Unit-II

Lasers

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Lasers are more used as a strong electromagnetic **beam** than a **light beam**. **LASERS** are having vast applications in Engineering and Medical fields such as welding and cutting, Computer engineering, weapon industry and in various surgeries. It is important to understand the phenomena of LASER light. Its working principle and fabrication will be enlighten in this unit.

Introduction:

LASER, perhaps one of the most exciting discoveries of 20th century, is an acronym for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation. It has unique properties made it different from conventional light sources such as tube light or electric bulb. In conventional light source, there is no coordination among different atoms emitting radiation. The light beams from LASERS with coherence lengths of upto 10^{14} cycles will make many possible experiments and practical applications.

We know that Light comes from a source as the sum of total radiations by billion and billions of atoms or molecules in the source. In recent years, some sources are developed which are highly coherent i.e the radiation given out by all the emitters in the source is in mutual agreement not only in phase but also in the direction of emission and polarisation. These coherent sources are called LASERS.

Characteristics of Laser Light

(i) High in Coherence: Coherence is one of the unique properties of laser light. It arises from the stimulated emission process. Since a common stimulus triggers the emission events which provide the amplified light, the emitted photons are in step and have a definite phase relation to each other. This coherence is described in terms of temporal and spatial coherence.

(ii) High Monochromaticity: A laser beam is more or less in single wave length. i.e. the line width of laser beams is extremely narrow. The wavelengths spread of conventional light sources is usually 1 in 10^6, where as in case of laser light it will be 1 in 10^5.I.e. if the frequency of radiation is 10^{15} Hz., then the width of line will be 1 Hz. So, laser radiation is said to be highly monochromatic. The degree of non-monochromaticity has been expressed as

$= (d\lambda/\lambda) = d\nu/\nu$, where $d\lambda$ or $d\nu$ is the variation in wavelength or variation in frequency of radiation.

(iii) High Directionality: Laser beam is highly directional because laser emits light only in one direction. It can travel very long distances without divergence. The directionality of a laser beam has been expressed in terms of divergence. Suppose r_1 and r_2 are the radii of laser beam at distances D_1 and D_2 from a laser, and then we have. Then the divergence, $\Delta\theta = (r_1 - r_2)/ D_2 - D_1$. The divergence for a laser beam is 0.01 mille radian where as incase of search light it is 0.5 radian.

(iv) High intensity: In a laser beam lot of energy is concentrated in a small region. This concentration of energy exists both spatially and spectrally, hence there is enormous intensity for laser beam. The power range of laser is about 10^{-13}w for gas laser and is about 10^9 w for pulsed solid state laser and the diameter of the laser beam is about 1 mm. then the number of photons coming out from a laser per second per unit area is given by

$$N_l = P/ h\nu\pi r^2 \approx 1022 \text{to} 1034 \text{photons/m}^{-2}\text{-sec}$$

By assuming $h\nu = 10^{-19}$ Joule, Power $P = 10^{-3}$to10^9watt $r = 0.5\times10^{-3}$meter

Based on Planck's black body radiation, the number of photons emitted per second per unit area by a body with temperature T is given by

$N_{th} = (2h\pi C/ \lambda^4) (1/e^{(h\nu/kT)}-1)$
$d\lambda \approx 10^{16}$photons/m^2.sec By assuming T=1000k,
$\lambda = 6000A^0$

This comparison shows that laser is a highly intensive beam.

- **Basic Principles of LASER**

In order to consider the principle of LASER ,let us study the quantum processes that take place in a material medium when it is exposed to Laser radiation. In lasers, the interaction between matter and light is of three different types. They are: absorption, spontaneous emission and stimulates emission.

Absorption: Consider that the assembly of atoms is exposed to light radiation i.e a stream of photons with energy hυ. Out of infinite energy levels consider two energy levels E_1 and E_2 of an atom.

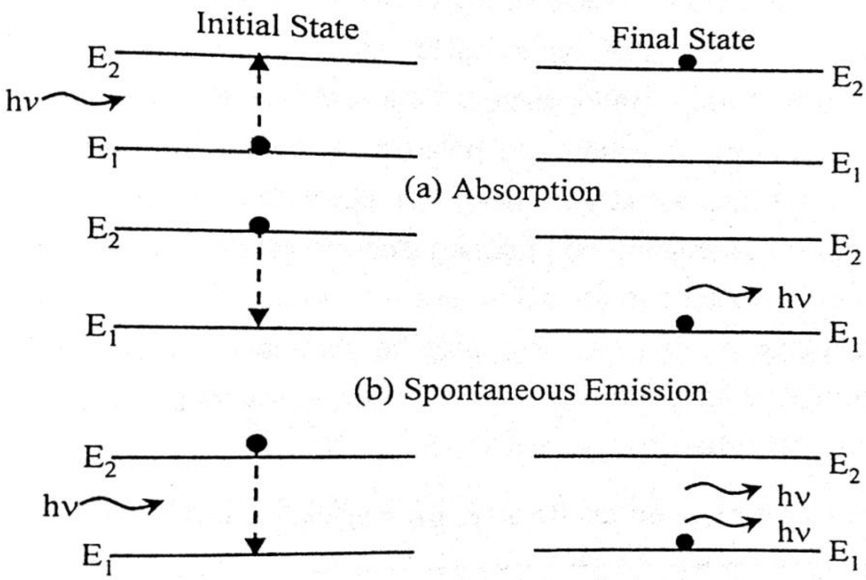
Let an atom is in the energy level E_1 can absorb a photon and go to the excited state of energy E_2.This process is called Absorption. As shown in fig (a) The dot represents an atom. Transition between these states involves absorption and emission of a photon of energy E_2-E_1=hν_{12}. Where 'h' is Planck's constant. The process of particles transfer from normal state to higher energy state is Excitation and the particles itself is said to be excited.

The particle in the excited state can remain for a limited time known as **Life time**. The life time for hydrogen atom is 10^{-8} sec.

Also the excited atoms can return to ground state by emitting a photon of frequency υ i.e energy h υ. This emission process can take place in two ways: 1) Spontaneous Emission 2) Stimulated Emission.

Spontaneous emission As shown in fig (b), an atom initially present in the excited state makes transition voluntarily on its own after its life time. Without any aid of external stimulus or an agency to the ground state and emits a photon of energy h ν_{12}(=E_2-E_1). This is called spontaneous emission. These are incoherent.

Stimulated emission As shown in fig (c), a photon having energy hν_{12}(E_2-E_1) impinges on an atom present in the excited state and the atom is stimulated to make transition to the ground state and gives off a photon of energy hν_{12}. The emitted photon is in phase with the incident photon. These are coherent. This type of emission is known as stimulated emission.



(a) Absorption

(b) Spontaneous Emission

(c) Stimulated emission

Life Time: The duration of time spent by the particle to stay in excited state is called life time of the particle. The life time for hydrogen atom is 10^{-8} sec.

Meta stable state: The excited energy state where the particle will stay for sufficiently long time than its life time. The life time in metastable state is 10^{-3}- 10^{-4} s. Because of this state population inversion is achieved in lasers, hence this state is very essential in laser radiation.

Differences between Spontaneous and Stimulated emission

Spontaneous emission	Stimulated emission
• Spontaneous emission takes place when excited atoms make a transition to lower state on their own without any external aid.	• Stimulated emission takes place when a photon of energy equal to $h\nu_{12}$ (=E_2-E_1) stimulates an excited atom to make transition to lower state.
• Postulated by Bohr.	• Postulated by Einstein
• Polychromatic radiation.	• Monochromatic radiation.
• Less intensity.	• High intensity.
• Less directionality, more angular spread during propagation.	• High directionality, less angular spread during propagation.
• Spatially and temporally incoherent radiation.	• Highly coherent radiation
• Ex: Normal conventional light sources like mercury vapour lamp.	• Ex: Laser light from source.

Population inversion

Consider a two level energy system E_1 and E_2.Usually in a system the number of atoms (N_1) present in the ground state (E_1) is larger than the number of atoms (N_2) present in the higher energy state (E_2).

Suppose a photon of energy equal to E_2-E_1= hν is incident on the system. Then both absorption and stimulated emission process takes place. Both are equally probable. If there are more number of atoms in the lower level i.e ground state($N_{1>}$ $N_{2)}$, there will be more absorption than stimulated emission. Under thermal equilibrium conditions ,

$$\frac{N_2}{N_1} = \exp\left(-\left(\frac{E_2 - E_1}{KT}\right)\right)$$

where K and T are Boltzmann constant and absolute temperature respectively. Thus it is necessary to increase the population of the upper energy level so that it is greater than that of lower energy level. This is called Poulation Inversion.

“It can be defined as making the number of particles more in higher energy level than in lower energy level using a process”

When population inversion is reached between any two staes, the lower state is called “Negative temperature state”

Pumping: The process or method used to obtain population inversion is called “Pumping”. Population inversion can be achieved by a different pumping mechanisms.Some of them are (i) optical pumping (ii) electrical discharge (iii) inelastic collision of atoms (iv) chemical reaction and (v) direct conversion.

- ## Einstein’s Coefficients and relation between them

Consider a system in thermal equilibrium. LetN_1 be the number of atoms per unit volume in energy state E_1 and N_2 is the number of atoms per unit volume in energy state E_2. ‘ν’ is frequency such that h ν=E_2-E_1. Then the energy density of interacting photons ρ (ν) is given by

$$\rho(\nu) = h\nu \quad \rightarrow(1)$$

When these photons interact with atoms, both upward (absorption) and downward (emission) transitions occur. At equilibrium these transition rates must be equal.

Upward Transition/Absorption

In absorption the probability of the particles moving from E_1 to E_2 depends on the number of atoms available in the lower energy state as well as the energy density of interacting radiation. i.e.

$$P_{12} \,\alpha\, N_1$$

$$\alpha\, \rho(\nu)$$

$$P_{12} = B_{12} N_1 \rho(\nu) \quad \rightarrow (2)$$

Where the constant of proportionality B_{12} is the Einstein coefficient of absorption

Downward Transition:

Spontaneous emission

Once the atoms are excited by absorption, they stay in the excited state for a short duration of time called the lifetime of the excited state. After their life time they move to their lower energy level spontaneous by emitting photons.

Probability of atoms moving from excited state to lower state depends on the number of atoms in the excited energy state only.

$$\text{i.e., } P_{21\text{-Spontaneous}} \,\alpha\, N_2$$

$$= N_2 A_{21} \rightarrow (3)$$

Where the constant of proportionality A_{21} is the Einstein coefficient of spontaneous emission.

Stimulated emission: Before excited atoms de excites to their lower energy states by spontaneous emission they may interact with photons resulting in stimulated emission of photons. Therefore Probability of atoms from excited to lower state by stimulated emission depends on the number of atoms available in the excited state as well as energy density of interacting photons

$$\text{i.e. } P_{21}\text{-}_{Stimulated} \ \alpha \ N_2$$

$$\alpha \ \rho(\nu)$$

$$= N_2 \, \rho\,(\nu)\, B_{21} \qquad \rightarrow (4)$$

Where the constant of proportionality B_{21} is the Einstein coefficient of stimulated emission.

For a system in equilibrium, the upward and downward transition rates must be equal and hence we have

Absorption = spontaneous emission + Stimulated emission

$$P_{12} = P_{21}\text{-}_{Spontaneous} + P_{21}\text{-}_{Stimulated}$$

$$N_1 \, \rho\,(\nu)\, B_{12} = N_2 \rho(\nu) B_{21} + N_2 A_{21} \qquad \rightarrow (5)$$

Hence

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

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

$$= \frac{A_{21}}{\frac{N_1}{N_2} B_{12} - B_{21}}$$

In laser emission we can write $B_{12}=B_{21}$-----(6), then above equation can be written as

$$= \left(\frac{A_{21}}{B_{21}}\right)\left(\frac{1}{\frac{N_1}{N_2} - 1}\right) - - - - - - (7)$$

According to Boltzman distribution law; $\frac{N_1}{N_1} = \exp\left(\frac{E_2 - E_1}{KT}\right)$ and $E_2\text{-}E_1 = h\nu$

Equation (7) can be written as,

$$\rho\ (\nu) = \left(\frac{A_{21}}{B_{21}}\right)\left(\frac{1}{\exp\left(\frac{h\vartheta}{KT}\right) - 1}\right) - - - - (8)$$

From Plank's radiation law we can write energy density as

$$\rho\ (\nu) = \left(\frac{8\pi h\vartheta^3}{c^3}\right)\left(\frac{1}{\exp\left(\frac{h\vartheta}{KT}\right) - 1}\right) - - - (9)$$

Compare equations (8) and (9), Then

$$\frac{A_{21}}{B_{21}} = \frac{8\pi h\vartheta^3}{c^3} - - - - - - (10)$$

Equation (6) and (10) are the relation between Einstein coefficients.

- **Lasing Action**

The below figure shows the active medium in optical resonator and being excited by a pumping agent.The resulting laser action consists of the following steps:

Step 1: Pumping: The atoms in the pumping are in initially in the ground state as shown in fig (a).By supplying energy from an external source ,the atoms are excited from the ground level to an excited state.

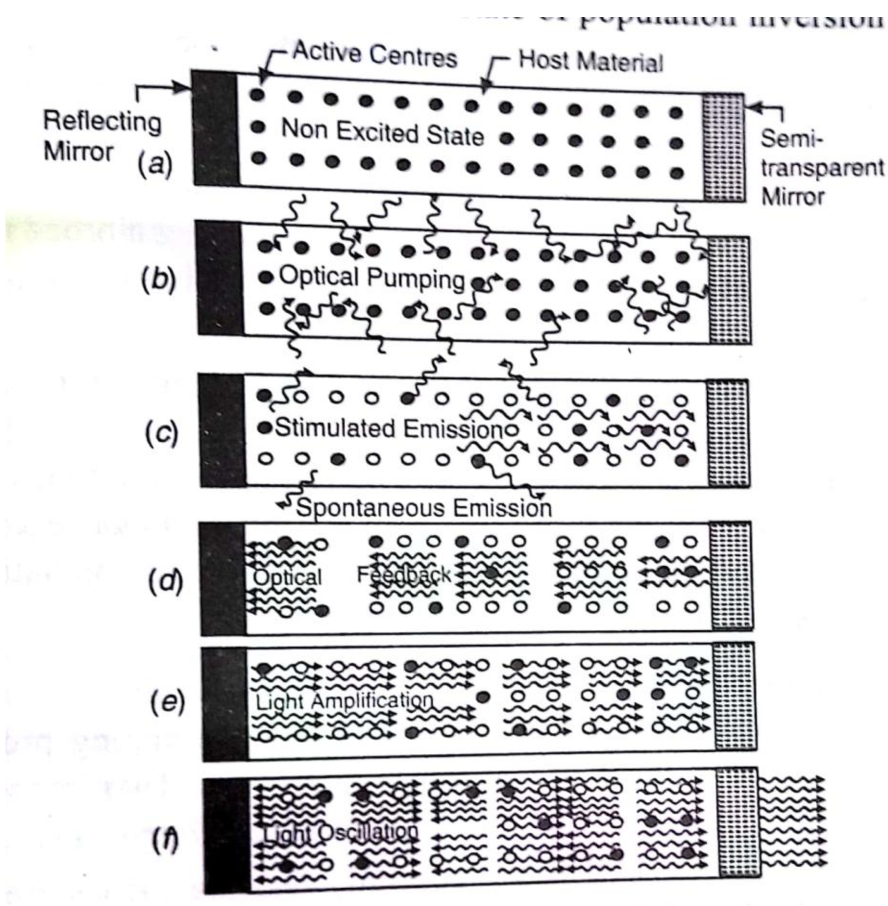
Step 2: Population Inversion: The life time of atoms at the excited state is very small .Thus the atoms drop spontaneously from the excited state to the metastable state.As the life time of atoms at the metastable state is comparatively longer, the atoms go on accumulating at the metastable state. As soon as the number of atoms at the metastable state exceeds that of the ground state,the medium goes into the state of population Inversion.

Step 3: Spontaneous Emission: Some of the atoms from metastable state may emit photons spontaneously in various directions.Each spontaneous photon travelling in axial direction will stimulate the atoms along the direction of its propogation.The photons emitted in a direction other than the axial direction will pass through the sides of the medium and are lost forever.

Step 4:Amplification:A majority of photons travelling along the axis cause stimulated emission and are reflected back on reaching the end mirror.As the photons are reflected back and forth between the mirrors,stimulated emission sharply increasesand the amplification of light takes place.

Step 5:Oscillations: At each reflection at the front end mirror,Light is partially transmitted through it.A steady,strong LASER beam will emerge from the front end mirror when there is a maximum intensity of laser beam.When the medium is exposed to pump frequency radiation ,a large number of atoms will be excited to E3 level.However they rapidly undergo downward transitions to metastable state E2 through non-radiative transitions.The pumping continues and after a short time there will be a large accumulation of atoms at level E2.Then population inversion ncondition is achieved between the two states E1 and E2.A photon can trigger stimulated emission.

Once stimulated emission starts,metastable state is emptied and the population of ground state increases rapidly.As aresult population inversion ends.Then again laser beam will emerge when population inversion is re-established.



The following are the three parts are to produce laser

(i) <u>Active medium</u>: A medium from which the laser is produced. It is the material should emit a photon in de excitation of particle.

(ii) Resonant cavity: Two parallel and opposite mirrors out of which one is fully reflected and other is partial reflector. This is used for amplification of laser.

(iii) Pumping system/ exciting system: it is used to achieve population inversion in active medium.

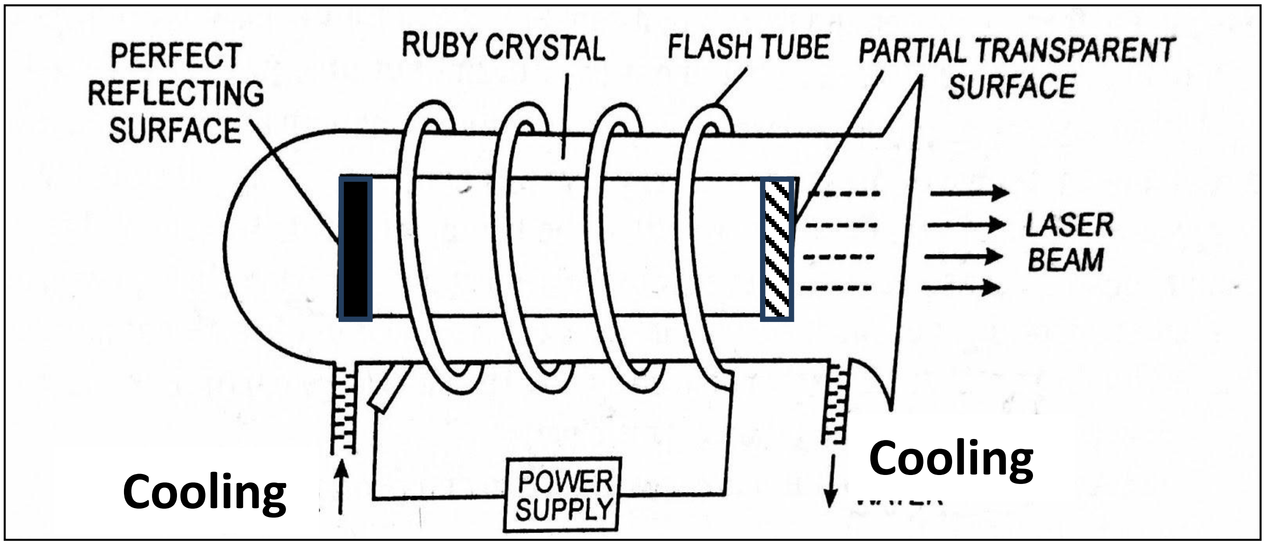
- **Ruby laser:**

Ruby Laser is a three level solid state was constructed by T.Maiman in the year 1960. It is a pulsed laser having very high output power. Ruby crystal is aluminum oxide [Al_2O_3] doped with 0.05% of chromium atom. It consists of a cylindrical shaped ruby crystal rod of length varying from 2 to 20cms and diameter varying 0.1 to 2cms. This end faces of the rod are highly flat and parallel. One of the faces is highly silvered and the other face is partially silvered so that it transmits 10 to 25% of incident light and reflects the rest so as to make the rod-resonant cavity. Basically, These chromium atoms serve as activators. Due to presence of 0.05% of chromium, the ruby crystal appears in pink color. The ruby crystal is placed along the axis of a helical xenon or krypton flash lamp of high intensity.

Construction:

Ruby ($Al_2O_3+Cr_2O_3$) is a crystal of Aluminum oxide in which some of Al^{+3} ions are replaced by Cr^{+3} ions. When the doping concentration of Cr^{+3} is about 0.05%, the color of the rod becomes pink. The active medium in ruby rod is Cr^{+3}ions. In ruby laser a rod of 4cm long and 5mm diameter is used and 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.

The ruby rod is surrounded by helical xenon flash lamp tube which provides the optical pumping to raise the Chromium ions to upper energy level (rather energy band). The xenon flash lamp tube which emits intense pulses lasts only few milliseconds and the tube consumes several thousands of joules of energy. Only a part of this energy is used in pumping Chromium ions while the rest goes as heat to the apparatus which should be cooled with cooling arrangements as shown in below fig.



Working:

Ruby crystal is made up of aluminum oxide as host lattice with small percentage of Chromium ions replacing aluminum ions in the crystal chromium acts as dopant. A dopant actually produces lasing action while the host material sustains this action. The energy level diagram is shown in below figure. The pumping source for ruby material is xenon flash lamp which will be operated by some external power supply.

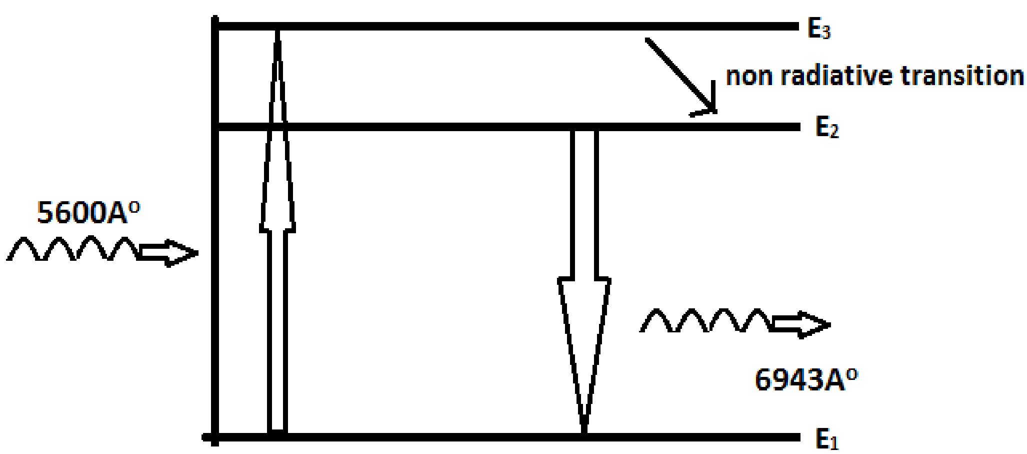


Fig: Energy level diagram of Ruby laser

Chromium ions will respond to this flash light having wavelength of $5600A^0$. When Cr^{+3} ions are excited to energy level E_3 from E_1 the population in E_3 increases. Chromium ions stay here for a very short time of the order of 10-8 seconds then they drop to the level E_2 which is mat stable state of life time 10^{-3}s. Here the level E_3 is rather a band, which helps the pumping to be more effective. The transitions from E_3 to E_2 are non-radiative in nature i.e energy is emitted in the form of heat. During this process heat is given to crystal lattice. Hence cooling the rod is an essential feature in this method. The life time in mete stable state is 10^{5}times greater than the lifetime in E_3. As the life of the state E_2 is much longer, the number of ions in this state goes on increasing while ions. In this state goes on increasing while in the ground state (E_1) goes on decreasing. By this process population inversion is achieved between the exited Meta stable state E_2 and the ground state E_1. When an excited ion passes spontaneously from the metastable state E_2 to the ground state E_1, it emits a photon of wave length $6943A^0$. This photon travels through the rod and if it is moving parallel to the axis of the crystal, is reflected back and forth by the silvered ends until it stimulates an excited ion in E_2 and causes it to emit fresh photon in phase with the earlier photon. This stimulated transition triggers the laser transition. This process is repeated again and again because the photons repeatedly move along the crystal being reflected from its ends. The photons thus get multiplied. When the photon beam becomes sufficiently intense, then it emerges through the partially silvered end of the crystal.

Drawbacks of ruby laser:

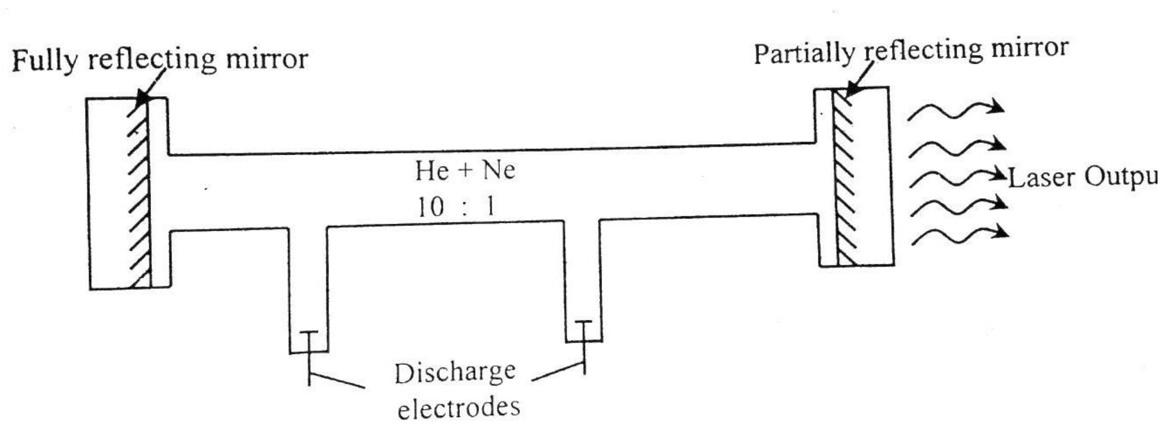
1. The laser requires high pumping power to achieve population inversion.
2. It is a pulsed laser (output laser is not continuous).

- ## Helium-Neon laser:

He- Ne laser is a gaseous laser system and is used to produce continuous laser. It was fabricated by Ali Javan and others in 1961. It is a four level laser system.

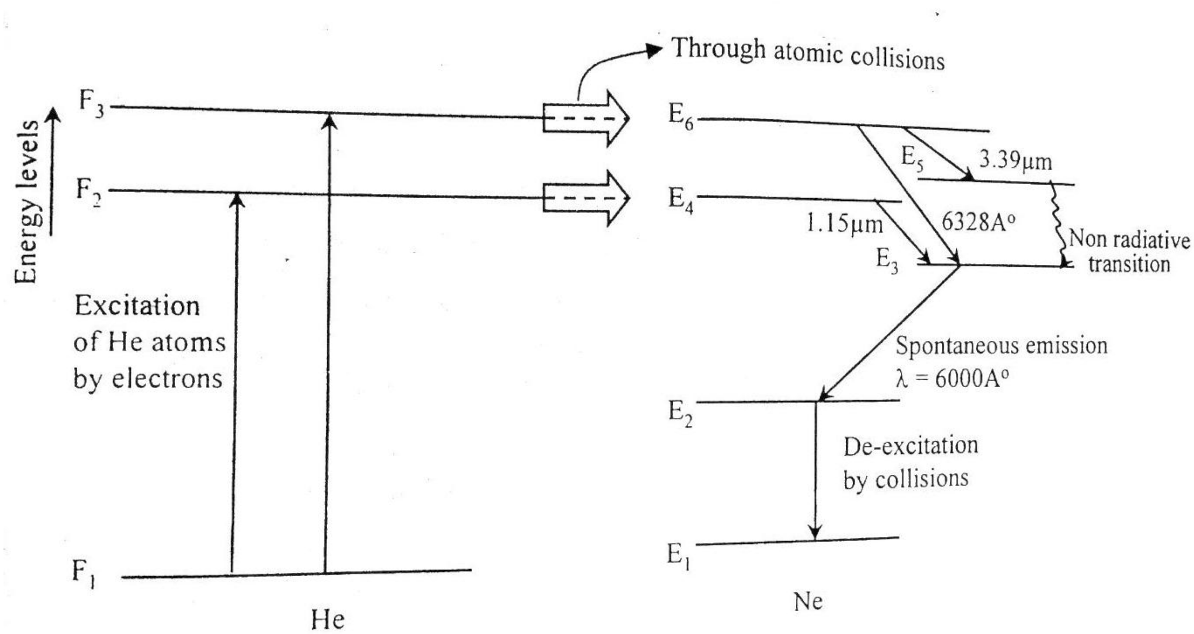
Construction:

The experimental arrangement is shown in below figure. It consists of a long, narrow cylindrical discharge tube made up of fused quartz. The diameter of the tube will vary from 2 to 8 mm and length will vary from 10 to 80 cm which has electrodes connected to R.F Generator. The tube is filled with Helium (He) and Neon (Ne) gases in the ratio of 10:1. The pressure of helium gas is 1mm of Hg and neon gas is 0.1mm of Hg There is a majority of He atoms and minority of Ne atoms. At one end of tube a perfect reflector is arranged while on the other end a partial reflector. The active material is excited due to energy discharge through the gas mixture by means of radio frequency generator with a frequency of several MHz.



Working:

The schematic energy diagram of He-Ne gas mixture is shown in below figure. In He atom three active energy levels are present , they are named as F_1, F_2 and F_3. Ne atom have six active energy states named as E_1, E_2, E_3, E_4, E_5 and E_6.



When electric discharge passed through the He-Ne gas mixture, then the electrons are accelerated towards the positive electrode. During their passage they collide with He and Ne atoms but only He atoms suitable to excite to the upper state F_2 and F_3. These are meta stable states of He atoms. Now, these excited He atoms are interact with ground state Ne atoms. This interaction makes the Ne atoms to excite to meta stable states E_4 and E_6 and He atoms return to their ground state. As energy is continuous there will be a population inversion takes place between E_6 , E_5 states and E_4, E_3 states.

After achieving population inversion,

- Few Ne atoms de excite from E_6 to E_5. During this transition a photon of wavelength 3.39µm will be emitted.
- Many other Ne atoms are de excited E_6 to E_3. During this transition a photon of wavelength 6328A^o will be emitted. This is important and major wavelength in this system.
- Other Ne atoms de excite from E_4 to E_3. During this transition a photon of wavelength 1.15µm will be emitted.
- Here multiple reflections will be done for the transition between E_6 and E_3 using reflecting mirrors for stimulated emission.
- After reaching all the Ne atoms to E_3 state, spontaneously these atoms will de excite to E_2 state. During this transition wavelength of 6000A^o is emitted spontaneously.
- Finally Ne atoms take non radiative transitions by making collisions with walls of the tube from E_2 to E_1.

As the energy exchange between He and Ne atoms is continuous, output laser is also continuous.

These He-Ne lasers are extensively used in making Holograms and interferometry applications.

Semiconductor laser:

The semiconductor laser is also called a diode laser. Among the different semiconductors there are direct band gap semiconductors and indirect band gap semiconductors. In case of direct band gap semiconductors, direct recombination of holes and electrons takes place which emit photons. But in case of indirect band gap semiconductors direct recombinations will not takes place and photons won't be released. GaAs (Gallium Arsenide) is one of the best direct band gap semiconductor.

Principle: When a direct band gap semiconductor diode is connected under forward bias, at a certain voltage hole from P-region and Electrons from n-region are combined in depletion region as a result Photons will be released. This phenomenon is called "Electro luminescence". The wavelength of emitted photon is depends on the energy gap of a semiconductor diode.

We know that $E_c - E_v = h\vartheta$

where 'ϑ' is frequency of emitted photon, 'h' is planks constant

$$\text{Since } \vartheta = \frac{C}{\lambda}$$

$$E_g = h\frac{C}{\lambda} \quad E_c - E_v = E_g$$

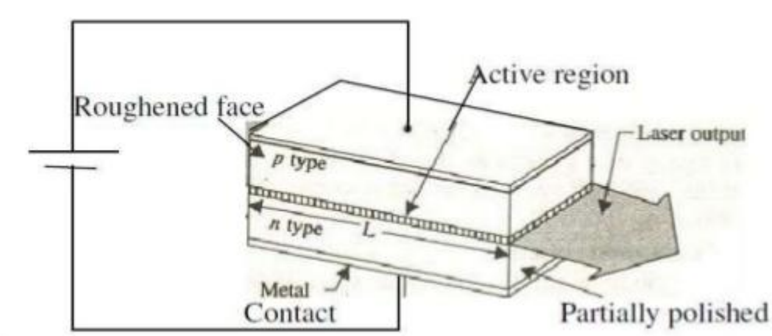
$$\lambda = \frac{hC}{E_g}$$

so, wave length of emitted photon 'λ' is depends only on energy gap (E_g)

Construction:

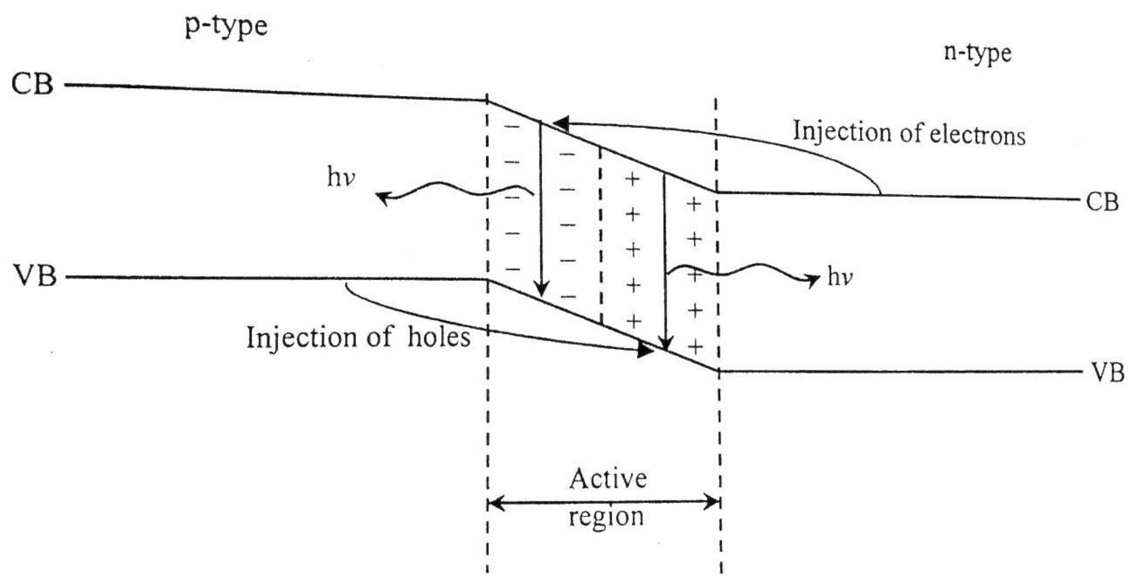
In P-N junction, If p and n type materials are prepared from the same material then it is called as Homo junction semiconductor laser source. If p and n type materials are prepared from different materials then they are called as Hetero junction semiconductor laser source.

The basic mechanism responsible for light emission from a semiconductor is the recombination of electrons and holes at p-n junction when a current is passed through the diode. The active medium is a p-n junction diode made from crystalline Gallium Arsenide . The p-region and n-region in the diode are obtained by heavily doping with suitable dopants. At the junction the sides through which emitted light is coming out are well polished and parallel to each other. Since the refractive index of GaAs is high, the reflectance at the material air interface is sufficiently large so that the external mirrors are not necessary to produce multiple reflections. This p-n junction should be connected under forward bias as shown in fig.



Working:

When a current is passed through a p-n junction p region being positively biased, holes are injected from p-region into n-region and n-region being negatively biased electrons are injected from n-region into p-region and is shown in fig. the electrons and holes will recombine and release of light energy takes place in or near the junction as shown in below figure.



The electrons are minority charge carriers in p-side and holes are minority charge carriers in n-side. The continuous injection of charge carriers creates population inversion of minority charge carriers in n- and p- sides respectively. The excess minority charge carriers diffuse away from the junction recombine with majority charge carriers of n- and p type semiconductors, resulting in the release of photons. Further, the emitted photons increase the recombinations by stimulation of majority charge carriers. Thus the stimulated emission takes place more effectively.

Drawbacks of homo junction lasers:

- Output laser is discontinuous (only pulsed laser).
- Threshold current density is very large (400 amp/mm^2)
- Output laser has poor directionality and poor coherence
- Lifetime is less

Advantages of hetero junction lasers:

- Output laser is continuous
- Low threshold current density (5-10 amp/mm^2)
- Output laser has more directionality
- High coherence and high monochromaticity is achieved
- Life time of device is more

Applications of lasers:

Lasers are widely used in all the fields. It play a vital role in fields of science, Engineering and medicine.

In science:

- A wide variety of interferometrie techniques.
- Raman spectroscopy.
- Laser induced breakdown spectroscopy.
- Atmospheric remote sensing.
- Investigating non linear optics phenomena
- Holographic techniques employing lasers also contribute to a number of measuremen techniques.
- Laser (LADAR) technology has application in geology, seismology, remote sensing and atmospheric physics.
- Lasers have been used abroad spacecraft such as in the cassini-huygens mission.
- In astronomy lasers have been used to create artificial laser guide stars, used as reference objects for adaptive optics telescope.

In Communications:

- Lasers are used in optical fiber communications. In optical fiber communications, lasers are used as light source to transmit audio, video signals and data to long distances without attention and distortion.
- The narrow angular spread of laser beam can be used for communication between earth and moon or to satellites.
- As laser radiation is not absorbed by water, so laser beam can be used in under water (inside sea) communication networks.

In Engineering:

- Lasers are used in metal cutting, welding, surface treatment and hole drilling. Using lasers cutting can be obtained to any desired shape and the curved surface is very smooth.
- Welding has been carried by using laser beam.
- Dissimilar metals can be welded and micro welding is done with great case.

- Lasers beam is used in selective heat treatment for tempering the desired parts in automobile industry.
- Lasers are widely used in electronic industry in trimming the components of ICs

In Medicine:

- Lasers are used in medicine to improve precision in work like surgery.
- Brain surgery is an example of precision surgery Birthmarks, warts and discoloring of the skin can easily be removed with an unfocussed laser.
- The operations are quick and heal quickly and, best of all, they are less painful than ordinary surgery performed with a scalpel.
- Cosmetic surgery (removing tattoos, scars, stretch marks, sun spots, wrinkles, birthmarks and hairs) see lasers hair removal.
- Extensively used in Eye surgery, refracting surgery and Soft tissue surgery.
- Laser scalpel (general surgery, gynecological, urology, laparoscopic).
- “No-touch” removal of tumors, especially of the brain and spinal cord.
- In dentistry for caries removal, endodontic/periodontic, procedures, tooth whitening, and oral surgery.
- Lasers are used in cancer treatments.
- Using in endoscopy surgeries.
- Lasers are used to blast the stones in kidneys.

Optical fibers:

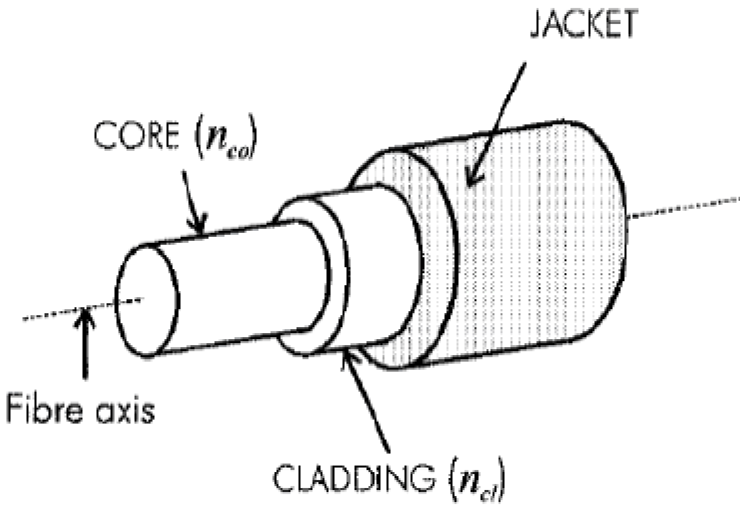
Optical fibers are used most often as a means to transmit laser light between the two ends of the fiber and find wide usage in fiber-optic communications, where they permit transmission over longer distances and at higher bandwidths (data rates) than electrical cables. It is a flexible, transparent fiber made by drawing glass (silica) or plastic to a diameter slightly thicker than that of a human hair. Fibers are used instead of metal wires because signals travel along them with less loss; in addition, fibers are immune to electromagnetic interference, a problem from which metal wires suffer excessively. Fibers are also used for illumination and imaging, and are often wrapped in bundles so they may be used to carry light into, or images out of confined spaces, as in the case of a fiberscope. Specially designed fibers are also used for a variety of other applications, some of them being fiber optic sensors and fiber lasers.

Optical fiber is a thin flexible medium having cylindrical shape consisting of three sections.

(i) Core
(ii) Cladding
(iii) The outer jacket

The structure of optical fiber is shown in below figure.

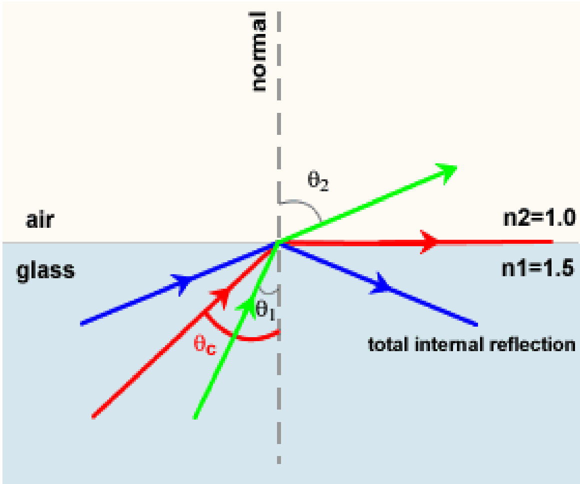
The fiber has core surrounded by a cladding material whose refractive index is slightly less than that of the core material to satisfy the condition of total internal reflection and cladding also give mechanical support to core. To protect the fiber material there is a protective cover called outer jacket.



Principle:

Total internal reflection is the principle in optical fibers. It occurs when a propagated wave strikes a medium boundary at an angle larger than a particular critical angle with respect to the normal to the surface. If the refractive index is lower on the other side of the boundary and the incident angle is greater than the critical angle, the wave cannot pass through and is entirely reflected.

The **critical angle** is the angle of incidence, where the angle of refraction is 90^oaand above which the total internal reflection occurs. This is particularly common as an optical phenomenon, where light waves are involved, but it occurs with many types of waves, such as electromagnetic waves in general or sound waves. As shown in below figure.



When a wave reaches a boundary between different materials with different refractive indices, the wave will in general be partially refracted at the boundary surface, and partially reflected. However, if the angle of incidence is greater than the critical angle then the wave will not cross the boundary, but will instead be totally reflected back internally. This can only occur when the wave in a medium with a higher refractive index (n_1) reaches a boundary with a medium of lower refractive index (n_2). For example, it will occur with light reaching air from glass, but not when reaching glass from air.

According to law of refraction

$$n_1 sin\theta_1 = n_2 sin\theta_2$$

$$\text{When } \theta_1 = \theta_c \; then \; \theta_2 = 90^o$$

$$n_1 sin\theta_c = n_2 sin90$$

$$sin\theta_c = \frac{n_2}{n_1}$$

$$\theta_c = sin^{-1}\left(\frac{n_2}{n_1}\right)$$

In case of total internal reflection, there is absolutely no absorption of light energy at the reflecting surface. Hence entire incident light will be reflected to same medium. As there is no loss of energy during reflection, hence optical fibers are designed to guide laser light over long distances.

- **QUESTIONS:**

1. What are the characteristics of laser? Explain them.
2. Define following
   I. Metastable state
   II. Life time
   III. Population
   IV. Population Inversion
   V. Excitation
3. Differentiate spontaneous and stimulated emission.
4. Briefly explain process of Absorption,Spontaneous Emission and Stimulated Emission with neat diagrams.
5. Explain lasing action in laser?
6. What are three main components of laser source?
7. What is the importance of resonant cavity in lasers?
8. Write a short note on (i) Population inversion (ii) Pumping
9. What are Einstein coefficients? Obtain relation between them.
10. Explain construction and working of Ruby laser with neat sketch.
11. With suitable diagrams explain the construction and working of He-Ne laser
12. Describe construction and working of semiconductor laser with neat diagram.
13. Brief up the differences between Homo junction and Hetero junction laser.
14. Discuss the applications of lasers in different fields.
15. What are the different parts in Optical Fiber cable? Give Diagram
16. Write a note on the phenomenon of Total Internal Reflection in Optical Fibers .