UNIT – II LASER AND FIBER OPTICS

TOPIC – I: Spontaneous and stimulated emission- Population inversion

Introduction

Laser is an artificial light source having many superior features than the conventional light sources. **LASER** stands for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation.

Laser is a device which produces powerful, monochromatic, collimated beam of light in which the light waves are coherent.

Laser emerges as a narrow beam that can travel over long distances without much loss of intensity and divergence. Actually, laser amplifies light waves.

In 1960, Dr.T.H.Maiman demonstrated the first laser, namely ruby laser. Since then, the development of laser has been extremely rapid with laser action demonstrated in gases, liquids, solids, semiconductors, etc.

The discovery of laser made an enormous impact in scientific and engineering applications particularly in the fields of telecommunication, metrology, biology, medicine and computers.

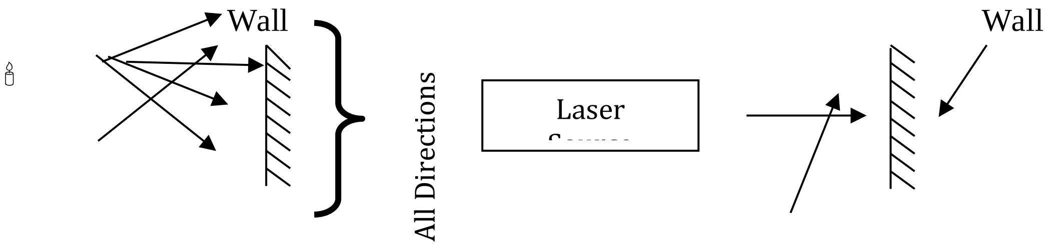
Characteristics of Laser

Laser is basically a light source, but has striking properties such as high brightness, directionality, coherence etc. The most important features of laser are described below:

- **High directionality**
- **High intensity**
- **Monochromaticity**
- **Coherence**

Directionality

Laser light has a high degree of directionality. The ordinary light source emits light in all directions. But, Laser emits light in only one direction. The divergence of laser beam is very small .The directionality of Laser is represented in Fig .1.



Ordinary light source Fig.1. Laser Beam

Intensity or brightness

We know that laser emits light in a narrow beam and its energy is concentrated in a small region. This concentration of energy gives a high intensity or brightness

Monochromaticity

Ordinary light spreads over a wide range of frequency of thousands of megacycles per second. A laser beam on the other hand, is highly monochromatic, i.e., it contains only a single frequency and has very little spreading.

Coherence

The light originating from a source consists of wave trains. When these wave trains are identical in phase and direction, they are coherent

Laser has a high degree of coherence. The coherence of laser emission results in extremely high power of 4×10^{16} watt/ m^2. A laser beam can be focused to a very small region of about 0.7 μm diameter.

These properties make a laser beam superior to other conventional light sources like flame, sunlight, etc.

Stimulated absorption, spontaneous emission and stimulated emission

To understand the working principle of laser, we must study the quantum processes that occur in a material medium when exposed to light radiation.

Let us assume that an assembly of atoms (material) is exposed to light radiation (a stream of photon with energy *hf or hv*)

Under the action of external light radiation, the following three different processes may occur and compete with each other in the medium.

- Stimulated absorption
- Spontaneous Emission
- Stimulated Emission

Stimulated absorption

An atom in ground state with energy E_1 absorbs a photon of energy *hf or hv* and goes to the excited state (higher energy state) with energy E_2 (Fig.2), provided the photon energy *hf* *or hv* is equal to the energy difference (E_2 - E_1). This process is called **Stimulated absorption.**

For each transition like this, energy is removed from the incident light beam. The number of transitions at any instant is proportional to the number of atoms in state E_1 and the number of photons in the incident beam.

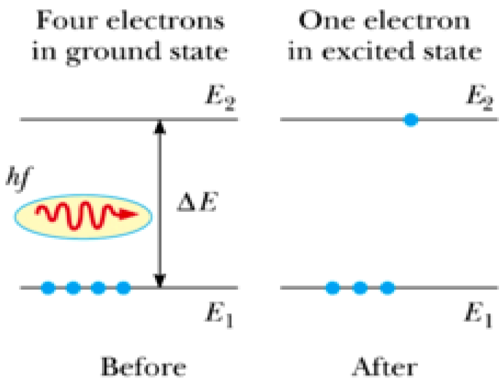


Fig .2 Stimulated absorption

Atoms in the excited state will not stay in this state for a longer time. It is the natural tendency of atoms in excited state to seek out the lowest energy configuration (lowest energy level). So the atoms in excited state quickly return to ground state by emitting a photon of frequency *v* and energy *hf or hv.*

Spontaneous Emission

The atom in excited state E_2 (higher energy state) returns to ground state E_1 (lower energy state) by emitting a photon of energy *hf or hv* (equal to E_2 - E_1) without the action of an external agency

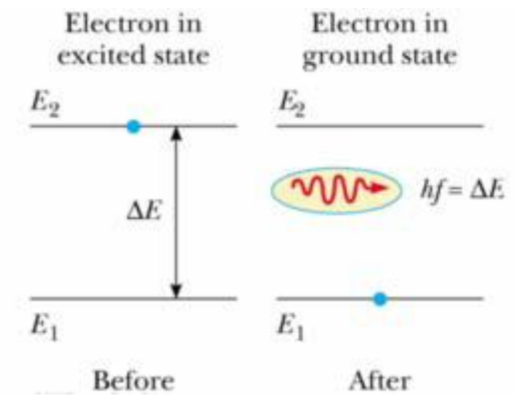


Fig .3 Spontaneous Emission

Such an emission of radiation that is not triggered by any external influence is called Spontaneous Emission.It is a random process and is uncontrollable.

Stimulated Emission

Einstein discovered that there must be another mechanism by which an atom in excited state can return to ground state.

He found that if there is an interaction between an atom in excited state and a photon then during interaction, the photon triggers the excited atom to make transition to the ground state E1 .This transition generates a second photon, which would be identical to the triggering photon with respect to frequency, phase and propagation direction.

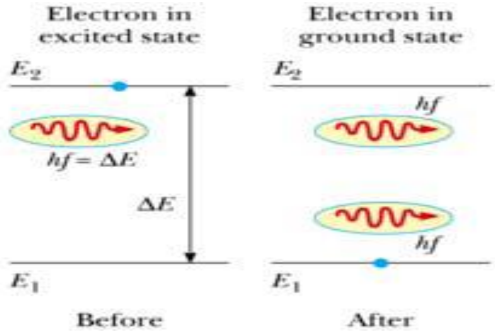


Fig .4 Stimulated Emission

This process of forced emission of photons caused by the incident photons is called ***Stimulated Emission***. It is the key process to the operation of a laser.In other words, stimulated emission means that the incidence of photon energy on an atom in excited state stimulates the emission of similar photon of same energy by transition of atom to lower energy state. It is also called Induced Emission.

Stimulated Emission are multiplied through a chain reaction. The multiplication of photons through stimulated emission leads to coherent, powerful, monochromatic, collimated beam of light. This light is known as laser light.

The photon emitted during stimulated emission has the same energy, phase, frequency and direction as that of the incident photon.

Thus, we have two coherent photons in this case. These photons are now incident on two other atoms in the state E2. This will result in induced emission of two more photons.

If the process continues in a chain, we will ultimately be able to increase the intensity of coherent radiation enormously.

The essential condition for this type of amplification of light intensity is that the number of atoms must be sufficiently increased in the upper energy state E2.

Laser requires that stimulated emission occurs almost exclusively. This can be achieved by population inversion.

Population inversion

Population inversion creates a situation in which the number of atoms in higher energy state is greater than the number of electrons in lower energy state.

Usually at thermal equilibrium, the number of atoms N_2 i.e., population of higher energy state is much lesser than the population of lower energy state N_1 i.e., $N_1 > N_2$.

The Process of making $N_2 > N_1$, i.e., the number of atoms N_2 in higher energy state is more than the number of atoms N_1 in lower energy state, is called population inversion.

Conditions for population inversion

- There must be atleast a pair of energy levels ($E_2 > E_1$) separated by the desired radiation (say) of energy *hf or hv*.
- There must be a source to supply energy to the medium.
- The atoms must be raised continuously to the excited state.

Pumping Methods

The process of supplying energy to the medium in order to transfer it into the state of population inversion is called pumping action.

The pumping action is essential for producing a laser beam. The methods commonly used for pumping action are:

(i) *Optical Pumping (excitation by photons)*

(ii) *Electrical discharge method (excitation by electrons)*

(iii) *Direct conversion*

(iv) *Inelastic collision between atoms.*

Optical Pumping (excitation by photons)

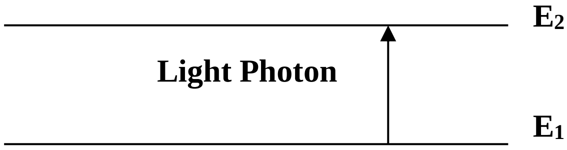


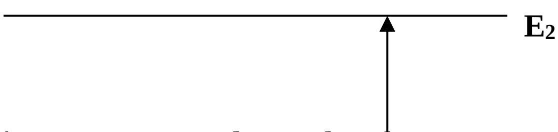
Fig 12.5 Optical Pumping

When atoms are exposed to electro magnetic radiations (of energy *hv*), atoms in the lower state absorbs these radiations and go to the excited state Fig .5.

This method of pumping is called optical pumping. It is used in solid state lasers like ruby laser and Nd - YAG laser. In ruby laser, xenon flash lamp is used.

Electrical discharge method (excitation by electrons)

In this method, electrons are generated in an electrical discharge tube. These electrons are accelerated to high velocities by a strong electric field. These accelerated electrons collide with gas atoms or molecule Fig 12.6.



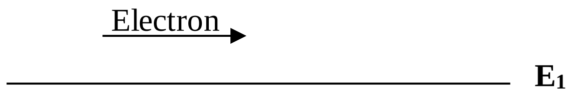


Fig .6 Electrical discharge method

By this process, energy from the electrons is transferred to gas atoms. Some atoms gain energy and go to the excited state, which results in population inversion. This method is called electrical discharge method.

$$A + e \longrightarrow A^* + e_1$$

where A is the gas atom at ground state.

A^* is the same gas atom in excited state

e is the electron with higher kinetic energy.

e_1 is the same electron with lesser energy.

This method is used in gas lasers like argon and CO_2 laser.

Direct Conversion

In this method electrical energy is directly converted into light energy. This method is used in a semiconductor laser (e.g. GaAs) Fig 12.7.

Inelastic atom - atom collision

In this method, a combination of two gases (say A and B) is used. Excited states of A & B coincides or nearly coincides in energy Fig .8.

In the first step during electrical discharge, A atoms excited to their higher state A* (metastable state) due to collision with electrons.

$$A + e \longrightarrow A^* + e_1$$

Now A atoms at higher state collide with B atoms in the lower state. Due to this, B atoms gain energy and are excited to a higher state. Hence, A atoms lose energy and return to a lower state.

$$A^* + B \longrightarrow A + B^*$$

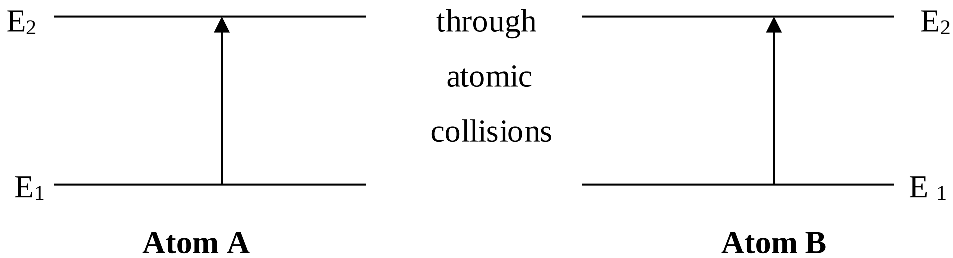


Fig .8 Inelastic atom - atom collision

The result is population inversion in the energy states of B. *Inelastic collision* is used in He - Ne laser.

Basic components of a laser

(i) Active material or medium

It is the basic material in which atomic or molecular transitions take place, leading to the laser action. It may be a solid, liquid, gas, dye or semiconductor. A Medium in which population inversion can be achieved is called an active medium.

(ii) Pumping System

It is a device with which population inversion can be achieved in an active material

(iii) Optical Resonator

An Optical Resonator consists of a pair of reflecting surfaces of which one is fully reflecting and the other partially reflecting.The active material is placed between the two surfaces. The photons generated due to transitions between the energy states of active material are bounced back and forth between the two reflecting surfaces, the inducing more and more stimulated transition leading to laser action Fig .9.

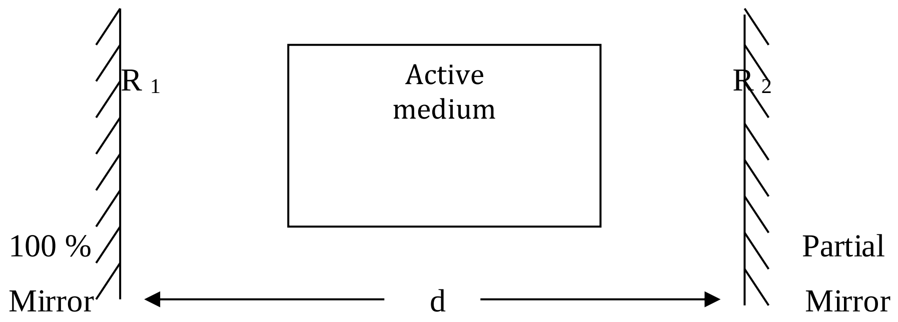


Fig .9 Optical Resonator