I INTRODUCTION

LASER stands for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation. Laser is a device which emits a powerful, monochromatic collimated beam of light. The emitted light waves are coherent in nature.

The first laser, ruby laser was invented by Dr. T.H. Maiman in the year 1960. Since then, the development of lasers is extremely rapid. The laser action is being demonstrated in many solids, liquids, gases and semiconductor.

1.1 CHARACTERISTICS OF LASER

Laser is basically a light source. Laser light has the following important characteristics

- High Directionality
- High Intensity
- Highly Monochromatic
- Highly Coherence

1. Directionality

Ordinary light spreads in all directions and its angular spread is 1m/m.

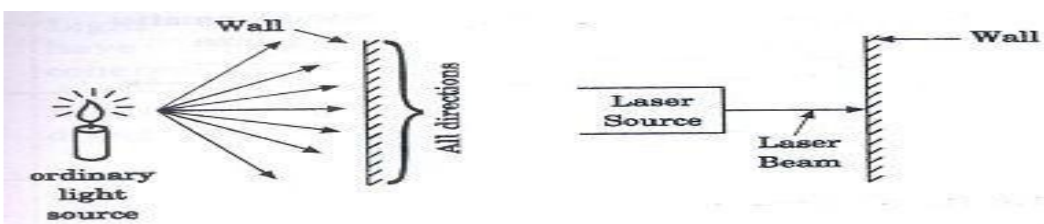


Fig. 1.1 Directionality property of Laser

But it is found that laser is highly directional and is angular spread is 1mm/m. For example, the laser beam can be focused to very long distance with a few divergence or angular spread shown in Fig. 1.1.

2. Intensity

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 mill watt power of He-Ne laser appears to be brighter than the sunlight (Fig. 1.2).

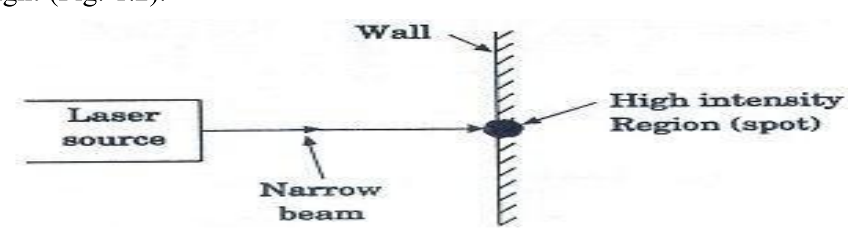


Fig. 1.2 Intensity variation

3. Monochromatic

Laser beam is highly monochromatic; the wavelength is single, whereas in ordinary light like mercury vapour lamp, many wavelengths of light are emitted Fig.1.3.

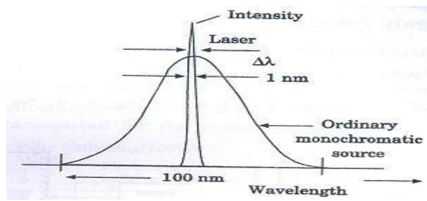


Fig. 1.3 Monochromaticity nature of Laser

4. Coherence

It is an important characteristic of laser beam. In lasers the wave trains of same frequency are in phase, the radiation given out is in mutual agreement not only in phase but also in the direction of emission and polarization. Thus it is a coherent beam. Due to high coherence it results in an extremely high power. Fig. 1.4 shows the coherence nature of Laser

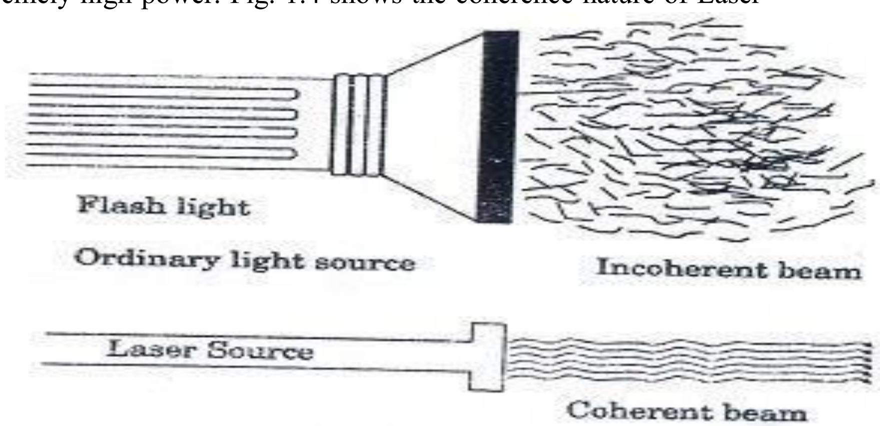


Fig. 1.4 shows the coherence property of Laser

Differences between ordinary light and Laser beam.

S.No.	**Ordinary light**	**Laser beams**
1	In ordinary light the angular spread is more	In laser beam the angular spread is less.
2	They are not directional.	They are highly directional.
3	It is less intense	It is highly intense
4	It is not a coherent beam and is not in phase	It is a coherent beam and is in phase
5	The radiation are polychromatic	The radiations are monochromatic
6	Example: Sun light, Mercury vapor lamp	He- Ne Laser, CO_2 laser

1.2 STIMULATED ABSORPTION, SPONTANEOUS EMISSION AND STIMULATED EMISSION

Process 1 - Stimulated absorption

An atom in the lower energy level or ground state energy level E_1 absorbs the incident photon radiation of energy $h\upsilon$ and goes to the higher energy level or excited level E_2 as shown in figure 1.5. This process is called absorption.

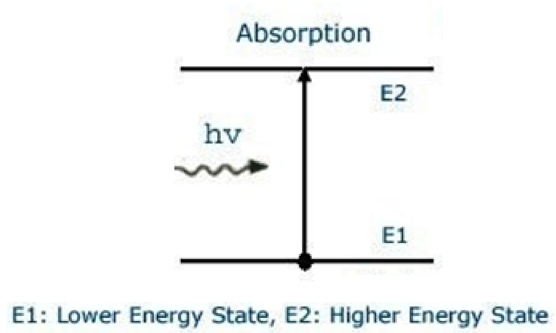
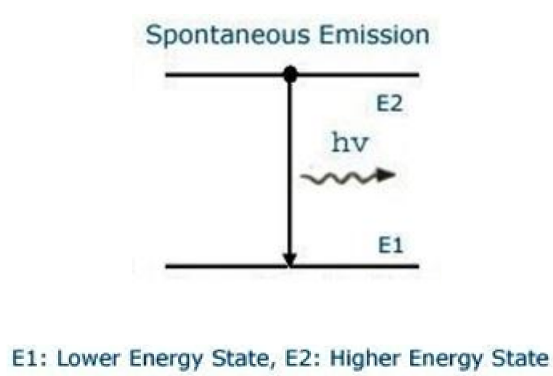


Fig. 1.5 Absorption and emission process in Laser

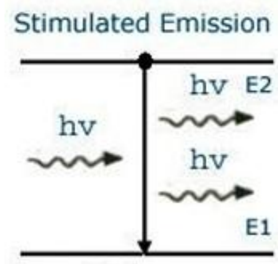
Process 2- Spontaneous Emission

The atom in the excited state returns to the ground state by emitting a photon of energy $E = E_2 - E_1 = h\upsilon$ spontaneously without any external triggering as shown in the figure. This process is known as spontaneous emission. Such an emission is random and is independent of incident radiation.



Process 3 - Stimulated Emission

The atom in the excited state can also return to the ground state by external triggering or inducement of photon thereby emitting a photon of energy equal to the energy of the incident photon, known as stimulated emission. Thus results in two photons of same energy, phase difference and of same directionality as shown.



E1: Lower Energy State, E2: Higher Energy State

Table 1.1 Differences between Stimulated and spontaneous emission of radiation

S. No.	Stimulated Emission	Spontaneous emission
1.	An atom in the excited state is induced to return to the ground state , thereby resulting in two photons of same frequency and energy is called Stimulated emission	The atom in the excited state returns to the ground state thereby emitting a photon, without any external inducement is called Spontaneous emission.
2	The emitted photons move in the same direction and is highly directional	The emitted photons move in all directions and are random
3	The radiation is highly intense, monochromatic and coherent	The radiation is less intense and is incoherent
4	The photons are in phase, there is a constant phase difference	The photons are not in phase (i.e.) there is no phase relationship between them.

1.3 POPULATION INVERSION

Population Inversion creates a situation in which the number of atoms in higher energy state is more than that in the lower energy state. Usually at thermal equilibrium, the number of atoms N_2 i.e., the population of atoms at higher energy state is much lesser than the population of the atoms at lower energy state N_1 that is $N_1 > N_2$. The Phenomenon of making $N_2 > N_1$ is known as Population Inversion (Fig. 1.6).

Fig. 1.6 . Population Inversion

Condition for Population inversion

1. There must be at least two energy levels $E_2 > E_1$.
2. There must be a source to supply the energy to the medium.
3. The atoms must be continuously raised to the excited state.

1.4 META STABLE STATES

An atom can be excited to a higher level by supplying energy to it. Normally, excited atoms have short life times and release their energy in a matter of nano seconds (10^{-9}) through spontaneous emission. It means atoms do not stay long to be stimulated. As a result, they undergo spontaneous emission and rapidly return to the ground level; thereby population inversion could not be established. In order to do so, the excited atoms are required to 'wait' at the upper energy level till a large number of atoms accumulate at that level. In other words, it is necessary that excited state have a longer lifetime.

A Meta stable state is such a state. Metastable can be readily obtained in a crystal system containing impurity atoms. These levels lie in the forbidden gap of the host crystal. There could be no population inversion and hence no laser action, if metastable states don't exist.

1.5 EINSTEIN'S "A & B" COEFFICIENTS - DERIVATION

We know that, when light is absorbed by the atoms or molecules, then it goes from the lower energy level (E_1) to the higher energy level (E_2) and during the transition from higher energy level (E_2) to lower energy level (E_1) the light is emitted from the atoms or molecules. Fig. 1.7., process involved in Laser.

Let us consider an atom exposed to light photons of energy, three distinct processes take place. ***(a). Absorption (b). Spontaneous emission (c). Stimulated Emission***

a). Absorption

An atom in the lower energy level or ground state energy level E_1 absorbs the incident photon radiation of energy $h\nu$ and goes to the higher energy level or excited level E_2 as shown in figure. This process is called absorption.

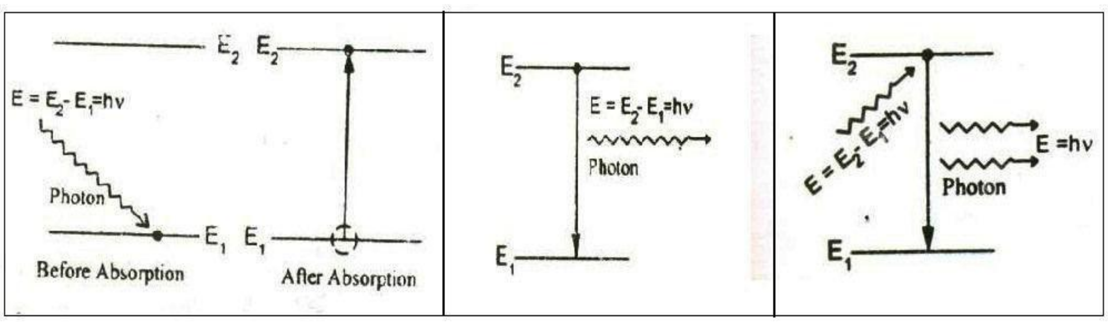


Fig. 1.7 Various process involved in Laser

If there are many numbers of atoms in the ground state then each atom will absorb the energy from the incident photon and goes to the excited state then,

The rate of absorption is proportional to $\rho(v)\, N_1$ ------------ (1)

$= B_{12}\, \rho(v)\, N_1$ ----------(2)

$\rho(v)$ = Energy density of incident radiation, N_1 = no. of atoms in the ground state and B_{12} - is a constant which gives the probability of absorption transition per unit time.

Normally, the atoms in the excited state will not stay there for a long period of time, rather it comes to ground state by emitting a photon of energy . Such an emission takes place by one of the following two methods.

b). Spontaneous emission:

The atom in the excited state returns to the ground state by emitting a photon of energy spontaneously without any external triggering as shown in the figure. This process is known as spontaneous emission. Such an emission is random and is independent of incident radiation. If N_1 and N_2 are the numbers of atoms in the ground state (E_1) and excited state (E_2) respectively, then

The rate of spontaneous emission is proportional to N_2 ———————————(3)

$$= A_{21}N_2 \text{ ———————————(4)}$$

Where A_{21}- is a constant which gives the probability of spontaneous emission transitions per unit time.

c). Stimulated Emission:

The atom in the excited state can also return to the ground state by external triggering or inducement of photon thereby emitting a photon of energy equal to the energy of the incident photon, known as stimulated emission. Thus results in two photons of same energy, phase difference and of same directionality as shown.

Therefore, the rate of stimulated emission is proportional to N_2 ———————————(5)

$$= B_{21}\rho(v)N_2 \text{ ———————————(6)}$$

Where B_{21}- is a constant, which gives the probability of stimulated emission transitions per unit time.

Einstein's theory

Einstein's theory of absorption and emission of light by an atom is based on Planck's theory of radiation. Also under thermal equilibrium, the population of energy levels obeys the Maxwell Boltzmann distribution law

Under thermal equilibrium

The Rate of Absorption = The Rate of Emission

$$B_{12}\,\rho(v)N_1 = A_{21}\,N_2 + B_{21}\,\rho(v)N_2$$

$$B_{12}\,\rho(v)N_1 - B_{21}\,\rho(v)N_2 = A_{21}\,N_2$$

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

$$\rho(v) = \frac{A_{21}\,N_2}{[B_{12}\,N_1 - B_{21}N_2]}$$

Dividing Numerator and Denominator by $B_{12}\,N_2$

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

$$\rho(\nu) = \frac{\frac{A_{21}}{B_{12}}}{\frac{N_1}{N_2} - \frac{B_{21}}{B_{12}}} \quad ---------(7)$$

We know from the Boltzmann distribution law

$$N_1 = N_0 e^{-\frac{E_1}{k_B T}}$$

$$N_2 = N_0 e^{-\frac{E_2}{k_B T}}$$

$$\frac{N_1}{N_2} = e^{-\frac{(E_1 - E_2)}{k_B T}} = e^{\frac{(E_2 - E_1)}{k_B T}} = e^{\frac{h\nu}{k_B T}} \quad (\because E_2 - E_1 = h\nu) \quad ---(8)$$

$\frac{N_1}{N_2} = e^{\frac{h\nu}{k_B T}}$ in eq (7)

$$\rho(\nu) = \frac{A_{21}}{B_{12}} \left[\frac{1}{e^{\frac{h\nu}{k_B T}} - \frac{B_{21}}{B_{12}}} \right]$$

$$\rho(\nu) = \frac{A_{21}}{B_{21}} \left[\frac{1}{e^{\frac{h\nu}{k_B T}} - 1} \right] ------ (9)$$

This equation has a very good agreement with Planck's energy distribution radiation law.

$$\rho(\nu) = \frac{8\pi h\nu^3}{c^3} \left[\frac{1}{e^{h\nu/k\,T} - 1} \right] ----(10)$$

Therefore comparing equations (9) and (10), we can write

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

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

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

The constants ***A*** and ***B*** are called as Einstein Coefficients, which accounts for spontaneous and stimulated emission probabilities.

Generally Spontaneous emission is more predominant in the optical region (Ordinary light). To increase the number of coherent photons stimulated emission should dominate over spontaneous emission. To achieve this, an artificial condition called Population Inversion is necessary.

1.6 PRINCIPLE OF LASER ACTION

Let as consider many number atoms in the excited state. We know the photons emitted during stimulated emission have same frequency, energy and are in phase as the incident photon. Thus result (fig. 1.7) in 2 photons of similar properties.

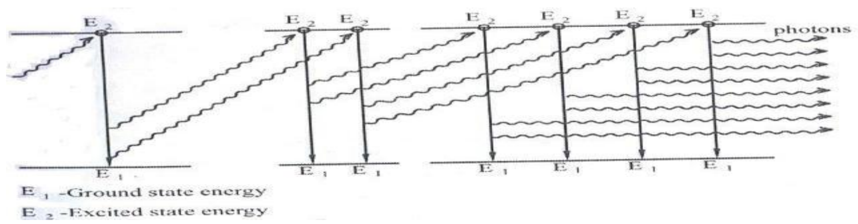


Fig. 1.7 Amplification in Laser process

These two photons induce stimulated emission of 2 atoms in excited state there by resulting in 4 photons. These 4 photons induce 4 more atoms and give rise to 8 photons etc., as shown in figure.

Principle:

Due to stimulated emission, the photons multiply in each step-giving rise to an intense beam of photons that are coherent and moving in the same direction. Hence Stimulated Emission of the Radiation termed LASER amplifies the light.

ACTIVE MEDIUM

A medium in which population inversion can be achieved is known as active medium.

ACTIVE CENTER

The material in which the atoms are raised to the excited state to achieve Population Inversion is called Active Center.

1.7 PUMPING ACTION

The process to achieve the population inversion in the medium is called Pumping action. It is essential requirement for producing a laser beam.

Methods of pumping action

The methods commonly used for pumping action are:

1. Optical pumping (Excitation by Photons)
2. Electrical discharge method (Excitation by electrons)
3. Direct conversion
4. In elastic atom – atom collision between atoms

1. Optical pumping

When the atoms are exposed to light radiations energy, atoms in the lower energy state absorb these radiations and they go to the excited state. This method is called Optical pumping. It is used in solid state lasers like ruby laser and Nd-YAG laser. In ruby laser, xenon flash lamp is used as pumping source.

2. Electrical discharge method (Excitation by electrons)

In this method, the electrons are produced in an electrical discharge tube. These electrons are accelerated to high velocities by a strong electrical field. These accelerated electrons collide with the gas atoms.

By the process, energy from the electrons is transferred to gas atoms. Some atoms gain energy and they go to the excited state. This results in population inversion. This method is called Electrical discharge method. It is represented by the equation

$$A + e^* = A^* + e$$

Where A – gas atom in the ground state A* = same gas atom in the excited state

e* = Electrons with higher Kinetic energy e – Same electron with lesser energy.

This method of pumping is used in gas lasers like argon and CO_2 Laser.

3. Direct Conversion

In this method, due to electrical energy applied in direct band gap semiconductor like Ga As, recombination of electrons and holes takes place. During the recombination process, the electrical energy is directly is converted into light energy.

4. In elastic atom – atom collision

In this method, a combination of two gases (Say A and B are used). The excited states of A and B nearly coincides in energy.

In the first step during the electrical discharge atoms of gas A are excited to their higher energy state A* (metastable state) due to collision with the electrons . $A + e^* = A^* + e$

Now A* atoms at higher energy state collide with b atoms in the lower state. Due to inelastic atom - atom collision B atoms gain energy and they are excited to a higher state B*. Hence, A atoms lose energy and return to lower state. $A^* + B = A + B^*$

1.8 OPTICAL RESONATOR

An optical resonator consists of a pair of reflecting surfaces in which one is fully reflecting (R_1) and the other is partially reflecting (R_2). The active material is placed in between these two reflecting surfaces.

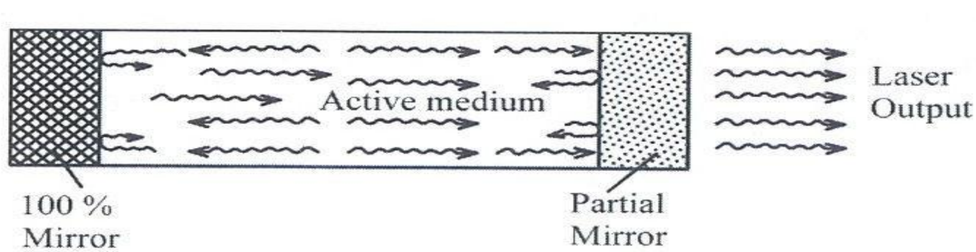


Fig. 1.8 View of optical resonator

The photons generated due to transitions between the energy states of active material are bounced back and forth between two reflecting surfaces. This will induce more and more stimulated transition leading to laser action.

Based on the type of active medium, Laser systems are broadly classified into the following categories.

S.No	TYPES OF LASER	EXAMPLES
1.	Solid State laser	**Ruby Laser**, Nd:YAG laser
2.	Gas laser	CO_2 Laser, He – Ne LASER Argon – ion
3.	Semiconductor Laser	GaAs laser, GaAsP laser

Solid State Laser - Ruby LASER

It is the first solid-state laser demonstrated by Maiman in the year 1960. It is three-level laser system.

Active Medium:

The active element in Ruby Lasers is pure aluminium oxide (Al_20_3) doped with a trace amount (0.05%) of chromium impurity.

Its sides are translucent and formed like a cylinder.

The cylinder has a diameter of a few millimeters and a length of a few cm. The ruby is pink because of the chromium ions.

Pumping System:-

Pumping source is a flash lamp, which provides a flash of light of wavelength's 4200Ǻ & 5600 Ǻ.

Ruby is a crystal of aluminium oxide (Al_2O_3) in which some of the aluminium ions (Al^{3+}) are replaced by chromium ions (Cr^{3+}).

This is done by doping small amounts of c h r o m i u m oxide pink or red color depending upon the concentration of chromium ions Al_2O_3 does not participate in the laser action. It only acts as the host.

Length of ruby crystal is usually 2 cm to 30 cm and diameter 0.5 cm to 2 cm.

High temperature is produced during the operation of the laser, the rod is surrounded by liquid nitrogen to cool

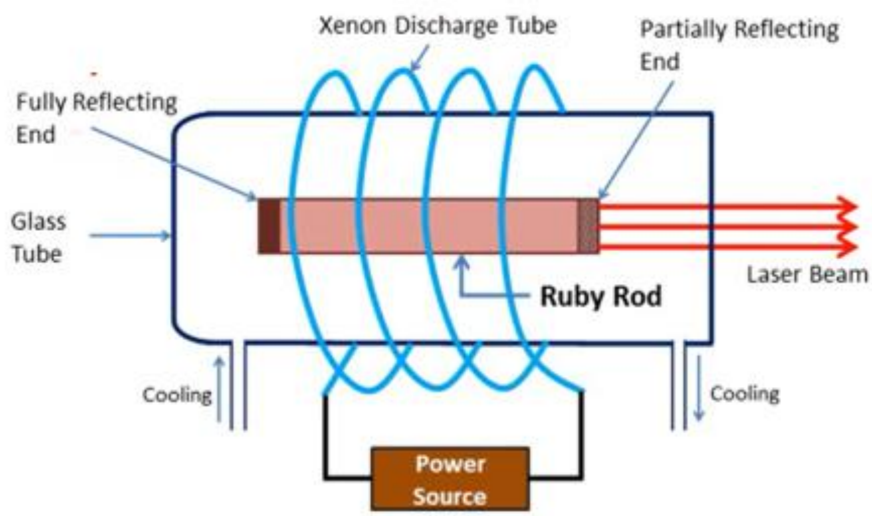


Fig. 2.3 Construction of Ruby laser

Active medium or active center: Chromium ions act as active centers in ruby crystal. So it is the chromium ions that produce the laser

Pumping source: A helical flash lamp filled with xenon is used as a pumping source. The ruby crystal is placed inside a xenon flash lamp. Thus, optical pumping is used to achieve population inversion in ruby laser.

Optical resonator system: The ends of ruby crystal are polished, grounded and made flat. The one of the ends is completely silvered while the other one is partially silvered to get the output. Thus the two polished ends act as optical resonator system.

Working

- ✓ Ruby is a three level laser system.
- ✓ there are three levels E_1, E_2 and (E_3 & E_4). E_1 is the ground level, E_2 is the metastable level, E_3 and E_4 are the bands. E_3 & E_4 are considered as only one level because they are very closed to each other.
- ✓ Pumping: The ruby crystal is placed inside a xenon flash lamp
- ✓ A part of this energy is absorbed by chromium ions in the ground state.
- ✓ optical pumping raises the chromium ions to energy levels inside the bands E_3 and E_4. This process is called stimulated absorption.

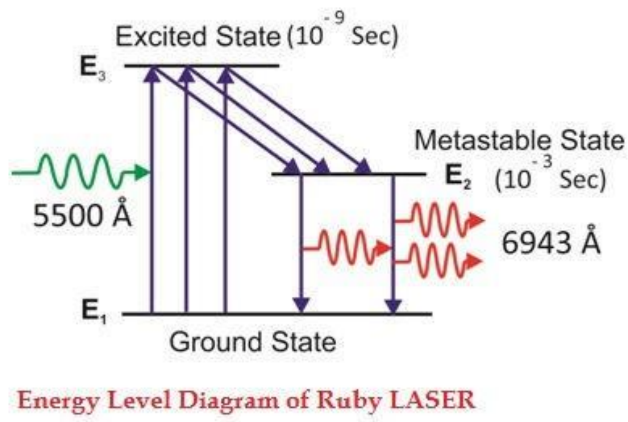


Fig. 2.4

- Cr^{3+} ions in the excited state loose a part of their energy
- The transition from excited states to metastable state is non-radiative transition or in other words there is no emission of photons.

The number of chromium ions goes on increasing in E_2 state, while due to pumping

As a result, the number of chromium ions become more in excited state(metastable state) as compared to ground state E_1.

Hence, the population inversion is achieved between states E_2 and E_1.

Photon travels through the ruby rod and if it is moving in a direction parallel to the axis of the crystal, then it is reflected to and fro by the silvered ends of the ruby rod until it stimulates the other excited ions and cause it to emit a fresh photon in phase with the stimulating photon.Emitted photons will knock out more photons by stimulating the chromium ions and their total number sufficiently increases.

Output: the output wavelength of ruby laser is 6943 Å, and it is in the form of pulses.

APPLICATIONS

1. Ruby Laser is used in Laboratory experiments
2. Ruby lasers are used in industrial cutting and welding.
3. They are used for hair removal and tattoo
4. It is used in interferometry Holography,
5. Used in Light Detection and Ranging (LIDAR)

Drawbacks

- The laser requires high pumping power because the laser transition terminates at the ground state and more than half of ground state atoms must be pumped to higher state to achieve population inversion.
- The efficiency of ruby laser is very low because only green component of the pumping light is used while the rest of components are left unused.
- The laser output not continuous but occurs in the form of pulses of microseconds duration.
- The defects due to crystalline imperfections are also present in this laser.

Molecular Gas laser

In a molecular gas laser, laser action is achieved by transitions between vibrational and rotational levels of molecules. Its construction is simple and the output of this laser is continuous.

In CO_2 molecular gas laser, transition takes place between the vibrational states of Carbon dioxide molecules.

It was the first molecular gas laser developed by Indian born American scientist Prof. C. K. N. Pillai.

It is a four level laser and it operates at 10.6 μm in the far IR region. It is a very efficient laser.

Energy states of CO_2 molecules.

A carbon dioxide molecule has a carbon atom at the center with two oxygen atoms attached, one at both sides. Such a molecule exhibits three independent modes of vibrations.
They are

a) Symmetric stretching mode.

b) Bending mode

c) Asymmetric stretching mode.

Symmetric stretching mode

In this mode of vibration, carbon atoms are at rest and both oxygen atoms vibrate simultaneously along the axis of the molecule departing or approaching the fixed carbon atoms.

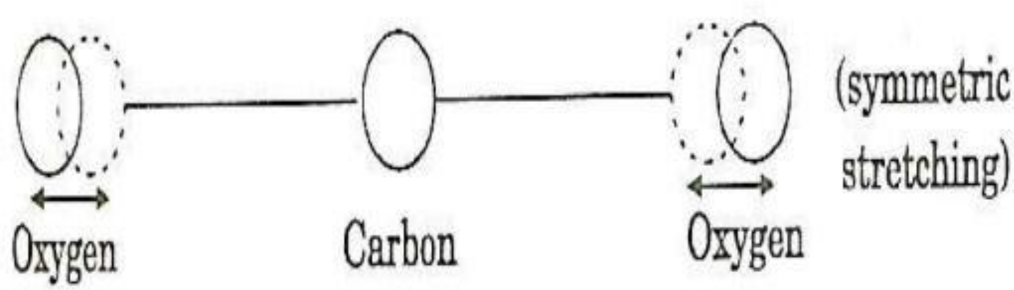


Fig. 2.9

Bending mode:

In this mode of vibration, oxygen atoms and carbon atoms vibrate perpendicular to molecular axis.

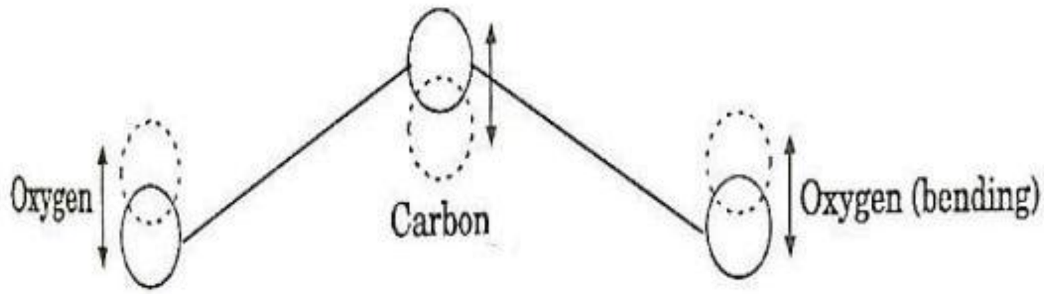


Fig.2.10

Asymmetric stretching mode:

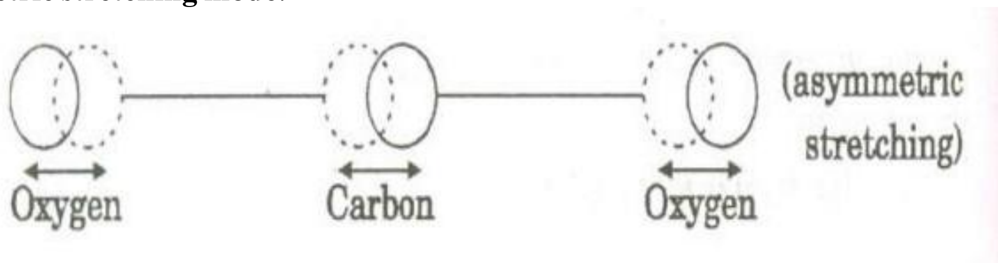


Fig. 2.11

In this mode of vibration, oxygen atoms and carbon atoms vibrate asymmetrically, i.e., oxygen atoms move in one direction while carbon atoms in the other direction.

Principle:

The active medium is a gas mixture of CO_2, N_2 and He. The laser transition takes place between the vibrational states of CO_2 molecules.

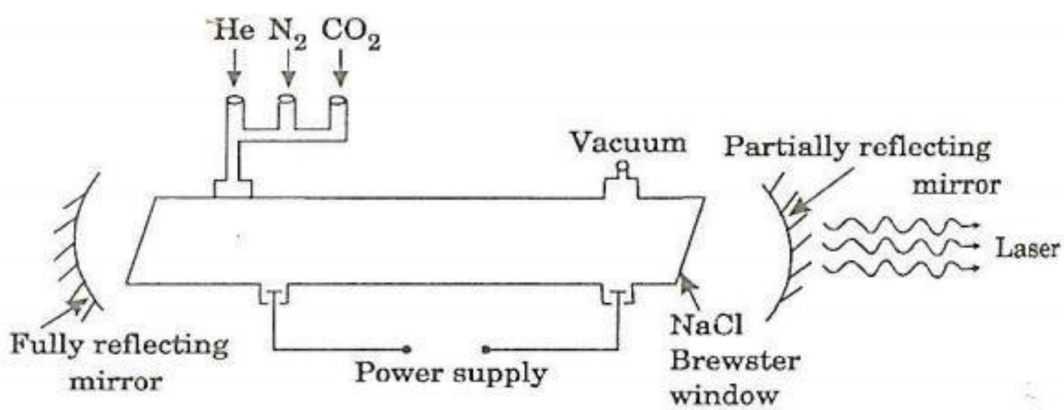


Fig. 2.12

Construction:

It consists of a quartz tube 5 m long and 2.5 cm in the diameter. This discharge tube is filled with gaseous mixture of CO_2 (active medium), helium and nitrogen with suitable partial pressures.

The terminals of the discharge tubes are connected to a D.C power supply. The ends of the discharge tube are fitted with NaCl Brewster windows so that the laser light generated will be polarized.

Two concave mirrors one fully reflecting and the other partially form an optical resonator.

Working:

Figure shows energy levels of nitrogen and carbon dioxide molecules.

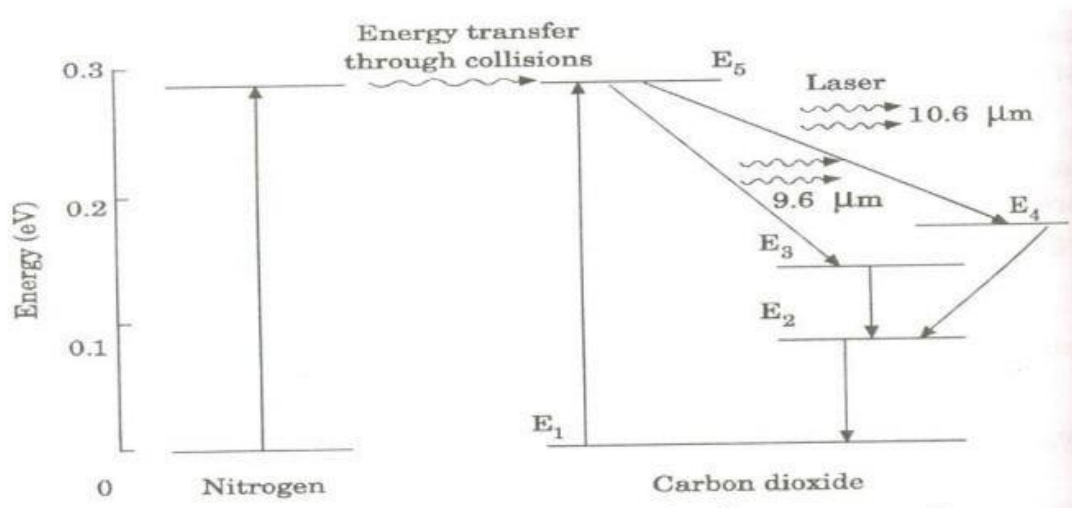


Fig. 2.13

When an electric discharge occurs in the gas, the electrons collide with nitrogen molecules and they are raised to excited states. This process is represented by the equation

$N_2 + e^* = N_2^* + e$

N_2 = Nitrogen molecule in ground state e^* = electron with kinetic energy N_2^* = nitrogen molecule in excited state e= same electron with lesser energy

Now N_2 molecules in the excited state collide with CO_2 atoms in ground state and excite to higher electronic, vibrational and rotational levels.

This process is represented by the equation $N2^* + CO_2 = CO_2^* + N_2$

N_2^* = Nitrogen molecule in excited state. CO_2 = Carbon dioxide atoms in ground state CO_2^* = Carbon dioxide atoms in excited state N_2 = Nitrogen molecule in ground state.

Since the excited level of nitrogen is very close to the E_5 level of CO_2 atom, population in E_5 level increases.

As soon as population inversion is reached, any of the spontaneously emitted photon will trigger laser action in the tube. There are two types of laser transition possible.

1.Transition E5 to E4 :

This will produce a laser beam of wavelength 10.6µm

2.Transition E5 to E3 This transition will produce a laser beam of wavelength 9.6 µm. Normally 10.6 µm transition is more intense than 9.6 µm transition. The power output from this laser is 10kW.

The power output from this laser is about 10kW. The nature of output may be continuous wave or pulsed wave. The wavelength of output is 9.6 µm and 10.6 µm.

Applications:

1. High power CO_2 laser finds applications in material processing, welding, drilling, cutting soldering etc.
2. The low atmospheric attenuation (10.6µm) makes CO_2 laser suitable for open air communication.
3. It is used for remote sensing
4. It is used for treatment of liver and lung diseases.
5. It is mostly used in neuro surgery and general surgery.
6. It is used to perform microsurgery and bloodless operations.

SEMICONDUCTOR LASER

Laser action can also be produced semiconductors. The most compact of all the lasers in semiconductor diode laser. It is also called injection laser. There are two types of semiconductor diode lasers (***i.) Homo - junction laser (ii.) Hetero- Junction laser.***

HOMO – JUNCTION SEMICONDUCTOR DIODE LASER

Definition

It is specifically fabricated p-n junction diode. This diode emits laser light when it is forward biased.

Principle

When a p-n junction diode is forward biased, the electrons from n – region and the holes from the p- region cross the junction and recombine with each other. During the recombination process, the light radiation (photons) is released from a certain specified direct band gap semiconductors like Ga-As. This light radiation is known as recombination radiation.

The photon emitted during recombination stimulates other electrons and holes to recombine. As a result, stimulated emission takes place which produces laser.

Construction

Figure 1 shows the basic construction of semiconductor laser. The active medium is a p-n junction diode made from the single crystal of gallium arsenide. This crystal is cut in the form of a platter having thickness of 0.5μm. The platelet consists of two parts having an electron conductivity (n-type) and hole conductivity (p-type).

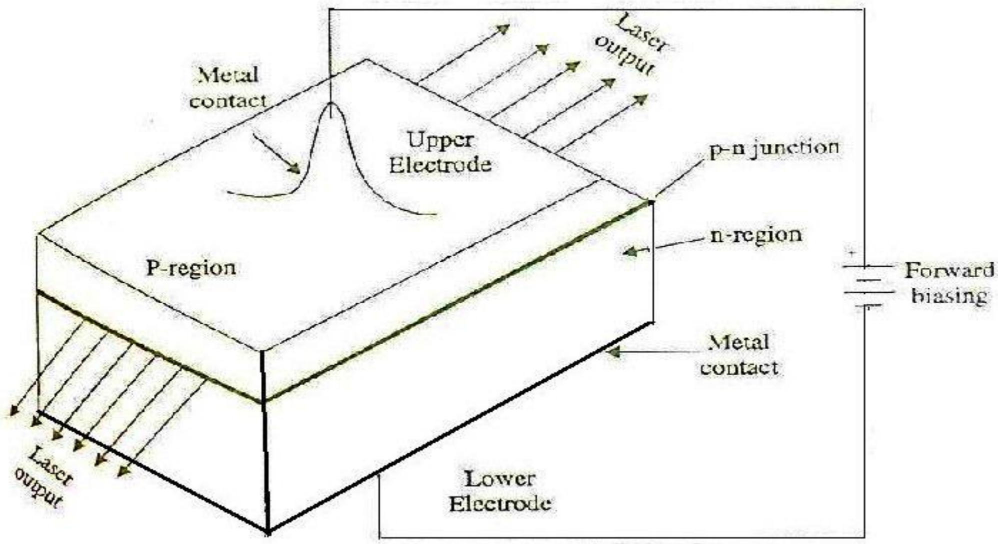


Fig. 1 Construction of semiconductor Laser

The photon emission is stimulated in a very thin layer of PN junction (in order of few microns). The electrical voltage is applied to the crystal through the electrode fixed on the upper surface. The end faces of the junction diode are well polished and parallel to each other. They act as an optical resonator through which the emitted light comes out.

Working

Figure 2 shows the energy level diagram of semiconductor laser. When the PN junction is forward biased with large applied voltage, the electrons and holes are injected into junction region in considerable concentration. The region around the junction contains a large amount of electrons in the conduction band and a large amount of holes in the valence band.

If the population density is high, a condition of population inversion is achieved. The electrons and holes recombine with each other and this recombination's produce radiation in the form of light. When the forward – biased voltage is increased, more and more light photons are emitted and the light production instantly becomes stronger.

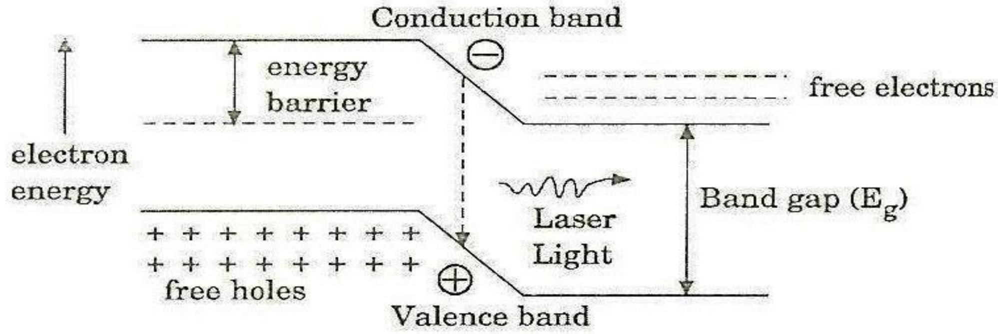


Fig.2 shows the energy level diagram of semiconductor laser.

These photons will trigger a chain of stimulated recombination resulting in the release of photons in phase.

The photons moving at the plane of the junction travels back and forth by reflection between two sides placed parallel and opposite to each other and grow in strength. After gaining enough strength, it gives out the laser beam of wavelength 8400Å.
The wavelength of laser light is given by

From Planck's law $E_g = h\upsilon = h\frac{c}{\lambda}$

$$\lambda = \frac{hC}{E_g} = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{1.4 \times 1.6 \times 10^{-19}} = \textbf{8874 Å}$$

where Eg is the band gap energy in joule.

The nature of output is continuous wave or pulsed output. Gallium arsenide laser gives infrared radiation in the wavelength 8300 Å to 8500Å.

Application

1. It is widely used in fiber optic communication
2. It is used to heal the wounds by infrared radiation
3. It is also used as a pain killer
4. It is used in laser printers and CD writing and reading

Applications of lasers

Due to high intensity, high monocromacity and high directionality of lasers, they are widely used in various fields like

1. communication
2. computers
3. chemistry
4. photography
5. industry
6. medicine
7. military
8. scientific research

1. communication

In case of optical communication semiconductors laser diodes are used as optical sources and its band width is (10^{14}Hz) is very high compared to the radio and microwave communications.

- More channels can be sent simultaneously
- Signal cannot be tapped
- As the band width is large, more data can be sent.
- A laser is highly directional and less divergence, hence it has greater potential use in space crafts and submarines.

2. 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.

3. 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 are molecules.

4. Photography

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

5. Industry

- Lasers can be used to blast holes in diamonds and hard steel
- Lasers are also used as a source of intense heat
- Lasers are used to drill holes in ceramics.
- Lasers are used to cut glass and quartz.
- Lasers are used for heat treatment in the tooling and automotive industry.
- Lasers are used in electronic industry in trimming the components of ICS.
- High power lasers are used to weld or melt any material.
- Lasers are also used to cut teeth in saws and test the quality of fabric.

6. Medicine

- Lasers are used for cataract removal.
- Lasers are used for eye lens curvature corrections.
- Lasers are used in bloodless surgery.
- Lasers are used in cancer diagnosis and therapy.
- Lasers are used in destroying kidney stones and gallstones.
- 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.
- Lasers used in the elimination of moles and tumours which are developing in the skin tissue.
- Lasers are used in plastic surgery.
- Lasers are used in the treatment of mouth diseases.

7. Military

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

8. Scientific field

- Lasers are used for isotope preparation.
- Lasers are employed to create plasma.
- Lasers are used in air pollution, to estimate the size of the dust particles.
- Lasers are used in the field of 3D-photography
- Lasers used in Recording and reconstruction of hologram.
- Lasers used to produce certain chemical reactions.
- Lasers are used in Raman spectroscopy to identify the structure of the molecule.
- Lasers are used in the Michelson- Morley experiment.