Unit-2 : Laser & it's Applications.

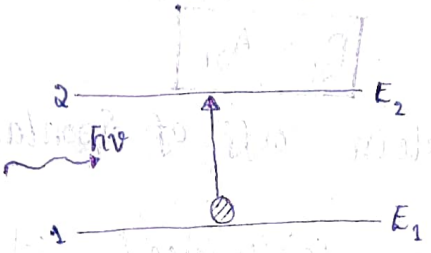
LASER - Light Amplification by Stimulated emission of Radiation. Are highly coherent, energetic.

→ Coherent forces - The forces acts towards the waves.

Interaction of Light with material :-

- Absorption
- Spontaneous emission
- Stimulated emission / Induced emission.

1. Absorption :



$E_2 - E_1 = h\nu$

$\boxed{\Delta E = h\nu}$

- The absorbed
- At room temperature, most of the atoms stay in the ground state [E_1].
- Electron, can be raised to the excited state (E_2) by the absorption of the photon of energy [$h\nu$].
- This process is known as absorption of radiation.
- No. of photon's falling from 1 & 2, probability of occurence of absorption from state 1 to S2 is given by $\boxed{P_{12} \propto u(\nu)}$

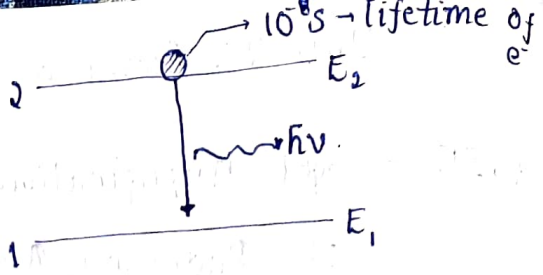
$u(\nu)$ → energy density. (or) energy falling from unit volume.

$\boxed{P_{12} = B_{12}\, u(\nu)}$ → ①

B_{12} - Constant.
↳ Einstein Coeff. of absorption of radiation.

→ [$u(\nu)$ → Energy density.]

2. Spontaneous Emission :-



$$E_2 - E_1 = h\nu$$

$$\boxed{\Delta E = h\nu}$$

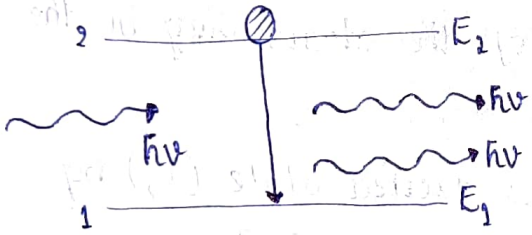
→ If an e^- is in the excited state (E_2) it can come down to lower energy state (E_1) by emitting a photon of energy ($h\nu$) in random direction.

→ This process is known as Spontaneous Emission.

→ The probability of occurence of a Spontaneous emission from S_1 to S_2 is. $\boxed{P_{21} = A_{21}}$

→ [where, A_{21} is Einstein coeff. of Spontaneous emission].

3. Stimulated Emission (or) Induced :-



$$E_1 - E_2 = h\nu$$

$$\boxed{\Delta E = h\nu}$$

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 occurence of Stimulated emission from S_2 to S_1.

$$\boxed{P'_{21} \propto u(\nu)}$$

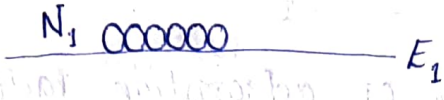
$$\boxed{P'_{21} = B_{21} u(\nu)}$$

[B_{21} - Einstein Coeff. of Stimulation emission of radiation].

→ Normal population :

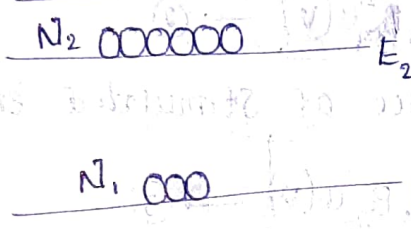
$N_1 > N_2$

At room temperature.



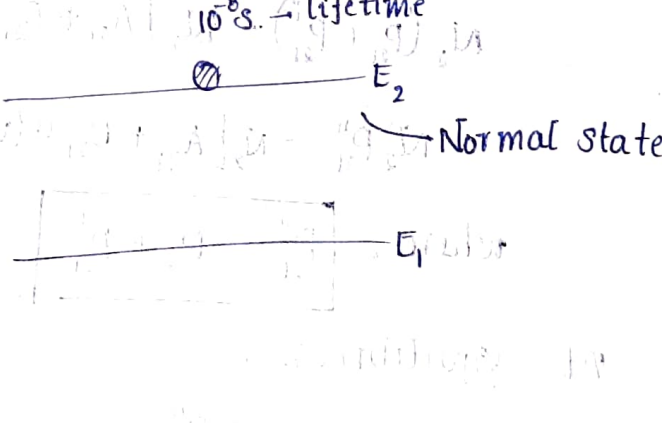
- The number of e's in the lower energy state is higher than to the no. of e's in the higher energy state.

→ Population Inversion :-



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

→ Metastable state :-



- Metastable state is also an excited state but, the lifetime of the metastable state is higher than the Normal excited state.
- Lifetime of a ~~Metatypi~~ Metastable state is 10^{-5}sec - 10^{-3}sec.
- In ground metastable state we don't have any Laser.

→ Rln b/w Einstein A & B Coefficients :

E_2 — N_2 ——— 2

E_1 — N_1 ——— 1

- probability of occurence of adsorption radiation.

$$N_1 P_{12} = N_1 B_{12} u(\nu) \longrightarrow (1)$$

- probability of occurence of Spontaneous emission of radiation.

$$N_2 P_{21} = N_2 A_{21} u(\nu) \longrightarrow (2)$$

- probability of occurence of Stimulated emission of radiation.

$$N_2 P'_{21} = N_2 B_{21} u(\nu) \longrightarrow (3)$$

Total emission probability,

$$N_2 P_{21} + N_2 P'_{21} = N_2 \left[A_{21} + B_{21} u(\nu)\right]$$

$$N_2 (P_{21} + P'_{21}) = N_2 \left[A_{21} + B_{21} u(\nu)\right]$$

$$N_2 P''_{21} = N_2 \left[A_{21} + B_{21} u(\nu)\right]$$

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

At equilibrium,

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

$$N_1 B_{12} u(\nu) = N_2 \left[A_{21} + B_{21} u(\nu)\right]$$

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

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

$$u(\nu) = \frac{A_{21}}{B_{21}\left(N_1/N_2 \, B_{12}/B_{21} - 1\right)} \longrightarrow (4)$$

⇒ Relation between Einstein A & B Coefficients :-

$$N_1 P_{12} = N_1 B_{12} u(\nu) \longrightarrow (1)$$

$$N_2 P_{21} = N_2 A_{21} \longrightarrow (2)$$

$$N_2 P_{21} = N_2 B_{21} u(\nu) \longrightarrow (3)$$

~~Total emi~~

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

$$\left(\begin{array}{l} P_{12} \propto u(\nu) \\ P_{21} \propto u(\nu) \end{array}\right)$$

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

According, to Boltzman Law,

$$N \propto e^{-E/kT} \longrightarrow (6)$$

$$\frac{N_1}{N_2} = \frac{e^{-E_1/kT}}{e^{-E_2/kT}} = e^{(E_2 - E_1)kT}$$

$$= e^{h\nu/kT}.$$

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

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

According, to planck's fraction formula.

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

→ planck's radiation formula.

Compare (7) & (8)

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

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

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

→ 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.

He-Ne Laser ⟶ Ne

Nd-YAG Laser ⟶ Nd

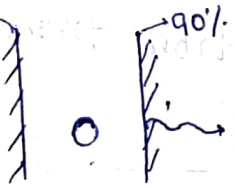
Ruby Laser ⟶ Cr^{3+}.

→ ii) Pumping Method / Optical pumping :- The method by which we can excite (or) raise electrons from lower energy state to upper energy state.

Ex: Ruby Laser, Nd-YAG Laser.

→ Electrical discharge :- Ex: He-Ne Laser.

iii)→ Resonant Cavity :- It is an arrangement of two parallel mirrors.



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

→ Ruby Laser ⟶ 3 leveled layer.

→ He-Ne, Nd-YAG ⟶ 4 leveled layer.

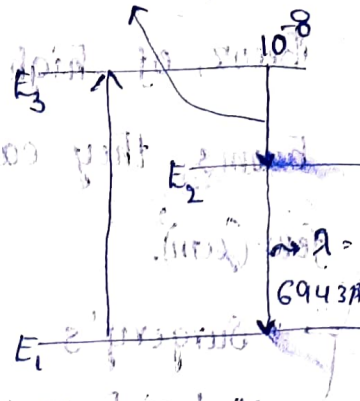
⇒ Ruby Layer :-

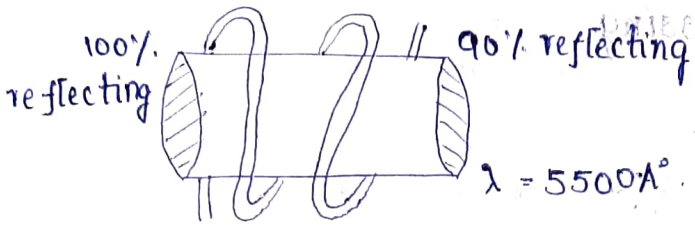
→ Ruby Rod → $Cr_2O_3 + Al_2O_3$:-

→ Active action → Cr^{+3}

→ It is a 3 level laser.

Pumping → Optical Pumping.





- The wavelength of Ruby Layer = $6943Å^\circ$ ⇒ $\lambda = 6943Å^\circ$
- Due, to reason → visible region.
- Xenon flash light → Optical Pumping.
  - → $5500Å^\circ$.
- This is Solid state laser

⇒ Properties of Laser :-

i. Directionality :- $> 10^{-5}$ radians

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

- In Surveying purpose
- Remote Sensing. → Radar – Radio detection & Ranging
- Lidar – light detection and ranging.

ii. High Power :-

- Continuous laser having power level aproximately 10^5 W
- Pulse laser having a total energy = ~ 50,000 J.
  - Welding
  - Cutting
  - Laser fusion.

(artificial Sun).

iii. Tight focussing :-

Becoz, of high directional property of laser being beams they can be focused to areas aproximate few $(\mu m)^2$.

→ Surgery's
→ Material processing
→ Compact-dise

iv. Monochromatic :-

Laser light is higly Monochromatic.

A v. Coherent :-

All the rays are moving in same phase.

→ classification of Laser :-

1. On the basis of active medium/Lasing medium.
   (or)(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 mole.

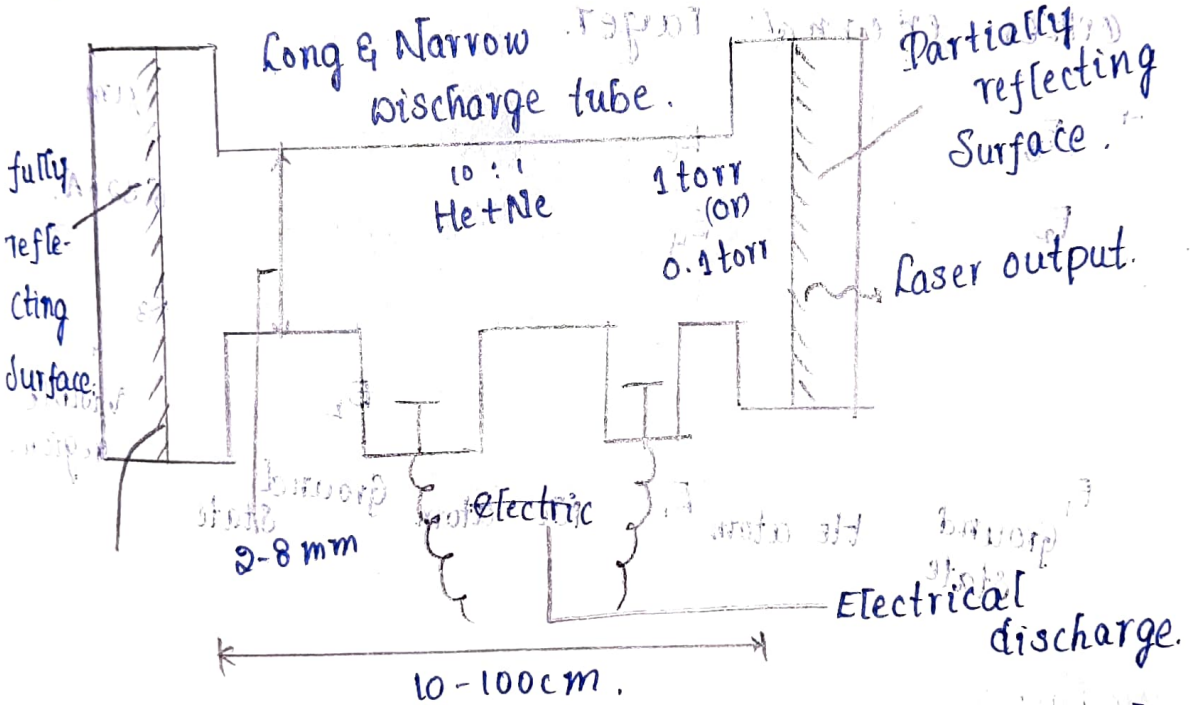
→ He-Ne Laser with Electrical discharge.

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

→ Selective pumping is done.

→ The Gas laser 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 Jawan", "William R. Benett Jr.", "Donald R. Harriot".



i. The He-Ne laser consists of a long and narrow discharged tube.

ii. The diameter of the tube is 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 10' km.

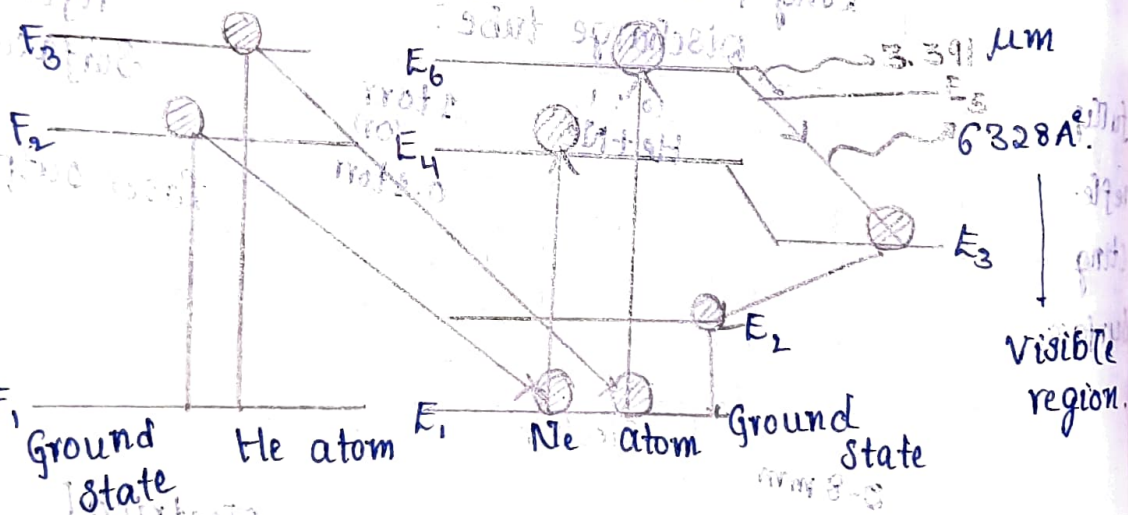
→ The actual lasing ~~act~~ action takes place in many attempts.

→ And He is used for selective pumping of the upper ~~D~~ layer of Ne.

→ 'He' is helping in population inversion with Ne.

→ Laser resonator may consists off either 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.

→ The He atoms collide with neon groundstate electrons & inside 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^-s from E_2 level collide with the walls of narrow tube and loose their energies.

→ Due to the gaseous laser we use discharged tube.

Inert behaviour.

Nd-YAG Laser.

- Four-level laser, solid-state laser.

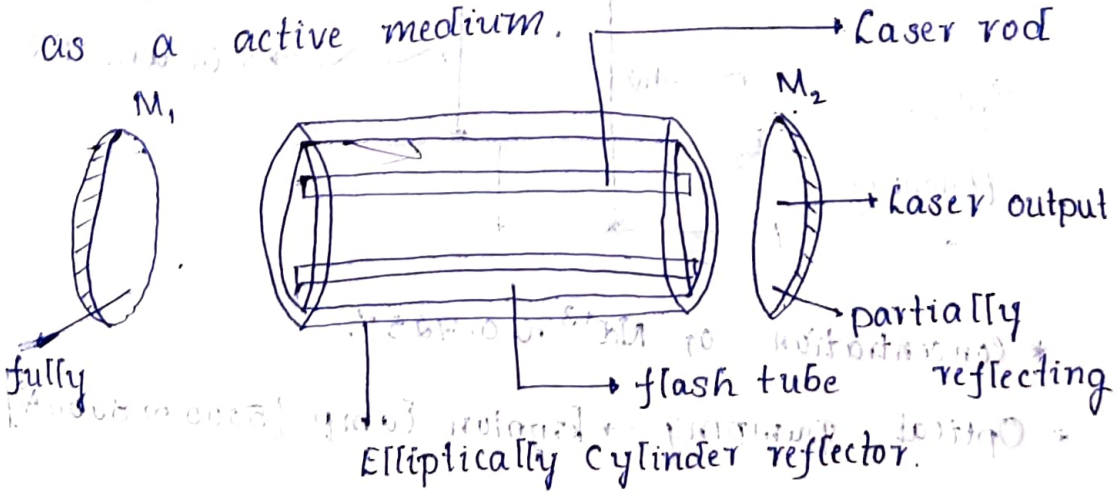
→ YAG → Yttrium Aluminium Garnet $[Y_3Al_5O_{12}]$.

↓

optically isotropic crystal.

→ 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 a active medium.



→ The System consist of an elliptically cylindrical reflector.

→ Housing, the laser rod at one focus and a flash ~~lamp~~ or tube along the other focus line.

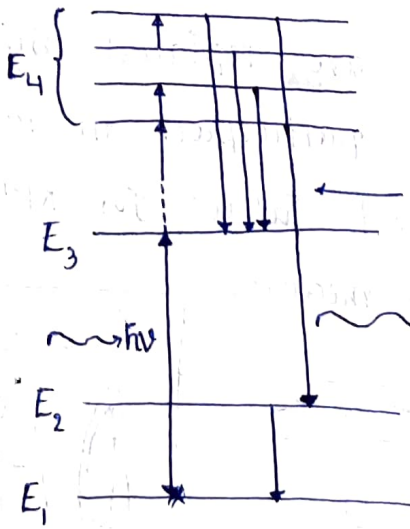
→ Light leaving from one focus of the ellipse will pass through the other focus, after reflection from the silvered surface of the reflector.

→ 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 :-



Optical Pumping.

Conc. of Nd → 0.725% [very less]

fast & non-radiative transistion.

1.06 μm IR.

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

* Optical pumping → krypton lamp [5000 ~ 8000 A°].

→ The energy level structure of the Nd atom is preserved to a certain extent due to its relatively low concentration [0.725%].

→ The pumping of Nd ions to upper energy states is done by Kryptan lamp. [$\lambda \rightarrow 5000 \sim 8000 A^{\circ}$].

→ 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 transistion.

→ when e^- jump from E_3 state to E_2 there will be emission of wavelength 1.06μm & this wavelength fall in Infrared region.

→ e^- jump from E_2 state to E_1 state by Spontaneous aemission. This is a continuous working mode laser. [CW mode Laser].

⇒ Semi-conductor Laser :

→ Semiconductor, intrinsic, Extrinsic, p type, n-type, forward bias, Reverse bias, direct band gap Semicondu

→ Those materials conductivity lies b/w conductor & Insulator is known as Semi-Conductors.

Ex: Ge, Si, Ga, As.

no. 7 lev no. 1 lev → have less no of es

→ Intrinsic → Pure Semi-Conductor without impurities

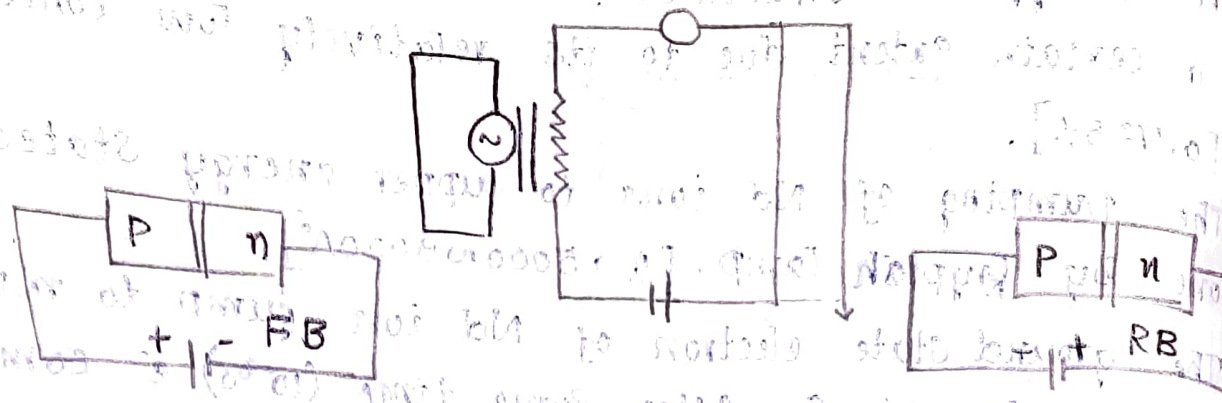
→ Extrinsic → Impure Semi-Conductors with impurities

p → trivalent impurity

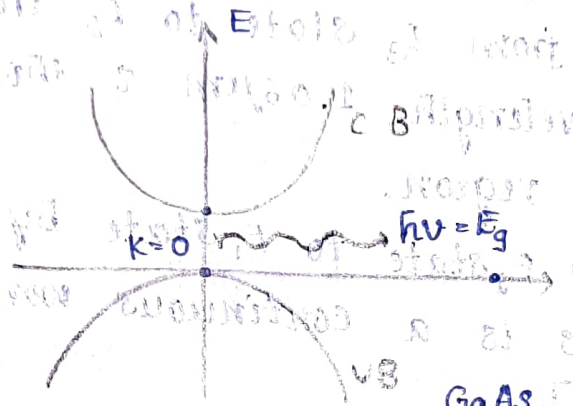
n → Pentavalent impurity

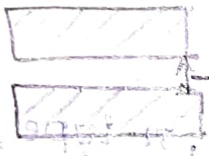
Al^{+3}, Al^{+5} → donor

acceptor



→ Direct Band gap Semiconductor :

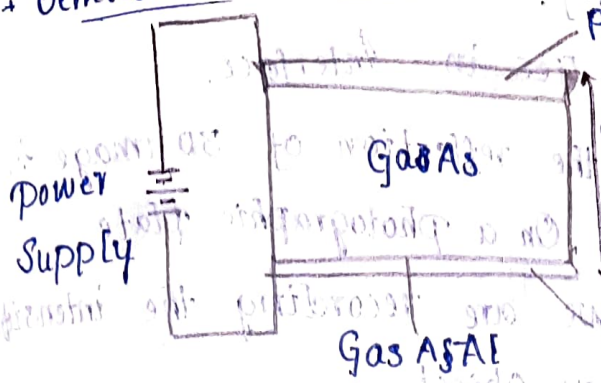




Semiconductor

- In direct band gap Semiconductor conduction band minima & valence band maxima are lying in the same k value.
- when an e⁻ from conduction band minima jump 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 :-



Si, Ge
↓ direct
In band, heat produced

~~λ = 7000Å~~ 0.2mm 30,000Å 0.2μm

Ge, As
↓
Light produces.

→ It has very small size to exhibit high efficiency & can be operated at low temperature.
→ It is operated in forward bias & doping is very high in n, p type semiconductors.
→ when current is passed through a p-n jn diode in forward bias.
→ whole smooth's from p region to n region.
→ And e^- move from n region - p region.
→ At the junction e^- and whole combined & emit photons due to transistion of e^0s from conduction band to valence band.
→ It is made from GaAs with thickness 0.2μm.
→ 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 [λ = 7000Å - 30,000Å.]
→ Holography :- a. photographic method. } for capturing object
b. Holographic method.

→ In photographic only Intensity recorded.
→ In Holographic both Intensity & phase are recorded.

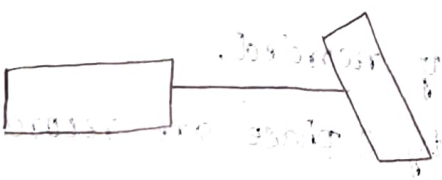
$I \propto A^2$ → phase of the wave.

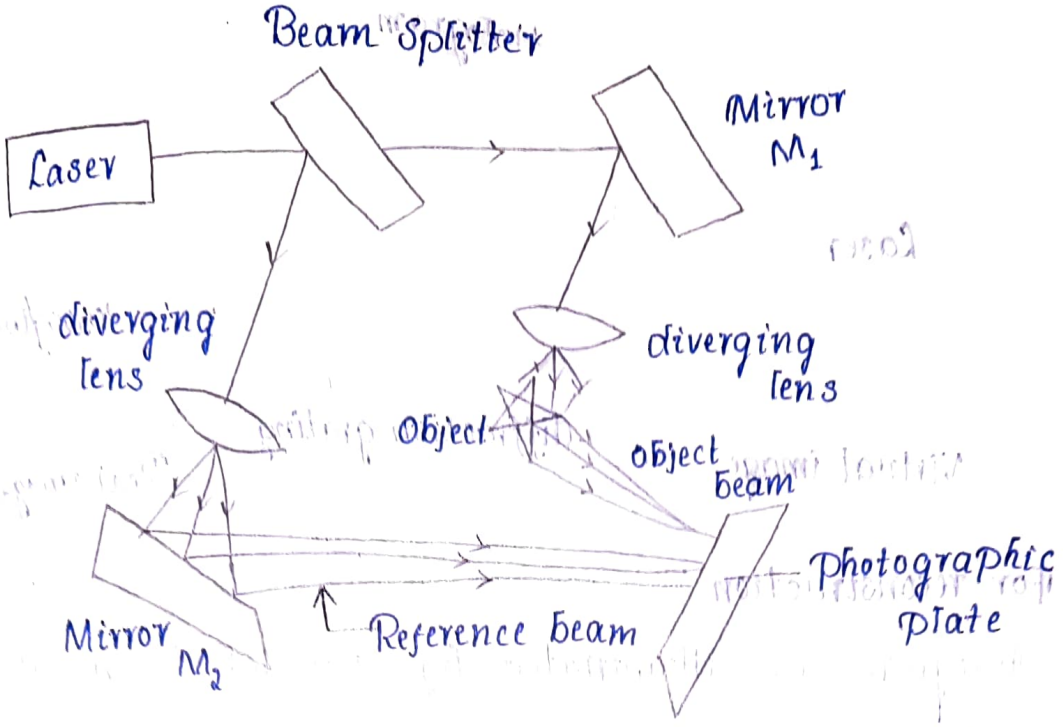
[phase → depth of the image].

- 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 :- discovered by "Dennis Gabor" in 1948.
- It is a combination of two words in greek are

  Holography – Holo + graph
  (whole) (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 :-





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].

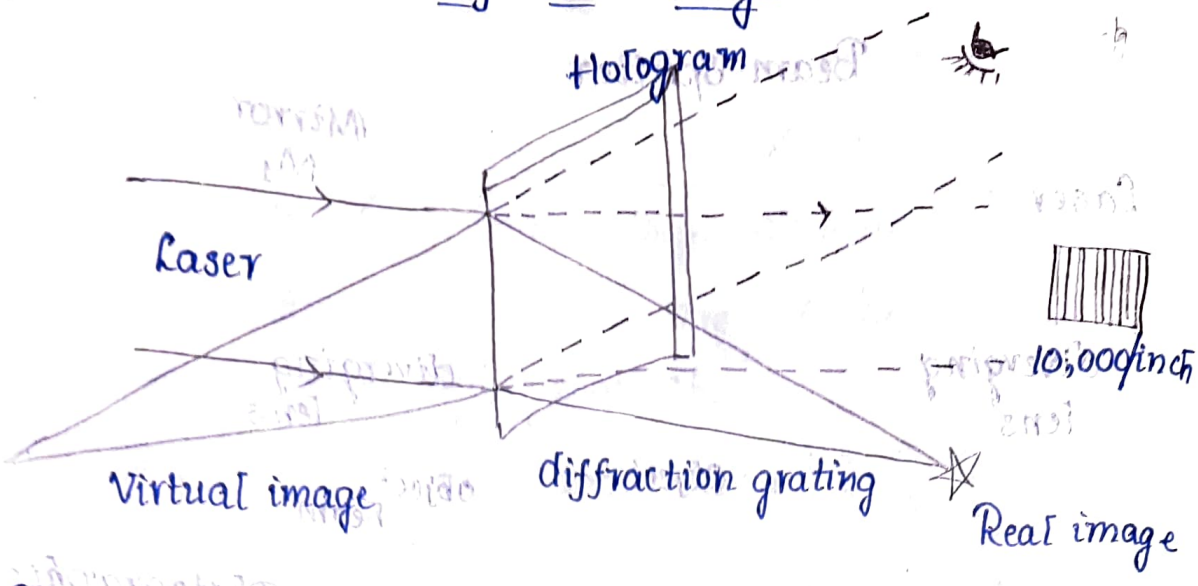
iv. Object beam is the light scattered off from the object.

v. The refrence beam is the light, reaching the photo graphic plate directly.

vi. A broad laser be is divided into two parts, by using a beam splitter.

vii. At the photographic plate object beam & refrence 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 diffraction grating. (Small glass studied to find diffraction)

iii) Due to diffraction a real image is formed & this image can be photographed becoz, laser light is falling in this image.

iv) Virtual image will be formed at the location of the object