# Engineering Physics
## (2024 Pattern)

## Theory Notes

Of

## Unit No. 1
## Fundamentals Photonics

## Ch. No. 1

# LASER

By

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# LASER & Optic Fibre

## CH - 1 - LASER

IMP

Q What is LASER?

Q What is the full form of LASER

→ The word LASER stands for 'Light Amplification by Stimulated Emission of Radiation'

IMP Q What is excited state?

→ An excited state of system (such as atom) is any quantum state of the system that has a higher energy than the groun state. It has life time around $10^{-8}$ sec.

IMP Q What is metastable state?

→ It an excited state which has life time more than $10^{-8}$ sec. i.e. $10^{-3}$ sec.

IMP Q State the three waves by which energy of atomic system can be changed.

→ 1] Absorption
2] Spontaneous Emission
3] Stimulated Emission

IMP

Q Explain the following terms:
1] Absorption
2] Spontaneous Emission
3] Stimulated Emission

→ 1] Absorption:-

In this process, the ground state electrons absorb energy which is equal to the energy difference between the two energy states

$(E_2-E_1)$, the electron jumps from ground state $(E_1)$ to the excited state or higher energy level $(E_2)$.

The electrons in the excited energy level are called excited electrons.

The light or photons energy applied to excite the electrons can be mathematically written as

$$E = h\nu = E_2 - E_1.$$

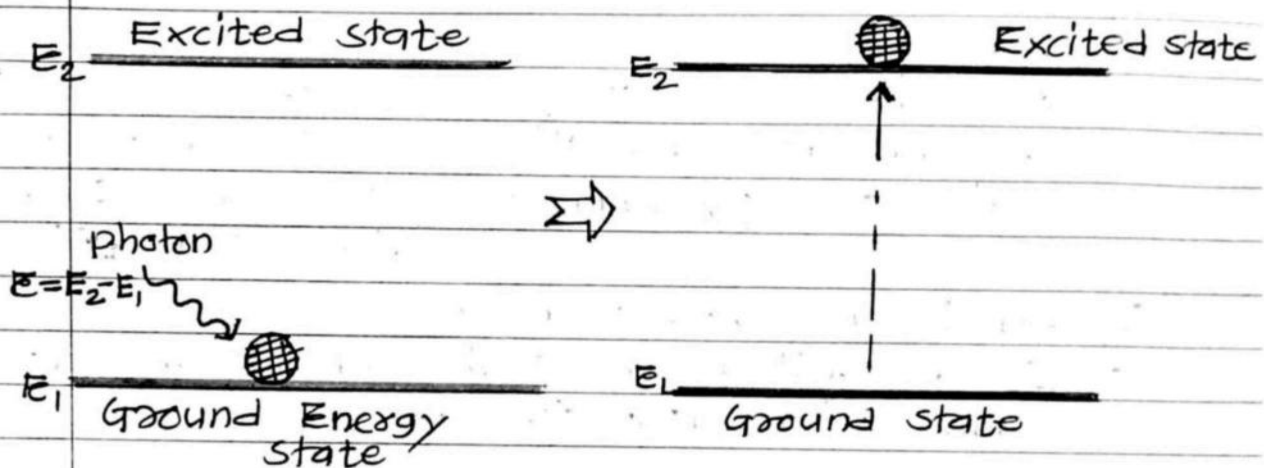



fig-ⓐ During absorption, (electron absorbing photon energy)

fig-ⓑ After absorption (electron jumped to excited state)

Fig- Absorption

2] Spontaneous Emission:-

This state comes after absorption.

The electron in excited state $(E_2)$ do not stay for a long period because the lifetime of electrons in excited state is very small, of the order of $10^{-8}$ sec. Hence, after completing the life time, they fall back to the ground state $(E_1)$ by releasing energy in the form of photons of energy $(E_2-E_1)$

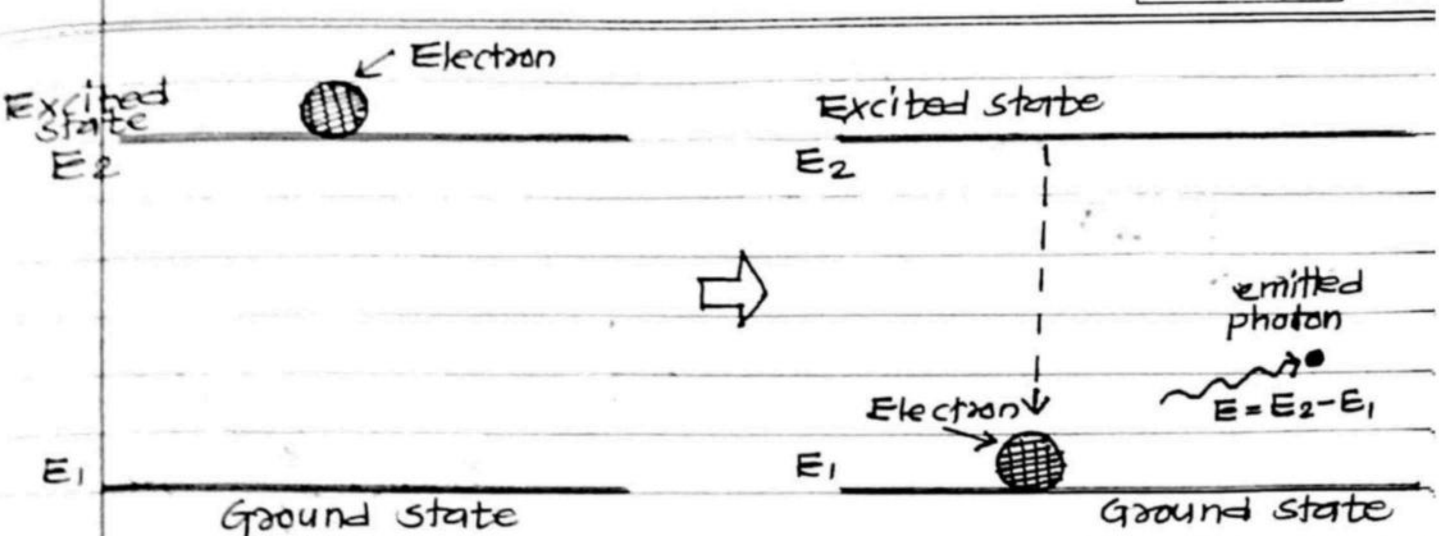


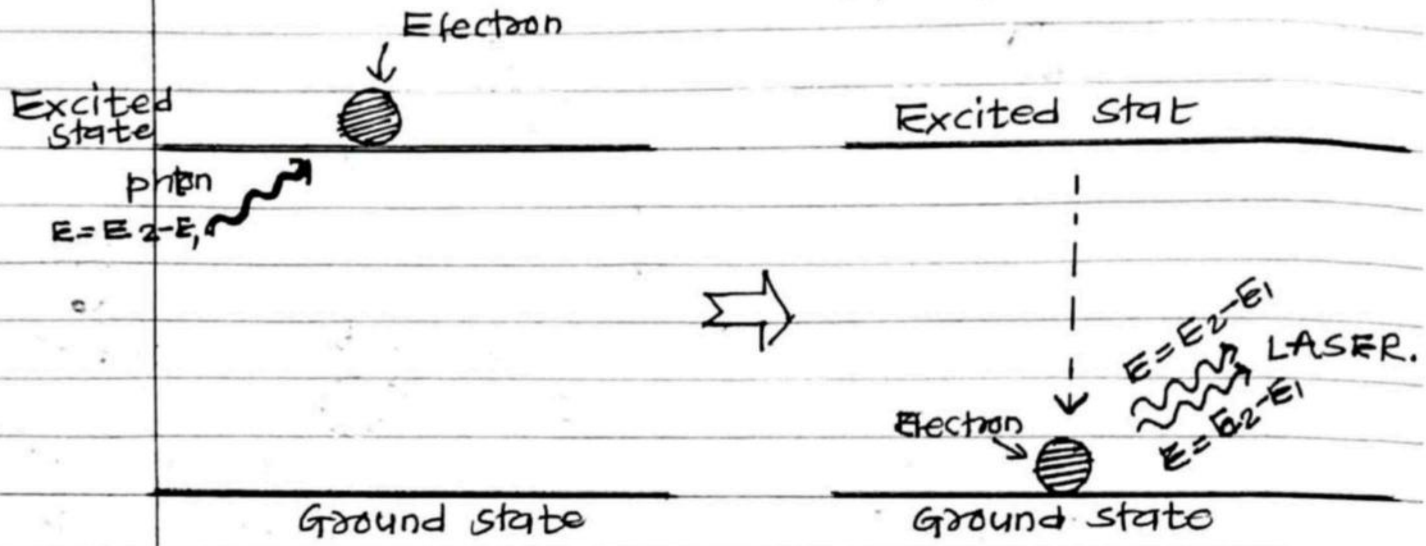

fig-(1) Electron in excited state before photon emission

fig-(2) Photon emission during transition

fig- Spontaneous emission

3] Stimulated Emission:-

- Stimulated emission plays important role in production of LASER.
- If a photon of energy $E_2 - E_1$ interacts with an atom in the energy state $E_2$ i.e. excited state, this photon forces the atom to undergo transition to the ground state $E_1$ giving rise to another photon of the same energy $E_2 - E_1$ in phase with each other.
- The emitted photons have same phase, same frequency, same wavelength and polarization. Hence the light produced by stimulated emission is coherent.




fig(a) photon incident on excited electron

fig-(b) During transition two photons are ~~was~~ released

Fig- Stimulated Emission

IMP) Properties of LASER

Q State the properties of LASER

→ Properties:

1] Extreme Brightness
2] Coherence
3] Monochromatic
4] Strong Unidirectionality

Q Explain any two properties of LASER.

⇒ 1) Extreme Brightness:-

- LASER light is muchmore brighter and intense than that from any other conventional source.
- This is due to the emitted and incident photons are perfectly in phase.
- Because of very high intensity of LASER beam, it can produce temperature of the order of $10^4$°C, at a focus point.
- Due to its narrow band width, laser beam can be focused on a very small area of $10^{-6}$ cm².

2] Coherence :-

- The light emerging from a LASER is coherent both in space and time.
- The existance of finite band width $\Delta\nu$ means that the different frequencies present in a LASER can get out of phase with each other.
- If two waves different by frequency $\Delta\nu$, the time required to get out of phase by Full cycle is $1/\Delta\nu$.
- This is called as 'coherence time' of a beam and is denoted by $\Delta\tau$

i.e. $$\Delta\tau = \frac{1}{\Delta\nu}$$

For LASER with $\Delta\nu = 1$ MHz has $\Delta\tau = 1\,\mu s$

3] Monochromaticity :-

- When LASER produces only one wavelength then it is fully monochromatic.
- This is impossible, in principle and practice.
- If $\Delta\lambda$ is the range of wavelengths included in LASER beam of wavelength $\lambda$, $\Delta\nu$ is the corresponding frequency.
- This frequency band $\Delta\nu$ is called the 'line width'.
- For white light consisting of all visible frequencies, then line width is $\sim 10^{14}$ Hz, while for good LASER it is about $10^{2}$ Hz.

4] Strong Unidirectionality :-

- A LASER has high degree of unidirectionality and can travel very large distance without deviation.
- For typical LASER, the divergence is about $10^{-3}$ radiance.
- This means that the LASER beam diverge by ~1mm

by ~ 1mm of every meter that it travels.

- The reason is that the active material is placed in a resonant cavity.
- The light is reflected back and forth in the cavity and light travelling parallel to the axis gets emitted as the LASER beam.

IMP

Q Explain the terms:
  1] Population Inversion
  2] Resonant cavity (optical Resonator) (optical cavity)

⟹ 1] Population Inversion:

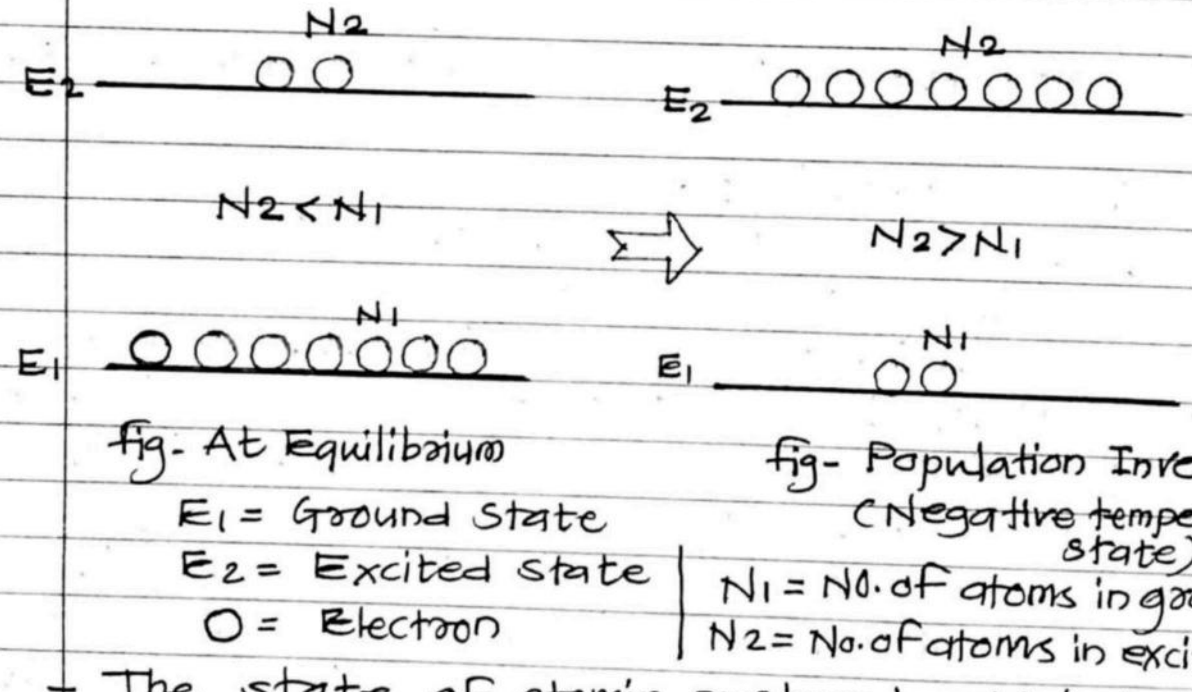



fig- At Equilibrium

fig- Population Inversion (Negative temperature state)

$E_1$ = Ground state
$E_2$ = Excited state
O = Electron

$N_1$ = No. of atoms in ground state
$N_2$ = No. of atoms in excited state

- The state of atomic system in which large percentage of atoms in an excited state than the ground state is called as '<u>population inversion</u>'. ← Defⁿ
- If a large number of atoms can be excited to upper energy levels, then probability of stimulated emission and hence light amplification becomes greater.

- Normally, a system of atoms is in temperature equilibrium and there are always more atoms in ground state than excited state.
- When this distribution is disturbed by pumping energy into the system, a population inversion will take place.

## 2] Resonant cavity (Optical Resonator) (optical cavity)

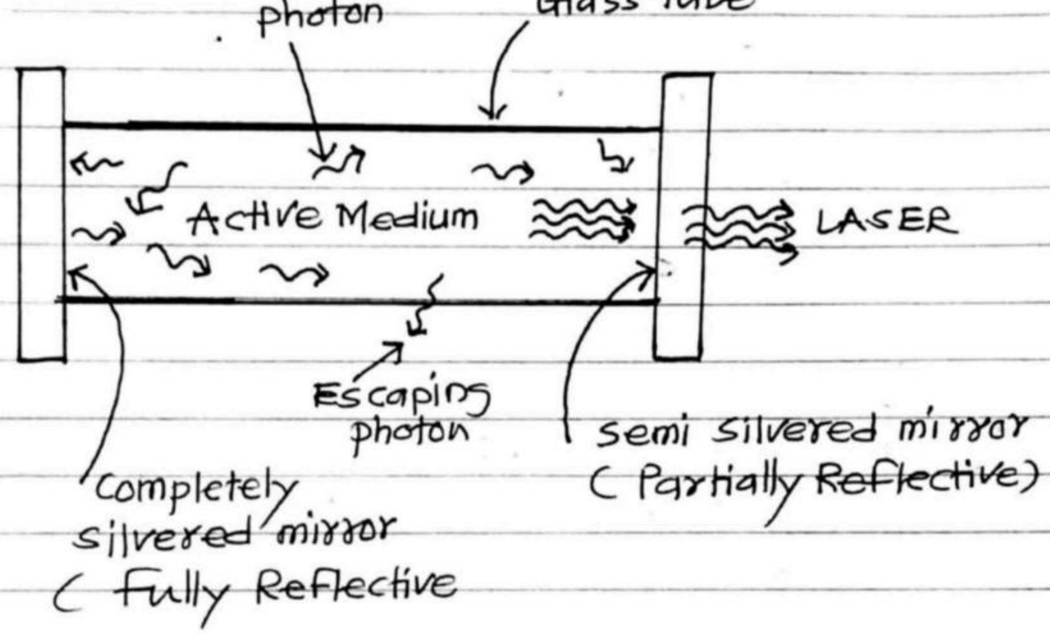
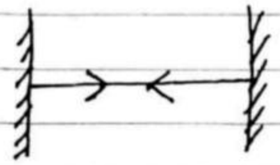



Fig - Resonant cavity

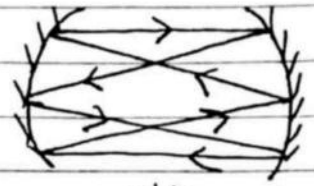
- In resonant cavity two mirrors are used which are facing each other.
- One of the mirrors of the resonant cavity is completely silvered and the other partially silvered.
- For the production of LASER, active medium is placed in resonant cavity for amplification perpose
- Because of resonant cavity LASER beam travels in straight line.
- Photon emitted by active medium performs several reflections and then emerges out when becomes

perpendicular to the surface of partially reflecting mirror.

- Here are some resonant cavity configurations



(a)



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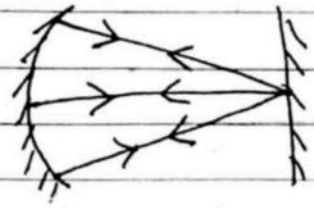


(c)

IMP

Q Explain the terms:
 1] Active medium (Active system)
 2] Pumping

→ 1] <u>Active medium (Active system)</u> :-

- The material that emits coherent radiations is called active medium.
- Also a system in which population inversion is achived is called an active medium.
- Active system or medium consist of a collection of atoms, molecules or ions and is able to amplify light waves.
- In LASER device active medium is placed between resonant cavity.
- Active medium is the source of optical gain within a LASER. The gain results from the stimulated emission.
- Example: In $CO_2$ LASER $CO_2$ is the active medium.

2] <u>Pumping</u> :-
- The method of raising atoms from lower energy levels to higher energy levels is called as 'pumping'.
- The pumping is used for achieving population inversion which is necessary for optical amplification to take place.
- There are different methods of pumping those are 1) Optical Pumping 2) Electrical Pumping 3] Thermal Pumping

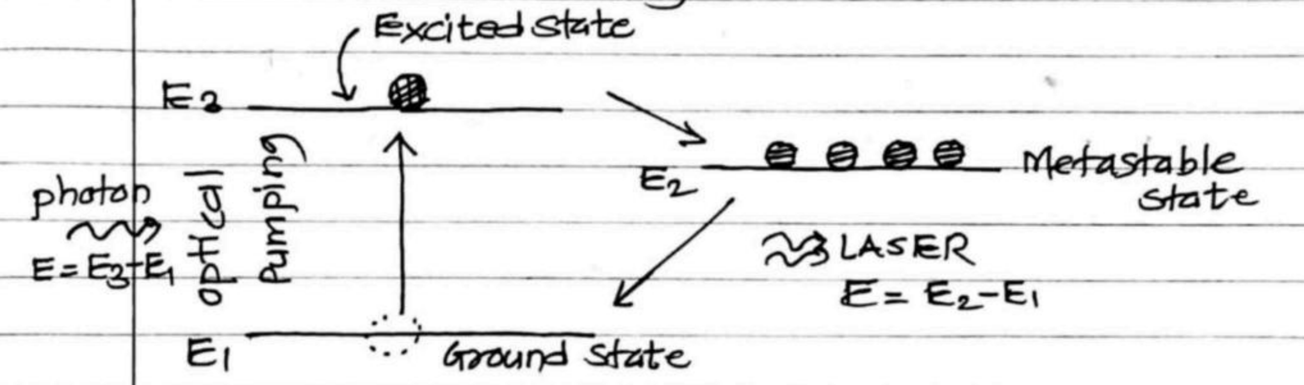
[IMP]

Q. State the types of pumping. Explain the any two of them.

⟹ Types of pumping:

1] Electrical Pumping
2] Optical pumping
3] Inelastic atom - atom collision

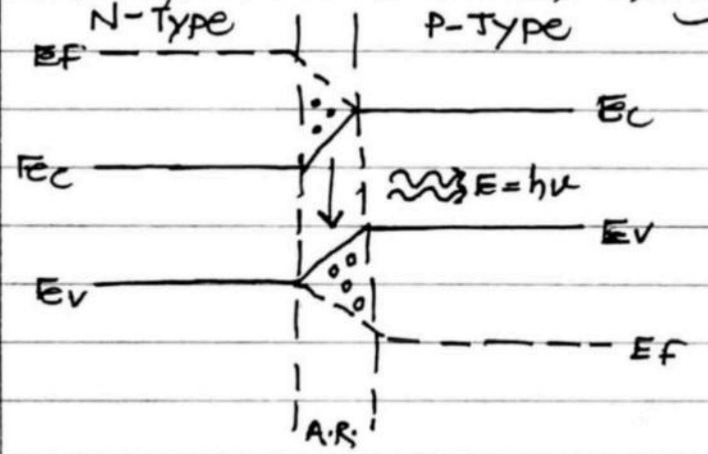
1] ~~Electrical~~ Optical Pumping:-




- In optical pumping, photons are used to excite the atoms in the medium.
- For this perpose, a discharge tube is used to excite atoms in ground state, similar to a light source in the laser medium.
- Optical pumping is suitable for any medium which is transparent to light.
- Example ⇒ Ruby LASER.

2] Electrical pumping:

- Electrical pumping is used for some medium which conducts electricity without affecting LASER activity.
- Electrical pumping is used in case of semiconductor LASER. In this case, atoms are not excited but the charge carriers (electron & holes) are excited and a state of population inversion is created in the junction region.
- Electrical pumping is also used in gas LASER
- Example of electrical pumping: Semiconductor LASER




o = hole
• = electron
AR = Active Region

EF = Fermi Energy level
Ec = Conduction Energy level
Ev = Valence energy level

IMP

# $CO_2$ LASER

Q Explain principle, construction and working of $CO_2$ LASER. — 6M

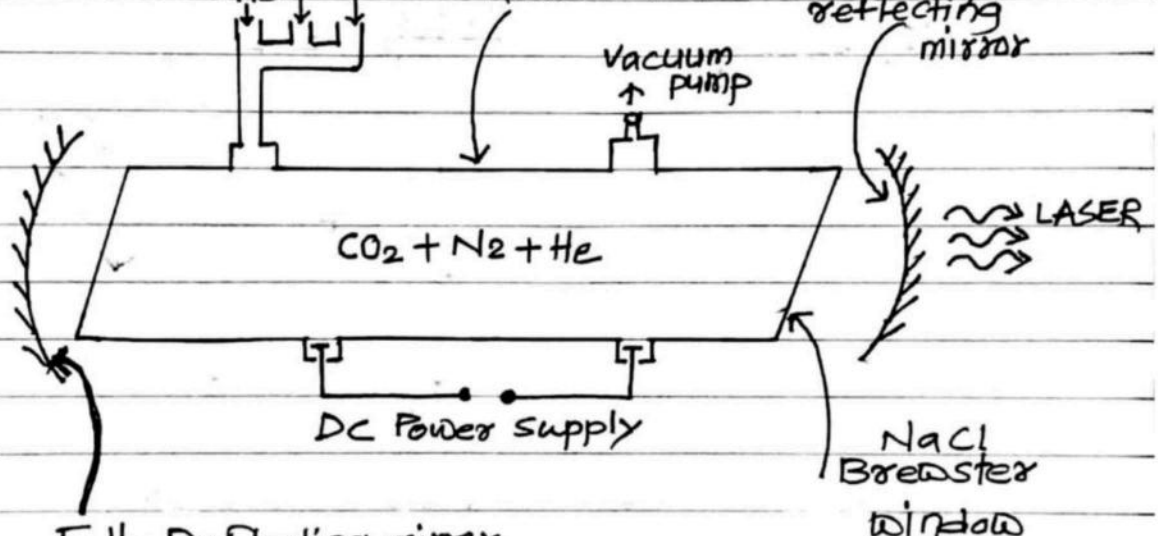
⟹ $CO_2$ LASER:

- $CO_2$ LASER was the first molecular gas LASER developed by Indian Born American scientist Prof. C.K.N. Pillai.
- It is a four level LASER system and it operates at 10.6 μm in the far IR region.
- It is a very efficient laser.

## 1) Principle

- In $CO_2$ LASER, the active medium is a mixture of $CO_2$, $N_2$ and He.
- The LASER transition takes place between the vibrational states of $CO_2$ molecules.

## 2] Construction




- It consists of a quartz tube 5 m long and 2.5 cm in the diameter.
- This discharge tube is filled with gaseous mixture of $CO_2$, Nitrogen and Helium with suitable partial pressures.
- The proportion of $CO_2$:$N_2$:He is 1:2:3.

- The pressures maintained are about:
  1. Pressure of Helium (He) = 7 Torr
  2. Pressure of Nitrogen ($N_2$) = 1.2 Torr
  3. Pressure of $CO_2$ = 0.33 Torr

- The terminals of the discharge tubes are connected to a D.C. Power Supply.

- The ends of the discharge tube are fitted with NaCl Brewster windows so that the LASER light generated will be polarized.

- Two concave mirrors, one is fully reflecting and other partially reflecting, form an optical resonator.

3] Working:

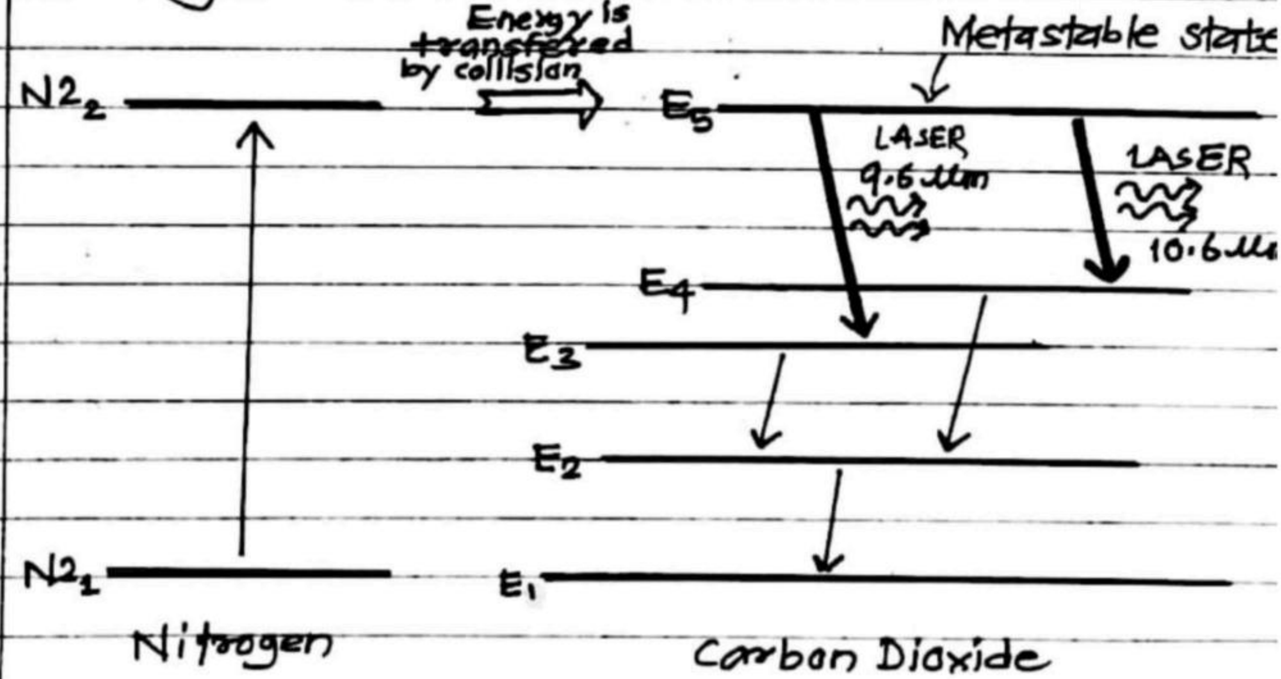



fig - Energy level diagram of $CO_2$ LASER

- The high voltage across the electrodes excites the gas molecules.
- The $N_2$ molecules in the gas are excited to higher levels and transfer energy to $CO_2$ molecules by

collisions as shown in above fig.

- The $CO_2$ molecules are excited to the metastable state $E_5$ where population inversion takes place.
- Transition from $E_5$ to $E_4$ gives rise to 10.6 μm wavelength LASER and the transition from $E_5$ to $E_3$ gives rise to 9.6 μm wavelength which are both in far infrared region. Wavelength of 10.6 μm is dominating.
- Helium (He) depopulates the lower energy levels in $CO_2$ which facilitates population inversion.
- The carbon dioxide LASER is high power LASER producing power as high as 10 KW. It also has very high efficiency of the order of about 40%.

IMP

## Heterojunction Semiconductor LASER

**Q** Explain principle, construction and working of Heterojunction semiconductor LASER. – 6M

⟹ **Principle:**

- Heterojunction semiconductor LASER consist of a P-N junction with the different materials on the both sides of the junction.
- When P-N Junction is forward biased, the electrons from N region and holes from P region recombine with each other at the junction.
- During recombination process light is released from certain specified direct band gap semiconductor

**Construction:**

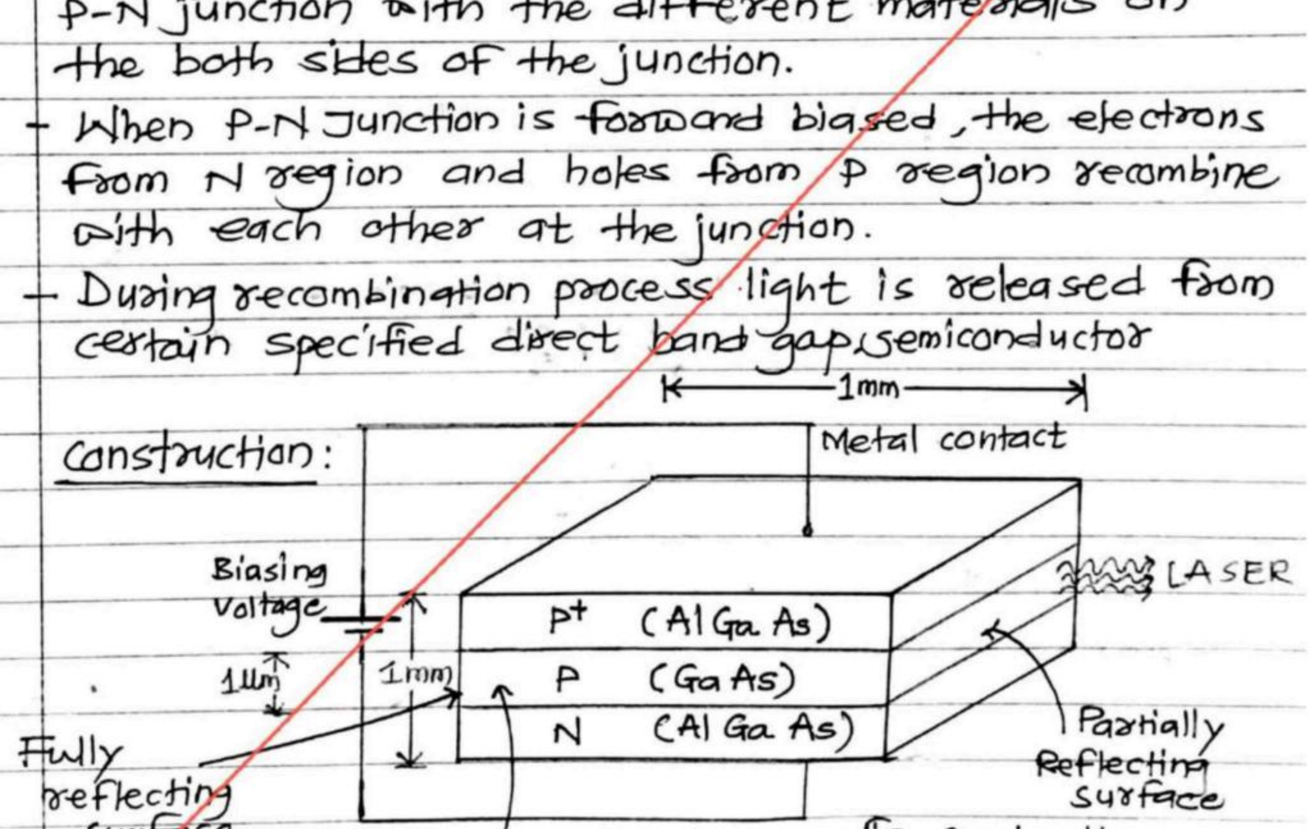



fig - Construction Diagram

- This LASER consist of three layers of semiconductor material as shown in fig.
- A low band gap material like <u>GaAs</u> ($\Delta E = 1.4$ eV) is sandwiched between two higher band gap layers like <u>Al Ga As</u> ($\Delta E = 2$ eV)
- Middle layer have high refractive index than outer layers.
- The typical dimensions of this LASER are 1mm in width, height and length.
- <u>Middle layer</u> has thickness about 1 µm. Which acts as <u>active region</u>.
- <u>Resonant Cavity</u> is formed by coating / polishing two opposite surfaces and remaining pair of surfaces is roughned to prevent lasing action in that direction
- Electrical contacts are provided to upper and lower layer for electrical pumping (i.e. forward bias)

<u>Working</u>:

• - Electron
o - Hole

- 

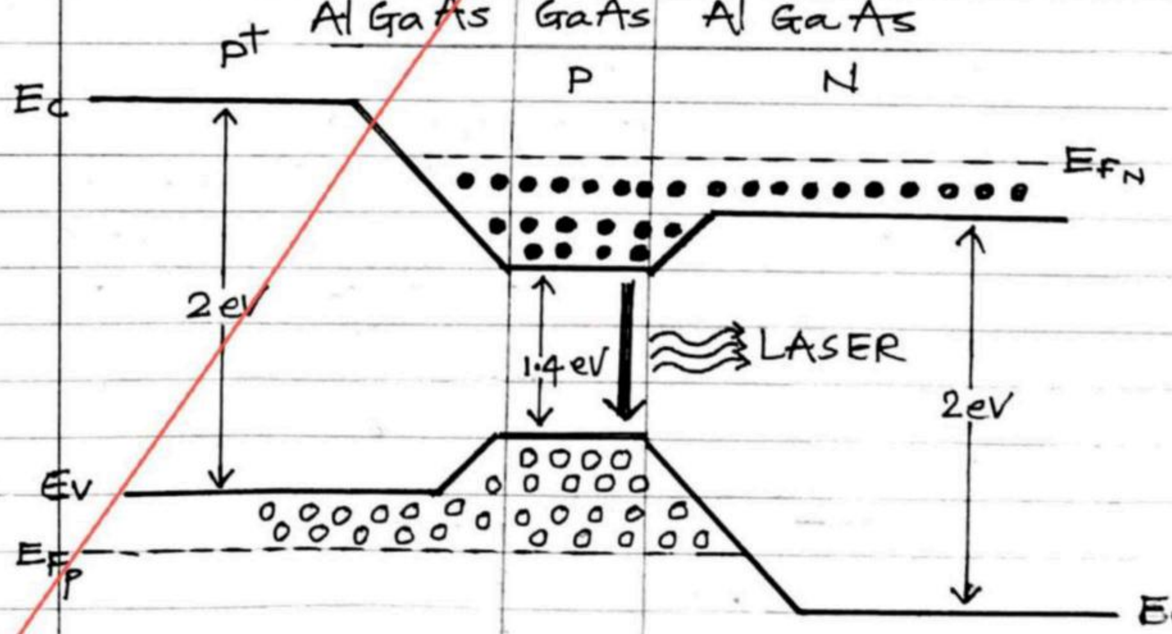



fig- Energy Band Diagram of Heterojunction P-N Junction diode

- When P-N Junction is forward biased, the electrons and holes are injected into the junction region

- The region around the junction contains large amount of electrons in the conduction band and holes in the valence band.

- Thus population inversion is achived.

- At this stage some of the injected charge carriers causes spontaneous emission and this spontaneously emitted photons trigger stimulated emission.

- Thus these photons are moving along the resonant cavity and the LASER busts out through the partially silved end after getting sufficient strength.

- As middle layer has larger refractive index than outer layers, so light is confined to the middle layer by the total internal reflection.

- A coherent beam of LASER having wavelength in between 8000 $A^0$ emerge out from the junction region as shown in energy band diagram.

- The output of LASER is continuous mode with power 1 mW.

IMP

# Medical Applications of LASER

Q Explain any two applications of LASER in medical field. (12)

Medical Applications of LASER

1] Reconstructive Surgery (Plastic Surgery):-

- Reconstructive Surgery is called plastic surgery.
- It involves replacing skin of some part of body and grafting it at some other part.
- For doing plastic surgery CO2 LASER is mostly used.

2] Eye Surgery:

- The highly collimated beam of a laser can be further focused to a microscopic dot of extremely high energy density.
- This makes it useful as a cutting instrument.
- LASERs are used for photocoagulation of the retina to halt ~~redi~~ retinal hemorrhaging and for the tacking of retinal tears.

3] Blockage of Coronary Artery:

- The artery plague leads to the narrowing of artery, which results into passage of less blood through in it.
- The problems like blood pressure, heart-attacks arises due to it.
- With the help of LASER these problems can be sorted out.

[IMP]

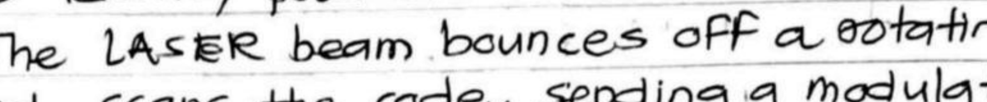
## Applications of LASER in IT.

Q Explain any two applications of LASER in IT.

→ Applications in IT. -

① Barcode Scanner

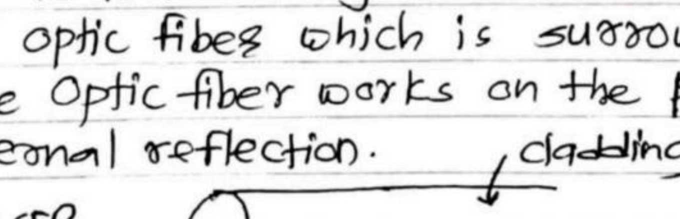
- LASER is used to scan the barcode printed on the product.
- Supermarket scanners typically use helium - neon (He-Ne) LASER to scan the universal barcodes to identify products.
- The LASER beam bounces off a rotating mirror and scans the code, sending a modulated beam to a light detector and then to computer which has the product information stored.
- Semiconductor LASERs can also be used for this purpose.
- In scanning process a photodiode measures the reflected light from the barcode.
- Then an analog signal is created from photodiode and then converted into a digital signal.



Barcode Analog Signal Digital Signal.

② Optic Fiber Communication -

- Optic fiber communication is the fastest way of communication.
- In Optic fiber communication Information is sent in the form of Light (LASER) through the core of optic fiber which is surrounded by cladding.
- The Optic fiber works on the principle of total internal reflection.




μ of core is more than μ of cladding

fig - Optic fiber.

IMP

Divergence property of LASER

Q Explain the divergence property of LASER

→ Divergence:

- Beam divergence is an angular measure of the increase in beam diameter with distance from the optical aperture from which the beam emerges.
- For typical LASER the divergence is about $10^{-3}$ radiance.
- this means the laser beam diverge by ~ 1 mm. of every meter that it travels.
- For many applications, LASER of a lower-divergence beam is preferable.

Q Explain Inelastic Atom-Atom Collision Pumping

→ In this type of pumping a combination of two types of gases, say X and Y are used.

- The excited state of gas X is represented as $X^*$ where as Y represented as $Y^*$
- Both X and Y gases have same excited states ($X^*$ and $Y^*$)
- When electric discharge is passes through the gas mixture, it excites X gas to $X^*$ and $X^*$ colliedes over Y then Y gets excited i.e. $Y^*$

$$X^* + Y \longrightarrow X + Y^*$$

Eg. He-Ne LASER is an example of such type of collision

IMP

Q Write a note on holography.

Q What is Holography? Explain the term holography recording & reconstruction.

→ Holography:

- Holography is technique of producing three dimensional images of the object.
- Holography works on the phenomenon of interference of light.
- With the holography entire recording of the object takes place.
- In holography amplitude as well as phase of the light is recording.

Holography is done in two steps
1) Recording
2) Reconstruction

Recording:-

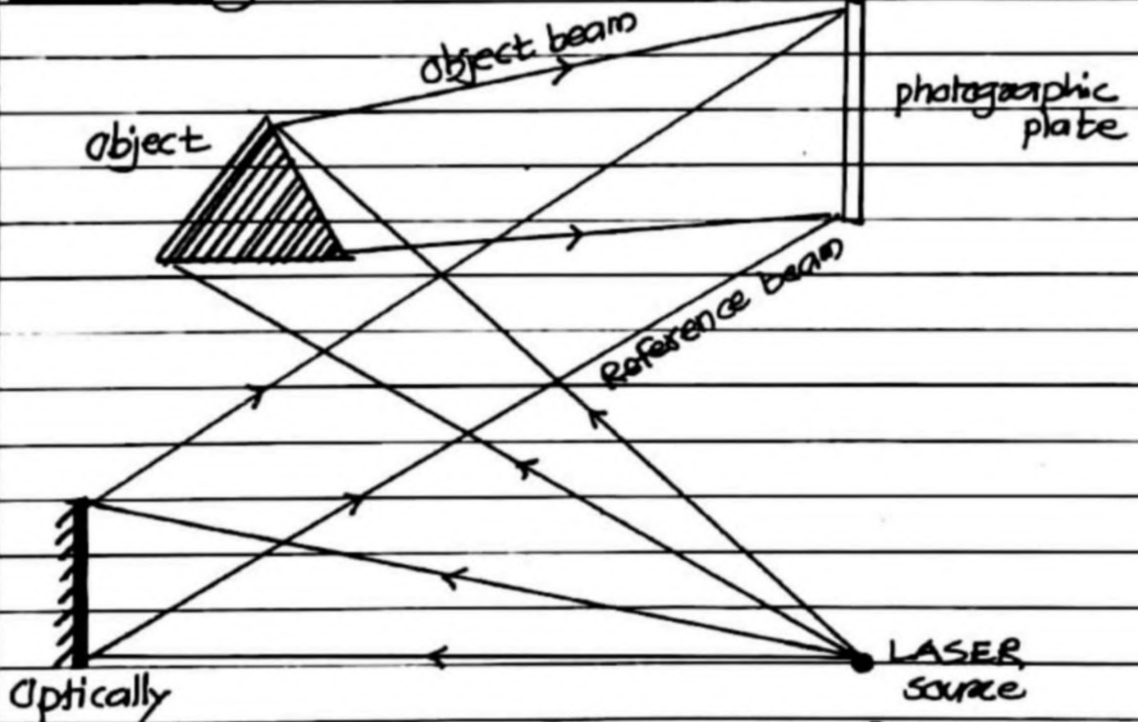
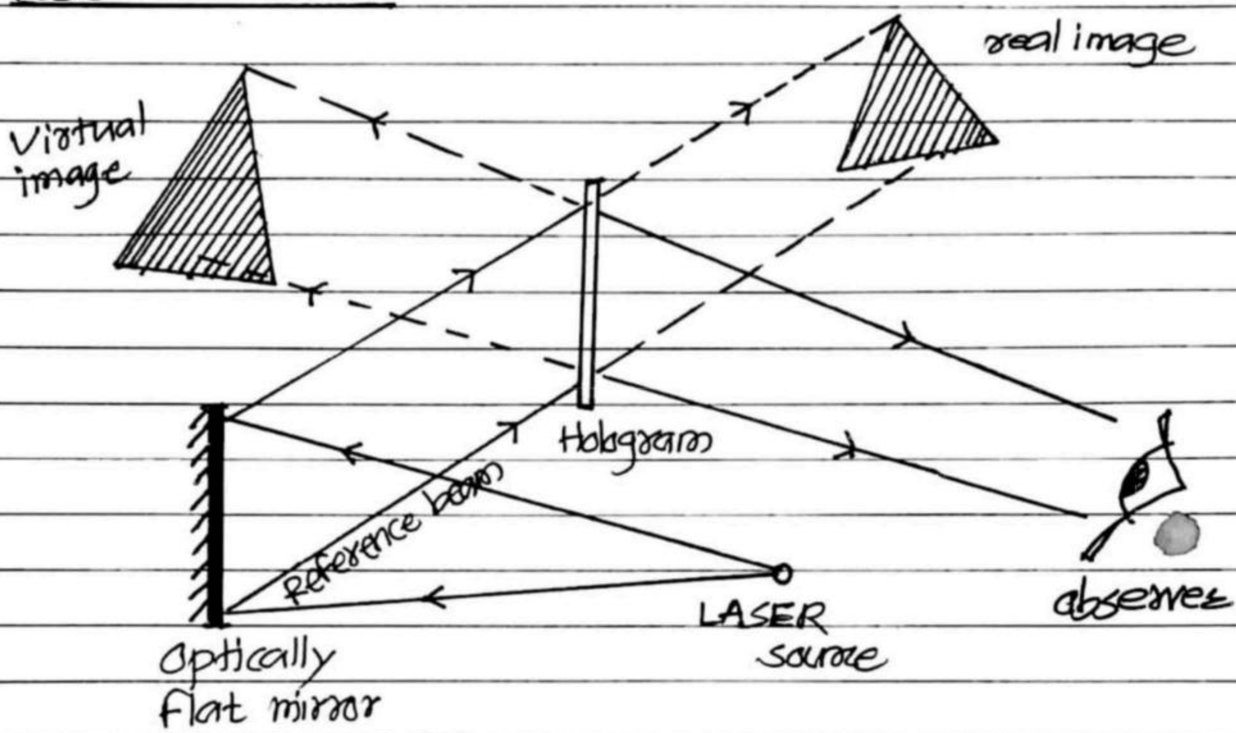



fig- Recording of hologram

- Coherent light from LASER source is partly reflected from a mirror known as reference beam.
- Partly reflected from object known as object beam.
- Interference occurred between reference beam & object beam is recorded on a photographic plate as shown in above fig.
- Developed photographic plate is known as hologram. It consist of alternate bright and dark fringes

## Reconstruction




- To see the three dimensional image of the object, the hologram is illuminated by the reference beam.
- The hologram acts as a diffraction grating.
- One of the first order diffracted beam a real three three dimensional and inverted image
- The other first order diffracted beam produces a virtual three dimensional image which is formed at the same place where object was placed during recording.

IF hologram is broken even though the complete three dimensional image can be formed.

IMP Q State the applications of holography.

→ Applications

1. It is used in three dimensional display of an object.
2. Holograms are capable of storing large amount of data.
3. Holographic storage mainly used in ROM devices.
4. It is used in determination of Young's modulus metal rod.
5. Acoustic holography is used to obtain images of embryo in mother's womb.

IMP Q Write a difference between holography & photography.

| | Photography | Holography |
|---|---|---|
| 1. | Two dimensional image is recorded | 2. Three dimensional image is recorded |
| 2. | Only amplitude is recorded | 2. Amplitude as well as phase is recorded. |
| 3. | Once the photograph is developed no need to carry photoghaphic plate to see the image | 3. Need to carry hologram to see the image recorded. |
| 4. | Image is developed on the paper | 4. Image is formed in the space. |

Q State the applications of LASER

→

Industrial applications

1) Cutting
2) Drilling
3) Welding
4) Surveying & Ranging

Applications in Imformation technology (IT)

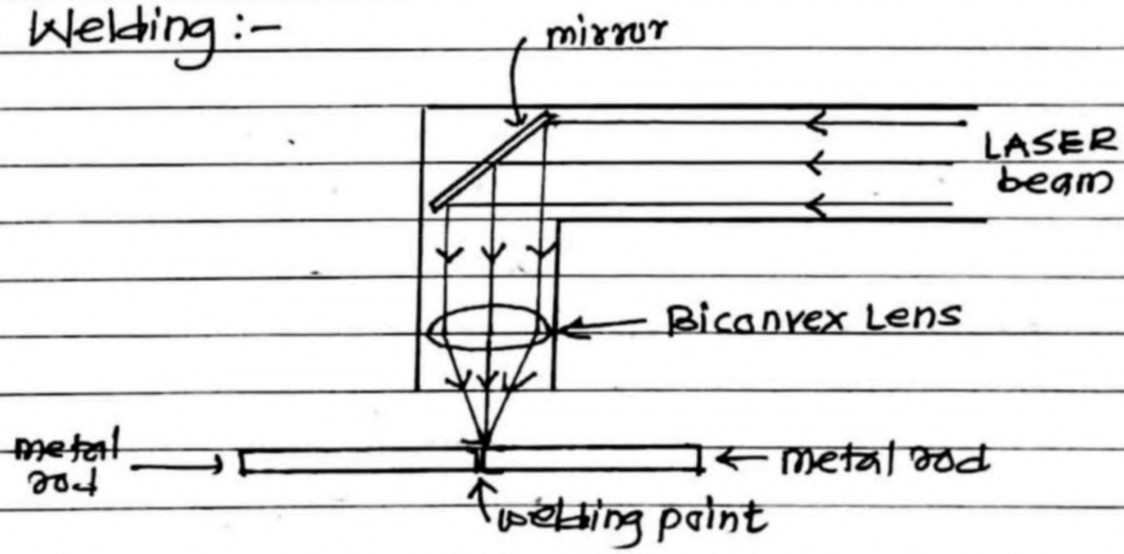
1) To write CD disk
2) LASER scanner
3) LASER printer
4) In optical fibre communication
5) In security system

Medical applications

1) In bloodless cancer surgeries
2) In plastic surgeries for treating skin diseases.
3) In eye surgeries

Q Explain any one engineering application of LASER.

→ Welding :-



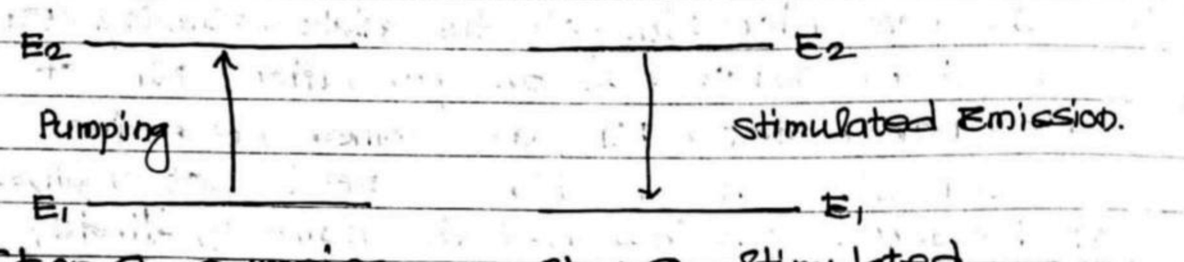
Procedure -

- To metal rods to be welded are held in contact at their ends as shown in above figure.
- High power Laser beam is focussed on the contact point by using biconvex lens.
- The metal at point of focus melts and solidifies on cooling which causes the two rods to stick together.
- As the laser can be focussed to very sharp point, therefore heat affected area is very small.
- LASER welding doesnot cause distortion on the rod.
- Such types of welding used in aircrafts manufacturing.
- $CO_2$ and Nd Yag LASERs are used for this purpose.

## Various Level LASER system

Q. Explain two level, three level and Four Level Lases system?

1] Two Level Laser System



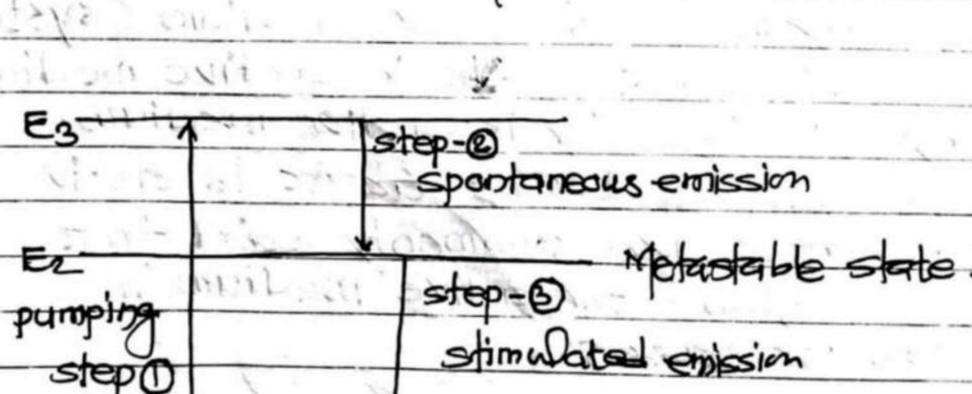

Step-1 pumping   step2 - stimulated emission

IF only two energy levels are involved in the laser action, the laser system is known as two level laser system.

for two level lases system, Quantum Efficiency is $\eta = \frac{E_2 - E_1}{E_2 - E_1} = 1$

Semiconductor Lases is the example of two level energy system. The lases action occurs between conduction band and valence band.

2] Three level lases system.




Step 1 - pumping
Step 2 - Spontaneous emission
Step 3 - Stimulated emission

In three level laser system, the atoms are pumped from the energy level $E_1$ to $E_3$. The life time of the atoms is least in the energy level $E_3$ i.e. $E_3$ is unstable state. Atoms makes transition from $E_3$ to $E_2$ level. $E_2$ is metastable state. The life time of atoms is longer in energy state $E_2$ as compare to $E_3$. Therefore population of atoms becomes more in $E_2$ as compared to $E_1$.

$$\text{Quantum Efficiency } (\eta) = \frac{E_2 - E_1}{E_3 - E_1} = \text{less than one.}$$

Ruby LASER is example of three level laser system.

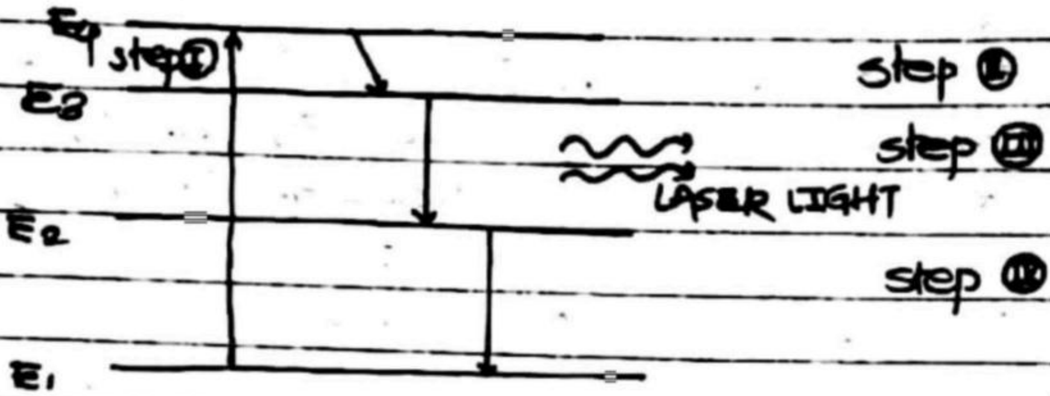
3] Four LAVEL LASER System:

The atoms from ground state $E_1$ are raised to excited state $E_4$, by pumping. From Energy state $E_4$ the atoms decays to energy state $E_3$ by spontaneous emission. Transition rate of atoms from energy state $E_4$ to $E_3$ is much faster as compared to transition rate of atoms from energy state $E_3$ to $E_2$. $E_3$ is metastable state. The population inversion is built up between $E_3$ and $E_2$. The laser action takes place between $E_3$ and $E_2$ by stimulated emission.

The atoms from Energy Level $E_2$ simply get de excited to the lower energy level $E_1$. The rate of relaxation of the atoms from energy state $E_2$ to $E_1$ should be faster than the rate of arrival of the atoms from $E_3$ to $E_2$.

He-Ne Laser is the example of four level laser system. ⟶

$$\text{Quantum Efficiency} = \frac{E_3 - E_2}{E_4 - E_1} < 1$$




Step - I  pumping

step II  spontaneous emission

step III  stimulated emission

step IV  De-excitation

# Engineering Physics

Theory Notes
(2024 Pattern)
of

Unit No.1 Ch-2

# Optic Fibre

By

Prof. S. J. Gadakh

**Optical fibers:** Critical angle, acceptance angle, acceptance cone, numerical aperture, total internal reflection and propagation of laser; Classification of optical fibers: Single mode & multimode, step index & graded index, Attenuation: attenuation coefficient, causes of attenuation; Advantages of optical fiber communication, numerical problems on parameters of optical fiber.

# Optic Fiber

Prof. S.J. Gadakh

Introduction :-

- An optical Fiber is a flexible, transparent fiber made by drawing glass (silica) or plastic to a diameter slightly thicker than that of the human hair.

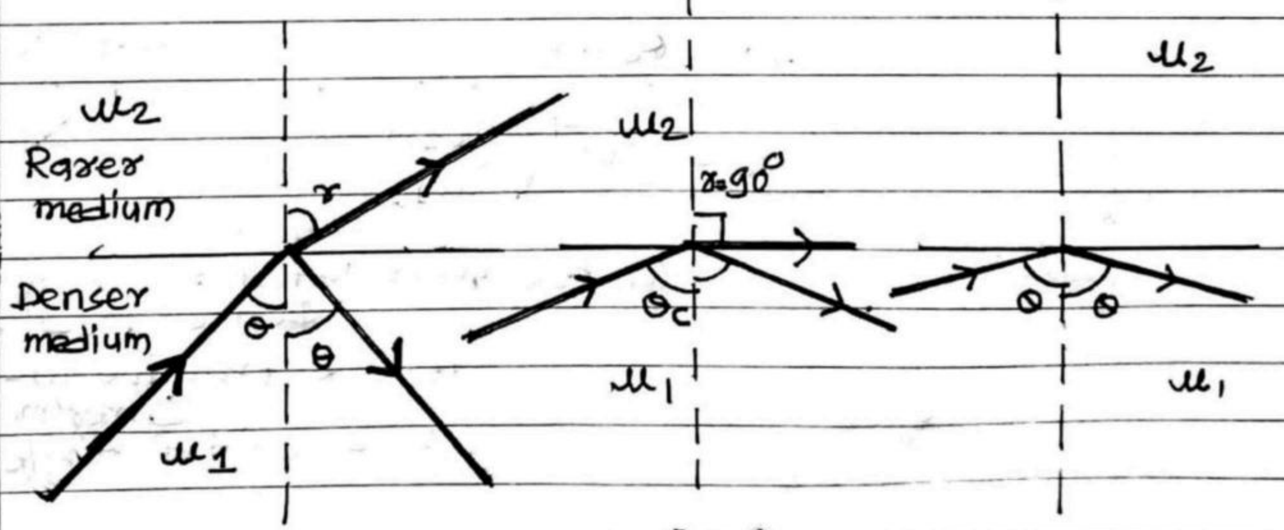
- Optical fibers are used most often as a means to transmit light between the two ends of the fiber and find wide usage in fiber optic communications, where they permit transmission over longer distances and at higher bandwidths than electrical cables.

- Optical fibers typically include a core surrounded by transparent cladding material with lower index of refraction.

- light is kept in the core by phenomenon of total internal reflection which causes the fiber to act as a waveguide.

Q What is total internal reflection

Total Internal Reflection:-




ⓐ $\theta < \theta_c$ ⓑ $\theta = \theta_c$ ⓒ $\theta > \theta_c$

$\theta_c \rightarrow$ critical angle

fig - Total Internal reflection

Statement:- Refer fig - ©

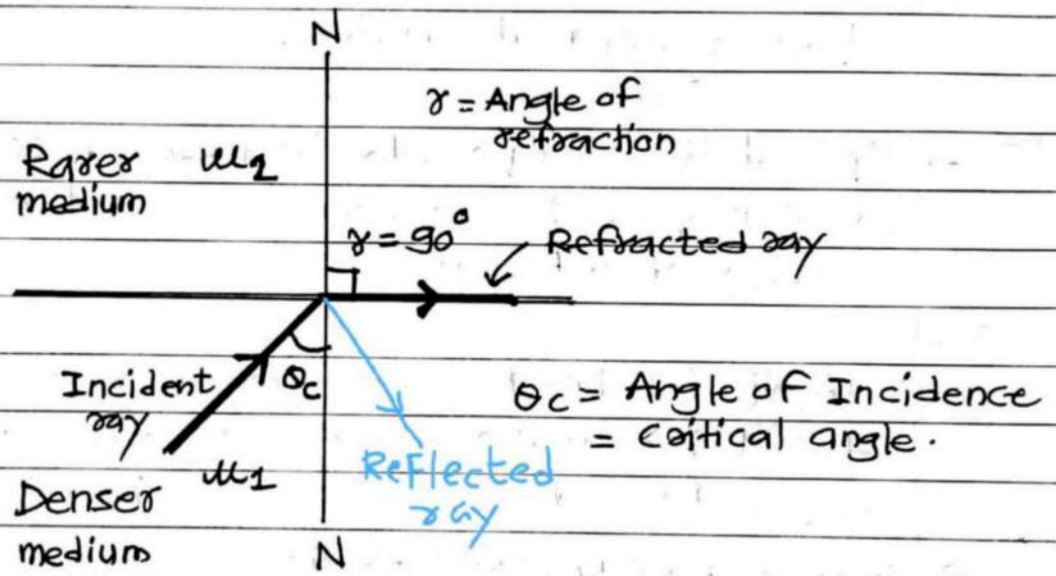
- The complete reflection of light ray reaching an interface with less dense medium when the angle of incidence exceeds the critical angle. this phenomenon is known as Total Internal Reflection TIR.

IMP Q What is Critical Angle?

IMP Q Define the term Critical Angle.

→ Critical Angle :-

Definition: The critical angle is the angle of incidence of a ray of light, moving from denser medium to rarer medium, such that the angle of refraction becomes 90°.




By Snell's law,

$$\mu_1 \sin\theta_c = \mu_2 \sin r$$

But r = 90° in this case $\sin 90° = 1$

$$\boxed{\theta_c = \sin^{-1}\left(\frac{\mu_2}{\mu_1}\right)}$$

where, $\mu_1$ = Refractive index of Denser medium
$\mu_2$ = Refractive index of rarer medium
$\theta_c$ = Critical Angle.

MP) Q. Define optical fiber? Draw neat labeled diagram of optical fiber. Page No.: 03 Prof. S.J. Gad

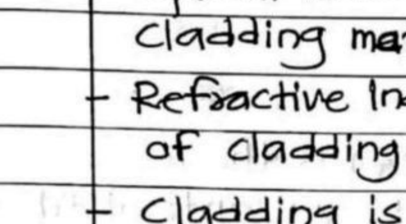
Q. What is optical fiber? Draw neat labeled diagram of optical fiber.

→ **Optical fiber:-**

Definition: An optical fiber is a thin flexible, transparent strand of drawing glass ($SiO_2$) or plastic that acts as light pipe to transmit the signal between two ends of fiber in the form of light.

- Optical fiber typically includes a core surrounded by cladding material.
- Refractive index of core is more than refractive index of cladding.
- Cladding is mostly made-up of pure silica of refractive index 1.444 and the core made-up of dopped silica of refractive index 1.475.
- Diameter of core varies from 2 $\mu m$ to 62.5 $\mu m$ as per the requirment.
- Cladding diameter is almost fixed that is 125 $\mu m$.

**Structure of optical fiber.**



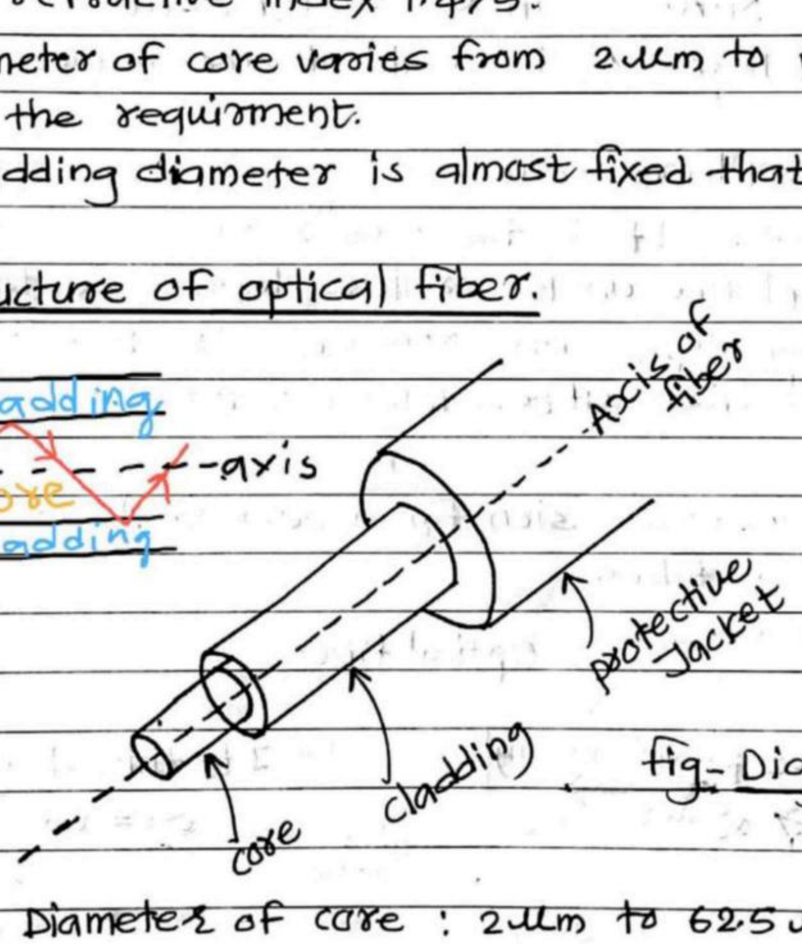




fig- Diagram of Optical fiber.

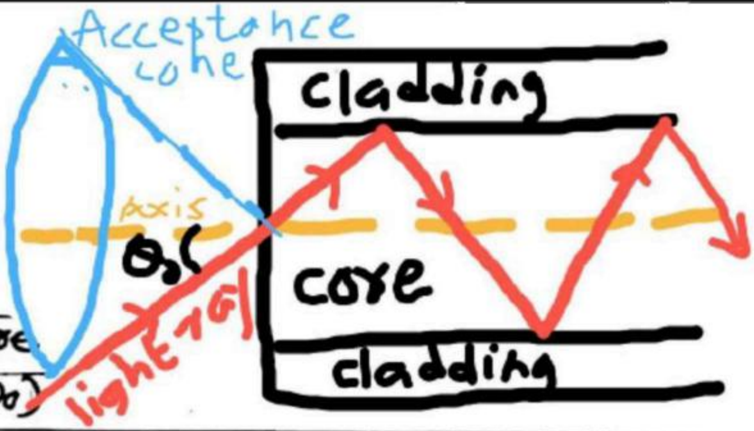
Diameter of core : 2 $\mu m$ to 62.5 $\mu m$

Diameter of cladding : 125 $\mu m$

Refractive index of core $\mu_1$ > Refractive index of cladding $\mu_2$.

IMP Q Define:

1] Acceptance angle
2] Acceptance cone
3) Numerical Aperture




→ 1) Acceptance Angle ($\theta_0$)

Definition: It is the maximum angle made by the light ray with the axis of optical fiber so that light can propagate through the core of fiber.

2) Numerical Aperture (N.A)

Definition: Numerical Aperture (N.A) is the light gathering capacity or ability of an optical fiber.

Numerical Aperture (N.A) is given by,

$$\boxed{N.A. = \sin\theta_0 = \sqrt{\mu_1^2 - \mu_2^2}}$$

$\mu_1$ = R.I. of core
$\mu_2$ = R.I. of cladding

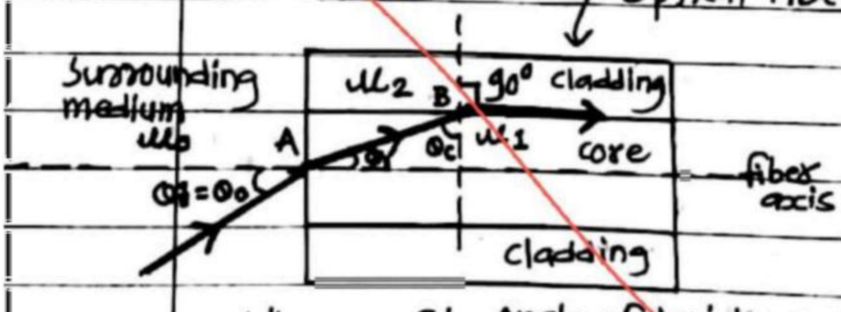
Where $\theta_0$ is angle of acceptance.

3) Acceptance Cone:

Definition: It is the cone in which the light incident at acceptance angle or less than acceptance angle and then light can propogate through the core of optical fiber after total internal reflection.

IMP Q Derive an expression for a numerical aperture (N.A.) of optical fiber.

→ Derivation:-




In this diagram
$\theta_i = \theta_0$

Where, $\theta_i$ = Angle of incidence made by incident ray with axis of optical fiber
$\theta_0$ = Acceptance angle
$\theta_c$ = critical angle
$\mu_1$ = R.I. of core
$\mu_2$ = R.I of cladding

- I above diagram, ray incident on fiber axis making angle $\theta_i$ which equals to the acceptance angle $\theta_0$.
- The ray incident on core cladding interface making critical angle $\theta_c$ with normal which equals to the $(90 - \theta_1)$ where $\theta_1$ is the angle made by light ray with fiber axis in the core.
- Angle of refraction is $90^\circ$ at interface.

- At point A in above diagram, by Snells law

$$\mu_0 \sin \theta_0 = \mu_1 \sin \theta_1$$

$$\therefore \quad \sin \theta_0 = \frac{\mu_1}{\mu_0} \sin \theta_1 \quad \text{—①}$$

- At point B, angle of refraction is $90^\circ$ i.e. $r = 90^\circ$

$$\therefore \quad \mu_1 \sin (90^\circ - \theta_1) = \mu_2 \sin 90^\circ \qquad \because \sin 90^\circ = 1$$

$$\mu_1 \cos \theta_1 = \mu_2 \qquad \therefore \cos \theta_1 = \frac{\mu_2}{\mu_1} \quad \text{—②}$$

As $\sin \theta_1 = \sqrt{1 - \cos^2\theta}$

from eq②, we get, $\sin \theta_1 = \sqrt{1 - \frac{\mu_2^2}{\mu_1^2}}$

$$\therefore \sin \theta_1 = \frac{1}{\mu_1}\sqrt{\mu_1^2 - \mu_2^2}$$

Substituting this value in eq$^n$ ①

$$\sin \theta_0 = \frac{\mu_1}{\mu_0} \cdot \frac{1}{\mu_1}\sqrt{\mu_1^2 - \mu_2^2}$$

$$\sin \theta_0 = \frac{1}{\mu_0}\sqrt{\mu_1^2 - \mu_2^2}$$

$$\sin \theta_0 = \frac{\sqrt{\mu_1^2 - \mu_2^2}}{\mu_0}$$ But the Numerical aperture is $\sin \theta_0$

$$\therefore \quad N.A. = \sin \theta_0 = \frac{\sqrt{\mu_1^2 - \mu_2^2}}{\mu_0}$$

If the fiber is surrounded by an air, then $\mu_0 = 1$

$$\therefore \quad \boxed{N.A. = \sin \theta_0 = \sqrt{\mu_1^2 - \mu_2^2}}$$

$\theta_i < \theta_0$ OR $\sin \theta_i < N.A.$ is the condition for transmission of light through optical fibes.

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## Types of Optical fiber

- Based on material used

1. Glass fiber:

- Glass optic fiber consist of a glass core surrounded by a glass cladding of smaller refractive index.
- Glass fibers have lower attenuation and larger mechanical strength compared to the plastic fiber.
- Most commonly used material for glass fiber is silica ( $SiO_2$).
- Silica is doped either ~~with~~ aluminium oxide to increase its refractive index
- Silica is doped with fluorine to decrease the refractive index.
- Silica fibers can be drawn into thinner fibers compared to plastic and hence are more suitable for long distance communication

2. Plastic fibers:

- The plastic fibers are made up of core of polystyrene and cladding of poly-methyl methacrylate commonly known as PMMA.
- Although plastic fibers have the advantage of being more flexible compared to the glass fibers, they have more attenuation and can not be drawn into very thin fibers
- They are more suitable for short distance.

Q. Explain types of fibes

Q Explain the terms:
1. single mode fibes.
2. Multimode fiber.

## Types of optical fiber [IMP]

### Based on number of modes

1] Single mode fibers (Mono Mode)

- In this type, fiber optic cable has a small diametral core that allows only one mode of light to propagate.

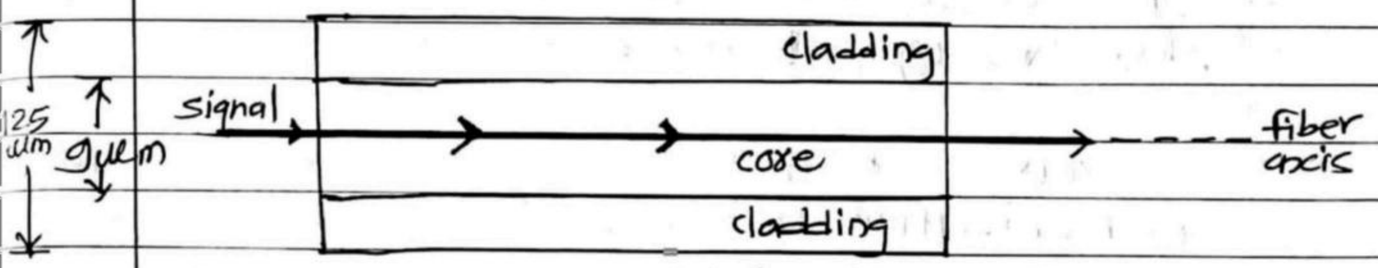
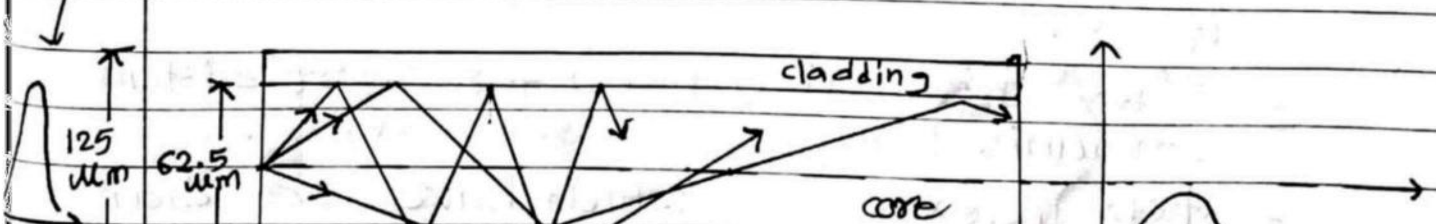



fig- Single mode fiber.

- Because of this the number of light reflections created as the light passes through the core decreases, lowering attenuation and creating the ability for the signal to travel further.
- This type of fiber is commonly used for long distance communication.
- Single mode fiber is usually 9 µm core and 125 µm diameter of cladding.

2] Multimode Fibers:

- Multimode fiber optic cable has a large diametrical core that allows multiple modes of light to propagate



- Range of core is from 50 $\mu m$ to 62.5 $\mu m$ and cladding diameter is 125 $\mu m$.

- Because of large diametrical core, the number of light reflections created as the light passes through the core increases.

- It creates the ability for more data to pass through at a given time.

- This type of fiber is used for short distance communication because of the high dispersion and attenuation rate.

IMP
Q. Explain any two types of optical fiber.

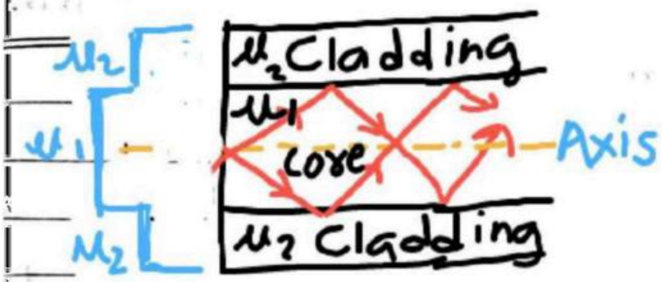
Types of Optical fiber

3] Based on the variation in refractive index along the diameter.

Q. Explain the terms:
IMP 1. Step index fiber
2. Graded index fiber.

1] Step index fibers:

- Such fibers have a core of homogeneous transparent material of refractive index $\mu_1$.
- ~~it has a~~ It has a cladding of another homogeneous transparent material of refractive index $\mu_2$.
- There is an abrupt change in refractive index at the core-cladding interface due to which they are known as step Index fibers.
- They are mainly used for short distance communication.
- Step index fibers which have core diameters in the range of 2 $\mu m$ to 10 $\mu m$ are known as single mode step index fibers.

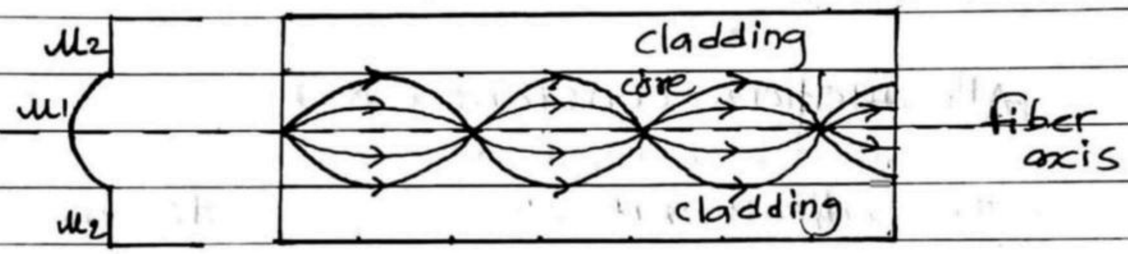



$\mu_1$ = R.I. of core, $\mu_2$ = R.I. Clading

fig - ~~Single~~ Step Index fiber

2] Graded index fibers:

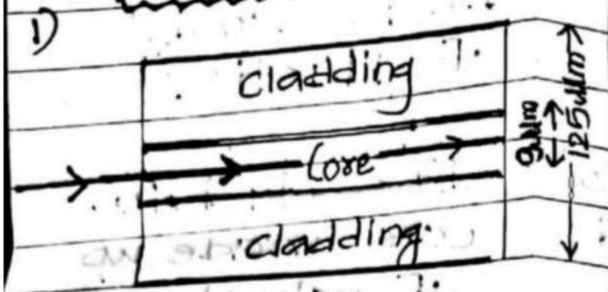
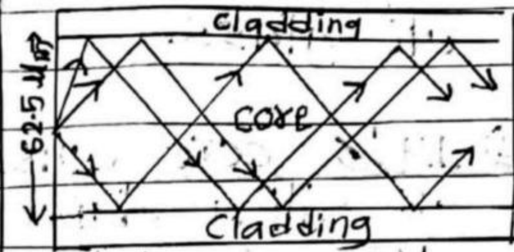
- In graded index fibers, the refractive index is maximum at the axis of core, decreases gradually upto the cladding and then remains constant throughout the cladding.
- Refractive index of cladding is uniform.




- The ray travelling at an angle to the axis travel in curved paths due to gradually decreasing refractive index.
- Although these rays travel longer distances compared to the axial ray, they travel in region of small refractive index and hence travel faster.
- This reduces intermodal dispersion.
- The core diameter is typically about 20 $\mu m$ to 100 $\mu m$ with cladding thickness is about 25 $\mu m$.
- They are commonly used for medium distance communication.

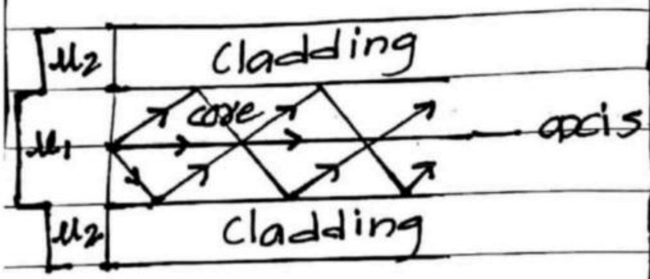
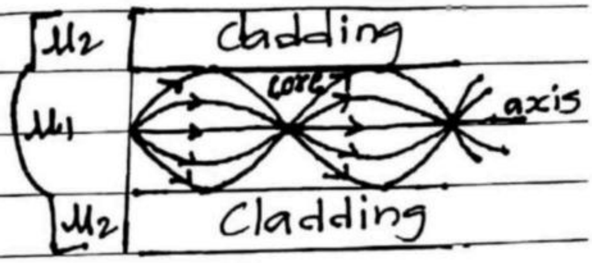
Q) Distinguish between single mode and multi-mode optical fiber. (01)

Ans→

| Single Mode Fiber | Multi-Mode Fiber |
|---|---|
| 1)  |  |
| 2) It has small diametrical core. The diameter of core is around 9 µm. | It has large diametrical core. The diameter of the core is around 62.5 µm. |
| 3) It allows only one mode of light to propagate. | It allows multiple modes of light to propagate. |
| 4) It has less attenuation. | It has high attenuation. |
| 5) There are less number of reflection of light ray inside the core. | There are large number of reflection of light ray inside the core. |
| 6) It is used for long distance communication. | It is used for short distance communication. |
| 7) Less data can be sent at a time. | Large amount of data can be sent at a time. |
| 8) Optical power loss due to dispersion is less. | Optical power loss due to dispersion is high. |

Q.) Distinguish between Step-Index and Graded-Index fiber 

Ans →

| Step-Index Fiber | Graded-Index Fiber |
| --- | --- |
| 1)   |   |
| 2) It has a core of homogeneouse transparent material | In this fiber, the refractive index is maximum at the axis of core and decreases gradually upto the cladding |
| 3) The light ray travels in a straight line between two reflections. | The light ray travels in a curved path through out the core. |
| 4) The range of the diameter of core is from 2 μm to 10 μm. | The range of the diameter of core is from 20 μm to 100 μm. |
| 5) It is used for short distance communication. | It is used for medium distance communications. |

[IMP] Q What is attenuation and attenuation constant

⟹

## Attenuation:

- The power loss of optical signals when they travel through optical fibers is known as attenuation

- The power loss PL in decibel (dB) is given by,

$$P_L = -10 \log_{10}\left(\frac{P_{out}}{P_{in}}\right)$$

- Where $P_{out}$ is the output power and $P_{in}$ is the input power.

## Attenuation constant ($\alpha$):

- The attenuation constant ($\alpha$) for optic fiber is defined as the power loss per unit length and is expressed in dB/Km. It is given by

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

Where L is length of cable in Km.

- Attenuation in optic fibers is due to Absorption, Dispersion and bending.

IMP

**Q** What are the reasons of optical power loss or attenuation in the optical fiber. Explain any two in brief.

- Reasons for power loss
- Reasons for Attenuation
  1] Absorption
  2] Bending
  3] Dispersion

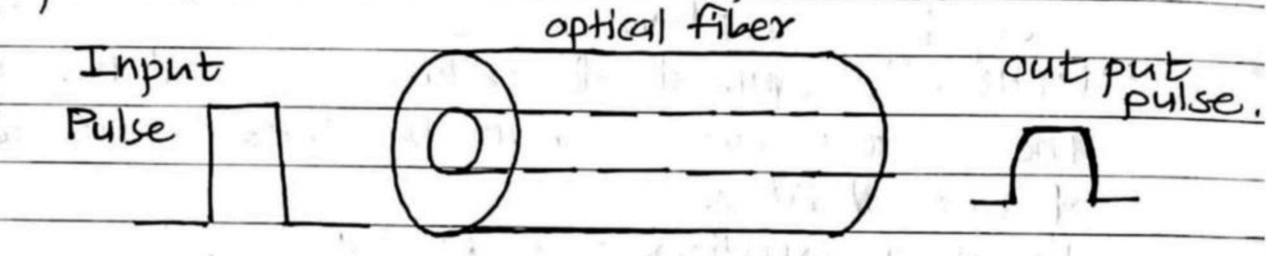
~~Optical loss Due to~~

1] Optical Power loss due to absorption:
- Light absorption is the major cause of losses in optical fiber during optical transmission.
- The light is absorbed in the fiber by the materials of optical fiber.
- Light absorption in optical fiber is also known as material absorption.
- Actually the light power is absorbed and transferred into other forms of energy like heat, due to molecular resonance and wavelength impurities
- It is impossible to manufacture materials that are total pure.
- Thus fiber optic manufacturers choose to dope germanium and other materials with pure silica to optimize the fiber optic core performance

2] Optical Power loss due to bending:
- Bending loss is the common problems that can cause fiber optic loss generated by improper fiber optic handling.
- There are two basic types:
  1] Micro Bending
  2] Macro Bending

- Macro bending refers to a large bend in the fiber with more than 2 mm radius.
- Here are some causes of bending :-
  1) Fiber core deviate from the axis.
  2) Defects of manufacturing
  3] Environmental variations like change in temperature, humidity or pressure.
  4) Mechanical constraints During the fiber laying process.

3] Optical power loss due to Dispersion :-




- Dispersion in optic fibers is the broadening of a pulse during transmission through the fiber.

- If the optical pulse is sent through the optical fiber then it gets broades as shown in above diagram.

- Types of dispersions in optical fiber
  1] Intermodal Dispersion
  2] Chromatic Dispersion
  3] Waveguide Dispersion

1] Intermodal Dispersion :-

- Intermodal Dispersion occurs in mutimode fibers in which signal is spread in time because the propogation velocity of the optical signal is not the same for all modes.

- The distance travelled by the axial mode is smaller than the higher order modes due to which different modes reach the other end of the fiber at different time this is known as intermodal dispersion.

2] Chromatic Dispersion:
- The different wavelengths in an optical signal transmitted through the fiber will travel with different speeds. This results in broadning the pulse, this broadning is called chromatic dispersion or material dispersion.

3] Waveguide Dispersion:
- Due to difference in refractive index of core and cladding, the optical power of larger frequencies is confined more towards the core and the smaller frequencies is more towards cladding, this leading to the pulse broadning and this broadning is known as waveguide dispersion.

IMP)

Q Explain communication through optical fiber by using block diagram of optical fiber communication

⇒ Optical Fiber communication system

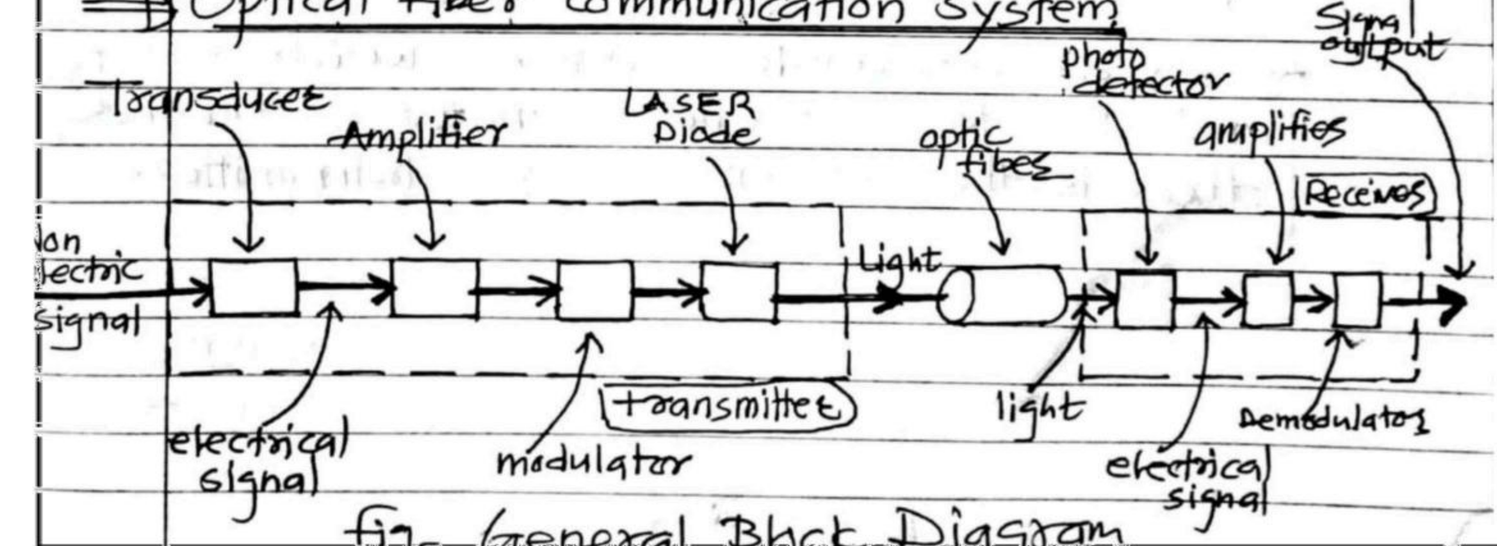



fig- General Block Diagram

Explanation:-

- A non electrical signal like sound, in telecommunication, is converted into electrical signal by a transducer.

- The signal is amplified, modulated and then fed to a laser diode or light emitting diode which converts electrical signal into a light signal.

- Thus the transmitter transmits a light signal.

- The light signal is transmitted through the optic fiber.

- In the receiver, the light signal is converted into corresponding electrical signal by a photo-detector which is amplified by an amplifier.

- The amplified electrical signal is then demodulated and in telecommunication is fed to a speaker which converts it into sound signal.

- In data transfer systems, which transfer digital Data from one computer to another, there is the transducer in the transmitter.

IMP

Q State any five advantages of optical fibes.

→ ADVANTAGES OF OPTICAL FIBERS

1] They are not affected by corrosion and atmospheric conditions.

2] Optic fibers have longer life than copper cables.

3] The fiber optic communication system is not affected by electromagnetic disturbances, specially during thunderstorms as optic fibers are made up of dielectric materials.

4] As the frequency of light is large ($\sim 10^{14}$ Hz), large bandwidth is available. Hence more channels become available due to which data transfer speed ~~are~~ is larger.

5] There is no cross talk.

6] There is more security as the signals are confined to the core and cannot be tapped

7] Quality of communication is better as the transmission losses are low.

8] There is good electrical isolation between transmitter and receiver.

9] They occupy smaller space compared to copper cables for the same number of communication channels.

# IMPortant Formulae from Optic Fiber

1] Critical angle ($\theta_c$) :-

$$\theta_c = \sin^{-1}\left(\frac{\mu_2}{\mu_1}\right)$$

Where, $\theta_c$ = Critical angle
$\mu_1$ = Refractive index of core (denser)
$\mu_2$ = Refractive index of cladding (rarer)

2] Acceptance angle ($\theta_0$) :-

$$\theta_0 = \sin^{-1}(N.A.)$$

$$\theta_0 = \sin^{-1}\left(\sqrt{\mu_1^2-\mu_2^2}\right)$$

Where, $\theta_0$ = Acceptance angle
$\mu_1$ = Refractive index of core
$\mu_2$ = Refractive index of cladding

3] Numerical Aperture (N.A.):-

$$(N.A.) = \sin\theta_0 = \frac{\sqrt{\mu_1^2-\mu_2^2}}{\mu_0}$$

If optical fiber placed in air then $\mu_0 = 1$

$$N.A. = \sqrt{\mu_1^2-\mu_2^2}$$

$$N.A. = \sin\theta_0$$

4) Fractional Index change ($\Delta$):

$$\Delta = \frac{\mu_1-\mu_2}{\mu_1}$$

5] Attenuation

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

Where, L = length in km
P = Power.

6] Power loss

$$P_L = -10\log_{10}\left(\frac{P_{out}}{P_{in}}\right)$$

7] $\alpha = \frac{P_L}{L}$

Problem No. 1

A fiber cable has an acceptance angle of $30^0$ and a core index of refraction of 1·4. Calculate the refractive index of the cladding.

→ Soln:

Given Data: $\mu_1 = 1.4$ , $\theta_0 = 30^0$ , $\mu_2 = ?$

Formula: $\sin \theta_0 = \sqrt{\mu_1^2 - \mu_2^2}$

$$\sin 30 = \sqrt{(1.4)^2 - \mu_2^2}$$

$$\mu_2^2 = (1.4)^2 - \sin^2 30$$

$$\boxed{\mu_2 = 1.3077} \rightarrow \text{Ans}$$

Problem No-2

Calculate the numerical aperture and acceptance angle of an optical fiber having $\mu_1 = 1.49$ and $\mu_2 = 1.44$

→ Soln:

Given Data: $\mu_1 = 1.49$ , $\mu_2 = 1.44$ , N.A. = ?

Formula:

$$N.A. = \sqrt{\mu_1^2 - \mu_2^2}$$

Angle of acceptance $\theta_0 = \sin^{-1}(N.A.)$

~~Given~~ $N.A. = \sqrt{(1.49)^2 - (1.44)^2}$

$$\boxed{N.A. = 0.3827} \leftarrow \text{Ans}$$

Angle of acceptance $\theta_0 = \sin^{-1}(N.A.)$

$= \sin^{-1}(0.3827)$

$$\boxed{\theta_0 = 22.5^0} \leftarrow \text{Ans.}$$

3] Calculate the numerical aperture and hence the acceptance angle for an optical fiber whose core and cladding has refractive index of 1.59 and 1.40 respectively.

→ Sol^n:

Given: $\mu_1 = 1.59$, $\mu_2 = 1.40$, $\theta_0 = ?$, $N.A. = ?$

~~Formula~~: $N.A. = \sqrt{\mu_1^2 - \mu_2^2}$

Substitution: $N.A. = \sqrt{(1.59)^2 - (1.40)^2}$

$$\boxed{N.A. = 0.7537} \leftarrow \text{Ans}$$

Angle of acceptance $\theta_0 = \sin^{-1}(N.A.)$

$= \sin^{-1} 0.38275$

$$\boxed{\theta_0 = 48.91^\circ}$$

4] Calculate the fractional index change for a given optical fiber if the refractive index of core is 1.563 and R.I. of cladding is 1.498.

→ Given Data: $\mu_1 = 1.563$, $\mu_2 = 1.498$, $\Delta = ?$

Formula: $\Delta = \dfrac{\mu_1 - \mu_2}{\mu_1}$

$$\Delta = \frac{1.563 - 1.498}{1.563}$$

$$\boxed{\Delta = 0.0416}$$

5] A fiber with an input power of 9.0 $\mu W$ has a loss of 1.5 dB/km. If the fibre is 3000 m long, What is the output power?

→ Given Data: $P_{in} = 9.0 \mu W$

$P_{in} = 9.0 \times 10^{-6} W$

$\alpha = \dfrac{P_L}{L} = 1.5$ dB/km

~~$L = 3000 m = 3 km$~~

$sol^n$

$P_L = \alpha \times L$ ← formula

$= 1.5 \times 3$

$\boxed{P_L = 4.5}$ ← Ans

$P_L = -10 \log_{10}\left(\frac{P_{out}}{P_{in}}\right)$ ← formula

$4.5 = -10 \log_{10}\left(\frac{P_{out}}{9 \times 10^{-6}}\right)$

$\boxed{P_{out} = 3.193 \times 10^{-6} \text{ Watt}}$ ← Ans

OR

$\boxed{P_{out} = 3.193 \, \mu W}$ ← Ans

6] The optical Power of 1 mW is launched into an optical fiber of length 100 m. If the power emerging from the other end is 0.3 mW, calculate the fiber attenuation.

→ Given Data: $L = 100 \text{ m} = 0.1 \text{ km}$

$P_{in} = 1 \text{ mW} = 1 \times 10^{-3} \text{ W}$

$P_{out} = 0.3 \text{ mW} = 0.3 \times 10^{-3} \text{ W}$

$\alpha = ?$

$sol^n$

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

$= \frac{-10}{L} \log_{10}\left(\frac{0.3 \times 10^{-3}}{1 \times 10^{-3}}\right)$

$= \frac{-10}{0.1} \log_{10}(0.3)$

$\boxed{\alpha = 52.29 \text{ dB/km}}$