: Photon wavelength, λ = 590 nm = 590 x 10^{-9} m

Temperature, T = 250 °C = 523 K

The ratio of stimulated emission rate, $R_{21(St)}$ to the spontaneous emission rate $R_{21(Sp)}$ is calculated through

$$\frac{R_{21(St)}}{R_{21(Sp)}} = \frac{1}{\exp\left(\frac{hc}{\lambda k_B T}\right) - 1}$$

$$= \frac{1}{\exp\left(\frac{6.626 \times 10^{-34} \times 3 \times 10^{8}}{590 \times 10^{-9} \times 1.38 \times 10^{-23} \times 523}\right) - 1}$$

$$= 5.33 \times 10^{-21}$$

4. What is the maximum core diameter for a fibre, if it is to operate in single mode at a wavelength of 1550 nm if the NA is 0.12?

Solution:

$$V = \frac{2\pi a}{\lambda} \times N.A$$

where V is the V number.

Solving for a yields, $a = \frac{V\lambda}{2\pi\ N.A}$

For Single mode operation, V must be 2.405 or less. The maximum core diameter occurs when $V = 2.405$.

$$a_{max} = \frac{2.405 \times 1550\ nm}{2\pi \times 0.12} = 4.95\ \mu m$$

$$d_{max} = 2a = 9.9\ \mu m$$

5. Compute the numerical aperture and the acceptance angle of an optical fibre from the following data

Refractive index of the core n_1 = 1.55

Refractive index of the cladding n_2 = 1.50

Surrounding medium (air) n_0 = 1

Solution:

Numerical aperture of an optical fibre is given by

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

$$NA = \sqrt{1.55^2 - 1.50^2} = 0.3905$$

Acceptance angle (θ_A) is given by

$$\theta_A = \sin^{-1}(NA)$$

$$\theta_A = \sin^{-1}(0.3905) = 22.99°$$

6. Compute NA, acceptance angle and critical angle of the fibre having core refractive index n_1 = 1.50 and the refractive index of the cladding n_2= 1.45.

Solution

Given data: Refractive index of core, n_1 = 1.50

Refractive index of cladding, n_2 = 1.45

Numerical aperture, NA of the optical fibre is calculated as given below

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

$$NA = \sqrt{1.5^2 - 1.45^2} = 0.3841$$

With numerical aperture, the acceptance angle is calculated as given below

Acceptance angle, $\theta_A = \sin^{-1}(NA) = \sin^{-1}(0.3841) = 22.59°$

With the core and cladding refractive indices, the critical angle is calculated by

Critical angle, $\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right) = \sin^{-1}\left(\frac{1.45}{1.5}\right) = 75.16°$

7. Calculate the numerical aperture of an optical fibre whose core and cladding are made of materials of refractive indices 1.6 and 1.5 respectively.

Solution

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

$$NA = \sqrt{1.6^2 - 1.5^2}$$

$$= 0.55677$$

8. An optical fibre of core and cladding materials of refractive indices 1.6 and 1.45 respectively. Calculate the angle of cone in which any light ray that enters should undergo total internal reflection and get propagated along the length of optical fibre.

Solution

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

$$NA = \sqrt{1.6^2 - 1.45^2}$$

$$= 0.6764$$

Acceptance angle (θ_A) is given by

$$\theta_A = \sin^{-1}(N.A)$$

$$\theta_A = \sin^{-1}(0.6764) = 42.563°$$

∴ Angle of cone $= 2\theta_A = 2(42.563°) = 85.126°$

9. For 589 nm light, calculate the critical angle for the following materials surrounded by air. (a) diamond, n = 2.419 (b) flint glass, n = 1.66 (c) ice, n = 1.309.

Solution

$\text{Sin}(\theta_C)=\frac{n_2}{n_1}$. For air, n_2=1, so $\text{Sin}(\theta_C)=\frac{1}{n_1}$

(a) Diamond: n_1=2.419, $\text{Sin}(\theta_C)$=0.41, θ_C= 24.42°

(a) Flint glass: n_1=1.66, $\text{Sin}(\theta_C)$=0.60, θ_C= 37.04°

(a) ice : n_1=1.309, $\text{Sin}(\theta_C)$=0.76, θ_C= 49.81°

10. A certain optical fibre has an attenuation of 3.5 dB/km at 850 nm. If 0.5 mW of optical power is initially launched into the fibre, what is the power level in mW after 4 km.

Data:

Attenuation α = 3.5 dB/km.

Initial power level, P_{in} = 0.5 mW.

Length of the cable, L = 4 km.

Solution:

$\alpha = \frac{10}{L}\log\frac{P_{in}}{P_{out}}$ =3.5 dB/km

$$\therefore 10\log\frac{0.5\text{mW}}{P_0} = \alpha L$$

$$= (3.5\ \text{dB/km})(4\ \text{km}) = 14\ \text{dB}$$

$$P_0 = \left(\frac{0.5\ \text{mW}}{25.11}\right) = 19.9\ \mu\text{W}$$

11. An optical fibre has a NA of 0.20 and a refractive index of cladding 1.59. Determine the acceptance angle for the fibre in water which has a refractive index of 1.33.

Solution

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

When the fibre is in air $n_0 = 1$

$$\text{NA} = \sqrt{n_1^2 - n_2^2} = 0.20$$

$$n_1 = \sqrt{N.A^2 + n_2^2} = 1.6025$$

When the fibre is in water $n_0 = 1.33$

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

$$= \frac{\sqrt{1.605^2 - 1.59^2}}{1.33} = 0.15$$

Acceptance angle $\theta_A = \sin^{-1}(\text{N.A}) = \sin^{-1}(0.15) = 8.63°$

12. Calculate the number of guided modes propagating in the multimode step index fibre having diameter of 60 μm and numerical aperture of 0.25, operating at a wavelength of 2.7 μm.

Solution

The number of modes for a step index fibre is given by

$$N_{step} = \frac{\pi^2}{2}\left(\frac{dxNA}{\lambda}\right)^2$$

$$N_{step} = \frac{\pi^2}{2}\left(\frac{60x10^{-6} \text{ x } 0.25}{2.7x10^{-6}}\right)^2$$

$$N_{step} = 152.31$$

$$N_{step} = 152 \text{ modes}$$

13. A step index fire has a core refractive index of 1.48. If the core diameter and the numerical aperture of the fibre are respectively 50 μm and 0.5, find the refractive index of the cladding and the maximum number of modes of light of wavelength 1 μm the fibre can carry.

Given data

n_1=1.48

d= 50 x 10^{-6} m, NA=0.5

λ= 1 x 10^{-6} m

Formula

i) Refractive index of cladding can be calculated from the expression of numerical aperture as follows

$$n_2 = \sqrt{n_1{}^2 - NA^2} = \sqrt{1.48^2 - 0.5^2} = \sqrt{1.9404} = 1.393$$

ii) The number of modes for a step index fibre is given by

$$N_{step} = \frac{\pi^2}{2}\left(\frac{dxNA}{\lambda}\right)^2$$

$$N_{step} = \frac{\pi^2}{2}\left(\frac{50x10^{-6} \text{ x } 0.5}{1x10^{-6}}\right)^2 = 3084.3 = 3084 \text{ modes}$$

iii) The number of modes for a step index fibre is given by

$$N_{grad} = \frac{N_{step}}{2} = 1542.1 = 1542 \text{ modes}$$

14. **A signal of 100 mW is injected into a fibre of length 1 km. The outcoming signal from the other end is 40 mW. Find the fibre attenuation.**

Solution:

P_{in} = 100 mW

P_{out} = 40 mW

L = 1 km

Attenuation

$$\alpha = \frac{10}{L}\log_{10}\left(\frac{P_{in}}{P_{out}}\right)$$

$$\alpha = \frac{10}{1}\log_{10}\left(\frac{100}{40}\right)$$

= 3.98 dB/km

15. A multimode step index fiber has a core diameter of 70 µm, a core refractive index of 1.5 and a cladding refractive index of1.47. Determine the V-number and the number of modes supported by the fiber when it transmits a light of wavelength 8380 Å

Given data:

n_1=1.5, n_2=1.47, d=70 µm, a=35 x 10^{-6} m, λ=8380 Å

Normalised frequency is obtained by

$$V = \frac{2\pi a}{\lambda}\sqrt{n_1^2 - n_2^2}$$

$$V = \frac{2\pi \times 35 \times 10^{-6}}{8380 \times 10^{-10}}\sqrt{1.5^2 - 1.47^2}$$

$$V = 78.29$$

Number of modes supported by a step index fiber

$$N_{step} = \frac{V^2}{2} = \frac{78.29^2}{2}$$

$$N_{step} = 3065$$

VIDEO LINKS

- Introduction to Lasers
  https://youtu.be/WgzynezPiyc
- Stimulated Emission
  https://youtu.be/YHmGNDMV1cY
- Difference between Spontaneous and Stimulated Emission of Radiation
  https://youtu.be/WZ_GjUHctkE
- Semiconductor laser construction
  https://youtu.be/LZgUkZUYHaA
- Principle of Semiconductor Laser
  https://youtu.be/NpePZjTXqRw
- Structure of optical fibre
  https://youtu.be/aylVgs2iDDw
- Total Internal Reflection
  https://youtu.be/Lic3gCS_bKo
- Single Mode Fibre
  https://www.Youtube.Com/watch?V=45x0pub3yk0
- Multimode Fibre
  https://www.youtube.com/watch?v=uzXLhTW9wWQ
- Step and Graded Index Fibre
  https://www.youtube.com/watch?v=Ry1Vjrqonb0
- Attenuation and Dispersion
  https://youtu.be/VfKpqFKOccE
- Losses in Fibre
  https://youtu.be/NvvSS2Sf7Co

QUIZ

After completing the course, students are instructed to take the following quiz to quantify their understanding of the concepts on Laser and Fibre Optics.

1. https://forms.gle/vbytmj2Qz2JNKvJZ7
2. https://forms.gle/dkhSsw5VR8sDd33n6
3. https://forms.gle/bC2kg4ssXFuh12Hu5
4. https://forms.gle/MAtFLuk8BKABdopx8
5. https://forms.gle/uMdtvPp9B7rG9FsFA
6. https://forms.gle/vyponaqq8WsiZPm78

RESULTS

Repeat your learning, if your score is less than 60%.

Congratulations, if your score is above 90%.

ASSIGNMENT ON LASER

1. Calculate the relative population of sodium atoms in sodium lamp in the first excited state and the ground state at a temperature of 280°C (λ = 590 nm).

Answer: N_2/N_1: 6.7518 x 10^{-20}

2. Calculate the long wavelength limit of an extrinsic semiconductor, if the ionization energy is 0.02 *eV*. **(Dec 2003)**

Answer: Wavelength λ = 6.2109 x 10^{-5} m

3. Energy required to remove an electron from sodium metal is 2.3 *eV*. Does sodium exhibit photo electric effect from an orange light having wavelength 6000 Å.

Answer: Energy E = 2.07 *eV*, which is less than 2.3 *eV*. So, it does not exhibit photo-electric effect from an orange light having wavelength 6000 Å

4. For a heterojunction semiconductor laser, the band gap of the semiconductor used is 1.44 *eV*. By doping, the band gap of the semiconductor is increased by 0.2 *eV*. Calculate the change in wavelength of the laser?

Answer: Change in wavelength = 1051 Å

5. Calculate the wavelength of radiation emitted by a semiconducting material with band gap energy 2.8 *eV*. What is the color of the radiation?

Answer: Wavelength λ = 4436 Å and Blue colour

6. Given E_g = 1.43 eV. Find the wavelength of the light emitted by the diode for the given energy gap. Also find the colour of light emitted.

Answer : λ = 8671.32 Å, IR

7. Calculate the ratio of the stimulated emission to spontaneous emission at a temperature 300 °C for the Sodium D-line.

Answer : 2.919 x 10^{-19} m

ASSIGNMENT ON FIBRE OPTICS

1. A step – index has a numerical aperture of 0.16, a core refractive index of 1.45 and a core diameter of 90 µm. Calculate (a) acceptance angle and (b) refractive index of the cladding. **(Ans: 9°12′ , 1.44)**

2. Find the numerical aperture and the acceptance angle for a step-index for which n_1 = 1.5, n_2 = 1.48 and n_0= 1. **(Ans: 0.244 , 14°7′)**

3. Calculate the numerical aperture and hence the acceptance angle for an optical whose core and cladding has refractive index of 1.59 and 1.40 respectively. **(Ans: 0.7537 , 48°54′)**

4. Two layers of glass are placed one over the other. Find the critical angle for which the total internal reflection takes place if the light travels from n_1 = 1.45 to n_2 = 1.40. **(Ans: 74°54′)**

5. A has n_{core} = 1.44 and $n_{cladding}$ = 1.40. Find (i) NA (ii) acceptance angle. **(Ans: 0.337 , 19°41′)**

6. A silica optical has a core refractive index of 1.50 and of cladding refractive index 1.47. Determine critical angle, NA, and acceptance angle.

   (Ans: 78°31′ , 0.2985 , 17°22′)

7. Calculate the refractive indices of the core and cladding material of a fibre from the following data. NA = 0.22, Δ = 0.012. **(Ans: 1.42 , 1.40)**

8. Calculate the total number of guided modes propagating in the multimode step index having diameter of 50µm and numerical aperture of 0.2 and operating at a wavelength of 1µm. **(Ans: 245 modes)**

9. Find the refractive index of the core and cladding if the NA is 0.3 and the relative refractive index difference is 3%. **(Ans: 1.2247, 1.1873)**

10. A signal of 100 mW is injected into a . The out coming signal from the other end is 40mW. Find the loss in dB. **(Ans: 3.979 dB)**

PART A – QUESTIONS WITH ANSWERS

1. What are the characteristics of laser light? (K2, CO1)

The characteristics of laser light are:

- Highly directional,
- Highly monochromatic,
- Highly intense,
- Highly coherent and in-phase, and
- Less angular spread.

2. List out the important components of a laser. (K2,CO1)

The important components of a laser are

(i) Active medium

(ii) Pumping system

(iii) Optical resonator

3. Can a two-level system be used for the production of laser? Why? (K2,CO1)

A two-level system cannot be used for the production of laser since there should be a meta-stable state for stimulated emission.

4. Define the term "stimulated emission". (K2,CO1)

Stimulated emission is the process by which an atom or molecule in an excited state undergoes a transition to the ground state when excited state is exposed to the external radiation.

5. Narrate the principles of laser action. (K2,CO1)

The excited state atoms are stimulated by external energy source to make transitions to the lower energy state. During transitions, the atoms emit coherent photons in the direction as that of the incident photon. The released photons are then used to stimulate the excited atoms and hence coherent photons are emitted in the medium. The light is amplified by stimulated emission of radiation.

6. What are the conditions needed for laser action? (K2,CO1)

The two important conditions required for laser action are:

(i) Population inversion should be achieved, and

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

7. Define population inversion. (K2,CO1)

The establishment of a situation in which there are more number of atoms in the excited state than the ground state is called population inversion.

8. What is pumping and metastable state? (K2,CO1)

Pumping Process: The process of raising more number of atoms to the excited state artificially is called as pumping process.

Meta stable state: An energy level (or) state whose lifetime is greater than that of hydrogen atom (10^{-8} sec), then the energy state is called meta stable state.

9. Mention the methods of achieving population inversion? (K2,CO1)

i. Optical pumping
ii. Electrical discharge method
iii. Direct conversion
iv. Inelastic atom–atom collision
v. Chemical reaction

10. What is the principle of semiconductor laser? (K2,CO1)

The electron in conduction band combines with a hole in the valence band and produces energy in the form of a light. This photon induces another electron from conduction band to move to the valence band and stimulates the emission of coherent photons.

11. What are the advantages of hetero-junction semiconductor laser?

(K2,CO1)

The advantages of heterojunction laser over homojunction laser are as follows

- The power output of heterojunction laser is very high when compared to that of homo-junction laser.

- The hetero-junction semiconductor laser produces continuous wave output but in homo-junction the output wave is pulsed and will be continuous only for some time.
- The hetero-junction laser has high directionality and high coherence but in homo-junction, the beam has large divergence.

12. Mention the applications of laser in engineering and medicine.

(K2,CO1)

Engineering applications:

i. Welding

ii. Cutting

iii. Drilling

iv. Microelectronic application: It is used in making photo masks, writing and reading CD's and DVD's, designing thin film circuits.

Medical applications:

i. Drill minute holes in cell walls of human body.

ii. Treat the detached retina.

iii. Carry out microsurgery and bloodless operations.

iv. Treat cancer and tumors in human beings and animals.

13. List the two major differences of homojunction and heterojunction semiconductor lasers. **(K2,CO1)**

- A homojunction uses the same semiconductor material with different doping on both sides of the junction whereas a heterojunction uses two semiconductor materials having different band gap energies on both sides of the junction.
- Power output is low for homojunction and high for heterojunction laser.

14. What is meant by Cavity loss? **(K2,CO1)**

The optical cavities are also known as optical resonators are used to amplify the light within the cavity, so the mirrors used are highly reflective. The loss of light occurs in the resonating cavity during laser transition is called as cavity loss.

15. Why does cavity loss occur?

(K2,CO1)

Losses inside an optical cavity are due to

Misalignment of the laser mirrors: When the optical cavity mirrors are not exactly aligned perpendicular to the laser axis and symmetric, the radiation within the cavity will not be limited during its path between the mirrors.

Absorption and scattering losses in optical elements: Since optical elements are not ideal, each interaction with optical element inside the cavity cause some losses.

Diffraction losses: Each time a laser beam passes through a limiting aperture it diffracts, which causes some losses.

16. What is the basic principle of fibre optic sensor?
(K1, CO1)

It measures change in parameters like temperature, pressure, displacement, phase etc, by their influence on intensity of light passing through an optical fibre.

17. What are the different types of fibre optic sensors? (K1, CO1)

The different types of sensors are

(i) Intrinsic sensors (or) Active sensors

(ii) Extrinsic sensors (or) Passive sensors

18. Give the applications of fibre optic sensors. (K1, CO1)

Sensors are devices used to measure temperature, pressure, displacement, etc., accurately with the change in intensity of light produced by it, while passing through an optical fibre.

19. What are the losses that occur during optical fibre communication?

(K1, CO1)

- During the transmission of light through the optical fibre, three major losses will occur, attenuation, distortion and dispersion.
- **Attenuation** is mainly caused due to the absorption, scattering and radiation of light inside the fibres.
- **Distortion** and **dispersion** occurs due to spreading of light and also due to manufacturing defects.

20. What are the conditions to be satisfied for total internal reflection? (K2, CO1)

The conditions to be satisfied for observing total internal reflection are as follows

(i) Light should travel from denser medium to rarer medium.

(ii) The angle of incidence θ_1 on core should be greater than the critical angle θ_c, i.e., $\theta_1 > \theta_c$

(iii) The refractive index of the core (n_1) should be greater than the refractive index of the cladding (n_2). i.e. $n_1 > n_2$

21. Define critical angle (K1, CO1)

The incident angle θ_1 that produces an angle of refraction of 90º is called the critical angle, θ_c. $\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$

22. Define acceptance angle. (K1, CO1)

Acceptance angle is the maximum angle to the axis at which light may enter into the fibreso that it can have total internal reflection inside the fibre.

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

23. Define Numerical aperture. (K1, CO1)

It is the light collecting efficiency of the fibre. It is the measure of the amount of light rays that can be accepted by the fibre. It is equal to the sine of the acceptance angle. $NA = sin\theta_0$ and $NA = \sqrt{n_1^2 - n_2^2}$

24. How will you classify optical fibres? (K1, CO1)

Optical fibres are classified into three major categories based on (i) Material (ii) Number of modes and (iii) Refractive index profile

(i) Based on the material it can be classified into

a) Glass fibre b) Plastic fibre

(ii) Based on number of modes they are classified as

a) Single mode fibre b) Multimode fibre

(iii) Based on refractive index profile they can be classified as

a) Step-index fibre b) Graded index (GRIN) fibre

25. Differentiate single mode and multimode fibres. (K1, CO1)

S.No	Single Mode Fibre	Multimode Fibre
1	In single mode fibre only one mode can be propagated.	The fibre in this case allows large number of modes of light to propagate through it
2	The single mode fibre has a smaller core diameter and difference in refractive index of core and cladding is small.	Here, since the core diameter is large, the core and cladding refractive index difference is large.

26. Differentiate between step index and graded index fibres. (K1, CO1)

S.No	Step Index Fibre	Graded Index Fibre
1	If the variation of refractive index of the core from optical fibre axis to core-cladding is in the form of step. Then it is called step index fibre.	If the variation of refractive index of core is represented by a gradual decrease from core axis to core-cladding interface. Then it is called graded index fibre.
2	Meridional ray propagation (ray passes through fibre axis)	Skew ray propagation (ray do not pass through fibre axis)

PART B – QUESTIONS

1. **Illustrate spontaneous and stimulated emission. Derive Einstein's A and B coefficients for lasing action. (K2,CO1)**
2. **For atomic transitions, derive Einstein's relations and hence deduce the expressions for the ratio of spontaneous emission rate to stimulated emission rate. (K2,CO1)**
3. **Illustrate the schematic sketch of normal and population inversion state of a laser and obtain Einstein's coefficients A and B. (K2,CO1)**
4. **Explain population inversion and drive the ratio of stimulated emission rate to stimulated absorption rate with the help of Einstein's coefficients. (K2,CO1)**
5. **Compare homojunction and heterojunction semiconductor lasers. (K2,CO1)**
6. **Explain the principle, construction and working of homojunction semiconductor diode laser with necessary diagrams. (K2,CO1)**
7. **Explain the principle, construction and working of heterojunction semiconductor diode laser with necessary diagrams. (K2,CO1)**
8. **Explain the following with the necessary diagram: (i) Optical resonating cavity (ii) Optical amplification. (K2,CO1)**
9. **Compare a homojunction semiconductor laser with a heterojunction semiconductor laser and detail their features. (K2,CO1)**
10. **Explain in detail the Engineering applications of lasers in data storage. (K2,CO1)**

11. Describe the propagation of light through an optical fibre.

Make use of Snell's law and derive an expression for numerical aperture and acceptance angle of an optical fibre. (K3,CO1)

12. Explain in detail how optical fibres are classified according to the material, refractive index and modes of propagation. (K2, CO1)

13. Interpret the mechanisms of attenuation, dispersion and bending losses in optical fibres. (K2, CO1)

14. What is meant by attenuation? Demonstrates the different mechanisms which are responsible for attenuation in the optical fibres. (K2,CO1)

15. Summarize in detail with a block diagram the optical fibre communication system. (K2 ,CO1)

16. Explain the construction and working of active and passive fibre optic sensors. (K1,CO1)

17. Explain with a neat diagram, the working of displacement sensor and pressure sensor. (K1,CO1)

SUPPORTIVE ONLINE CERTIFICATION COURSES

NPTEL COURSES

1. **Laser Fundamentals and Applications**
   https://nptel.ac.in/courses/104/104/104104085/
   Duration of the course: 8 weeks
2. **Optics**
   https://nptel.ac.in/courses/115/107/115107095/
   Duration of the course: 8 weeks
3. **Optic Communication Technology**
   https://nptel.ac.in/courses/108/106/108106167/
   Duration of the course: 10 weeks
4. **Optic Communication Systems and Techniques**
   https://nptel.ac.in/courses/108/104/108104113/
   Duration of the course: 12 weeks

COURSERA COURSES

1. **Light Emitting Diodes and Semiconductor Lasers**
   https://www.coursera.org/learn/leds-semiconductor-lasers
   Duration of the course: 4 weeks

SPIE COURSES

1. **What are Lasers Good For?**
   https://spie.org/education/courses/coursedetail/SC364?f=Online&SSO=1
   Duration of the course: 4 weeks

REAL TIME APPLICATIONS IN DAY–TO–DAY LIFE AND INDUSTRY

1. **5 Ways Laser Technology Is Used in Everyday Life**
   https://www.andysowards.com/blog/2018/5-ways-laser-technology-used-everyday-life/
2. **Laser Pointer**
   https://www.youtube.com/watch?v=3gZ_HZkSzl4
3. **Laser Engraver**
   https://www.youtube.com/watch?v=5HvFPYaVtQs
4. **Laser Printer**
   https://www.youtube.com/watch?v=EwvmNv1leUo
5. **Particle size determination using Laser**
   https://youtu.be/W4_HVXLHEbY
6. **Medical Application : Eye Cataract surgery**
   https://youtu.be/NydjSIwrnpU
7. **Laser Tattoo Removal**
   https://www.youtube.com/watch?v=VISJ9P4mToA
8. **World's first lecture delivered via hologram**
   https://www.youtube.com/watch?v=DkOKrVV3SS0

CONTENT BEYOND THE SYLLABUS

1. **Construction and Working of Nd-YAG laser**
   https://www.slideshare.net/jaydipkanpariya1/ndyag-laser-working-and-construction
2. **Working of He Ne Laser**
   https://youtu.be/RyY4PEpV2RQ
3. **How Does an Endoscope Work?**
   https://www.youtube.com/watch?v=NfP-_LY3yhU
4. **Optical cables, how do they work?**
   https://www.youtube.com/watch?v=jZOg39v73c4

PRESCRIBED TEXTBOOKS AND REFERENCE BOOKS

TEXTBOOKS

1. M.N. Avadhanulu and P.G. Kshirsagar, "A text book of Engineering Physics", S. Chand and Company, New Delhi, 2014.

REFERENCE BOOKS

1. R.K Gaur and SL Gupta, "Engineering Physics", Dhanpat Rai Publications (P) Ltd., 8th Edition, New Delhi 2001,
2. RA Serway, and J.W. Jewett, "Physics for Scientists and Engineers", Cengage Learning, 9th Edition, 2014
3. R. Wolfson, "Essential University Physics, Vol.1&2 with Mastering Physics", Pearson, Global Edition, 3rd Edition, 2017
4. B.K. Pandey, and S. Chaturvedi, "Engineering Physics", Cengage Learning India, 2012

MINI PROJECT SUGGESTIONS

1. **Laser Security System**

   https://www.electronicshub.org/laser-security-system

2.Homemade Optical - Fibre Optic Lighting Cable

   https://www.youtube.com/watch?v=RiYOw5NsoKY

3. **Make your own Spectrometer**

   https://www.fizzicseducation.com.au/150-science-experiments/light-sound-experiments/make-your-own-spectrometer/

   Students can record the video of this activity done at home with explanation.

4. **Sound Transfer by Laser**

   https://www.youtube.com/watch?v=4x97jqwO5nQ

   ttps://www.youtube.com/watch?v=DtCwJU6YMaA

5.Laser Security System

   https://www.electronicshub.org/laser-security-system/

6. **Laser Communication System**

   https://www.allaboutcircuits.com/projects/build-a-laser-communication-system/

7. **Laser Applications in Science Education**

   https://spie.org/etop/1995/230_1.pdf

8. **Optical Night Lamp**

   https://youtu.be/GVakZh1PfOcData

9. **Total Internal Reflection**

   https://www.youtube.com/watch?v=SE0gDqBAom4

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