# SNS COLLEGE OF ENGINEERING

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## AN AUTONOMOUS INSTITUTION

Approved by AICTE, New Delhi & Affiliated to Anna University, Chennai.

**UNIT – II LASER AND FIBER OPTICS**

**TOPIC – V: Semiconductor lasers and applications**

**Solid - State Diode lasers (Semiconductor diode laser)**

Lasing action can also be produced in semiconductors. The most compact of all lasers is the semiconductor diode laser. It is also called **injection laser.** A semiconductor diode laser is a specially fabricated p - n junction device that emits coherent light when forward - biased.

**Type of semiconductor diode laser**

There are two types of semiconductor diode lasers.

**(i). Homo - junction laser**

Homo - junction means that a p - n junction is formed by a single crystalline material.

**Example:** Gallium arsenide (Gs - As).

**(ii). Hetero - junction laser**

Hetero - junction means that the junction has one material on one side and a different material on the other side. It is also called modern laser diode.

**Example:** Hetero - junction laser can be formed between Gs - As and Ga -Al -As.

**Direct band gap semiconductor**

In this type of semiconductor, there is a large possibility for direct combination of hole and electron. During recombination process, a photon of light is released.

Ga - As is a direct band gap semiconductor, and hence it is used in light emitting diodes and lasers. The wavelength of light emitted depends on the band gap energy of the material.

**Indirect band gap semiconductor**

During the recombination of hole and electron, heat energy is released.

**Example :** Germanium and silicon.

**H**

when forward - biased.

**Principle**

When p-n junction diode is forward-biased. Fig 13.7, electrons from n-region and holes from p- region recombine with each other at the junction.

During the recombination process, light radiation (photons) is released from certain specified direct band gap semiconductors like Ga - As. This radiation is called **recombination radiation** Fig 15, and the corresponding energy is called **activation energy.** The wavelength of light emitted depends on activation energy. The photon emitted during recombination stimulates other charges and as a result, stimulated emission takes place, which produces laser.

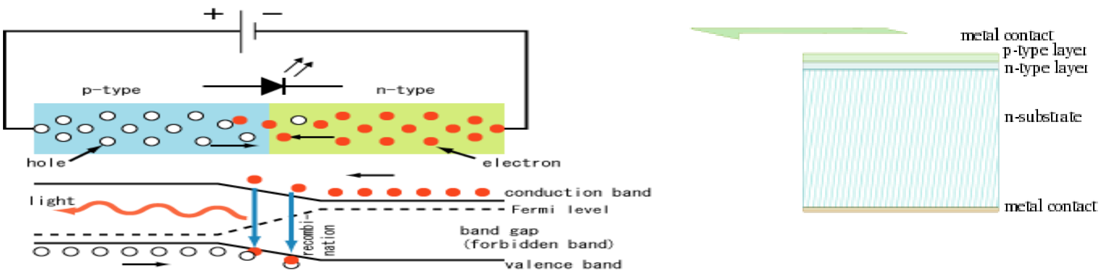


**Fig 15. Energy level and schematic diagram of Homojunction semiconductor laser**

## Construction

Fig .15. illustrates the basic construction of semiconductor laser. The active medium is a p-n junction diode made from a single crystal of gallium arsenide. It is cut in the form of a platelet having a thickness of 0.4 mm.

The platelet consists of two parts exhibiting an electron conductivity (n-type) and hole conductivity (p-type).

The photon emission is stimulated in very thin layer of (in the order of few microns) p-n junction. Electric voltage is applied to the crystal through the electrode fixed on the upper surface.

The end faces of the junction diode are well polished and parallel to each other. They act as a optical resonator through which the emitted light comes out.

## Working

The p-n junction is forward - biased with large applied voltage. The electrons and holes are injected into junction region in considerable concentration.

The region around the junction contains a large amount of electrons within the conduction band and large amount of holes in the valance band.

If population density is high, a condition called population inversion is achieved. The electrons and holes recombine with each other and produce radiation in the form of light.

When forward - biased voltage is increased, more and more light photons are emitted, and light production instantly becomes stronger. These photons trigger a chain of stimulated recombination resulting in the release of photons in phase.The photons moving at the plane of the junction travels back and forth by reflection between the two sides placed parallel and opposite to each other and grow in strength.

After gaining enough strength, it gives out the laser beam of wavelength 8400 Å.

**Characteristics**

- **Type :** It is a solid state semiconductor laser
- **Active medium:** A p-n junction diode made from a single crystal of gallium arsenide is used as active medium.
- **Pumping method:** The direct conversion method is employed for the pumping action.
- **Power Output:** The Power output from this laser is 1 mW.
- **Nature of Output:** The nature of output is continuous wave or pulsed wave.
- **Wavelength of output:** Gallium arsenide laser gives infra red radiation in the wavelength range 8300 to 8400 Å.

**Advantages**

- It is very small in dimension. The arrangement is simple and compact.
- It exhibits high efficiency.
- The laser output can be easily modulated by controlling the junction current.
- It is operated with lesser power than ruby and $CO_2$ laser.
- It requires very little auxiliary equipment.

**Disadvantages**

- It is difficult to control the mode pattern and mode structure of laser.
- The output is usually in the form of a wide beam (from $4^0$ to $14^0$).
- The purity and monochromacity are poorer than other types of laser.

**Applications**

- It is mostly used in fibre optic communication.
- It is used in laser diodes, which are more powerful and coherent that LED.
- It is used to heal wounds by infrared radiation.
- It may be used as a pain killer.
- It is used in laser printers and CD writing and reading.

## Applications of Laser

**Introduction**

Lasers are being used in communications, laser radars (LIDAR), landing systems, laser pointers, guidance systems, scanners, metal working, photography, holography, and medicine. Lasers also have a number of military applications , principally for target acquisition, fire control, and training. These lasers are termed rangefinders, target designators, and direct-fire simulators.

**Laser in Material Processing**

Material processing involves cutting, welding, hole drilling, evaporation and surface treatment. In most of the material processing application the following lasers are used.

1. $CO_2$ laser with continuous waves or pulsed
2. Nd - YAG laser.

**Welding**

In this technique, a focused laser beam is incident on spot where the two parts are to be welded. The spot contact points are get welded. Fig 14.1.

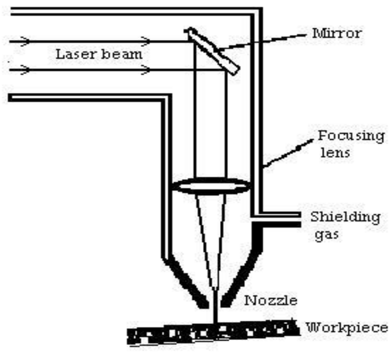


**Fig 16.Laser welding**

Laser welding is capable of a fast and highly accurate local melting at a given point or along a line. The heat affected area is very small. This is significant feature where welding is to be made in the vicinity of heat sensitive components as in the case of microelectronics.

Spot welding as well as seam welding can be performed using laser. Spot welding uses moderate powers of pulsed solid lasers such as ruby and NdYAG glass lasers. Spot welding is suitable for precision welding in a thermally sensitive environment.

**Advantages of Laser Welding**

- Laser welding is more advantageous than the familiar welding techniques like arc welding, resistance welding and electron beam welding.
- This type of welding is contact less, therefore there is no possibility for introducing harmful impurities in the weldment.
- Laser welding can be performed in atmospheric pressure unlike electron beam welding when vacuum is a must.

**Heat Treatment** A powerful laser beam is allowed to hit a metal surface. That portion gets heated. As the beam is moved away to other areas, the heated spot cools down rapidly. This procedure is used for heat treatment of metal surfaces which enhances the strength of the metal.

Laser heat treatment provides selective treatment of the desirable areas which are subjected to the more intense use. For example laser heat treatment in used in automobile industry to strengthen cylinder blocks, valve guides, gears camshafts etc.

One Kilowatt $CO_2$ laser operating in the continuous wave mode is often used for laser heat treatment.

**Advantages**

The advantages are the considerable speed with which the treatment is effected, high strengthening efficiency and least distortion of shape and size of the specimen being processed.

**Laser Cutting**

Arrangement for a gas laser cutter is shown in Fig 17. Considerable portion of energy required for cutting is supplied in this case by exothermal reactions between metal and oxygen (burning of metal in the oxygen jet). The oxygen jet also blows away and removes cutting products and melt from the cutting area, at the same time cooling the adjacent edges of the cut metal.

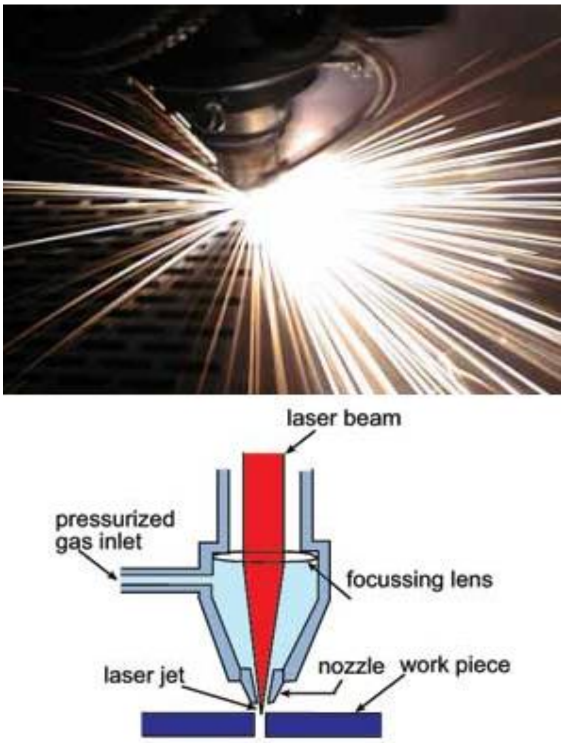


**Fig 17. Laser cutting**

Hence oxygen blow reduces laser power requirement increases the depth the velocity of cutting and produces high quality cut.

**Advantages**

Advantages of laser cutting are:

- wide range of processed materials (paper, cloth, plywood, glass, ceramics, sheet metal);
- minimum mechanical distortion and minimum thermal damage introduced in the material being cut.
- chemical purity of cutting processes;
- possibility of cutting in two and even three dimensions according to a complicated profile;
- easy automation of the process and high production rates.

Examples of laser cutting applications are laser cutting of cloths in garment factory, metal cutting in the fabrication of space craft.

**LIDAR** (**Li**ght **D**etection **a**nd **R**anging)

**LIDAR** (**Li**ght **D**etection **a**nd **R**anging) is an optical remote sensing technology that measures properties of scattered light to find range and/or other information of a distant target.

**Working of LIDAR**

The prevalent method to determine distance to an object or surface is to use laser pulses. Like the similar radar technology, which uses radio waves, which is light that is not in the visible spectrum, the range to an object is determined by measuring the time delay between transmission of a pulse and detection of the reflected signal. LIDAR technology has application in Geomatics, archaeology, geography, geology, geomorphology, seismology, remote sensing and atmospheric physics.

There are several major components to a lidar system:

- **Laser** — 600-1000 nm lasers are most common for non-scientific applications. They are inexpensive but since they can be focused and easily absorbed by the eye the maximum power is limited by the need to make them eye-safe. Laser settings include the laser repetition rate (which controls the data collection speed). Pulse length is generally an attribute of the laser cavity length, the number of passes required through the gain material (YAG, YLF, etc.), and Q-switch speed. Better target resolution is achieved with shorter pulses, provided the Lidar receiver detectors and electronics have sufficient bandwidth.

- **Scanner and optics** — How fast images can be developed is also affected by the speed at which it can be scanned into the system. There are several options to scan the azimuth and elevation, including dual oscillating plane mirrors, a combination with a polygon mirror, a dual axis scanner. Optic choices affect the angular resolution and range that can be detected. A hole mirror or a beam splitter are options to collect a return signal.
- **Photodetector and receiver electronics** — Two main photodetector technologies are used in lidars: solid state photodetectors, such as silicon avalanche photodiodes, or photomultipliers. The sensitivity of the receiver is another parameter that has to be balanced in a LIDAR design.
- **Position and navigation systems** — Lidar sensors that are mounted on mobile platforms such as airplanes or satellites require instrumentation to determine the absolute position and orientation of the sensor. Such devices generally include a Global Positioning System receiver and an Inertial Measurement Unit (IMU).

**Advantages Of Lidars**

- Lidars are well suited to study boundary layer phenomena. They are also well suited to study aerosols in the boundary layer, free troposphere, and the stratosphere.
- Lidars are also very mobile. They have been placed and used on aircraft and ships in addition to ground-based units.

**Holography - 3D Images**

A photograph is a two dimensional record of light intensity received from a three dimensional object.

Holography, a technique for recording optical images, was developed by Gabor in 1947. The term holo means **Whole or complete** and graphy mean **recording.** Holography literally means **complete recording.**

Holography records both the amplitude and the phase of light waves to produce a **three - dimensional effect (3D image).**

A three - dimensional image of an object is produced due to the interference of coherent light waves on a photographic plate.

**Basic principle**

In holography, the image of an object is not directly recorded but te light waves reflected from the object after interference with direct ray are recorded. The photographic record is called a **hologram.**

It should be noted that a hologram, has no resemblance to the original object but it contains all information about the object in the form of optical code.

When the hologram is illuminated by coherent source of light, a three - dimensional image of the original object is formed. The process of image formation from hologram is known as **reconstruction Process.**

**Steps in holography**

Holography is a two step process.

- Transformation of the object into hologram i.e., an object illuminated by coherent light is made to produce interference fringes in a photographic plate.
- Retransformation or reconstruction of hologram into an image of the object i.e., reillumination of the developed interference pattern by light of same wavelength to produce a three - dimensional image of the original object.

**Construction or Recording of a Hologram**

Holography is based on the principle of interference, and hence light waves with high degree of coherence are required for its realization. Hence, laser beam is used for preparing hologram. *The process of making a hologram is called recording or construction of hologram.*

The arrangement for recording a hologram is shown in Fig 18. A beam from helium - neon laser is divided into two beams, by means of a beam splitter ‘S’. One beam called the object beam, passes through the beam splitter, illuminates the object whose hologram is to be recorded. A part of this light scatters and falls on a photographic plate P.

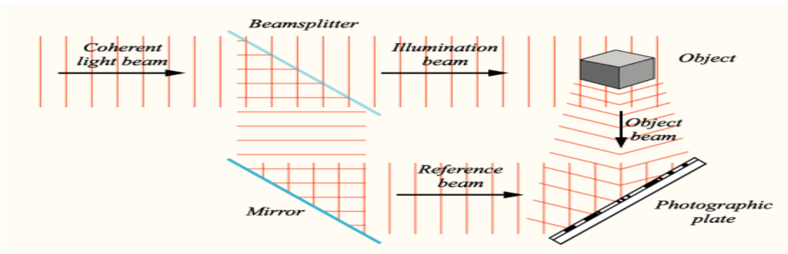


**Fig 18. Holographic recording process**

The reflected beam, called the reference beam, also falls on the photographic plate. These two beams interfere with each other and produce interference pattern, which is recorded on the plate. The pattern is very fine, the spacing between fringes being as small as 0.001mm. When the plate is developed, we get a hologram, which appears transparent.

The hologram is quite unintelligible and gives no hint of the image recorded on the plate. However, it contains all information about the object that could be easily reconstructed.

**Reconstruction of a Holographic Image**

The method of displaying a hologram is called reconstruction in which the object is recreated from the hologram by directing a beam of light at the plate as shown in Fig 19.

The laser beam, now known as readout beam, interacts with the interference pattern in the plate and produces two images from the diffracted beams emerging from the hologram. One of them appears at the original position occupied by the object, called virtual image, and the other, the real image, can be photographed directly without using a lens. The real image will appear inverted in depth but with no lateral inversion.

The hologram contains all the geometrical characteristics of an object in the form of interference pattern.

The virtual image, which can be seen by looking through the hologram, appears in complete three - dimensional form. If you move your eye from the viewing position, the perspective of the picture changes and it is possible to see the other side of the object.

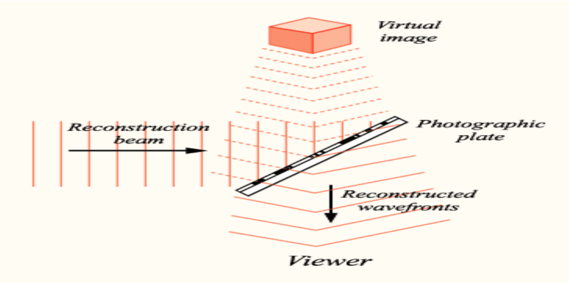


**Fig 19. Holographic reconstruction process**

**Applications of holography**

- Holography is a very reliable method of data storage.
- Holographic non-destructive testing is used to discover stresses in a pipe fitting, stress points on a wheel, and vibration pattern of a guitar.
- It helps us to determine the degree and nature of deformation of the observed surface and to study vibrational objects.
- Holography is likely to replace photography in very near future. It is expected to play a vital role in the development of every branch of science.

**Medical applications of Laser**

**Laser treatment** Lasers help to detect caries. This exploits the fact that a tooth with caries bacteria will continue to glow after it has been irradiated with green laser light. Indeed, this fluorescence provides detection of caries to a depth of one millimeter.

**Optical corrections**

Short-sighted people normally have eyeballs that are too long. This means that the image projected by the lens falls just in front of the retina rather than directly on it. The result is blurred vision, which worsens with increasing distance to the object. However, there is another cause of shortsightedness. Instead of the eyeball being too long, it can be that the refractive power of the lens and cornea is too great. One remedy is to wear glasses, which offset the excessive refractive power and therefore provide a sharp focus. Alternatively, it is also possible to modify the lens and cornea using laser surgery. This involves removing thin layers of the cornea by means of a computer-controlled laser and thereby altering its refractive power. Using this method, corrections of up to six diopters can be madeEye surgeons were using pulses from ruby lasers to weld detached retinas back in place without cutting into the eye.

**For treating heart problems**

Angina pectoris, which may herald a heart attack, has a range of symptoms, including a tightness in the chest, difficulty breathing, dizziness and sweating. These all result from an insufficient flow of blood — and therefore supply of oxygen — to the heart muscle. Remedies here include medication to increase blood flow or, in severe cases, coronary bypass surgery.

Alternatively, relief can also come from 10 to 20 small holes burned right through the heart muscle and into the heart cavity by means of a laser. Using a small catheter, the laser is maneuvered into position close to the heart without the need for major surgery. It is not yet fully understood just why this therapy should work. Born of an intuition, the basic idea behind it is to supply the heart muscle with richly oxygenated blood from the ventricle.

**Treating cancer**

Laser-induced thermotherapy offers a relatively non-invasive and risk-free method of removing liver tumors. In the course of a one-hour operation, a cannula measuring 20 centimeters in length and four millimeters across is inserted via a small abdominal incision and guided toward the cancerous growth by means of successive X-ray images. As soon as the tip of the cannula has been maneuvered into position, a laser beam is fired through it. This heats the cancerous tissue to a temperature of 80 degrees Celsius and destroys the tumor with pinpoint accuracy.