CHAPTER 2

Laser and Fibre Optics

Module 2

Syllabus

(Prerequisites : Absorption, Recombination, Energy bands of p-n junction, Refractive index of a material, Snell's law).

(A) Laser : Spontaneous emission and stimulated emission; Metastable state, Population inversion, Types of pumping, Resonant cavity, Einstein's coefficient; Helium Neon laser; Nd:YAG laser; Semiconductor laser, Applications of laser- Holography.

(B) Fibre optics : Numerical Aperture for step index fibre; Critical angle; Angle of acceptance; V number; Number of modes of propagation; Types of optical fibres; Fibre optic communication system.

Part A - Laser

2.1 Introduction

MU - May 2014

University Question

Q. What is acronym of 'LASER' ? How are they different than X-rays ? **(May 14, 3 Marks)**

- LASER is acronym for Light Amplification by Stimulated Emission of Radiation. A laser beam is highly parallel coherent beam of light of very high intensity. Production of laser light is a particular consequence of interaction of radiation as a rule with matter. The interpretation of the interaction is done on the basis of ideas related to energy levels of the concerned system from which light is derived.
- In case of gases, it may be noted that, though different gases have different energy level patterns, any gas as a rule will have discrete energy levels, the energy quantization rules always hold good. Hence matter, irrespective of its state of existence, is referred to as a quantized system.
- Since LASER is high energy beam, at times it is compared with x-rays. But both of them differ completely. Some points at which LASER differs from x-rays are :
  (1) LASER is highly coherent where an x-ray is not.
  (2) LASER has it wavelength of the order of visible spectrum, where as x-rays has very small wavelength.
  (3) Stimulated emission is essential for LASER where as x-ray needs high energy electron and their retardation.

2.2 Interaction of Radiation with Matter

- The understanding of the working principle of laser requires an appreciation of quantum process that takes place in a material when it is exposed to radiation.

- A material medium is composed of identical atoms or molecules each of which is characterized by a set of discrete allowed energy states. An atom when it receives or releases an amount of energy equal to the energy difference between those two states, is termed as a transition.
- For sake of simplicity, we will restrict our attention to two energy levels E_2, an excited state and E_1, a lower energy state. Let a monochromatic radiation of frequency ν be incident on the medium.
- The radiation may be viewed as a stream of photons, each photon carrying an energy $h\nu$. If $h\nu = E_2 - E_1$, the interaction of radiation with atoms leads to following distinct processes.

2.2.1 Absorption

- An atom in lower energy state E_1 may absorb the incident photon and may be excited to E_2 as shown in Fig. 2.2.1. This transition is known as stimulated absorption corresponding to each transition made by an atom one photon disappears from the incident beam.

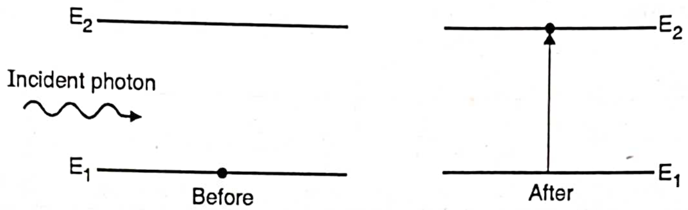


Fig. 2.2.1 : Induced absorption

The transition may be written as

$$A + h\nu = A^* \quad \text{...(2.2.1)}$$

Where A = Atom in lower energy state

A^* = Atom in excited state

The number of atoms N_{ab} excited during the time Δt is given by

$$N_{ab} = B_{12} N_1 Q \Delta t \quad \text{...(2.2.2)}$$

Where N_1 = Number of atoms in state E_1

Q = Energy density of the incident beam

B_{12} = Probability of an absorption transition.

2.2.2 Spontaneous Emission

- Excited state with higher energy is inherently unstable because of a natural tendency of atoms to seek out lowest energy configuration. Therefore excited atoms do not stay in the excited state for a relatively longer time but tend to return to the lower state by giving up the excess energy $h\nu = E_2 - E_1$ in the form of spontaneous emission or stimulated emission.
- The excited atom in the state E_2 may return to the lower state E_1 on its own out of natural tendency to attain the minimum potential energy condition.
- During the transition the excess energy is released as a photon of energy $h\nu = E_2 - E_1$. This type of process in which photon emission occurs without any external agency is called **spontaneous** or **natural emission**. Fig. 2.2.2 represents natural emission and shows the transition.

$$A^* \rightarrow A + h\nu \quad \text{...(2.2.3)}$$

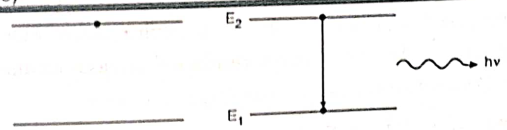


Fig. 2.2.2 : Natural or Spontaneous emission

- The number of spontaneous transitions N_{sp} taking place in the medium during time Δt depends only on the number of atoms N_2 lying in the excited state E_2. It is given by,

$$N_{sp} = A_{21} N_2 \Delta t \qquad \ldots(2.2.4)$$

where, N_2 = Number of atoms in the state E_2

A_{21} = Probability of a spontaneous emission.

2.2.3 Stimulated Emission

MU - May 2016

University Question

Q. Explain the term stimulated emission. **(May 16, 3 Marks)**

- An atom in excited state need not wait for spontaneous emission to occur. There exists an additional possibility according to which an excited atom can make a downward transition and emit a radiation.
- A photon of energy $h\nu = E_2 - E_1$ can induce the excited atom to make a downward transition releasing the energy in the form of a photon.
- Thus the interaction of a photon with an excited atom triggers the excited atom to drop to the lower energy state giving up a photon.
- This phenomenon is called **forced emission** or **stimulated emission** as shown in Fig. 2.2.3. The process may be represented as

$$A^* + h\nu = A + 2h\nu \qquad \ldots(2.2.5)$$

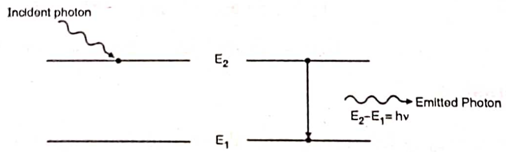


Fig. 2.2.3 : Stimulated emission

- The number of stimulated transition N_{st} occurring in the material during time Δt may be written as

$$N_{st} = B_{21} N_2 Q \Delta t \qquad \ldots(2.2.6)$$

Where

B_{21} = Probability of a stimulated emission.

- Einstein had predicted this probability and it is considered as one of the essential requirements of laser. The main features are :

- The emitted photon is identical to the incident photon in all respects. It has the same frequency ν as that of incident photon. Both the photons travel in the same direction.
- The process is controllable from outside.
- Multiplication of photons takes place in the process. One photon induces an atom to emit a second photon, these two travelling along the same direction de excite two atoms in their path producing a total four atoms which in turn stimulates four atoms generating eight photons and so on. It suggests that electromagnetic waves of the number as atoms in light source are very large, coherent emission leads to enormously high intense light than incoherent emission.

2.2.4 Difference between Spontaneous Emission and Stimulated Emission

MU - Dec. 2013, Dec. 2014, Dec. 2015, May 2018, Dec. 2018, Dec. 2019

University Question

Q. What is the difference between spontaneous and stimulated emission? **(Dec. 13, Dec. 14, Dec. 15, May 18, Dec. 18, Dec. 19, 3 Marks)**

2.10

Table 2.2.1 : Difference between Spontaneous emission and Stimulated emission

Sr. No.	Spontaneous emission	Stimulated emission
1.	It is a natural process.	Artificial, induced process.
2.	Cannot be controlled.	Can be controlled effectively.
3.	No multiplication of photons takes place.	Multiplication of photons takes place.
4.	Not useful for LASER.	Essential for LASER.

2.3 Active Medium

A medium in which light gets amplified is called an active medium. The medium may be a solid, liquid or gas. Therefore the medium where we get population inversion and laser as output is active medium.

Solid : Ruby laser, Nd-YAG laser

Gas : He-Ne laser, CO_2 laser

Liquid : Dye laser

2.4 Population Inversion

MU - May 2013, May 2016, May 2017

University Questions

Q. What is a population inversion state? Explain its significance in the operation of LASER. **(May 13, May 17, 3 Marks)**

Q. Explain the population inversion. **(May 16, 3 Marks)**

In order to understand population inversion, we must know what do we mean by,

(a) Population of energy level

(b) Boltzmann factor

(a) Population of energy level

- For the sake of simplicity, let us consider the atomic state of matter, where we have set of allowed energy levels for an atom. The set of allowed energy levels is the energy level scheme is same for all the atoms of same type.
- If we consider an assembly of identical atoms, then we can compare the energies of all those atoms in a single energy level scheme. Normally, the numbers of atoms are required to possess one or the other energy values which are permitted only in this energy scheme, each of energy states will be having many atoms as its members. The number of atoms in a particular state is referred to as its **population.**

(b) Boltzmann factor

- The population of different energy states of any physical system are related to each other, provided, the system is in thermal equilibrium. The relation is given by Boltzmann factor. Among the various energy states, if we consider any two energy states E_1 and E_2 with population N_1 and N_2 respectively, and if $E_2 > E_1$, then Boltzmann factor is the ratio (N_2/N_1) given by,

$$\frac{N_2}{N_1} = e^{-(E_2-E_1)/KT} \qquad \ldots(2.4.1)$$

Where K is Boltzmann constant,

$$\text{Since } E_2 > E_1,\ e^{-(E_2-E_1)/KT} < 1$$

$$\therefore N_2 < N_1$$

Hence for a system in thermodynamic equilibrium, it is mandatory that the population of any higher state is always lesser than that in any of the lower states.

- **Population inversion is the state of a system at which the population of a particular energy state is more than that of a specified lower energy state** i.e. $N_2 > N_1$. Under normal condition population inversion condition does not exist. However it is possible to achieve the population inversion condition in certain system, which has metastable states.
- It is considered as a precondition of LASER. It makes LASER possible with the help of metastable state.

2.5 Metastable States

- By providing energy, if an atom is made to go to one of its excited states, it stays there over a brief interval of time not exceeding 10^{-8} sec., and then returns to one of the lower energy states.
- In case the state to which the atom is excited is a metastable state, then the atom stays there for unusually long time, which is of the order of 10^{-3} to 10^{-2} seconds. **This property is essential for achieving population inversion.**
- Metastable states may be considered as a special privilege enjoyed by atoms of some specific elements. Such states are not created. Infact, existence of metastable states helps us decide which element is useful for population inversion and which one is not. Like He is useful in He-Ne, Nd is useful in Nd -YAG etc.

2.6 Pumping and Pumping Types

University Question **MU - Dec. 2016, Dec. 2017**

Q. What is pumping in LASER ? Give the types of pumping. **(Dec.16, Dec. 17, 5 Marks)**

The process of raising large number of atoms from lower energy level to a higher energy level is called pumping.

Types of pumping

- **Optical pumping :** Which uses strong light source for excitation.
- **Electrical pumping :** Which uses electron impact for excitation.
- **Chemical pumping :** Which uses chemical reactions for excitation.
- **Direct pumping :** Which uses direct conversion of electric energy into light.

2.7 Pumping Schemes

Any atom has large number of energy levels but for pumping process only few are of some use. Important pumping schemes which are famous.

(a) Three level	(b) Four level

2.7.1 Three Level Pumping Scheme

Consider the case of three energy levels taking part E_1, E_2 (Metastable state) and E_3 as shown in Fig. 2.7.1.

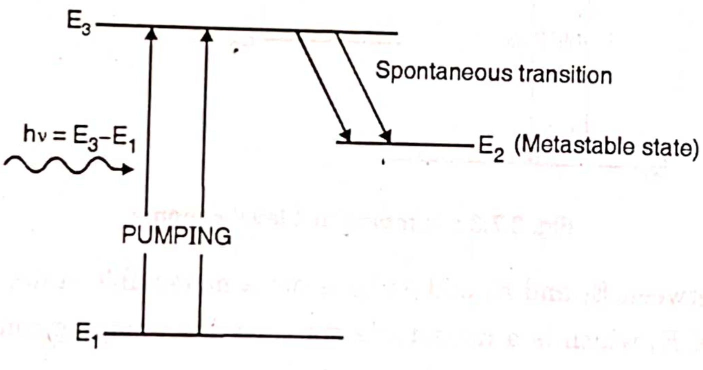


Fig. 2.7.1 : Pumping in 3 level scheme

- For pumping we select a radiation with frequency satisfying $h\nu = E_3 - E_1$. As E_3 is not a metastable state, spontaneous emission will take place between $E_3 \rightarrow E_2$.
- Laser materials are selected such that energy levels will have very small probability for transition $E_3 \rightarrow E_1$. (These probabilities are calculated through selection rules which are described in terms of quantum numbers.)

- As E_2 is a metastable state, probability of transition $E_2 \rightarrow E_1$ is very small. (Pumping is never done between $E_1 \rightarrow E_2$ as it describes a two level pumping scheme which is not used due to reasons given at later stage).
- As pumping continues, E_2 gets filled up and population inversion takes place between E_2 and E_1.
- As E_1 is ground state, a large number of atoms must be pumped to E_2 to have population inversion, hence a very high pumping power is needed for this scheme.
- A photon with energy $h\nu = E_2 - E_1$ may trigger the stimulated emission process as shown in Fig. 2.7.2.

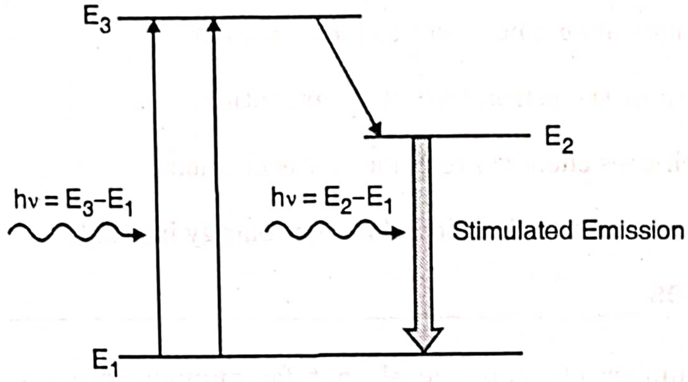


Fig. 2.7.2 : Stimulated emission in 3 levels

2.7.2 Four Level Scheme

- Consider the following case, where four energy levels are taking part into laser emission process.

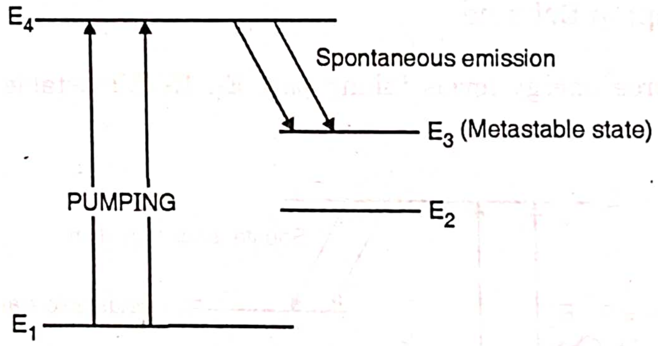


Fig. 2.7.3 : Pumping in 4 level scheme

- Pumping is created between E_1 and E_4 and as E_4 is not a metastable state, spontaneous emission wi transfer atoms to level E_3 which is a metastable state. As the pumping continues, E_3 also gets atom from E_4.
- Population inversion between E_3 and E_2 is achieved.
- As there is no pumping from E_1 to E_2, we have E_2 virtually empty and hence population inversio between E_3 and E_2 is achieved. As there is no pumping from E_1 to E_2, we have E_2 virtually empty an hence population inversion between E_3 and E_2 is somewhat easier than that of 3 level scheme.
- A photon with energy $h\nu = E_3 - E_2$ triggers stimulated emission as shown in Fig. 2.7.4.
- After reaching to E_2, through stimulated emission, atoms will generate spontaneous emission to go to E i.e. the ground state.

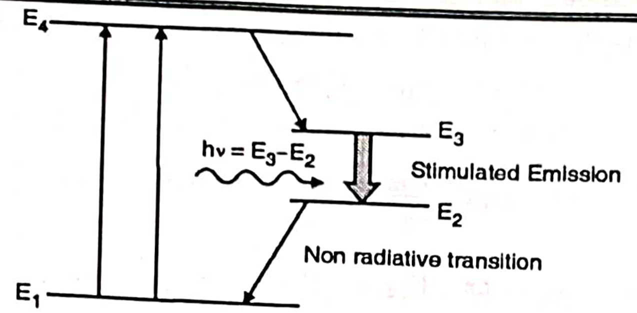


Fig. 2.7.4 : Stimulated emission in 4 level scheme

7.3 Two Level Scheme

Selection rules which are described in terms of quantum numbers, and the relation linked to quantum echanics.

$$\Delta E \cdot \Delta t \geq \frac{h}{2\pi}$$

One can find that two level pumping scheme is not suitable for population inversion.

8 Einstein's Co-efficient

In sections 2.2.2 and 2.2.3, we have discussed spontaneous and stimulated emission. Einstein was the first to calculate the probability of such transition assuming the atomic system to be in equilibrium with electromagnetic radiation.

Under thermal equilibrium the number of upward transition is equal to number of downward transition per unit volume per second.

$$\therefore \quad A_{21} N_2 + B_{21} N_2 Q = B_{12} N_1 Q \qquad \text{...(2.8.1)}$$

From Equation (2.8.1) we get,

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

$$Q = \frac{\frac{A_{21}}{B_{21}}}{\frac{B_{12}}{B_{21}} \frac{N_1}{N_2} - 1}$$

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

$$= \exp\left(\frac{h\nu}{KT}\right)$$

$$\therefore \quad Q = \frac{\frac{A_{21}}{B_{21}}}{\frac{B_{12}}{B_{21}} \cdot \exp\left(\frac{h\nu}{KT}\right) - 1} \qquad \text{...(2.8.2)}$$

Equation (2.8.2) must agree with Planck's energy distribution formula which is given by,

$$Q = \frac{8\pi h\nu^3}{c^3} \cdot \frac{1}{\exp\left(\frac{h\nu}{KT}\right) - 1} \qquad \text{...(2.8.3)}$$

Now by comparing Equations (2.8.2) and (2.8.3), we get,

$$\frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3} \quad \text{...(2.8.4)}$$

$$\text{and} \quad \frac{B_{12}}{B_{21}} = 1$$

$$\text{or} \quad B_{12} = B_{21} \quad \text{...(2.8.5)}$$

2.9 Important Characteristics of Laser Beam

MU - May 2015

University Question

Q. Compare light from ordinary source with laser light. **(May 15, 3 Marks)**

Q.6 **Highly coherent**

- The light is coherent with waves all exactly in phase with another. It means an interference pattern can be obtained by using two laser sources.
- There are two types of coherences, (i) Temporal coherences (ii) Spatial coherences
  (i) **Temporal coherence :** In the wave propagation system correlation between the waves at one place at different times, is called "**temporal coherence**".
  (ii) **Spatial coherences :** In the propagation wave correlation between different places but not along the path is called "**spatial coherence**".
- From the above description it is clear that these two types of coherence are independent of each other. That is an electromagnetic wave with partial temporal coherence can have perfect spatial coherence.

Highly monochromatic

Q.6
- A laser produces light in more or less single wavelength i.e. the line width associated with laser beam are extremely narrow.
- In general traditional (conventional) sources of light are not strictly monochromatic. But it is observed that the laser light is almost perfectly monochromatic (one only). However in all practical practices the laser light is not perfectively monochromatic, but its degree of monochromaticity is very high. It divergence from monochromaticity is due to ***Doppler effect*** of the fast moving atoms or molecules from the laser source.
- Let us consider that such a monochromatic light of wave length λ and its spreading is denoted by $\Delta\lambda$ which is called **line width,** e.g. sodium vapor monochromatic source of light gives two bands (spectrum) of wave length $\Delta\lambda_1$ and $\Delta\lambda_2$ which *are 5890 A° and 5893 A° respectively.*
- Mathematically **degree of non-monochromaticity 'τ'** is defined as the ratio of line width $\Delta\lambda$ to the original wavelength λ that is $\tau = \frac{\Delta\lambda}{\lambda}$.
- The reciprocal of τ is known as degree of monochromaticity and hence it is clear that $1/\tau$ is high when beam spreading is low.

- In general lasers beam generate light in a very narrow band. The degree of monochromoticity is described in terms of *wavelength bandwidth* or *frequency bandwidth*. It is clear that the narrow *line width* of laser, gives higher degree of the monochromocity laser light.
- However, narrowness of *line width* is depends on the type of laser, and special techniques used to improve monochromaticity.
- There are certain factors responsible for increasing its monochromaticity :
  (i) Laser light originally emitted by stimulated emission from single set of *atomic energy levels*. This is its basic principle; hence from origin its monochromaticity is very high.
  (ii) Here electromagnetic waves of frequency $\nu = (E_2 - E_1)$ only can be amplified, and it has a particular range which is called *line width*. The line width is decided by factors like Doppler effect of moving atoms and molecules.
  (iii) In the system of laser generation the *laser cavity* forms a *resonant system* in which *laser oscillation* is sustained only at the resonant frequencies of the cavity. This phenomenon leads to the further descries in *laser line width*. Therefore laser light is usually very pure in wavelength.

Highly directional

- A laser beam diverges hardly at all. Such a beam sent from the earth to a mirror left by the Apollo-II expedition, remained narrow enough to be detected on its return to the earth. (Distance between moon and earth is around 3,84,000 km).
- This is one of the important properties of the laser due to its high directionality. Directionality or Collimation means it does not spread out much. A conventional light source emits light in all directions. On the other hand, laser emits light only in one direction without spreading or very little divergence of it.
- The width of laser beam is extremely narrow and hence a laser beam can travel to long distances without spreading.
- The directionality of laser beam is due to its laser cavity system in which very nearly parallel front back mirrors arrangement is made. The perfectively collimated beam is never expanding at all. Its divergence angle is zero.
- It can be brought to focus extremely sharp. Further Laser beam is well defined wave-front therefore it is highly directional. Its high directionality allows us to focus it into a point by passing the beam through a suitable convex lens.
- In the laser system diffraction plays an important role in fixing the size of laser spot which can be focused at a given distance.
- A narrow laser beam produced in the resonator cavity that diverges at some angle depending on the design of resonator, output aperture's size, and resulting diffraction effects on it. These diffraction effects generally called as beam-spreading effect.
- Finally we get the high directionality laser beam due to the diffraction effects which can make minimum divergence and spot size of the beam. High directionality laser beam is the prime demand in the laser based devices and instruments.

Brightness

The laser beam is highly intense as compared to ordinary source of light.

Highly energetic

The laser beam is highly intense. To understand it clearly here is an example : To achieve an equal energy density to that in laser beam, a hot object would have to be at temperature of 10^{30} K. This makes laser suitable for applications like cutting, drilling and welding.

Table 2.9.1 : Difference between LASER and ordinary light

Sr. No.	LASER	Ordinary light
1.	It is highly monochromatic.	It is poly chromatic.
2.	It is highly coherent.	It is not coherent.
3.	Stimulated emission is responsible for it.	Spontaneous emission is responsible for it.
4.	Highly direction.	Not directional.
5.	Highly energetic.	Poor energy is associated.
6.	Example : He-Ne, Nd : YAG etc.	Example : Sunlight, LED

2.10 He-Ne Laser

MU - May 2013, Dec. 2014, May 2015, May 2017, May 2019

University Questions

Q. With a neat energy level diagram describe the construction and working of He-Ne laser. What are its merits and demerits. **(May 13, 8 Marks)**

Q. With neat energy level diagram describe the construction and working of He-Ne Laser. **(Dec. 14, May 15, May 17, May 19, 8 Marks)**

Principle

- Gas lasers are usually employ a mixture of two gases say A and B where atoms of type A are initially excited by electron impact and they in turn transfer their energy to atoms of type B which are actual active centers.
- Here the energy transfer is done by atomic collisions between A and B where two of their energy levels are equal. It is also known as resonance transfer energy. It can be expressed as

$$e_1 + A = e_2 + A^*$$

$$A^* + B = A + B^*$$

- Here A* and A represented the energy values of the atom of type A in metastable state and ground state respectively. B and B* represent the energy values of the atom of type B in ground state and excited state respectively.

Construction Q.7.

- The He-Ne laser consists of a long and narrow discharge tube which is filled with Helium and Neon in the ratio 10 : 1 with pressure of 1 mm of mercury. Flat glass quartz plates which function as Brewster windows are sealed to the tube at both ends. Two optically plane mirrors are fixed on either side of the tube normal to its axis as shown in Fig. 2.10.1.

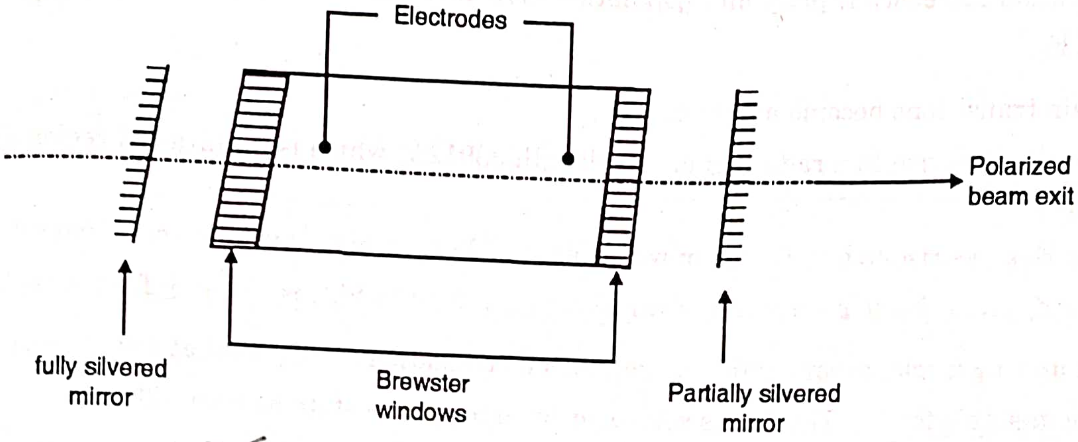


Fig. 2.10.1 : He-Ne laser tube (schematic presentation)

- One of the mirror is fully silvered with 100% reflectivity, where as the silvering of the other is slightly less so that 1% of the incident laser beam could be trapped by transmission.

Working

Energy level diagram :

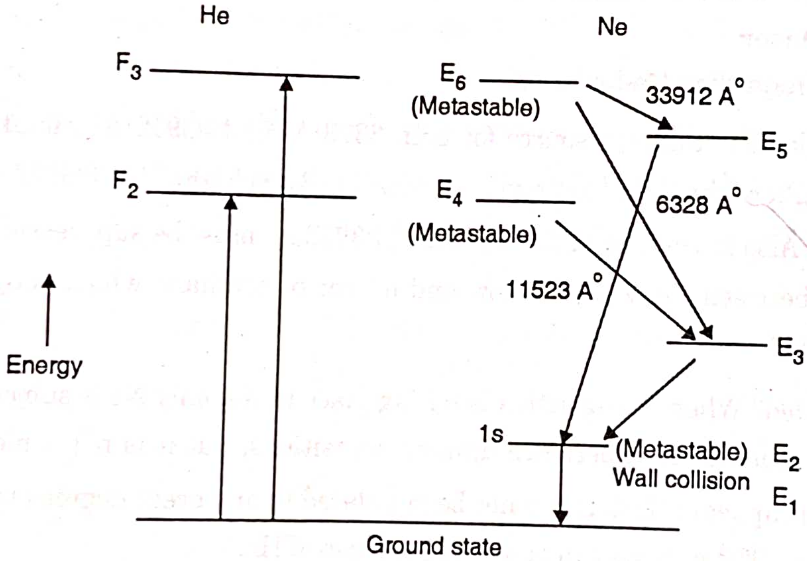


Fig. 2.10.2 : Energy level diagram of He-Ne

- When a voltage of about 1 kV is applied across the tube, a slow discharge of the gases is initialized in the tube. During the discharge, many electrons are rendered free from the gas atoms and are accelerated towards positive electrode and collide with Helium. Since He atoms are large in number, excitation of He takes place and as discussed in the principle above, we get

$$e_1 + He = e_2 + He^*$$

He atoms are excited to two energy levels F_2 and F_3 which are non-metastable states which leads to an increase of population in each of them.

- For Ne energy states metastable states E_6 and E_4 are very close to F_3 and F_2 of He atom*. Therefore when He atoms collides with a Neon atoms, because of the matching of energy levels, resonant transfer of energy takes place from He to Ne atoms. As a result, the Ne atoms get elevated to the E_6 and E_4 levels, whereas the He-atoms returns to ground state. This is represented as

$$He^* + Ne = He + Ne^*$$

- The population increases rapidly and population inversion takes place between E_6 and E_4 with respect to E_5 and E_3.
- Three main transitions become available.
  (a) E_6 to E_5 gives rise to a radiation of wavelength 33912A° which is in infra-red region and hence not visible.
  (b) E_6 to E_3 gives rise to a radiation of wavelength 6328 A°, which is visible and of red colour.
  (c) E_4 to E_3 gives rise to a radiation of wavelength 11523 A° which is also in infra-red region.
- From E_5 and E_3 levels, atoms undergo spontaneous transitions to E_2 level at much faster rate. But E_2 level is metastable for Ne. The atoms will come down to ground state by wall collision.
- This effect is inversely proportional to the diameter of the discharge tube and hence **the diameter of the He-Ne laser is only of few millimeters in diameter to enable efficient depopulation of E_2 level.**
- Since the discharge in the tube is maintained continuously, the cycle of events also takes place continuously and the emission of laser is also continuous, because of which He-Ne laser is referred as a **continuous wave laser.**

Some important points regarding He-Ne laser

(a) In He-Ne laser, E_6 level is common source for both 6328 A° and 33912 A° radiations. Since the longer wavelength have higher stimulated emission probability (B_{21} is high), the 33912A° captures major share from 3s population. Also it tends to prevent 6328A°, 33912 A° must be suppressed. One of the way to do so to fill the space between Brewster window and mirror by methane which is opaque for 33912A° but transparent to 6328A°.

(b) Why Helium is needed? When lasing action is taking place in Ne, only Ne is subjected to discharge, then it is E_5 state most probable to experience upward transitions, but it is not a metastable. As far as E_6 state is concerned, it appears that, it can not be populated to any great degrees by collision between the Ne atoms themselves. The only way to populate E_6 is use of He.

Merits

(a) Continuous output.

(b) Highly monochromatic.

(c) Highly stable.

(d) No separate cooling is needed.

(e) As gases are found in pure form their optical properties are well defined.

Demerit

Very low output power.

Applications

(a) In holography.

(b) Research activities.

(c) Communication.

2.11 Nd : YAG Laser

MU - May 2016, Dec. 2017, May 2018, Dec. 2019

University Questions

Q. With neat energy level diagram, explain principle, construction and working of Nd :YAG laser. **(May 16, Dec. 19, 8 Marks)**

Q. Explain construction and working of Nd : YAG laser. **(Dec. 17, May 18, 7 Marks)**

- It is a solid state laser.
- Nd represents Neodymium (Nd^{+3} ions are used).
- YAG represents Yittrium Aluminium Garnet ($Y_3 Al_5 O_{12}$).
- Some of the Y^{+3} ions are replaced by Nd^{+3}. The crystal atoms of YAG do not take part into lasing action, but serve as a host lattice in which Nd^{+3} resides.

Construction

- As shown in Fig. 2.11.1, an elliptically cylinder reflector with both of its axis occupied by a flash lamp and Nd : YAG rod respectively. The light leaving one focus of the ellipse will certainly pass through the other focus after reflection from reflecting surface. Hence entire light generated by flash tube is focussed on the Nd : YAG rod.
- Optical resonator is formed by highly silvered reflecting surfaces as shown in Fig. 2.11.1.

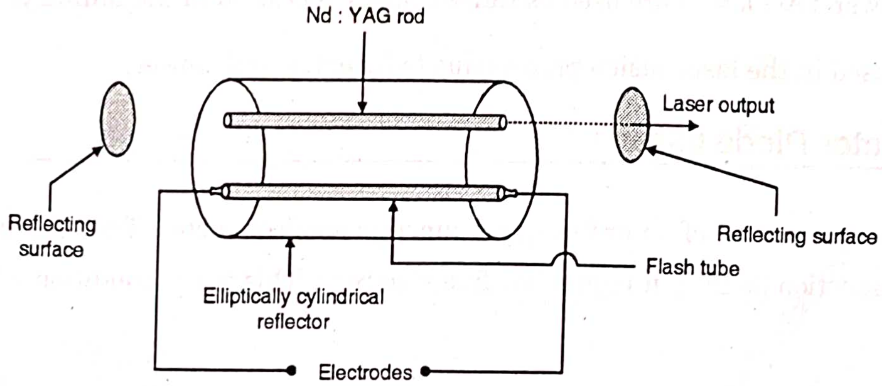


Fig. 2.11.1 : Nd : YAG laser

Function Working

- In Fig. 2.11.2 we have energy levels E_1, E_2 and E_3 of Nd along with many other levels of YAG. E_1 is ground state and E_3 offers metastable state.
- Pumping takes place with light of wavelength 5000 A° to 8000 A° which excites Nd^{+3} ions to higher states. The metastable state E_3 rapidly gets populated due to downward transitions from higher energy levels as none of them is metastable.
- Population inversion takes place between E_3 and E_2. A continuous laser of 10600 A° in infrared region is given out due to stimulate emission taking place between E_3 and E_2.

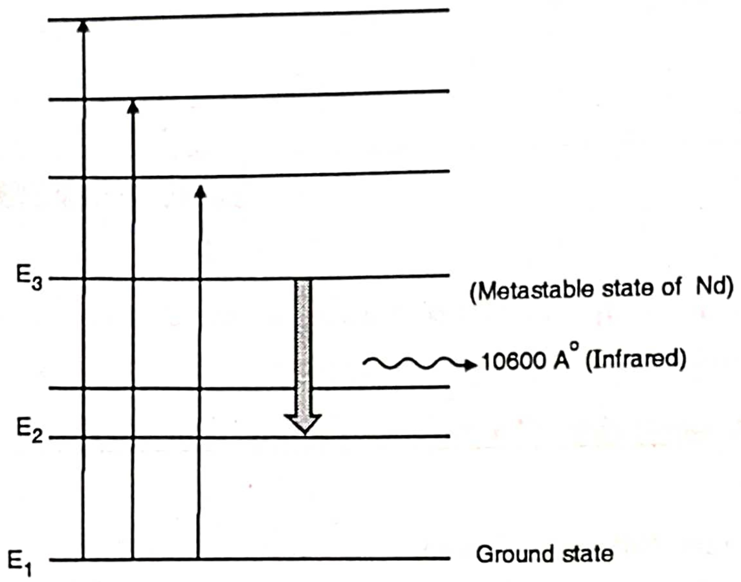


Fig. 2.11.2 : Energy levels of Nd along with YAG

Applications

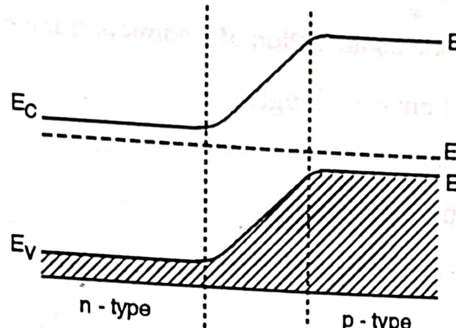
Due to steady and reliable source of laser energy the Nd-YAG laser has number of applications. Few major applications are :

1. The main industrial applications are in the mechanical process like cutting welding and drilling.
2. These lasers are widely used in the medical field. The special wavelength of 1.064 μm of laser used in the fiber optics endoscopes with YAG lasers are used to gastrointestinal treatment.
3. Due to its high power YAG lasers are used as range finders operation in the military.
4. These lasers are used in the laser fusion process due to its extra high power.

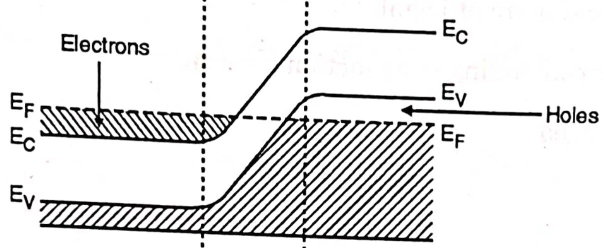
2.12 Semiconductor Diode Laser

- Fig. 2.12.1(a) shows a scheme of an ordinary p-n junction semiconductor. The valence band in p-region has holes and conduction band in n region has free electrons. This is the condition when semiconductor is lightly doped.

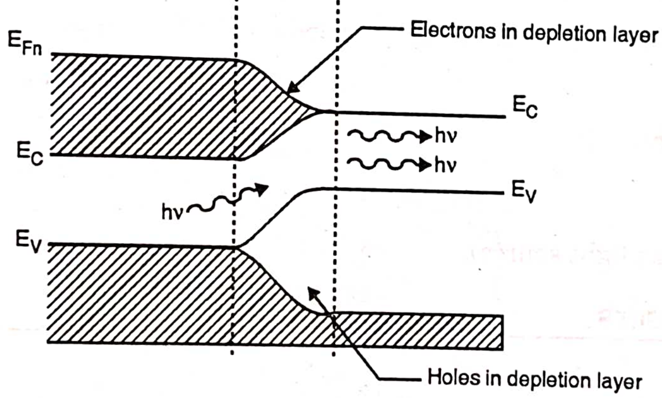
- When it is heavily doped, we get some electrons shifted to conduction band and holes are seen in valence bands. But this does not create population inversion at all (Fig. 2.12.1(b)). The Fermi level on n-side is found on conduction band and on p-side it is found on valence band but it is in equilibrium at both sides.
- When a forward biased is applied, energy level diagram gets altered as shown in Fig. 2.12.1(c). Electrons from conduction band of n-type and holes from valence band of p-type are injected into depletion layer.



(a) Lightly doped p–n junction (unbiased)



(b) Heavily doped p–n junction (unbiased)



(c) A forward biased and heavily doped p-n junction above threshold value.

Fig. 2.12.1 : Energy bands in semiconductor laser

- A threshold current (A minimum forward current) is defined below which electron-hole recombination will have spontaneous emission and p-n junction works as LED. A forward current above the threshold value, carrier concentration in depletion region will reach very high values which describes population inversion state. The emission of light due to recombination of electrons and holes will be stimulated emission and produces laser.

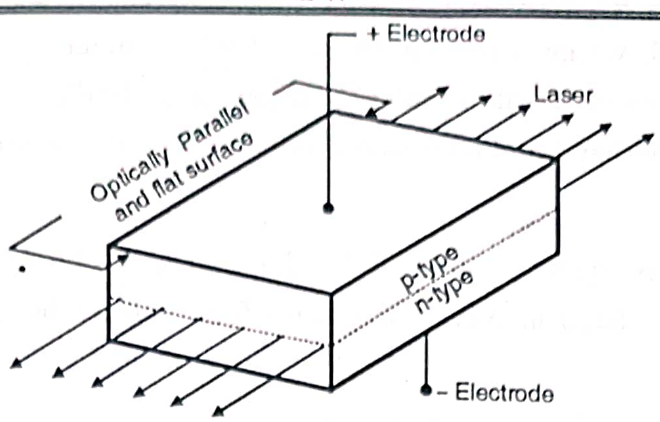


Fig. 2.12.2 : Schematic construction of a semiconductor diode

- Some of the semiconductor lasers and their wavelength.
  (a) GaAs : 8400 A° (at room temperature)
  (b) GaAsP : 6500 A° (at room temperature)

Merits

(a) Simple and compact.

(b) Requires very little power and more efficient.

(c) Output can be controlled by controlling the junction current.

(d) Metastable state is not required.

Demerits

(a) Highly temperature sensitive.

(b) Less monochromatic.

Applications

(a) Laser printers and copiers.

(b) CD players.

(c) Optical communication (as light source).

2.13 Application of Lasers

2.13.1 Holography

MU - Dec. 2013, May 2014, Dec. 2015, Dec. 2016, May 2017, Dec. 2017, May 2018, May 2019, Dec. 20

University Questions

Q. What is the difference between holography and photograph? Discuss the construction and reconstruction of image holography with neat diagram. **(Dec. 13, May 18, 8 Marks)**

Q. What is holography ? Explain its construction and reconstruction with neat diagram. **(May 14, Dec. 15, May 17, 8 Marks)**

Q. What is the fundamental principle of a Hologram ? How is it produced and how the real image is constructed by it. **(Dec. 16, 8 Marks)**

Q. What is holography ? Differentiate between holography and photography. **(Dec. 17, May 19, Dec. 19, 5 Marks)**

- The advent of lasers has made the art of holography possible. Photography can be thought of as a new approach to the problem of generating images. An ordinary photograph represents a two dimensional recording of a three dimensional scene.
- The emulsion on the photographic plate is sensitive only to intensity variations. In this process the phase information carried by the electromagnetic wave scattered from the object is lost. Since only the intensity pattern is recorded, the 3D character of the object is lost.
- The principle behind the holograph is "During the recording process one superimposes on the scattered wave (emanating from the object) another coherent wave (called reference beam) of the same wavelength".
- These two waves interfere in the plane of the recording medium and produce interference fringes. This is known as recording process. The interference fringes-characteristic of the object is formed. The recording medium records the intensity distribution in the interference pattern.
- This interference pattern has recorded in it not only the amplitude distribution but also the phase of the electromagnetic wave scattered from the object. Since the recorded intensity pattern has both the amplitude and phase recorded in it has been called "hologram" (Holos in Greek means whole).
- The holograms have little resemblance to the object. It has in it a coded form of a wavefront. The reproduction of the image is known as reconstruction in which a wave identical to the one used as reference wave is used.
- When hologram is illuminated by the reconstruction wave, two waves are produced. One wave appears to diverge from the object and provides the virtual image of the object. The second wave converges to form a second image which is real.

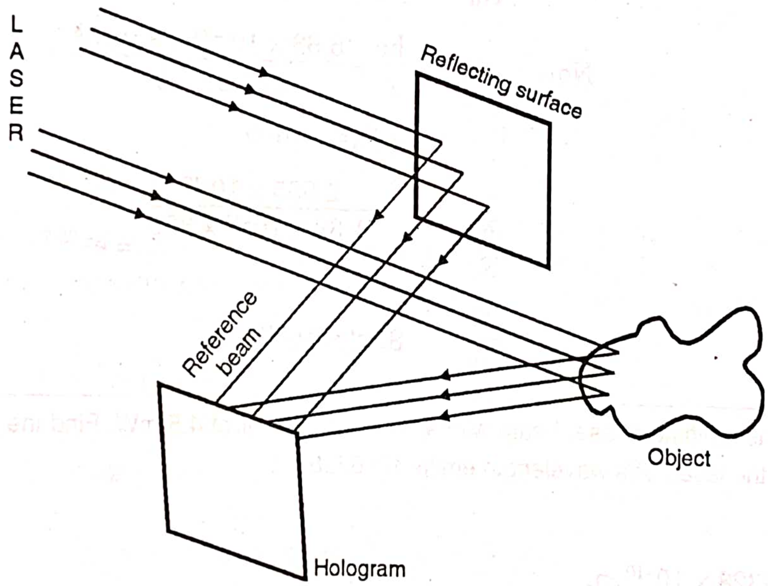


Fig. 2.13.1(a) : Construction of hologram