KSU CET

S1 & S2 Notes

2019 Scheme

Manifest the leadership in you

MODULE - 5

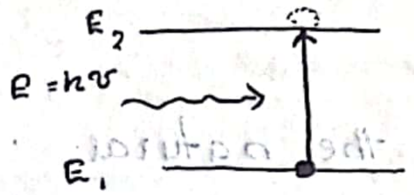
LASER (Light Amplification by Stimulated Emission of Radiation)

Properties :

1) Directionality
2) Monochromaticity
3) Coherence
4) Intensity & brightness.
5) Focussing

Interaction of light with atom

1) Stimulated absorption / induced absorption.



The phenomenon of transition of atoms from lower energy level E_1 to higher energy level E_2 by absorbing a photon of energy $h\nu$ is called stimulated absorption.

$$E_2 - E_1 = h\nu$$

energy absorbed by atom $= E_2 - E_1 = h\nu$

h → plank's constant

ν → frequency of photon

$$\nu = \frac{E_2 - E_1}{h}$$

Absorption rate eqn :

N_1 ⇒ no. of atoms / unit volume in E_1

Absorption rate is propotional to N_1 & also propotional to energy density of radiation in the atom (ρ)

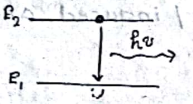
$$\frac{dN_1}{dt} \propto \rho N_1$$

$$\frac{dN_1}{dt} = B_{12}\rho N_1 \Rightarrow \text{Absorption rate equ}^n.$$

B_{12} is constant of propotionality, & it is called Einstein's coefficient of stimulated absorption.

a) Emission

i) spontaneous emission.



Emission of photons by the natural deexcitation transition of atoms, molecules, ions etc.

⇒ uncontrolled natural process.

⇒ Each atom emits photon independently. beam will be incoherent.

N_2 ⇒ no. of atoms per unit volume in E_2.

Rate of spontaneous emission is directly propotional to the N_2

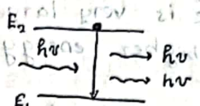
$$\frac{dN_2}{dt} \propto N_2$$

$$\frac{dN_2}{dt} = A_{21}N_2.$$

A_{21} ⇒ Einstein's co-efficient of spontaneous emission.

(represents probability of spontaneous emission)

ii) stimulated emission.



⇒ controlleble process

⇒ Incident photon & stimulated photon are ~~face~~ phase with each other. Both are coherent.

⇒ continued as chain action. large no. of photons produced in short time.

$$\frac{dN_2}{dt} \propto N_2 \qquad \rho \rightarrow \text{energy density of radiation.}$$

$$\frac{dN_2}{dt} \propto B_{21}\rho N_2.$$

B_{21} → Einstein's co-efficient of stimulated emition

Einstein's coefficient are mathematical quantity which are a measure of probability of absorption or emission of light by an atom or molecule.

Population inversion

No. of atoms in energy level is known as population of that energy level.

Ground level is densily populated than excited level (in normal temp.)

⇒ The particular state in which the excited level is densily populated than ground level is called inverse population inversion.

Population inversion is the essential condition for stimulated emission to over right absorption.

Metastable state. (upper lasing level)

The state were the life time is very large is called meta stable state. higher energy state.

Diff. b/w spontaneous emission & stimulated emission.

Spontaneous emission	stimulated emission.
=> Excited atom return to lower energy state without help of any external agency.	with help of external agency excited atom return to lower energy state
=> The emission is not due to population inversion	Due to population inversion
=> uncontrolled process	controlled regular process
=> rate of emission depends on the no. of atoms in excited state	rate of emission depends on the no. of atoms in excited state & energy density
=> The photon emitted by the proces will not be coherent	- Photon emitted is coherent & unidirectional
=> emission can't be multiplyed by chain reaction.	Emission can be multiplyed by chain reaction.
=> travelling diff. direcⁿ as white light	=> travelling in a particular direcⁿ as a narrow beam with defenite frequency
beam is not monochromatic	beam is monochromatic

A : Einstein's coefficient of spontaneous emission

B : Einstein's coefficient of stimulated emission

[rate of stimulated absorption = rate of stimulated emission.]

$$B_{12} = B_{21}$$

$$\frac{A}{B} = \frac{8\pi h\nu^3}{c^3}$$

$$\frac{A}{B} = \frac{8\pi h}{\lambda^3}$$

Basic components of laser

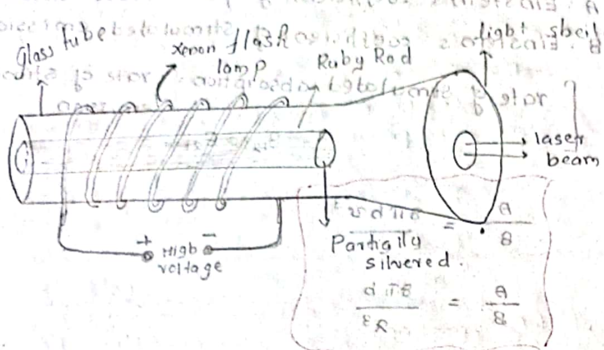
1) Active medium : population inversion take place. (lasing medium)
   - Solid laser – Ruby laser.
   - gas laser – He-Ne laser,

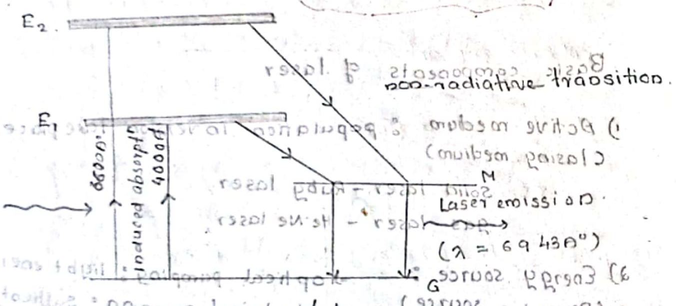
2) Energy source : (Pumping source)
   - => optical pumping : light energy
   - => electrical pumping : Suffient intense electric discharg
   - => chemical " : exothermic chemical reacⁿ.
   - => heat "
   - => electron beam "

   ~~hat~~ heat pumping : Active material is heated to high tempt & rapidly cool to get necess ary population inversion.

3) optical resonator cavity : ~~High intense~~ to obtain high intense beam.

Ruby laser :





E_1, E_2 = higher energy state

M = Metastable state (energy level diagram)

G = Ground level

⇒ The first developed laser by Teodor Maiman.

⇒ It is a 3 level solid state laser.

⇒ Active material : Ruby rod

→ optical pumping : light energy : Xeon flash lamp.

⇒ optical resonant : 2 end faces of ruby rod forms optical resonant.

⇒ Cr^{3+} give pink clr to Ruby.

Applica^n

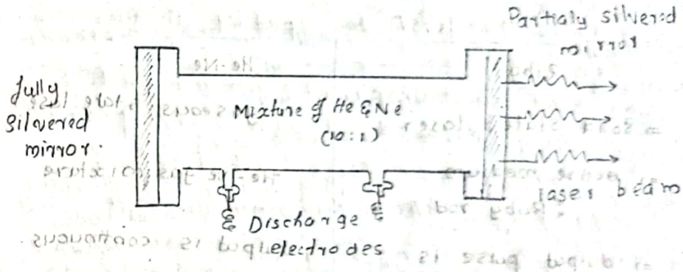
⇒ Used remote sensing

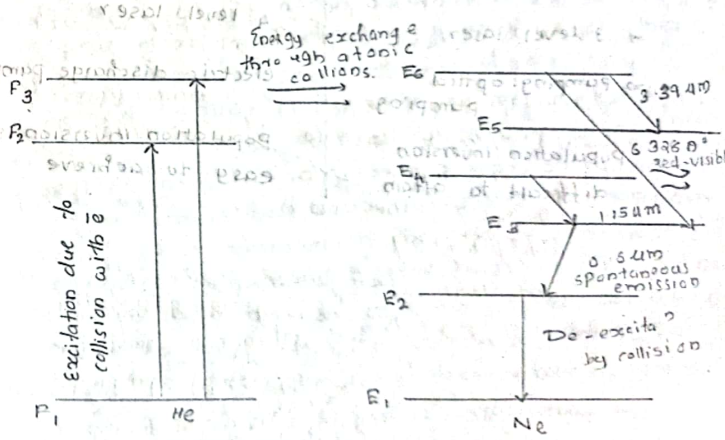
⇒ Used for drilling, welding

⇒ used for surgery, opthalmology

⇒ used for spectoscopy

He - Ne laser





⇒ He-Ne mixture (10:1)

⇒ 4 level gas laser

⇒ Active medium : He-Ne gas mixture

⇒ Pumping source : Electric discharge pumping

⇒ optical resonator : Mirrors M_1 & M_2.

He - pumping agent

Ne - Lasing agent

Advantage

⇒ continuous

⇒ stabe frequency.

Ruby	He-Ne
⇒ Solid state laser	gaseous state laser
⇒ active medium : Ruby rod	He-Ne gas mixture
⇒ output pulse is not continuous	output is continuous.
⇒ 3 level laser	4 level laser
⇒ Pumping: optical pumping	electric dischage pumping
Population inversion difficult to attain.	Population inversion is easy to achieve

20/06/20 Tutorial_3

1) what are the basic components of laser system? How are these requirements satisfied in the case of a Ruby laser?

(i) Active medium

(ii) Pumping source

(iii) optical resonator.

In the case of Ruby laser:

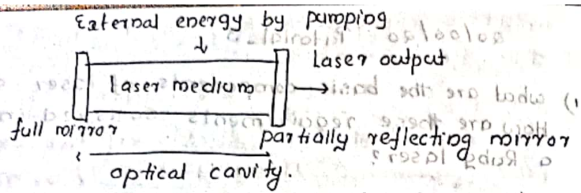
⇒ Active medium : Ruby rod. Al_2O_3 is doped with Cr)

⇒ Pumping source : optical pumping - xenon flash tube.

⇒ optical resonator : 2 end faces of the ruby rod. one is fully silvered & other is partially silvered

2) what is an optical resonator? Explain its role in laser emission.

It is a laser device similar to the resonant circuit of an oscillator. It consist of a pair of mirrors (M_1 & M_2) facing each other & set on the axis. One of the mirror is fully silvered so that it is 100% reflecting but M_2 is partially silvered so that it is partially reflecting & partially transparent or provided with a small hole along the axis of the resonater to let laser beam out of the device. The active material is placed b/w the mirrors. The photons emitted during stimulated emission are reflecting b/w M_1 & M_2 many times. In each time they stimulate more excited atoms to jump back to ground state. Hence, a large number of coherent, monochromatic photons are produce & emerges through partially silvered mirror M_2 as laser beam.



3) Explain the construction & working of a ruby laser with schematic & energy level diagram.

=> It is a 3 level solid state laser.

=> It is the first developed by Theoder Maiman in 1960

=> Ruby is a transparent, pink coloured precious stone of Al_2O_3 doped with 0.05% of Cr_2O_3

=> Energy source : Xenon flash tube

=> pumping : optical pumping

=> Lasing medium : Ruby rod

=> optical resonator : 2 end faces of the ruby rod. one is fully silvered, & the other is partially silvered.

Working :

=> Ruby cylinder is enclosed in a cylindrical glass tube surrounding with xenon flash tube. ~~as~~ in Xenon flash tube provides enough energy for optical pumping

-> When Xenon flash tube is on, the Cr^{3+} ion absorbs the energy & get excited to higher energy levels.

-> Transition to E_1 & E_2 are caused by 6600 Å & 4000 Å respectively

-> Since the life time of E_1 & E_2 is too small, they are suddenly jumps to metastable state M.

-> Thus, the transition from excited states to metastable state is non radiative transition or in other words there is no emission of photons.

-> Since the life time of metastable state is higher (10^{-3} sec) no. of Cr ions get increased & population inversion is achieved

-> The spontaneously emitted photons in the system stimulate the laser action.

-> Large no. of photons are emitted by stimulated emission from metastable state to ground state.

-> These photons are shuttled b/w 2 end faces of the rod, thus highly coherent beam is produced.

-> Wavelength of laser output is ~~693~~ 6943 Å.

Overheating is avoided by cooling the system using a coolant like liquid nitrogen which is circulated around the rod.

4) Draw neat diagram of He-Ne laser & explain its construction. Explain its working with the help of energy level diagram.

⇒ The first gas laser to be operated successfully
⇒ It is a 4 level gas laser
⇒ Energy source: RF discharge power
⇒ pumping: electric discharge pumping
⇒ Lasing medium: He-Ne gas mixture (10:1)
⇒ optical resonator: 2 mirrors M_1 & M_2
⇒ Here He is pumping agent & Ne is lasing agent.

Construction:

The He-Ne laser consist of a long & narrow discharge tube which is filled He & Ne in ratio 10:1. The electrodes are connected to a high voltage source of few kV dc. The mirror are arranged on either end of the tube - one totally reflecting & other partially reflecting. The end windows of the tube are set at Brewster's angle, so that output beam is plane polarized.

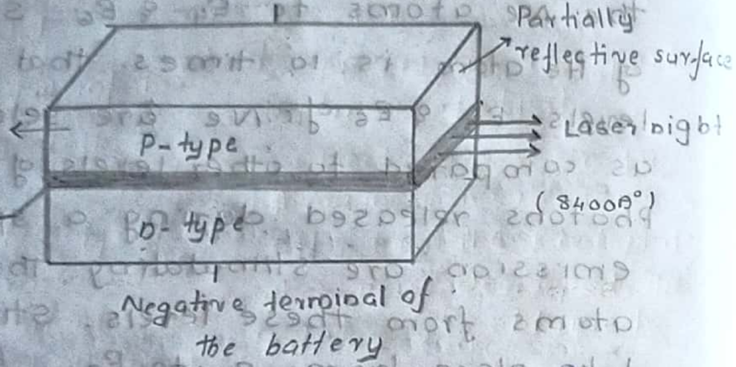
Working:

When an electrical discharge is passed through the gas, the e which are accelerated down the tube collide with He & Ne atoms & excite them to higher energy levels. The He atoms tend to accumulate at levels F_2 & F_3 due to their long life times.

The level E_4 & E_6 of Ne atoms have almost the same energy as F_2 & F_3. As a result the excited He atoms colliding with the Ne atoms in the ground state can excite the Ne atoms to E_4 & E_6. Since the pressure of He atom is 10 times that of Ne, the levels E_4 & E_6 of Ne are selectively populated as compared to other levels of Ne. Some of the photons released during a spontaneous emission are stimulating the excited Ne atoms from these levels. Stimulated emission take place from E_6 to E_5, E_6 to E_3 & E_4 to E_3 emitting the flowing radiations.

1. E_6 to E_3 transition produces a laser beam of wavelength 6328 Å. It is in the visible region. The beam is red in colour & it is the most important beam.
2. E_6 to E_5 transition produces a laser beam of wavelength 3.39 μm in the far infrared region.
3. E_4 to E_3 transition produces a laser beam of wavelength 1.15 μm in the far infrared region. The quantity & quality are enhanced by the shuttling of photons b/w the reflecting mirrors M_1 & M_2. Finally the laser beam is emerging through the partially polished mirror. The windows permit only those vibrations which are parallel to the direction. So we get a continuous supply of plane polarized light.

Semi-conductor laser / laser diode.



=> P-n junction diode

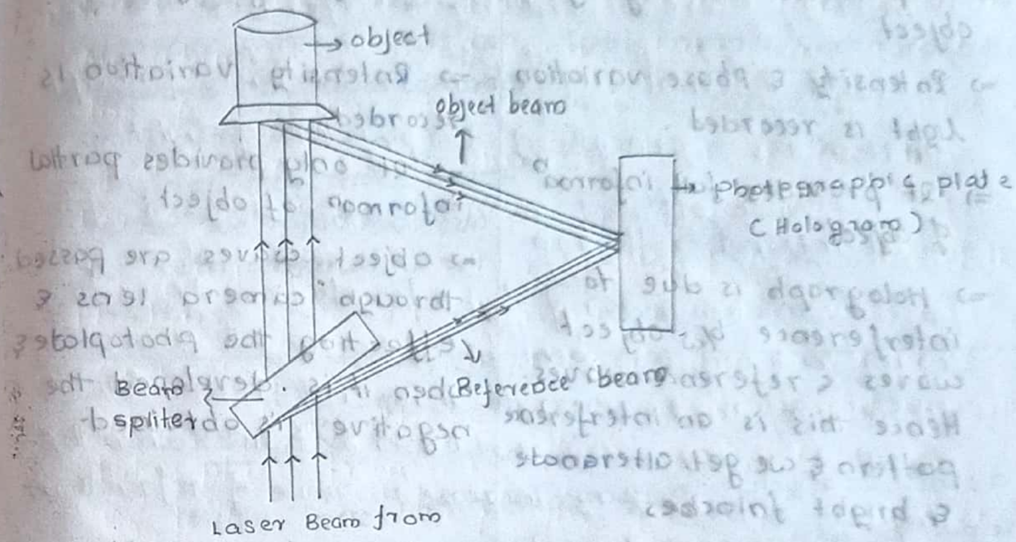
=> Active medium: Depletion region

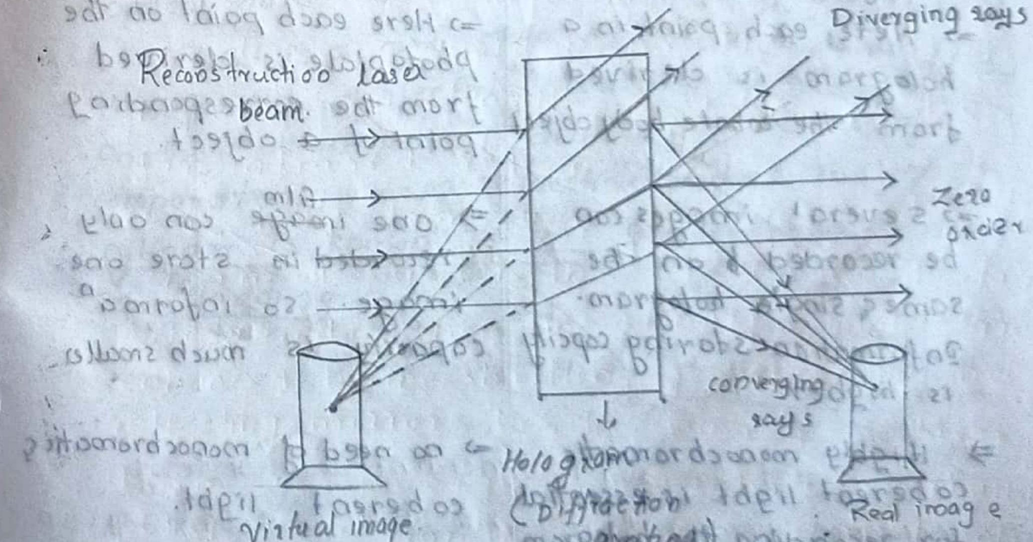
=> Pumping source: forward biasing.

=> optical resonator: 2 end faces

$E_g = h\nu$ E_g: Band gap energy (J)

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





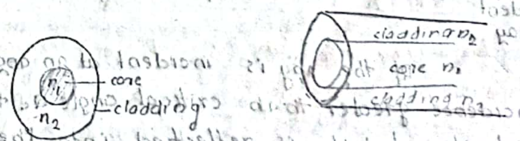
Holograph	ordinary photograph.
=> It provides 3D image of object.	=> 2D image of object.
=> Intensity & Phase variation light is recorded.	=> Intensity variation is recorded.
=> It provides full informa^n of object	=> It only provides partial informa^n of object.
=> Holograph is due to interference b/w object waves & reference waves. Hence this is an interference pattern & we get alternate dark & bright frinches	=> object waves are passed through camera lens & effecting the photoplate & when it is developed the negative is obtained.
=> There is no resembles b/w ~~negative plate &~~ ~~image~~. the object & image.	=> There is resembles b/w negative plate & image
=> Here each point in a hologram is derived from the whole body object	=> Here each point on the photoplate is derived from the corresponding point of a object.
=> Several images can be recorded & on the same & single hologram. Information storing capcity is higher.	=> One ~~image~~ film can only ~~recorded~~ in store one image. So informa^n capacity is much smaller.
⇒ Highly monochromatic coherent light is essential for recording the hologram	=> no need of monochromatic & coherent light.
=> lenses, photoplate, chemical process are not required	=> consist of lenses, Photoplates & chemical process.
=> Informa^n can be recorded in the form of Interference pattern using particular reference waves. This can ~~Informa~~ be read & decorded only with the help of original reference beam Hence the infor ma^n can be kept confidential & secret.	=> Information is recorded with ordinary light & hence the informa^n can't kept secret & confidential.

FIBRE OPTICS

Fibre optics is the branch of physics which deals with the transmission & reception of light waves using optical fibres which acts as a guiding media.

optical fibre

It is a very thin cylindrical shaped, transparent, dielectric material surrounded by another transparent dielectric material of comparatively lower refrective index. The inner cylinder is known as core & outer cylinder is known as cladding



n_1 : refractive index of core

n_2 : refractive index of cladding

$n_1 > n_2$

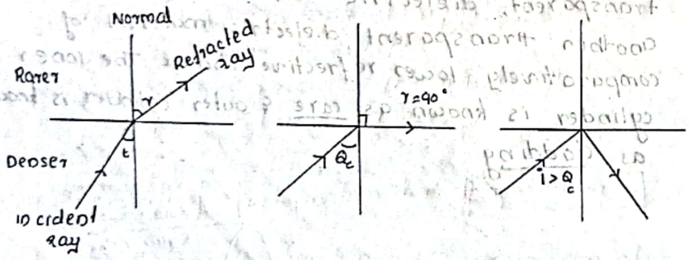
→ Light admitted through one end of the core propagate through it by repeated total internal reflection at the boundary of core & cladding interference.

Total internal reflection is the basic principle of fibre optics principle of propagation of light.

Total internal reflection

when a ray of light travels from denser to rarer medium, it is bent from the normal. ie angle of reflection in the rarer medium is greater than the angle of incidence in the denser medium. when the angle of incidence is increased, angle of refraction also get increased.

Angle of incidence in the denser medium for which the refracted ray is grazing along the surface of seperaⁿ of the media is called critical angle θ



If the ray is incident at an angle of incidence greater than critical angle θ_c the ray is not refracted but it is reflected into the same denser medium. This is called total internal reflection.

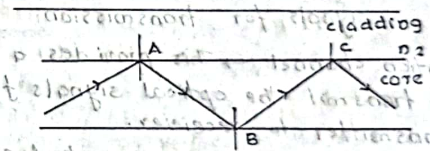
Internal reflection

Conditions for total internal reflection are

1) The ray must travel from denser to rarer medium
2) Angle of incidence in the denser medium must be greater than the critical angle θ_c

Propagation of light through an optic fibre.

In an optic fibre, the innermost cylindrical layer is called core. It is made of glass & its refractive index is higher. So it is a denser medium. This layer is surrounded by another cylindrical shell called cladding. It is also made of glass & it refractive index is made smaller so it is a rarer medium.



when a ray of light is incident from core to the cladding at an angle of incidence 'i', greater than the critical angle at A, it undergoes total internal reflection at the core-cladding interface. And it is again incident at B at an angle greater than critical angle on the core-cladding interface. So it again undergoes TIR & the ray is travelling along BC. The g ray is undergoing successive total internal reflection at points on the core - cladding interface. Thus the wave is propagated through the optical fibre in zig-zag manner by the multiple total internal reflection principle without any loss of energy.

Fibre optic communication system.

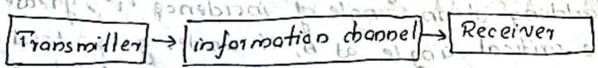
One of the most important applications of optic fibre is in the field of communication system. Optic fibre communication system has so many advantages over traditional system of communication like radiofrequency communication. Optic fibre communication system basically consist of 3 sections

1) Transmitter
2) Information channel
3) Receiver.

Transmitter → This converts electrical signals into optical signals for transmission.

Information channel → This provides a path / passage to transmit the optical signals from the transmitter to receiver.

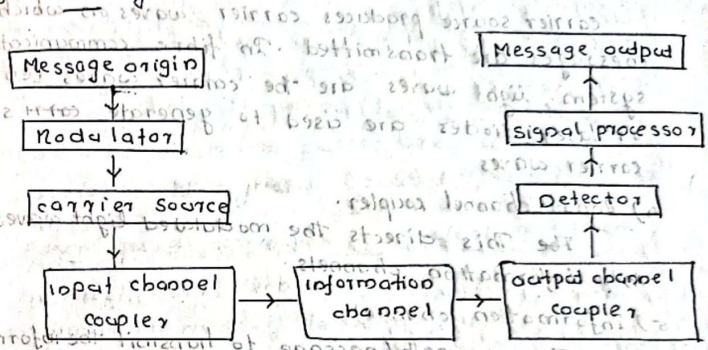
Receiver → This receives the optical signals & converts back into electrical signals.



Block diagram & functions of each components:

The message origin, modulator, carrier source & input channel coupler together constitute transmitter. Optic fibre are used as information channel. Output channel couple detector, signal processor & message output constitute receiver.

Block diagram



Function of each components

1) Message origin

Message origin converts all the non- electrical message into electrical signals using a transmitter.

eg: Microphone converts sound energy into electrical energy.

2) Modulator.

Imposing a message on a carrier wave for propagation is called modulation.

It has 2 main functions:

i) It converts the electrical message into the proper format.

ii) It impress this signal onto the wave generated by the carrier source.

2 distinct categories of modulation are used, ie analog modulation & digital modulation. In optic fibre communication digital modulation is preferred since the message can be transmitted

over a large distance with very low power.

3) Carrier source.

Carrier source produces carrier waves on which the messages are transmitted. In fibre communication system, light waves are the carrier waves. LEDs or laser diodes are used to generate ~~carri~~ stable carrier waves

4) Input channel coupler.

~~The~~ This directs the modulated light waves into information channels.

5) Information channel.

This is a path/passage to transmit the informa^n from a transmitter to the receiver. ie it conveys the modulated light signals from the input channel coupler to the output channel coupler.

Here very fine & long optic fibres are used as information channel. Modulated light signals are transmitted through the optic fibre over very large distances by the principle of multiple total internal reflections.

6) Output channel coupler.

This directs the modulated light signals from the information channel (optic fibre) to the detector.

7) Detector.

This detects & seperates the message from the modulated signals. ie the demodulation takeplace. Here light signals are converted into electric current using a photo detector.

8) Signal processor

This fillters & selects the required frequency from the waves. The selected frequency is amplified. The unwanted frequency is filtered out.

9) Message output.

Here original message is reproduced from the signal. The electrical pulses are converted into non-electrical signals (sound, pictures, video)

Advantages of optic fibre communication system.

Optical fibre technology is replacing the conventional mode of telecommunication network, primarily because of extreme large information carrying capacity of light waves & the cost effectiveness of optical fibres. Optical fibres have several other additional advantages from conventional cables.

1. Extremely ~~&~~ wide band width

This mean that a greater volume of information or message can be carried out over in a fibre optic system.

2. Smaller diameter, lighter weight cable.

Optical fibres because of their light weight & flexibility can be handled more easily than copper cable.

3. Lack of cross talk b/w parallel fibres.

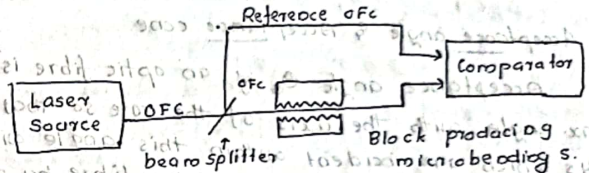
In conventional communication circuits signals often stay from circuit to another, resulting in other calls being heard in the background. So since total internal reflection is the basic principle behind optic fibre communication. there is no leakage of signal. Hence no cross talk.

4) Electrical isolation:
The optical fibres are made of glass & plastics. These are very good electrical insulators. i.e optic fibre cables are electrically isolated.

5) low cost
6) low transmission loss
7) Much safer than Cu cables
8) Templ resistant
9) flexible & strong
10) longer life span
11) Immunity to electromagnetic interference:
The optical fibre are made from glass & plastics. They are insulators & free from electromagnetic interference & radio frequency interferences.

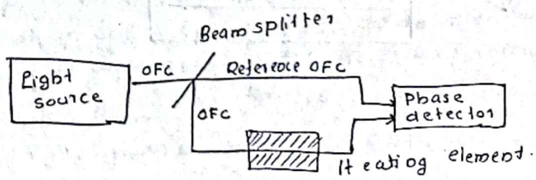
Fibre optic sensors:
Fibre optic sensors are very sensitive devices used to measure physical quantities like, templ, pressure, displacement, liquid level, electric current rotation etc - very accurately with the help of optic fibres.
A sensor has 3 components - a source of light, a fibre coil for sensing & a detector

There are diff. types of fibre optic sensors
1) Intensity modulated sensor
Here a change in physical parameter produces a change in intensity of light through fibre which can be measured & calibrated to find the physical parameters.



→ Laser light from the source is passed through a reference fibre & through a fibre placed b/w blocks.
→ If a force is applied on the block, it produces micro bendings in the fibre.
→ Due to this bending, some intensity of light is lossed & can be calculated by comparing with reference fibre.

2) Phase modulated sensor
→ Here a change in physical parameter produces a change in phase of light which can be detected & calculated for measuring physical quantity.
eg: Templ sensor.



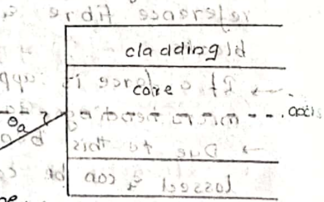
→ Light from the source is passed through a reference fibre & a fibre which is passing through a heating element.

→ when heat is applied, the length of fibre increases, which produces a phase change of at light.

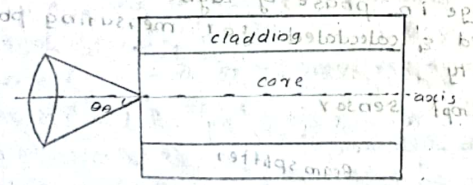
→ It can be detected by comparing with reference fibre & calculated.

Acceptance angle & Acceptance cone.

Acceptance angle θ_a of an optic fibre is that max. angle with the axis of the core so that all the rays which are incident within this angle will be accepted & propagated through the fibre by multiple total internal reflection.



A cone at the end of the fibre with the acceptance angle as semi-vertex angle with the axis of the core is called acceptance cone. All the light rays incident within this cone will be accepted & transmitted.



Numerical Aperture (NA)

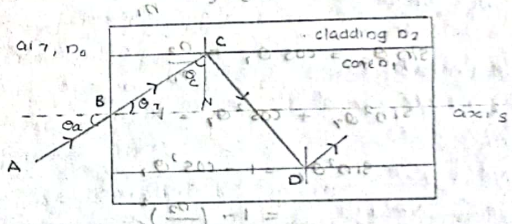
It is the light gathering power of an optic fibre. It measures the amount of light accepted by the fibre. Numerical aperature (NA) represents the sensibility/fig. of merit of the fibre.

Numerical Aperture (NA) of an optic fibre is the sine of acceptance angle θ_a.

$$NA = \sin\theta_a$$

NA depends on the acceptance angle. If θ_a is larger NA will also be higher. If NA is larger, fibre can accept more light from the source. Numerical aperture is b/w 0.13 & 0.50.

Derivation



Consider a light ray AB incident at B at the edge of the core of an optic fibre from the air. It is incident at an angle θ_a with the axis of the core. It is refracted along BC at an angle θ_r (critical propagation angle). This refracted ray is incident at C, at an angle just greater than the critical angle. hence it undergoes total internal reflection.

At B, By Snell's law,

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

$n_0 \sin\theta_a = n_1 \sin\theta_r$

$\sin\theta_a = n_1 \sin\theta_r$ ($n_0 = 1$, air) —— (1)

Ado. NA = $\sin\theta_a$

$NA = n_1 \sin\theta_r$ —— (2)

In $\triangle BCN$, $\cos\theta_r = \frac{BN}{BC}$

$\sin\theta_c = \frac{BN}{BC}$

$\cos\theta_r = \sin\theta_c$ —— (3)

At C, at critical angle, $\frac{\sin\theta_c}{\sin 90} = \frac{n_2}{n_1}$

$\sin\theta_c = \frac{n_2}{n_1}$ —— (4)

$\sin\theta_c = \cos\theta_r = \frac{n_2}{n_1}$

$\sin^2\theta_r + \cos^2\theta_r = 1$

$\sin^2\theta_r = 1 - \cos^2\theta_r$

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

$= \frac{n_1^2 - n_2^2}{n_1^2}$

$n_1^2 \sin^2\theta_r = n_1^2 - n_2^2$

from eqn (2) $\Rightarrow n_1 \sin\theta_r = NA$.

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

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

(represents aperture in terms of n_1 & n_2.)

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

$NA = \sin\theta_a$

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

where n_1 → refractive index of core.

n_2 → " cladding

θ_a → acceptance angle

θ_c → critical angle

NA → Neumerical Aperature.

Q. If an optic fibre has a core of refractive index 1.52 & cladding of refractive index 1.42. then calculate NA, acceptance angle & critical angle.

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

$= \sqrt{1.52^2 - 1.42^2}$

$= 0.5422$

$NA = \sin\theta_a$

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

$= \sin^{-1}(0.5422)$

$= 32° 50'$

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

the critical angle $\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$

$= \sin^{-1}\left(\frac{1.42}{1.52}\right)$

$= 69° 6'$

Q. The numerical aperture of an optic fibre is 0.295 & refractive index of core is 1.54. Calculate the refractive index of the cladding & the acceptance angle.

NA = 0.295

$n_1 = 1.54$.

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

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

$$= 1.54^2 - 0.295^2$$

$$= 2.28$$

$$n_2 = 1.51$$

$$\theta_a = \sin^{-1}(NA) = \sin^{-1}(0.295)$$

$$= 17.157^\circ = 17^\circ 9'$$

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

$NA = \sin\theta_a$

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

2. The neumerical aperture of an optic fibre is 0.5075 & the refractive index of the cladding is 1.475. Calculate the refractive index of the core, acceptance angle & critical angle for TIR.

$NA = 0.5075$

$n_2 = 1.475$

$n_1 = ?$

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

$n_1^2 = NA^2 + n_2^2 = 0.5075^2 + 1.475^2$

$= 2.43$

$n_1 = 1.55$

$$\theta_A = \sin^{-1}(NA) = \sin^{-1}(0.5075)$$

$$= 30.49^\circ = 30^\circ 29' 24''$$

$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right) = \sin^{-1}\left(\frac{1.475}{1.55}\right)$$

$$= 72.10^\circ = 72^\circ 6'$$

Classification of optic fibre.

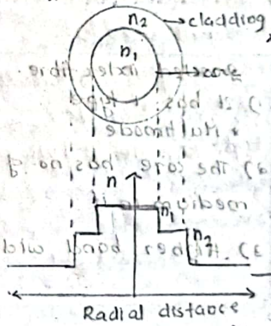
Optic fibres are classified into 2.

1) step index fibre 2) Graded index fibre.

1) Step index fibre.

An optic fibre with a core of constant refractive index(n_1) & a cladding of slightly lower refractive index (n_2) is known as step index fibre.

Step index fibre is characterized by a core having const (completely uniform) refractive index through out its bulk.



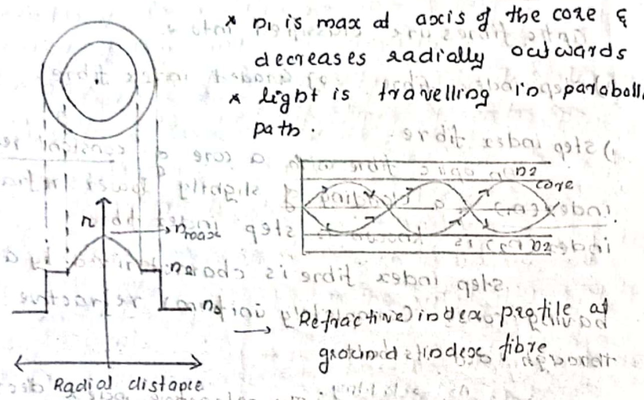
* The refractive index decreases from n_1 to n_2 abruptly at the core-cladding boundary.
* Due to the step like profile, it's called step index fibre.

2) Graded index fibre

A graded index fibre is characterized by a core made of very thin layers of transparent material of gradually diminishing refractive index. It is surrounded by a cladding made of material having lower but const refractive index.

Because of the gradual diminishing of the refractive index, the light incident on one end of the core undergoes a bending towards the axis & finally reflected back at the core-cladding interface.

* Here n_1 is varying & n_2 is const.
* n_1 is max at axis of the core & decreases radially outwards
* light is travelling in parabollic path.



→ Refractive index profile of graded index fibre

Additional

step index fibre	graded index fibre
1) It has 2 types * Single mode * Multiple mode	1) It has 1 type * Multimode
2) The core has only one medium in it.	2) The core has no. of medium in it
3) Lower band width	3) Higher band width.

Industrial & technological applications.

1. optical fibres are used as sensors to measure or monitor displacement, pressure, tempt, flow rate, liquid level, chemical composition etc.
2. optical fibre has wide application in security alarm systems, electronic instrumentation system, industrial automation.
3. They are used for remote monitoring & surveilliance.
4. They are used in cable T.V, CCTV, LAN, WAN etc.
5. They are used for signalling & decorative purpose.
6. They are used for transfer of infrared energy.
7. They are used to know the level of atm pollution & presence of foreign suspended particles. A beam of light sent from one end of a fibre get scattered by the particles & from the variation of the intensity of the received light the extent of pollution can be accounted.
8. Fibre optic system maintain high secrecy, so they are used in defence communication system in controlling ships, aircrafts, submarines, missiles.
9. Intranet & internet connections are made through optical fibre.
10. A fibre optic communication system has a large band width so that it can be accomodate a large no. of channels. Fibre optic system are suitable for the transmission of digital data generated by computers.
11. They are used to send a large no. of telephone signal without any interference.

Medical applications

1. Optical fibre are used as biosensors to measure & monitor many significant parameters in the human body, including tempt, blood pressure, blood flow, O_2 saturation levels & to estimate the proportion of haemoglobin in the blood.
2. They are used to test the tissues & blood vessels which are far below the skin.

3. They are also used to examine heart, pancrease etc

4. Endoscope is a tubular optical instrument using optical fibre to visualise the internal parts of human body without performing surgery. There are diff. types of endoscope.

a) Gastroscope - Examine the stomach & to photograph tumors & ulcers.

b) Bronchoscope - to see upper passages of lungs.

c) Orthoscope - to see the small spaces within joints.

d) Peritoneoscope - to test the abdominal cavity lower parts of liver & gall bladder.

e) Cytoscope - to tumors, inflammation & stone in the urinary bladder.

f) Couldscope - to test female pelvic organs.

~~NANO~~.

NANO TECHNOLOGY

visible rays - 300 - 600 nm.

Human eye resolution : 0.20 mm
with lens : 0.1 mm

materials [Synthesised
→ natural.

→ Normal grains in solids 1-10 Nm.

→ SEM : Scanning e microscope (1981)

Atomic limit : 0.1 - 0.2 nm.

→ X-ray : 0.1 - 10 nm
(distance b/w atoms in ~~rang~~ a crystal)

→ Nano - Dwarf (Greek)

→ Nano scale : 0.1 - 100 nm.

→ Nano Science : is the science of objects in the size regime of ~~nan~~ nanometers where matter exibibits unusual properties.

→ 29th Dec 1959 : Ridhard Feynmann,
'There ~~a~~ is plenty of room ~~at the~~ at the bottom.

→ Norio Taniguchei in 1974 coined the term 'Nano technology'

→ Bottom up approach.

→ Natures nano : Lotus leaf : water reppeallent.
~~Spe~~ Spiders web : strength.
Butterfly feathers - colours.
→ Gecko's fell - stickey effect
→ Hb - 5 nm.
→ manmade nanotechnology - wootz steel (600BC)

- Lycurgus cups (AD 004)

Human hair - 80,000 nm width (80 μm)

RBC - 7000 nm wide (7 μm)

→ Nano science is a convergence of physics, chemistry, material science & biology which deals with the manipulation & characterisation of matter on length scale b/w molecular & microsize.

→ Nanotechnology is the principle of manipulation of atom by atom through control of the structure of matter and the molecular level.

It entails the ability to build molecular systems with atom by atom precision, yielding a variety of nanomaterials.

→ engine of creation - The coming era of Nanotechnology (by Eric Drexler (1986)).

Significance of the nanoscale.

→ Most of the properties of a solid depends on the size of the solid.

→ Bulk material properties like resistivity, density, elastic modulus etc are averaged properties.

→ when the size of the material become smaller & smaller, this averaging no longer works & the properties of materials change drastically in nanometer range.

→ 2 main factors that causes significant change in the properties of nanomaterials are

1) increased surface to volume ratio

2) Quantum confinement

surface to volume ratio

→ It is assumed that the particles are spherical then

$$\frac{\text{Surface area}}{\text{volume}} = \frac{4\pi R^2}{4/3\pi R^3} = \frac{3}{R}$$

→ for cube. $= \frac{6\times a^2}{a^3} = \frac{6}{a}$

→ ~~Ionic~~ As particle size decreases a greater proportion of atoms are found on the surface compared to those inside.

for a particle of size 30nm → 5%

10nm → 20%

3nm → 50%.

→ In any material, an atom on the surface is different form that inside because of the diff. in potentials.

→ as chemical reactions occur b/w particles, that are on the surface, a given mass of nanomaterial will be much more reactive than the same mass of material made up of large particles

→ This means that materials that are inert in bulk form are reactive in nanoparticle form

Quantum confinement

The independent Schrodinger equ in 1D. $\{ \hat{H}\psi = E\psi \}$

$$-\frac{\hbar^2}{2m}\frac{\partial^2\psi}{\partial x^2} + V\psi = E\psi$$

$$\psi = Ae^{ikx} + Be^{-ikx}$$

In 3D

$$-\frac{\hbar^2}{2m}\nabla^2\psi + V\psi = E\psi$$

$$\psi(x,y,z) = \psi(x)\,\psi(y)\,\psi(z)$$

$$= Ae^{ik_x x}\,Be^{ik_y y}\,Ce^{ik_z z}$$

particle in a Box - 1D

$$-\frac{\hbar^2}{2m}\frac{\partial^2\psi}{\partial x^2} + V\psi = E\psi \qquad \psi = 0 \text{ at } x=0,\ x=L$$

$$E_n = \frac{\pi^2 n^2 \hbar^2}{2mL^2}$$

$$\psi = \sqrt{\frac{2}{L}}\sin\left(\frac{n\pi}{L}\right)x$$

$$E_n = \frac{\pi^2\hbar^2}{2m}\left\{\frac{n_x^2}{L_x^2} + \frac{n_y^2}{L_y^2} + \frac{n_z^2}{L_z^2}\right\}$$

$$\psi_n = \sqrt{\frac{2}{L_x}}\sqrt{\frac{2}{L_y}}\sqrt{\frac{2}{L_z}}\sin\left(\frac{n_x\pi}{L_x}\right)x \cdot \sin\left(\frac{n_y\pi}{L_y}\right)y\ \sin\left(\frac{n_z\pi}{L_z}\right)z$$

$$= \sqrt{\frac{8}{L_xL_yL_z}}\sin\left(\frac{n_x}{L_x}\right)\pi x \cdot \sin\left(\frac{n_y}{L_y}\right)\pi y \cdot \sin\left(\frac{n_z}{L_z}\right)\pi z$$

→ Exciton
- → Frenkel exciton
  - strong binding
  - Restricted ~~matter~~ motion.
- → Wannier - Mott exciton (low binding energy)
  - weak binding.
  - unrestricted translation motion.

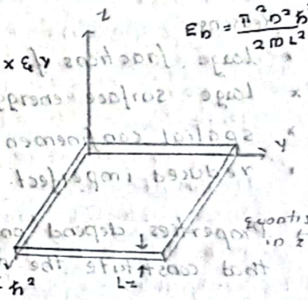
→ Bohr radius - 5.29×10^{-11} m.

→ Exciton Bohr radius (EBR)

1. Nano sheets. - (1D confined.)
2. Nano wire (nano tubes - (2D confined)
3. Quantum Dot - (3D confined).

Nanosheets

$$E_n = \frac{\pi^2 n^2 \hbar^2}{2mL^2}.$$



→ Particles can move along x & y direction freely.

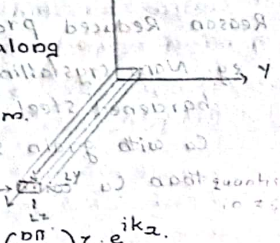
→ 2 degrees of freedom.

$$-\frac{\hbar^2}{2m}\frac{\partial^2\psi_z}{\partial z^2} + V\psi_z = E\psi_z$$

Total: $E = \frac{\pi^2\hbar^2 n^2}{2mL_z^2} + \frac{k_x^2\hbar^2}{2m} + \frac{k_y^2\hbar^2}{2m}$

$$\psi = \sqrt{\frac{2}{L_z}}\sin\left(\frac{n\pi}{L_z}\right)z\ e^{ik_x}\,e^{ik_y}$$

Nanowire.



→ Particles can move freely along x-direction

→ only one degree of freedom.

$$E_n = \frac{\pi^2 n^2\hbar^2}{2mL_z^2} + \frac{\pi^2 n^2\hbar^2}{2mL_y^2} + \frac{k_x^2\hbar^2}{2m}$$

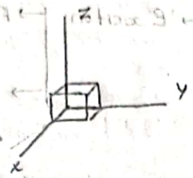
$$\psi = \sqrt{\frac{2}{L_y}}\sqrt{\frac{2}{L_z}}\sin\left(\frac{n\pi}{L_y}\right)y\ \sin\left(\frac{n\pi}{L_z}\right)z \cdot e^{ik_x}.$$

 nned with CamScanner

Quantum Dot.

→ Particles can't move freely in any direction

→ No degrees of freedom



$$\psi = \sqrt{\frac{8}{L_x L_y L_z}} \sin\left(\frac{n\pi}{L_x}\right)x \cdot \sin\left(\frac{n\pi}{L_y}\right)y \cdot \sin\left(\frac{n\pi}{L_z}\right)z.$$

Properties of Nanomaterials

→ Properties diff. from their bulk counterpart.

Reasons

- large fractions of surface atoms.
- Large surface energy.
- spatial confinement.
- reduced imperfect.

→ Properties depend on the size of atom clusters that constitute the material.

~~Chemical properti~~

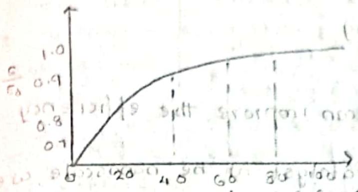
Mechanical properties

→ Reaches theoretical strength.

Reason: Reduced probability of defect.

eg. Nano crystalline nikel is as strong as hardened steel.

Cu with grain size of 6nm is 5 times harder than Cu with 50 μm of size.



E → Young's modulus of nano crystalline material

E_0 → Y of material with conventional grain size

Electrical properties.

→ Electrical conductivity decreases due to increased surface scattering & change of electronic structures.

→ As the bulk material reduces its size, continuous energy bands are replaced by discrete energy levels & band gap increases as the size decreases

As a result some metal nanowire become semiconductors & semiconductor become insulators ~~when dimeters are~~ when diameters are reduced.

Optical properties.

→ The reduction in material dimension has profound effect on optical properties.

1) The energy level seperation in nanocluster depends on the size of nanostructures.

→ This affect the energies needed for the transition of e to excited states.

→ Hence the clusters of diff. size will have diff. colors.

eg: Nanoscale gold particles can be orange, purple, red, green etc depending on size of the clusters.

2). Surface Plasmon Resonance (SPR) is the coherent excitation of all the free ēs within the conduction band upon interaction with electromagnetic field leading to an in phase oscillation.

Applications of nanotechnology

- Energy field

1. Using nanomaterials we can improve the efficiency of solar cells.
2. By designing zeolite catalyst at the nanoscale, we can access & use fossil fuels much more efficiency.
3. Nanomaterials with greater surface area helps in the development of super capacitors, with increased energy density & power output than conventional materials.

- Medical field

4. When nanoscale robots called 'nanobots' are released into the bloodstream in a programmed manner, cancer can be detected in a very early stage.
5. Nanoparticles can be used for antibacterial treatment.
6. Nano particles are used in bone tissue engi. & for detection of proteins.
7. Nano particles can be used for tumour destruction via heating.
8. Cutting tools made of nanocrystalline materials are much stronger, harder, wear resistant & erosion resistant.
9. Sensor made of nanocrystaline materials are highly sensitive to changes in environment. They have application as smoke detectors, ice detectors in air craft wing, etc.
10. Nanotechnology holds a strong promise in defence field. It helps to develope smaller, lighter & more effective weapons. Also help to produce new materials for military purpose.

Problems

Q. The volume of a hall is $3000\ m^3$. It has a total absorption of $100\ m^2$ sabine. If the hall is filled with audience who add another $80\ m^2$ sabine, then find the diff in reverbation time.

$V = 3000\ m^3$.

Absorption of sound by hall $= 100\ m^2$ sabine.

Absorption of sound by audience $= 80\ m^2$ sabine.

Total absorption of the hall with audience $= 180\ m^2$ sabine

Reverbation time when hall is empty, $T_1 = \frac{0.163V}{\Sigma a s}$

$= \frac{0.163V}{A} = \frac{0.163 \times 3000}{100}$

$= 4.89s$

Reverbation time when hall is full with audience, $T_2 = \frac{0.163V}{A} = \frac{0.163 \times 3000}{180}$

$= 2.71$

change in reverbation time $= T_1 - T_2$

$= 2.17s$

Q. An auditorium has dimensions $45m \times 10m \times 8m$. The avg. absorption co-efficients of wall, ceiling & floor are 0.8, 0.4 & 0.5 respe. Evaluate the reverbation time of the hall.

$l = 45m \quad b = 10m \quad h = 8m$.

$V = 45 \times 10 \times 8 = 3600\ m^3$

Area of wall, $S_1 = (2 \times 8 \times 45) + (2 \times 8 \times 10)$

$= 720 + 160$

$= 880\ m^2$

Area of ceiling, S_2 = 45×10 = 450 m²

Area of floor, S_3 = 450 m²

$\alpha_1 = 0.8$ $\alpha_2 = 0.4$ $\alpha_3 = 0.5$

Avg. ~~absorption co-efficient of the wall~~ = $\frac{\alpha_1 S_1 + \alpha_2 S_2 + \alpha_3 S_3}{S_1+S_2+S_3}$

= ~~$\frac{880 \times 0.8 + 450 \times 0.4 + 450 \times 0.5}{880+450+450}$~~

= ~~$\frac{704+180+225}{...}$~~

$\Sigma \alpha S = \alpha_1 S_1 + \alpha_2 S_2 + \alpha_3 S_3$.

= 880×0.8 + 450×0.4 + 450×0.5

= 704 + 180 + 225

= 1109 m² sabine

Reverbation time, $T = \frac{0.163V}{A} = \frac{0.163 \times 3600}{1109}$

= 0.529 s

Q. A hall has dimensions of 25m × 20m × 8m. The reverbation time is 4s. Determine the avg. absorption co-efficient of the surface.

V = 25 × 20 × 8 = 4000 m³.

T = 4 s.

$T = \frac{0.163V}{A}$

$A = \frac{0.163V}{T} = \frac{0.163 \times 4000}{4}$ = 163 m² sabine.

Area of wall, S_1 = (2×25×8) + (2×20×8)

= 400 + 320

= 720 m²

Area of ceiling S_2 = Area of floor, S_3 = 25×20

= 500 m²

ΣS = 720 + 500 + 500

= 1720 m²

$\alpha = \frac{A}{\Sigma S}$.

$\Sigma \alpha S$ = 163

$\alpha = \frac{163}{1720} = 0.095$

Q. A hall has a volume of 2000 m³ with a total absorption equivalent to 100 m³ of open window. What will be effect of reverblation time. If the audience fills the hall, thereby increasing the absorption by 150 m² of an open window?

V = 2000 m³.

Absorption of sound by hall = 100 m² sabine.

Absorption of sound by full audience = 150 m² sabine.

Total absorption of the hall with full audience } = 250 m² sabine

Reverbation time when hall is empty, $T_1 = \frac{0.163V}{\Sigma \alpha S}$

$= \frac{0.163 \times 2000}{100}$

= 3.26 s

Reverbation time when hall is full with audience $T_2 = \frac{0.163 \times 2000}{250}$.

$= 1.304 s$

change in reverbation time $= T_1 - T_2$

$= 1.956 s$

Q A hall of dimension 20m x 10m x 5m has absorption co-efficients for the wall 0.02 for the ceiling 0.4 & for the floor 0.4 respec. find the avg absorption co-efficient of the wall & reverbation time

$l = 20m$ $b = 10m$ $h = 5m$

$V = 20 \times 10 \times 5 = 1000 m^3$

Area of wall, $S_1 = 2 \times 10 \times 5 + 2 \times 20 \times 5$
$= 300 m^2$

Area of ceiling, $S_2 = 20 \times 10 = 200 m^2$.

Area of floor, $S_3 = 20 \times 10 = 200 m^2$.

$\alpha_1 = 0.02$ $\alpha_2 = 0.04$ $\alpha_3 = 0.04$

Avg. absorption co-efficient of the hall.

$= \frac{\alpha_1 S_1 + \alpha_2 S_2 + \alpha_3 S_3}{S_1 + S_2 + S_3}$

$= \frac{0.02 \times 300 + 0.04 \times 200 + 0.4 \times 200}{300 + 200 + 200}$

$= 0.134$

$A = \Sigma \alpha S = 94$ m² sabine

Reverbation time, $T = \frac{0.163 V}{A}$

$= \frac{0.163 \times 1000}{93}$

$= 1.734 s$

Q A class room has a dimension 30m x 10 x 6 m. The reverbation time is 3.2sec. Calculate the total absorption of its surfaces & avg. absorption co-efficient.

$V = 30 \times 10 \times 6 = 1800 m^3$

$T = 3.2 s$

$T = \frac{0.163 V}{A}$

Total absorption, $A = \frac{0.163 V}{T} = \frac{0.163 \times 1800}{3.2}$

$= 91.69$ m² sabine

Avg. absorption co-efficient, $\alpha = \frac{\Sigma \alpha S}{\Sigma S} = \frac{A}{\Sigma S}$.

$\alpha = \frac{91.69}{\Sigma S}$.

Area of wall, $S_1 = 2 \times 30 \times 6 + 2 \times 10 \times 6$
$= 480 m^2$

Area of ceiling, S_2 = Area of floor, $S_3 = 30 \times 10 = 300 m^2$

$\Sigma S = 480 + 300 + 300$
$= 1080 m^2$

$\alpha = \frac{91.69}{1080} = 0.084$