U. AMULYA

DVY Reddy

4 LASERS AND HOLOGRAPHY

…chapter of Interference of light, we have used the term coherence between two sources of … The two sources are coherent, when they vibrate in the same phase or there is a constant phase …ence. We know that light from a source comes as the sum total of radiations by billions and …s of atoms or molecules in the source. The phase is different at different times. Now, the …tion is that to what extent may the radiation from different atoms of a given source be related in … in direction of emission and in polarisation, *i.e.*, the coherence of a given source. In recent …, some sources are developed which are highly coherent. *These coherent sources are called* …. The word laser stands for ***light amplification by stimulated emission of radiation***. The …etical basis for the development of laser was provided by Albert Einstein in 1917. In 1954, the …iction of Einstein was put to practical use by C.H. Townes and his co-workers. In 1960, the first … device was developed by T.H. Maiman. It is often called as Ruby laser. The Ruby laser emits …ght of wavelengths 694.3 nm. Soon after, A. Javan developed the first gas laser using He and … gases. It is called Helium-Neon laser. It emits visible light at wavelength 632.8 nm and also in …ared region at 1150 nm. With the advancement of technology, laser has revolutionized the world …dustry and technology. The most important features of laser are:

(i) ***high degree of coherence,***

(ii) ***high directionality,***

(iii) ***extraordinary monochromacity,***

(iv) ***high intensity.***

…owing are the characteristics of laser beam:

1. **High directionality:** An ordinary source of light radiates light in all directions. On the other …nd, a laser source emits radiation only in one direction, *i.e.*, a laser beam is highly directional. …h directionality of laser radiation is of special significance in advanced researches.

2. **High intensity:** The intensity of light is defined as the energy passing normally per unit area … second through a point normal to the direction of flow. For an ordinary spherical source, at a …ance r, the intensity I is given by

$$\boxed{I = \frac{P}{4\pi r^2}}$$

where P is power of the source.

In case of laser beam, the energy is concentrated in a very small region. For example, 1 W laser source will appear many times more intense than an ordinary 100 W source.

3. **Divergence:** The light from conventional source spreads out in the form of spherical wavefronts. Hence, they are highly divergent. The divergence or angular spread of the laser beam is extremely small.

4. **Monochromacity:** Light from a laser beam is nearly monochromatic while light from an ordinary source is never monochromatic. The light from normal monochromatic source spreads over a wavelength range of the order of 100 Å to 1000 Å. On the other hand, in case of laser, the spread is of the order of a few angstroms only.

5. **Coherence:** The laser beam is completely coherent. It is possible to observe interference effect from two independent laser beams.

4.3 ABSORPTION OF RADIATION

We know that an electron in an atom revolves around the nucleus in discrete orbits. When the atom absorbs sufficient energy by any means in the ground state, the electrons of the atom absorb energy and are excited to higher energy levels. Now, the atom is said to be in excited state.

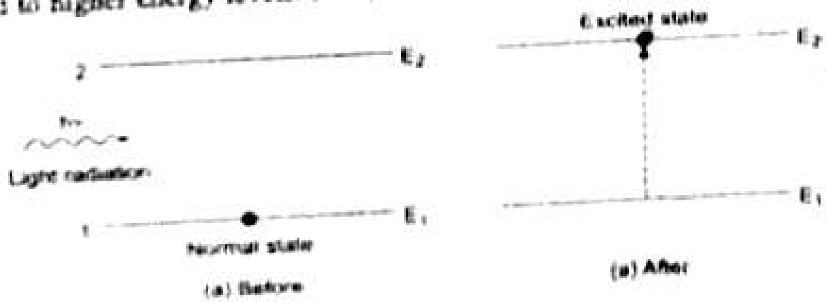

Fig. (1) Absorption Phenomenon

Let us consider two energy levels 1 and 2 of an atom with energies E_1 and E_2 as shown in Fig. (1). Let the atom is exposed to light radiation, i.e. a stream of photons with energy $h\nu$. Suppose the atom is initially in lower state 1. The process of atom transfer from normal state (1) corresponding to minimum energy of the system to a higher energy state is termed as excitation. Now the atom is said to be in excited state. In this process, the absorption of energy from external field takes place. An atom residing in energy state E_1 can absorb a photon and go to excited state with energy E_2 provided the photon energy $h\nu$ equals the energy difference $(E_2 - E_1)$. Therefore,

$$h\nu = E_2 - E_1$$

or

$$\nu = (E_2 - E_1)/h$$

The process is called stimulated absorption or simply absorption.

Usually, the number of excited particles (atoms) in the system is smaller than the non-excited particles. The time duration which a particle can exist in the ground state (normal state) is unlimited. On the other hand, the particle can remain in excited state for a limited time known as ***life time***. The life time for the excited hydrogen atom is of the order of 10^{-8} sec. However, there exist some excited state in which the life time is greater than 10^{-8} sec. These states are called as ***metastable***

SPONTANEOUS EMISSION

...know that absorption of a photon of frequency $[\nu = (E_2 - E_1)/h]$, excites the atom from normal (ground state) E_1 to excite state E_2. The excited state with higher energy E_2 is not a stable... After a short interval of time, the atom jumps back to ground state by emitting a photon of ...quency ν as shown in Fig. (2). This type of emission is called as ***spontaneous emission***.

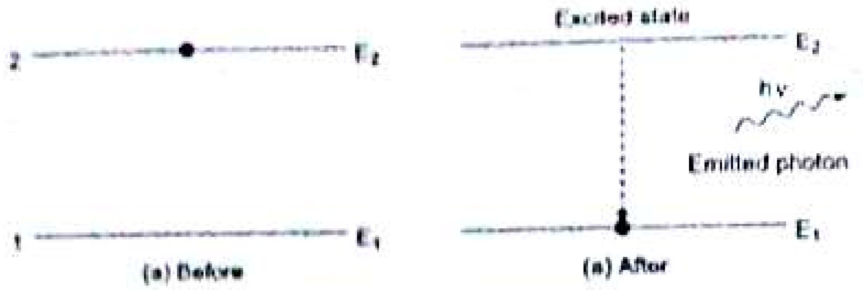

Fig. (2) Spontaneous Emission

The spontaneous emission is random in character. If there is an assembly of atoms, the radiation ...ted spontaneously by each atom has a random direction and a random phase. Thus, radiation in ...case is a random mixture of quanta having various wavelengths. The waves neither coincide in ...elength nor in phase. Therefore, the spontaneous emission is ***incoherent*** and has *broad* ...trum.

STIMULATED (INDUCED) EMISSION

...know that average life time of an atom in the excited state is $\approx 10^{-8}$ s. During this short interval ...a photon of energy $h\nu$ is incident on the atom (*i.e.*, when it is still in the excited state) as shown in ...(3). Now, the atom jumps to lower energy state, emitting an additional photon of same ...quency ν. Hence, two photons move together. This process is called ***stimulated emission***. The direction of propagation, phase and energy of the emitted photon is exactly same as that of incident ...ulating photon. Therefore, the result is an enhanced beam of coherent light.

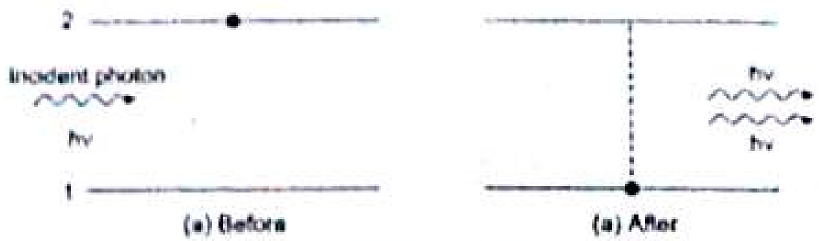

Fig. (3) Stimulated Emission

According to Einstein, an interaction between the excited atom and incident photon can trigger the ...ted atom to make a transition to ground state. The transition generates a second photon which would ...identical to the triggering photon in respect of frequency, phase and propagation direction. So, in ...ulated emission, the emitted wave is of the same frequency and phase as that of stimulating incident ...n. Their superposition increases the amplitude of the stimulating wave, *i.e.*, there is an amplification.

The difference between spontaneous and stimulated emission is shown in tabular form:

	Spontaneous emission	Stimulated emission
1.	Emission of light photon takes place immediately during the transition of atom from higher energy level to lower energy level.	Emission of light photon takes place by inducement of a photon having energy equal to emitted photon's energy.
2.	The emission has a broad spectrum, *i.e.*, many wavelengths.	The emission has monochromatic radiation, *i.e.*, single wavelength.
3.	Incoherent radiation.	Coherent radiation.
4.	Less intense.	High intense.
5.	Less directionality and more angular spread.	High directionality and less angular spread during propagation.
	Example: Light from sodium or mercury vapour lamp.	**Example:** Light from laser source.

4.6 EINSTEIN'S A AND B COEFFICIENTS AND TRANSITION PROBABILITIES

Let us calculate the rate of transitions between two energy states 1 and 2 having energies E_1 and E_2 [Fig. (1)]. The probable rate of occurrence of the absorption transition $1 \rightarrow 2$ depends upon the properties of states 1 and 2. This is proportional to the energy density $u(\nu)$ of the radiation of frequency ν incident on the atom. The energy density is defined as radiant energy per unit volume in the frequency interval ν and $\nu + d\nu$. Therefore, the probable rate of occurrence of absorption transition is given by

$$P_{12} = B_{12}\, u(\nu) \qquad \ldots(1)$$

where B_{12} is proportionality constant and is known as ***Einstein's coefficient of absorption of radiation.***

The probability of spontaneous emission $2 \rightarrow 1$ [Fig. (2)] is determined only by the properties of states 2 and 1. This is denoted by A_{21} and is known as ***Einstein's coefficient of spontaneous emission of radiation.*** This is independent of energy density $u(\nu)$.

The probability of stimulated emission transition $2 \rightarrow 1$ [Fig. (3)] is proportional to energy density $u(\nu)$ of the stimulating radiation and is given by

$$B_{21}\, u(\nu)$$

where B_{21} is known as ***Einstein's coefficient of stimulated emission of radiation.***

The total probability for an atom in state 2 to state 1 is therefore,

$$P_{21} = A_{21} + B_{21}\, u(\nu) \qquad \ldots(2)$$

Relation between different Einstein's coefficients

Let us consider an assembly of atoms in thermal equilibrium at temperature T with radiation of frequency ν and $\nu + d\nu$ and energy density $u(\nu)$. Let N_1 and N_2 be the number of atoms in lower energy state 1 and higher energy state 2 respectively at any instant.

The number of atoms in state 1 that absorb a photon and rise to state 2 per unit time is given by

$$N_1\, P_{12} = N_1\, B_{12}\, u(\nu) \qquad \text{[using eq. (1)]} \quad \ldots(3)$$

The number of atoms in state 2 that drop to state 1, either by spontaneous emission or by stimulated emission is given by

$$N_2\, P_{21} = N_2[A_{21} + B_{21}\, u(\nu)] \qquad \text{[using eq. 2]} \quad \ldots(4)$$

Under the condition of equilibrium, the number of atoms absorbing radiation per unit time equal to the number of atoms emitting radiation per unit time.

$$N_1 P_{12} = N_2 P_{21}$$

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

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

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

$$= \frac{A_{21}}{B_{21}} \times \frac{1}{\left[\left(\frac{N_1}{N_2}\right)\left(\frac{B_{12}}{B_{21}}\right) - 1\right]} \quad \ldots(5)$$

Thermodynamically, it was proved by Einstein that the probability of stimulated absorption is equal to the probability of stimulated emission, *i.e.*,

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

$$u(\nu) = \frac{A_{21}}{B_{21}} \times \frac{1}{\left(\frac{N_1}{N_2} - 1\right)} \quad \ldots(6)$$

According to Boltzmann distribution law, the ratio of N_1 and N_2 is given by

$$\frac{N_1}{N_2} = \exp.\left[\frac{E_2 - E_1}{kT}\right] = \exp.\left[\frac{h\nu}{kT}\right] \quad \ldots(7)$$

where k is Boltzmann constant.

Substituting the value of (N_1/N_2) from eq. (7) in eq. (6), we get

$$u(\nu) = \frac{A_{21}}{B_{21}} \times \frac{1}{[\exp.(h\nu/kT) - 1]} \quad \ldots(8)$$

According to Planck's radiation law, the energy density of radiation is given by

$$u(\nu) = \frac{8\pi h \nu^3}{c^3} \times \frac{1}{[\exp.(h\nu/kT) - 1]} \quad \ldots(9)$$

Comparing eqs. (8) and (9), we get

$$\boxed{\frac{A_{21}}{B_{21}} = \frac{8\pi h \nu^3}{c^3}} \quad \ldots(10)$$

where c is velocity of light.

Equation (10) shows that the ratio of Einstein's coefficient of spontaneous emission to Einstein's coefficient of stimulated emission is directly proportional to the cube of frequency (*i.e.*, ν^3). This shows the probability of spontaneous emission increases rapidly with the increase of energy difference between two states.

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By supplying energy from the external source, the atoms in the ground state (E_0) are pumped to excited state E_2. In the optical pumping, the laser medium is irradiated by radiation of frequency ν_0 such that $h\nu_0 = (E_2 - E_0)$. The atoms are excited by stimulated absorption.

Step 2: Population inversion

The atoms from energy level E_2 may drop to the metastable level E_1 by spontaneous emission. This occurs almost instantaneously. As E_1 is a metastable state, the excited atoms stay comparatively for a longer time. As a result, soon the number of atoms in energy level E_1 becomes much larger than in energy levels E_2 and E_0 energy level E_0. In this way population inversion occurs between energy

Step 3: Stimulated emission

It is important to mention here that a photon of energy $h\nu = (E_1 - E_0)$ may be emitted due to spontaneous emission. This photon will passs through laser medium. Now, this photon produces stimulated emission from energy level E_1 to E_0.

4.1 MAIN COMPONENTS OF A LASER (ACTIVE MEDIUM, ENERGY SOURCE AND OPTICAL RESONATOR)

There are three main components of laser. These are:

1. ***Active medium***: When the active medium is excited, it achieves population inversion. The active medium may be a solid, liquid or gas. Depending on the active medium, we have different types of lasers, *i.e.*, solid state laser (ruby), liquid lasers and gas lasers (He-Ne, CO_2 lasers).
2. ***Energy source***: The energy source raise the system to an excited state.
3. ***Optical resonator***: The optical resonator consists of two mirrors facing each other. The active medium is enclosed in this cavity. Out of the two mirrors, one is fully reflective while the other is partially transparent. The function of the optical resonator is to increase the intensity of laser beam.

These components are shown schematically in Fig. (7).

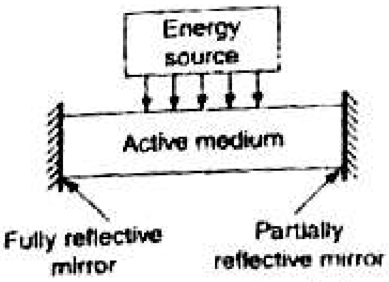


Fig. (7) Main Components of a Laser

Action of optical resonator

The action of optical resonator is as follows:

(i) Initially, the active centres are in non-excited state.

(ii) Using suitable pumping process, the material is taken into population inversion state. For this purpose, energy source is used.

(iii) At the initial stage, spontaneous photons are emitted in all directions. The photons that travel in specific direction are selected while others are rejected.

(iv) The stimulated photons are to be made to pass through the medium a number of times. The mirrors constituting the resonator cause the directional selectivity. The photons travelling in random directions are lost. On reaching the partially reflective mirror, some photons are transmitted out while the remaining are reflected back.

(v) The reflected photons de-excite more and more atoms. At fully reflecting mirror, some photons are absorbed while a major number of photons are reflected. The beam is now amplified.

(vi) The amplified beam undergo multiple reflections at the mirrors and gains in strength.

(vii) When the amount of amplified light becomes equal to the total amount of light lost (through the sides of the resonator, through the mirrors and through absorption of the medium), the laser beam oscillation begins. When the oscillations build up to enough intensity then they emerge through front mirror as a highly collimated intense beam, *i.e.*, laser light.

.12 RUBY LASER

...t us consider the case of an actual laser known as Ruby laser. It uses a crystalline substance of the ...tive material. The different parts are shown in Fig. (8).

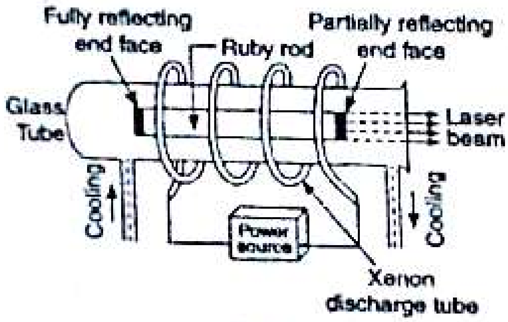


Fig. (8)

...in parts of Ruby laser

...consists of three main parts:

1. ***An active working material:*** A rod of ruby crystal.

2. ***A resonant cavity:*** Made of fully reflecting plate of the left of ruby crystal and a partially ...flecting plate at the right of ruby crystal. Both the plates are optically plane and exactly parallel to ...h other.

3. ***Exciting system:*** A helical xenon flash tube with power supply source.

4. ***The Cooling system:*** Water circulating system in glass tube surrounding it.

...nstruction

...uby ($Al_2O_3 . Cr_2O_3$) is a crystal of aluminium oxide Al_2O_3 in which some aluminium atoms are ...placed by chromium atoms (Cr_2O_3). The active material in the ruby are chromium ions Cr^{3+}. ...hen ruby crystal contains about 0.5% of chromium, its colour is pink. The ruby crystals are grown ...n special furnaces with varying length and diameter. In a ruby laser, a pink rod of 4 cm length and 0.5 ... cm diameter is generally used. The end faces of the rod are made strictly parallel grounded and polished to high degree. The end faces are then silvered in such a way that one end face becomes fully ...reflecting while the other end partially reflecting. Sometimes separate pieces are attached at the end ...faces. The ruby rod is surrounded by a helical xenon flash tube which provides the pumping light to ...raise the chromium ions to upper energy level. The flash of the xenon tube lasts several milliseconds and the tube consumes several thousand joules of energy. Only a part of this energy is used in pumping the Cr^{3+} ions while the rest heats up the apparatus. For this purpose a cooling arrangement is used.

Working

An energy diagram illustrating the operation principle of ruby laser is shown in Fig. (9). In figure E_1, E_2 and E_3 represent the energy level of chromium ion. In normal state, the chromi... are in lower energy level E_1. When the ruby crystal is irradiated with light of xenon flash ... chromium atoms are excited to upper energy level E_3 where light absorption band is 5500 Å.

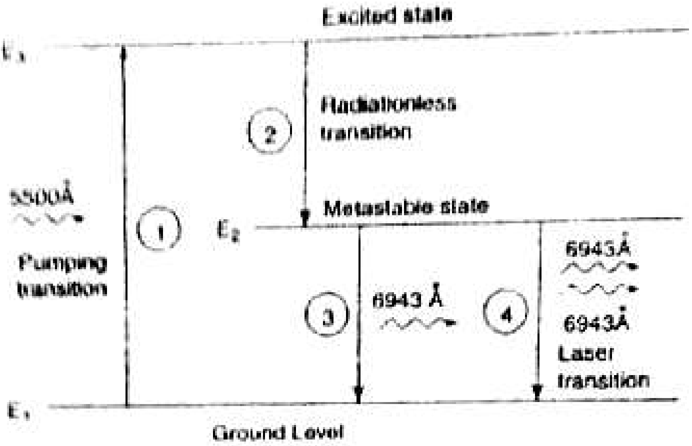


Fig. (9) Energy Levels of Ruby Laser

The transition 1 is optical pumping transition. The excited ions give up, by collision, part of their energy to crystal lattice and decay to the metastable state E_2. The corresponding transition 2 is thus, radiationless transition. We know that metastable state has relatively longer life time ($\approx 10^{-3}$ sec) than usual life time ($\approx 10^{-8}$ sec). Thus, the number of ions in state E_2 goes on increasing while due to pumping, the number of ions in ground state E_1 goes on decreasing. In this way, population inversion is established between metastable state E_2 and ground state E_1.

The state of inverted population is not a stable one. The probability of spontaneous transition at any moment is very high. When the ion passes spontaneously from the metatstable state to ground state, it emits a photon of wavelengths 6943 Å. This photon travels through the ruby rod. If this photon is moving parallel to the axis of the crystal, it is reflected back and forth by the silver ends until it stimulates an excited atom. Now, it causes the ion to emit a fresh photon. The excited atom after emitting photon returns to ground level. The emitted photon is in phase with the stimulating photon. This stimulated transition 4 is laser transition. The process is repeated again and again because the photons repeatedly move along the crystal being reflected from its ends. This results in amplified strong laser beam, of wavelength-6943 Å.

Characteristics of Ruby laser

Following are the few characteristics of ruby laser:

1. ***Type.*** This is a three level solid state laser.
2. ***Active medium.*** Ruby rod is used as active medium.
3. ***Pumping method.*** Optical pumping is employed for pumping action i.e., achieving population inversion.
4. ***Optical resonator.*** The two ends of ruby rod which are polished with silver (one is fully silvered while the other is partially silvered) are used as optical resonator.
5. ***Power output.*** The power output is $10^4 - 10^6$ watts.
6. ***Frequency of output.*** The frequency of output beam is 4.32×10^{14} Hz.

Wavelength of output. The wavelength of output beam is 6943 Å.

Nature of output. The nature of output is pulsed beam of light.

vantages of Ruby laser

wing are the disadvantages of Ruby laser.

The monochomaticity is affected due to crystalline imperfections, thermal distortion and ing.

During the operation of Ruby laser, a very high temperature is produced. Hence a frequent g is necessary.

Aligning the crystal and mirrors is very difficult.

The laser requires high pumping power.

The efficiency of ruby laser is very small. Here, only the green component of pumping ght ized while the rest of the components of incident light are left unused.

The laser output is not continuous. The output occurs in the form of pulses of microsec nd on.

ations and uses of Ruby laser

It is used in laboratory experiments.

It is used in soldering and welding.

It is used for drilling of brittle material on a very small area.

It is used to test the quality of the materials.

Ruby lasers are generally used as a high power source of pulsed coherent radiation in the interferometry, holography, etc.

It is used in the treatment of detached retina.

It is used in light detection and ranging (LIDAR).

n drawback of ruby laser is that the output beam is not continuous though very intense. or nuous laser beam, gas lasers are used. In gas lasers the vapours of metals are employed as edia. The main advantages of gas lasers are exceptionally high monochromaticity, n st ctrum and high stability of frequency. Hence, they have wide applications in various of science and engineering particularly in communications. The output power of as moderate but inferior to that of crystal lasers. In 1961, A. Javan, W. Bennett and D. Her ot continuous He-Ne gas laser.

uction

perimental arrangement of He-Ne laser is shown in Fig. (10).

Fig. (10)

The gas laser consists of a fused quartz tube with diameter of about 1.5 cm and 80 cm long. This tube is filled with a mixture of neon (Ne) under a pressure of 0.1 mm of mercury and helium (He) under a pressure of 1 mm of mercury. There is a majority of helium atoms and minority of neon atoms. At one end of the tube, there is a perfect reflector while on the other end is a partial reflector. The active material is excited by means of a high frequency generator with a frequency of several tens of MHz and an input of about 50 watt.

Working

The energy level diagram of He-Ne laser is shown in Fig. (11).

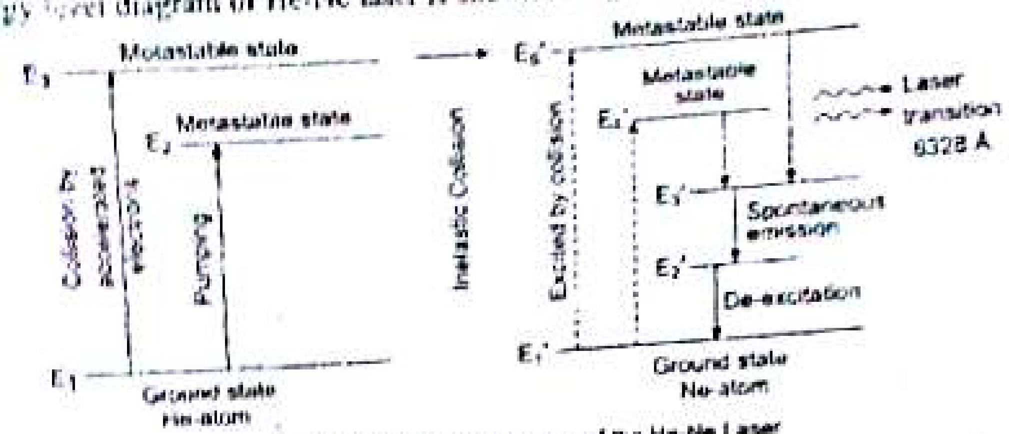


Fig. (11) Energy level Diagram of the He-Ne Laser

When a discharge passes through the gas mixture, helium atoms are excited to higher energy levels E_2 or E_3 through collisions with accelerated particles. This is termed as pumping. The states E_2 and E_3 are metastable states from which there are no allowed transitions. The excited helium atoms then collide inelastically with neon atoms still in ground state and transfer energy to them. The advantage of this collision process is that fairly light neon atoms can easily jumped to energy states E_6', E_4' and E_3'. It is important to mention here that after collision, the helium atoms are returned to ground state. The higher Ne states E_6' and E_4' are metastable states and have longer life times than E_3'. Therefore, a population inversion takes place between states E_6', E_4' and E_3'.

When an excited Ne atom passes from metastable states E_6' and E_4' to state E_3', it emits a photon. This photon travels through the gas mixture. If the photon is moving parallel to the axis of the tube, it is reflected back and forth by the mirror-ends until it stimulates an excited Ne-atom. Thus, it causes a fresh photon in phase with stimulating photon. The stimulated transition is a laser transition. This process continues till a beam of coherent radiation builds up in the tube. When the beam becomes sufficiently intense, a portion of it escapes through the partially silvered end.

Difference between Ruby laser and He-Ne laser

S.No.	Ruby laser	He-Ne laser
1	It produces a pulsed laser beam.	It produces a continuous laser beam.
2	It is a three level system.	It is a four level system.
3	Optical pumping method is used for absorption.	Electric discharge is used as pumping.
4	It has active medium in solid state.	It has active medium in gaseous state.
5	Cooling arrangement is required.	No cooling arrangement is required.
6	It emits light of 6943Å.	It emits light of 6328Å.

racteristics of He-Ne laser

1. *Type.* It is a four energy levels (3 in Ne and 1 in He) laser.
2. ***Active medium.*** It uses a mixture of helium and neon gases as the active medium.
3. ***Pumping method.*** Electric discharge method is used for pumping action *i.e.*, for achieving ulation inversion.
4. ***Optical resonator.*** A pair of plane mirrors facing each other is used as optical resonator.
5. ***Frequency of output.*** The frequency of output beam is about 4.7×10^{14} Hz.
6. ***Wavelength of output.*** The wavelength of laser output is 6328 Å.
7. ***Nature of output.*** The nature of output is continuous waves.
8. ***Power output.*** The power output of laser beam is 0.5 – 50 milliwatts.

antages or merit of He – Ne laser

1. This operates in a continuous wave mode.
2. It is more monochromatic and more directional than solid state lasers.
3. It has high stability of frequency.
4. No cooling is required.
5. It is less inexpensive.

plications and uses of He – Ne laser

1. It is used in laboratory experiments to produce interference and diffraction patterns.
2. It is used in optical communication without fibre for moderate distance.
3. It is used for aligning the ruby laser.
4. It is used in ophthalmology.
5. It can be used to produce holograms i.e., 3D photographs.

ngst the different types of lasers available, carbon dioxide laser is considered to be one of the st efficient and powerful laser. Although it is commonly called a CO_2 laser, it actually uses a gas ture containing CO_2, N_2 and He.

Carbon Dioxide (CO_2) is the gas in which the lasing process occurs, but other gas additives to laser tube improve the total efficiency of the laser. Oscillations occur between two vibrational d in carbon dioxide while the efficiency is greatly improved by nitrogen and helium. The dard CO_2 laser includes a mixture of CO_2 with N_2 and He in the active medium. The optimal ortion of these three gases in the mixture depends on the laser system and the excitation hanism. In general, for a continuous wave laser the proportions are:

$$CO_2 : N_2 : He—1 : 1 : 8$$

Carbon Dioxide (CO_2) is a linear molecule, and the three atoms are situated on a straight line h the Carbon atom in the middle.

In Figure (12), the three vibrational modes of CO_2 molecules are shown.

These are

1. Symmetric stretch mode (v_1).
2. Bending mode (v_2).
3. Asymmetric stretch mode (v_3).

2. It is first molecular gas laser.
3. It has extremely high efficiency.
4. The output of the laser is continuous.
5. It has very high output power. The output power may be increased by increasing the length of the tube.

Applications of CO_2 lasers

The most significant area in which the CO_2 laser is used is in the general material processing. This includes cutting, drilling, removal of material, melting, etching, welding, alloying, hardening, annealing, etc.

The other important area is in medical applications. Here, the laser is used for cauterising and cutting. Cauterising is the process of burning or destroying infected tissues in a wound. In these applications, a very intense source of heating can be applied to a very small area.

Note: **(CO) Laser** is very similar to the CO_2 laser, except for the active gas -CO. It emits at about half the wavelength of the carbon dioxide laser. The spectrum output of these lasers is: 5-6 micron [μm]. One of the problems with this laser is the gas CO which is poisonous.

4.15 Nd-YAG LASER

Energy level Diagram

The energy level diagram of a Nd-YAG laser is shown in Fig. (15)

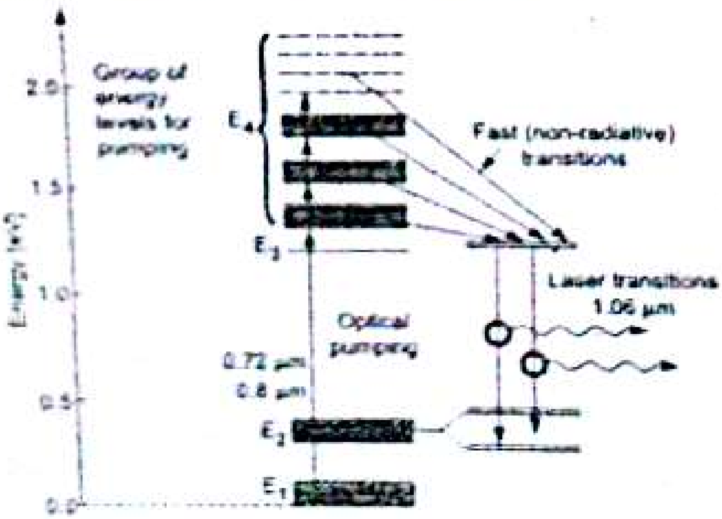


Fig. (15) Energy level diagram of a Nd-YAG laser

As can be seen from the energy level diagram, Nd lasers are four level lasers. Nd ions have two absorption band and excitation is done by optical pumping, either by flash lamps for pulsed lasers or by arc lamps for continuous wave lasers. From these excited energy levels, the Nd ions are transferring into the upper laser level by a non-radiative transition. The stimulated emission is from the upper laser level to the lower laser level and the wavelength of the emitted photons are around 1.06 μm. From the lower laser level, there is a non-radiative transition to the ground level.

Structure

The cylindrical crystal forms the laser cavity and has reflective ends. One end is coated so that it is 100% reflected and the other is either sufficiently reflective or is coated to allow only part of the ified light to pass enough feedback, so that oscillation may occur. Figure (16) shows a YAG laser.

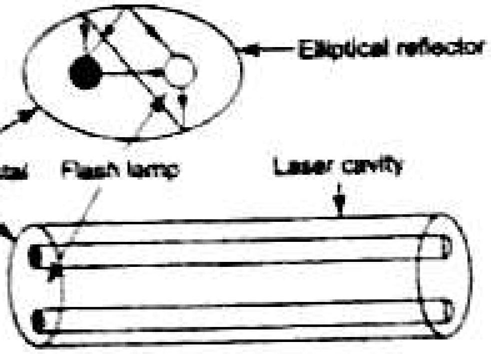


Fig. (16) Nd-YAG laser

eration

pulation inversion results from shining light on Nd-YAG crystal. The Nd-YAG laser is optically mped solid-state laser. It can produce very high power emissions. Nd-YAG absorbs mostly in the nds between 730 – 760 nm and 790 – 820 nm. If the light is intense enough, atoms within the ystal that absorb this light transit from ground state into the absorption bands. This is done by a ash lamp emitting in the blue and ultra-violet region. Often a quartz tube is filled with a noble gas through which high energy stored in a capacitor is discharged.

Atoms transition is efficient from their broad absorption bands (level E_4 in figure) to the upper ergy levels. The radiative decays to the ground-state from these bands have long lifetimes (in μs) as compared to the fast transitions to the upper energy levels (in nanosecond). Approximately 99% of the ions that are excited to the absorption band transfer to the upper energy levels. These levels are characterized by a relatively long lifetime (ms). Due to this long lifetime, they de-excite almost solely due to spontaneous emission.

Nd-YAG laser is a four-level system. The cross-section of stimulated emission is large because of the narrow line-width and the threshold of pumping is low. However, the absorption bands are also narrow. Hence, the excellent radiation emitted by the flash lamp is not fully utilized. As a result, attempts have been made to use gases like krypton in the pumping lamp which matches the emission bands. In several commercial operations, the emission in the infrared region of the Nd-YAG laser is frequency-doubled, to bring it to the visible region. This is done by using a non-linear interaction in the YAG crystal.

Applications

1. In the field of cosmetic medicine for hair removal and the treatment of minor vascular defects.
2. For soft tissue surgeries in oral cavity.
3. In the medical field for correcting posterior capsular opacification (after-cataract operation).
4. In manufacturing as a means for engraving, etching or marking a variety of metals and plastics.
5. For cutting and welding steel and super alloys.
6. For flow visualization techniques in fluid dynamics.

4.16 [illegible]

Principle

We know that 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 electrons from N-region into the P-region. The electrons and holes recombine and release of energy takes place in or very near the junction region. The amount of this energy, called the activation energy or energy gap, depends on the particular type of semiconductor. In case of some semiconductors like germanium and silicon, most of the energy is released in the form of heat because the recombination of carriers of opposite sign takes place through interaction with the atoms of the crystals. But in case of other semiconductors such as Gallium Arsenide (GaAs) and others, the energy is released as light because the atoms of the crystals are not involved in the release of energy. The wavelengths of emitted light depends on activation energy of the crystal. Photons emitted at the moment of recombination of an electron with a hole will stimulate recombination of other carriers of electric charges. The result will be stimulated emission of radiation. If these radiations moving in the plane of the junction are made to move back and forth in the plane of the junction by reflection at opposite parallel sides and perpendicular to the plane of junction, a very powerful laser beam of stimulated radiation can be produced.

Construction

A semiconductor diode laser is a specially fabricated P-N junction which limits coherent light when it is forward biased.

A semiconductor diode is made up of an active layer of gallium arsenide (Ga As) of thickness 0.2 microns. It is sandwiched in between *a N*-type Ga As Al and *P*-type Gl As Al layer as shown in Fig. (17).

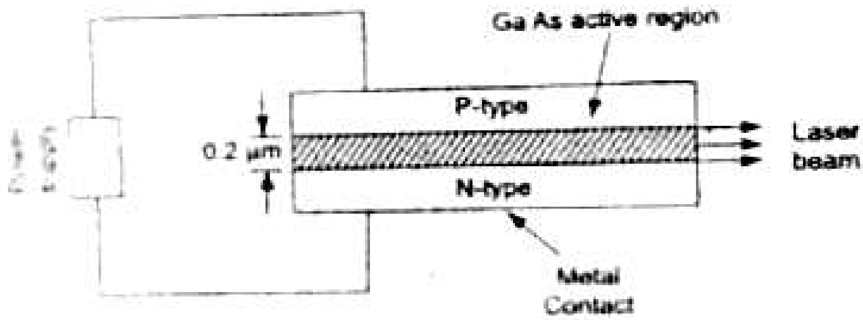


Fig. (17) Semiconductor diode laser

The resonant cavity is provided by polishing opposite faces of Ga As crystal.

The pumping occurs by passing electric current through the diode by an ordinary power supply

A laser beam of wavelength ranging from 7000 Å to 30, 000 Å can be produced by this system.

The semiconductor diode lasers are simple, compact and highly efficient. They require ver

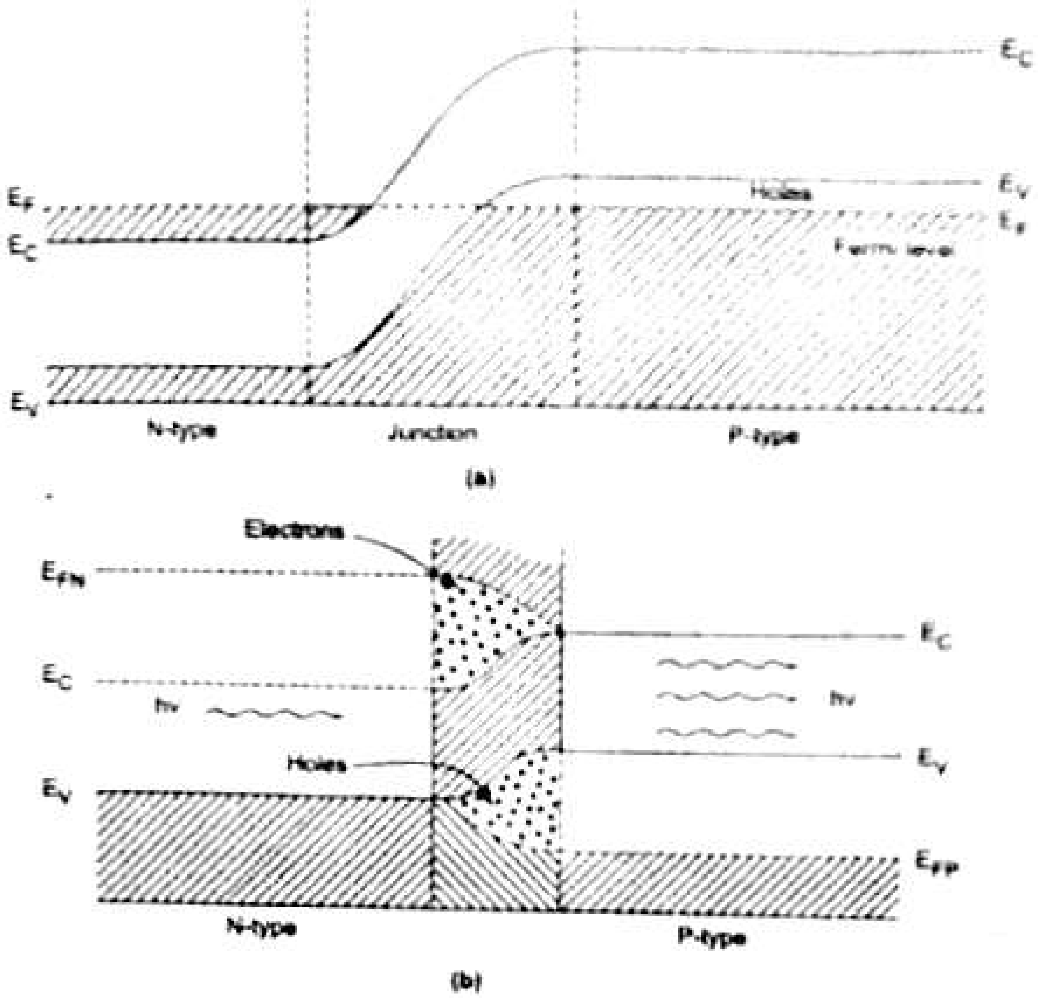
little power and little auxiliary equipment.

Working

The energy band diagram of a P-N junction diode having highly doped P- and N- regions is show in Fig. 18 (a).

With very large doping on N-side, the donor levels as well as portion of the conduction band a occupied. The Fermi-level lies within the conduction band. Similarly, on the heavi doped P-side, the acceptor levels are unoccupied and holes exist in the valence band. The Fer level lies within the valence band. ***At thermal equilibrium, the Fermi level is uniform across t*** ***junction*** as shown in Fig. 18 (a).

When a forward bias is applied to the junction, the energy levels shift. The new distribution energy levels is shown in Fig. 18 (b).



(a) Heavily doped P-N junction without bias

(b) Heavily doped P-N junction with forward biased above threshold value

Fig. (18) Energy band structure of a semiconductor diode

When a forward bias is applied and current reaches a threshold value, the carrier concentration in depletion region increases to a very high value. As is obvious from from Fig. 18 (b), the upper levels in depletion region have high population density of electrons while the lower levels in the same region are vacant. Similarly, a large concentration of holes appears within the valence band. This is the state of ***population inversion***. The narrow region where the population inversion is achieved is called ***inversion region*** or ***active region.***

The photons that propagates in the junction plane induce the conduction electrons to jump into the vacant states of valence band. The stimulated electron-hole recombinations cause emission of coherent radiation of very narrow bandwidth.

Efficiencies

When exciting currents are small, only a small part of carriers undergo recombination. The process is spontaneous. The laser radiation is random and incoherent. But when the current density is increased the emission becomes more and more coherent and the radiation intensity markedly increases. Now, efficiency of Ga As lasers reaches 40 percent. When cooled to 20 K, semiconductor lasers have delivered an output of more than two watts of continuous power, which is the most continuous power produced by a laser. It is believed that semiconductor lasers may reach 100% efficiency. They are capable of ensuring a high stability of the output frequency, which is the characteristic only of gas lasers.

Properties or characteristics of semiconductor laser

1. *Type.* It is a solid state laser.
2. *Active medium.* A P-N junction diode made from a single crystal of gallium arsenide is used as active medium.
3. *Pumping method.* Direct conversion method is employed for pumping action.
4. *Nature of output.* The nature of output is continuous wave output.
5. *Power Output.* The power output of this laser is 1 mW.
6. *Wavelength of output.* Ga-As laser gives infrared radiation in wavelength range 8300 to 8500Å.

Advantages or merits of semiconductor laser

1. The arrangement is simple and compact i.e., it is very small in dimension.
2. It has high efficiency.
3. It can be operated at low power in comparison with ruby and CO_2 laser.
4. The laser output can be modulated by controlling the junction current.
5. It can be fused in the fibre itself, so that the problem of coupling is eliminated.

Applications of semiconductor laser

1. It is used in fibre optical communication.
2. It is used to heal the wounds by means of infrared radiation.
3. It is used to produce laser diodes. The laser diodes are more powerful and coherent than LEDs.
4. It can be used as relief to kill the pain.

4.17 APPLICATIONS OF LASER

The lasers are put to a number of uses in different branches of science due to their narrow band width and narrow angular spread. A few applications are listed below:

1. Communications

(i) Due to the narrow band width, lasers are used in microwave communication. We know that in microwave communication the signal is mounted on carrier waves by the process of modulation. As the band width of carrier waves is limited, the number of channels of message which can be carried simultaneously is limited. But by the use of lasers, more channels of message can be accommodated because the band width is very small.

(ii) Due to narrow, angular spread, the laser beams have become a means of communication between earth and moon or other satellites. The earth-moon distance has been measured with the use of lasers.

(iii) Laser radiation is not absorbed by water and hence it can be utilized in under water communication networks.

(iv) Fibre guides. A laser beam in conjunction with optical fibre can be used to transmit audio signals over long distances without attenuation or disturbance

2. Computers

By the use of lasers, the storage capacity for information in computers is greatly improved due to narrowness of bandwidth. The IBM corporation is trying to transmit an entire memory bank from one computer to another by the use of laser beam

3. Industry

The lasers have wide industrial applications. Lasers can be focussed into a very fine beam, resulting in raising the temperature about 1000 K. So, they can blast holes in diamonds and hard steels.

...edicine

...have wide medical applications. They have been used successfully in the treatment of ...hed retinas. Preliminary success had also been obtained to treat the human and animal cancers. ...-surgery is also possible because laser beams can be focussed on very small areas (due to the ...w angular spread) and hence one harmful component can be destroyed without seriously ...ging the neighbouring regions.

...litary Applications

...tudy is also oriented for military purposes. Due to high energy density, a laser beam can be ...to destroy very big objects like aircrafts, missiles, etc. in a few second by directing the laser ...into the target. As such it is called *'death ray'* or *'ray weapon'*. Laser beam can be used in ...gun. In a laser gun, highly convergent beam is focussed on enemy targets at a short range.

...hemical Applications

...s have wide chemical applications. They can initiate or hasten certain chemical reactions ...h could not be possible in the absence of suitable photons. They can be used for investigating ...ructure of molecules. Raman spectroscopy is one in which laser have made so much impact ...separate branch named as Laser Raman Spectroscopy has grown rapidly. By the use of lasers, ...aman spectrum can be obtained for much smaller samples and faster too. Not only that but ...interactions also arise due to high intensity excitation which provide additional information.

...eather forecasting

...res of clouds, wind movements, etc. can be obtained with laser beam. The data so obtained can ...ed in weather forecasting.

...sers in photography

...laser, we can get three dimensional lensless photography. Using interference techniques, we ...ke hologram which is analogous to negative of the photographic film.

...OLVED EXAMPLES

...XAMPLE 1 *Calculate the energy and momentum of a photon of a laser beam of ...velength* 6328 Å

...ion The energy of photon is given by

$$E = h\nu = \frac{hc}{\lambda}$$

... c is velocity of light.

...iven that, $\lambda = 6328$ Å $= 6328 \times 10^{-10}$ m, $c = 3 \times 10^8$ m/s

... $= 6.62 \times 10^{-34}$ J-s.

$$E = \frac{(6.62 \times 10^{-34}) \times (3 \times 10^8)}{(6328 \times 10^{-10})} = 3.14 \times 10^{-19} \text{ joule}$$

$$E = \frac{3.14 \times 10^{-19}}{1.6 \times 10^{-19}} \text{ eV} = \mathbf{1.96\ eV}$$