JULY 2021

AP MODULE 5 SOLUTIONS

TYPED NOTES

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Lasers and Fiber Optics

Applied Physics Module 5 QB Solutions

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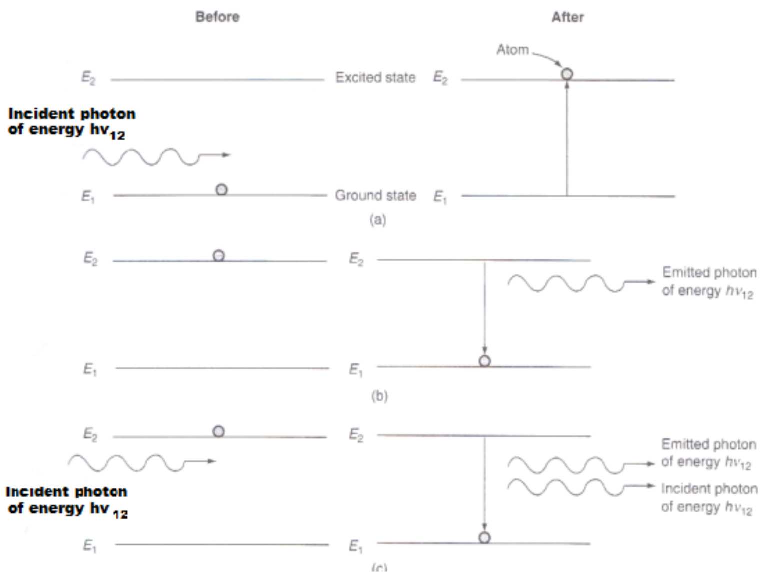
PART - A

1Q) Mention the three distinct processes by which a transition can take place.

> The three distinct processes are as follows:
> → absorption
> → spontaneous emission
> → stimulated emission



(a) Absorption ;(b) Spontaneous emission;(c) Stimulated emission

2Q) What do you mean by coherence? Name two types of coherence

> In physics, coherence means property of waves – coherent waves are able to interfere as they have a constant phase relation.
> Physicists distinguish between two types of coherence:
> → spatial (transverse) coherence
> → temporal (longitudinal, spectral) coherence
> In order to observe interference patterns, both types of coherence must exist.

3Q) State the properties of the laser beam that makes it different from normal light

> Sunlight is made up of different wavelengths, or colors, of light. Laser light however contains only one wavelength. This property makes lasers monochromatic, the meaning of one color. Another property of lasers is that all the wavelengths are in phase, meaning they wave together. This property is called coherency. Laser light travels in the same direction also known as directionality, parallel to one another. This is what makes laser light beams very narrow and concentrated (High intensity) on one spot rather than spread out like with other light.

4Q) List out the different types of lasers.

> Lasers are typically identified by their gain medium and are often classified by the radiating species that give rise to stimulated emission. These radiating species can include atoms and

> molecules in a dilute gas, organic molecules dissolved at relatively low concentration in liquid solutions, semiconductor materials, and dielectrics such as crystalline solids or glasses that are doped with a high concentration of ions. These laser categories are generally referred to as gas, liquid, semiconductor, and solid-state
> Examples:
> Ruby laser (Solid-state laser)
> $HeNe$ laser (Gas state laser)
> CO_2 laser (Gas state laser)

5Q) What is the advantage of using lasers as light sources in CD players?

> The main problem with cassettes was the physical contact between the player and the record or tape being played, which gradually wore out. In a CD player, the only thing that touches the CD is a beam of light and the laser beam bounces harmlessly off the surface of the CD, so the disc itself should (in theory) never wear out. Another advantage is that the CD player can move its laser quickly to any part of the disc, so you can instantly flip from track to track or from one part of a movie to another.

6Q) What are the three important requisites for laser action to take place?

> The three main important requisites for laser action to take place are:
> → Active material or medium

> → Pumping
> → Optical Resonator

7Q) What does the term laser stand for? Illustrate about the principle of laser.

> LASER stands for light amplification by stimulated emission of radiation. It is different from conventional light (such as tube light or electric bulb), there is no coordination among different atoms emitting radiation. A laser is a device that emits light (electromagnetic radiation) through a process called stimulated emission.

8Q) Recall the role of the metastable state in achieving the population inversion.

> Because each atom's residence time in the metastable state is relatively long, the population tends to increase and leads to a population inversion between the metastable state and the lower ground state (which is continuously being depopulated to the highest level).

9Q) Define the terms lifetime and population of an energy state.

> Lifetime: The lifetime is the time measured for an excited atom when in a higher energy level.
> Lifetimes can vary in duration depending on the atom and on the energy level. Excited-state lifetimes are typically a few nanoseconds (10-9 s, or a billionth of a second), but they could

> be as short as a picosecond (10-12 s, or a thousand times shorter still) or as long as a few milliseconds (10-3 s).
> Population: Number of atoms present in energy levels. More the number of atoms in a particular energy level more the population.

10Q) List any two applications of lasers in engineering.

> → Welding has been carried by using laser beam, dissimilar metals can be welded and micro welding is done with great case.
> → Lasers beam is used in selective heat treatment for tempering the desired parts in automobile industry

11Q) Explain the basic principle used in optical fiber for transmission of light.

> The basic principle used in optical fiber for transmission of light is total internal reflection.
> Total internal reflection is the optical phenomenon when waves travelling in one medium strike at sufficiently oblique incident angle against the boundary with another medium of lower refractive index.

12Q) Define Acceptance angle, Acceptance cone and Numerical Aperture of an optical fiber.

> **Acceptance Angle**: It is the angle at which we have to launch the beam at its end to enable the entire light to propagate through the core.
> (or)

> The acceptance angle of an optical fiber is defined based on a purely geometrical consideration (ray optics): it is the maximum angle of a ray (against the fiber axis) hitting the fiber core which allows the incident light to be guided by the core

> **Acceptance Cone**: The cross section of an optical fiber is circular; the light waves accepted by the core are expressed as a cone. The larger the acceptance cone, the larger the numerical aperture(NA); this means that the fiber is able to accept and propagate more light.
>
> **Numerical Aperture**: The numerical aperture (NA) of an optical system is a measure for its angular acceptance for incoming light.

13Q) List any two applications of optical fibers in day to day life

> → Optical Fibers used for Broadcasting TV
> → Optical fibers used for Internet (Ethernet cable)
> → Optical Fiber for Lightening and Decorations

14Q) Mention any three advantages of optical fiber communication system.

> Advantages of Optical fiber for communication:
> → Increase in speed and accuracy of the transmission data.
> → Fiber optics cables are lighter and more flexible.
> → Optical fiber cables can carry more data.

15Q) How is attenuation loss in optical fiber measured? Mention its units.

> Attenuation lose in an optical fiber is calculated using the following formula:
> $dB = 10 \times \log_{10}\left[\frac{PowerOut}{PowerIn}\right]$
>
> $dB = 10 \times \log_{10}[PowerRatio]$
>
> $loss = \frac{10 \times \log_{10}[PowerRatio]}{TotalLength}$
>
> Units: Decibels per unit length $(dB/cm, dB/km, etc.)$

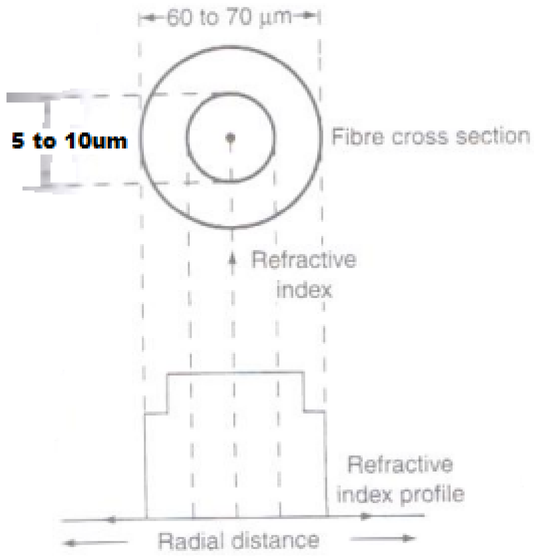
16Q) Recall the expressions for Acceptance angle and Numerical aperture of an optical fiber

> Acceptance Angle: It is the angle at which we have to launch the beam at its end to enable the entire light to propagate through the core.

> The acceptance angle of an optical fiber is defined based on a purely geometrical consideration (ray optics): it is the maximum angle of a ray (against the fiber axis) hitting the fiber core which allows the incident light to be guided by the core

> Numerical Aperture: The numerical aperture (NA) of an optical system is a measure for its angular acceptance for incoming light.

17Q) Illustrate a neat sketch of the refractive index profile of step-index optical fiber.



18Q) Mention the principle behind propagation of light signal through an optical fiber.

> In optical fibers, propagation of light takes place due to total internal reflection. When light falls one end of the optical fiber; it gets refracted into the fiber. The refracted ray of light falls on the interface separating the fiber and coating an angle which is greater than the critical angle.

19Q) State the expressions for Snell's law and critical angle associated with an optical fiber

> **Snell's Law**: Snell's law is used to determine the amount of refraction that is occurring between two media
> $$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1}$$

Here v_1 and v_2 are the velocities of light in their respective medium and n_1 and n_2 are the refractive index of two different mediums.

Expression for critical angle:
Let θ_1 be the critical angle θ_c
Let $\theta_2 = 90^\circ$ so that, $\sin\theta_2 = 1$
Therefore,

$$\sin\theta_c = (\frac{n_2}{n_1})$$

$$\theta_c = \sin^{-1}(\frac{n_2}{n_1})$$

Therefore the critical angle θ_c is $\sin^{-1}(\frac{n_2}{n_1})$

20Q) Enlist different types of attenuation in optical fibers that occur during propagation of light signals.

→ Absorption loss
→ Radiative losses
→ Scattering loss
→ Dispersion loss

PART - B

1Q) Illustrate the characteristics of lasers, and highlight the phenomenon of lasing action required for the production of laser light

Characteristics of Lasers:
Coherence: Coherence is one of the unique properties of laser light. It arises from the stimulated emission process. Since a

common stimulus triggers the emission events which provide the amplified light, the emitted photons are in step and have a definite phase relation to each other. This coherence is described in terms of temporal and spatial coherence

Monochromaticity: A laser beam is more or less in single wavelength. I.e. the line width of laser beams is extremely narrow. The wavelengths spread of conventional light sources is usually 1 in 10^6, where as in case of laser light it will be 1 in 10^5 .I.e. if the frequency of radiation is 10^{15} Hz., then the width of line will be 1 Hz. So, laser radiation is said to be highly monochromatic.

$$\xi = (d\lambda/\lambda) = dv/v$$

Where $d\lambda$ or dv is the variation in wavelength or variation in frequency of radiation.

Directionality: Laser beam is highly directional because laser emits light only in one direction. It can travel very long distances without divergence. The directionality of a laser beam has been expressed interms of divergence.
Suppose r_1 and r_2 are the radii of laser beam at distances D_1 and D_2 from a laser,
and then we have.

$$\Delta\theta = (r_1 - r_2)/D_2 - D_1$$

High intensity: In a laser beam lot of energy is concentrated in a small region. This concentration of energy exists both spatially and spectrally, hence there is enormous intensity for the laser

beam. The power range of laser is about $10-13W$ for gas laser and is about $109W$ for pulsed solid-state laser and the diameter of the laser beam is about $1mm$. Then the number of photons coming out from a laser per second per unit
area is given by:

$N_1 = P/hv\pi r^2 \approx 1022$ to $1034 photons/m^{-2} sec$
By assuming $h\nu = 10^{-19}$ Joule, Power $P = 10^{-3}$
to 10^9
watt $r = 0.5 \times 10^{-3} meter$

Phenomenon for Lasing Action
→ Active material
→ Population Inversion
→ Pumping
→ Metastable state
→Optical Resonator

2Q) Explore the phenomena's of absorption and pumping mechanism related to excitation of atoms from lower to higher energy states?

Absorption is the process in which optical energy is converted to internal energy of electrons, atoms, or molecules. When a photon is absorbed, the energy may cause an electron in an atom to go from a lower to a higher energy level, thereby changing the internal momentum of the electron.

Laser pumping is the act of energy transfer from an external source into the gain medium of a laser. The energy is absorbed in the medium, producing excited states in its atoms, population

> inversion is achieved. In this condition, the mechanism of stimulated emission can take place and the medium can act as a laser or an optical amplifier. The pump power must be higher than the lasing threshold of the laser.
> Commonly used pumping types are: —
> 1. Optical pumping
> 2. Electric discharge
> 3. Atom-Atom collision
> 4. Direct conversion
> 5. Chemical reactions
> 6. Injection current
>
> After completion of lifetime of electrons in the Meta stable state, they fall back to the lower energy state
> or ground state by releasing energy in the form of photons. This process of emission of photons is called
> spontaneous emission.

3Q) Demonstrate the construction and working of a Ruby laser in detail, with the help of a neat suitable diagram.

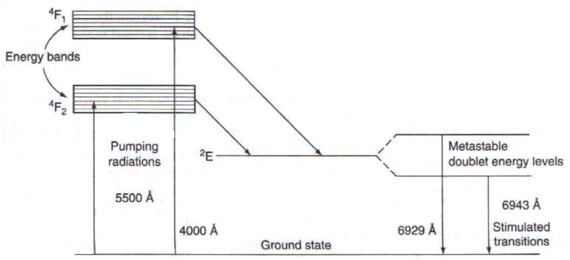
> **Construction**:
> Ruby $(Al_2O_3 + Cr_2O_3)$ is a crystal of Aluminum oxide in which some of Al^{+3} ions are replaced by Cr^{+3} ions. When the doping concentration of Cr^{+3} is about 0.05%, the color of the rod becomes pink. The active medium in ruby rod is Cr^{+3} ions. Both ends are silvered such that one end is fully reflecting and the other end is partially reflecting.
> The ruby rod is surrounded by helical xenon flash lamp tube which provides the optical pumping to raise the Chromium ions to upper energy level (rather energy band). The xenon flash lamp

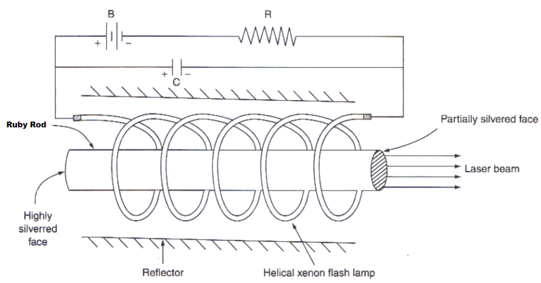
> tube which emits intense pulses lasts only few milliseconds and the tube consumes several thousands of joules of energy. Only a part of this energy is used in pumping Chromium ions while the rest goes as heat to the apparatus which should be cooled with cooling arrangement

> **Working**:
> → Ruby crystal is made up of aluminum oxide as host lattice with small percentage of Chromium ions replacing aluminum ions in the crystal chromium acts as dopant. A dopant actually produces lasing action while the host material sustains this action.
>
> → The pumping source for ruby material is xenon flash lamp which will be operated by some external power supply. Chromium ions will respond to this flash light having wavelength of $5600A^\circ$. When the Cr^{+3} ions are excited to energy level E_3 from E_1 the population in E_3 increases.
>
> → Chromium ions stay here for a very short time of the order of 10^{-8} seconds then they drop to the level E_2 which is metastable state of life time $10^{-3}s$. Here the level E_3 is rather a band, which helps the pumping to be more effective. The transitions from E_3 to E_2 are non-radioactive in nature.
> During this process heat is given to crystal lattice. Hence cooling the rod is an essential feature in this method. The life time in mete stable state is 10^5 times greater than the lifetime in E_3.
>
> → As the life of the state E_2 is much longer, the number of ions in this state goes on increasing while ions in the ground state (E_1) goes on decreasing. By this process population inversion is achieved between the exited metastable state E_2 and the ground

state E_1. When an excited ion passes spontaneously from the metastable state E_2 to the ground state E_1, it emits a photon of wave length $6943A^\circ$.

→ This photon travels through the rod and if it is moving parallel to the axis of the crystal, is reflected back and forth by the silvered ends until it stimulates an excited ion in E_2 and causes it to emit fresh photon in phase with the earlier photon. This stimulated transition triggers the laser transition. This process is repeated again and again because the photons repeatedly move along the crystal being reflected from its ends. The photons thus get multiplied. When the photon beam becomes sufficiently intense, such that part of it emerges through the partially silvered end of the crystal.





4Q) Narrate the construction and working of the He-Ne gaseous laser in detail, with the help of a neat diagram

Construction:
The helium-neon laser consists of three essential components:
→Pump source (high voltage power supply): In order to produce the laser beam, it is essential to achieve population inversion. In general, the lower energy state has more electrons than the higher energy state. However, after achieving population

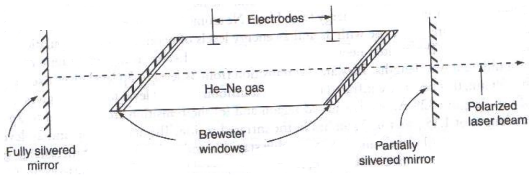
inversion, more electrons will remain in the higher energy state than the lower energy state. In helium-neon lasers, a high voltage DC power supply is used as the pump source. A high voltage DC supplies electric current through the gas mixture of helium and neon.

→ Gain medium (laser glass tube or discharge glass tube): The gas mixture is mostly comprised of helium gas. Therefore, in order to achieve population inversion, we need to excite primarily the lower energy state electrons of the helium atoms. In He-Ne laser, neon atoms are the active centers and have energy levels suitable for laser transitions while helium atoms help in exciting neon atoms.

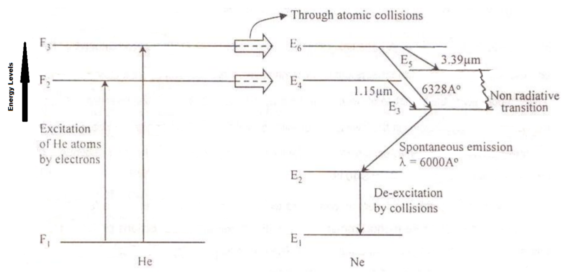
→ Resonating cavity: The glass tube (containing a mixture of helium and neon gas) is placed between two parallel mirrors. These two mirrors are silvered or optically coated. Each mirror is silvered differently. The left side mirror is partially silvered and is known as an output coupler whereas the right side mirror is fully silvered and is known as the high reflector or fully reflecting mirror. The fully silvered mirror will completely reflect the light whereas the partially silvered mirror will reflect most part of the light but allows some part of the light to produce the laser beam.

Working:
When a discharge is passed through the gaseous mixture, electrons are accelerated down the tube. These accelerated electrons collide with the helium atoms and excite them to higher energy levels. The different energy levels of Helium atoms and Neon atoms. The helium atoms are excited to the levels F_2 and F_3 these levels happen to be metastable energy states.

Energy levels and hence Helium atoms exited levels spend sufficiently large amount of time before getting de-excited. As shown in the fig, some of the excited states of neon can correspond approximately to the same energy of excited levels F2 and F3. Thus, when Helium atoms in level F_2 and F_3 collide with Neon atoms in the ground level E_1, an energy exchange takes place. This results in the excitation of Neon atoms to the levels E_4 and E6and de excitation of Helium atoms to the ground level (F_1). Because of long life times of the atoms in levels F_2 and F_3, this process of energy transfer has a high probability. Thus the discharge through the gas mixture continuously populates the neon atoms in the excited energy levels E_4 and E_6. This helps to create a state of population inversion between the levels $(E_4 and E_6)$ to the lower energy level $(E_3 and E_5)$. The various transitions
$E6 \rightarrow E5, E4 \rightarrow E3, E6 \rightarrow E3$ leads to the emission of wave lengths $3.39mm, 1.15um, 6328A^\circ$. Specific frequency selection may be obtained by employing mirrors.
The excited Neon atoms drop down from the level E_3 to the E_2 by spontaneously emitting a photon around wavelength $6000A^\circ$. The pressures of the two gases in the mixture are so chosen that there is an effective transfer of energy from the Helium to the Neon atoms. Since the level E_2 is a meta stable state, there is a finite probability of the excitation of Neon, atoms from E_2 to E_3 leading to population inversion, when a narrow tube is used, the neon atoms in the level E_2 collide with the walls of the tube and get excited to the level E_1. The transition from E_5 to E_3 may be non radioactive. The typical power outputs of He-Ne laser lie between 1 and 50 mw of continuous wave for inputs of 5-10W.



Helium-Neon gas laser



5Q) Enlist the importance of lasers in various fields like industry, medicine, science, etc., by giving their applications.

> **Industrial Applications**:
> → Lasers are used in metal cutting, welding, surface treatment and hole drilling. Using lasers cutting can be obtained to any desired shape and the curved surface is very smooth.
> → Welding has been carried by using laser beam. Dissimilar metals can be welded and micro welding is done with great case.
> → Lasers beam is used in selective heat treatment for tempering the desired parts in automobile industry.
> → Lasers are widely used in electronic industry in trimming the components of ICs

> **Medical Applications**:
> → Precision surgery (No touch, Heal quickly, Less painful than ordinary surgery)
> → Cosmetic surgery
> → Eye surgery and refracting
> → Soft tissue surgery
> → Dental surgery

> **Scientific Research**:
> → Raman spectroscopy
> → Laser induced breakdown spectroscopy

> → LIDAR (Light Detecting And Ranging)
> → Space applications (Cassini - Huygens)

6Q) Discuss in detail the phenomenon's of spontaneous emission and stimulated emission

> If an atom is in an excited state, it may spontaneously decay into a lower energy level after some time, releasing energy in the form of a photon, which is emitted in a random direction. This process is called spontaneous emission. emission takes place without interaction with other photons, and the direction and phase are random.
> Stimulated emission takes place when the excited electron interacts with another photon. Both the direction and phase are "copied" from the other photon when stimulated emission takes place, and it is the most important phenomenon for creating a highly directional and highly coherent light source

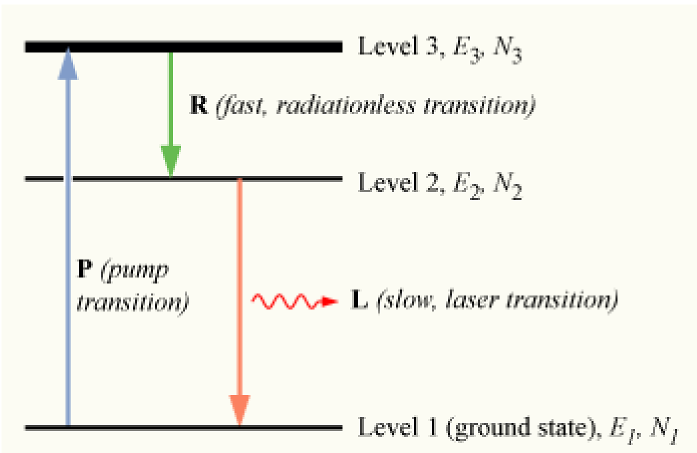
7Q) What do you mean by population inversion? Explain it using three energy level diagram. Also discuss why population inversion is essential for laser action

> Population inversion
> Usually in a system the number of atoms (N_1) present in the ground state (E_1) is larger than the number of atoms (N_3) present in the higher energy state (E_3). The process of making $N_3 > N_1$ called population inversion. Here (N_2) and (E_2) represent meta stable state.
> Conditions for population inversion are:
> a) The system should posses at least a pair of energy levels $(E_2 > E_1)$, separated by an energy of equal to the energy of a

photon $(h\nu)$.
b) There should be a continuous supply of energy to the system such that the atoms must be raised continuously to the excited state.

Population inversion can be achieved by a number of ways. Some of them are:
(i) optical pumping
(ii) electrical discharge
(iii) inelastic collision of atoms
(iv) chemical reaction
(v) direct conversion

Population inversion is essential as atoms prefer to stay at stable states or stable energy level and with the help of population inversion we can excite atoms to higher energy level and because of neutrons or protons it creates extra energy in the nucleus and causes the atom to become unbalanced or unstable in energy the atoms will be unstable and release the energy gained in the form of photons.



8Q) Illustrate the purpose of an active medium and optical resonator in a laser system

> Active Medium:
> The active medium (is the source of optical gain within a laser) determines the possible wavelengths that can be emitted from the laser. These wavelengths are determined by the specific transitions between the laser energy levels in this material.
> For HeNe laser, Ne acts as an active medium and in Ruby laser, the Ruby rod acts as an active medium.

> Optical Resonator:
> An optical resonator is needed to build up the light energy in the beam. The resonator is formed by placing a pair of silvered mirrors facing each other so that light emitted along the line between the mirrors is reflected back and forth, where one mirror is partially coated (to allow the laser to pass through) and the other mirror is fully coated.

9Q) How light amplification is achieved in a laser system

> After completion of lifetime of electrons in the Meta stable state, they fall back to the lower energy state
> or ground state by releasing energy in the form of photons. This process of emission of photons is called
> spontaneous emission.
> When this emitted photon interacts with the electron in the Meta stable state, it forces that electron to fall back to the ground state. As a result, two photons are emitted. This process of emission of photons is called stimulated emission.
> When these photons again interacted with the electrons in the

> Meta stable state, they force two Metastable state electrons to fall back to the ground state. As a result, four photons are emitted. Likewise, a large number of photons are emitted.
> As a result, millions of photons are emitted by using small number of photons

> Amplification of light is achieved by lasing action
> Phenomenon for Lasing Action:
> → Active material or medium
> → Population Inversion
> → Pumping
> → Metastable state
> → Optical Resonator

10Q) Explain the pumping process involved in laser emission. Also discuss in detail different pumping mechanisms.

> Laser pumping is the act of energy transfer from an external source into the gain medium of a laser. The energy is absorbed in the medium, producing excited states in its atoms, and population inversion is been achieved.
> Population inversion can be achieved by a number of ways.
> Some of them are:
> (i) optical pumping
> (ii) electrical discharge
> (iii) inelastic collision of atoms
> (iv) chemical reaction
> (v) direct conversion

11Q) Describe an optical fiber? Explore its construction and principle with a neat diagram

Introduction

1. An optical fiber (or fiber) is a glass or plastic fiber that carries light along its length.
2. Optical fibers are widely used in fiber-optic communications, which permits transmission over long distances and at higher band widths (data rates) than other forms of communications.
3. Specially designed fibers are used for a variety of other applications, including sensors and fiber lasers. Fiber optics, though used extensively in the modern world, is a fairly simple and old technology.

Construction of Optical Fiber

Optical fiber is a cylinder of transparent dielectric medium and designed to guide visible and infrared light over long distances. Optical fibers work on the principle of total internal reflection. Optical fiber is very thin and flexible medium having a cylindrical shape consisting of three sections:

1) The core material
2) The cladding material
3) The outer jacket

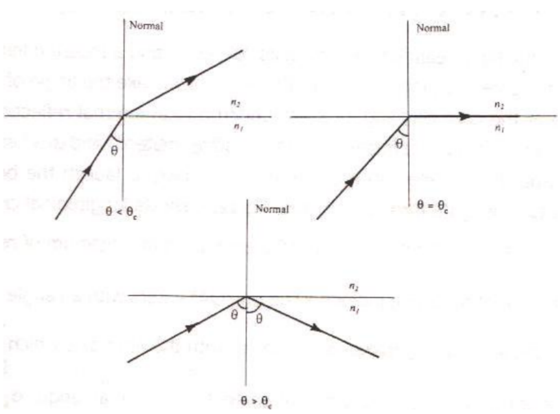
The structure of an optical is shown in figure. The fiber has a core surrounded by a cladding material whose reflective index is slightly less than that of the core material to satisfy the condition for total internal reflection. To protect the fiber material and also to give mechanical support there is a protective cover called outer jacket. In order to avoid damages there will be some cushion between cladding protective cover.

Principle of Optical Fiber:

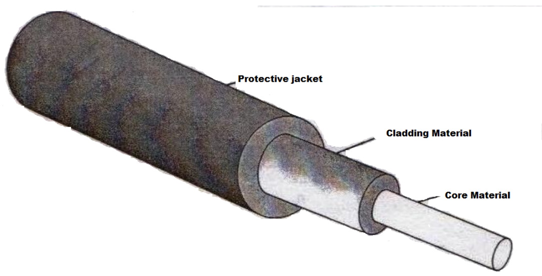
When a ray of light passes from an optically denser medium into an optically rarer medium, the refracted ray bends away from the

> normal.
> When the angle of incidence is increased angle of refraction also increases and a stage is reached when the refracted ray just grazes the surface of separation of core and cladding. At this position the angle of refraction is 90°. This angle of incidence in the denser medium is called the critical angle (θ_c) of the denser medium with respect to the rarer medium.
> If the angle of incidence is further increased then light is totally reflected. This is called total internal reflection.

> According to the law of refraction:
> $\theta_c = sin^{-1}(\frac{n2}{n1})$
> here n_1 and n_2 are the refractive index of the respective medium.

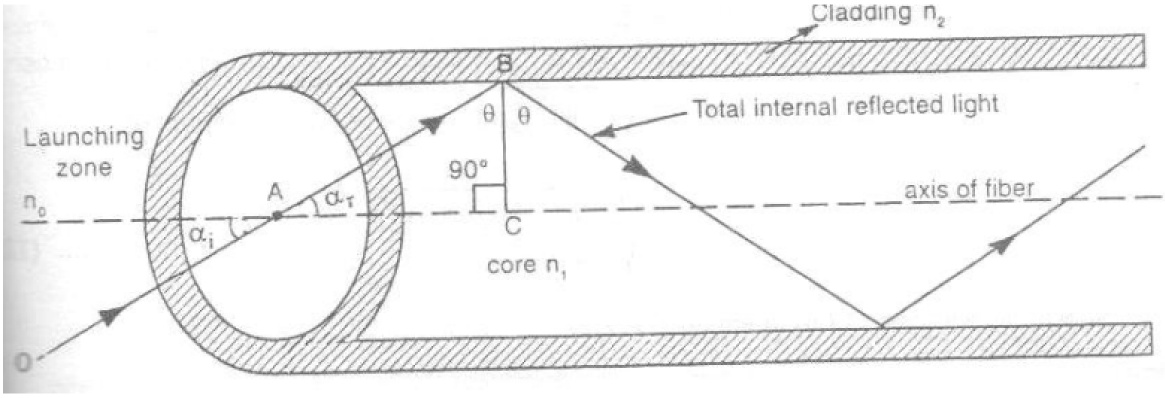


Total internal reflection.



12Q) Derive an expression for angle of acceptance of an optical fiber in terms of refractive indices of core and cladding

> Acceptance angle (θ): It is the maximum angle made by the light ray with the fiber axis, so that light can propagate through the fiber after total internal reflection.



Expression:
Let the refractive index of the core be n_1 and n_2. Here $n_1 > n_2$. The light ray reflects an angle and strikes the core cladding interface at angle θ. If the angle θ is greater than the critical angle θ_c, the light ray undergoes total internal reflection.

According to Snell's law:
$n_0\, sin\alpha_i = n1 sin\alpha_r \;\; \rightarrow (1)$

From the right angle triangle ABC
$\alpha_r + \theta = 90^\circ$
$\alpha_r = 90^\circ - \theta \qquad\qquad \rightarrow (2)$

Substituting (1) and (2)
$n_0\, sin\alpha_i = n_1\, sin(90^\circ - \theta) = n_1\, cos\theta$
$sin\alpha_i = (\frac{n_1}{n_0})cos\theta \qquad \rightarrow (3)$

When $\theta = \theta_c$, $\alpha_i = \alpha_m$ = maximum α value
$sin\alpha_m = (\frac{n_1}{n_0})cos\theta_c \qquad \rightarrow (4)$

From equation $\theta c = sin^{-1}(\frac{n_2}{n_1})$ and $sin\theta_c = (\frac{n2}{n1})$
$cos\theta_c = \sqrt{(1 - sin^2\theta_c)} = \sqrt{1 - (\frac{n_2}{n_1})^2} = \frac{\sqrt{n_1^2 - n_2^2}}{n_0} \qquad \rightarrow (5)$

Substitute (4) and (5)

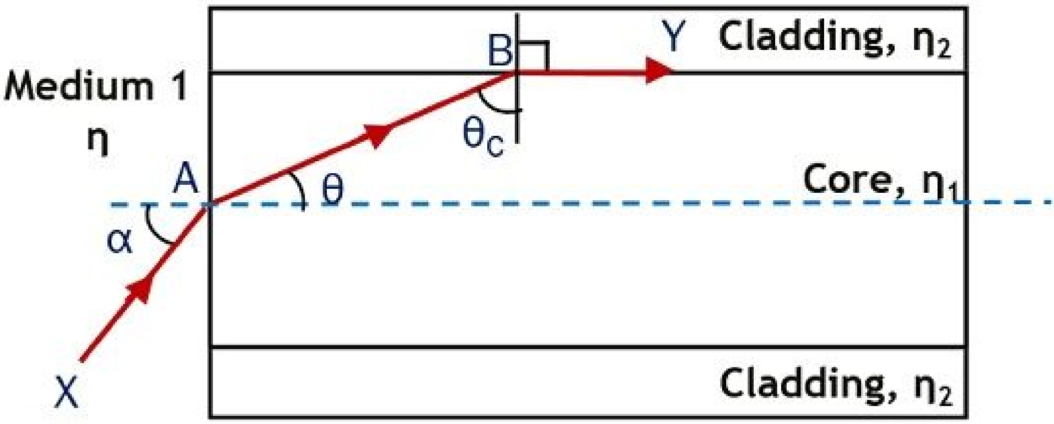
$$sin\alpha_m = (\frac{n_1}{n_0})\frac{\sqrt{n_1^2 - n_2^2}}{n_1} = \frac{\sqrt{n_1^2 - n_2^2}}{n_0} \qquad \rightarrow (6)$$

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

$$sin\alpha_m = \sqrt{n_1^2 - n_2^2} \quad \rightarrow (7)$$

This maximum angle is called the acceptance angle or the acceptance cone half-angle of the fiber.

13Q) What is a Numerical aperture? Determine an expression for numerical aperture of an optical fiber.



Ray propagation through Optical Fiber

Let n be refractive index of medium

let n_1 be refractive index of Core

let n_2 be refractive index of Cladding

Lets apply Snell's law for medium-core;

$$n \sin\alpha = n_1 \sin\theta \qquad \text{———} \; eq^n 1$$

From the above figure;

$\theta = \frac{\pi}{2} - \theta_c$ ———- $eq^n 2$

Substituting $eq^n 2$ in $eq^n 1$

$n \sin\alpha = n_1 \sin(\frac{\pi}{2} - \theta_c)$

$n \sin\alpha = n_1 \cos\theta_c$

$\sin\alpha = \frac{n_1}{n} cos\theta_c$ ——— $eq^n 3$

We know that;

$\cos\theta = \sqrt{1 - \sin^2\theta_c}$ ———- $eq^n 4$

Applying Snell's law at core-cladding interface, we get;

$n_1 \sin\theta_c = n_2 \sin 90^\circ$ ———— $eq^n 5$

$n_1 \sin\theta_c = n_2$

$\sin\theta_c = \frac{n_2}{n_1}$ ——— $eq^n 6$

Substituting $eq^n 6$ in $eq^n 4$

$\cos\theta_c = \sqrt{1 - [\frac{n_2}{n_1}]^2}$ ———- $eq^n 7$

Substituting $eq^n 7$ in $eq^n 3$, we get;

$\sin\alpha = \frac{n_1}{n}\sqrt{1 - [\frac{n_2}{n_1}]^2}$

$\sin\alpha = \sqrt{\frac{n_1^2 - n_2^2}{n}}$

We know that refractive index of air is 1. So lets consider the

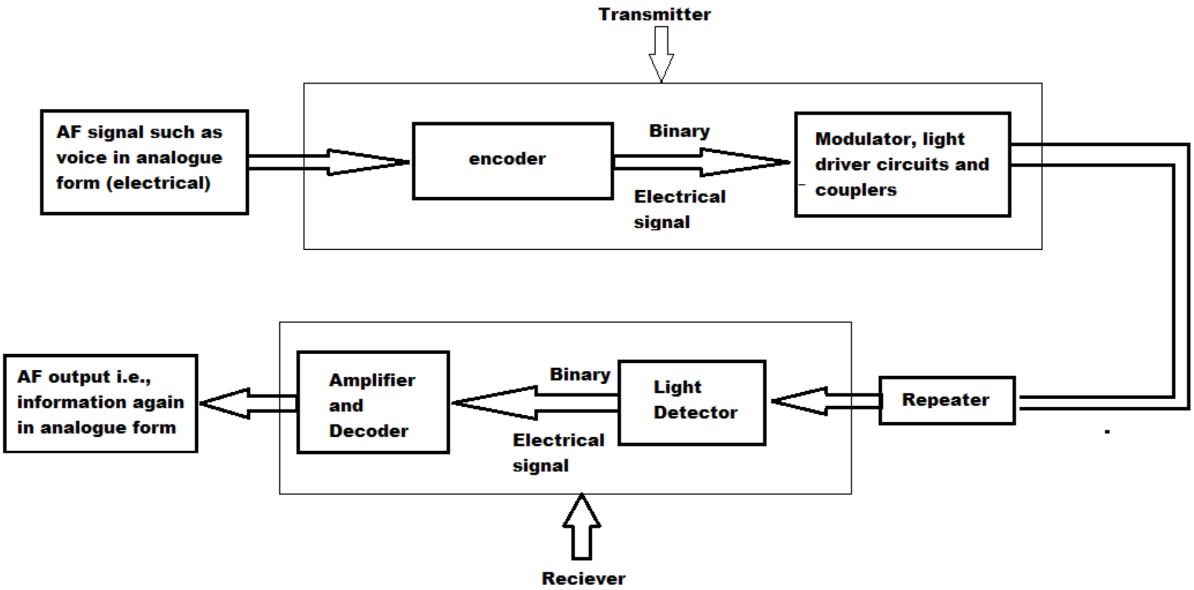
> refractive index of the medium "n" be 1.
>
> So;
>
> $\sin\alpha = \sqrt{n_1^2 - n_2^2}$
>
> $NA = \sqrt{n_1^2 - n_2^2}$
>
> Therefore Numerical Aperture is: $\sqrt{n_1^2 - n_2^2}$

14Q) Compare different types of optical fibers based on the number of modes propagation through the core medium of an optical fiber.

Difference between single mode fibers and multi mode fibers:

Single mode fiber	Multimode fiber
In single mode fiber there is only one path for ray propagation	In multimode fiber, large number of paths is available for light ray propagation.
A single mode step index fiber has less core diameter (< 10 μm) and the difference between the reflective indices of core and cladding is very small.	Multi mode fibers, large number of paths are available for light ray propagation.
In single mode fibers, there is no dispersion.	There is signal distortion and dispersion takes place in multimode fibers.
The band width is about 50 MHz for multimode step index fiber where as it is more than 1000 MHz km in case of single mode step index fiber.	The band width of the fiber lies in between 200 MHz km to 600 MHz km even though theoretically it has an infinite bandwidth.
NA of multimode step index fiber is more where as in single mode step index fibers, it is very less.	NA of graded index fibers is less.
Launching of light into single mode fibers is difficult.	Launching of light into multimode fibers is easy.
Fabrication cost is very high.	Fabrication cost is less

15Q) Draw the block diagram of fiber optic communication system and explain the functions of each block in the system.



Fiber optics essentially deals of with communication(including voice signals, video signals or digital data) by transmission of light through optical fibers. Optical fiber communication system essentially consists of three parts:

(a)transmitter(b) optical fiber and (c) receiver.

The transmitter includes modulator, encoder, light source, drive circuits and couplers. The receiver includes amplifier and decoder, binary electrical signal and light decoder.

1. Encoder:

It is an electric circuit where in the information is encoded into binary sequences of zeros and one.

2. Transmitter:

An electric signal is applied to the optical transmitter. The optical transmitter consists of driver circuit and the light source.

Driver circuit drives the light source.

Light source converts electrical signal to optical signal.

3. Optical fiber:

The optical fiber acts as a wave guide and transmits the optical pulses towards the receiver, by the principle of total internal reflection.

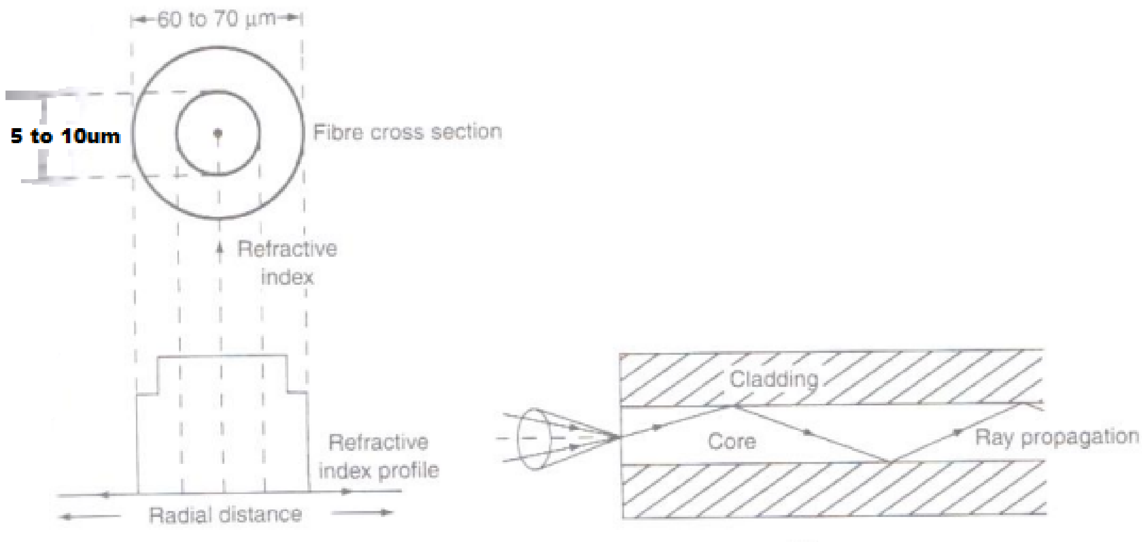
4. Receiver:

The light detector receives the optical pulses and converts them into electrical pulses. These signals are amplified by the amplifier.

5. Decoder:

The amplified signals are decoded by the decoder.

16Q) Describe the step index fiber with a neat diagram and explain the transmission of a signal through it.



step-index profile is a refractive index profile characterized by a uniform refractive index within the core and a sharp decrease in refractive index at the core-cladding interface so that the cladding is of a lower refractive index. The step-index profile corresponds to a power-law index profile with the profile parameter approaching infinity. The step-index profile is used in most single-mode fibers and some multimode fibers.

A step-index fiber is characterized by the core and cladding refractive indices n_1 and n_2 and the core and cladding radii a and b.

<u>Transmission of signal in step index fiber</u>: Generally the signal is transmitted through the fiber in digital form i.e. in the form of 1's and 0's. The propagation of pulses through the multimode fiber. The pulse which travels along path 1(straight) will reach first at the other end of fiber. Next the pulse that travels along with path 2(zig-zag) reaches the other end. Hence, the pulsed signal received at the other end is broadened. This is known as intermodal dispersion. This imposes limitation on the separation between pulses and reduces the transmission rate and capacity. To overcome this problem, graded index fibers are used.

17Q) Illustrate the advantages of optical fibers in communication system over ordinary cable communication.

Advantages of optical fibers in communication system over ordinary cable communication is as follows:
→ Fiber optic cables transmit data at much higher speed than copper wires. This is because the speed of light is greater than the speed of electrons.

→ Fiber optic cables have a much larger bandwidth of over 60 Tbps in comparison to 10 Gbps bandwidth of copper wires.

→ Fiber optic cables have very low attenuation. Repeaters need to be added only after every 50 km as compared to 5 km in copper wires.

→ Fiber optic cables are not affected by electromagnetic interferences and power fluctuations. They are minimally affected by power failures.

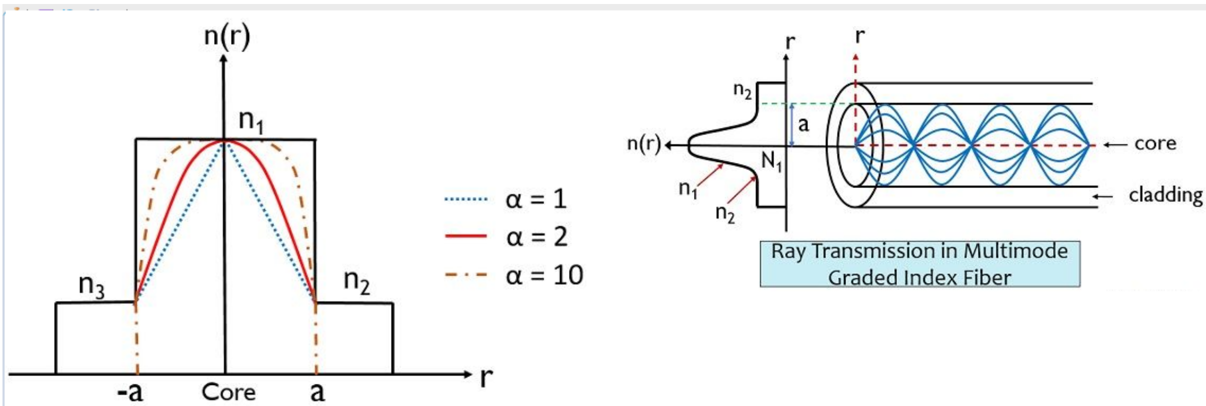
→ Fiber optic cables are much more secured since they cannot be tapped easily.

→ As fiber cables are made up of glass, they very less affected by the corrosive chemicals. Hence they are much suited to harsh factory conditions in comparison to copper wires.

→ Fiber cables are thin and lightweight. A fiber cable weighs around 4 lbs/1000 ft as compared to 39 lbs/1000 ft weight of copper cable.

→ The life cycle of fiber cables is 30-50 years, which is much higher than copper cables.

18Q) Discuss in detail graded index optical fiber with a neat figure and explain the transmission of signal through it.



Graded index is an optical fiber whose core has a refractive index that decreases with increasing radial distance from the optical axis of the fiber.

> Because parts of the core closer to the fiber axis have a higher refractive index than the parts near the cladding, light rays follow sinusoidal paths down the fiber. The most common refractive index profile for a graded-index fiber is very nearly parabolic. The parabolic profile results in continual refocusing of the rays in the core, and minimizes modal dispersion.
> Multi-mode optical fiber can be built with either graded index or step index. The advantage of the multi-mode graded index compared to the multi-mode step index is the considerable decrease in modal dispersion. Modal dispersion can be further decreased by selecting a smaller core size (less than 5-10μm) and forming a single mode step index fiber.
> **Transmission of signal graded index fiber**: In multimode graded index fiber, large number of paths is available for light ray propagation. To discuss about inter modal dispersion, we consider ray path 1 along the axis of fiber.

19Q) What do you mean by attenuation in optical fibers? Write a brief note on different losses in optical fibers

> In optical fibers, attenuation is the rate at which the signal light decreases in intensity. For this reason, glass fiber (which has a low attenuation) is used for long-distance fiber optic cables; plastic fiber has a higher attenuation and, hence, shorter range. There also exist optical attenuators that decrease the signal in a fiber optic cable intentionally.
>
> **Absorption loss**:
> Absorption loss is related to the material composition and fabrication process of fiber. Absorption loss results in dissipation

of some optical power as hear in the fiber cable. Although glass fibers are extremely pure, some impurities still remain as residue after purification. The amount of absorption by these impurities depends on their concentration and light wavelength.

Radiative losses:

Radiative losses also called bending losses, occur when the fiber is curved. There are two types of radiative losses: Micro bending losses. Macro bending losses.

Scattering loss:

Basically, scattering losses are caused by the interaction of light with density fluctuations within a fiber. Density changes are produced when optical fibers are manufactured.

Dispersion loss:

Dispersion is a measure of the temporal spreading that occurs when a light pulse propagates through an optical fiber. Dispersion is sometimes referred to as delay distortion in the sense that the propagation time delay causes the pulse to broaden.

20Q) Write a note on the applications of optical fibers in different fields.

Optical Fibers uses in Medical industry

Because of the extremely thin and flexible nature, it used in various instruments to view internal body parts by inserting into hollow spaces in the body. It is used as lasers during surgeries, endoscopy, microscopy and biomedical research.

Optical Fibers used in Communication

In the communication system, telecommunication has major uses of optical fiber cables for transmitting and receiving purposes. It is used in various networking fields and even increases the speed and accuracy of the transmission data. Compared to copper wires, fiber optics cables are lighter, more flexible and carry more data.

Optical Fibers used in Defense Purpose

Fiber optics are used for data transmission in high-level data security fields of military and aerospace applications. These are used in wirings in aircraft, hydrophones for SONARs and Seismic applications.

Optical Fibers are used in Industries

These fibers are used for imaging in hard to reach places such as they are used for safety measures and lighting purposes in automobiles both in the interior and exterior. They transmit information in lightning speed and are used in airbags and traction control. They are also used for research and testing purposes in industries.

Optical Fibers used for Broadcasting

These cables are used to transmit high definition television signals which have greater bandwidth and
speed. Optical Fiber is cheaper compared to the same quantity of copper wires. Broadcasting companies
use optical fibers for wiring HDTV, CATV, video-on-demand and many applications.

Uses of Optical Fiber for Lightening and Decorations

By now, we got a fair idea of what is optical fiber and it also gives an attractive, economical and easy way
to illuminate the area and that is why it is widely used in decorations and Christmas trees.

Optical Fibers used in Mechanical Inspections

On-site inspection engineers use optical fibers to detect damages and faults which are at hard to reach
places. Even plumbers use optical fibers for inspection of pipes.

PART - C

1Q) Find the relative population of the two states in a ruby laser that produces a light beam of wavelength $6943A^\circ$ at $300K$.

> Given;
> $\lambda = 6943A^\circ$,
> $T = 300K$,
> Ratio of population of two states: normal or Boltzmann distribution:
> $(\frac{N_2}{N_1}) = e^{-\Delta E/kT}$
>
> Here,
> $\Delta E = \frac{hc}{\lambda}$
>
> and we know that,
> $h = 6.63 \times 10^{-34} J =$ plank's constant,
> $c = 3 \times 10^8 m/s =$ speed of light
> $k = 1.38 \times 10^{-23} m^2 kg/s^2 K^1 =$ Boltzmann's Constant
>
> $$\Delta E = \frac{6.63\times10^{-34}\times3\times10^8}{6943\times10^{-10}} = \frac{1.989\times10^{-25}}{6943\times10^{-10}} = 2.8647 \times 10^{-19}$$
>
> $$(\frac{N_2}{N_1}) = e^{\frac{-\Delta E}{kT}} = e^{\frac{-2.8647\times10^{-19}}{1.38\times10^{-23}\times300}} = e^{-69.1956} = 8.88 \times 10^{-31}$$
>
> Therefore the relative population of the two states is 8.88×10^{-31}

2Q) For a He-Ne laser at 1 m and 2 m distances from the laser the output beam spot diameters are 4 mm and 6 mm respectively. Calculate the divergence.

> Given;
> $d_1 = 4mm = 4 \times 10^{-3}m$
> $d_2 = 6mm = 6 \times 10^{-3}m$
> $l_1 = 1m$
> $l_2 = 2m$
>
> Beam divergence is:
> $\theta = \frac{d_2 - d_1}{(l_2 - l_1)}$
>
> So,$\theta = \frac{(6-4)\times 10^{-3}}{(2-1)} = \frac{2\times 10^{-3}}{1} = 2 \times 10^{-3} radians$
>
> Therefore the divergence is of 2×10^{-3} radians.

3Q) A He-Ne laser emits light at a wavelength of $632.8nm$ and has an output power of $2.3mW$. How many photons are emitted in each minute by this laser when operating?

> Given;$\lambda = 632.8nm = 632.8 \times 10^{-9}m$,
> $P = 2.3mW = 2.3 \times 10^{-3}W$,
>
> To find the number of photons emitted in each minute;
> Since;
> $P = n \times E$, since n is no. of photons and E is the energy of the photon
>
> we know that;

$E = \frac{hc}{\lambda}$
and;
$h = 6.63 \times 10^{-34} J =$ plank's constant,
$c = 3 \times 10^{8} m/s =$ speed of light,
Therefore;
$E = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{632.8 \times 10^{-9}} = 3.14 \times 10^{-19}$

Now (we know P and E values);
$P = n \times E$

$2.3 \times 10^{-3} = n \times 3.14 \times 10^{-19}$

$n = \frac{2.3 \times 10^{-3}}{3.14 \times 10^{-19}} = 7.324 \times 10^{15}$

Lets assume N is equal to photons per minute;
$N = n \times 60$

$N = 7.324 \times 10^{15} \times 60 = 439.44 \times 10^{15}$

Therefore 439.44×10^{15} number of photons are emitted for each minute by the laser while operating.

4Q) Solve the value of the wavelength of emitted radiation from a semiconductor diode laser, which has a bandgap of 1.44eV.

Given;
$E_g = 1.44eV = 1.44 \times 1.602 \times 10^{-19} = 2.306 \times 10^{-19} J$

To find wave length (λ);

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

here;
$h = 6.63 \times 10^{-34} J =$ plank's constant,
$c = 3 \times 10^8 m/s =$ speed of light,

So,
$2.306 \times 10^{-19} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{\lambda} => \lambda = \frac{6.36 \times 10^{-34} \times 3 \times 10^8}{2.306 \times 10^{-19}} = 8.6253 \times 10^{-7}$

Therefore wavelength is $8.6253 \times 10^{-7} m = 862 nm$

5Q) A semiconductor diode laser has a wavelength of 1.55μm. Estimate its band gap in eV.

Given;
$\lambda = 1.55 um = 1.55 \times 10^{-6} m$

To find E_g band gap;
here;
$h = 6.63 \times 10^{-34} J =$ plank's constant,
$c = 3 \times 10^8 m/s =$ speed of light,

So,
$E_g = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{1.55 \times 10^{-6}} = 1.283 \times 10^{-19} J$

$E_g = 0.801 eV$

Therefore the band gap in eV is $E_g = 0.801 eV$

6Q) A step-index fiber has a numerical aperture of 0.16 and core refractive index of 1.45. Estimate the acceptance angle of the fiber and refractive index of the cladding.

> Given;
>
> N.A. $= 0.16, n_1 = 1.45$
>
> For Refractive index of the cladding:
>
> $N.A. = \sqrt{(n_1)^2 - (n_2)^2}$
>
> $0.16 = \sqrt{(1.45)^2 - (n_2)^2}$
>
> $(n_2)^2 = (1.45)^2 - (0.16)^2$
>
> $(n_2)^2 = 2.1025 - 0.0256$
>
> $n_2 = \sqrt{2.0769} \Rightarrow n_2 = 1.4411$
>
> **Therefore the refractive index of the cladding** is 1.4411
>
> For Acceptance angle:
>
> $\sin\theta_a = \frac{N.A.}{n_0}$
>
> let refractive index of the air be equal to $1 = n_0$
>
> $\sin\theta_a = \frac{0.16}{1}$
>
> $\theta_a = \sin^{-1}(0.16)$
>
> $\theta_a = 9^\circ 12'$

> **Therefore acceptance angle** (θ_a) is : $9^\circ 12'$

7Q) The refractive indices of core and cladding materials of a step index fiber are 1.48 and 1.45 respectively. Simulate i) Numerical aperture ii) Acceptance angle.

> Given;
> Refractive index of core $= n_1 = 1.48$
> Refractive index of the cladding $= n_2 = 1.45$
>
> (i)Find Numerical Aperture (N.A.):
> $N.A. = \sqrt{(n_1)^2 - (n_2)^2} = \sqrt{(1.48)^2 - (1.45)^2} = \sqrt{2.1904 - 2.1025} = \sqrt{0.0879} = 0.2964$
>
> (ii)Acceptance angle (i_{max}):
> $i_{max} = \sin^{-1}(N.A.) = \sin^{-1}(0.2964) = 17^\circ 14'$
>
> Therefore,
> Numerical aperture $= 0.2964$,
> Acceptance angle $= 17^\circ 14'$

8Q) An optical fiber has a numerical aperture of 0.2 and a cladding refractive index of 1.59. Solve the value of acceptance angle for the fiber in water which has a refractive index of 1.33.

> Given;
> Numerical Aperture, $N.A. = 0.2$,
> Refractive index of cladding, $n_2 = 1.59$,
> Refractive index of water, $n_0 = 1.33$

we know that;
$N.A. = \sqrt{(n_1)^2 - (n_2)^2} = 0.2$

And when in water; (since $n_0 = 1.33$)
$N.A. = \frac{\sqrt{(n_1)^2 - (n_2)^2}}{n_0} = \frac{0.2}{1.33} = 0.1504$

We also know that,
$N.A. = \sin(i_{max})$

$\sin(i_{max}) = 0.1504$

$i_{max} = \sin^{-1}(0.1504) = 8.65^\circ$

Therefore, the max acceptance angle 8.65°

9Q) Calculate the fractional index change for a given optical fiber if the refractive indices of the core and the cladding are 1.563 and 1.498 respectively

Given;
Refractive index of the core, $n_1 = 1.563$
Refractive index of the cladding, $n_2 = 1.498$

To find, fractional index change, $\Delta = ?$

$\Delta = \frac{n_1 - n_2}{n_1} = \frac{1.563 - 1.498}{1.563} = 0.0416$

Therefore the fractional index change for the given optical fiber is 0.0416.

10Q) When the mean optical power launched into an 8 Km length of fiber is 120 μW. The mean optical power at the fiber output is 3 μW. Find the overall signal attenuation and signal attenuation per Km.

> Given;
> Input power $= 120\mu W$
> output power $= 3\mu W$
> length of the optical fiber in km $= 8$
>
> To find Signal Attenuation: $dB = 10\log_{10}\frac{P_{Input}}{P_{Output}}$
>
> $dB = 10\log_{10}\frac{120\mu W}{3\mu W}$
>
> $dB = 10\log_{10} 40$
>
> $dB = 10\log_{10} 40 = 16.0dB$
>
> Signal Attenuation per km:
> $dB/km = 16.0/8 = 2.0dB/km$
>
> Single Attenuation : $16.0dB$
> Single Attenuation: $2.0dB/km$