Introduction to Lasers

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Introduction

- The word laser is an acronym that stands for "light amplification by the stimulated emission of radiation".
- Lasers are essentially highly directional, highly intense, highly monochromatic and highly coherent optical sources.
- Stimulated emission was postulated by einstein as early as in 1917.

- In 1960 , a solid state ruby laser is developed by maiman on this principle.
- In 1961, a gas state He-Ne laser is developed by Ali javan and others in Bell telephone laboratory.

LASER FUNDAMENTALS

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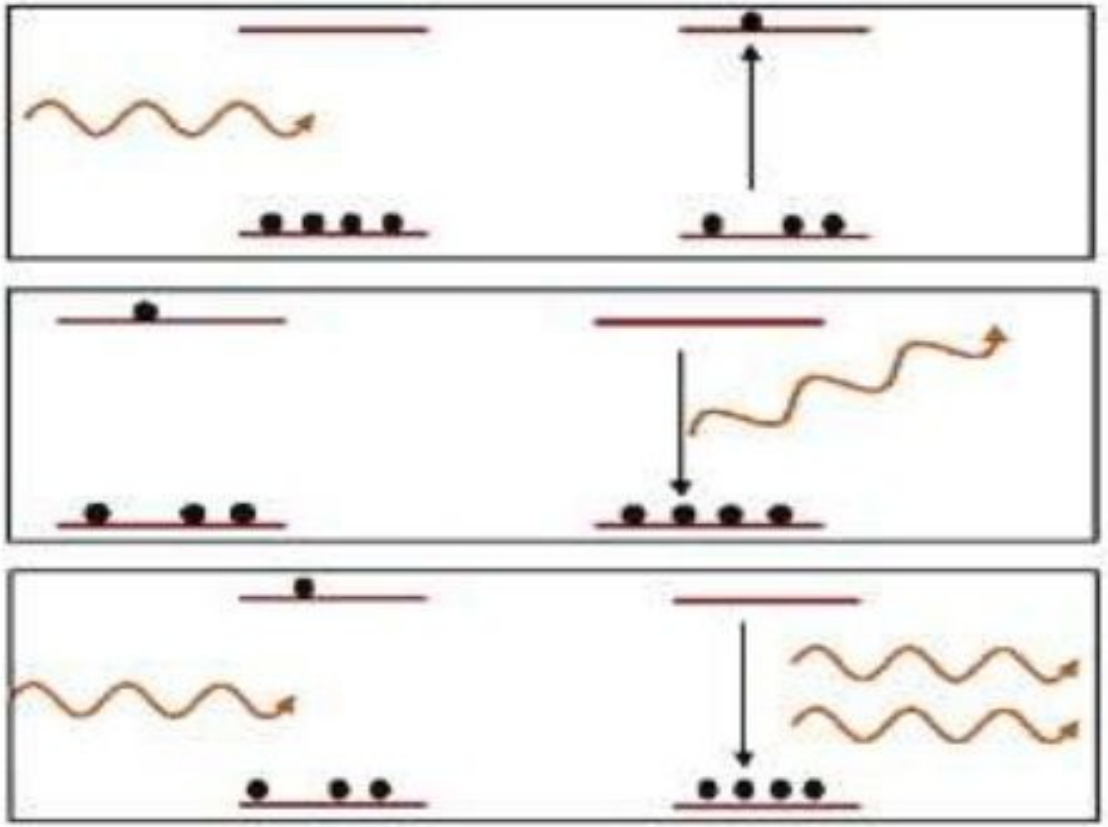
- The light emitted from a laser is **monochromatic**, that is, it is of one color/wavelength. In contrast, ordinary white light is a combination of many colors (or wavelengths) of light.
- Lasers emit light that is highly **directional**, that is, laser light is emitted as a relatively narrow beam in a specific direction. Ordinary light, such as from a light bulb, is emitted in many directions away from the source.
- The light from a laser is said to be **coherent**, which means that the wavelengths of the laser light are in phase in space and time. Ordinary light can be a mixture of many wavelengths.

These three properties of laser light are what can make it more hazardous than ordinary light. Laser light can deposit a lot of energy within a small area.

5

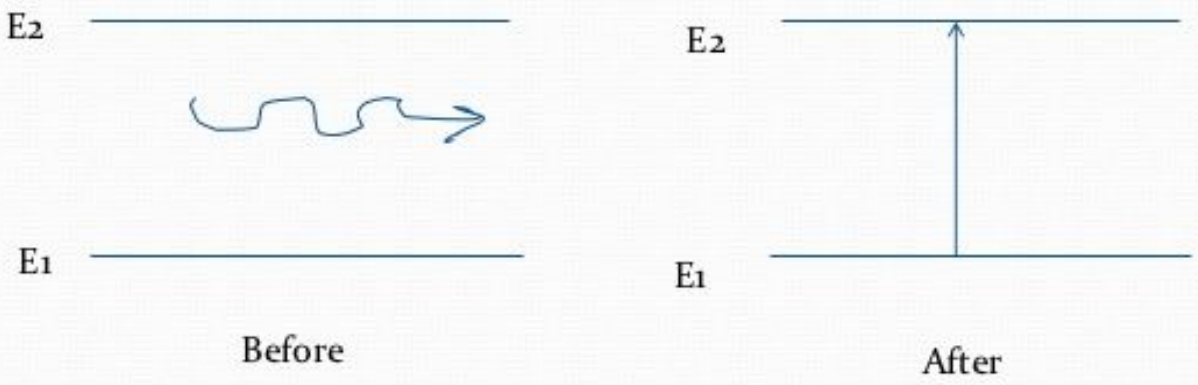
Principle of laser



Induced absorption (stimulated absorption)

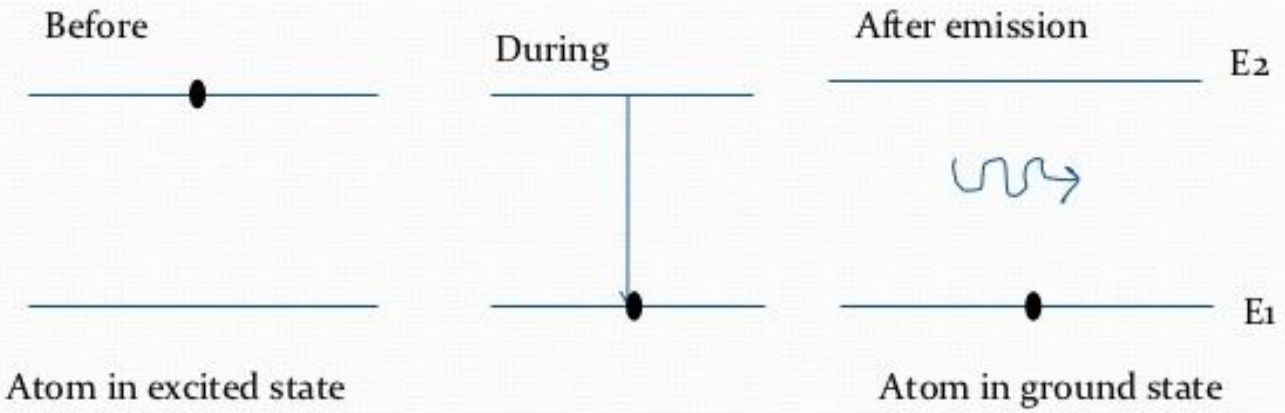
The process in which an atom sized system in lower energy state is raised in to higher energy state by electro magnetic radiation which is quanta of energy is equal to the difference of energy of the two states is called stimulated absorption.

i.e., $h\nu = E_2 - E_1$



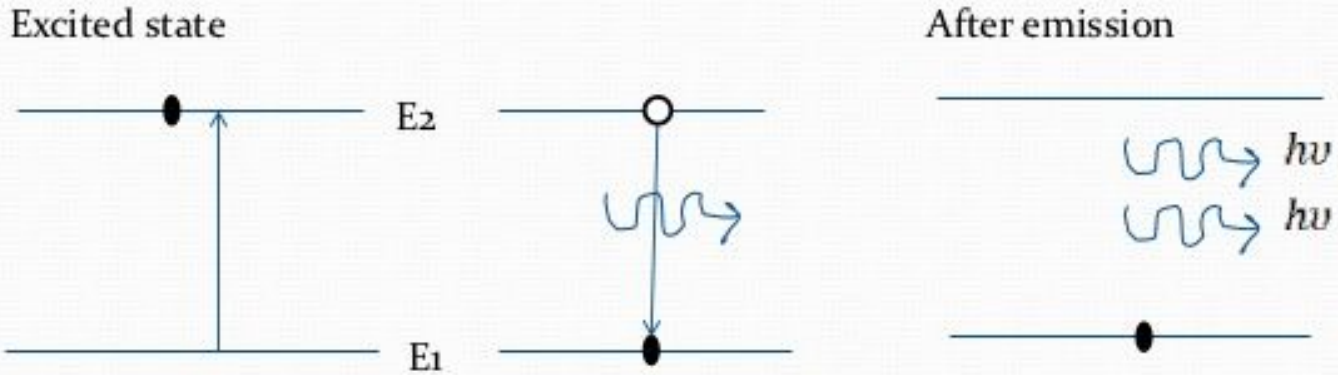
Spontaneous emission

In the atom initially at upper state E2, it can brought to E1 by emitting photon of energy hν.This is known as spontaneous emission.



Stimulated emission

According to Einstein's, under certain condition it is possible to force an excited atom emit a photon by another photon and the incident light wave must be in same phase .hence we get an enhance beam of coherent light



Population inversion

population inversion occurs when a system (such as a group of atoms or molecules) exists in a state with more members in an excited state than in lower energy states. The concept is of fundamental importance in laser science because the production of a population inversion is a necessary step in the workings of a standard laser.

COMMON COMPONENTS OF ALL LASERS

1. **Active Medium**

   The active medium may be solid crystals such as ruby or Nd:YAG, liquid dyes, gases like CO2 or Helium/Neon, or semiconductors such as GaAs. Active mediums contain atoms whose electrons may be excited to a metastable energy level by an energy source.

2. **Excitation Mechanism**

   Excitation mechanisms pump energy into the active medium by one or more of three basic methods; optical, electrical or chemical.

3. **High Reflectance Mirror**

   A mirror which reflects essentially 100% of the laser light.

4. **Partially Transmissive Mirror**

   A mirror which reflects less than 100% of the laser light and transmits the remainder.

LASER COMPONENTS

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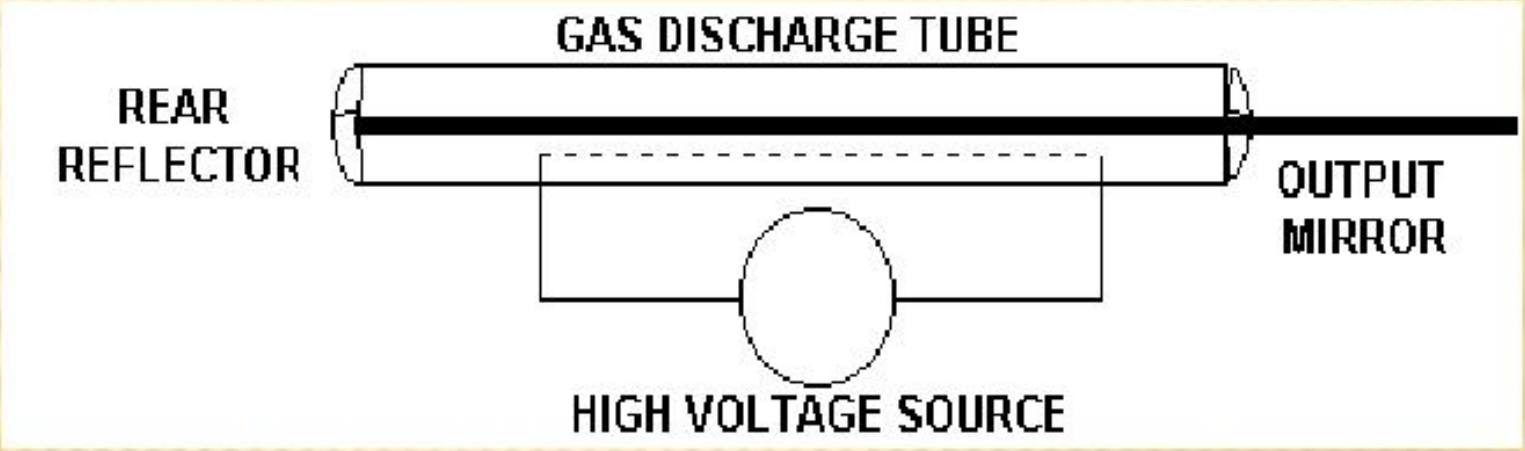


Gas lasers consist of a gas filled tube placed in the laser cavity. A voltage (the external pump source) is applied to the tube to excite the atoms in the gas to a population inversion. The light emitted from this type of laser is normally continuous wave (CW).

8

Active medium or working substance

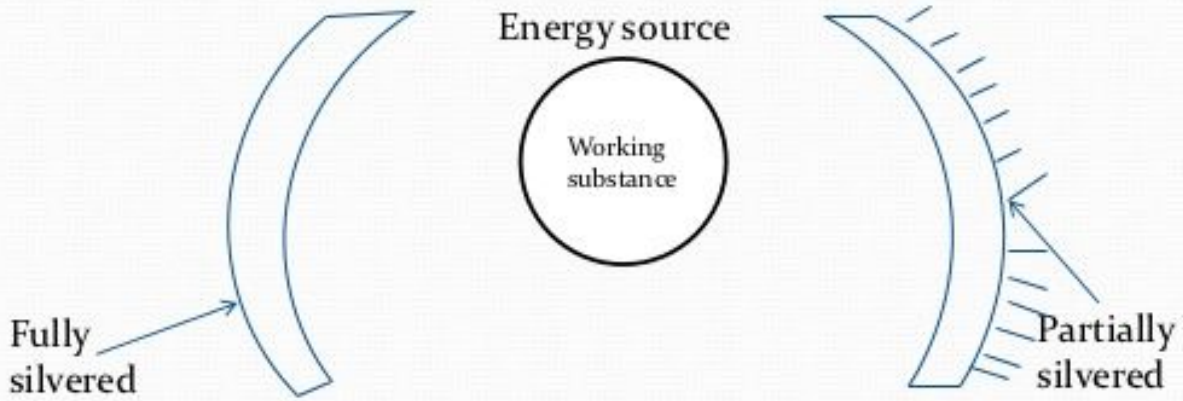
- This is the basic material in which atomic and molecular transitions take place leading to laser action.
- It is the medium where the stimulated emission take place
- Depending upon the active medium lasers are classified in to different types like solid, gas, dye or liquid, semiconductor laser

Pumping source or energy source

With the help of energy source the system can be raised to an excited state, with the help of this source the no. of atoms in higher energy state may be increased and hence the population inversion is achieved. the energy source may also be called pumping source.

Optical resonator

- It is specially designed cylindrical tube
- Set of mirrors at the ends of which are silvered one end being completely silvered at which the other is partially silvered
- Photons are emitted parallel to the axis of the active medium undergo multiple reflections between them
- So, the light intensity can be increased



Different types of lasers

There are basically four types of lasers

- Solid state laser
- Gas laser
- Liquid laser or dye laser
- Semi conductor laser

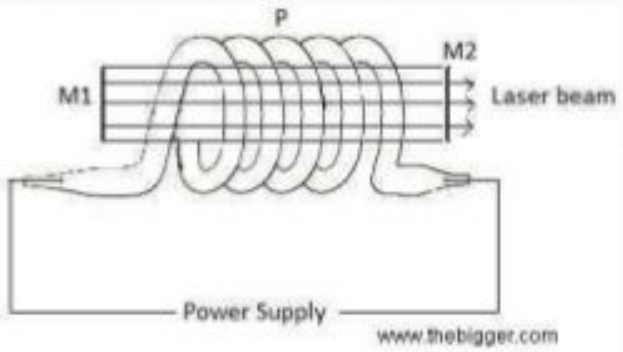
Kinds of lasers

Among the various kinds of lasers some important types of lasers are listed below:

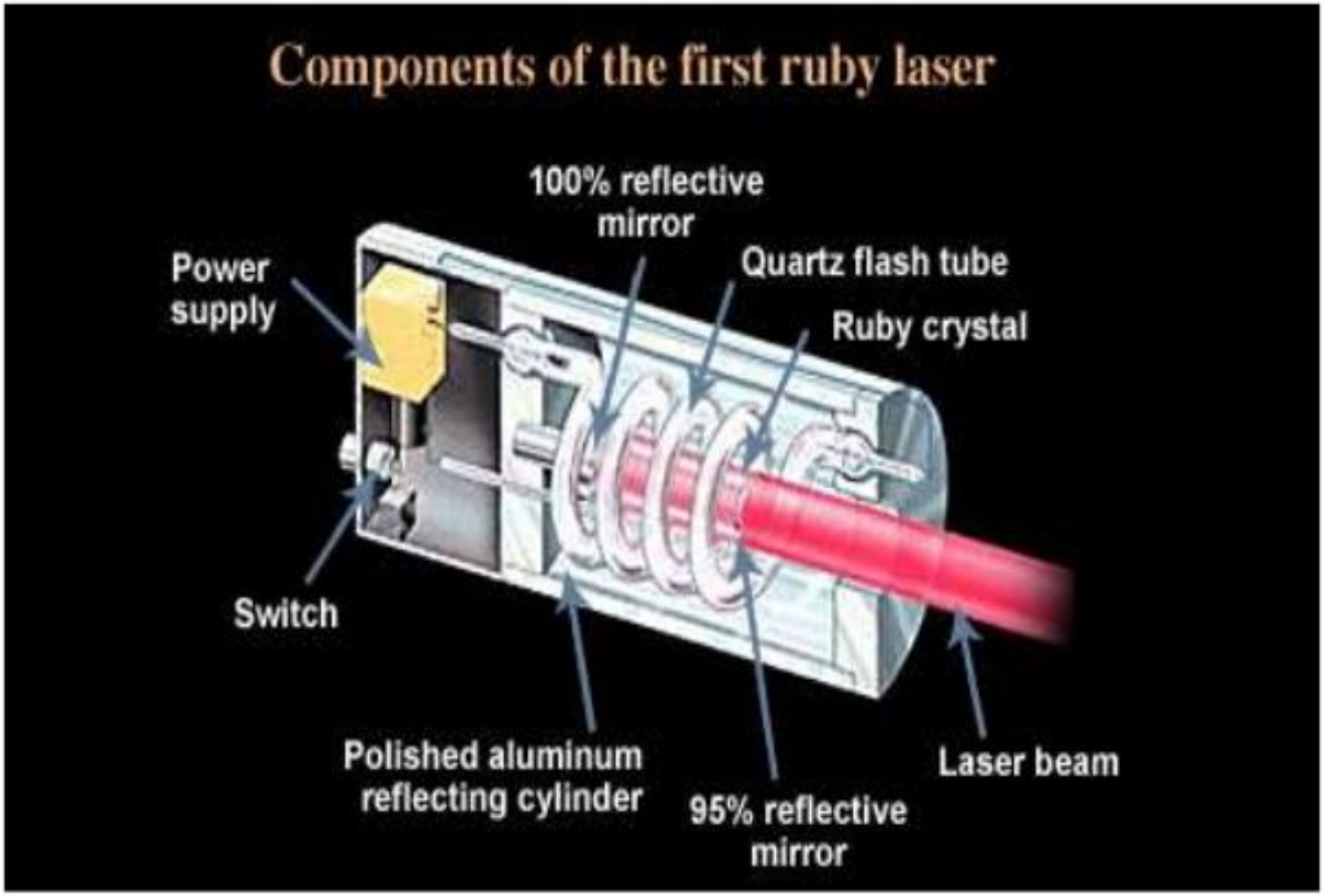
1) Solid state laser : Ruby laser
2) Gas laser : Co2 laser, He-Ne laser
3) Liquid laser : Europium chelate laser
4) Dye laser : Courmarin dye laser
5) Semiconductor laser : Inp laser

Solid state laser

- In this a ruby like crystal is used which acts as an active medium. It is basically cylindrical in shape. This crystal is surrounded by a xenon flash lamp T.
- This flash lamp is of helical shape. In this arrangement this lamp acts as a pumping arrangement. Both the ends E1 and E2 of the crystal are properly polished.
- Similar to the gas lasers, the surface M1 will do the complete reflection but on the other hand M2 will reflect partially.
- Whenever we will pass the current through the arrangement a laser beam of red color having large intensity will come out.



Construction and working of ruby laser



Construction :

- In ruby laser a cylindrical ruby rod made up of aluminum oxide which is doped with 0.05% weight of chromium oxide.
- One end of rod is fully silvered and the other one partially silvered so it act as optical resonator.
- The rod is surrounded by a glass tube which in turn is surrounded by the helical flash lamp filled with xenon gas.

Construction of Ruby Laser

- The ruby laser consists of a ruby rod . which is made of chromium doped ruby material. At the opposite ends of this rod there are two silver polished mirrors. Whose one is fully polished and other is partially polished. A spring is attached to the rod with fully polished end for adjustment of wave length of the laser light. Around the ruby rod a flash light is kept for the pump input. The whole assembly is kept in the glass tube. Around the neck of the glass tube the R.F source and switching control is designed in order to switch on and off the flash light for desired intervals.

Operation of Ruby Laser:

- When we switch on the circuit the R.F operates. As a result the flash of light is obtained around the ruby rod. this flash causes the electrons within ruby rod to move from lower energy band towards higher energy band. The population inversion take place at high energy band and electrons starts back to travel towards the lower energy band. During this movement the electron emits the laser light . This emitted light travels between the two mirrors where cross reflection takes place of this light. The stimulated lazer light now escapes from partially polished mirror in shape of laser beam.
- The spring attached with the fully polished mirror is used to adjust the wave length equal to $\lambda/2$ of lazer light for optimum lazer beam. The switching control of the R.F source is used to switch on and off the flash light so that excessive heat should not be generated due to very high frequency of the movement of the electron.

Advantages of Ruby laser

- From cost point of view, the ruby lasers are economical.
- Beam diameter of the ruby laser is comparatively less than CO_2 gas lasers.
- Output power of Ruby laser is not as less as in He-Ne gas lasers.
- Since the ruby is in solid form therefore there is no chance of wasting material of active medium.
- Construction and function of ruby laser is self explanatory.

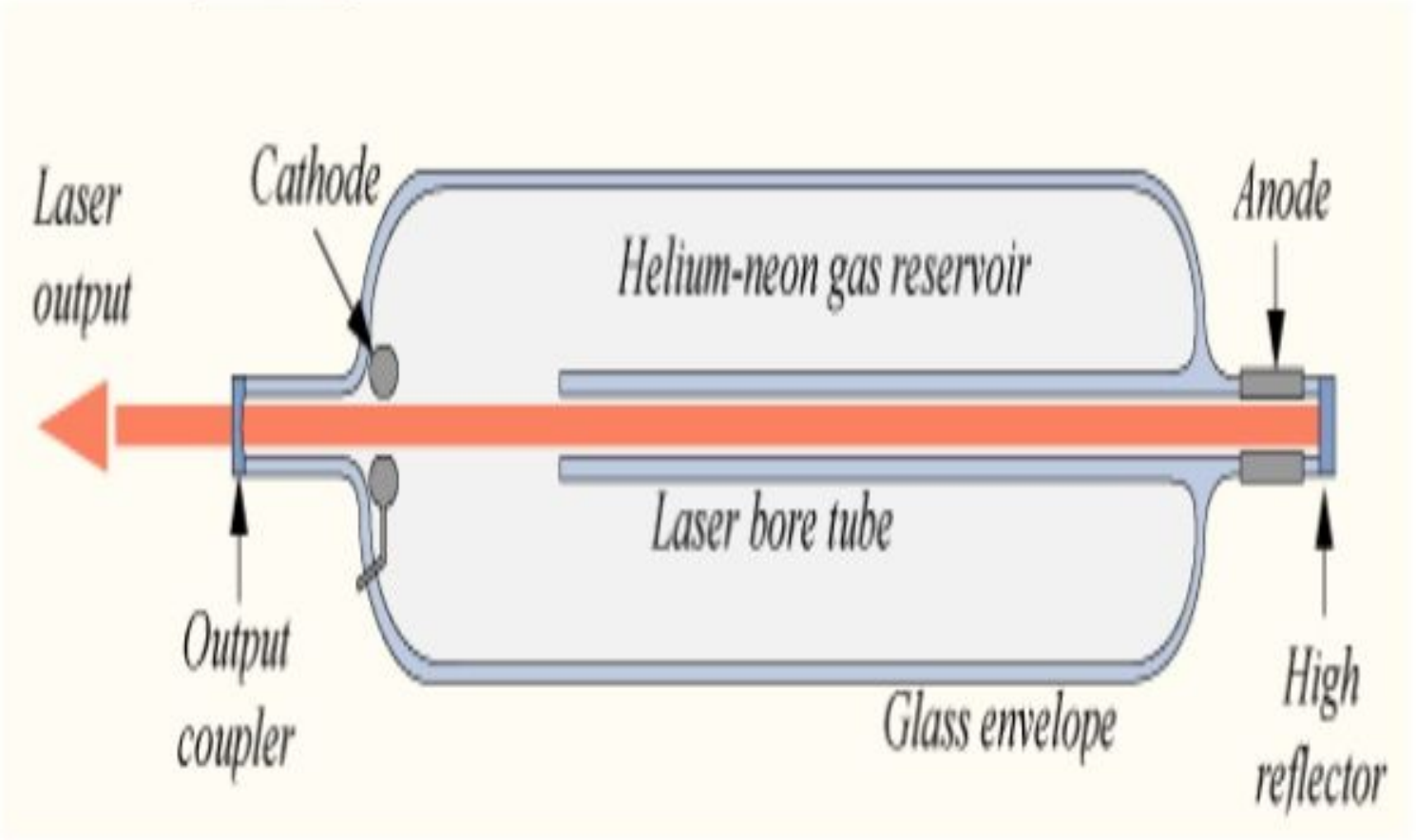
Disadvantages of Ruby Laser

- In ruby lasers no significant stimulated emission occurs, until at least half of the ground state electrons have been excited to the Meta stable state.
- Efficiency of ruby laser is comparatively low.
- Optical cavity of ruby laser is short as compared to other lasers, which may be considered a disadvantage.

Applications of ruby laser

- Used in retina surgery and in dermatology. It has the ability to concentrate the energy of optical radiation into a small area and the possibility of cutting and vapourising tissue.
- It is used in performing a non contact sharp contour tissue incision and removal of even tiny structuires without any damage to the surrounding tissues and any possible infection to the cut.
- In medical diagnostics.
- Used in cataract surgey,retina detachment surgery and glaucoma removal surgery.

Construction and working of He-Ne laser



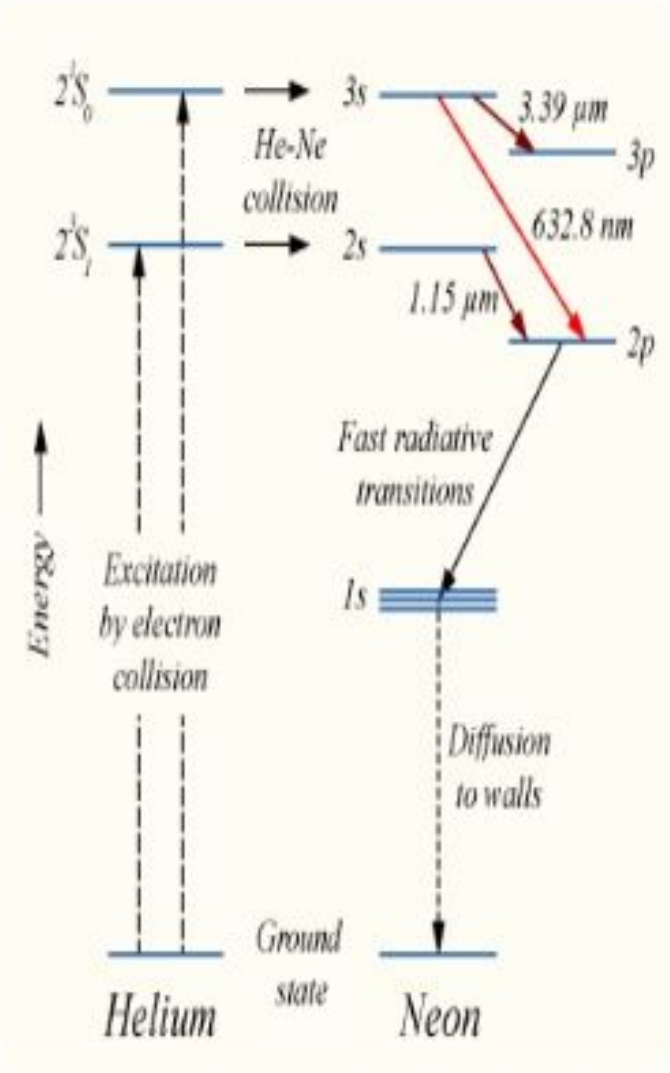
He-Ne laser

Construction:

- A He-Ne laser consists of large and narrow discharge tube filled with helium a and neon gases in the ratio 10:1.
- The tube is enclosed between fully and partially reflective mirrors which serve as optical cavity.
- The two end windows are set at Brewster's angle, so reflected radiations enter into the tube become polarized.

Working

- Helium atoms after transferring their energies to neon atoms are excited to 2s and 3s.
- The population in theses levels is more than those in lower levels 2p and 3p.
- The emission of radiation having wavelength 6328A^0 is red in colour and it gives continuous emission of radiation.



Advantages of He-Ne Laser

- He-Ne laser has very good coherence property
- He-Ne laser tube has very small length approximately from 10 to 100cm and best life time of 20.000 hours.
- Cost of He-Ne laser is less from most of other lasers.
- Construction of He-Ne laser is also not very complex.
- He-Ne laser provide inherent safety due to low power output.

Disadvantages of He-Ne Laser

- It is relatively low power device means its output power is low.
- He-Ne laser is low gain system/ device.
- To obtain single wavelength laser light, the other two wavelengths of laser need suppression, which is done by many techniques and devices. So it requires extra technical skill and increases the cast also.
- High voltage requirement
- Escaping of gas from laser plasma tube.

Applications of He-Ne laser

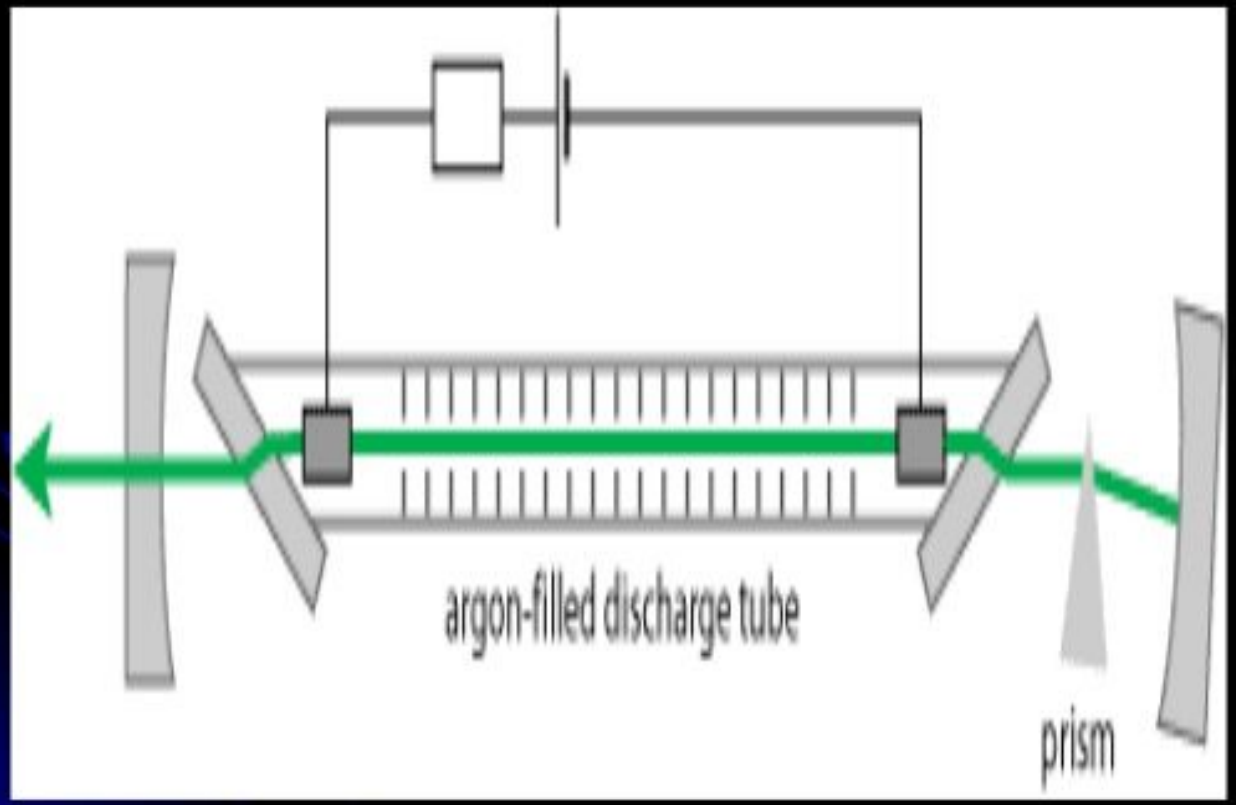
- The Narrow red beam of He-Ne laser is used in supermarkets to read bar codes.

- Measuring distances
- Red HeNe lasers have many industrial and scientific uses. They are widely used in laboratory demonstrations of optics in view of their relatively low cost and ease of operation .

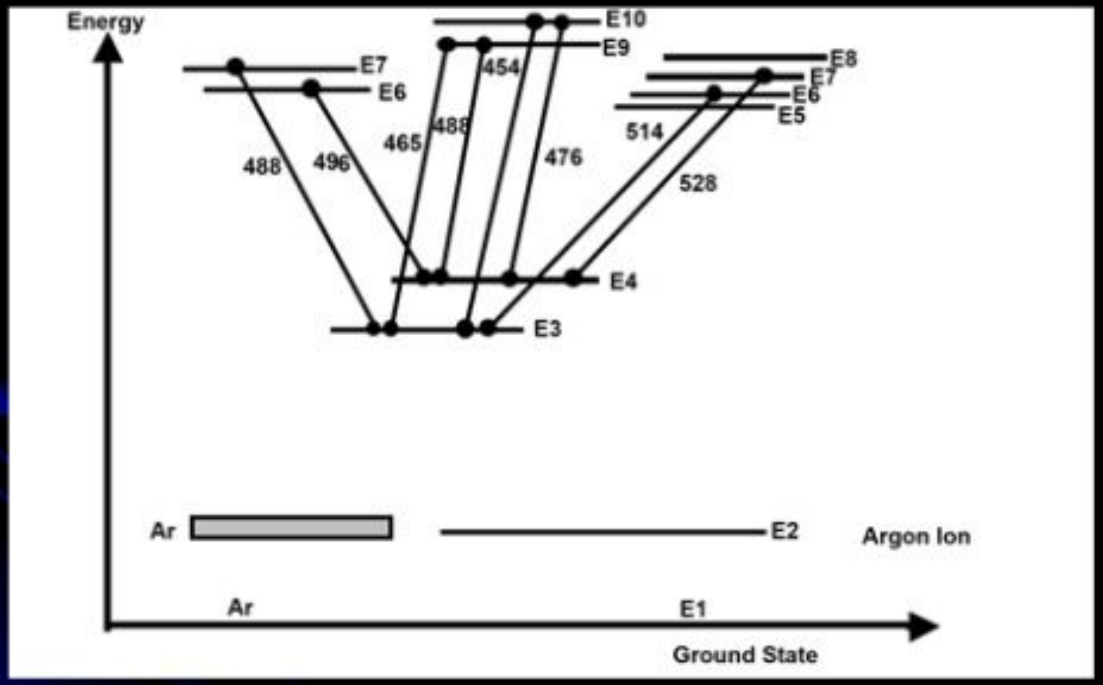
Argon ion laser

- as the name implies it uses high purity argon gas as the lasing medium.
- Based on light amplification in ionized argon in a gas discharge
- powerful gas lasers, which typically generate multiple watts of optical power in a green or blue output beam with high beam quality.

Construction & Working



ENERGY LEVEL DIAGRAM



Advantages of Argon Laser

- Production of multiple wave lengths is the main advantage plus characteristic of argon as well as other ion lasers.
- Argon lasers produce high power output as compared to He-Ne laser.
- Argon laser is a higher gain system.
- Argon laser like He-Ne has very less divergence, typically about 1 milli radian.

Disadvantages of Argon laser

- The overall efficiency of argon laser is very less usually lies between 0.01% and 0.1%.
- Large amount of power requirement is also its disadvantage.
- Construction is very difficult.
- Cost of argon laser is not as low as He-Ne laser.
- Power supply of high voltages required, because due to solenoid there is extra burden on it.

Applications of argon ion laser

- Raman Spectroscopy
- Holography
- Entertainment
- Forensics
- Ophthalmic Surgery
- Argon ion lasers are also used extensively in scientific, research and educational applications

CO_2 LASER

- CO_2 lasers belong to the class of molecular gas lasers.
- In the case of atoms, electrons in molecules can be excited to higher energy levels, and the distribution of electrons in the levels define the electronic state of the molecule.
- Besides, these electronic levels, the molecules have other energy levels.
- C.K.N. Patel designed CO_2 laser in the year 1964.

Active medium :

- It consists of a mixture of CO_2, N_2 and helium or water vapour. The active centres are CO_2 molecules lasing on the transition between the rotational levels of vibrational bands of the electronic ground state..

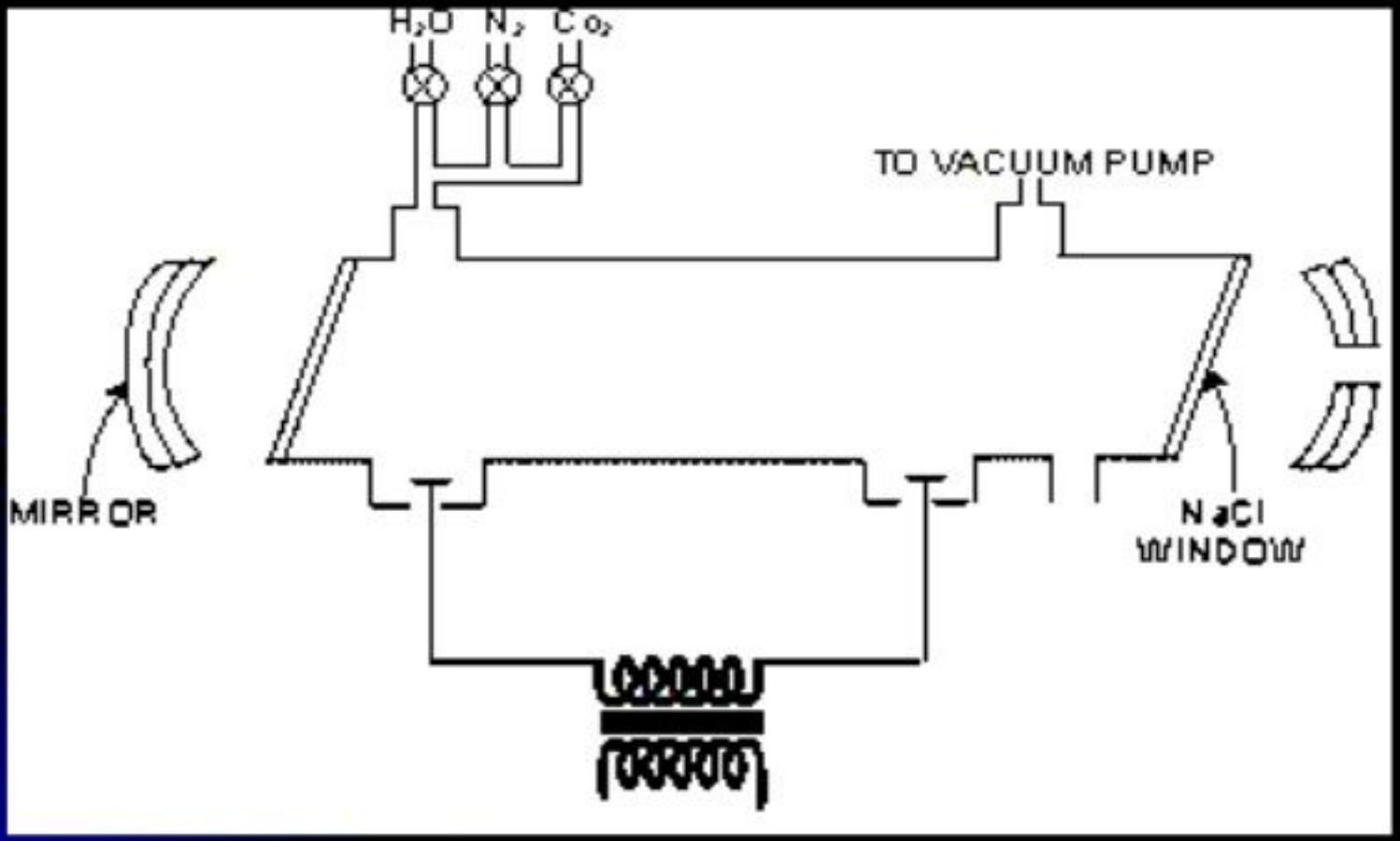
Optical resonators :

- A pair of concave mirrors placed on either side of the discharge tube, one completely polished and the other partially polished.

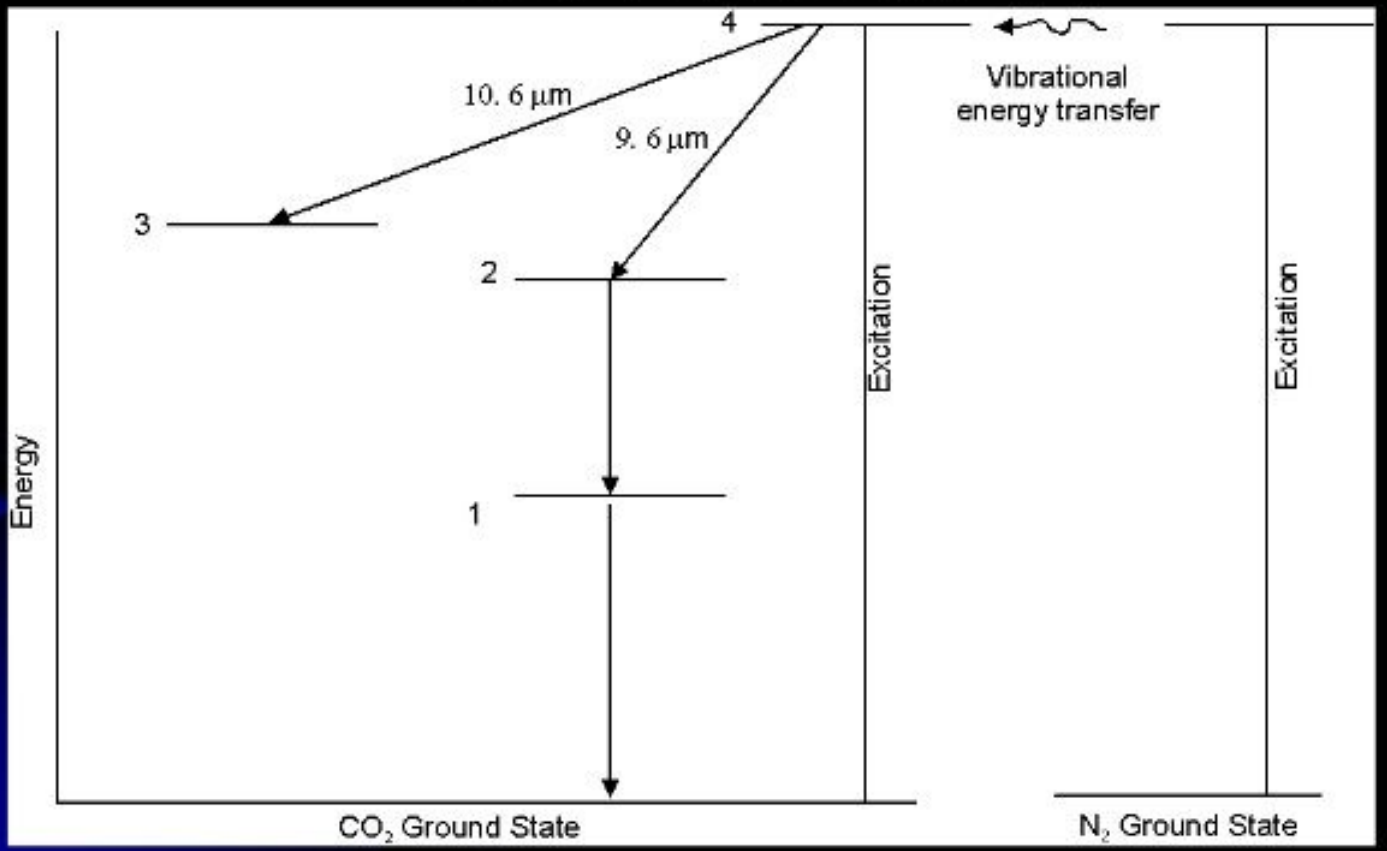
Pumping :

- Population inversion is created by electric discharge of the mixture

CONSTRUCTION AND WORKING OF CO_2 LASER



ENERGY LEVEL DIAGRAM OF CO2 LASER



ADVANTAGES

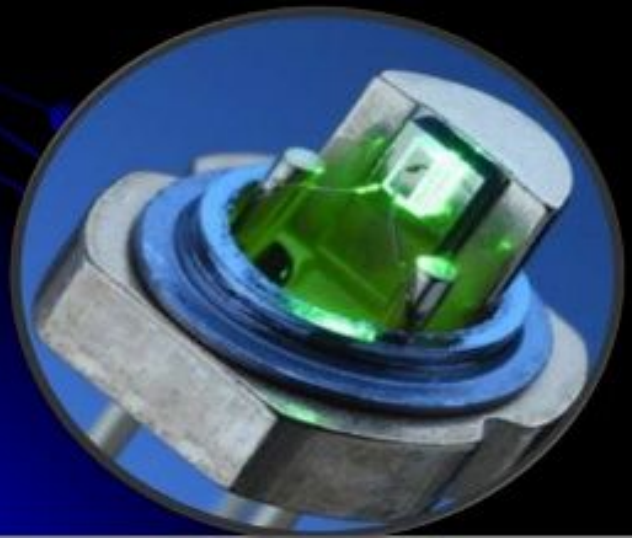
- A carbon dioxide (CO_2) laser can produce a continuous laser beam with a power output of several kilowatts.
- Can maintain high degree of spectral purity.
- High spatial coherence.
- The CO2 laser is the most efficient laser, capable of operating at more than 30% efficiency

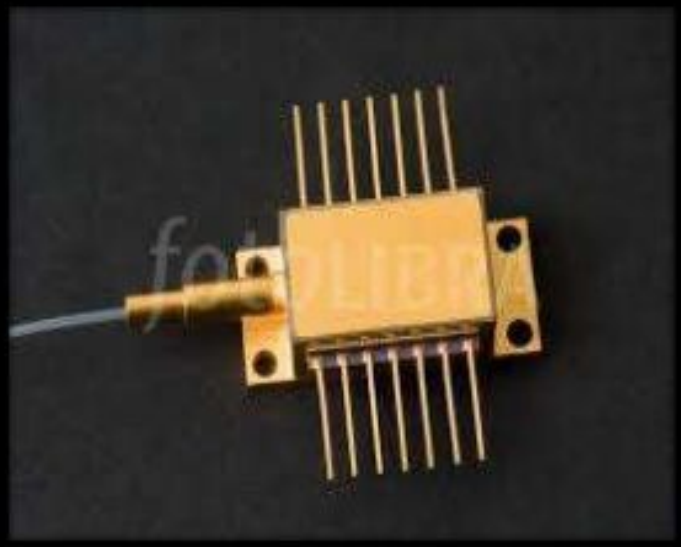
APPLICATIONS

- Because of the high power levels available (combined with reasonable cost for the laser), CO_2 lasers are frequently used in industrial applications for cutting and welding, while lower power level lasers are used for engraving.
- In surgical procedures because water (which makes up most biological tissue) absorbs this frequency of light very well.
- Other medical uses are
  - laser surgery,
  - skin resurfacing
  - dermabrasion.

SEMICONDUCTOR (Ga-As) LASERS

- The semiconductor laser is today one of the most important types of lasers with its very important application in fiber optic communication.
- Unlike other lasers, semiconductor laser does not need mirrors to obtain the reflectivity needed to produce feedback mechanism





Construction and working

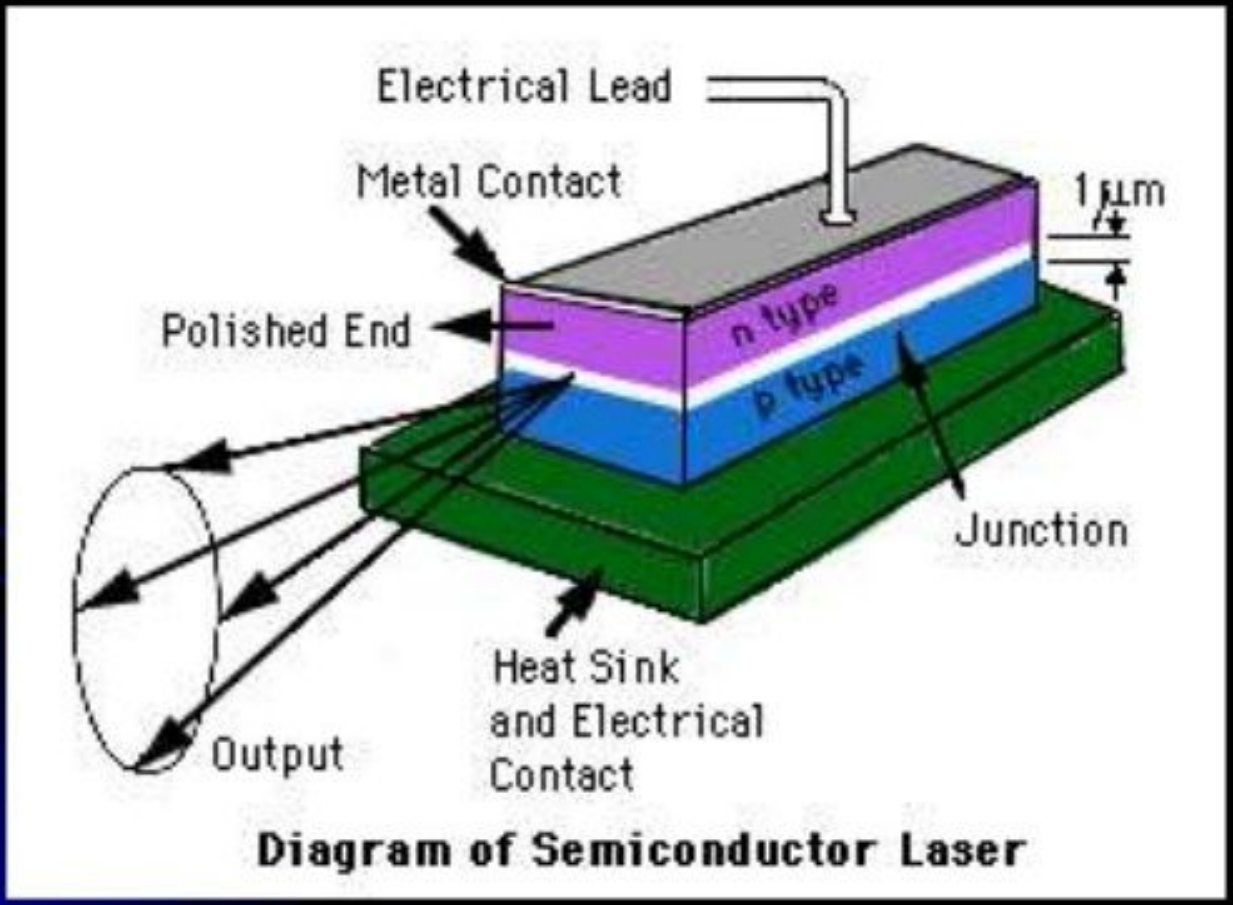


Diagram of Semiconductor Laser

Basic Mechanism :

- The basic mechanism responsible for light emission from a semiconductor is the recombination of electrons and holes at a *p-n* junction when a current is passed through a diode. There can be three interaction processes.

1) An electron in the valence band can absorb the incident radiation and be excited to the conduction band leading to the generation of eletron-hole pair.

2) An electron can make a spontaneous transition in which it combines with a hole and in the process it emits radiation

3) A stimulated emission may occur in which the incident radiation stimulates an electron in the conduction band to make a transition to the valence band and in the process emit radiation.

- To convert the amplifying medium into a laser

✓ Optical feedback should be provided

✓ Done by cleaving or polishing the ends of the *p-n* junction diode at right angles to the junction.

- The heterostructure laser is a laser diode with more than single P and N layers.
  GaAs/AlGaAs is a heterojunction laser. This increases the radiation efficiency

Advantages of Semiconductor Lasers

- Smaller size and appearance make them good choice for many applications.
- From cost point of view the semiconductor lasers are economical.
- Semiconductor lasers construction is very simple.
- No need of mirrors is in semiconductor lasers.
- Semiconductor lasers have high efficiency.
- The low power consumption is also its great advantage.

Disadvantages of Semiconductor Lasers

- Due to relatively low power production, these lasers are not suited to many typical laser applications.
- Semiconductor laser is greatly dependent on temperature. The temperature affects greatly the output of the laser.
- The lasing medium of semiconductor lasers is too short and rectangular so the output beam profile has an unusual shape.
- Beam divergence is much greater from 125 to 400 milli radians as compared to all other lasers.
- The cooling system requirement in some cases may be considered its disadvantage.

Application / Uses of Semiconductor Lasers

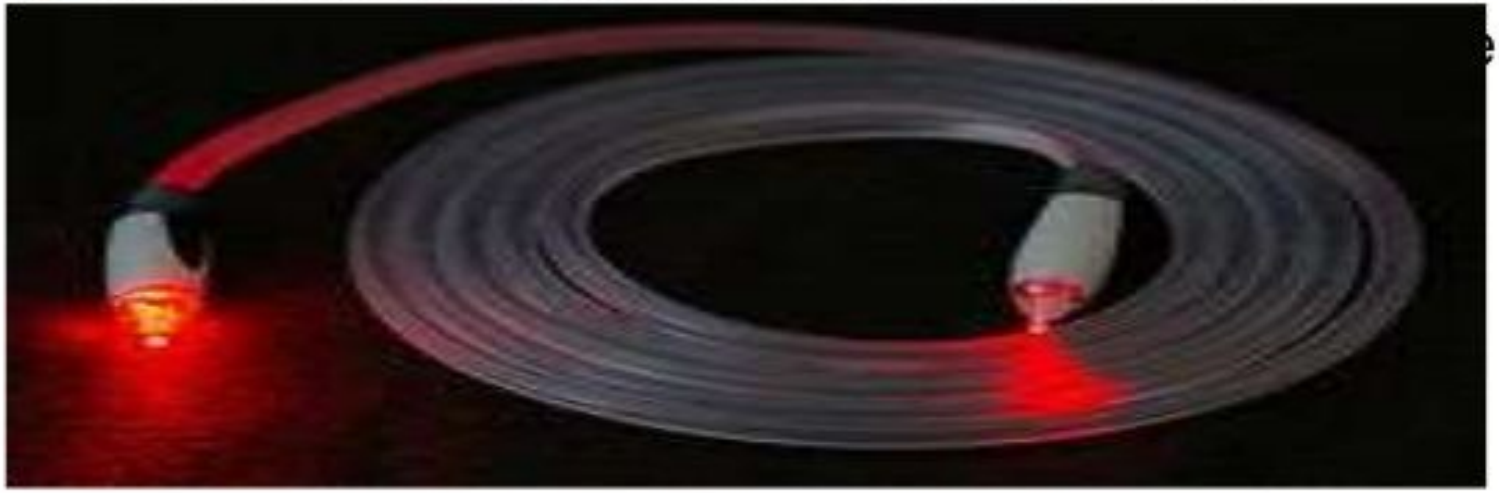
- The semiconductor laser can be pulsed at varying rate and pulse widths. Therefore this laser is a natural transmitter of digital data.
- Semiconductor laser is well suited for interface with fiber optic cables used in communication.

Applications of lasers

Lasers in communication:

In optical fiber communication laser bandwidth is very high compared to the radio and microwave communications.

- As it has large bandwidth,more amount of data can be sent.
- More channels can be simultaneously transmitted.
- lasers are also used in other communication



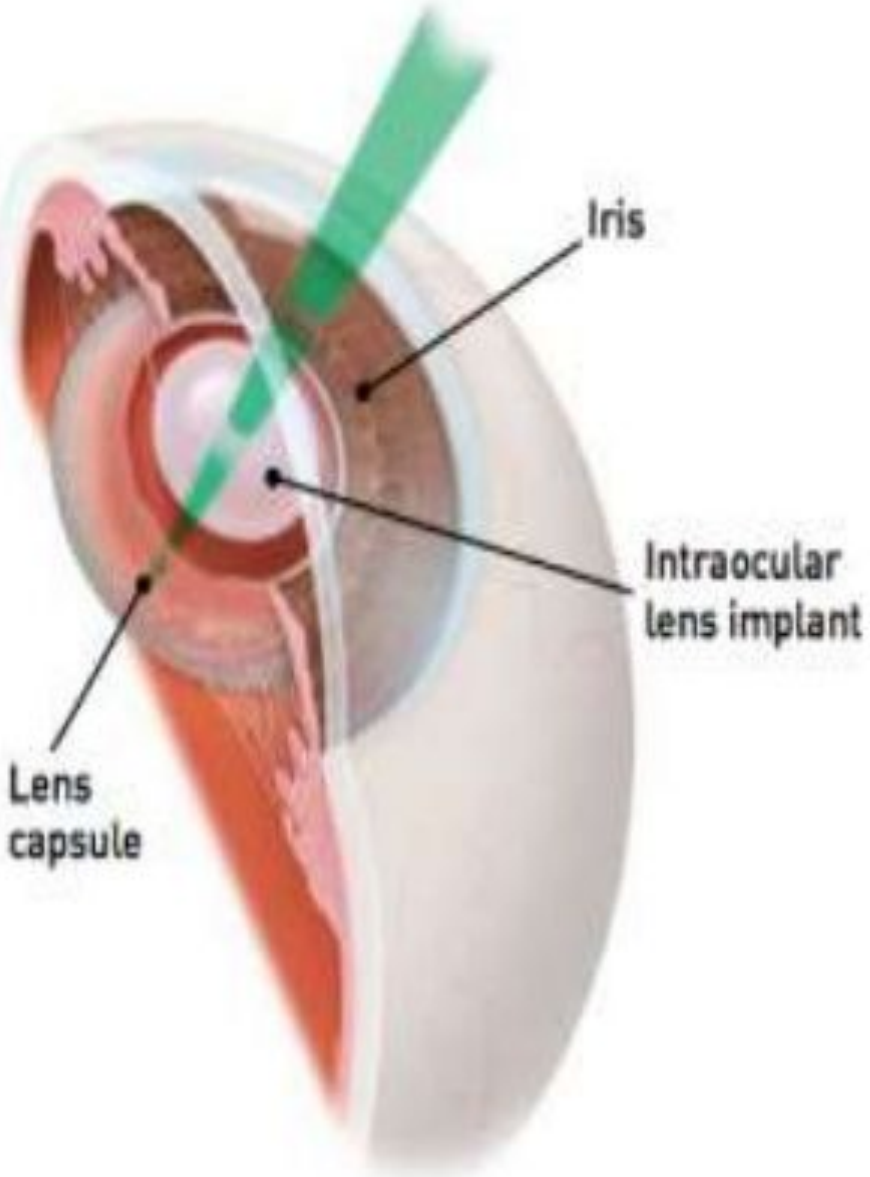
Lasers in industry:

- Lasers can be used to blast holes in diamonds and hard steel.
- Lasers can cut,drill,weld, remove metal from surfaces and perform these operations even at surfaces inaccessible by mechanical methods.
- Lasers range finder is used to measure distance to making maps by surveyors.

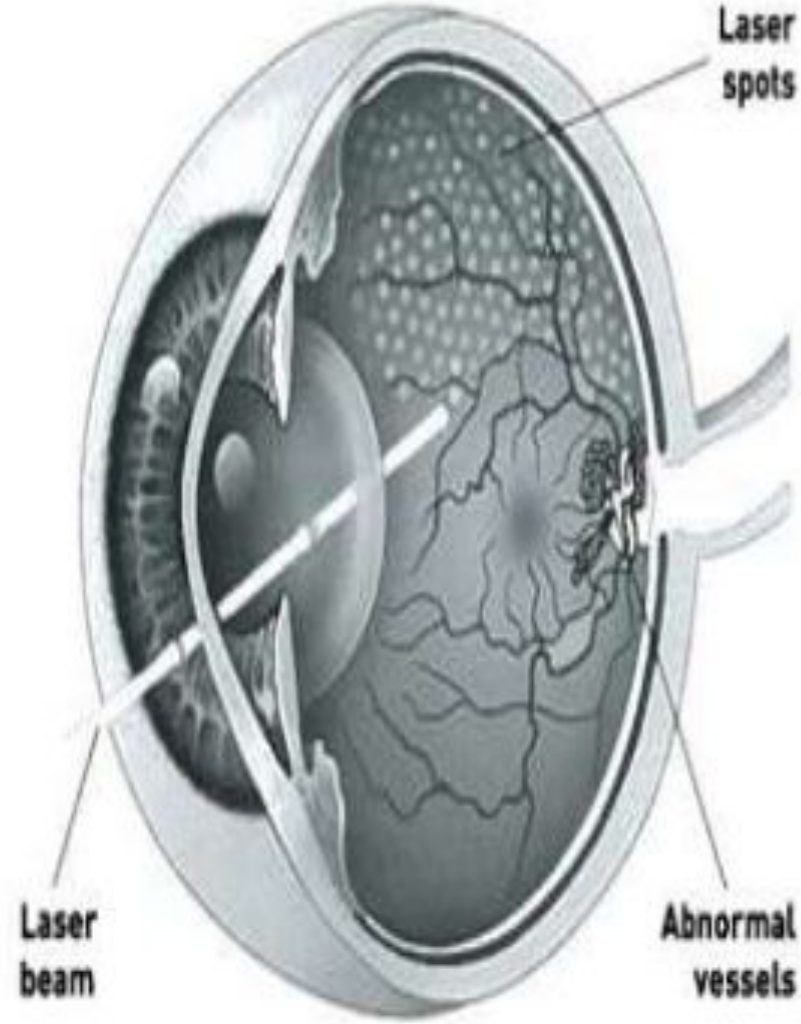
- Argon and Co2 lasers are used in treatment of liver and lungs .
- New kind of laser surgery that uses molecules to stitch together wounds .
- Co2 laser is particularly used in spinal and brain tumour excision and kidney stone extrusion.
- Lasers are used in the treatment of Glaucoma.

Laser used in eye treatment

- The laser can also repair a detached retina—one that has broken loose from the rear part of the eyeball
- The laser is very useful in removing extraneous blood vessels that can form on the retina—the thin, light-sensitive membrane at the back of the eyeball



A laser can make an opening in a cloudy lens capsule to restore normal sight.



LASER SURGERY CAN SLOW OR STOP THE GROWTH OF ABNORMAL BLOOD VESSELS IN THE RETINA CAUSED BY DIABETIC RETINOPATHY.

Lasers in military:

- A laser beam can be bounced off a target such as enemy air plane or ship,to determine its distance and speed.
- Laser can serve as a war weapon.
- High energy lasers are being employed to destroy enemy air crafts and missiles.

Advantages of lasers

- Lasers are used to cut glass and drill holes in ceramics.
- Lasers are used for bloodless surgery and in destroying kidney stones and gallstones.
- Lasers are used to study the internal structure of microorganisms and cells.
- Lasers are used in air pollution, to estimate the size of dust particles.

Disadvantages of lasers

- Lasers are known to be dangerous to the atmosphere and health.
- Laser printers are very costly when compared to other printers.
- When running the laser machine small amount of ozone are generated, which can damage the ozone layer.
- Some laser particles are also known to emit particles that may cause respiratory disease.

Problems

1- What is the bandgap of GaAs semiconductor laser if the wavelength of emission is $\lambda = 8500$ Å.

2- In a material at 300 K two energy levels have a wavelength separation of 1µm. Determine

a. The ratio of upper to lower energy level occupation densities when the material is in thermal equilibrium.
b. The effective temperature when they the levels are equally populated
c. The effective temperature when the upper level is twice as densely populated as the lower level.

Hint : Boltzmann equation……

3. Explain why Si is used for solar cells but not for lasers.

4. A laser beam of wavelength 740 nm has coherence time $4 * 10^{-5}$ s. Deduce the order of magnitude of its (a) coherence length (b) spectral half width and (c) the purity factor.

5- Imagine we chop a continuous laser beam (assumed to be perfectly monochromatic λ = 6328 Å) into 0.1 ns pulses using some sort of shutter. Compute the resultant line width, bandwidth and coherence lengths.

6- Describe stimulated emission of radiation from explaining the role of Einstein coefficient.

7. Explain the construction and working mechanism of Nd:YAG lasers. Discuss its advantages, disadvantages and its applications?

8. What is the difference between lasers and masers.

9. What is meant by population inversion.

10. Discuss the principles involved in the working of lasers.