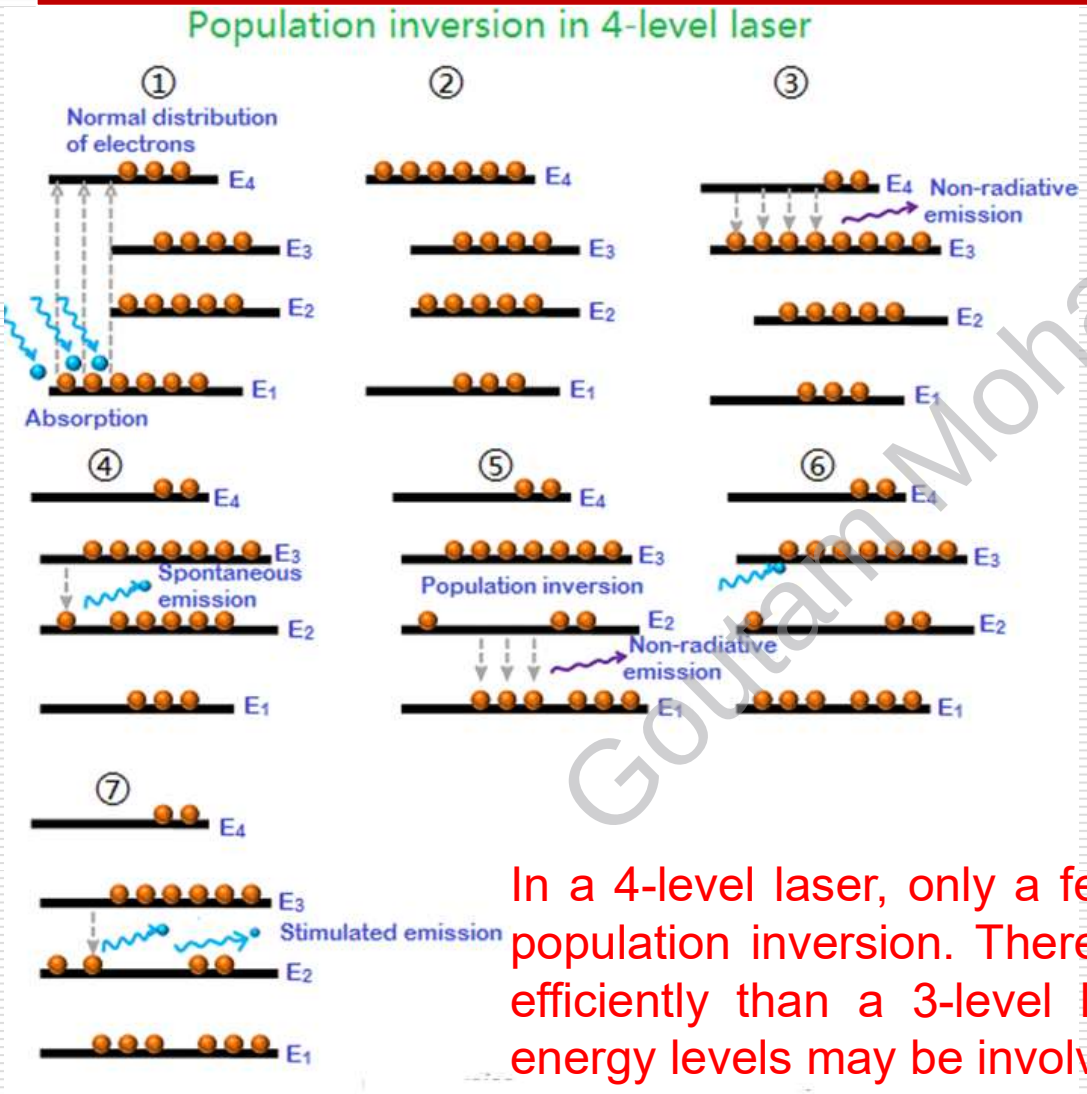
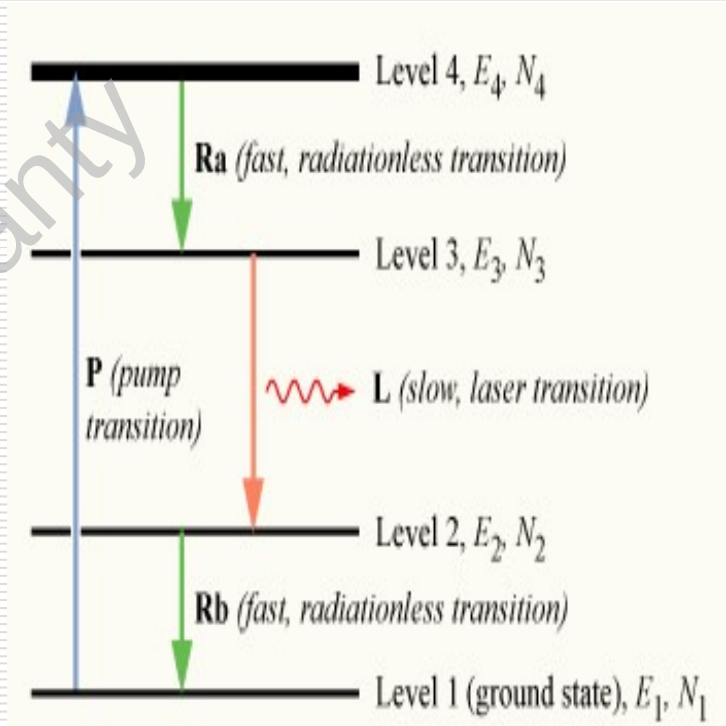
4-level laser





In a 4-level laser, only a few electrons are excited to achieve population inversion. Therefore, a 4-level laser produces light efficiently than a 3-level laser. In practical, more than four energy levels may be involved in the laser process.

Components of Laser

A laser or laser system consists of three important components:

- Pump source,
- Active medium
- Optical Resonator

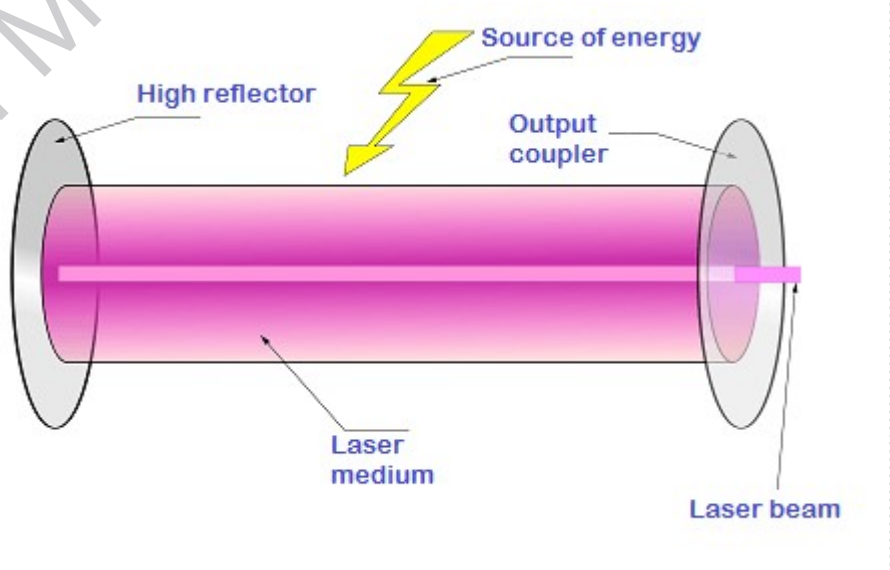
Components of Laser

Pump source:

- The pump source or energy source is the part of a laser system that provides energy to the laser medium. To get laser emission, first we need to produce population inversion.

Examples of energy source:

- ✓ electric discharges,
- ✓ light from another laser,
- ✓ chemical reactions,
- ✓ flash lamps.



Components of Laser

Active medium:

- The active medium is a medium in which laser action is made to take place. The laser medium will determine the characteristics of the laser light emitted.
- The laser medium can be solid, liquid, or gaseous where atoms/ions are lying in excited state to facilitate stimulated emission. It should capable of population inversion
- This is also called gain medium or laser medium

Example:

- ✓ Ruby laser is an example for solid-state laser. In this, a ruby crystal is used as an active medium. In this laser, xenon discharge tube which provides a flash light acts as pump source.

- ✓ Helium – Neon laser is an example for gaseous laser. In this, neon is used as an active medium. In this laser, radio frequency (RF) generator acts as pump source.

Components of Laser

Optical Resonator:

- The laser medium is surrounded by two parallel mirrors which provides feedback of the light. One mirror is fully reflective (100 % reflective) whereas another one is partially reflective (<100 % reflective). These two mirrors as a whole is called optical resonator. Optical resonator is also known as optical cavity or resonating cavity.
- The completely reflective mirror is called high reflector whereas the partially reflective mirror is called output coupler. The output coupler will allows amplified light to leave the optical cavity to produce the laser's output beam.
- This condition is must:

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

Where,
l = length of cavity,
λ = wavelength of laser
n= 1,2,3..

Methods of Achieving Population Inversion

- In order to achieve population inversion, we need to supply energy to the laser medium. The process of supplying energy to the laser medium is called pumping. The source that supplies energy to the laser medium is called pump source. The type of pump source used is depends on the laser medium.

- Optical pumping:
- Electric discharge or excitation by electrons
- Inelastic atom-atom collisions
- Direct conversion
- Chemical reactions

Methods of Achieving Population Inversion

- Optical pumping:
  - ✓ In this method, light is used to supply energy to the laser medium. For example xenon flash lamp
  - ✓ This method of pumping is used in solid state lasers such as ruby laser.

- Electric discharge or excitation by electrons:
  - ✓ In this method of pumping, electric discharge acts as the pump source or energy source.
  - ✓ A high voltage electric discharge (flow of electrons, electric charge, or electric current) is passed through the laser medium or gas.
  - ✓ The intense electric field accelerates the electrons to high speeds and they collide with neutral atoms in the gas. As a result, the electrons in the lower energy state gains sufficient energy from external electrons and jumps into the higher energy state.
  - ✓ This method of pumping is used in gas lasers such as argon lasers.

Methods of Achieving Population Inversion

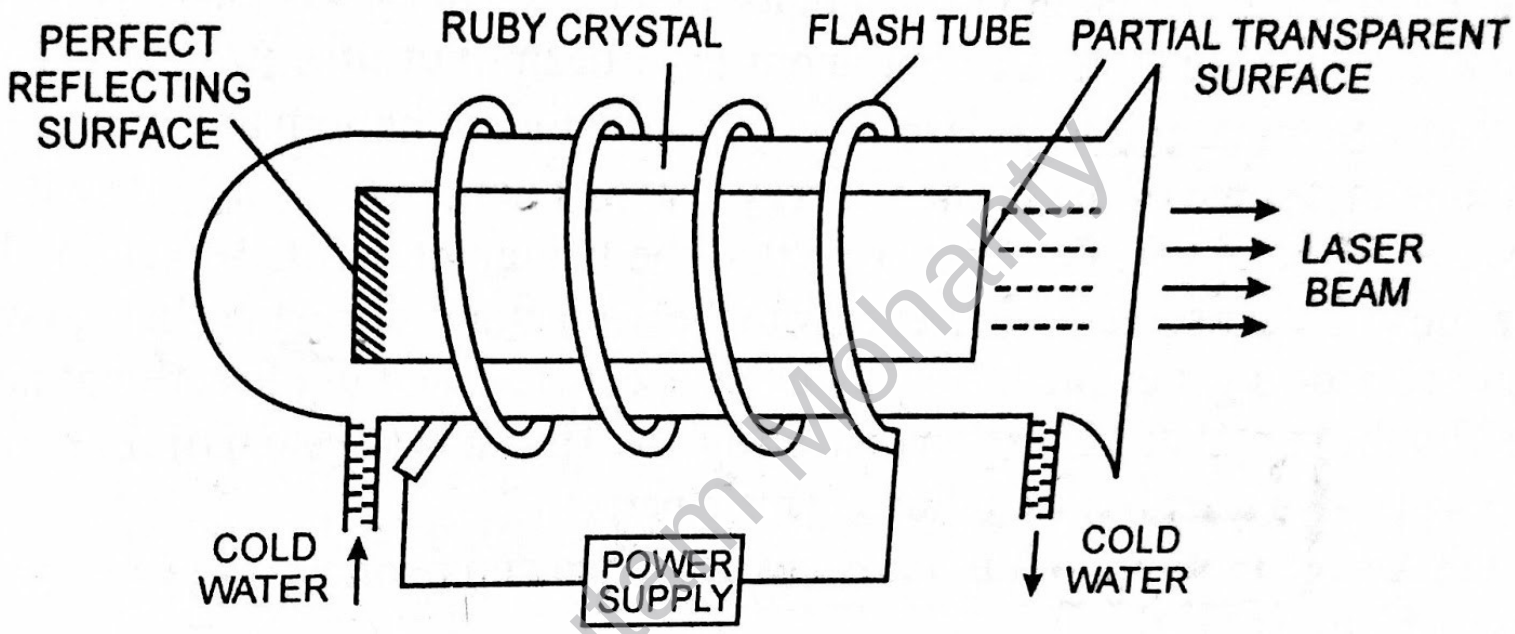
- Inelastic atom-atom collisions
  - ✓ In this method, pumping by electrical discharge provides the initial excitation which raises ONE type of atoms to their excited states. These atoms collide inelastically with another type of atoms and provide them sufficient energy to excite them to higher state and thus population inversion achieved
  - ✓ This method of pumping is used in gas lasers such as He-Ne laser.
- Direct Conversion:
  - ✓ In this method, the electrons combine with holes producing laser light. This it is direct conversion of electrical to light.
  - ✓ This method of pumping is used in gas lasers such as Semiconductor lasers.
- Chemical Reaction:
  - ✓ In this method, Radiation come out of a chemical reaction, without any need of other energy source. For example when hydrogen combine with fluorine, heat energy is produced
  - ✓ This method of pumping is used in gas lasers such as CO_2 lasers.

Ruby Laser

- In 1960, T. H. Maiman developed 1st Ruby Laser
- It is a 3-level solid state laser in which population inversion is achieved with the help of Xenon flash tube.
- It emits deep red light of wavelength 694.3 nm.

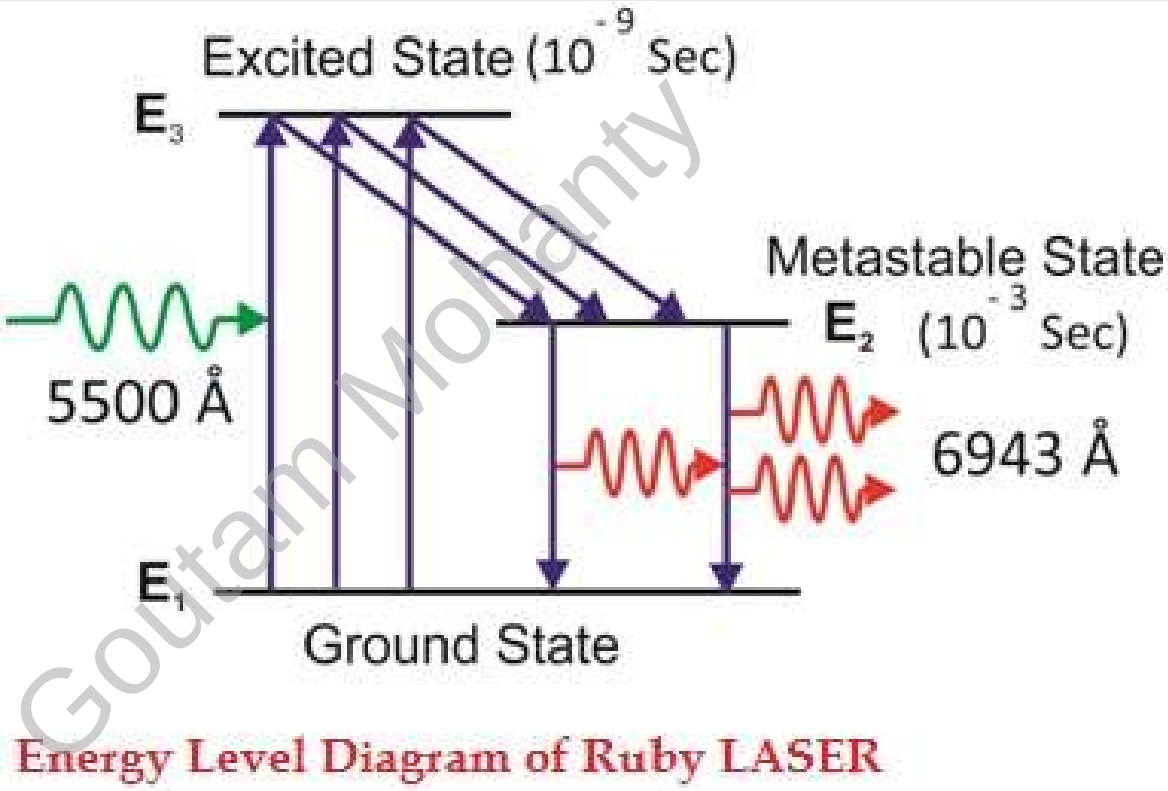
Construction:

- A ruby laser consists of three important elements: laser medium, the pump source, and the optical resonator.
- Laser medium: In a ruby laser, a single crystal of ruby (Al_2O_3 : Cr^{3+}) in the form of cylinder acts as a laser medium or active medium. The laser medium (ruby) in the ruby laser is made of the host of sapphire (Al_2O_3) which is doped with small amounts of chromium ions (Cr^{3+}). The length of the rod is about 2-30cm and diameter is 0.5-2cm.
- Energy Source: The Xenon flashtube is used as the energy source or pump source. The flashtube supplies energy to the laser medium (ruby). When lower energy state electrons in the laser medium gain sufficient energy from the flashtube, they jump into the higher energy state or excited state.



Optical Resonator: The ends of the cylindrical ruby rod are flat and parallel. The cylindrical ruby rod is placed between two mirrors. The optical coating is applied to both the mirrors. At one end of the rod, the mirror is fully silvered whereas, at another end, the mirror is partially silvered. The fully silvered mirror will completely reflect the light whereas the partially silvered mirror will reflect most part of the light but allows a small portion of light through it to produce output laser light.

- video



Energy Level Diagram of Ruby LASER

Drawback:

- ✓ It produces pulsed beam
- ✓ Efficiency is very low
- ✓ It requires high pumping power

He-Ne Laser

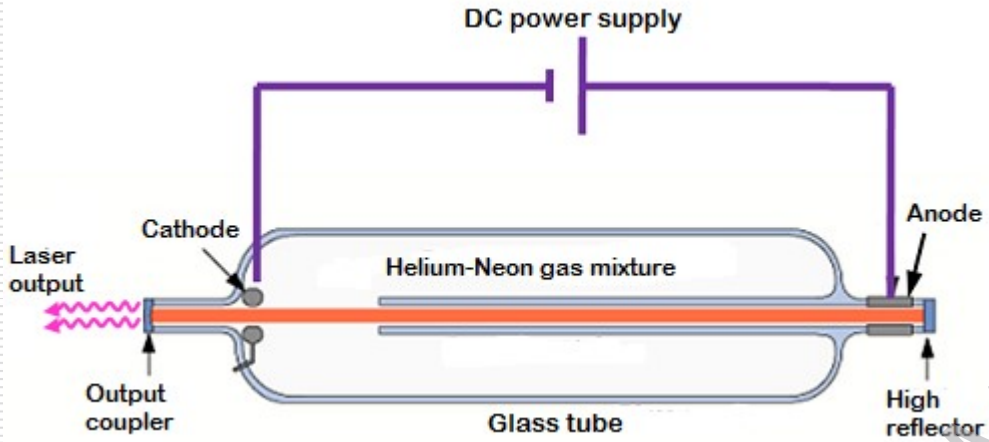
- In 1961, Ali Javan *et al*. developed He-Ne laser at Bell Telephone Laboratories, US.
- This laser is a 4-level as laser which produces continuous wave(CW).

Construction:

The helium-neon laser consists of three essential components

- ✓ Pump source (high voltage power supply)
- ✓ Gain medium (laser glass tube or discharge glass tube)
- ✓ Resonating cavity

He-Ne Laser

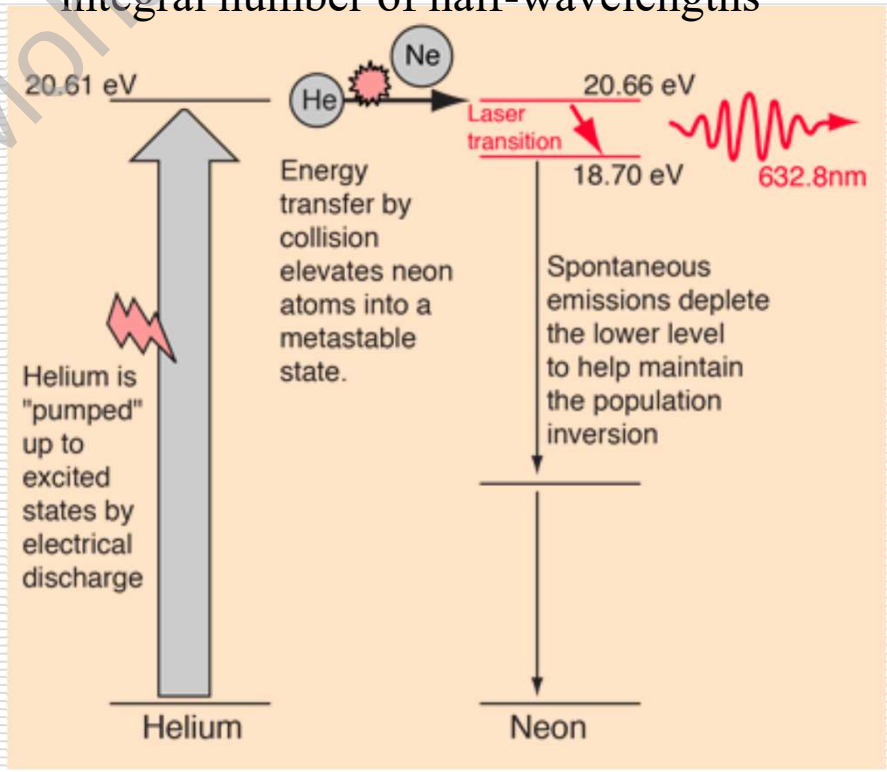


Construction:

- Mixture of gas He-Ne is 10:1
- Discharge tube 50cm length, 1 cm diameter
- Inside pressure is low at 1torr
- spacing of the mirrors is equal to an integral number of half-wavelengths

Working Principle:

- When the power is switched on
- He-atoms excited to 20.61eV
- He-atom give energy (0.05eV) to unexcited Ne-atom
- Ne-atom transit to 20.66eV
- Population inversion achieved
- Ne-atom transit from 20.66eV to 18.70eV
- Stimulation process occurs
- Laser having 632.8nm emits



He-Ne Laser

Advantages:

- Helium-neon laser emits laser light in the visible portion of the spectrum.
- High stability
- Low cost
- Operates without damage at higher temperatures

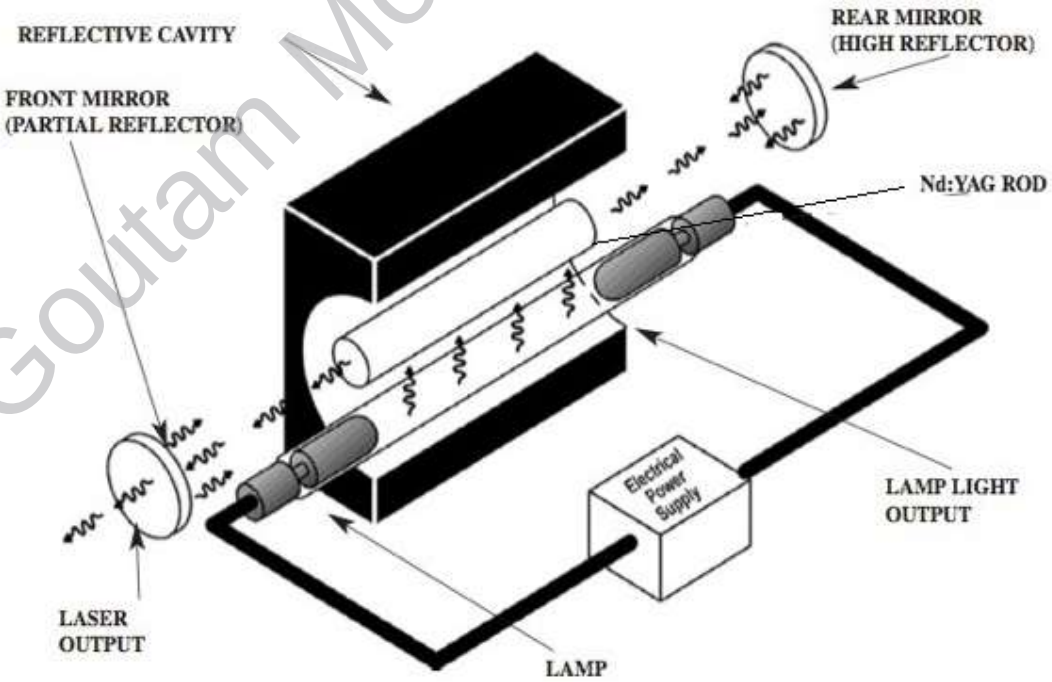
Applications:

- Helium-neon lasers are used in industries.
- Helium-neon lasers are used in scientific instruments.
- Helium-neon lasers are used in the college laboratories.

ND:YAG Laser

Introduction:

- It was developed by J.E.Geusic, H.M. Marcos and L.G. Van Vitert in 1964
- Nd stands for neodymium and YAG for Yttrium Aluminium Garnet ($Y_3Al_5O_{12}$).
- Nd: YAG is a solid state laser.
- It is 4-level laser.



ND:YAG Laser

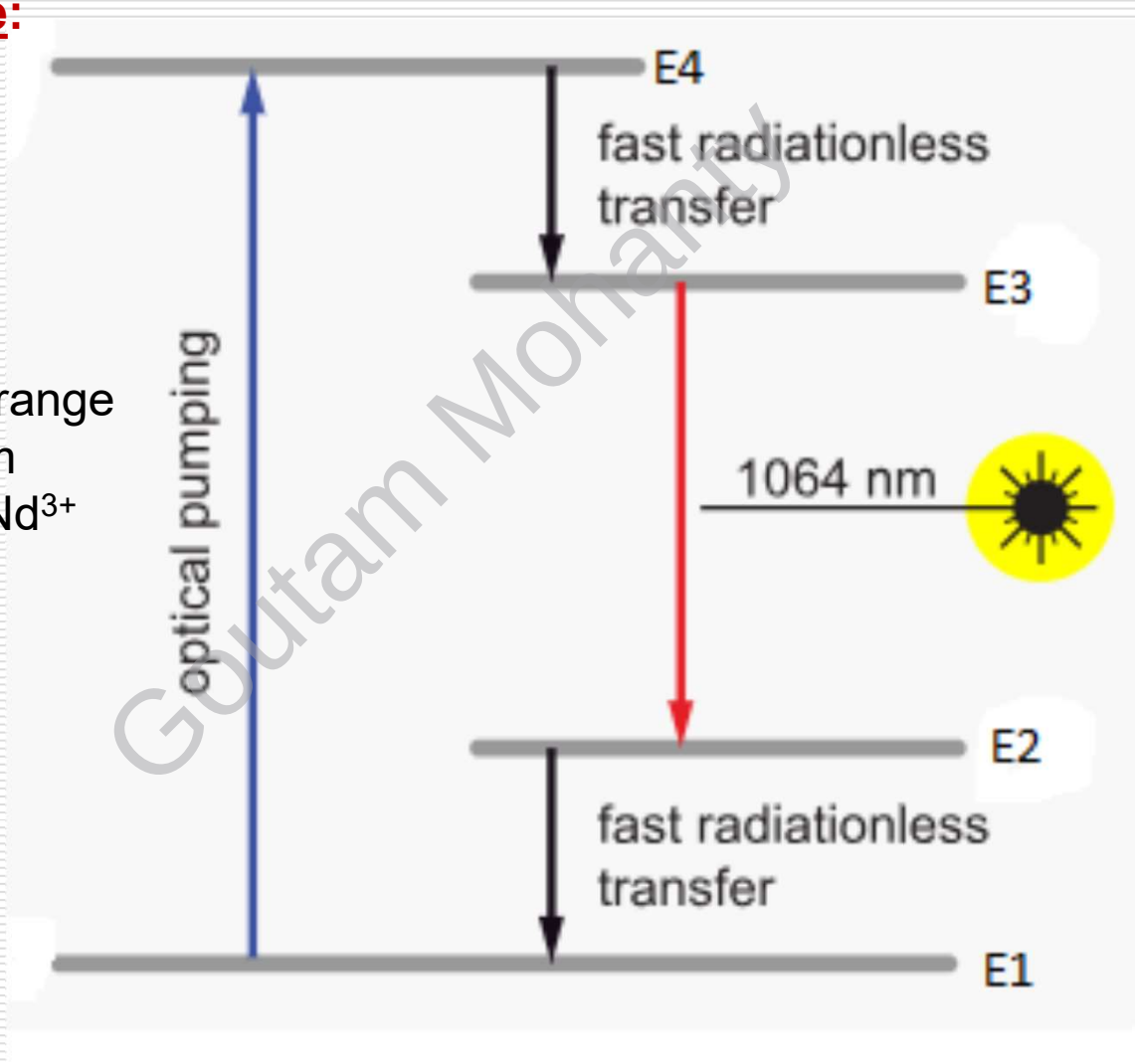
Construction:

- The rod $Y_3Al_5O_{12}$ is doped with 1% neodymium ions and Y^{3+} ions replaced by Nd^{3+} ions.
- The maximum length of the rod is 10 cm and diameter is 6-9 cm.
- Active medium: Nd^{3+} ions acts as an active medium or active centers. YAG is just host.
- Pumping source is xenon flash lamp or krypton flash lamp which excites Nd^{3+} ions to upper level
- Optical Resonator: The ends of the YAG rod are polished and silvered so as act as optical resonator.

ND:YAG Laser

Working Principle:

wavelength range 500 – 800nm excites the Nd^{3+} ions



ND:YAG Laser

Advantages

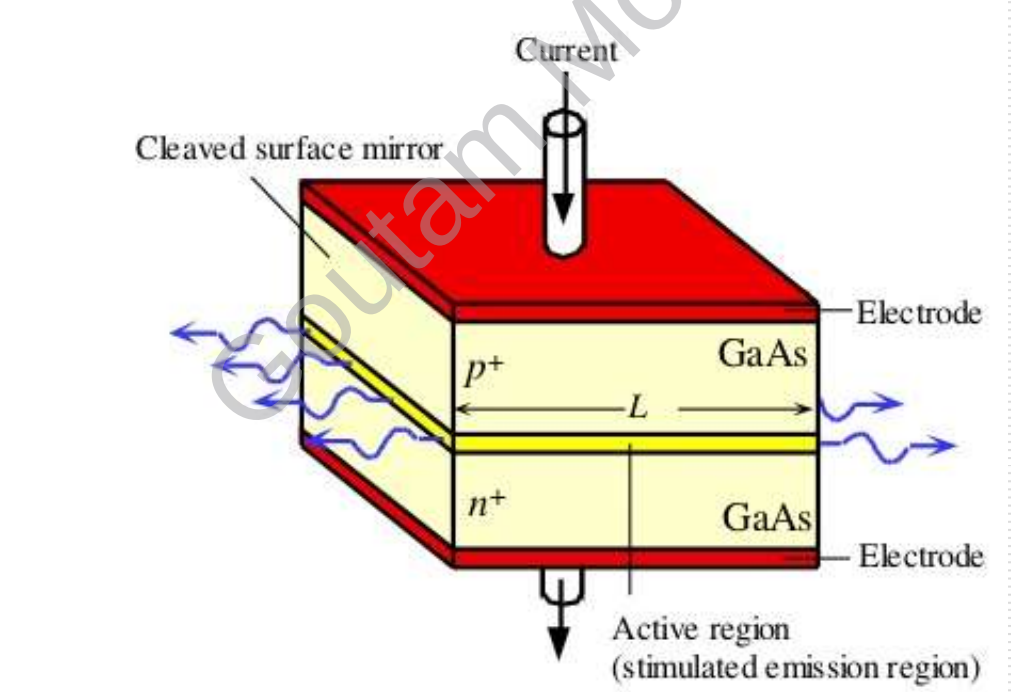
- CW is emitted
- Low power consumption
- Nd:YAG laser offers high gain.
- Nd:YAG laser has good thermal properties.
- Nd:YAG laser has good mechanical properties.
- The efficiency of Nd:YAG laser is very high(2%) as compared to the ruby laser(0.1%).

Applications

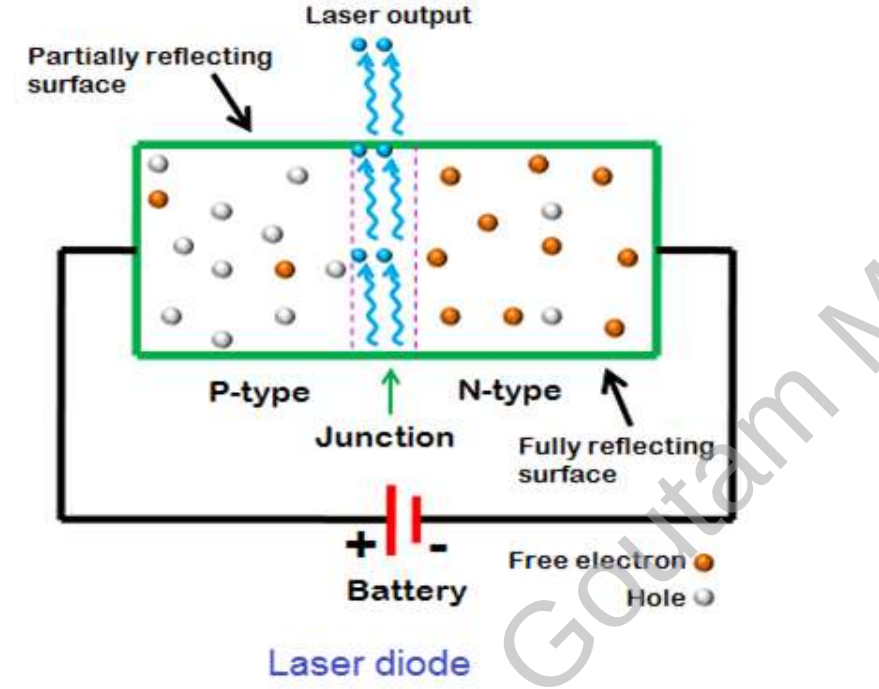
- Medical: remove skin cancers, to correct posterior capsular opacification (a condition that may occur after a cataract surgery).
- Nd:YAG lasers are used to remove skin cancers.
- Manufacturing: cutting and welding
- Nd:YAG lasers are used for etching or marking a variety of plastics and metals.
- Military

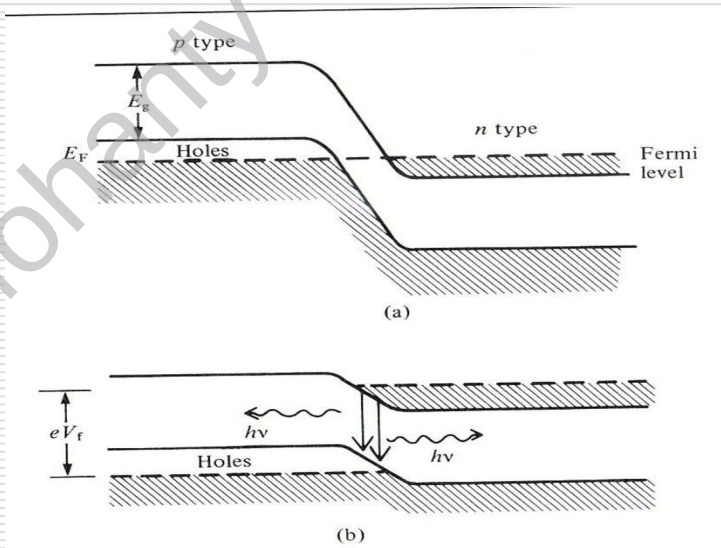
Semiconductor Laser

- In 1962, the 1st semiconductor laser at low temperature was developed by R.N. Hall and coworkers in USA.
- GaAs is used to make semiconductor laser.
- This laser is produces light in the infrared region(IR).
- Later semiconductor laser was developed in the visible region at room temperature.



Semiconductor Laser





Semiconductor Laser

Advantages:

- Simple construction
- Lightweight and portable
- Low cost
- Small size (0.1mm long)
- Highly reliable compared to other types of lasers.
- Longer operating life
- High efficiency (40%)
- Mirrors are not required in the semiconductor lasers.
- Low power consumption

Disadvantages:

- Not suitable for the applications where high powers are required.
- Semiconductor lasers are highly dependent on temperature

Applications:

- Laser diodes are used in laser pointers.
- Laser diodes are used in fiber optic communications.
- Laser diodes are used in barcode readers.
- Laser diodes are used in laser printing.
- Laser diodes are used in laser scanning.
- Laser diodes are used in range finders.
- Laser diodes are used in laser absorption spectrometry.

Applications of Laser

The most significant applications of lasers include:

- Lasers in medicine: destroy kidney stones, fiber-optic endoscope to detect ulcers in the intestines, eye lens curvature corrections, remove tumors successfully.

- Lasers in communications: optical fiber communications to send information over large distances with low loss, underwater communication networks, space communication, radars and satellites.

- Lasers in industries: cut glass and quartz, trimming the components of Integrated Circuits (ICs), photolithography.

- Lasers in science and technology: retrieve stored information from a CD, computer printers, detecting earthquakes and underwater nuclear blasts

- Lasers in military: determine the distance to an object, LiDAR's to accurately measure the distance to an object.