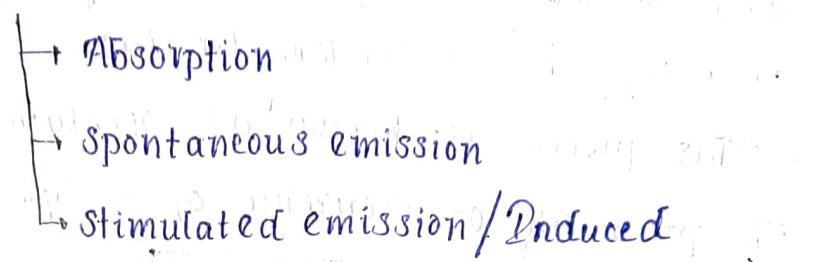


Unit-2 : Laser & its Applications.

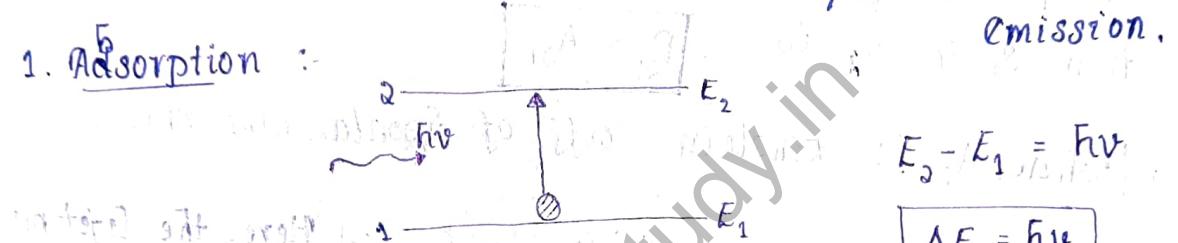
LASER - Light Amplification by Stimulated emission of Radiation. Are highly coherent, energetic.

→ Coherent forces - The forces acts towards the waves.

Interaction of light with material :-



1. Absorption :-



$$E_2 - E_1 = hv$$

$$\Delta E = hv$$

The absorbed

At room temperature, most of the atoms stay in the ground state [E₁].

- Electron, can be raised to the excited state (E₂) by the absorption of the photon of energy [hv].

- This process is known as absorption of radiation.

- No. of photon's falling from 1 & 2, probability of occurrence of absorption from state 1 to S₂ is given by $P_{12} \propto u(v)$

$u(v) \rightarrow$ energy density. (or) energy falling from unit volume

$$P_{12} = B_{12} u(v) \quad \boxed{①}$$

B_{12} - Constant.

L. Einstein Coeff. of absorption of radiation.

+ $[u(v) \rightarrow$ Energy density.]

Q. Spontaneous Emission :-

$$E_2 - E_1 = \hbar\nu$$

$$\Delta E = \hbar\nu$$

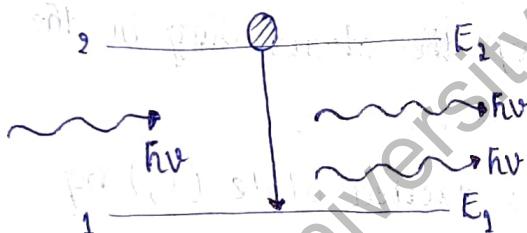
$10^{-8} \text{ s} \rightarrow \text{lifetime of } e^-$

- If an e^- is in the excited state (E_2) it can come down to lower energy state (E_1) by emitting a photon of energy ($\hbar\nu$) in random direction.

- This process is known as Spontaneous Emission.
- The probability of occurrence of a Spontaneous emission from S_2 to S_1 is. $P_{21} = A_{21}$

- [Where, A_{21} is Einstein coeff. of Spontaneous emission]

3. Stimulated Emission (or) Induced



$$E_2 - E_1 = \hbar\nu$$

$$\Delta E = \hbar\nu$$

:- Here, the lifetime of e^- varies due to Metastable State.

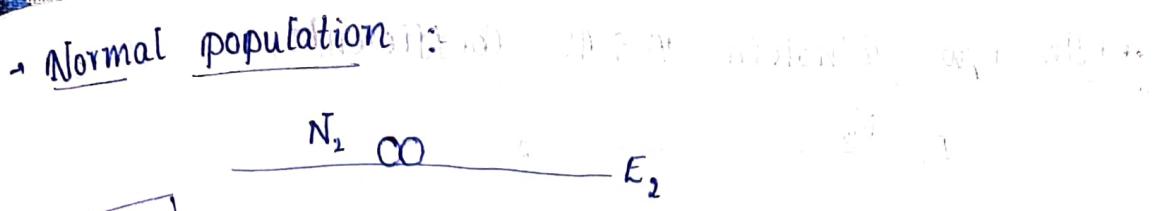
- According to, Einstein a photon can be used to trigger an excited electron in this process two photons will be emitted in the same direction.
- This Process is known as Stimulated Emission.
- The probability of occurrence of Stimulated emission from S_2 to S_1 .

$$P_{21} \propto u(v)$$

$$P_{21}' = B_{21} u(v)$$

B_{21} - Einstein coeff. of Stimulation emission of radiation.

→ Normal population: At room temperature, $N_2 > N_1$



$N_2 \text{ CO}$ E_2

$N_1 \text{ 000000}$ E_1

At room temperature.

The number of e's in the lower energy state is equal to the no. of e's in the higher energy state.

→ Population Inversion:

$N_2 \text{ 000000}$ E_2

$N_1 \text{ 000}$ E_1

$N_2 > N_1$

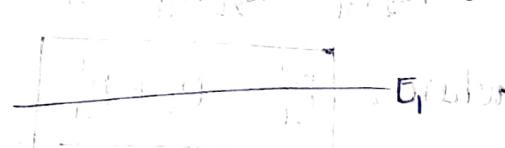
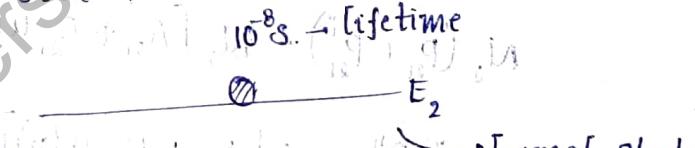
At room temperature, the number of e's in the higher energy state is higher than the no. of e's in the lower energy state.

If the no. of e's in the excited state is higher than the lower excited state.

than the lower excited state.

→ Metastable state:

Lifetime $\rightarrow 10^{-5} - 10^{-3}$ s



Metastable state is also an excited state, but, the lifetime of the metastable state is higher than the normal excited state.

Lifetime of a ~~metastable~~ Metastable state is $10^{-5} \text{ sec} - 10^{-3} \text{ sec}$.

In ground metastable state we don't have any laser.

+ R In b/w Einstein A & B Coefficients

$$E_2 \xrightarrow{N_2} 2$$

$$E_1 \xrightarrow{N_1} 1$$

→ probability of occurrence of adsorption radiation.

$$[N_1 P_{12} = N_1 B_{12} u(v)] \rightarrow ①$$

→ probability of occurrence of spontaneous emission of radiation.

$$[N_2 P_{21} = N_2 A_{21} u(v)] \rightarrow ②$$

→ probability of occurrence of stimulated emission of radiation.

$$[N_2 P'_{21} = N_2 B_{21} u(v)] \rightarrow ③$$

Total emission Probability,

$$N_2 P_{21} + N_2 P'_{21} = N_2 [A_{21} + B_{21} u(v)]$$

$$N_2 (P_{21} + P'_{21}) = N_2 [A_{21} + B_{21} u(v)]$$

$$N_2 P''_{21} = N_2 [A_{21} + B_{21} u(v)]$$

where, $P''_{21} = P_{21} + P'_{21}$

At equilibrium,

$$N_1 P_{12} = N_2 P''_{21}$$

$$N_1 B_{12} u(v) = N_2 [A_{21} + B_{21} u(v)]$$

$$\Rightarrow u(v) [N_1 B_{12} - N_2 B_{21}] = N_2 A_{21}$$

$$u(v) = \frac{N_2 A_{21}}{N_1 B_{12} - N_2 B_{21}}$$

$$[u(v) = \frac{A_{21}}{B_{21} (\frac{N_1}{N_2} B_{12} / B_{21} - 1)}] \rightarrow ④$$

\Rightarrow Relation Between Einstein A & B Coefficients :-

$$N_1 P_{12} = N_1 B_{12} u(v) \rightarrow ①$$

~~$$3N_2 P_{21} = N_2 A_{21} \rightarrow ②$$~~

~~$$N_2 P_{21} = N_2 B_{21} u(v) \rightarrow ③$$~~

Total emit

According, to Einstein $B_{12} = B_{21}$.

$$\begin{cases} P_{12} \propto u(v) \\ P_{21} \propto u(v) \end{cases}$$

$$u(v) = \frac{A_{21}}{B_{21} \left(\frac{N_1}{N_2} - 1 \right)} \rightarrow ⑤$$

According, to Boltzmann Law,

$$N \propto e^{-E/kT} \rightarrow ⑥$$

$$\frac{N_{12}}{N_2} = \frac{e^{-E_1/kT}}{e^{-E_2/kT}} = e^{(E_2 - E_1)/kT}$$

$$\therefore E_2 - E_1 = \Delta E = h\nu$$

$$\text{from 6 : } u(v) = \frac{A_{21}}{B_{21} (e^{h\nu/kT} - 1)} \rightarrow ⑦$$

According, to Planck's fraction formula.

$$u(v) = \frac{8\pi h\nu^3}{c^3} \cdot \frac{1}{(e^{h\nu/kT} - 1)} \rightarrow ⑧$$

Compare ⑦ & ⑧

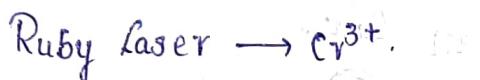
$$\left\{ \frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3} \right\}$$

$$v = \frac{c}{\lambda}$$

$$\frac{A_{21}}{B_{21}} = \frac{8\pi\hbar}{\lambda^3}$$

→ Main Component of a Laser :- 3-mEDIUMS.

i) Active Medium - The material on which laser action takes place is known as Active medium.
Should have meta. stable state.



ii) Pumping Method / Optical pumping :- The Ex: Ruby Laser, Nd-YAG Laser. method by which we can excite (or) raise electrons from lower energy state to upper energy state.

iii) Electrical discharge :- Ex: He-Ne Laser.

iv) Resonant Cavity :- It is an arrangement of two parallel mirrors. reflecting.

The role of resonance cavity is to amplify the no. of photons.

v) Ruby Laser → 3 leveled Layer.

vi) He-Ne, Nd-YAG → 4 leveled Layer.

Ruby Layer :-



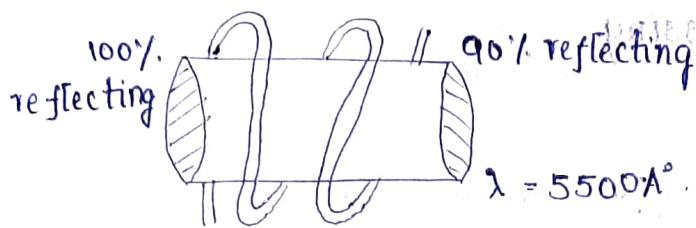
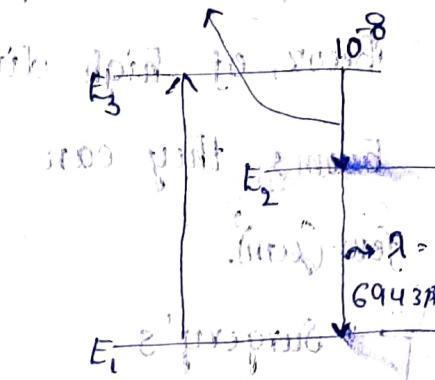
Radiation less
transition

preferable transition



\rightarrow It is a 3 level laser.

pumping \rightarrow Optical pumping.



- The wavelength of Ruby Layer is 6943\AA $\Rightarrow \lambda = 6943\text{\AA}$
- Due to reason \rightarrow visible region.
- Xenon flash light \rightarrow Optical Pumping.

$\rightarrow 5500\text{\AA}$. Used to excite electrons.

This is solid state laser used to emit light.

Properties of Laser :-

i. Directionality : $> 10^5$ radians.

The actual divergence of laser is $> 10^5$ radian.

In Surveying purpose

Remote Sensing \rightarrow Radar - Radio detection & Ranging

Lidar \rightarrow Light detection and ranging.

ii. High Power :

Continuous laser having power level approximately 10^5 W.

Pulse laser having a total energy $\approx 50,000\text{J}$.

Welding

Cutting \rightarrow Artificial Sun

Laser fusion

iii. Tight focussing :

Becoz, of high directional property of laser beams they can be focused to areas approximate few (μm).

→ Surgery's

→ Material processing

→ Compact disc

iv. Monochromatic

Laser light is highly Monochromatic.

A v. Coherent :-

All the rays are moving in same phase.

→ classification of Laser :-

1. On the basis of active medium/lasing medium.

(a) Solid state Laser → Ruby Laser,
Nd-YAG Laser, Semiconductor Laser.

2. (b) Liquid-state Laser → HF Laser, Dye Laser.

(c) Gas Laser → He-Ne Laser, CO_2 Laser.

2. On the basis of level scheme.

(a). Three levels Laser → Ruby Laser.

(b) Four Level Laser → He-Ne Laser, Nd-YAG Laser.

3. On the basis of laser output.

(a) Continuous Laser → Nd-YAG Laser.

(b) pulsed Laser → Cont. working mode.

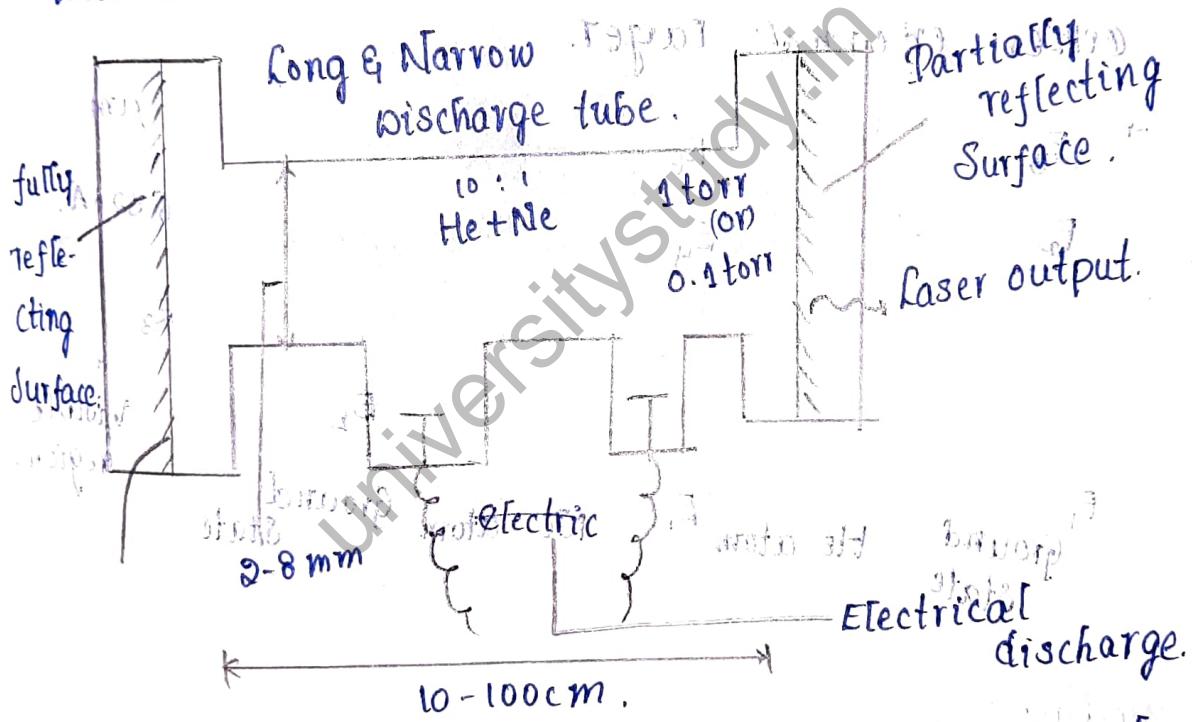
He-Ne Laser with Electrical discharge.

→ $10 : 1$ → the more amount 'He' will be there.
 $7 : 1$ → the less amount 'He' will be there.
 $18 : 1$

→ Selective Pumping is done to make lasers.

→ The Gas lasers are most widely used lasers.
 These lasers operate with rare gases as active medium.

→ The electrons are excited by electrical discharge
 it was discovered in 1961 by 'Ahni Taiwan',
 "William R. Bennett Jr.", "Donald R. Harriot".

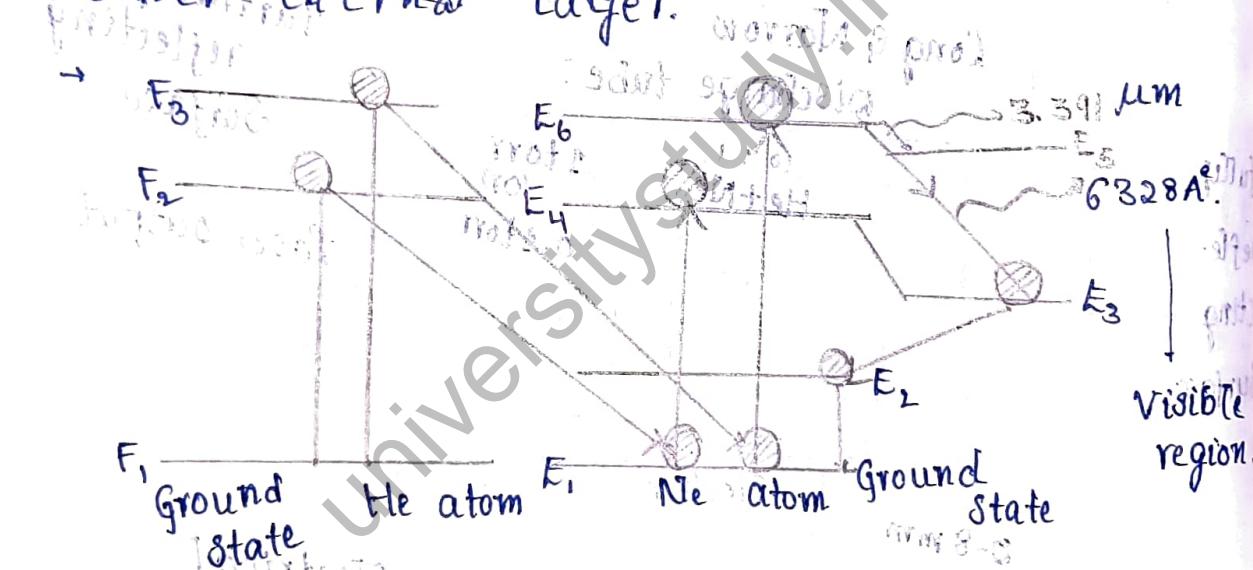


- i. The He-Ne laser consists of a long and narrow discharged tube.
- ii. The diameter of the tube is ~~22~~ 2-8mm and length of the tube is 10-100 cm.
- iii. The tube is filled with He, Ne gases with a typical pressure of one torr, 0.1 torr.

- The ratio He-Ne is many times higher than that of Ar-Ne.
- The actual lasing action takes place in attempt to achieve high efficiency.
- And He is used for selective pumping of the upper layer of Ne.

He is helping in population inversion with Ne.

Laser resonator may consists off other external layer.



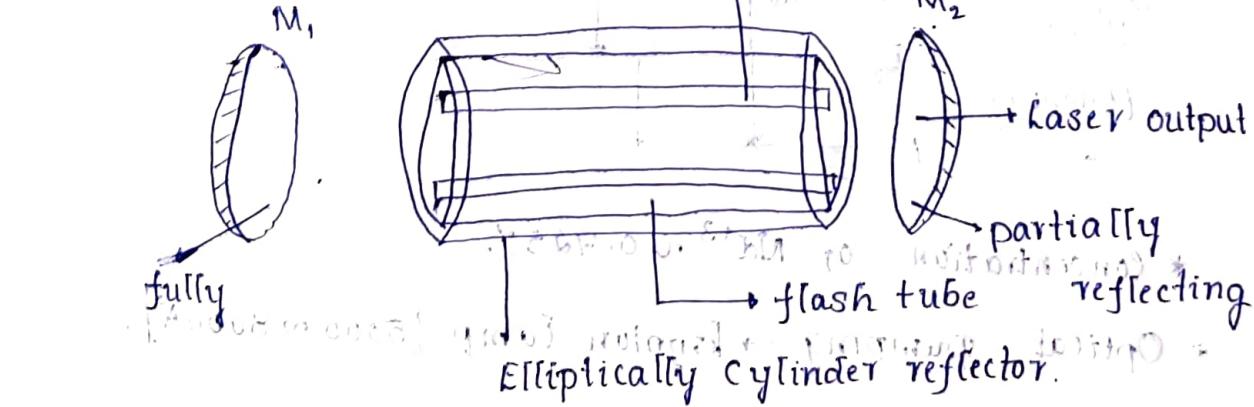
Working:

When an electric discharge is passed through the He-Ne gas, the electrons are accelerated down the tube or along the length of the tube & collide with He-Ne atoms & inside them to higher energy levels.

- The levels E_4, E_6 of neon atoms have almost same energy as F_2, F_3 of linear atoms.
- Then He atoms collide with neon groundstate electrons & insde the electrons to E_4, E_6 state.
- The levels E_4, E_6 are Selectively Populated as compared to other energy levels of neon.
- e^- from E_3 to E_2 level will come from Spontaneous emission.
- Now, e^- from E_2 level collide with the walls of narrow tube and loose their energies.
- Due to the gaseous laser we use discharged tube.

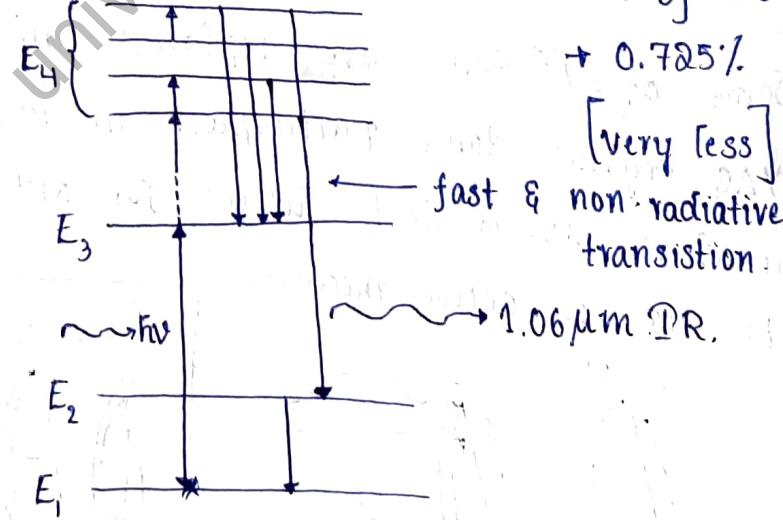
Nd-YAG Laser.

- Four-level laser, Solid-State laser.
- YAG \rightarrow Yttrium Aluminium Garnet $[Y_3Al_5O_{12}]$.
- Some of Y^{3+} ions are replaced by Nd^{3+} .
- YAG crystal don't participate in laser action but serve as a host lattice for Nd which acts as an active medium.



- The System consists of an elliptically cylindrical reflector.
- Housing, the laser rod at one focus and a flash lamp or tube along the other focus line.
- Light leaving from one focus of the ellipse will pass through the other focus, after reflection from the silvered surface of the reflector.
- Thus, entire flash tube light gets focused on the laser rod.
- The diameter & length of laser rod are 12mm & 10cm respectively.
- The two ends of the rod are polished, which constitute the Optical resonator $[M_1, M_2]$.

Working :-



* Concentration of $\text{Nd}^{+3} \approx 0.725\%$.

* Optical pumping \rightarrow krypton lamp $[5000 \sim 8000 \text{\AA}]$.

Conc. of Nd

+ 0.725%

[Very less]

fast & non-radiative transition

1.06 μm PR.

- The energy level structure of the Nd atom is preserved to a certain extent due to its relatively low concentration [0.705%].
- The pumping of Nd ions to upper energy states is done by krypton lamp. [$\lambda \rightarrow 5000 \text{~} 8000 \text{\AA}$].
- The ground state electron of Nd ion jump to multiple energy levels of E_4 . After some time (10^{-8} s) e^- comes to E_3 state through non-radiative transition.
- When e^- jump from E_3 state to E_2 there will be emission of wavelength $1.06 \mu\text{m}$ & this wavelength fall in Infrared region.
- e^- jump from E_2 state to E_1 state by Spontaneous emission. This is a continuous working mode laser. [cw mode laser].

→ Semi-conductor Laser : ~~Spontaneous~~

- Semiconductor, intrinsic, Extrinsic, p-type, n-type, forward bias, Reverse bias, direct band gap Semiconductors.
- Those materials conductivity lies b/w conductor & Insulator is known as Semiconductors.

Ex: Ge, Si, Ga, As.

- Intrinsic - Pure Semiconductors without impurities.
- Extrinsic - Impure Semiconductors with impurities

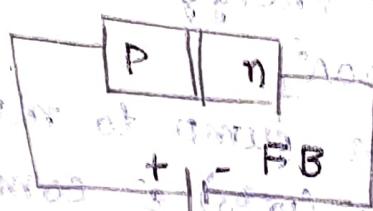
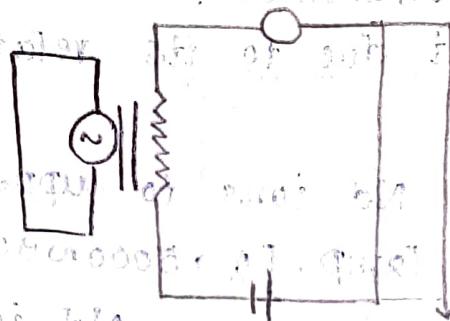
p - trivalent impurity

n - Pentavalent impurity

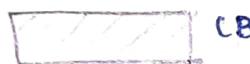
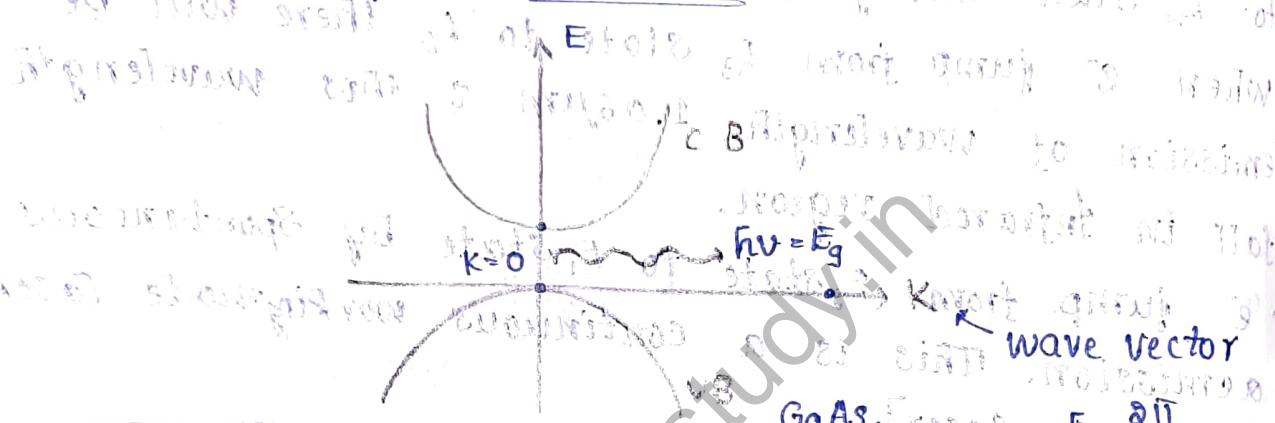
Al^{+3} , Al^{+5}

Donor

Acceptor



→ Direct Band gap semiconductor



Band gap

→ In a direct band gap Semiconductor conduction, band minima & valence band maxima are lying in the same k value.

→ When an e^- from conduction band minima jumps to the valence band maxima & combine with the hole. Energy will be liberated in the form of holes.

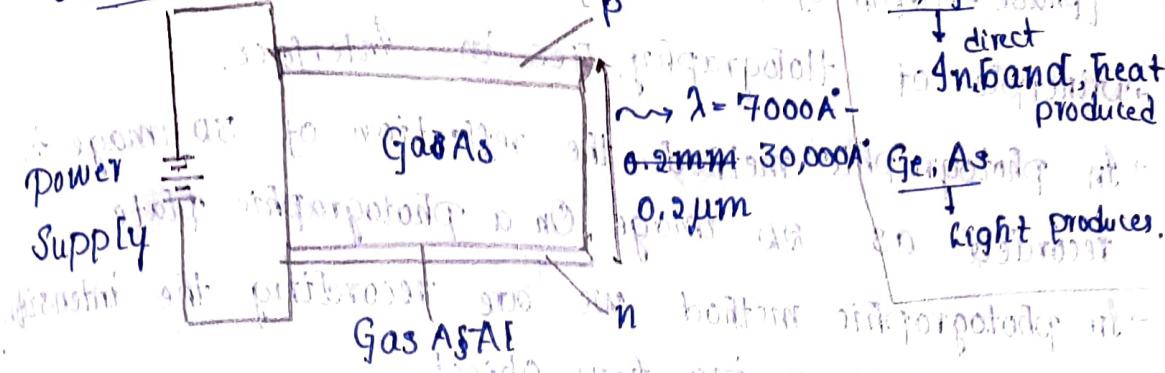
→ Holes are the majority charge carriers.

→ This energy released in the form of Photon.

This process is Recombination Process.

→ The released energy is known as Recombination energy.

Semiconductor Laser :-



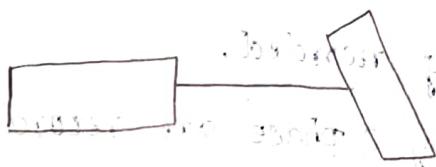
- It has very small size to exhibit high efficiency & can be operated at low temperatures.
- It is operated in forward bias & doping is in very high p-type & n-type semiconductors.
- When current is passed through a p-n-junction in forward bias, it goes from p-region to n-region.
- Whole smooth's from p-region to n-region.
- And e⁻ move from n-region - p-region.
- At the junction, e⁻ and hole combined emit photons due to transition of e⁻s from conduction band to valence band, from GaAs with thickness 0.2μm.
- It is made from GaAs with n-type & p-type conductors.
- GaAs is sandwiched b/w p-type & n-type conductors.
- The resonant cavity is provided by polishing opp. faces of a crystal.
- wavelength ranges b/w $\lambda = 7000 \text{ Å} - 30,000 \text{ Å}$.
- Holography :- a. photographic method. for capturing object
b. Holographic method.
- In photographic only Intensity recorded.
- In holographic both Intensity & phase are recorded.

$$|T \propto A^2| \rightarrow \text{Phase of the wave.}$$

[Phase \rightarrow depth of the image].

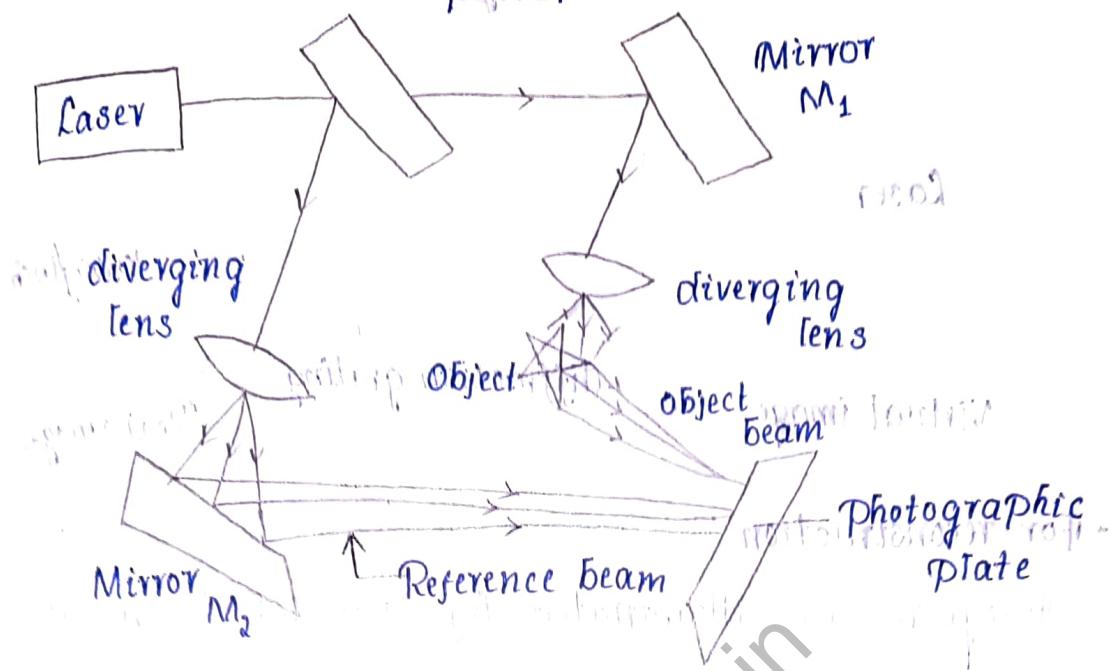
Principle of Holography lies in Interface.

- + In photographic method, the reflection of 3D image is recorded as 2D image. On a photographic plate.
- In photographic method we are recording the intensity of the light coming from object.
- Intensity is directly proportional to square of amplitude of the wave.
- So, the image obtained from photographic method contained information about amplitude of the wave only, and the phase of the wave is lost in this method.
- Holography was discovered by Dennis Gabor in 1948.
- It is a combination of two words in Greek are Holography = Holo + graphy
- Holo = whole (whole) graphy = to write
- Holography means writing complete image.
- In holograph both amplitude & phase of the wave are recorded, in the photographic plate.
- This recording is known as Hologram.
- Recording of the Hologram :-



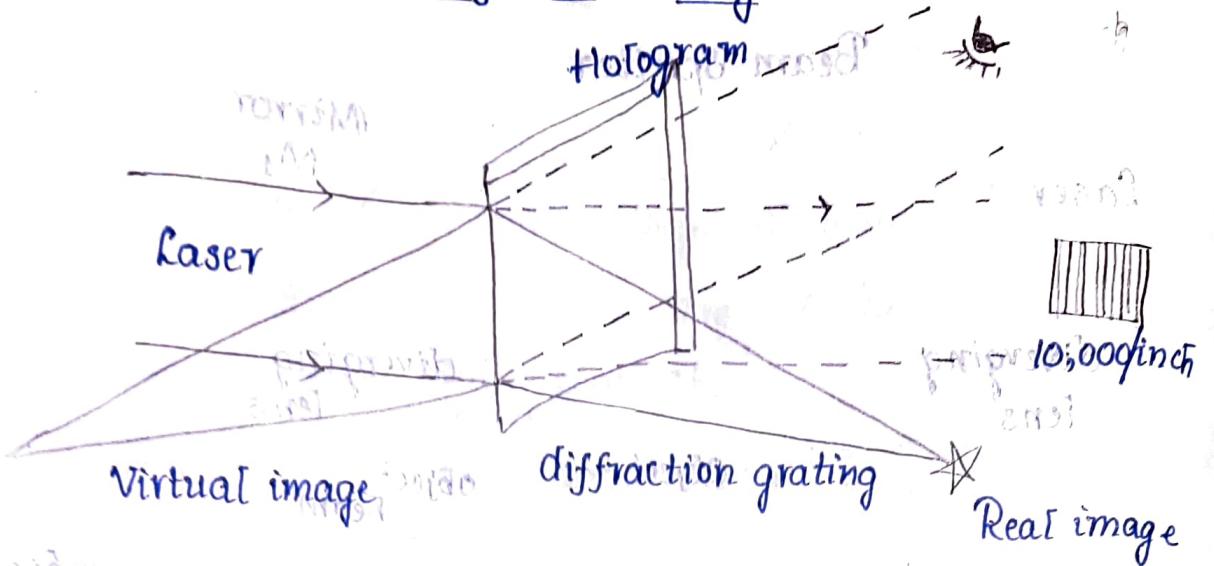
The process of forming a 3D image is called Interference. Light rays from the source and reflected from the prism interfere to form a 3D image.

Beam Splitter



- i. In the first step, image of the object is recorded in Hologram. [this step is known as Recording].
- ii. In the Second step, the Hologram is transformed into the image. [Reconstruction].
- iii. Hologram, is the result of interference of two beams. [they are reference Beam, Object Beam].
- iv. Object Beam is the light scattered off from the Object.
- v. The reference beam is the light, reaching the photographic plate directly.
- vi. A broad laser beam is divided into two parts, by using a Beam Splitter.
- vii. At the photographic plate object beam & reference beam combine both the beams interfere and form interference fringes. on the photographic plate.

⇒ Reconstruction of the image :-



* For reconstruction

- i) Hologram is illuminated by parallel beam of laser light.
- ii) Hologram is acting as diffraction grating.
- iii) Due to diffraction a real image is formed. In this image, can't be photographed bcoz laser light is falling in this image.
- iv) Virtual image will be formed at the location of the object.