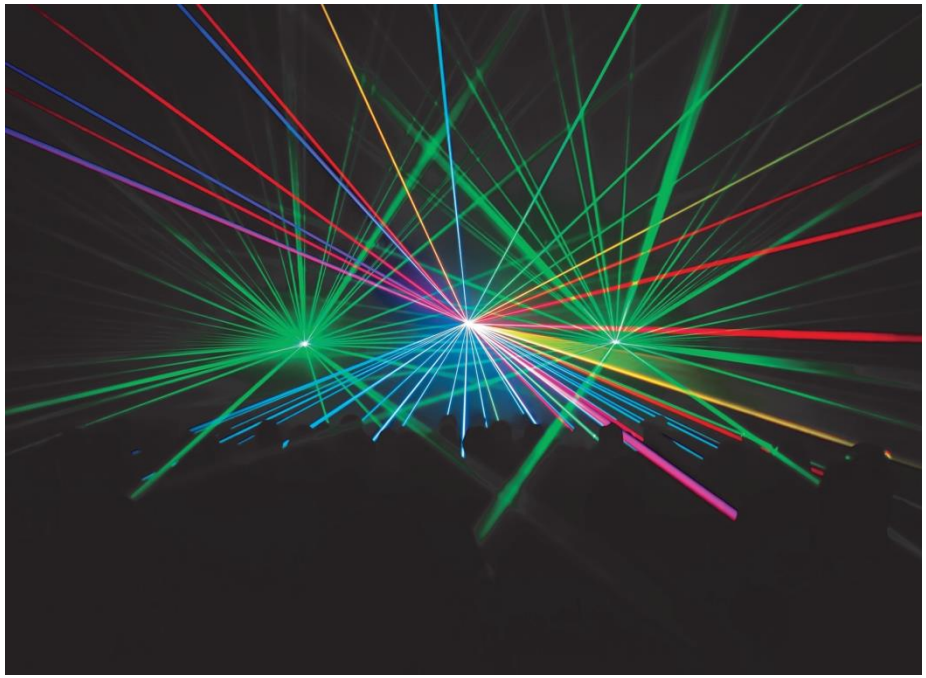
# UNIT IV

# Laser, Holography and Optical Fibre

## Lecture-2: Laser

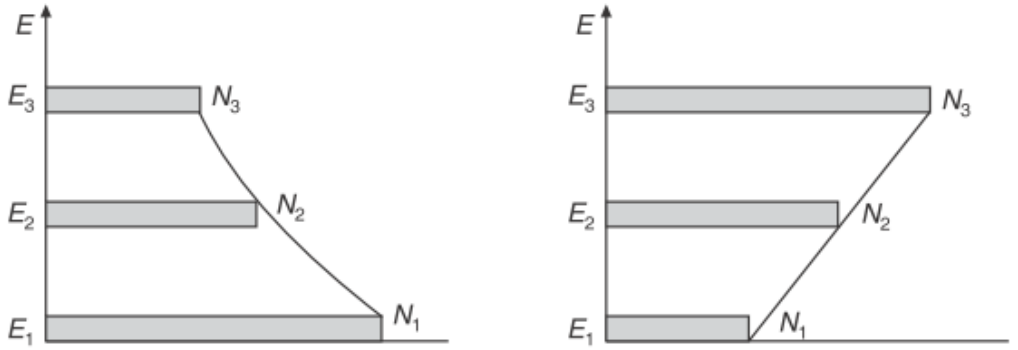


# Content of Lecture

- POPULATION INVERSION
- THE ESSENTIAL COMPONENTS OF LASER
- ACTIVE MEDIUM, POPULATION INVERSION AND OPTICAL RESONATOR.
- THREE LEVEL LASER
- FOUR LEVEL LASER
- RUBY LASER

# POPULATION INVERSION:

- At the state of thermal equilibrium, the number (population) of atoms in lower energy level ($E_1$) is more than the population of atoms at the higher energy level ($E_2$).
- But for emission processes and for laser action, it is essential that the number of atoms in higher energy level (E2) must be greater than the number of atoms in lower energy level (E1).
- The process by which this condition is achieved is known as the process of ***population inversion.*** At the condition of population inversion, stimulated emission can produce a cascade of light. Population inversion process is shown in fig.




**(a)** Equilibrium state

**(b)** Population inversion in such a way that $N_3 > N_2 > N_1$

# PUMPING MECHANISM

- The process by which atoms are raised from the lower energy level to the upper energy level is called ***pumping.*** In this process, it is necessary that atoms must be continuously promoted from the lower level to the excited level. Different methods of pumping are given below:

**(1) Optical Pumping:**

- In optical pumping, a light source (suitable photons) is used to supply luminous energy. Most often this energy is given in the form of short flashes of light.

**(2 )Electric Discharge:**

- In this method of pumping direct electron excitation occurs through an electric discharge.
- This method is preferred in gaseous ion lasers. An electric current flowing through the gas excites the atoms to the excited level from where they drop to the metastable upper laser level leading to population inversion.

# PUMPING MECHANISM

- **(3) Inelastic Collisions Between Atoms:**

❖ In an important class of lasers, pumping by electrical discharge provides the initial excitation which raises one type of atoms to their excited states.

❖ These atoms collide inelastically with another atoms and provide them enough energy to excite them to the higher energy level and thus help in population inversion. This type of pumping occurs in helium–neon laser

- **(4) Direct Conversion:**

❖ In light-emitting diodes (LEDs) and semiconductors, the electrons recombine with holes producing laser light. Thus, the direct conversion of electrical energy into radiation takes place.

- **(5) Chemical Reaction:**

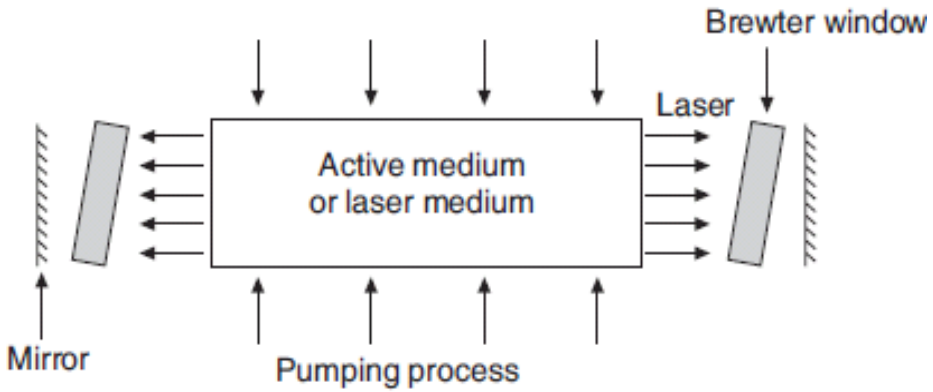
❖ In chemical lasers, radiations come out of a chemical reaction, without any need of other energy source.

# COMPONENTS OF LASER

❖In laser, the amplification of light is achieved by stimulated emission of radiations.

❖The stimulated emission produces completely coherent and intense radiations.

❖There are three essential components of laser action, which are shown in Fig



# Active Medium

- It is the medium in which the laser action is made to take place.
- It may be in solid, liquid, or gaseous state where atoms/ions are lying in excited state (metastable state) to facilitate stimulated emission.
- The most important characteristic of laser medium is that it should be capable to obtain the population inversion in it.

# Population Inversion:

- Under the normal conditions at thermal equilibrium, the lower state of energy is more populated than the higher states.
- In order to facilitate the stimulated emission (laser action), it is must that the number of excited atoms should be greater than the number of atoms in the ground state.
- This condition can be achieved by pumping mechanism in which energy is supplied to the atoms by external impetus through different processes such as optical pumping, electric discharge, direct conversion, and chemical reactions.

# The Optical Resonator

- It consists of a pair of plane or spherical mirrors in which one is perfect and the other is a partial reflector having common principal axis.
- The reflection coefficient of one of the mirrors is very near to 1 and that of the other is kept somewhat less than one.
- Due to the stimulated emission, there are waves between the two mirrors propagating along both the directions which undergo interference to form a standing wave.
- For a stable standing wave, the wavelength must satisfy the following condition:

$$l = \frac{n\lambda}{2}$$

- Where, n= 1,2,3 ……..
- l = length of the cavity

# THREE-LEVEL LASER

- Laser action is highly dependent on the pumping scheme and the number of excited atoms ready for stimulated emission.

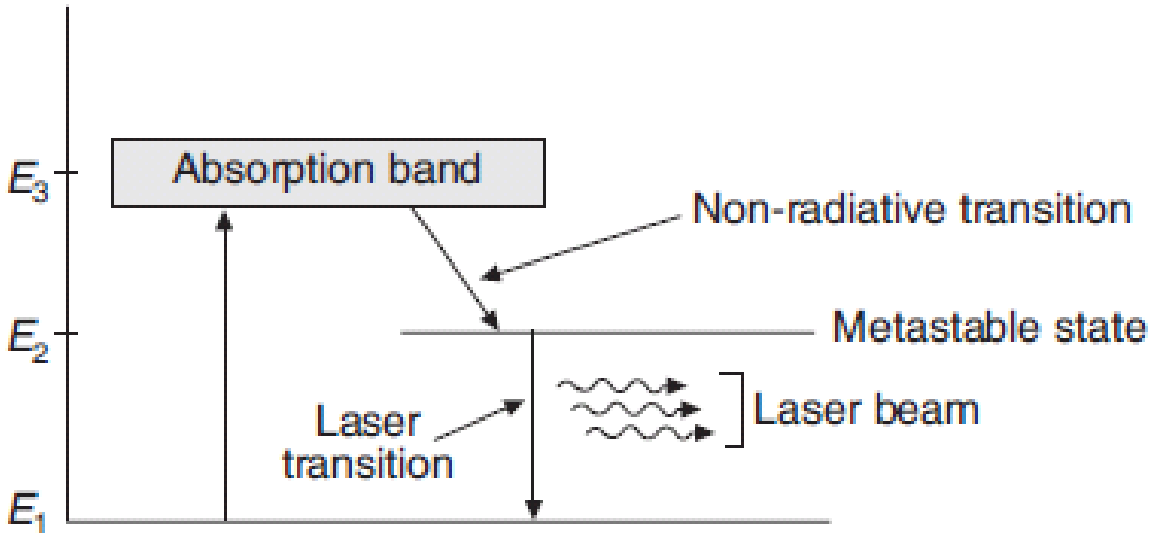
- The simplest method of pumping is two-level pumping scheme, but a two-level pumping scheme is not suitable for population inversion because in this scheme, the lifetime of spontaneous emission is very fast.

- In order to achieve suitable population inversion for laser action, three-level pumping scheme is used. In this scheme, the excited atoms ready for stimulated emission have more lifetime than the atoms excited under two-level pumping scheme.

- In this scheme, the lower laser level is either the ground state or the level whose separation from the ground state is small compared to $kT$.

# THREE LEVEL LASER

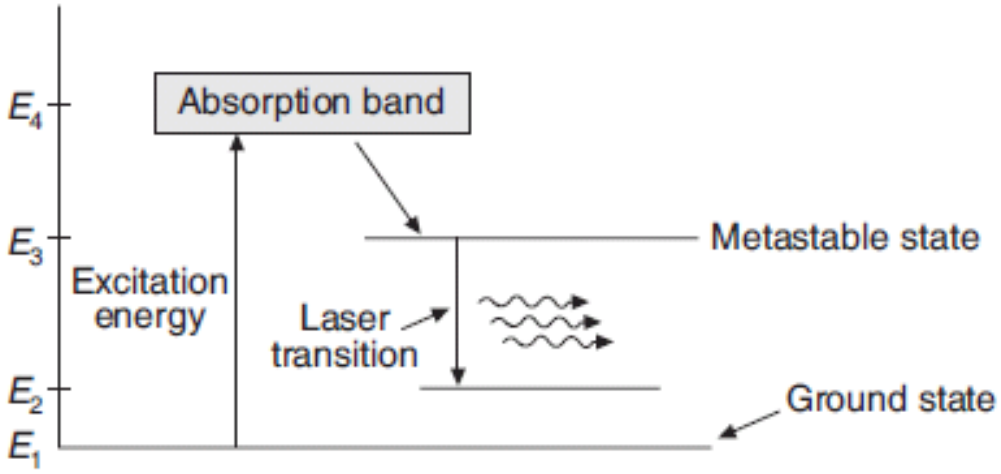
❖ A model of a three-level pumping scheme is shown in Fig.




❖The major disadvantage of three-level scheme is that it requires very high pump powers.

# FOUR-LEVEL LASER:

- A simple sketch of four-level pumping scheme is shown in Fig.
- In this scheme, the terminal energy level E2 is above the ground level by the energy more than kT.
- The pump energy elevates atoms to a short lived uppermost energy level E4 from where the atoms drop spontaneously to the metastable energy level E3.



# FOUR-LEVEL LASER

- An impetus of energy $h\nu = E_3 - E_2$ can initiate a chain of stimulated emissions, which give the laser transitions from $E_3$ to $E_2$.
- The atoms reaching at the energy level $E_2$ lose the rest of their excess energy by radiative or non-radiative transitions and finally reach the ground state $E_1$. Thus, the atoms are once again available for excitation.
- In comparison to the three-level scheme, the lower laser transition level in the four-level scheme is not the ground state, but it is above the ground level, which is virtually vacant.

# RUBY LASER

❖Historically, ruby laser is the first laser developed in 1960. It is a solid state, three-level laser.

## Principle

❖Ruby laser rod consists of a synthetic ruby crystal, $Al_2O_3$, doped with chromium ions with the concentration of about 0.05% by weight.

❖With this concentration of doping, there are about $1.6 \times 10^{25}$ $Cr^{3+}$ ions per cubic meter.

❖These ions have a set of three energy levels suitable for the laser action.

# Structure

❖The schematic diagram of a ruby laser is shown in Fig.

❖ A cylindrical ruby rod of length 4 cm and width 0.5 cm is used.

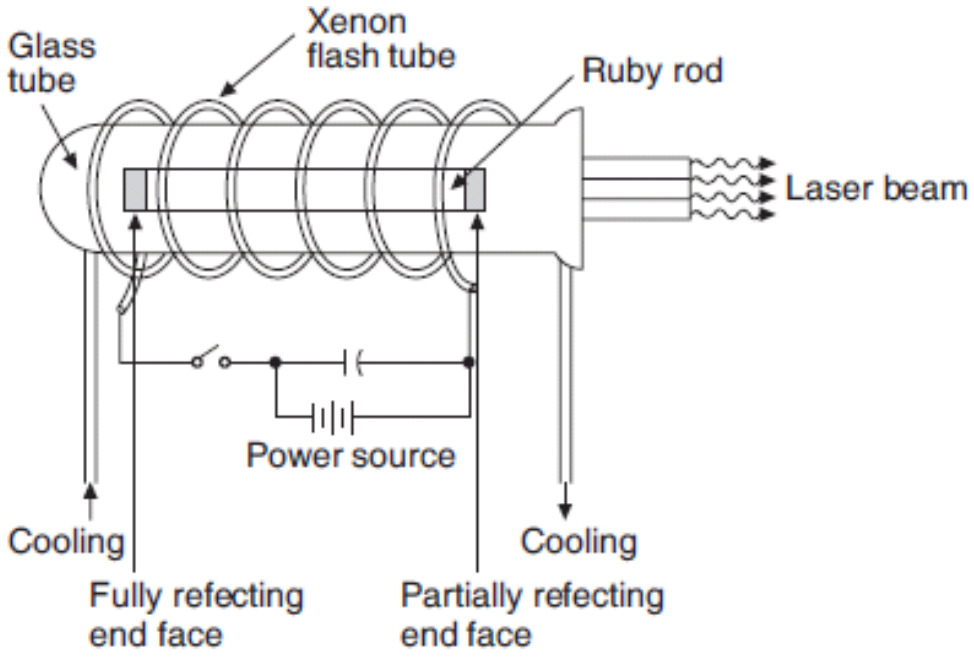
❖The end faces of ruby laser are polished in such a way that one face is partially reflecting and the other is fully reflecting.

❖ They are adjusted in such a way that both are exactly parallel to each other and perpendicular to the axis of the rod.

❖The rod is surrounded by a helical photographic flash lamp filled with xenon.

# Structure

- This xenon flash tube produces white light whenever activated by the power supply.
- For the cooling of cavity, there is a provision of circulating coolant around the ruby rod.

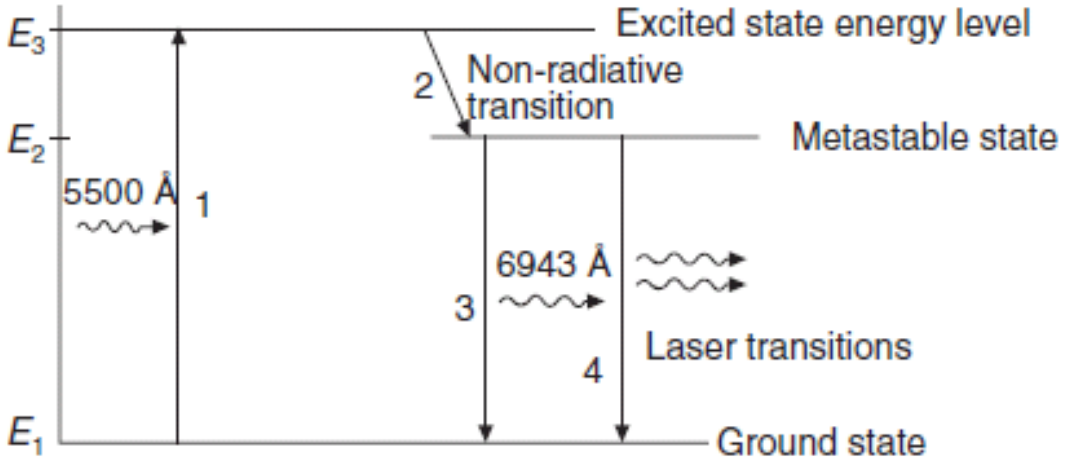


# Working

❖At the thermal equilibrium condition, most of the chromium ions are in the ground state E1.

❖When flash light falls upon the ruby rod, radiations of 5500 Å are absorbed by chromium ions and they are pumped to the excited state E3.

❖Energy level diagram and different transitions of ruby laser are shown in Fig.



# Working

❖The population inversion is achieved between E2 and E1.

❖Due to the transition of excited atom from E2 to E1 (transition 3), a photon of wavelength 6943 Å is emitted.

❖This photon travels through the ruby rod back and forth to get the suitable condition to stimulate another excited atom to emit a photon of same wavelength.

❖This process remains continued until the emitted photons becomes sufficiently intense.

❖ Now, a part of this intense photons beam emerges through the partially reflecting end of the system to give the laser light.

# Assignment Based on this Lecture

- Discuss the process of Population Inversion.
- What are the essential components of Laser.
- Explain the role of Active Medium, Population Inversion, Optical Resonator.
- Discuss the basic principal and working of three level laser.
- Discuss the basic principal and working of four level laser.
- Describe the Principle, Construction and Working of Ruby Laser.