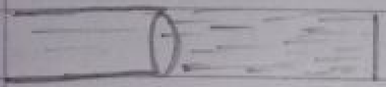
Laser and Fiber Optics

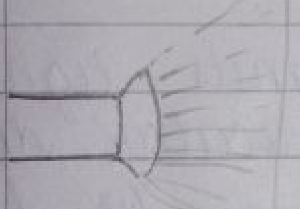
* Spontaneous & Stimulated Emissions :-

LASER → Light a amplification Due to Stimulated Emission of Radiations.

Properties of Laser :- 1) Monochromatic is visible
2) Coherent
3) Directional (Collimated i.e. with minimal divergence of Parallel.
4) High Intensity.



Normal Light :- 1) Polychromatic
2) Non-coherent
3) Non directional
4) Low Intensity



Uses of Laser :- 1) Laser Drilling
2) Laser Cutting
3) Unwanted Hair removal
4) Eye Surgery
5) Bar Reader
6) Laser Printer, 7) Laser show

→ In 1917, Albert Einstein gave the concept of Stimulated Emission.

→ Dr. T.H. MAIMAN fabricated first laser "Ruby Laser" in 19060.

Laser: Laser is a device that emits a collimated, monochromatic, highly intense, unidirectional beam of light. The full form of Laser is Light Amplification due to Stimulated Emission of Radiations.

Laser light is different from ordinary light of as it has following 4 special features..

1) Monochromaticity :- A laser emits light beam of single frequency & single wavelength.

2) Directionality :- A laser emits light beam in one particular direction, Intensity :- A laser beam can be focussed on a very small area. A 1 watt on Laser is thousand time more Intense than 100 w ordinary lamp.

Coherence :- laser beam is highly coherent ie there is definite phase anckorelation b/w photons in laser beam

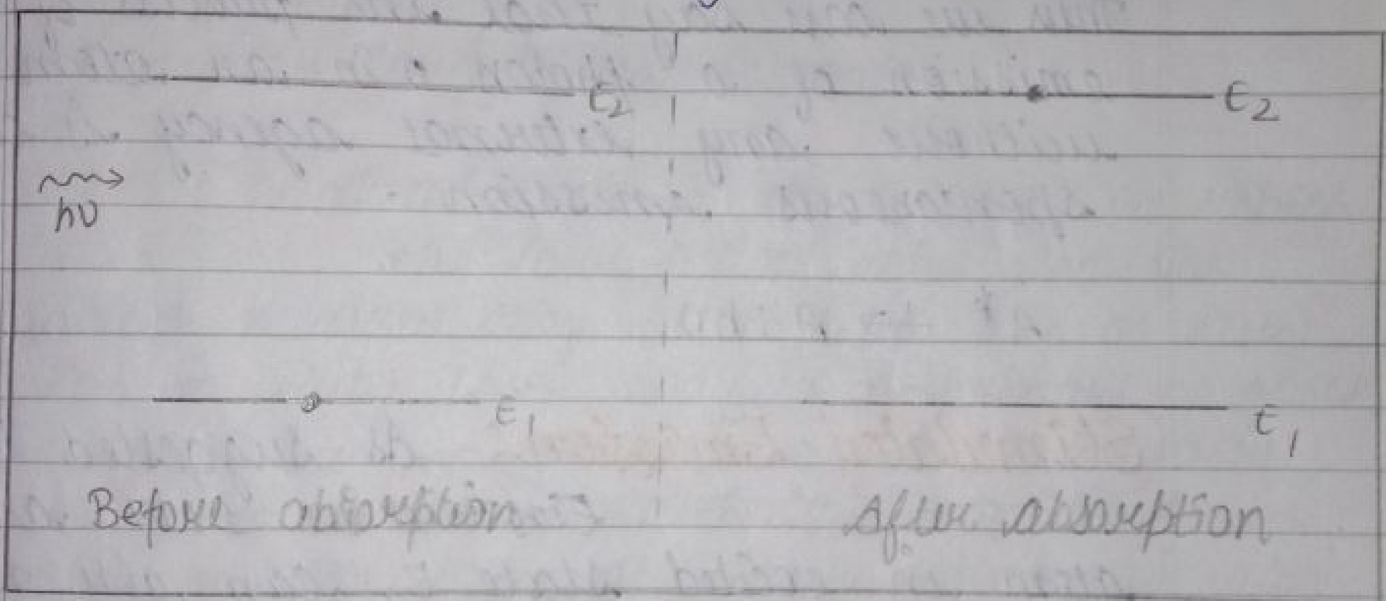
Stimulated Absorption: Let us consider that initially an atom is in lower energy state having energy E_1 of a photon of energy $h\nu$ is incident on an atom in lower state.

then the atom absorb this much amount of energy & jumps to excited state having energy E_2 such that $h\nu = E_2 - E_1$

This process is known as induced absorption or simulated absorption.
we may express it as

$$A + h\nu \rightarrow A^* \text{ (Excited State)}$$

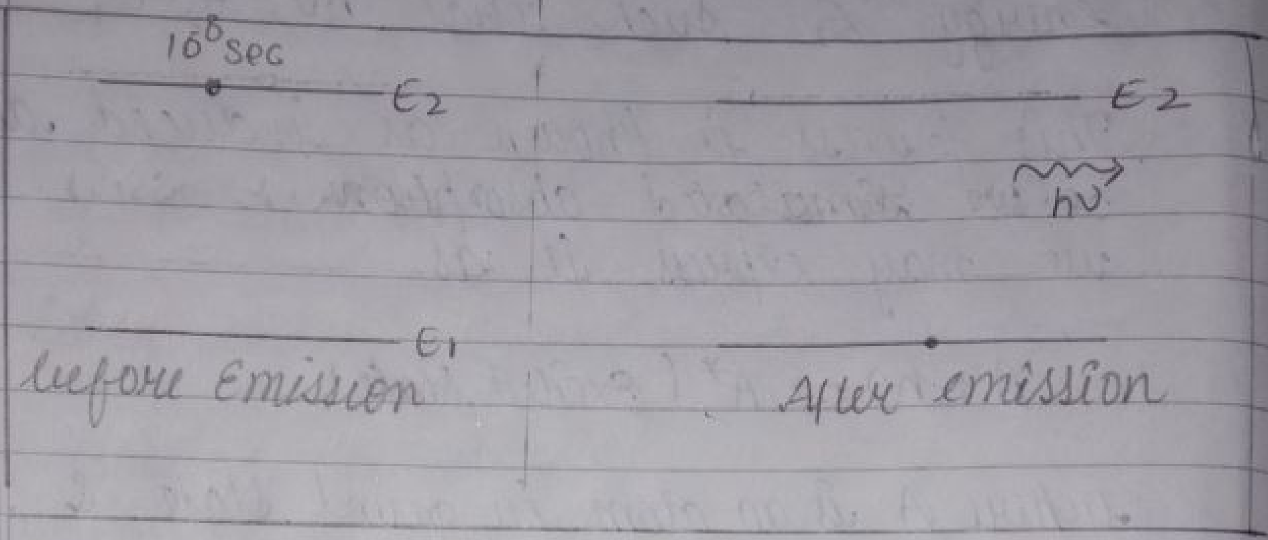
where A is an atom in ground state & A^* is



same atom in excited state.

Spontaneous Emission :- Consider that initially an atom is in higher energy state E_2 same normal life time of the atom in excited state is 10^{-8} sec, so the atom will make a transistion to lower energy state E_1 during this transistion, atom will release a photon of energy $h\nu$ where $h\nu = E_2 - E_1$.
The emission of photon occurs on its

own. This process is known as spontaneous emission.



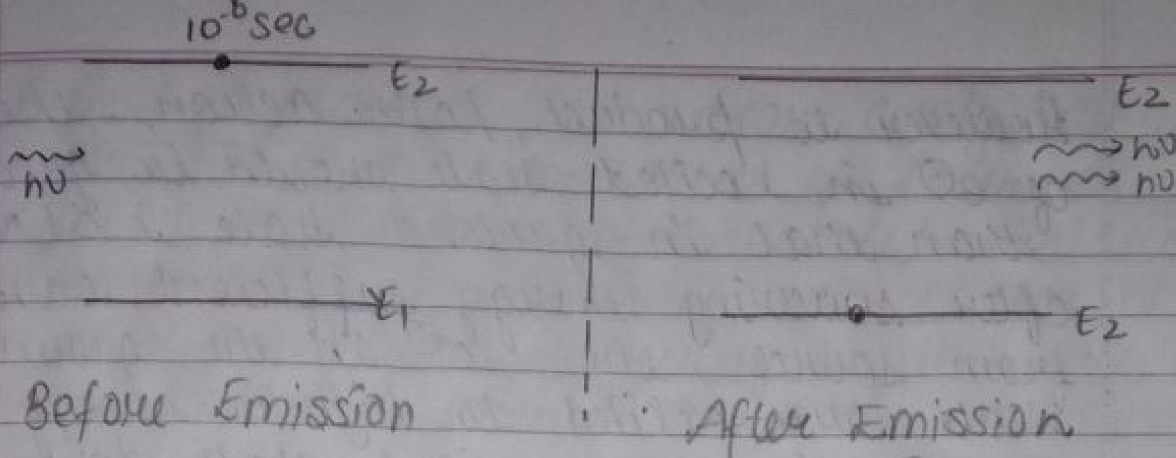
Thus we can say that the process of emission of a photon in an atom without any external agency is called spontaneous emission.

$$A^* \rightarrow A + h\nu$$

Stimulated Emission :- As suggested by Einstein in 1917 an atom in excited state E_2 can also make transistoin to lower energy state E_1 when biggered by photon of energy $h\nu$ During this transition, emission of second photon take place. The emitted photon has same frequency, same direction, same phase as that of incident photon.

This process may be expressed as

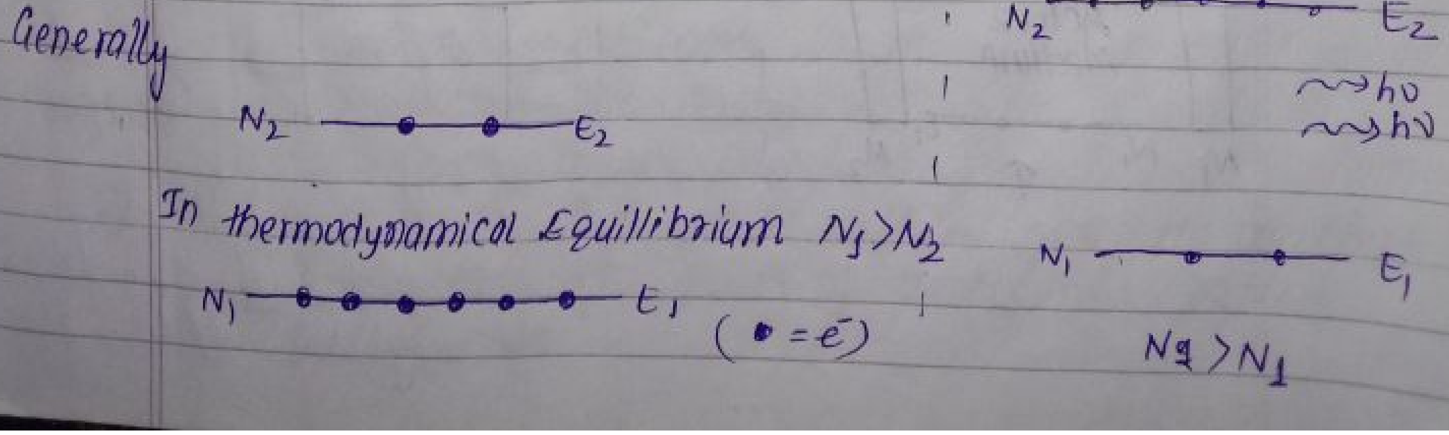
$$A^* + h\nu \rightarrow A + 2h\nu$$



Components of Laser :- There are 3 main components of laser is

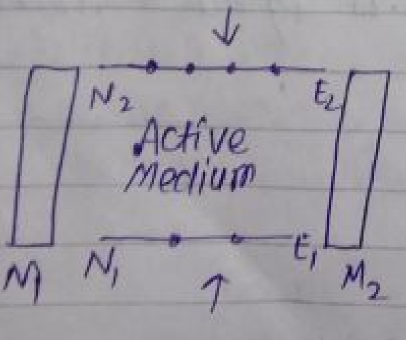
1) Active Medium
2) Pumping Source
3) Resonator Cavity/optical Resonator

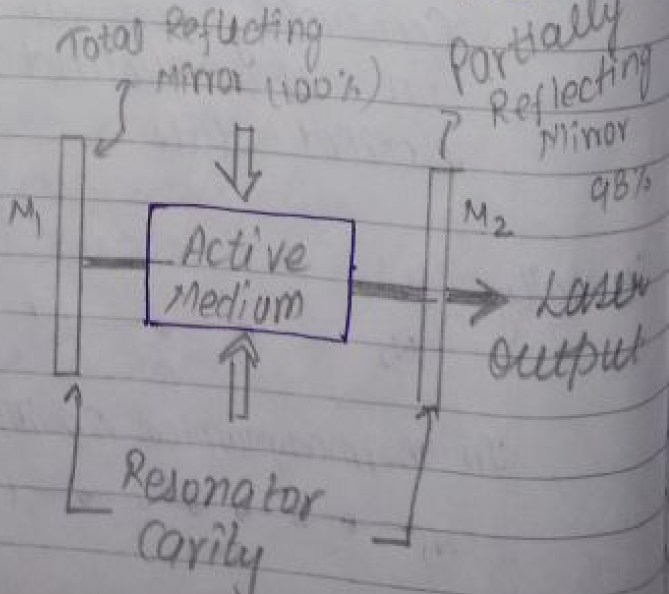
1) Active Medium :- It is the material in which the laser action takes place. The active medium may be a solid like as Ruby Rod in Ruby laser, may be a mixture of gases such as He – Ne gas mixture in He-Ne laser, may be a semicondutor such as Ga, As in Semiconductor laser etc. laser medium is also known as Active medium or gases medium. Generally in an active medium the no of $e^{\ominus}$ in the ground state is greater than in excited state



However to produce Laser action, the no. of $e^{\ominus}$ in excited state should be greater than that in ground state i.e. ($N_2 > N_1$). After receiving energy sufficient energy from source, the $e^{\ominus}$ in the ground state are excited to higher energy state. The $e^{\ominus}$'s in the excited state do not stay for longer time as the lifetime of $e^{\ominus}$ is in the excited state is only 10^{-8} sec. Hence after short period of time $e^{\ominus}$ in excited state will fall back to ground state by releasing energy in the form of photons. This process is known as spontaneous Emission.

2) Pumping Source (Energy Source):- The process by which population Inversion ($N_2 > N_1$) is achieved in a laser system is called pumping. The type of pumping method used depends on nature of Active Medium used in laser system. For eg. In solid state lasers such as Ruby laser we use optical pumping. In gaseous such as He-Ne Laser, we use Electrical pumping.





3) Optical Resonator (Resonator Cavity):- It is a key component of laser as it guides the process of stimulated Emission. It consists of a pair of mirrors out of which 1 is 100% reflecting & other 98% (partially) reflecting. The active medium is placed in between these 2 micro.meter (mirrors. Mirror (M_2) is called output coupler as it allows some of the light to leave the cavity to produce laser output beam.

Classification of Laser:-

Laser system may be classified by two ways:-

① On the basis of output beam.
② On the basis of active medium.

1. On the basis of Output beam:- According to the output beam, laser are of two types.

1) Continuous Wave Laser:- The laser which give the output in form of continuous wave are called continuous wave from. (CW Laser)

Example:- Nd-YAG laser
He-Ne laser
Argon-Ion laser
CO_2 laser.

2) Pulse Laser:- The laser which give the output in the form of pulses are called pulse laser.

Example: of pulse laser are Ruby laser, Nd-Glass laser, Nitrogen Laser

② On the basis of state of Active Medium:-
according to the state of active medium laser are of three types.

I Solid State Laser:- If the active material is in the Solid State, the laser is said to be Solid State. the
Example:- Ruby laser, Nd-YAG laser
Nd-Glass laser
Neadymium laser etc.

II Dye (Liquid Laser):- If active material is in the form of liquid the laser is solid to be liquid or dye Laser. In the dry or liquid laser active medium is formed by solution of certain dissolves in the liquid such as alcohal and water these dyes belong to the following laser:-

1) Polymethine dyes
2) xanthene dyes
3) Caurmarine dyes

There are more than 200 Lasers. these laser having the unique characteristic i.e. tunability and high gain,

III: Gas laser:- If active material is in the form of gas or vapour, the laser is said to be a gas laser there are three types of gas laser –

a) Atomic Lasers :- Example :- He-Neon Laser.
b) Ionic Laser :- Example : Argon-ion Laser
c) Molecular Laser :- Example :- CO_2 Laser, Eximer Laser, Nitrogen laser.

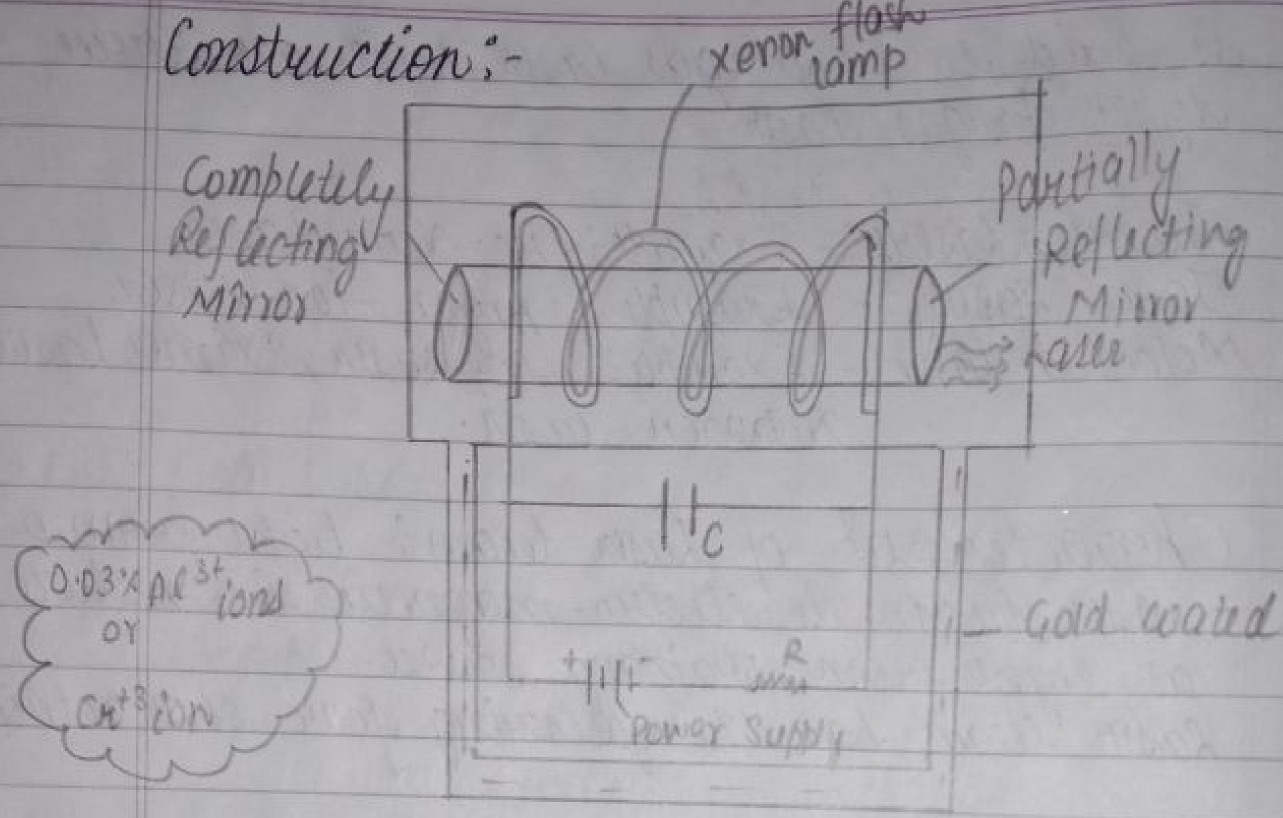
V.1. Characteristic of Laser beam :- light from a laser beam is electro-magnetic in nature as light from ordinary source.
Laser beam has the following four characteristi

1) High directionality
2) High intensity
3) Extra ordinary mono-chromacity
4) Highly coherent

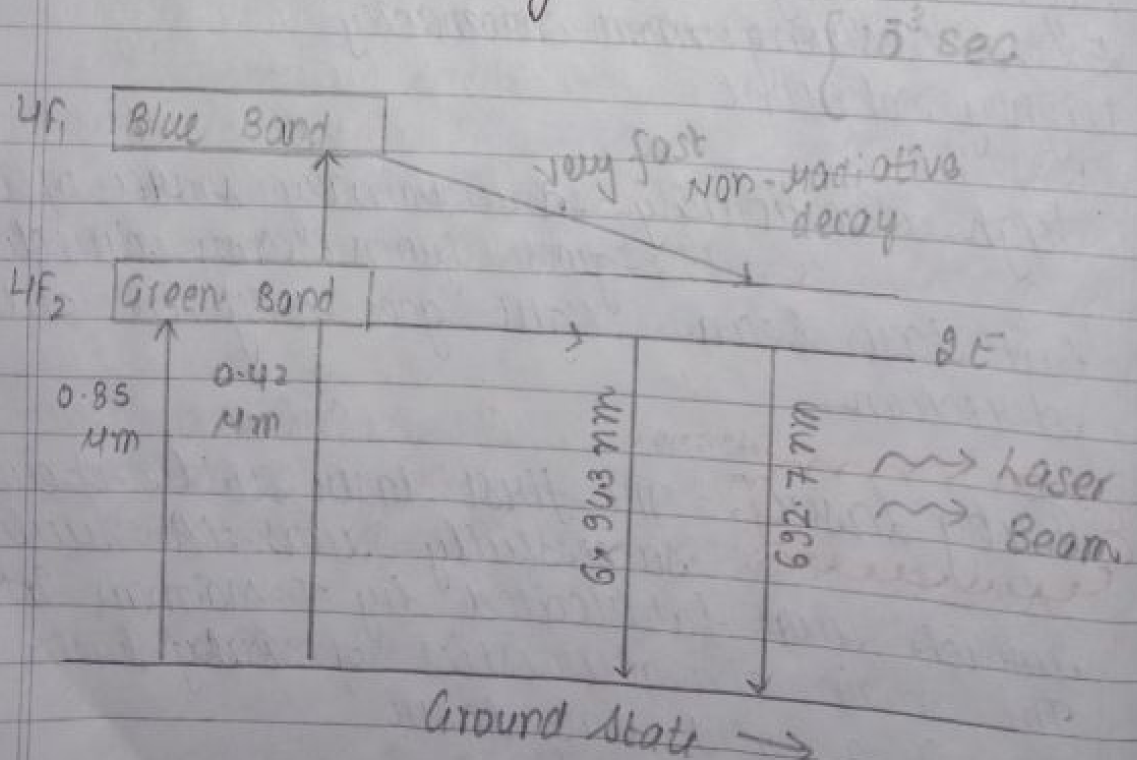
I. High directionality :- An ordinary source of light goes from any direction but laser beam light goes only in one direction.

Ruby Laser :- The first laser to be operated successfully was the ruby laser which was fabricated by T. Maiman in 1960
The main characteristics of Ruby laser are
1) It is a solid state laser
2) It is a 3 level laser
3) It is use optical pumping
4) Give the output in the pulse mode.

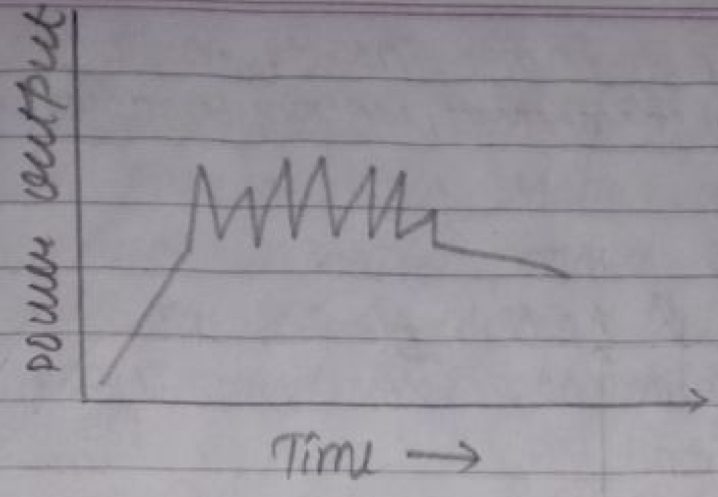
Construction:-



Principle of Working:-

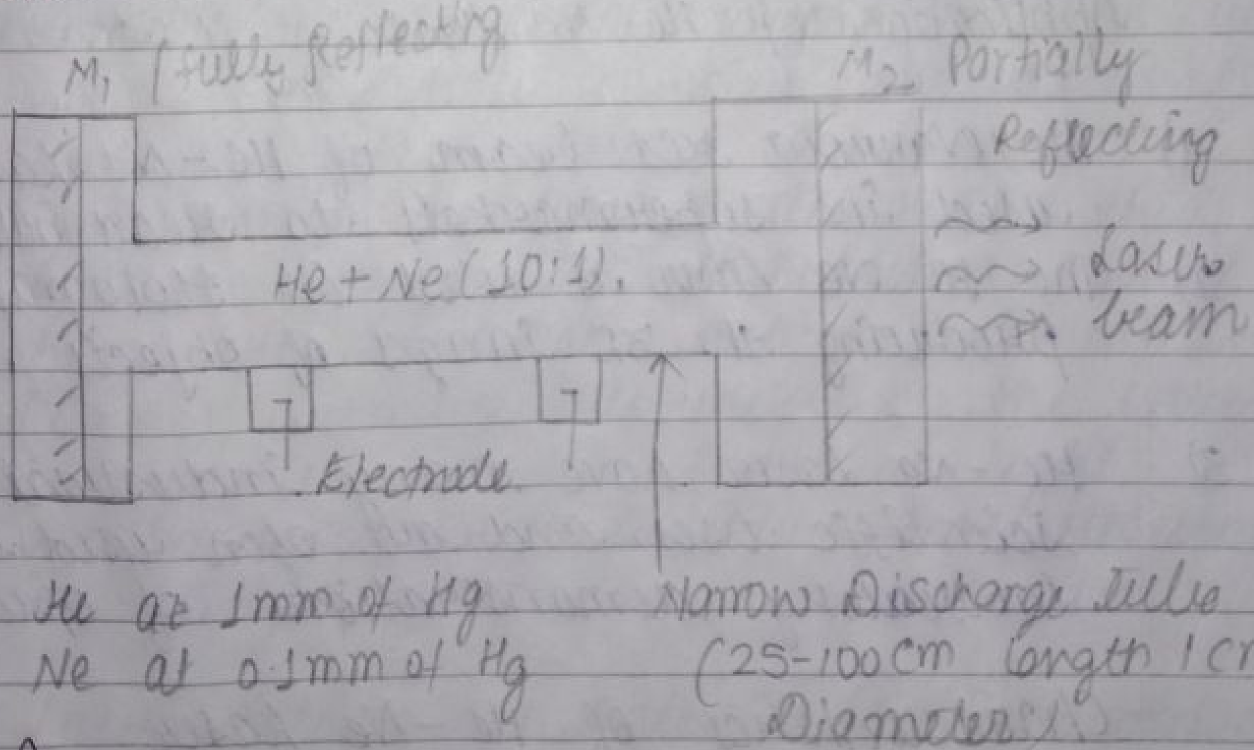


Spiking behaviour of Ruby Laser:-

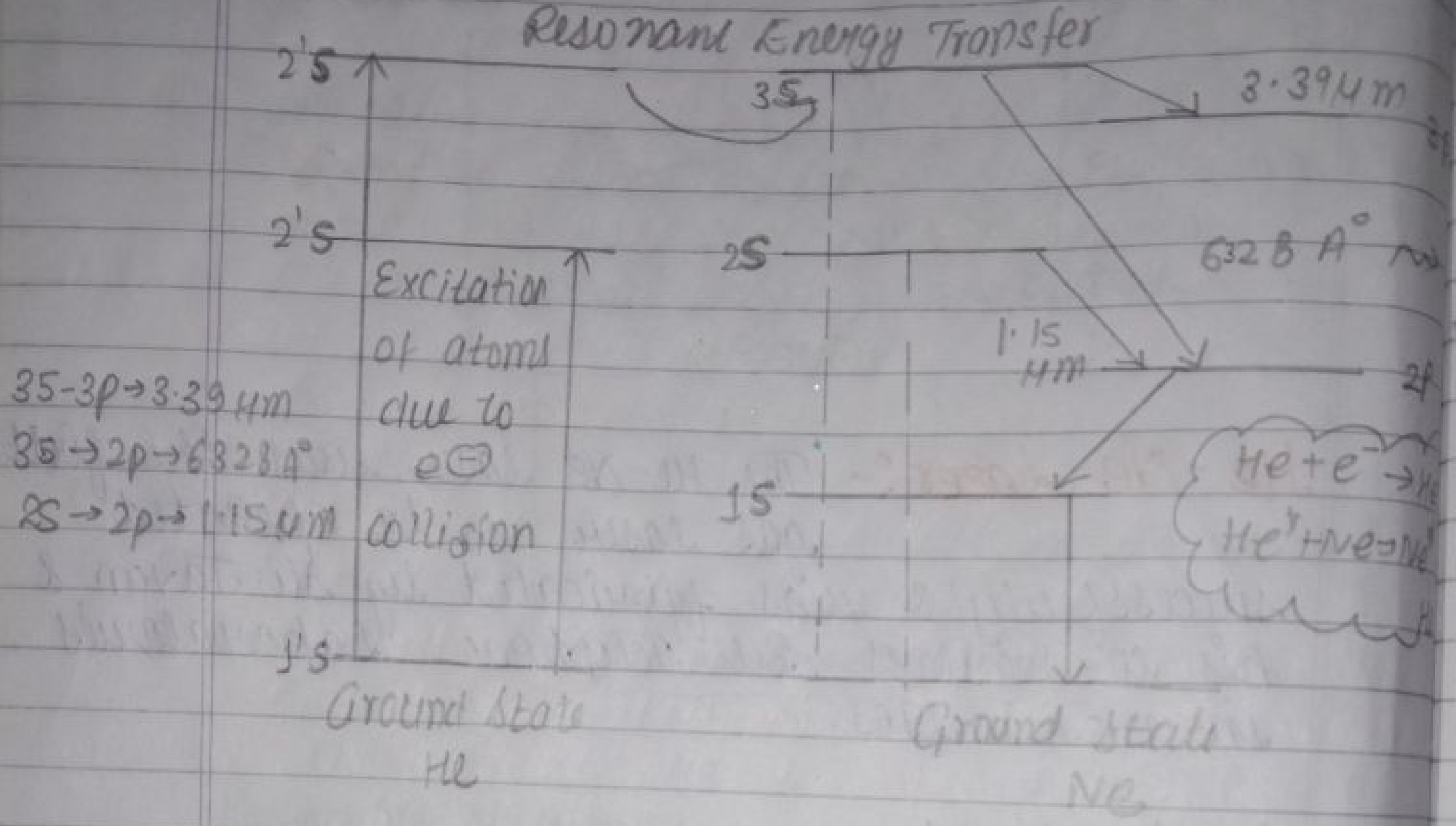


He-Ne Laser :- The He-Ne laser was the first gas laser to be operated successfully & was fabricated by Ali-Javan & his co-workers Bell Telephone Laboratories in U.S.A in 1961.

Construction :-



Principle . working & Energy level diagram :-



Applications of He-Ne Laser:-

1) The Narrow red beam of He-Ne Laser is used in supermarkets to read bar codes
2) The He-Ne Laser is used in Holography in producing the 3D Images of objects.

3) He-Ne Laser have many industrial and scientific uses, and are ofen used in Laboratory demonstrations of optics.

Characteristics of He-Ne Laser:-

1) It is four level laser.
2) It is easy to construct & reliable in operation.
3) It works in continous mode.

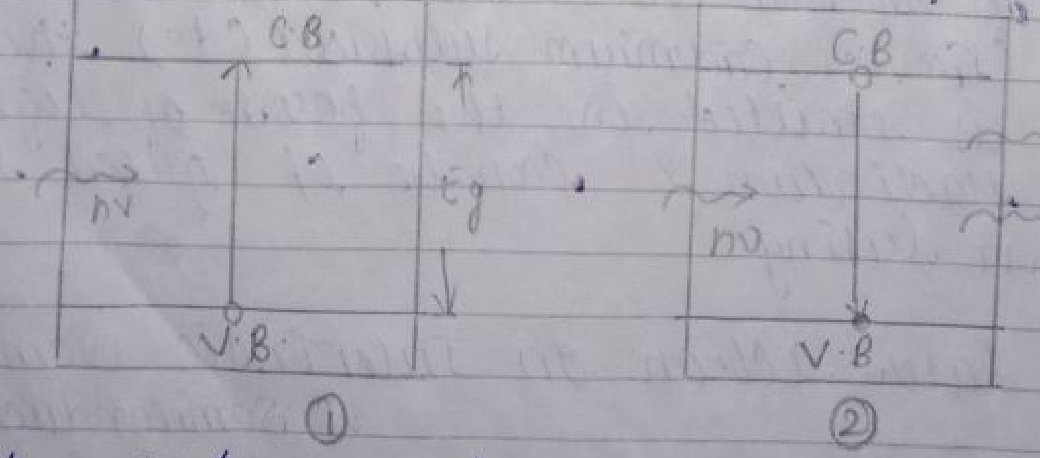
It does not require cooling apparatus.
The light from He-Ne Laser is more directinal, more monochromatic, more coherent as compared to solid-state lasers.
It employs electrical pumping

SEMICONDUCTOR LASER:- It is a type of laser some what similar to LED but LED works on the spontaneous emission where as semiconductor laser works on the principle of stimulated emission. The active medium in such laser is a semiconductor material.

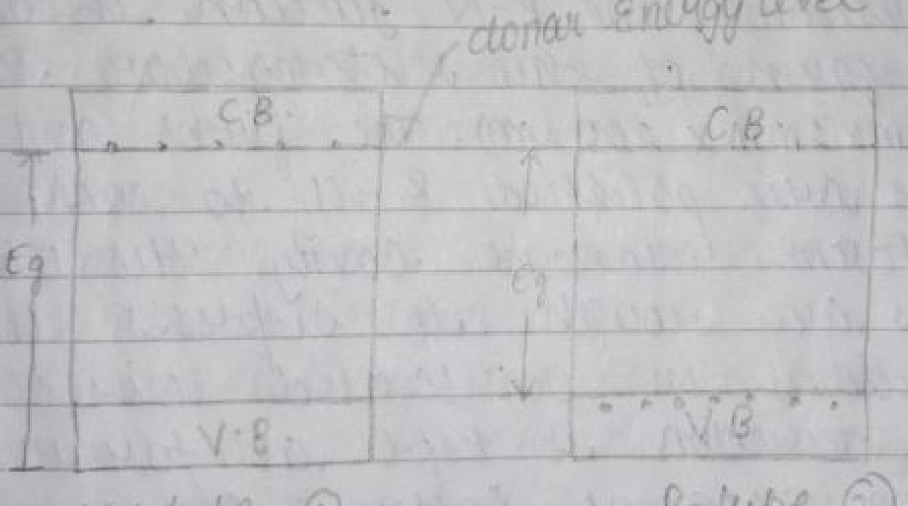
Principle:- In a semiconductor material, when $e^{\ominus}$ & hole combine, the excess of Energy is either emitted as heat energy or light energy. In case of Ge or Si the emitted energy is in the form of heat so of no use in laser action, whereas in (Ga As), Cadmium sulphide (Cds) the energy is emitted in the form of light radiation. & can be of great resistance in lasing.

Laser action in Interinsic Semiconductor:- A Semiconductor without impurity is known as Intrinsic Semiconductor. In Intrinsic semiconductor no. of $e^{\ominus}$ from top of valance band to the bottom of conduction band is viewed as generation

of e⊖ hole pair. The reverse transition of e⊖ from conduction band to valence band is also possible of & when it happens an e⊖ meet hole & process is viewed as e⊖ & hole recombination.
When semiconductor material is illuminated by photons whose energy is equal to or higher than band gap energy of semiconductor such a photon can be absorbed by e⊖ at the top of valence band. The excited e⊖ then jumps to CB leaving behind a hole in VB. Practically the same propability exists for photon to initiate the reverse process ie transfer of e⊖ from bottom of CB to VB when this transferred e⊖ combines with hole in VB, a quantum of energy equal to differenence in energy of 2 states emitted. This secondary emitted photon is in phase with primary photon.



When a pure semiconductor is doped with impurity atoms, the resulting material so formed is known as N-type semiconductor & similarity when a pure semiconductor is doped with tri-Valent impurity atoms, the resulting material so formed is known as P- type semiconductor. The energy band diagram of N-type & p-type semiconductor is shown in Fig. In fig ① the dona energy level is just below the bottom of C.B at $\Delta E = 0.01 eV$. when temp. of N-type semiconductor is gradually increased from 0K, the transistion of $e^{\ominus}$ from donar energy level to CB. takes place around 20 to 50K, the donar energy level will be deflected i.e. all donar atoms have donated their $e^{\ominus}$s into C.B. This makes the material n-type degenerate.



N-type ① P-type ②

In fig ② the acceptor energy level is just above the top of V.B. at $\Delta E = 0.01 eV$. When temp. of p-type semiconductor is gradually increased from 0K, the transistion of $e^{\ominus}$ from V.B. to acceptor energy level takes place around 20 to 50K, the acceptor enegy level will be completely filled & $e^{\ominus}$ raised to this level leaves behind holes in V.B. This makes the material

Advantages:-

1) Semiconductor laser have high efficiency.
2) The small dimentions of semiconductor lasers make it possible to constuuct quantum amplifiers with extermely high resistivity.
3) These laser can be integrated with FET, BJT to form optoelectronics circuits.
4) From cost point of view semiconductor lasers are economical
5) Low power consumption.
6) Semiconductor Laser instruction is very simple.

Disadvantages:-

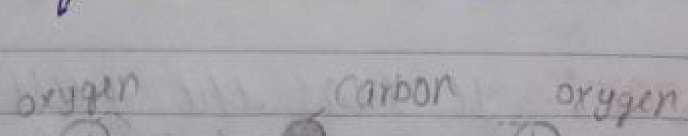
1) Semiconductor Laser is grately (greatly) dependent on temp.. The temp. affects the output of Laser.
2) Beam divergence is much greater from 125 to 400 miliradians.
3) Due to relatively low power production these lasers are not suited to many typical laser applications.

CO_2 Laser:- It was the first molecular laser developed by Indian born American Scientist CKN Patel at Bell Laboratories . USA in 1964. CO_2 laser is highest power continuous wave that is currently avaible (available) continuous wave power output of CO_2 laser can range from few watt to over 15,000 watts. It produces laser beam of wavelength 10.6 μm & 9.6 μm. The beam divergence of CO_2 laser ranges from .1 to 10 milliradians.

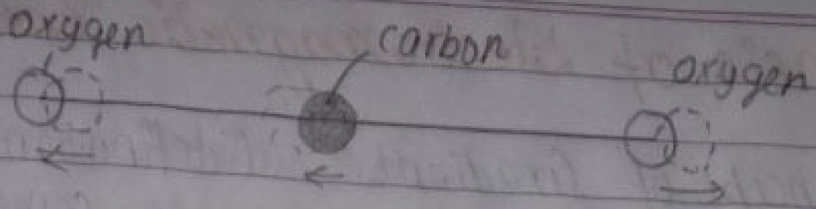
Principle:- The active medium is a gas mixture of CO_2, N_2 & He. The laser transition takes place b/w the vibrational states of CO_2 molecules vibrational modes of CO_2 molecule.
A CO_2 molecule has one carbon atom at the center with two oxygen atoms attached, one at both sides

Such a molecule exhibits 3 independent modes of vibrations which are as follow

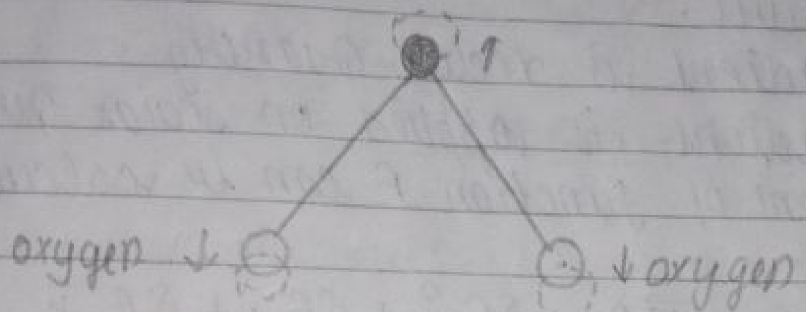
1) Symmetric stretching mode:- In this mode of vibration, central carbon atom is at rest & both oxygen atoms vibrate simultaneously along the axis of molecule departing or approaching the fixed carbon atom.



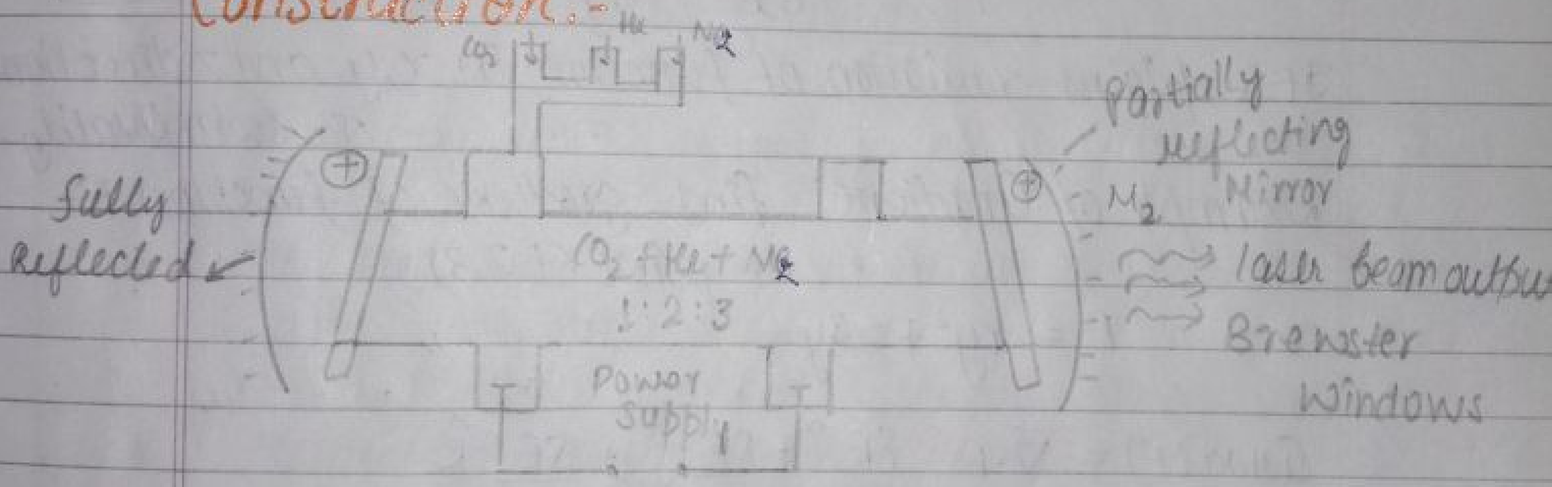
2) Asymmetric stretching mode:- In this mode of vibration, central carbon atoms & oxygen atoms vibrate asymmetrically i.e. oxygen atoms move in the other direction.



c) Bending Mode:- In this mode of vibration, oxygen atoms & carbon atom vibrate perpendicular to molecular axis.



Construction:-



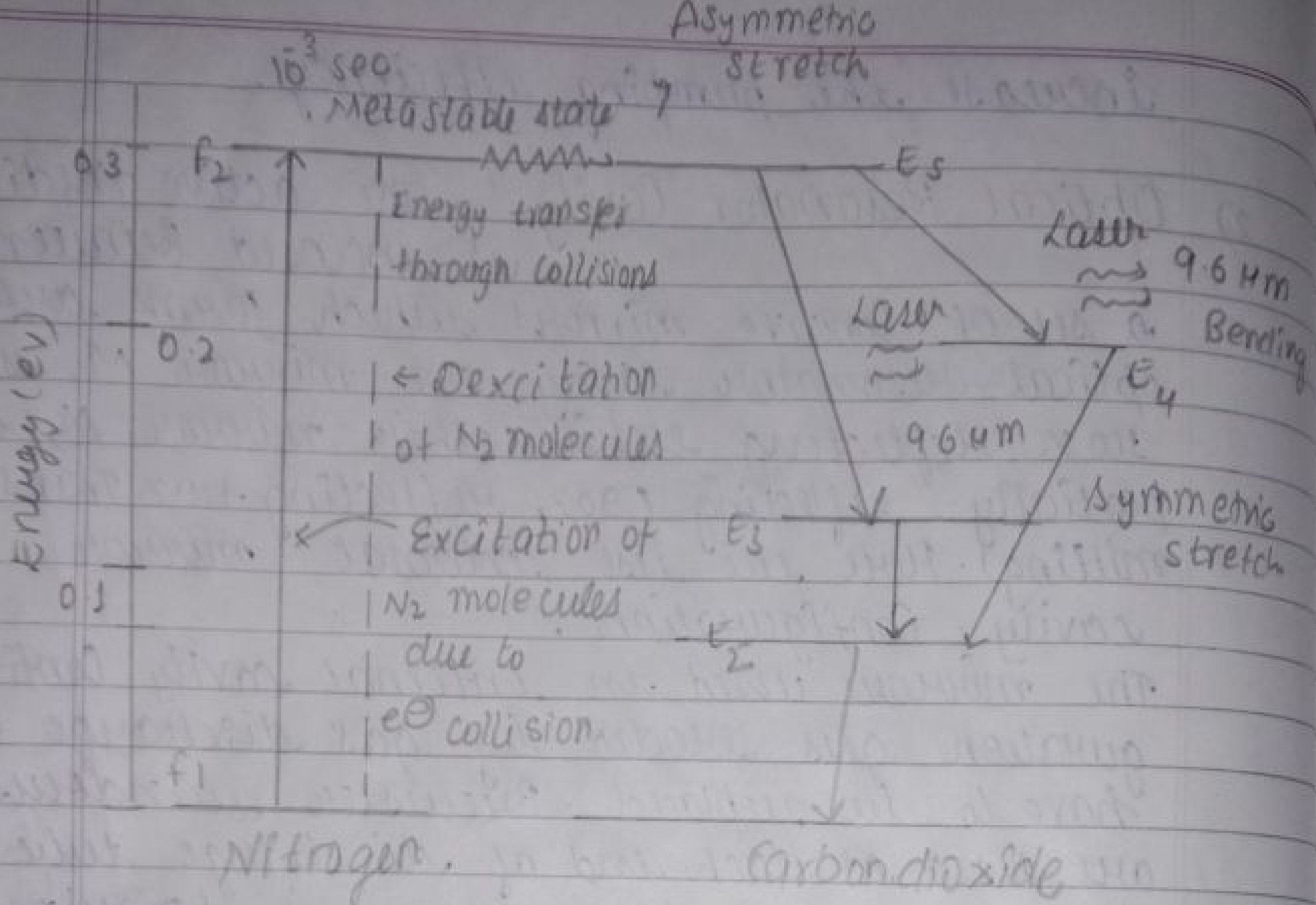
Active Medium:- The active medium in CO_2 laser is a gaseous mixture of $CO_2 + N_2$ + He in the ratio 1:2:3 filled in a Quartz discharge tube of length 5cm & diameter 2.5cm at a pressure of few mm of Hg. The active centers are the CO_2 molecule as lasing action will be achieved due to these molecules. The purpose of N_2 gas molecules is to help in excitation of CO_2 molecules by colliding with CO_2 molecules & transferring so N_2 molecules increase the pumping efficiency.

2) Optical Resonator Cavity :- The active medium is inclosed between a set of Concave mirrors which forms are optical resonator cavity. One mirror M_1 is 100% reflecting while other mirror M_2 is partially reflecting (90% reflecting +10% Transmitting). Here we use external mirror cavity Configuration.
The mirrors used in internal cavity Configuration gets eroded by gas discharge & have to be replaced. Brewster windows are used at each end of discharge tube so that output laser beam is polarized. Instead of using plane mirror, concave mirrors are used so that diffraction losses are minimised.

3) Pumping Source:- Electric discharge method is used for pumping & achieving population inversion. The 2 electrodes sealed inside the discharge tube are connected to a D.C. power supply of few Killo Volts

Working & Energy level diagram:- Fig shows energy levels of N_2 & CO_2 molecules when electric discharge occures in the gas the e⊖s collide with N_2 molecules & they are raised to excited states. This process is represented by eqn

$$N_2 + e^* \rightarrow N_2^* + e$$



The level F_2 is a metastable state & thus N_2 molecules excited to F_2 level spend sufficient amount of time before getting de-excited.

As excited level F_2 of N_2 molecule is very close to the E_5 level of CO_2 molecule. So when N_2 molecule in level F_2 collide with CO_2 molecules in ground state E_1, an energy exchange takes place & this results in excitation of CO_2 molecules to level E_5 & de-excitation of N_2 molecules to the ground level F_1.

This process is represented by eq^n

$N_2^* + CO_2 \rightarrow CO_2^* + N_2$. Thus population inversion is achieved b/w vibrational levels E_5 & E_4 or E_5 & E_3.

Thus E_5 is the upper laser level. E_4 & E_3 are lower laser levels.
The following transitions will occur
E_5 to E_4 with laser wavelength of 9.6 μm.
E_5 to E_3 with laser wavelength of 10.6 μm.
The CO_2 molecules in the levels E_4 & E_3 de-excite to level E_2 through inelastic collisions with unexcited CO_2 molecules.

This process is very fast so there will be accummulation of CO_2 molecules in E_2 level. To stop accumulation of CO_2 molecules in E_2 level He gas is added in gaseous mixture. CO_2 molecules return to ground state E_1 through inelastic collisions with He molecules. Other function of He is to conduct the heat away from the walls of discharge tube as He has high thermal conductivity.