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Unit-IV PHYSICAL MATERIAL AND OPTO-ELECTRONICS

PYQ

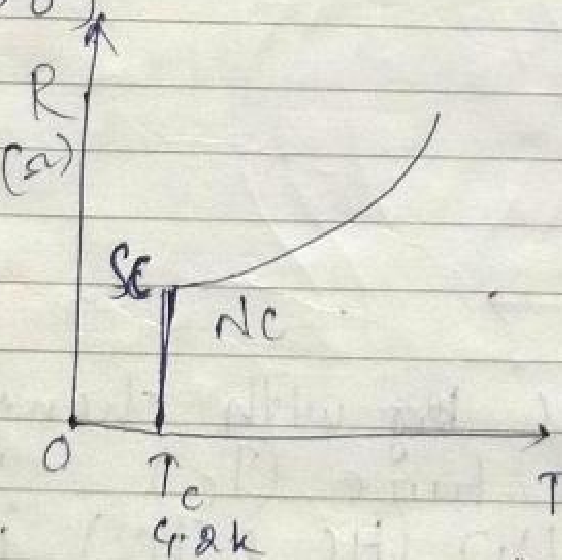
There are different types of materials which are used for various applications. They are :-

1) Superconducting materials
2) Magnetic Materials
3) Di-electric materials
4) Nano-materials
5) Semiconducting materials
5) Conducting materials

Superconducting Materials

$\boxed{R \propto t}$ $\boxed{0-t}$

When the resistivity of a conductor decreases and tends to 0, while ~~lowing~~ lowering its temperature, then this conductor is called superconductor and ~~them~~ the phenomenon is called superconductivity.
$(R \to 0)$



T_c = critical temperature

NC = Normal conducting

SC = Super conducting

Characteristics of superconductor :-

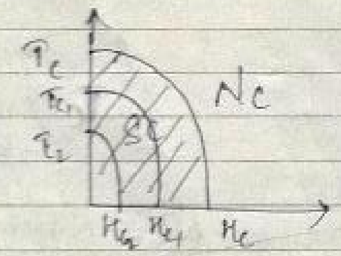
1) Critical temperature (T_c)
(or)
Transition Temp (T_c)

$T \geq T_c \longrightarrow NC$

$T \leq T_c \longrightarrow SC$

1) Critical temperature: It is the temperature where the normal conductor (NC) converts to Superconductor (SC).

2. Critical magnetic field (H_c)
The magnetic field affect the superconductivity.
Critical magnetic field is defined as the maximum value of magnetic field within which the material become superconductor and beyond this value it becomes normal conductor.



The H_c changes ~~by~~ with changing of critical temperature (T_c)
The relation b/w (H_c & T_c) is given by

$$\boxed{H_c = H_0\left[1-\left(\frac{T}{T_c}\right)^2\right]}$$

$H_0 \rightarrow$ critical magnetic fd at 0K.
$T \rightarrow$ any given temp

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3) ~~Isotopic~~ Isotopic Mass effect :-
The superconductivity depends on the isotopic mass of the substance
Mathematically, the critical temp is inversely proportional to the square root over of the isotopic mass.

$$T_c \propto \frac{1}{M^{1/2}} \Rightarrow \boxed{T_c M^{1/2} = \text{constant}}$$

If $T_{c_1}, M_1 \longrightarrow T_{c_2}, M_2$

$$\boxed{\frac{T_{c_1}}{T_{c_2}} = \left[\frac{M_2}{M_1}\right]^{1/2}}$$

4) Critical current and current density :-
Critical current depends on the critical magnetic field and the radius of the material.
Mathematically,

$$\boxed{I_c = 2\pi r H_c}$$

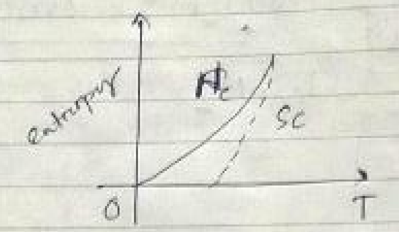
Where r = radius of the wire
H_c = Critical magnetic field

$\therefore$ Critical current density (J_c)

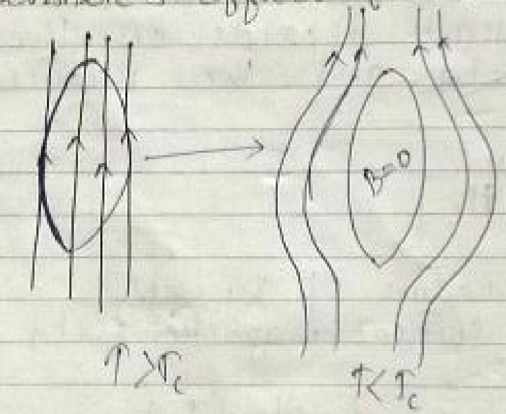
$$J_c = \frac{I}{A} = \frac{2\pi r H_c}{\pi r^2} = \frac{2}{r} H_c$$

$$\boxed{J_c = \frac{2H_c}{r}}$$

5. Entropy (S) :-
Entropy measures the disorderness of a system.
The entropy of a superconducting material is lower than the normal conductor.



6. Meissner's Effect (Flux exlusion principle)



cooling - lowering
rising - heat

When a superconducting substance is cooled under a magnetic field below critical temperature then its magnetic flux is expelled from the specimen as if the magnetic field inside the specimen is 0. (Diamagnetic material)
B = 0
⇒ χ = -ve

This effect is called as Meissner's effect.
⇒ A superconducting material i.e perfect diamagnetic material.

Q. The critical temp for Hg of isotopic mass 199.5 amu is 4.195 K. What will be the critical temp when mass changes to 203.5 amu ?

Given that
T_{c_1} = 4.195 K
M_1 = 199.5 amu
M_2 = 203.5 amu

$$\frac{T_{c_1}}{T_{c_2}} = \left[\frac{M_2}{M_1}\right]^{1/2}$$

$$= \frac{4.195}{T_{c_2}} = \left[\frac{203.5}{199.5}\right]^{1/2} = 1.020$$

$$\frac{4.195}{T_{c_2}} = 1.009$$

$$T_{c_2} = \frac{4.195}{1.009} = 4.15\,K.$$

$\boxed{T_{c_2} = 4.15\,k}$ Ans.

Q2 Calculate the critical current density (J_c) for 1mm diameter wire of

Al at 1K when T_c is equal to 1.196k

$H_0 = 7.9 \times 10^3$ A/m

$T_c = 1.196$ k , T = 1k

$2r = 1mm = 10^{-3}m$

$I_c = 2\pi r H_c$

$$H_c = H_0 \left[1 - \left(\frac{T}{T_c}\right)^2\right]$$

$$= 7.9 \times 10^3 \left[1 - \left(\frac{1}{1.196}\right)\right]^2$$

$$= 7.9 \times 10^3 \left[1 - (0.83)^2\right]$$

$$[1 - 0.698]$$

$$7.9 \times 10^3 \times 0.302$$

$$2.38 \times 10^3 \text{ A/m}$$

$I_c = \pi (2r) H_c = 7.42$ Amp

$$J = \frac{2}{r} H_c = \frac{2 \times 2 \times 2.38 \times 10^3}{10^{-3}}$$

$$= 9.48 \times 10^6 \text{ Am/m}^2$$

Q. Find the critical temp for lead (pb) if the critical magnetic field (H_c) is $\frac{1}{20}$th of that of at 0k. If the critical temp is 4.8 k.

$T_c = 4.8$k

$H_c = \frac{1}{20} H_0$

T = ?

$$\frac{1}{20} H_0 = H_0 \left[1 - \left(\frac{T}{4.8}\right)^2\right]$$

$$\frac{1}{20} = 1 - \frac{T^2}{(4.8)^2}$$

$$\frac{1}{20} = 1 - \frac{T^2}{23.04}$$

$$\frac{1}{20} = \frac{23.04 - T^2}{23.04}$$

$$1.152 = 23.04 - T^2$$

$$1.152 - 23.04 = -T^2$$

$$-21.88 = -T^2$$

$$T^2 = 21.88$$

$$T = \sqrt{(21.88)^2}$$

$$T = 4.67 \text{ K}$$

Types of superconductors :-

There are 2 types of superconductors :-

(1) Type-I or soft SC

(2) Type-II or Hard SC.

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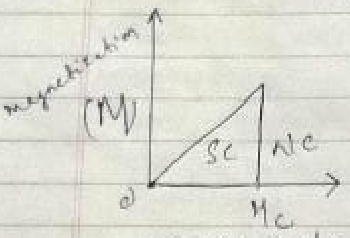
Type-I or Soft SC	Type-II or Hard SC
(i) It has low magnetic tolerance power i.e. when the magnetic field is slightly	(i) It has high magnetic tolerance power i.e. It doesnot loses its supercon-ductivity immediately and

increase then it loses its superconducting immediately and become normal conductor. Hence is called soft SC.
Ex:- lead, tin, mercury
(pb) (Sn) (Hg)

(ii) Graphical representation

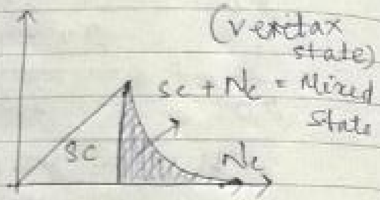


$H > H_c \rightarrow NC$
$H \leq H_c \rightarrow SC$

(iii) Type I SC satisfies the Meissner's effect perfectly.
(iv) It has only single critical magnetic field.

it last in superconducting state for a long time before reaching normal conducting state.
Ex:- Niobium, Vanadium

(ii) Graph

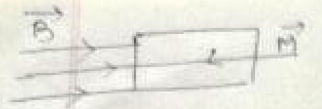


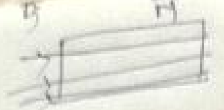
$H < H_{c_1} \rightarrow S_c$
$H > H_{c_2} \rightarrow NC$
$H_{c_1} < H < H_{c_2} \rightarrow$ Mixed state

(iii) Type II doesnot satisfying the Meissner's effect perfectly.
(iv) It has 2 critical magnetic field i.e. H_{c_1} & H_{c_2}

Applications
Superconducting materials are used for various applications. They are:
(i) SQUIDS: Super conducting Quantum Interface Devices
(ii) Used as CRYTRON
These are called as switching Devices
(iii) Used in Magnetic Levitation (Bullet Train)
(iv) Used as MRI (Magnetic resonance imaging)
(v) Used in Super computers and electronic devices
(vi) Used in transformers
(vii) Used as super electromagnets.

Magnetic materials :-
The magnetic behaviour of a material is known the magnetic material.
According to the magnetic behaviour a magnetic behaviour, a magnetic material is classified into 3 categories :-
(i) Diamagnetic material
(ii) Paramagnetic material
(iii) Ferromagnetic material





Dia	Para	Ferro
(i) The individual atoms, molecule or ions do not poses any net magnetic moment of their own.	(i) The individual atom molecules or ions poses a net magnetic moment of their own.	(i) The individual atom, ~~molecules~~ molecules or ions poses a very strong net magnetic moment of their own
(ii) When these materials are placed in an external magnetic field then they acquire magneticism in a direction opposite to the applied magnetic field.	(ii) When they are placed in an external magnetic field then they acquire more magneticism along a direction along the direction of applied magnetic field	(ii) when these materials are placed in an external magnetic field then they acquire very strong magneticism
(iii) The magnetic susceptivity is negative $\chi = -ve$ $\chi < 0$	(iii) The magnetic susceptivity is +ve & greater then 1 χ +ve & > 1.	(iii) $\chi = +ve$ & $\chi >> 1$
(iv) The magnetic susceptivity is independent of temperature.	(iv) The magnetic susceptivity is dependent on temp. i.e. inversely proportional to T. $\chi \propto 1/T$, $\chi = C/T$ C - curies constant	(iv) $\chi \propto 1/T$
(v) Ex:- Bi, Sb, Cu, Au, Hg, H_2O, Alcohol (ACOH) air, Quartz H_2 gas.	(v) Ex:- Al, Cr, Mn, $CuSO_4$ sol^n, crown glasses, Ni, O_2	(v) Ex:- Co, Fe, Ni.

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Di-electrical Materials

In a di-electrical material electric charge do not flow. like conductor but it gets slightly shifted from their equilibrium position when they are placed in external electrical field.

Examples: Different polymers, glass, paper, mica ~~paper~~ sheet

Characteristics / properties :-

(i) Dielectric materials are insulator and having high resistivity.

(ii) The forbidden gap of the dielectric materials is more than $\Delta E_g = 3eV$.

(iii) All the electron in this material are localised i.e. they are engaged in bonding.

(iv) The electrical conductivity is very low.

(v) The di-electrical material have -ve temp co-efficient of resistance.

Classification / types :-

Depending on the electrical dipole moment, dielectric material are classified into :

(1) Polar dielectric material

(2) Non-polar dielectric material.

Difference b/w Polar & non-polar DEM.

Polar DEM	Non-polar DEM
(i) It has inherent dipole moment	(i) It doesnot have dipole moment.
(ii) In the presence of electric field, the the +-ve charges are separated through the a small distance.	(ii) In the presence of electric field they cannot be separated by a small distance.
(iii) It shows the property of polarity	(iii) It doesnot show polarity.
(iv) These materials are polar compounds	(iv) These materials are non-polar compounds.
(v) The shape of the materials are symmetric	(v) the shape of the material are not symmetric.
(vi) Examples: amonia, NH_3,	(vi) Ex:- Benzene, ethane

Classification/type
Depending on the impact of physical parameters like temp, pressure etc, Dielectric materials are classified as:-
(1) Piezo electrical material → Piezo electrics
(2) Pyro electric material → Pyro electrics
(3) Ferro electric material → Ferroelectrics

Piezo	Pyro	Ferro
(i) These materials generate electricity even when mechanical stress is applied	These materials generate electricity when they are heated or cooled	These material shows electric polarization even in the
Ex:- (ii) crystals, Quartz, ammonium phosphate	Ex:- Quartz	Ex:- lithium niobite, Barrium titanite.
(iii) these materials are non-centro symmetric.	(iii) these materials are having uni-directional polarisation.	(iii) these material exhibit dielectric hysteresis.
(iv) these materials are non-polar in nature	(iv) These materials are non-centro symmetric.	(iv) Few ferro electric materials show both piezo and pyro properties.
uses ⇒ Generally it is used in microphones	uses Generally it is used in temperature sensor.	uses used in memory devices RAM

Application of dielectric materials:-
Dielectric materials are used widely in capacitor, transformer and different electrical devices.

Nano-Materials
When the size of the material (atoms) reduces to nano scale (10 nm to 100 nm) then various properties like electrical, physical, mechanical, optical, magnetic etc. have been enhanced.

Surface to volume ratio

$$S:V = \frac{4\pi R^2}{\frac{4}{3}\pi R^3} = \frac{3}{R}$$

Applications:

(i) Used in various structural application
(ii) Electrical circuits
(iii) Used as fabrics, textile.
(iv) Used as fibres.
(v) CNT - carbon-nano-tube
(vi) Used ~~as~~ as medicines / drugs.
(vii) Used in computers (hard disk)
(viii) Used as sensors.
(ix) Used in paint industries
(x) Used as nano composite materials

CNT - Carbon nano tube
Graphene
Fullerence

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Opto-electronics

(1) LASER - Light Amplification by Stimulated Emission Of Radiation

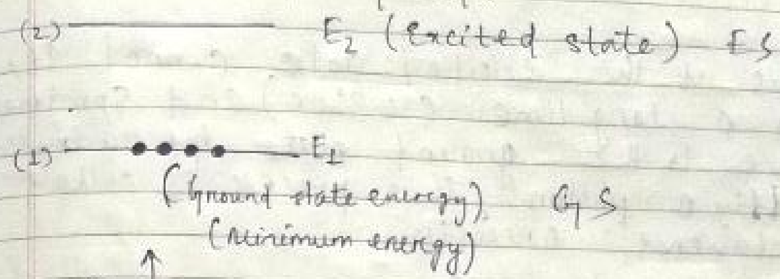
Characteristics of LASER :-

(i) It is highly intencified beam.
(ii) It is highly directive beam
(iii) It is highly coherence beam
(iv) More monochromatic light/beam

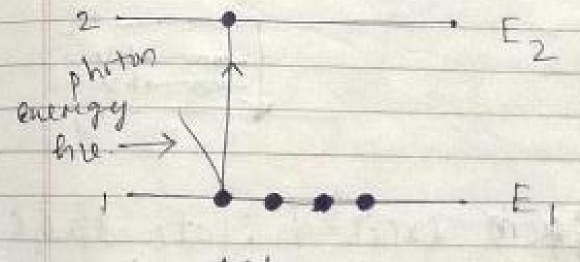
* Types of emissions :

1) Stimulated Absorption
2) Spontaneous Emission
3) Stimulated Emission

Stimulated Absorption :-



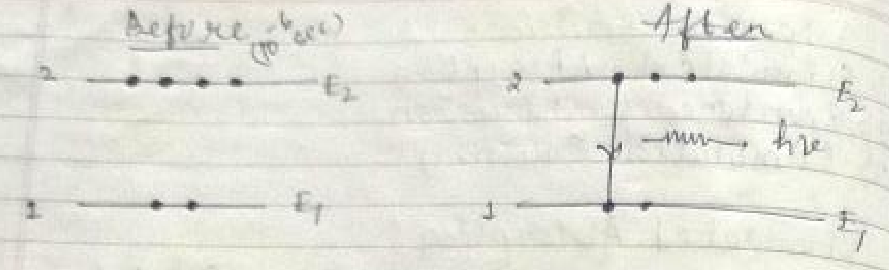
(Before)



After

Atoms are always available at GS (Ground state) and they move to higher excited state by absorption external ~~proton~~ photon. This process is called stimulated absorption.

Spontaneous emission :-



Atoms at the excited state cannot stay for a long time (10^{-6} sec) and spontaneously move to the ground state by radiating emitting a photon. This process is called spontaneous emission.

3) Stimulated Emission :-

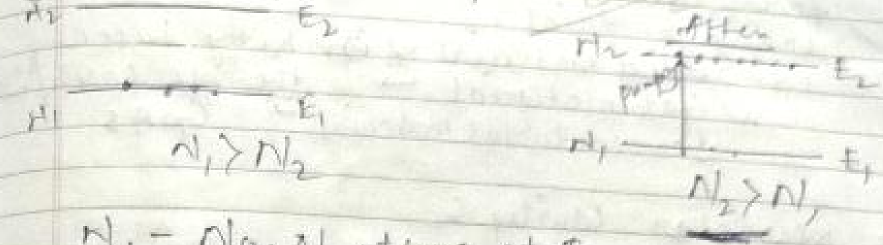
Atoms move from excited state to GS spontaneously by an external photon to produce 2 photons.
This process is called Stimulated emission.

Terms of LASER :-

1) Pumping :- It is a mechanism by which atoms are shifted / lifted to the ES

<u>EX</u> :- Optical pumping, Electric pumping chemical pumping

2) Population Inversion



N_1 - No. of atoms at E_1
N_2 - No. of atoms at E_2

→ Generally the no. of atoms at GS (N_1) is more than the no. of atoms at the ES (N_2) i.e $N_1 > N_2$

→ By pumping mechanism, the no. of atoms at the excited state is more then no. of atom in the GS i.e $N_2 > N_1$
This is called population inversion
Therefore population inversion can be achieved by pumping.

3. Active Center
The atom which is taking part in the lasing process is called active center.
Ex:- For Ruby laser → Cr
For He-Ne laser → Ne

4. Active medium :
It is the region / medium where the lasing process occurs

5. Lasing Material : the material which used

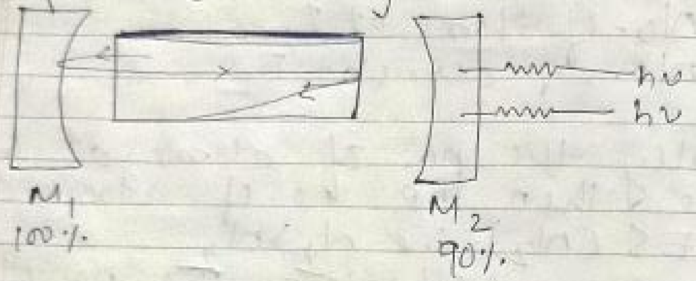
for lasing action is known as lasing material.

Ex:- Solid material → Ruby Laser

Gas material → He-Ne Laser

Semiconductor material → GaAs

6. Resonator Cavity :



→ The whole laser apparatus is kept in b/w 2 plate mirror.

→ 1 mirror is having perfectly reflecting surface (M_1)

→ Another is having partially reflecting surface (M_2)

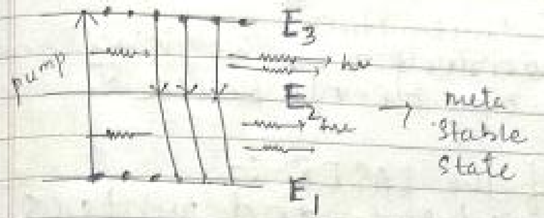
→ After amplification the laser beam is transmitted through the mirror M_2 as output ray/beam.

Classification or types of LASER :-

Depending on the working process it can be classified as

1) Three level laser
2) Four level laser

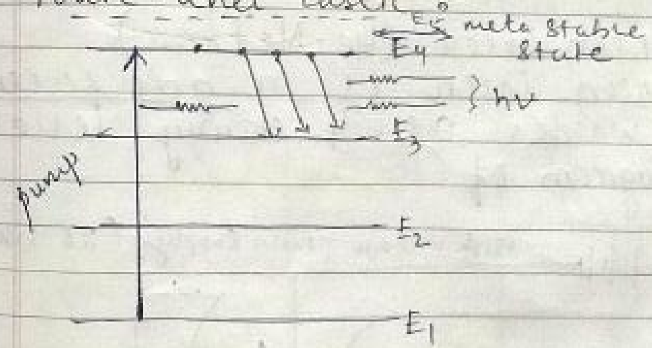
Three-level Laser :-



Meta Stable state :- It is an intermediate state b/w the higher state & its lower state where the atoms are staying for a long time as compare to the excited state

The lasing action occur b/w meta stable state and the lower level state. Ex:- Ruby laser

Four level laser :-



In 4-level laser, the lasing action occures b/w 4 energy levels where E_4 is the meta stable state & the lasing action occur b/w E_4 & E_3

Ex:- He-Ne laser

Imp^a **He-Ne Laser**

Imp Discuss the ~~constructure~~ construction, working and applications of He-Ne Laser

Applications of the LASER :-

(i) Used in computers and printers
(ii) Used for entertainment.
(iii) Used for target location in defence.
(iv) Used for laser welding.
(v) Used for medicad surgery (eye, dental, plastic surgery).
(vi) Used for medical applications.
(vii) Used for scientific applications.
(viii) Used for making small drills.
(ix) Used for reading OMR sheet & BCR (bar coded reading)

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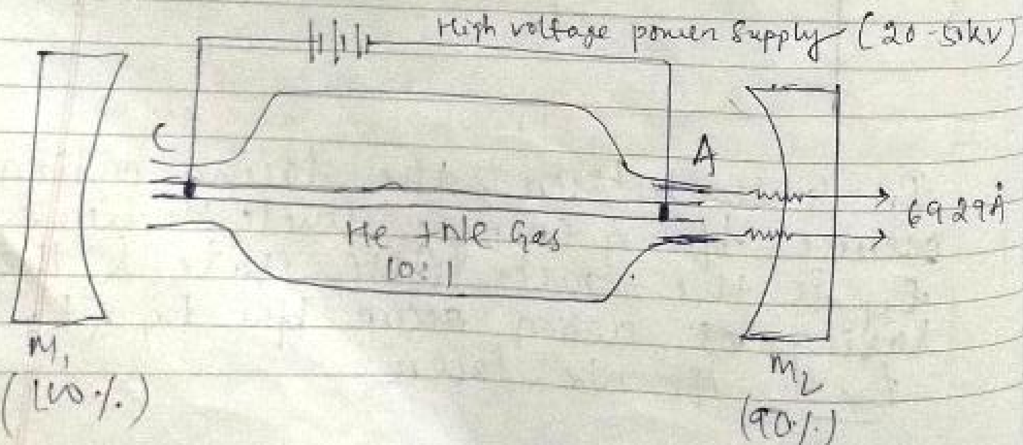
Helium-neon laser :(He-Ne Laser)

→ Helium-neon laser is a gas laser and it works as 4 energy level

→ The diagram of He-Ne Laser.



Construction :-

⇒ It is consist of very long and narrow discharge tube which contain a mixture of He-Ne gas with ratio 10:1.

→ Here Neon atom is the active center and Helium atoms are providing energy to the Neon atom.

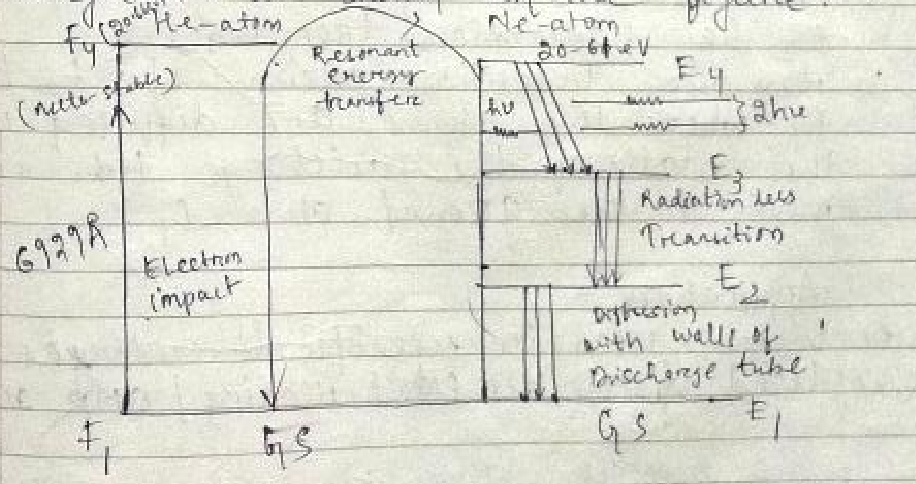
→ It consist of a cathode & anode connected to a very high voltage power supply. (20-50 kV)

→ Here the electric discharge is used for pumping mechanism.

→ The whole apparatus is kept in between the resonater cavity M_1 and M_2.

Working / Action :-

He-Ne laser works on the principle of 4 energy level and its energy level diagram is shown in the figure.



(i) When the power supply is activated then a high voltage passes through the gas mixture and electron and ions are produced by electric discharge (pumping).

(ii) The ~~ele~~ engeregic electron collides with He-Ne atoms and the atoms move to a meta stable state E_4 & E_4 respectively.

(iii) The helium atoms transfer the excess energy to the neon atom which is the active center by resonate energy transfer and the helium atom move to the ground state (E_1).

1) Neon atoms at the meta stable state E_4 move to the E_3 state by stimulated emission to produce the laser beam.

2) Now the transition occurs between E_3 to E_2 i.e. radiationless transition.

3) Now the transition occur b/w E_2 to E_1 where the atoms are diffused with the walls of the discharge tube and move to the ground state E_1.

Application :-

(i) Widely used in scientific laboratories.

(ii) Used for bar coded reading / OMR reading.

Optical fiber :- (Fiber optics) :-

→ Optical fiber are known as glass wires which are made of up glass materials like silica, quartz.

→ The wires/fibers are very thin having diameter (10-50) microns.

→ Optical fibers are used widely for statellite communication, telecommunication.

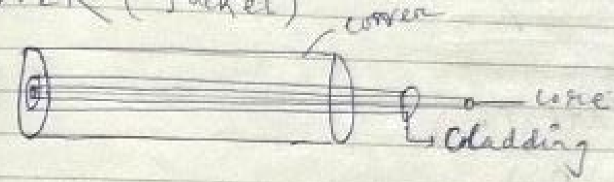
Parts of Fiber Optics :-

An optical fiber consists of 3 parts

1) CORE

2) CLADDING

3) COVER (Jacket)



Core :-

→ The center part of the optical fiber is called the core.

→ The core is made from a glass material having higher refractive index (n_1).

→ The diameter of the core is ~50 microns

Cladding :-

→ The core of optical fiber is surrounded by another glass material which is called the cladding.

→ The cladding is made from a glass material having low refractive index (n_2)

→ The diameter of the cladding is 50-100 microns.

Cover → The core & cladding are surrounded by a plastic or polymer material to protect the core & cladding is known as the cover.

→ The diameter of cover is 100-200 microns.

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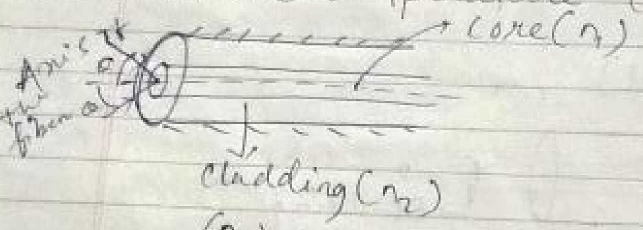
Terms / definition :-

1. Numerical Aperature (NA)



$(n_1 > n_2)$

It is defined as the light gathering capacity of the optical fibre. Mathematically, it is given by

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

n_1 – refractive index of core
n_2 = refractive index of cladding

2. Acceptance Angle (θ)
It is defined as the maximum angle of incidence of the input light within which light can pass through the fiber.
Mathematically, it is given as

$\boxed{\sin\theta = NA}$

$$\theta = \sin^{-1} NA$$

$$\boxed{\theta = \sin^{-1}\left(\sqrt{n_1^2 - n_2^2}\right)}$$

Total acceptance angle given as 2θ.

Q. The refractive index of core & cladding surfaces are 1.752 & 1.678 find NA & θ.

$$NA = \sqrt{n_1^2 - n_2^2} = \sqrt{(1.752)^2 - (1.678)^2}$$

$$= 0.503 \text{ (Ans)}$$

$$\theta = \sin^{-1}(0.503)$$

$$\theta = 30.19^\circ \text{ (Ans)}$$

Q. The NA of a fibre is 0.72 if the refractive of the core is 1.62 then find the θ & refractive of the cladding

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

$$NA^2 = n_1^2 - n_2^2$$

$$-n_2^2 = NA^2 - n_1^2$$

$$(0.72)^2 - (1.62)^2$$

$$0.51 - 2.62$$

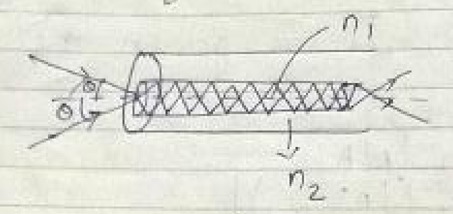
$$-n_2^2 = -2.11$$

$$n_2 = \sqrt{2.11}$$

$$n_2 = 1.45$$

$$\theta = \sin^{-1}(0.72) = 46.05^\circ$$

3. Principle of optical fibre :-



light sources passes through ~~the~~ the optical fiber by the successive total internal reflection. ($n_1 > n_2$)
This the principle of propagation of optical fibre.

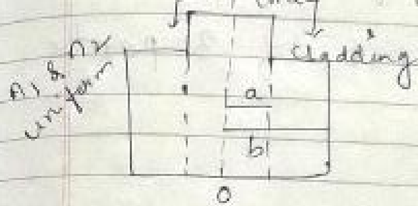
4. Types of Fibers :-
(a) according to the propagation of light :
There are 2 types:
1) Single mode fiber (SMF)
One light source can pass through the optical fiber.

2) Multimode fiber (MMF)
In this fiber many no. of light source can pass through the fiber.

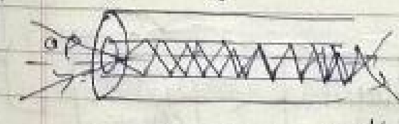
(b) According to RI of core / cladding.
2 types:
1) Step index fiber
2) Grad Index fiber

Step index fiber (SIF)

(i) In step IF the refractive index of core & cladding are uniform
(ii) The magnitude of core RI to the cladding RI is sudden. Hence it is known as SIF
(iii) Refractive index profile



(iv) path of the light
Since RI changes suddenly from core to cladding, then the light path through the fiber is zig-zag path.



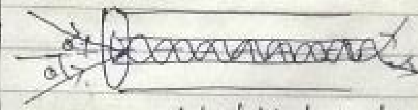
zig-zag path.

Grad Index fiber (GIF)

(i) In GIF, the RI of core is non-uniform whereas the RI of cladding is uniform.
(ii) The magnitude of refractive index of core gradually changes from the axis of the fiber toward the cladding.
(iii) RI profile

n_1 - varying
n_2 - uniform

(iv) path of the light



Helical path

Since, the core RI changes gradually toward the cladding, the path of the light through the fiber is helical path.

29/11/24

LQ

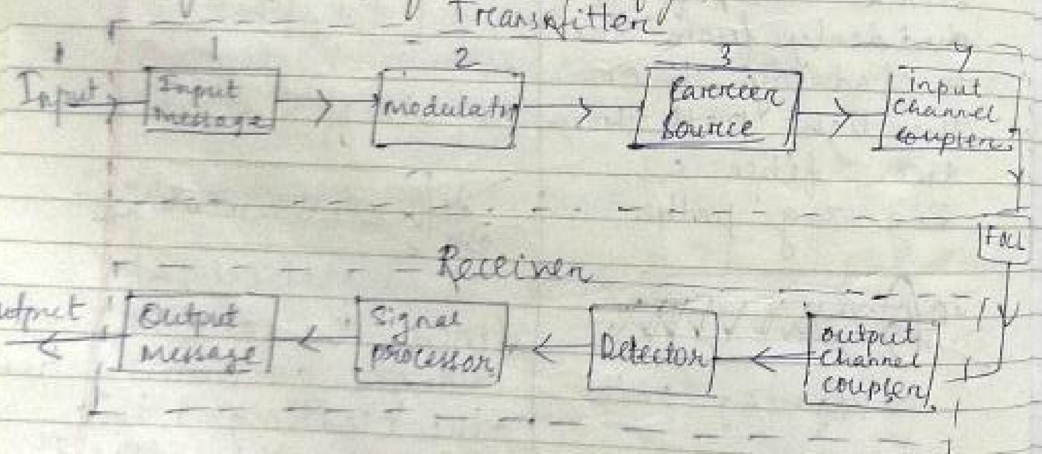
Fiber Optics Communication Link / System (FOCL / FOCS)

→ FOCL is widely used for communication system.

→ Generally it is consist of 3 parts

(a) transmitter
(b) Fiber link (FOCL)
(c) Receiver :

// The block diagram of FOCL / FOCS is given the following fig :-



(a) transmitter : It consist of
(i) input message
(ii) Modulator
(iii) Carrier Source
(iv) Input channel coupler

Input message :-
The non electrical signal like picture, sound etc are converted to electrical signal.

Modulator :- The information /data can be modulated and sent to the carrier source for transmission.

Carrier Source :- Generally laser, ~~...~~ LED or high frequency light source are used as carrier source for data transmission.

Input Chennel coupler :-
The modulated data through the carrier source are sent to the fiber link by input chennel coupler.

(b) FOCL :-
The data or information prepared by transmitter can be transmitted properly through FOCL.

(c) Receiver : It consists of
(i) Output channel coupler
(ii) Detector
(iii) Signal processor
(iv) Output message.

Output channel coupler :-
The information received through FOC...

Detector :-
The information or data is detected which was received from output channel coupler.

Signal processor :- In this unit the signal is processed for final transmissi...

Output message :- The electrical signal is converted to non-electrical signal.

Advantages :-
→ It has ~~...~~ immunity to electro magnetic interface.
→ It has high data security.
→ It is a non-conducting cable.
→ It has low weight and cost.
It has high bend width & high ~~connecting~~ conveying distance

Disadvantages :-
→ The cost for under laying is more as compared to over head connection.
→ Breaking of fibers
→ Replacing the fibers rather than repairing is costly.

Uses :-
→ ~~...~~ widely used in telecommunicating and satelite communication system.
→ It is used as different types of sensors like temperature, pressure, distance
→ Used in medical science.
ex :- endoscope
→ Used for super computers, rocket, satelites etc.

Fiber loss :-
During transmission of singal through the optical fiber, different factors (attenuating) are affecting the loss of signal (fiber loss)
Some factors are :-
(i) Loss due to dispersion.
(ii) loss due to bending.
(iii) loss due to material.
(iv) loss due to scattering.