Ruby Laser

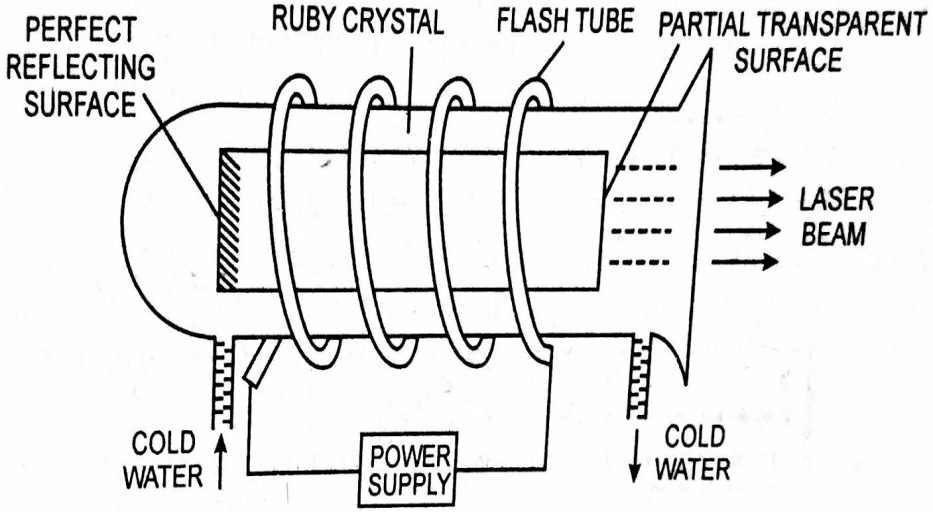
- In 1960, T. H. Maiman developed 1st Ruby Laser
- It is a 3-level solid state laser in which population inversion is achieved with the help of Xenon flash tube.
- It emits deep red light of wavelength 694.3 nm.

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.

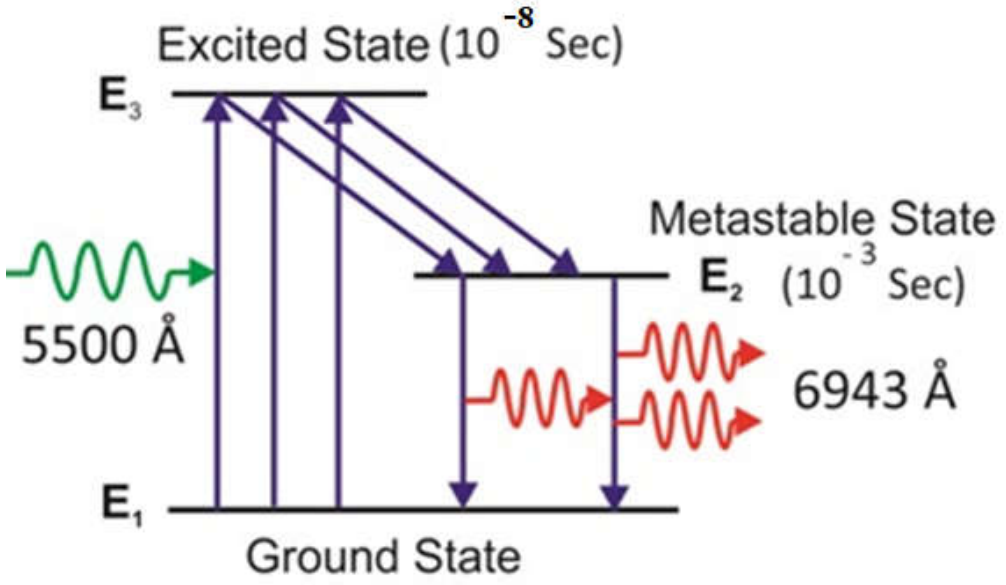
Energy Source: The Xenon flashtube is used as the energy source or pump source. The flashtube supplies energy to the laser medium (ruby). When lower energy state electrons in the laser medium gain sufficient energy from the flashtube, they jump into the higher energy state or excited state.

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.



(Ruby laser)

- Working Principle: In the normal state, most of the chromium ions are in the ground state E_1. When light from the flash tube of wavelength 550nm is made to fall upon the ruby rod, these incident photons are absorbed by the chromium ions that rise to the excited state E_3. Then they give a part of their energy to the crystal structure and reach the metastable state. i.e. the E_2 state.
- These ions in metastable state can remain a longer duration 10^{-3} sec. Therefore the number of ions in this state goes on increasing while at the same time number of ions in ground state goes on decreasing due to the optical pumping. Thus, the population inversion is established between the metastable state and the ground state.
- When an excited ion passes spontaneously from the metastable state to the ground state, it emits a photon of wavelength 694.3nm. This photon travels through the ruby rod back and forth to get the suitable condition to stimulate another excited ions present in the metastable state. Then by successive reflections of these photons at the ends of the rod, stimulated emission is achieved and we obtain an intense, coherent and unidirectional laser beam through the partially silvered face.



Energy Level Diagram of Ruby LASER

Drawback:

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

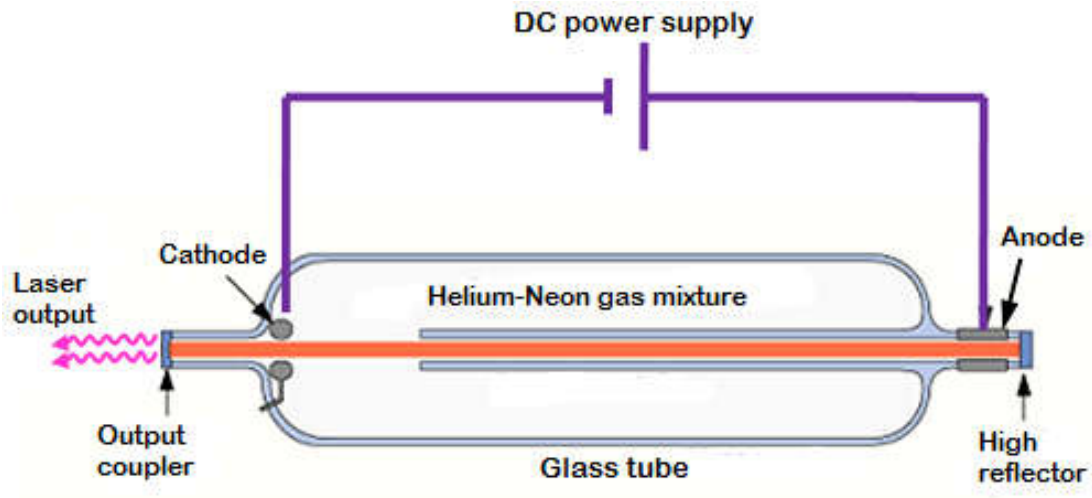
He-Ne Laser

- 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



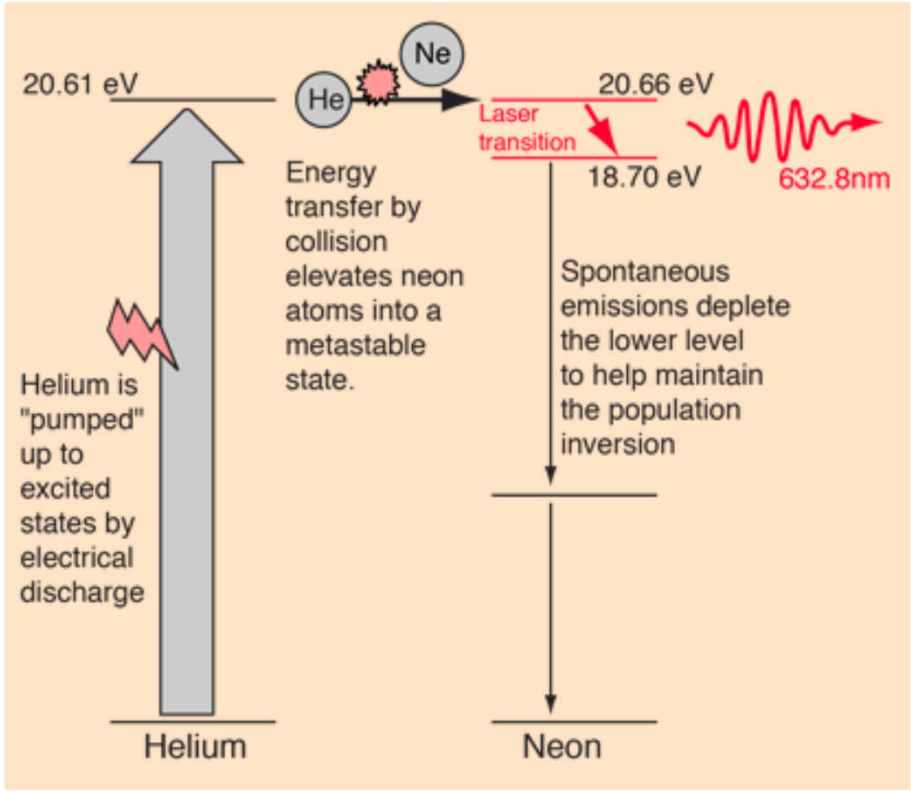
Schematic Diagram of He-Ne Laser

Construction:

- ✓The schematic of a typical He-Ne laser is shown in Figure. It consists of a long discharge tube of length about 50 cm and diameter 1 cm.
- ✓The tube contains a mixture of about 10 parts of helium and 1 part of neon at a low pressure (~ 1 torr).
- ✓At both ends of the tube are fitted optically plane and parallel mirrors, one of them being only partially silvered.
- ✓The spacing of the mirrors is equal to an integral number of half-wavelengths of the laser light.
- ✓In this, population inversion is achieved by electric discharge. An electric discharge is produced in the gas by means by electrodes outside the tube connected to a source of high-frequency alternating current.

Working Principle:

- ✓ When the power is switched on, the electrons from the discharge collide with and "pump" the He and Ne atoms to metastable states 20.61 eV and 20.66 eV respectively above their ground states.
- ✓ Some of the excited He atoms transfer their energy to ground-state Ne atoms in collisions, with the 0.05 eV of additional energy being provided by the kinetic energy of the atoms. Thus, the purpose of the He atom is to help in achieving a population inversion in the Ne atoms.
- ✓ When an excited Ne atom passes, from the metastable state at 20.66 eV to an excited state of 18.70 eV it emits a photon of wavelength 632.8nm.
- ✓ This photon travels through the gas-mixture and if it is moving parallel to the axis of the tube, is reflected back and forth by the mirror-ends until it stimulates an excited Ne-atom and causes it to emit a fresh 632.8 nm photon in phase with the stimulating photon.
- ✓ This stimulated transition from 20.66 eV level to 18.70 eV level is the laser transition. This process is continued and when a beam of coherent radiation becomes sufficiently intense, a portion of it escapes through the partially silvered end.
- ✓ The Ne atom passes from the 18.70 eV level, spontaneously to a lower metastable state emitting incoherent light and finally the Ne atom comes down to the ground state through collision with the tube walls. This radiation from lower metastable state to the ground state is radiationless transition.



Energy Level Diagram of 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

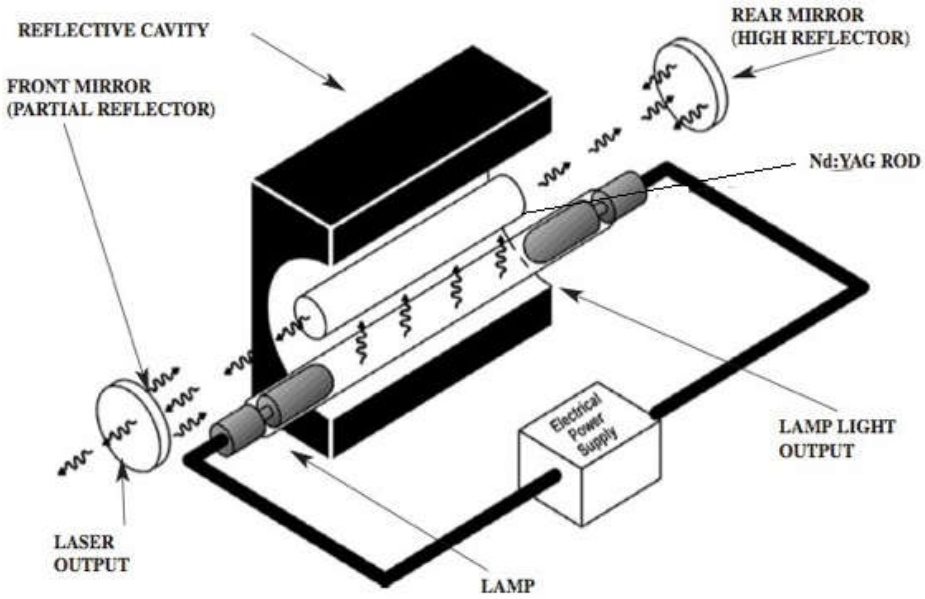
Applications:

- 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

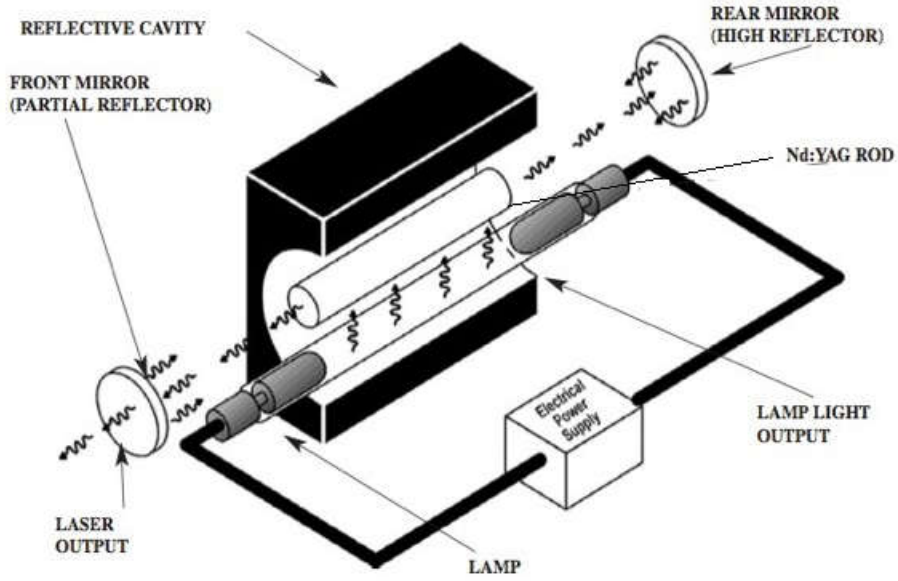
Introduction:

- 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.



Construction:

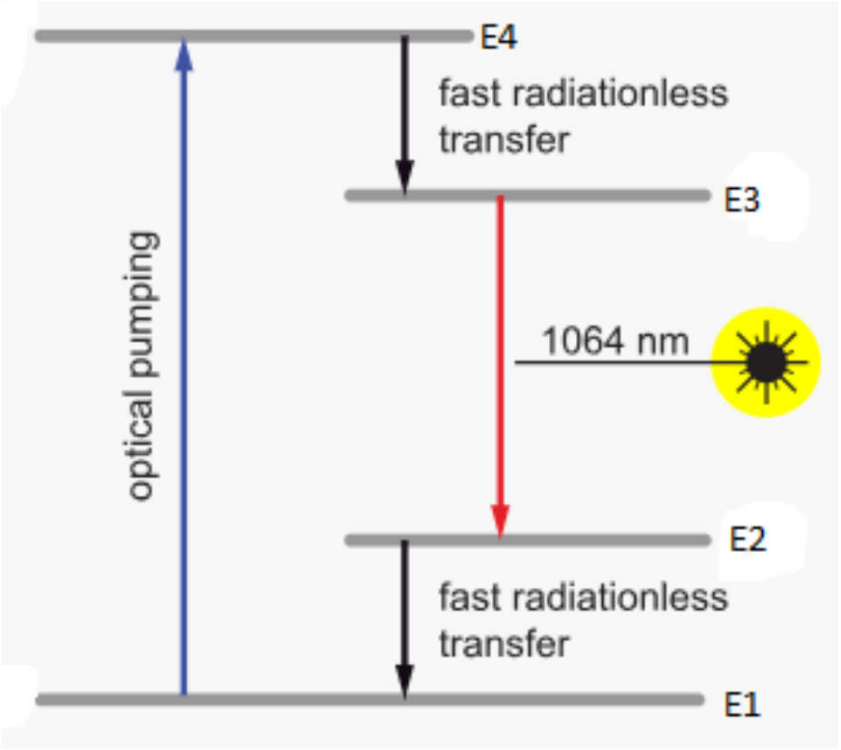
- ✓ The rod $Y_3Al_5O_{12}$ is doped with 1% neodymium ions and Y^{3+} ions replaced by Nd^{3+} ions.
- ✓ The maximum length of the rod is 10 cm and diameter is 6-9 cm.
- ✓ Active medium: Nd^{3+} ions acts as an active medium or active centers. YAG is just host.
- ✓ Pumping source: The pumping of Nd^{3+} ions to upper level is done by xenon flash lamp or krypton flash lamp. Thus optical pumping is used to achieve population inversion.
- ✓ Optical Resonator: The ends of the YAG rod are polished and silvered so as act as optical resonator.
- ✓ It consists of an elliptically cylindrical reflector housing the laser rod along one of its focus lines and a flash lamp along the other focus line. The light leaving one focus of the ellipse will pass through the other focus after reflection from the silvered surface of the reflector. Hence the entire flash of light gets focused on the laser rod.



Working:

It consists of four-level system. In this laser population inversion is achieved by optical pumping.

- The pumping of the Nd^{3+} ions to upper state (E4) is done by a krypton arc lamp. The optical pumping with radiation of wavelength range 500 – 800nm excites the Nd^{3+} ions from the ground state to higher states.
- As the higher states are short-lived states, hence the excited Nd^{3+} ions quickly make downward transitions to upper laser level (metastable state) E3. The lower laser level E2 is far above the ground level and hence it cannot be populated by Nd^{3+} ions through thermal transitions from the ground level. Thus population inversion is established between the E3 level and E2 level.
- The laser emission occurs in infrared (IR) region at a wavelength of 1064 nm. As Nd : YAG laser is an optically pumped four level laser, thus the population inversion can be maintained in the face of continuous laser emission. Thus this laser can be operated in continuous wave CW mode. The efficiency, of Nd : YAG laser is high in comparison to ruby laser which is about 2% (while for ruby laser it is only 0.1%).



(Energy -level diagram)

Advantages

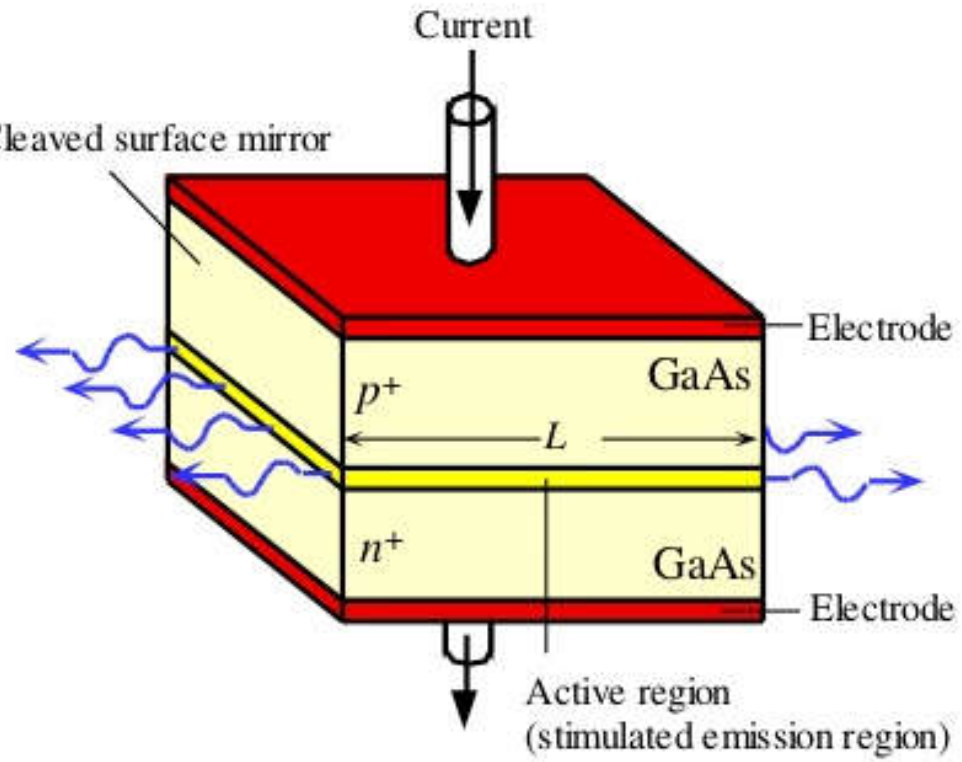
- Low power consumption
- Nd:YAG laser offers high gain.
- Nd:YAG laser has good thermal properties.
- Nd:YAG laser has good mechanical properties.
- The efficiency of Nd:YAG laser is very high(2%) as compared to the ruby laser(0.1%).

Applications

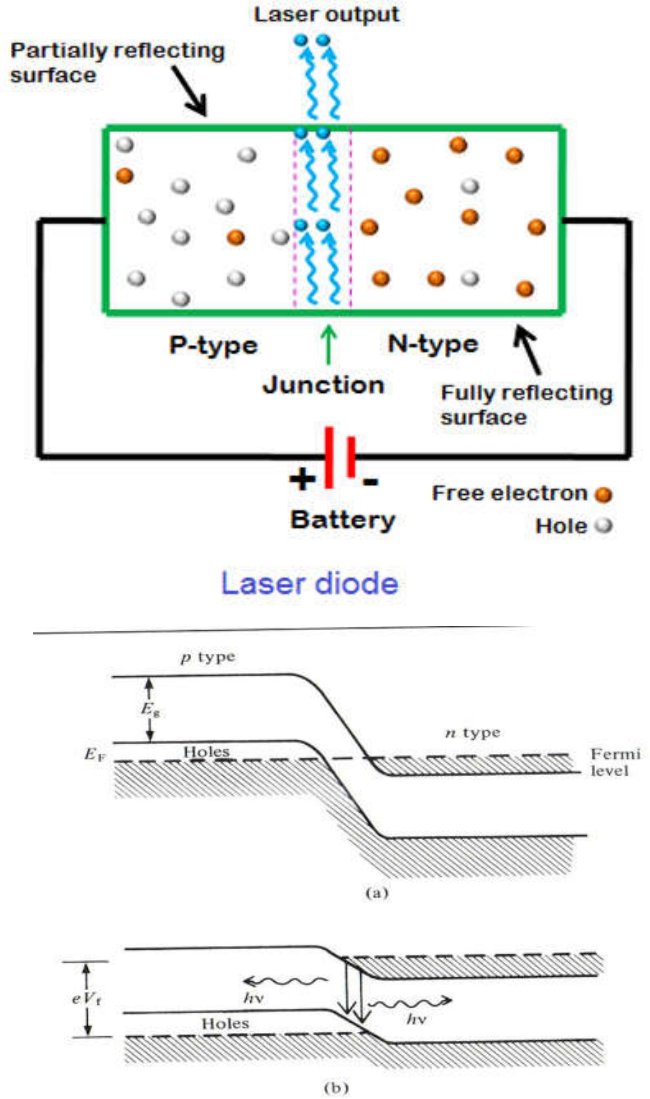
- Medical: remove skin cancers, to correct posterior capsular opacification (a condition that may occur after a cataract surgery).
- Nd:YAG lasers are used to remove skin cancers.
- Manufacturing: cutting and welding
- Nd:YAG lasers are used for etching or marking a variety of plastics and metals.
-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



- When DC voltage is applied across the laser diode, the free electrons move across the junction region from the n-type material to the p-type material. In this process, some electrons will directly interact with the valence electrons and excites them to the higher energy level whereas some other electrons will recombine with the holes in the p-type semiconductor and releases energy in the form of light. This process of emission is called spontaneous emission.
- The photons generated due to spontaneous emission will travel through the junction region and stimulate the excited electrons (free electrons). As a result, more photons are released. This process of light or photons emission is called stimulated emission. The light generated due to stimulated emission will moves parallel to the junction.
- The two ends of the laser diode structure are optically reflective. One end is fully reflective whereas another end is partially reflective. The fully reflective end will reflect the light completely whereas the partially reflective end will reflect most part of the light but allows a small amount of light.
- The light generated in the p-n junction will bounce back and forth (hundreds of times) between the two reflective surfaces. As a result, an enormous optical gain is achieved.
- The light generated due to the stimulated emission is escaped through the partially reflective end of the laser diode to produce a narrow beam laser light. All the photons generated due to the stimulated emission will travel in the same direction. Therefore, this light will travel to long distances without spreading in the space.

Advantages:

- Simple construction
- Lightweight and portable
- Very cheap
- 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

Applications: 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.

Holography

Introduction:

- The word holography originates from the Greek words "holos" (complete) and "graphos" (writing). Thus, it is the technique to record the complete picture of an object. The technique was proposed by Denis Gabor in 1947.

- An ordinary photograph records the two dimensional image of the picture because it records only the amplitude or intensity distribution. But in holography technique, both, the intensity as well as phase of the light wave is recorded.

- In holography, the light waves reflected from an object is recorded. These light waves consist of intensity and phase and the record is called a hologram. The hologram has no resemblance to the original object but it contains all the information about the object in a optical code.

Principle of Holography:

- The formation of hologram is done by a process called recording process. The formation of three-dimensional image from hologram is done with a process called reconstruction process. Thus holography consists of two processes :

I. Recording of hologram

II. Reconstruction of image

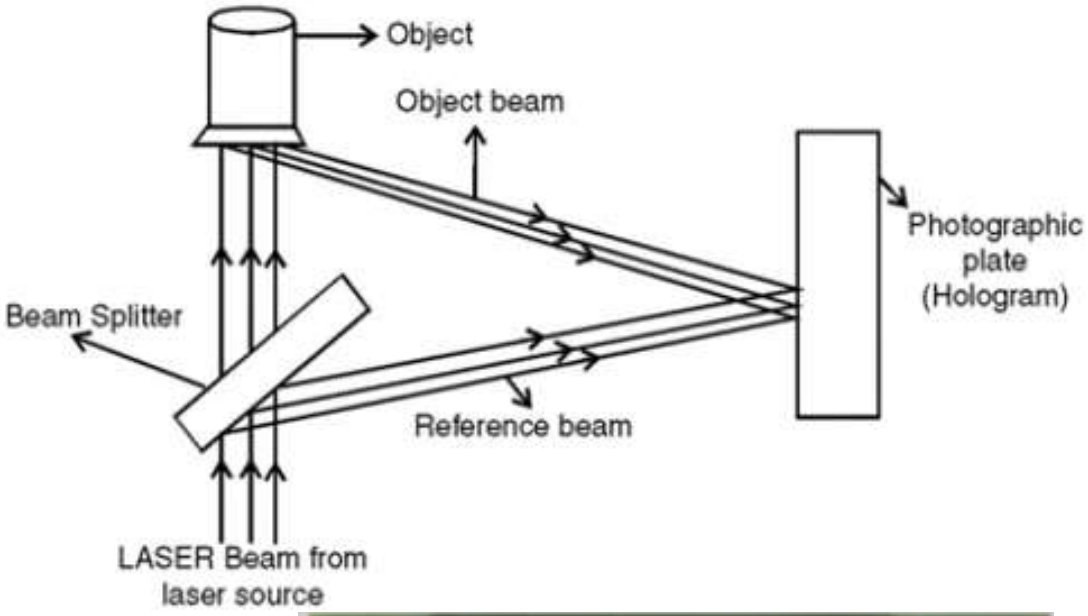
I. Recording of hologram:

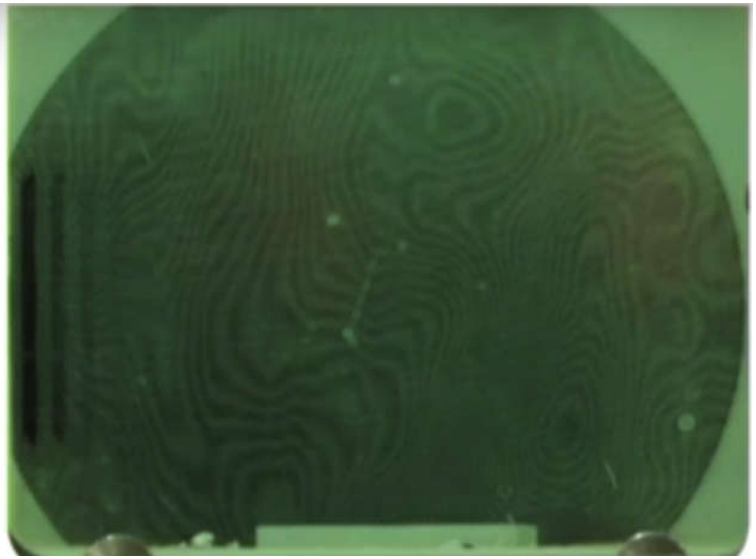
- The recording of hologram is based on the phenomenon of interference. It requires a laser source, a plane mirror or beam splitter, an object and a photographic plate. A laser beam from the laser source is incident on a plane mirror or beam splitter. As the name suggests, the function of the beam splitter is to split the laser beam. One part of splitted beam, after reflection from the beam splitter, strikes on the photographic plate. This beam is called reference beam.
- While other part of splitted beam (transmitted from beam splitter) strikes on the photographic plate after suffering reflection from the various points of object. This beam is called object beam.

I. Recording of hologram:

- The object beam reflected from the object interferes with the reference beam when both the beams reach the photographic plate. The superposition of these two beams produces an interference pattern (in the form of dark and bright fringes) and this pattern is recorded on the photographic plate.

- The photographic plate with recorded interference pattern is called hologram. Photographic plate is also known as Gabor zone plate in honour of Denis Gabor who developed the phenomenon of holography. Each and every part of the hologram receives light from various points of the object. Thus, even if hologram is broken into parts, each part is capable of reconstructing the whole object.



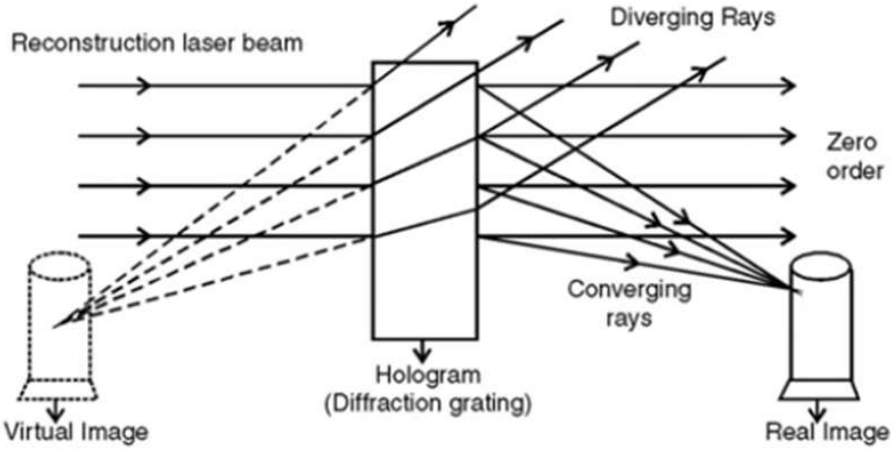


II. Reconstruction of image

- It is based on the principle of diffraction. In the reconstruction process, the hologram is illuminated by laser beam and this beam is called reconstruction beam. This beam is identical to reference beam used in construction of hologram. The hologram acts a diffraction grating. This reconstruction beam will undergo phenomenon of diffraction during passage through the hologram. The reconstruction beam after passing through the hologram produces a real as well as virtual image of the object.

- One of the diffracted beams emerging from the hologram appears to diverge from an apparent object when project back. Thus, virtual image is formed behind the hologram at the original site of the object and real image in front of the hologram. Thus an observer sees light waves diverging from the virtual image and the image is identical to the object.

- If the observer moves round the virtual image then other sides of the object which were not noticed earlier would be observed. Therefore, the virtual image exhibits all the true three dimensional characteristics. The real image can be recorded on photographic plate.



Rainbow holograms:

- Though for measurement purposes one uses a laser for reconstruction, with advancements in technology it has been possible to construct holograms that could be reconstructed using white light.
- Such holograms are termed as rainbow holograms. These are made by a double holographic process. An ordinary transmission hologram is used as the object and a second hologram is made through a slit. The slit process removes the coherence requirement of the viewing light and hence the 3D object could be viewed with white light.

Types of Hologram:

- Reflection hologram
- Volume hologram
- Multiple-channel hologram
- Rainbow hologram
- Dichromatic hologram
- Polymer hologram

Applications:

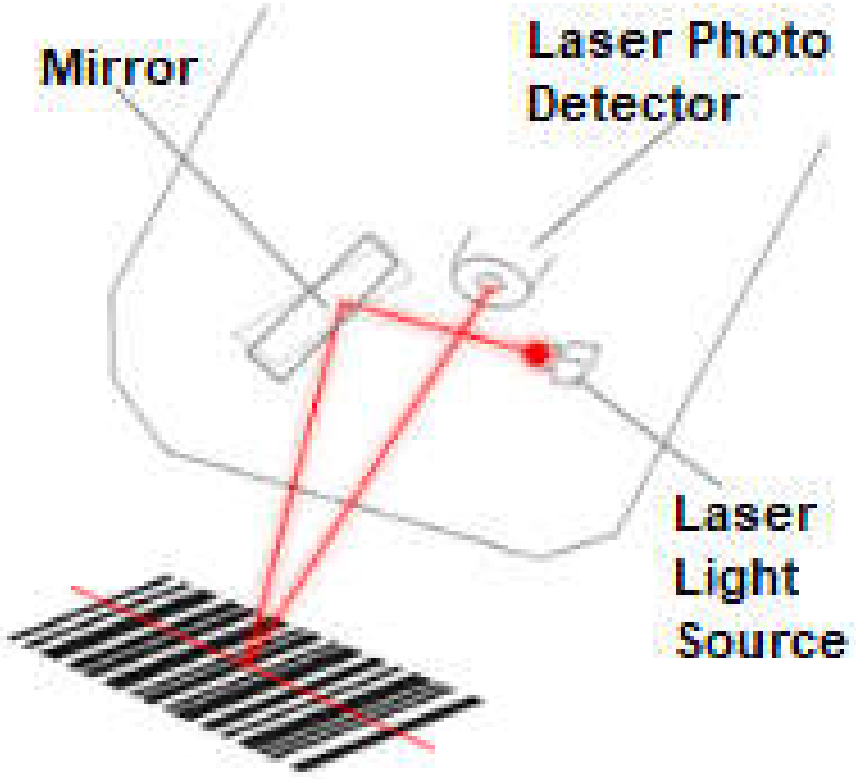
- Data storage
- Holographic Interferometric
- Interferometric microscopy
- Dynamic holography
- Optical phase conjugation
- Determine cubic dimension
- Atomic holography
- Electron holography
- Ultrasonic holography

Barcode Scanner Using Laser

- A bar code consists of white and black bars. Data retrieval is achieved when bar code scanners shine a light at a bar code, capture the reflected light and replace the black and white bars with binary digital signals.
- Reflections are strong in white areas and weak in black areas. A sensor receives reflections to obtain analog waveforms.
- The analog signal is converted into a digital signal via an A/D converter. (Binarization)
- Data retrieval is achieved when a code system is determined from the digital signal obtained. (Decoding process)

Working of barcode read

- ✓ Laser light is shone on the label surface and its reflection is captured by a sensor (laser photo detector) to read a bar code.
- ✓ A laser beam is reflected off a mirror and swept left and right to read a bar code Using laser allows reading of distant and wide bar code labels.



Thank You