LASERS

LASER: The word **LASER** stands for **or** short form of '***Light Amplification by Stimulated Emission of Radiation'***. The principle behind laser is put forward by C.H .TOWENS in 1954.The first LASER was built in 1960 by MAIMAN called as pulsed laser.

Characteristics of laser radiation:

Lasers differ from conventional light sources mainly in four ways, they are

1. Coherence
2. Directionality.
3. Monochromaticity.
4. High intensity

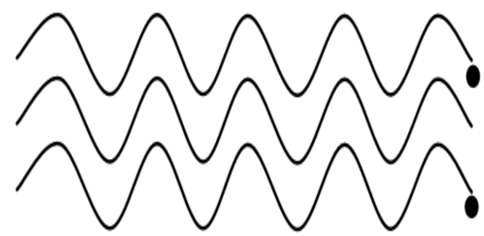
Coherence:

The light energy emitted is having a phase relation and does not change with time. Coherence is of two types, they are

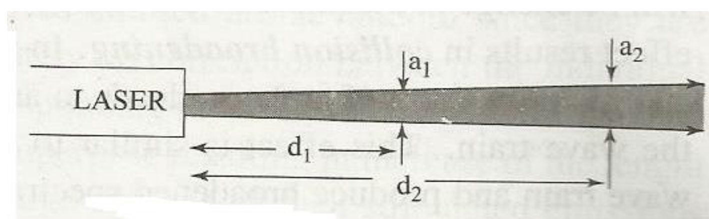
A. Temporal coherence.
B. Spatial coherence.

Temporal coherence: The predictable correlation of amplitude and phase at one point on the wave train w .r. t another point on the same wave train, then the wave is said to be temporal coherence. It measures the continuity of wave along it's length.

Spatial coherence: The predictable correlation of amplitude and phase at one point on the wave train w. r .t another point on a second wave, then the waves are said to be spatially coherence (or transverse coherence). It measures the maximum separation between any two points on the cross section of the wave front which maintain co-relation between them. Because of coherence a large amount of power10^{13} watts can be concentrated in a narrow space region



Directionality: Laser emits light only in one direction, this enables to focus the light to a point at a large distance. The directionality of a laser beam has been expressed in terms of divergence. Suppose a_1 and a_2 are the radii of laser beam at distance d_1 and d_2 from a laser then,

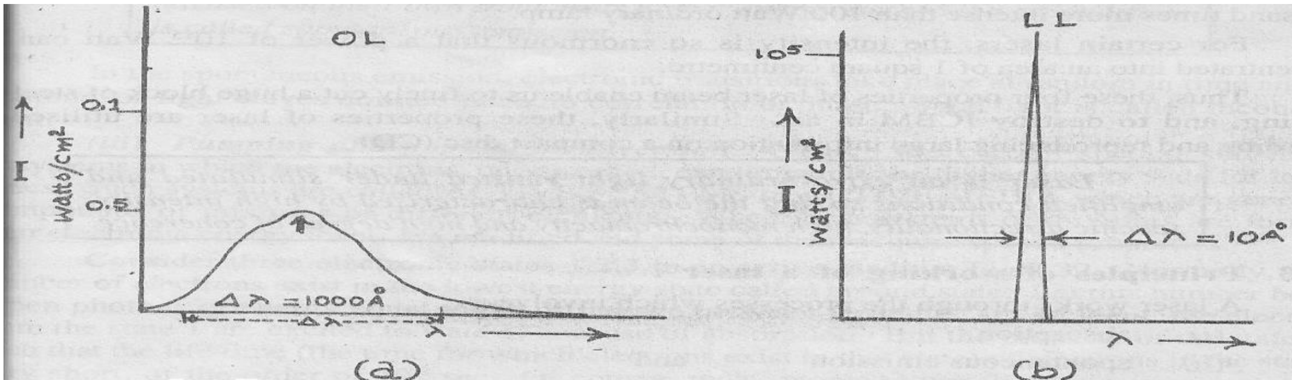


Directionality of a laser

The divergence $(\Delta\theta) = \frac{a_2 - a_1}{2(d_2 - d_1)}$

The divergence for a laser beam is 0.01 milli radian, where as in case of search light it's 0.5 radian.

Monochromaticity: The spread of light on either side of maximum intensity is called band width. The band width of laser light is narrow and so it is called highly monochromaticity. Because of this, large energy can be concentrated into a small band width. This narrow band width of a laser light is called high monochromaticity.



Band width of (a) a conventional monochromatic light (b) a laser light

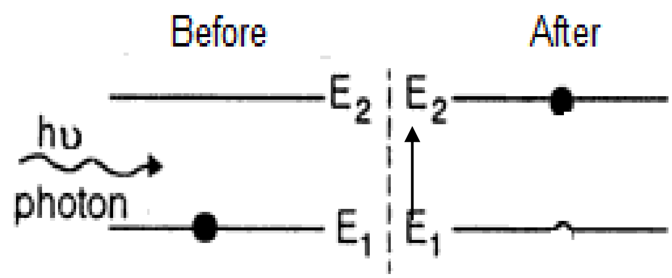
<u>INTENSITY</u>: Since an ordinary light spreads in all directions, the intensity reaching the target is very less. But in the case of laser, due to high directionality the intensity of laser beam reaching the target is of high intense beam. For example 1 mw power of He-Ne laser appears to be brighter than the sunlight.

<u>WORKING PRINCIPLE OF LASER:</u>

In the working of laser four processes are involved.

1. Absorption of energy or Stimulated absorption.
2. Spontaneous emission.
3. Pumping and population Inversion.
4. Stimulated emission of radiation.

Absorption of energy:



Let E_1 and E_2 are the two energy states and N_1 and N_2 be the number of atoms per unit volume of ground state and excited states and $\rho(\nu)$ be the density of photon.

If a photon of energy $E_2 - E_1 = h\nu$ interacts with an atom present in the ground state, the atom goes to excited stare. This is called ***absorption of energy***.

Absorption rate (N_{ab}) depends upon the number of atoms available in the lower energy state as well as the energy density of interacting photons $\rho(\nu)$.

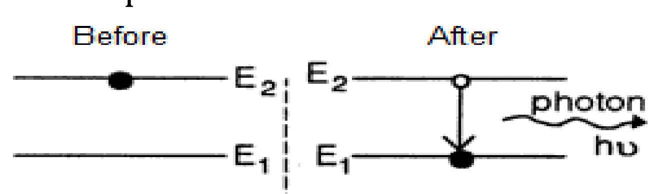
Absorption rate $(N_{ab}) \propto N_1$

$$N_{ab} \propto \rho(\nu)$$

$$\boxed{N_{ab} = B_{12} N_1 \rho(\nu)}$$

Where, B_{12} is known as Einstein coefficient of stimulated absorption.

Spontaneous emission:



Spontaneous emission

The life time of electron in excited state is $10^{-8} sec$. After $10^{-8} sec$ atoms return to ground state emitting energy in the form of incoherent light. This is called ***spontaneous emission.***

Spontaneous emission rate depends upon the number of atoms available in the excited state.

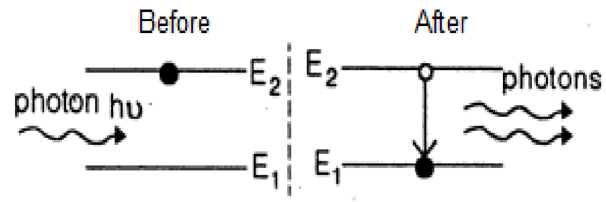
Spontaneous emission rate $(N_{sp}) \propto N_2$

$$\boxed{N_{sp} = A_{21} N_2}$$

Where, A_{21} is known as Einstein coefficient of spontaneous emission.

Stimulated emission:

Let a photon of energy $E_2 - E_1 = h\nu$ interacts with atom in excited state before $10^{-8}sec$ and returns to ground state emitting an additional photon of same ν, λ, and having same phase before $10^{-8}s$. This is known as ***stimulated Emission of radiation.***



Stimulated or induced emission

Stimulated emission rate (N_{ab}) depends upon the number of atoms available in the excited state as well as the energy density of interacting photons $\rho(\nu)$.

Stimulated emission rate $(N_{st}) \propto N_2$

$$N_{st} \propto \rho(\nu)$$

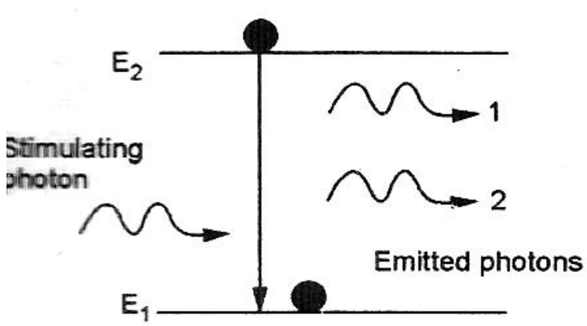
$$\boxed{N_{st} = B_{21} N_2 \rho(\nu)}$$

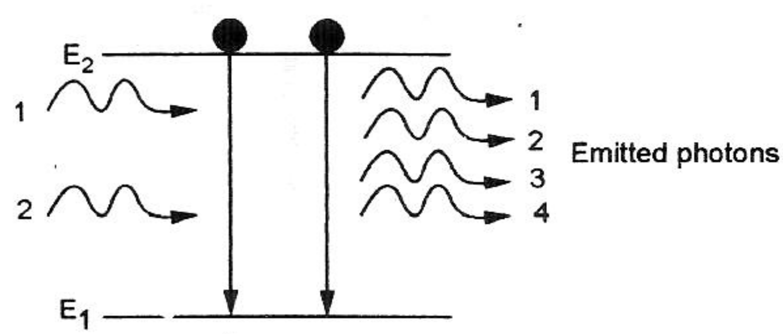
Where, B_{21} is known as Einstein coefficient of stimulated emission.

Difference between Spontaneous emission and Stimulated emissions

S.NO	***Spontaneous Emission***	***Stimulated Emission***
1	This theory was postulated by Bhor.	This theory was postulated by Einstein.
2	Emission occurs without stimulus energy.	Emission occurs by the stimulus energy
3	One photon is emitted.	Two photons are emitted.
4	Incoherent radiation.	Coherent radiation.
5	Low intense and random direction.	High intense and highly directional.
6	This process depends upon the properties of energy states only.	This process depends upon the properties of energy states and also the incident energy supplied to the atom in the higher energy state.
7	Example: : light from sodium or mercury lamp	Example: light from laser source

Lasing Action:





The principle of lasing action based on stimulated emission of radiation. In stimulated emission the emitted photons travel in the same direction as that of incident photons.

When these two photons incident on the other two atoms in the excited state, two stimulated emission occurs, so that four photons are emitted. These four photons causes four stimulated emissions and eight photons are emitted. In a similar way a chain reaction produced. This phenomenon is known as lasing action. Due to this monochromatic, high intense, high coherent beam comes out. This beam is called a laser beam.

METASTABLE STATE:

The excited state which has long life time is known as meta stable state. It is the more stable state which lies between the excited state and the lower state.

This state allows accumulation of large number of excited atoms at this level. Hence, the population inversion can be achieved.

This state can be obtained readily in a crystal containing impurity atoms. These states lie in the forbidden band gap of the host crystal.

POPULATION INVERSION:

Def: *Population inversion is the process by which the population of a particular higher energy state is made more than that of a specified lower energy state.*

Consider two level energy system . Let E_1 and E_2 be the two energy levels and N_1 and N_2 be the population of these energy levels respectively. At ordinary conditions, i.e., the population in the ground state is always greater than the population in the excited state. According to Boltzmann's distribution the population of an energy E_i is

$$N_i = N_0 e^{-E_i/kT} \tag{1}$$

Where N_0 is the population of the ground state with $E = 0, k$ is the Boltzmann's constant and T is the absolute temperature.

From eq. (1) it is clear that the population is maximum in the ground state and decreases exponentially as population go to a higher energy state.

If N_1 is the population in energy state E_1, N_2 in E_2 then,

$$N_1 = N_0 e^{-E_1/kT}$$

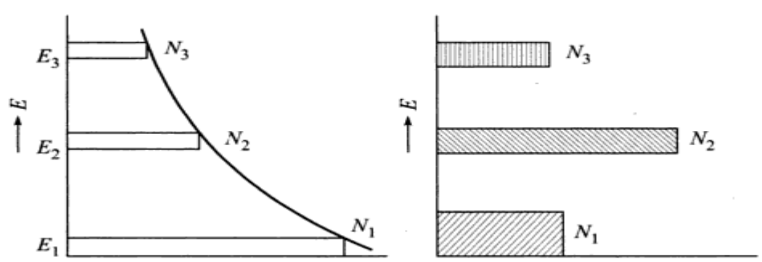
$$N_2 = N_0 e^{-E_2/kT}$$

$$\therefore \quad \frac{\mathrm{N_2}}{\mathrm{N_1}} = \frac{\mathrm{e}^{-\mathrm{E_2/kT}}}{\mathrm{e}^{-\mathrm{E_1/kT}}} \quad \text{or} \quad N_2 = N_1 e^{-(E_2 - E_1)/kT} \tag{2}$$

Since $\quad E_2 > E_1 \ and \ N_2 < N_1$

Under these conditions, the system absorbs appropriate electromagnetic radiation incident on it. Usually the population of atoms decreases with the increase in energy of the state.

To understand the concept of laser emission (stimulated emission), let us consider a three energy level system with energies E_1 and E_2,E_3 of populations $N_1, N_2 \ and \ N_3$.



(a) Normal population of a system ($N_1 > N_2$)
(b) Inverted population of a system ($N_2 > N_1$)

Population of atoms.

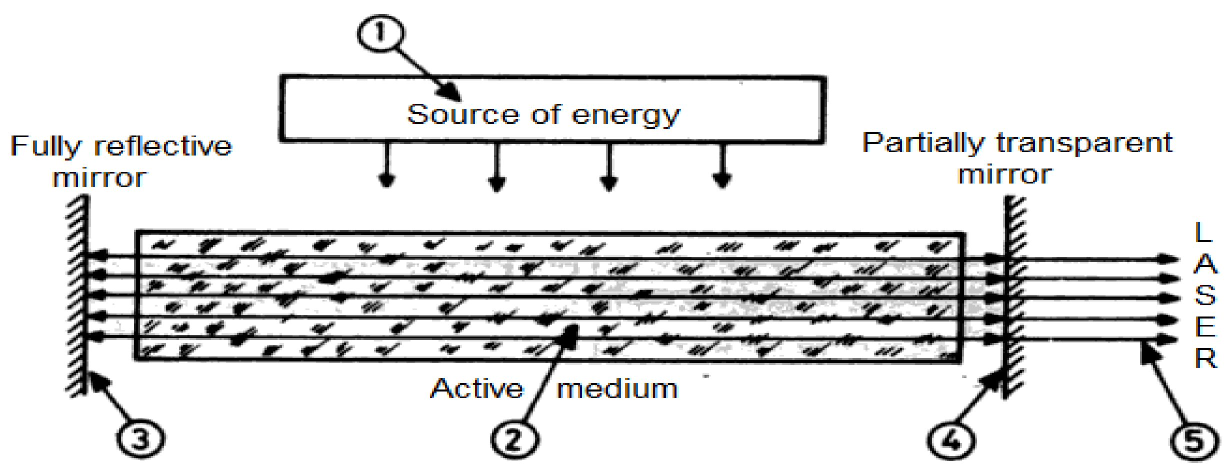
At normal conditions, $E_1 < E_2 < E_3$ and $N_1 > N_2 > N_3$. For Laser action to take place, stimulated emission should predominate over spontaneous emission and this is possible only when $N_2 > N_1$ i.e, higher energy levels are more populated than the lower energy levels when such condition is fulfilled, we say that population inversion is achieved.

PUMPING: The process of supplying suitable form of energy to the medium to achieve population inversion is called ***pumping.***

There are various pumping methods

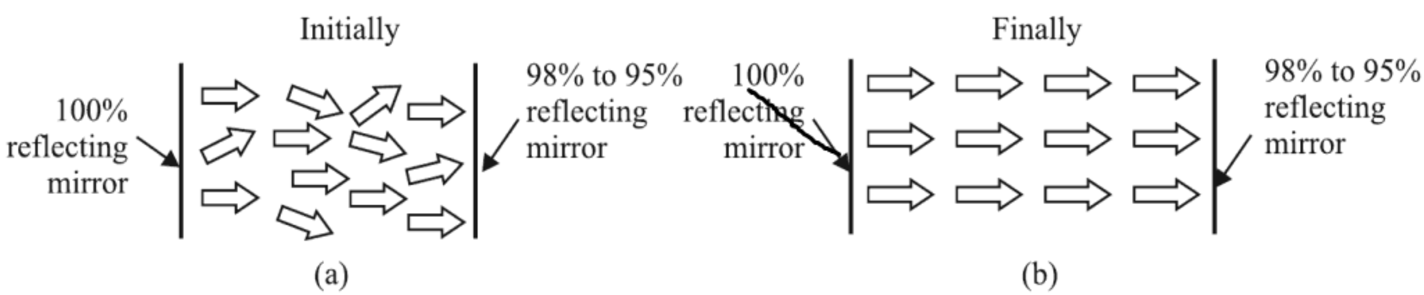
1. ***Optical pumping:*** In this method the medium is excited by supplying luminous energy from a light source. The energy is supplied in the form of a short flashes of light. This method is mostly used in solid state laser.
   Ex: Ruby laser.
2. ***Electrical Discharge:*** This method is used in gaseous laser. In this type of pumping electrons are accelerated to a high velocity by a strong electric field. The accelerated electrons collide with the neutral gas atoms and ionise the medium. Thus, due to ionisation they get raised to a higher energy level.
   Ex: He – Ne laser
3. ***Direct conversion:*** This method is used in semiconductor laser. The electrical energy is directly converted into light energy with the help of LED.
   Ex: Ga – As laser.
4. ***Chemical pumping:*** This method is used in chemical laser. In this method the energy comes from a chemical reaction without any need of energy source.
   Ex: $H_2 + F_2 \rightarrow 2HF$
5. ***Injection current pumping:*** This pumping mechanism is used in semiconductor laser. In these lasers by passing high current across the junction, the population inversion will create. In this laser, the population inversion always creates, among majority and minority charge carriers.
   Ex: InP , Ga – As lasers.

BLOCK DIAGRAM OF A LASER SYSTEAM:



It consists of mainly three parts.

1. ***Source of energy:*** It supplies suitable form of energy to the active medium to achieve population inversion.
2. ***Active medium:*** It is a medium in which meta stable state is present. In meta stable state only the population inversion takes place. It can be solid, liquid, gas or p-n junction.
3. ***Optical cavity or Cavity resonator:*** It is an enclosure of active medium and essentially consists of two mirrors. One mirror is fully reflective and other one is partly reflected. Due to mirrors arrangement emitted laser takes back and forth reflections until, it gains sufficient energy to come out. After getting sufficient energy stimulated emission takes place. The output laser is emitted from partly reflecting mirror.

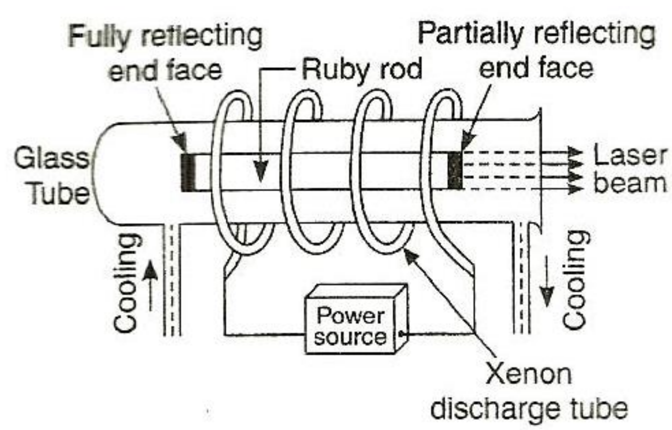


Optical resonator: shaping of a laser beam (a) Before and (b) After.

<u>RUBY LASER :</u>

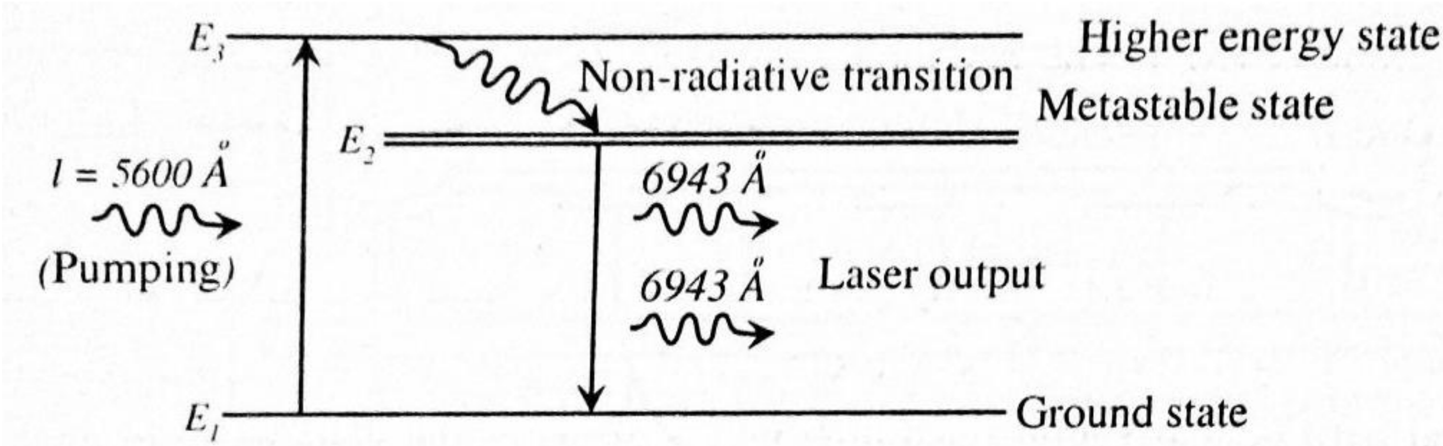
It is a three level solid state laser and was constructed by T. Maiman in the year 1960.

Construction:



a. Ruby laser is made up of a cylindrical shaped ruby crystal rod.
b. Ruby rods are prepared from Al_2O_3 doped with 0.05% chromium by weight. The ends of the rod are highly polished. Both ends are silvered such that one end is fully reflecting and the other end is partially reflecting.
c. A Xenon flash tube is arranged around the ruby rod and the ends of flash lamps are connected to a pulsed high voltage source, so that the lamp gives flashes of intense light, which supplies green colour flash light of wavelength 5600A^o to the active medium to achieve population inversion.
d. Only a part of flash light is used for the pumping the Cr^{3+} ions while the rest of flash light heats up the apparatus.
e. The ruby rod is protected from the heat by enclosing it in a hollow tube through which cold water is circulated.

WORKING:



1. In this ruby crystal Cr^{3+} ions are responsible for the stimulated emission of radiation.
2. The chromium (Cr) atoms have three active energy levels they are named as ground state (G), meta stable state (M), higher state (H).
3. Due to the supply of Xenon flash light having wavelength of 5600 A° to the ruby rod, the chromium ions begin to excite from ground state to excited state. Cr^{3+} ions stay here 10^{-8} s . After they return to meta stable state emitting thermal energy. In meta stable state Cr^{3+} ions stay $3x10^{-3}$s.
4. At an instant of time $N_2 > N_1$. i.e., so population inversion takes place between M and G. After $3x10^{-3}$s the Cr^{3+} ions reach G state emitting light (photons) of wavelengths 6943 A°.
5. This process repeated again and again until the photon beam becomes sufficiently intense, after it comes out through the partial silver polished surfaces and it serves as an output laser. The output beam of wavelength is 6943 A° and frequency is $4.32x10^{14}$Hz.

Applications:

i. Measurement of distances using pulse echo techniques.
ii. For drilling holes of small $\boldsymbol{l}/\boldsymbol{d}$ ratio $(where\ \boldsymbol{l}\ is\ length\ and\ \boldsymbol{d}\ is\ diameter)$ in hard metals.
iii. For trimming resistors and integrated circuit masks.
iv. For the welding of detached retina, to destroy tissue in a localized area, for the treatment of skin disorders, etc.
v. In pulsed holography.
vi. In scientific research such as plasma production, study on fluorescence, etc.

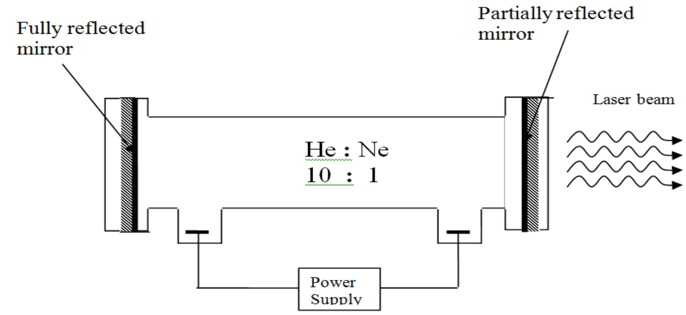
Drawbacks:

1. The laser requires high pumping power.
2. The laser output is not continuous. The output occurs in the form of pulses of microsecond duration.
3. The defects due to crystalline imperfection also present in this laser.

He-Ne laser:

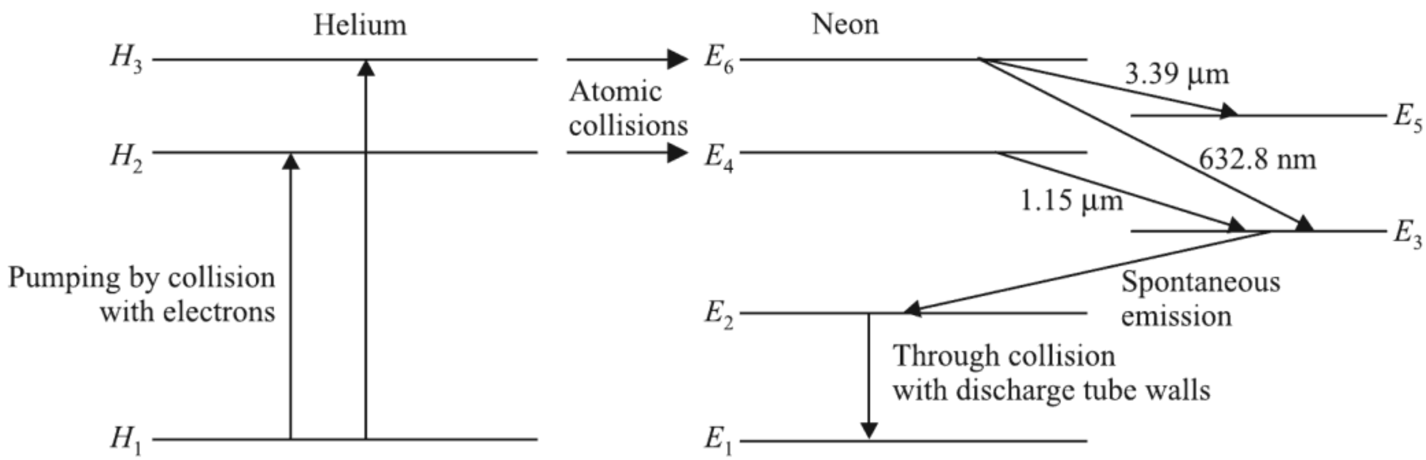
It is a four level gaseous laser and was fabricated by ***ALI JAVAN*** and others in the year 1961.

Construction:



1. It consists of a long, narrow cylindrical tube made up of fused quartz.
2. Flat quartz plates are sealed at the ends of the tube, the plates sealed at Brewster angle with the axis of the tube. So the plates are called Brewster windows.
3. The tube is filled with ***He*** and ***Ne*** gases in the ratio of ***10:1*** under a pressure of ***0.1- 1 mm of Hg***.
4. At one end of tube a perfect reflector is arranged while on the other end a partial reflector.
5. Two electrodes are fixed near the ends of the tube to pass electric discharge through the gas.

WORKING:



Energy level diagram of He and Ne for a He–Ne laser.

1. The energy levels of ***He*** are represented by ***H_1, H_2, H_3*** and those of ***Neon*** by ***E_1, E_2, E_3, E_4, E_5*** and ***E_6***. In these ***E_4*** and ***H_2***, E_6 and ***H_3*** have same energy and life time.
2. When the electrical field is applied, electrons present in the electrical field make collisions with the ***He*** and ***Ne*** atoms, but only ***He*** atoms are excite to ***H_2*** and ***H_3*** levels. In these levels ***He*** atoms lie for a long time.
3. ***He*** atoms in meta stable states return to the ground state transferring their energy to the ***Ne*** atoms. **Ne** atoms absorbs this energy excited to their meta stable states **E_4** and **E_6**.
4. As the energy exchange continue between **He** and **Ne** atoms, the population of the atoms in the excited state increases more and more. At a stage the population inversion will be achieved in the meta stable states **E_4** and **E_6**.

5. After achieving population inversion three possible transitions takes place in **He-Ne** system which produce laser light of three wavelengths.
   A. ***Transition from $E_6 \rightarrow E_3$*** gives rise to visible radiation of wavelength **6328 A°**, this wavelength lies in red region. It comes out the partially silvered mirror.
   B. ***Transition from $E_6 \rightarrow E_5$ and $E_4 \rightarrow E_3$*** gives rise to visible radiation of wave lengths $\mathbf{3.39\mu m}$ *and* $1.\mathbf{15\mu m}$ respectively. These wavelengths lie in IR region. The quartz absorbs last two wavelengths which are in IR region.
6. After reaching all the ***Ne*** atoms to ***E_3***, spontaneously they return to ***E_2*** emitting photons around ***6000 A°.***
7. The atoms in ***E_2*** makes collisions with discharge tube to return back to the ***E_1***.
8. These discharge tubes must be as narrow as possible bcz of to get more collisions otherwise the output will be decrease.
9. The excitation and de-excitation of '***He***' and '***Ne***' atoms is a continuous process and it gives continuous laser radiations.

Advantages:

1. ***He – Ne*** laser emits continuous laser radiation.
2. Due to the setting of end windows at Brewster's angle, the output laser is linearly polarised.
3. Gas lasers are more monochromatic and directional when compared with the solid state laser.

Drawbacks:

The coherence of gaseous laser is low compared to the solid state lasers.

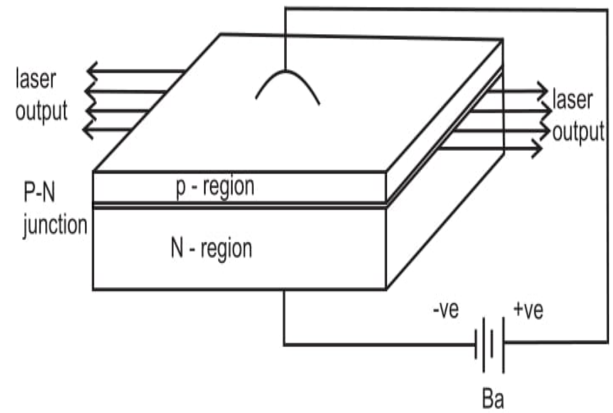
DIFFERENCE BETWEEN RUBY LASER AND He - Ne LASER		
S.NO	***RUBY LASER***	***He - Ne LASER***
1.	It is a solid state laser. Its active medium is a ruby rod.	It is a gaseous laser. Its active medium is a helium and neon gaseous mixture.
2.	It is a three level laser.	It is a four level laser.
3.	It produces laser light in the form of pulses.	It produces laser light in the form of a continuous wave.
4.	The output power is in the order of 10^9 W.	The output power is in the order of 10^{-3} W.
5.	The atoms are pumped into the higher energy levels by optical pumping.	The atoms are excited into the higher energy levels by atom-atom inelastic collision.

SEMICONDUCTOR LASER:

Ga – As Laser or Homojunction laser:

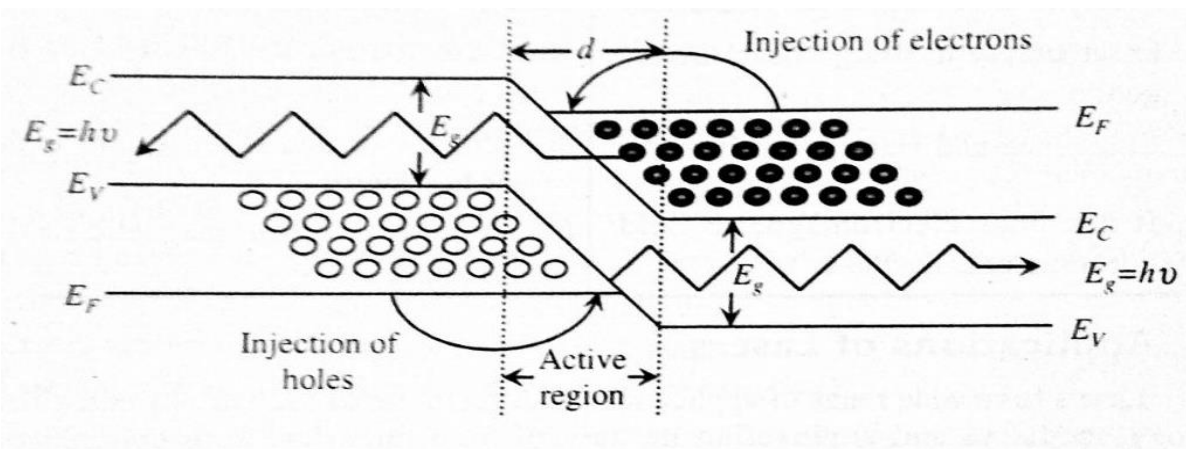
In 1962, Robert Hall fabricated a revolutionary type of lasers using semiconductors.

Construction:



1. In this laser system the active medium is a p-n junction diode made from single crystal of ***Ga - As***.
2. The p-region and n–region in the diode are obtained by heavily doping with 'Ge and Te' respectively in ***Ga - As***.
3. At the junction two sides are roughed to avoid laser emission and remaining two faces, one is partially polished and the other is fully polished.
4. These parallel faces constitute the resonant cavity and laser is obtained through partially polished face.
5. Two metallic contacts are provided in the top and bottom of the diode to provide bias.

Working:



Energy level diagram of p-n junction under high forward bais

1. The semiconductor laser device is always operated in forward bias condition.
2. When a huge current ($10^4\ amp/cm^2$) is passing through the p-n junction, hole from p-region injected into n-region and electrons from n-region injected into p-region.
3. The continuous injection of charge carriers creates the population inversion among majority and minority carriers in ***n*** and ***p*** sides respectively.
4. The electrons and holes recombine and release light energy in terms of photons.
5. The emitted photons travel along the junction layer causing further recombination. These photons takes back and forth reflections within the cavity resonator. After gaining sufficient energy they come out through partially reflecting mirror.
6. The emitted light from the ***Ga As*** laser is in the IR range.

7. The wavelength of the laser radiation of semiconductor laser depends upon the band gap $E_g(1.44\ eV)$.

   From Planck's law

$$E_g = \mathrm{h}\upsilon = \frac{\mathrm{hc}}{\lambda}$$

$$\lambda = \frac{\mathrm{hc}}{E_g} = \frac{6.63\times10^{-34}\times3\times10^{8}}{1.4\times1.6\times10^{-19}} = 8874\ \mathrm{A}^{\circ}$$

8. The wave length of emitted radiation depends up on the concentration of donor and acceptor atoms in ***Ga-As***.
9. The efficiency of the laser emission is increases when we cool the ***Ga As*** diode.

Advantages:

1. It is very small in dimension. The arrangement is simple and compact.
2. It exhibits high efficiency.
3. The laser output can be easily increased by controlling the junction current.

Disadvantages:

1. It has poor coherence and poor stability.
2. The laser beam has large divergence.
3. Threshold current density is very large$(400\ \ A/mm^2)$

Application of lasers:

Communication

- ✓ More channels can be sent simultaneously
- ✓ Signal cannot be tapped
- ✓ As the band width is large, more data can be sent.

Computers

- ✓ In LAN (local area network), data can be transferred from memory storage of one computer to other computer using laser for short time.
- ✓ Lasers are used in CD-ROMS during recording and reading the data.

Chemistry

- ✓ Lasers are used in molecular structure identification
- ✓ Lasers are also used to accelerate some chemical reactions.
- ✓ Using lasers, new chemical compounds can be created by breaking bonds between atoms and molecules.

Photography

- ✓ Lasers are also used in the construction of holograms.
- ✓ Lasers can be used to get 3-D lens less photography.

Industry

- ✓ Lasers can be used to blast holes in diamonds and hard steel
- ✓ Lasers are used to cut glass and quartz.
- ✓ High power lasers are used to weld or melt any material.

Medicine

- ✓ Lasers are used for cataract removal.
- ✓ Lasers are used in bloodless surgery.
- ✓ Lasers are used in cancer diagnosis and therapy.
- ✓ Argon and carbon dioxide lasers are used in the treat men of liver and lungs.
- ✓ Lasers used in endoscopy to scan the inner parts of the stomach.

Military

- ✓ High energy lasers are used to destroy the enemy air-crofts and missiles.
- ✓ Lasers can be used in the detection and ranging likes RADAR.

Scientific field:

- ✓ Lasers are used for isotope preparation.
- ✓ Lasers are used in air pollution, to estimate the size of the dust particles.
- ✓ Lasers used in Recording and reconstruction of hologram.