UNIT 3

Modern Optics

Learning Objectives

After studying this chapter, the student will be able to:

- Understand the principle of laser physics
- Know about the different types of Laser and their selected applications
- Recall the principle of hologram formation and reconstruction
- Understand few important industrial and medical applications of laser
- Learn how to use the holographic techniques for different purposes

3.1 INTRODUCTION

LASER is an acronym for Light Amplification by Stimulated Emission of Radiation. In laser, the intensity of light is amplified by a process called stimulated emission.

Lasers are optical phenomena which find major application in various fields such as medicine, engineering, fiber optic communication, industries, etc. Lasers are more powerful radiation than ordinary light radiation.

3.2 CHARACTERISTICS OF LASER

The following characteristics, distinguishes a laser beam from an ordinary light. They are:

1. Coherence
2. High intensity
3. High directionality
4. High monochromaticity

Laser light is highly powerful and is capable of propagating over long distances and is not easily absorbed by water.

3.2.1 Coherence

The wave trains which are identical in phase and direction are called coherent waves.

Since all the constituent photons of laser beam possess the same energy, momentum and propagate in same direction, the laser beam is said to be highly coherent.

3.2.2 High Intensity

Due to the coherent nature of laser, it has the ability to focus over a small area of 10^{-6} cm^2, i.e., extremely high concentration of its energy over a small area.

3.2.3 High Directionality

An ordinary light source emits light in all possible directions. But, since laser travels as a parallel beam it can travel over a long distance without spreading.

The angular spread of a laser beam is 1mm/meter. This reveals the directionality of the laser beam.

3.2.4 High Monochromaticity

The light from a normal monochromatic source spreads over a range of wavelength of the order 100 nm. But, the spread is of the order of 1nm for laser. Hence, laser is highly monochromatic, i.e., it can emit light of single wavelength.

3.3 EINSTEIN'S THEORY

Einstein explained the action of laser beam based on quantum theory of light. Production of laser light is a particular consequence of interaction of radiation with matter. Radiation interacts with matter under appropriate conditions and may lead to the transition of an atom or a molecule from one energy state to another. If the transition is from a higher state to a lower state, the system gives a part of its energy. But, if the transition is in the reverse direction, then it absorbs the incident energy.

There are three possible ways through which interaction of radiation and matter can take place. Among the three types, one is absorption that is also known as induced absorption and the other two are emissions.

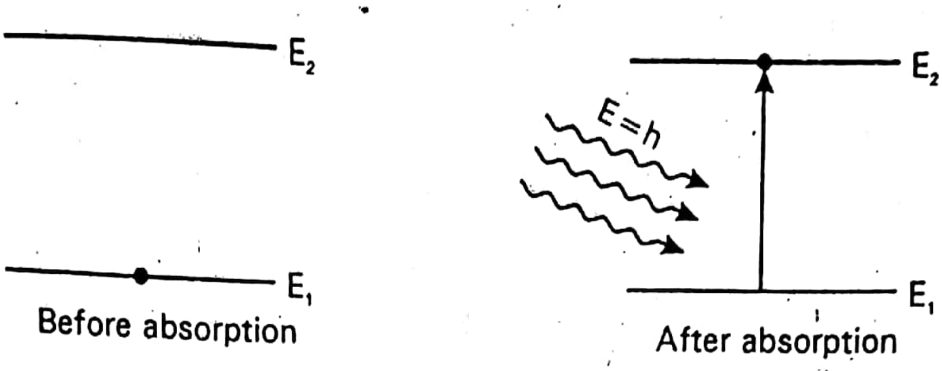
The emission of radiation can occur in two ways as suggested by Einstein. They are spontaneous emission and stimulated emission.

The interpretation of the interaction is done on the basis of ideas related to energy levels of the concerned system for which light is to be obtained.

All the three processes are described by considering an atom having only two energy levels E_1 and E_5.

(a) Induced Absorption (Absorption)

Let the atom be initially in the lower state E_1. *If a photon of energy $h\nu$ is incident on the atom in the lower state, the atom absorbs the incident photon and gets excited to the higher energy state E_2. This process is called induced aborption as shown in Figure 1.1.*



Atom + Photon $\longrightarrow$ Atom*

Figure 1: Induced absorption

The rate of absorption R_{12} is proportional to the population of the lower energy level N_1 and to the density of incident radiation ρ. Hence,

$$R_{12} \propto N_1 \rho$$

or

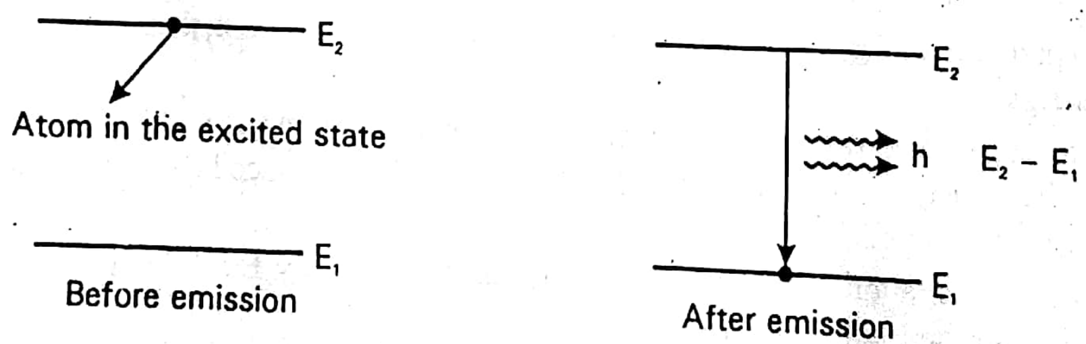
$$R_{12} = B_{12} N_1 \rho \qquad ...(1)$$

where B_{12} is the proportionality constant known as the probability of absorption of radiation per unit time.

(b) Spontaneous Emission

It is a process in which there is an emission of a photon whenever an atom transits from a higher energy state to a lower energy state without the aid of any external agency.

For this process to take place, the atom has to be in the excited state. Since, the higher energy level is an unstable one, the excited atom in the higher energy level E_2 spontaneously returns to the lower energy level E_1 with the emission of a photon of energy $h\nu = E_2 - E_1$ as shown in Figure 1.2.



Atom* $\longrightarrow$ Atom + Photon

Figure 1.2: Spontaneous emission

The rate of spontaneous emission of radiation $R_{21}(sp)$ is proportional to the population N_2 at the higher energy level E_5.

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i.e., R_{21} (sp) $\propto N_2$

$\therefore$ R_{21} (sp) = A_{21} N_2 ...(2)

where A_{21} is the proportionality constant known as the probability of spontaneous emission per unit time.

(c) *Stimulated Emission*

It is a process in which there is an emission of a photon whenever an atom transits from a higher energy state to a lower energy under the influence of an external agency, i.e., an inducing photon.

For this process also, the atom should be already in the excited state. Let a photon having an energy $h\nu = E_2 - E_1$ interact with an atom in the excited state. Under such interaction, the incident photon stimulates the excited atom in the level E_2 to transit to the lower energy level E_1, resulting in the emission of a photon of energy $h\nu = E_2 - E_1$ as shown in Figure . 3.

Both the inducing photon and the emitted photon will have the same phase, energy and direction of movement. This kind of emission is responsible for laser action, i.e., the stimulated emission of radiation is the principle used in laser action.

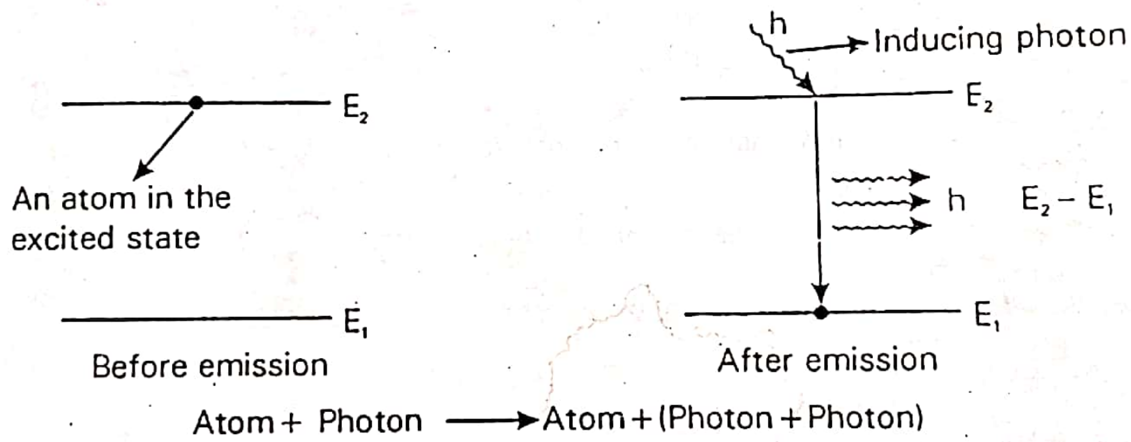

Figure .3: Stimulated emission

The rate of stimulated emission of radiation R_{21}(st) is proportional to the population N_2 at the higher energy level E_2 and to the density ρ of the inducing photon.

i.e., $R_{21}(st) \propto N_2\rho$

$\therefore$ $R_{21}(st) = B_{21}\ N_2\rho$ ...(3)

where B_{21} is the proportionality constant known as the probability of stimulated emission of radiation per unit time.

The coefficients B_{12}, A_{21} and B_{21} in the equations (1), (2) and (3) are called the Einstein's coefficients.

3.3.1 Relation between Einstein's Coefficients

Einstein obtained a mathematical expression for the existence of two different kinds of processes—spontaneous emission and stimulated emission.

Since the transition between the atomic energy states is a statistical process, it is not possible to predict which particular atom will make a transition from one state to another at a particular instant. But it is possible to calculate the rate of transmission between the states.

Let us assume that the atomic system is in equilibrium with electromagnetic radiation.

Hence at thermal equilibrium, the number of upward transitions is equal to the number of downward transitions per unit volume per second.

i.e., The rate of absorption = The rate of emission

$$B_{12} N_1 \rho = A_{21} N_2 + B_{21} N_2 \rho \qquad ...(4)$$

From the above equation,

$$(B_{12} N_1 - B_{21} N_2) \rho = A_{21} N_2$$

$$\rho = \frac{A_{21} N_2}{(B_{12} N_1 - B_{21} N_2)}$$

or

$$\rho = \frac{A_{21}}{\left(B_{12} \frac{N_1}{N_2} - B_{21}\right)} \qquad \text{[on dividing by } N_2\text{]} \qquad ...(5)$$

Under thermal equilibrium, the number of atoms N_1 and N_2 in the energy states E_1 and E_2 at a temperature T is given by Boltzmann distribution law. Hence, we have

$$N_1 = N_0 \, e^{\left(\frac{-E_1}{k_B T}\right)} \qquad ...(6)$$

$$N_2 = N_0 \, e^{\left(\frac{-E_2}{k_B T}\right)} \qquad ...(7)$$

where N_0 is the total number of atoms and k_B is the Boltzmann's constant.

$$\therefore \quad \frac{N_2}{N_1} = \frac{e^{\left(\frac{-E_2}{k_B T}\right)}}{e^{\left(\frac{-E_1}{k_B T}\right)}} = e^{\frac{-(E_2 - E_1)}{k_B T}}$$

$$\frac{N_2}{N_1} = e^{\left(\frac{-h\nu}{k_B T}\right)} \qquad \text{[Since } h\nu = E_2 - E_1\text{]}$$

or

$$\frac{N_1}{N_2} = e^{\left(\frac{h\nu}{k_B T}\right)} \qquad ...(8)$$

Substituting equation (8) in equation (5)

$$\rho = \frac{A_{21}}{\left[B_{12} e^{\left(\frac{h\nu}{k_B T}\right)} - B_{21}\right]} \qquad ...(9)$$

or
$$\rho = \frac{A_{21}}{B_{21}} \frac{1}{\left[\left(\frac{B_{12}}{B_{21}}\right) e^{\left(\frac{h\nu}{k_B T}\right)} - 1\right]} \qquad ...(10)$$

But from Planck's black body theory of radiation

$$\rho = \frac{8\pi h\nu^3}{c^3} \frac{1}{e^{\left(\frac{h\nu}{k_B T}\right)} - 1} \qquad ...(11)$$

Hence, comparing equations (10) and (11), we get

$$\frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3} \qquad ...(12)$$

$$B_{12} = B_{21} \qquad ...(13)$$

Take $B_{12} = B_{21} = B$ and $A_{21} = A$. ***The constants A and B are called Einstein's coefficients.***

Equation (13) shows that the probability of absorption is equal to the probability of stimulated emission.

From equation (12) it is seen that the ratio of spontaneous emission and stimulated emission is proportional to ν^3. It means that the probability of spontaneous emission dominates over stimulated emission.

5.3.2 Ratio of Spontaneous and Stimulated Emission Rates

From equations (2) and (3)

$$\frac{R_{21}(st)}{R_{21}(sp)} = \frac{B_{21}N_2\rho}{A_{21}N_2}$$

$$\frac{R_{21}(st)}{R_{21}(sp)} = \frac{B_{21}}{A_{21}}\rho \qquad ...(14)$$

But from equation (10),

$$\frac{B_{21}}{A_{21}}\rho = \frac{1}{\left[\frac{B_{12}}{B_{21}} e^{\left(\frac{h\nu}{k_B T}\right)} - 1\right]}$$

But $B_{12} = B_{21}$ from equation (13). Therefore, the above equation becomes

$$\frac{B_{21}}{A_{21}}\rho = \frac{1}{\left[e^{\left(\frac{h\nu}{k_B T}\right)} - 1\right]} \qquad ...(15)$$

Replacing the R.H.S. of equation (14) with equation (15), we get

$$\frac{R_{21}(st)}{R_{21}(sp)} = \frac{1}{\left[e^{\left(\frac{h\nu}{k_BT}\right)} - 1\right]}$$

or

$$\frac{R_{21}(sp)}{R_{21}(st)} = e^{\left(\frac{h\nu}{k_BT}\right)} - 1 \qquad ...(16)$$

Thus, when the energy of the incident photon is much greater than k_BT, the number of spontaneous emissions far exceeds the number of stimulated emissions. Hence, under this condition, i.e., $h\nu >> k_BT$, laser action is not possible.

In order to achieve more stimulated emission, the population N_2 of the excited state should be made larger than the population N_1 of the lower state. This condition is called population inversion.

Hence, in order to amplify a beam of light by stimulated emission, we have to create a population inversion state and increase the energy density of interacting radiation.

3.3.3 Difference between Stimulated and Spontaneous Emission

S. No.	Stimulated Emission	Spontaneous Emission
1.	Emission of a light photon takes place through an inducement i.e., by an external photon.	Emission of a light photon takes place immediately without any inducement.
2.	It is not a random process.	It is a random process.
3.	The photons get multiplied through chain reaction.	The photons do not get multiplied through chain reaction.
4.	It is a controllable process.	It is an uncontrollable process.
5.	More intense.	Less intense.
6.	Monochromatic radiation.	Polychromatic radiation.

Example 1

Find the ratio of population of the two energy states in a laser the transition between which is responsible for the emission of photons of wavelength 698.3×10^{-9} m. Assume the temperature to be 300 K.

Solution:

Given, $T = 300$ K; $\lambda = 698.3 \times 10^{-9}$ m; $\frac{N_2}{N_1} = ?$

Let ΔE be the energy difference between the two energy states.

$$\therefore \quad \frac{N_2}{N_1} = e^{\left(\frac{-\Delta E}{k_BT}\right)}$$

where, $\Delta E = \dfrac{hc}{\lambda}$

Hence, $$\frac{N_2}{N_1} = e^{-\left(\frac{6.625\times10^{-34}\times3\times10^{8}}{698.3\times10^{-9}\times1.38\times10^{-23}\times300}\right)}$$

$$= e^{-\left(\frac{1.9875\times10^{-25}}{2.89096\times10^{-27}}\right)} = e^{-68.748}$$

$\therefore$ $$\frac{N_2}{N_1} = \mathbf{1.3892 \times 10^{-30}}.$$

3.4 BASIC CONCEPTS IN LASER PHYSICS

3.4.1 Population Inversion

Population inversion is a state of achieving more number of atoms in the excited state compared to the ground state.

i.e., $N_2 > N_1$

If this condition is satisfied, then there is more chance for stimulated emission to take place. Hence, population inversion is an essential condition for producing laser.

Population inversion can be achieved by a process called pumping.

3.4.2 Pumping

Pumping is the mechanism of exciting atoms from the lower energy state to a higher energy state by supplying energy from an external source.

The most commonly used pumping mechanisms are discribed below.

Optical Pumping

In this type of pumping atoms are excited (i.e., population is inversion achieved) by means of an external optical source.

This type of pumping technique is adopted in solid state lasers such as ruby laser and Nd: YAG laser.

Electrical Pumping (Direct Electron Excitation)

In this type of pumping the electrons are accelerated to a high velocity by a strong electric field. These moving electrons collide with the neutral gas atoms and ionise the medium. Thus, due to ionisation they get raised to a higher energy level.

This technique of pumping is adopted in gas lasers such as CO_2 laser.

Direct Conversion

In this type of pumping, a direct conversion of electric energy into light takes place. This technique of pumping is adopted in semiconductor laser.

In addition to the above three, the other types of pumping are *inelastic collision between atoms and chemical methods which are, respectively, adopted in He-Ne gas laser and in dye and chemical lasers.*

Lasing

The process which leads to emission of stimulated photons after establishing the population inversion is referred to as lasing.

Life Time

The limited time for which a particle or an atom remains in the excited is known as life time. It is about a nano second.

Metastable State

Metastable states are the energy levels in an atomic system where the life time of atoms is very large (of the order 10^{-3} to 10^{-2} second). This property helps in achieving the population inversion.

Active Medium

A medium in which population inversion is achieved for laser action is called active medium. The medium can be solid, liquid, gas and plasma.

Based on the active medium and method of pumping, the lasers are classified into:

(1) Solid state lasers
(2) Liquid lasers
(3) Gaseous lasers
(4) Dye lasers
(5) Semiconductor laser

Optical Resonator

It is a pair of reflecting surfaces (mirrors) of which one is a perfect reflector and the other is a partial reflector.

It is used for amplification of photons thereby producing an intense and highly coherent output.

Principle of Laser

Laser is based on the principle of stimulated emission of radiation with light amplification. For stimulated emission of radiation to take place, the population of atoms in higher energy level should be greater than the lower energy level, i.e., $N_2 > N_1$. This can be achieved by pumping. Light amplification is achieved by photon multiplication within an optical resonator cavity.

Initially, the state of population inversion has to be achieved in the active medium which is within a resonator cavity. Then, a spontaneously emitted photon by one of the excited atom stimulates another atom it encounters in its path to release a second photon. Thus, these two photons which are coherent in nature stimulate other two atoms to produce another two photons. Hence, there will be four coherent photons. Thus, the photon number gets

2. It is widely used in open air communication.
3. It is used in pollution monitoring, remote sensing and in LIDAR (LIght Detection And Ranging).
4. It is used in medical field to perform microsurgery and bloodless surgery.

3.7 APPLICATIONS OF LASER

Some of the applications of laser in various fields are listed below.

(a) In Industry

In industries, lasers are applied to a larger extent for the following processes:

(1) For welding and melting.
(2) For cutting and drilling holes.
(3) To test the quality of the materials.
(4) For the heat treatment of metallic and non-metallic materials.

(b) In Medicine

(1) Used for the treatment of detached retinas.
(2) Used in performing micro and bloodless surgery.
(3) Used for the treatment of human and animal cancers and skin tumours.

(c) Military applications

(1) The laser beam can serve as a war weapon, i.e., A powerful laser beam can be used to destroy in a few seconds, the big size objects like aeroplanes, missiles etc., by pointing the laser beam on to them. For this reason, it can be even called as death ray.
(2) The laser beam can be used to determine precisely the distance, velocity and direction as well as the size and form of distant objects by means of the reflected signal. It is known as LIDAR.

(d) Science and engineering applications

(1) It is used in fiber optic communication.

(2) Communication between planets is possible with laser.

(3) It is used in holography.

(4) It is used in underwater communication between submarines, as they are not easily absorbed by water.

(5) It is used to accelerate some chemical reactions.

(6) It is used to create new chemical compounds by destroying atomic bonds between molecules.

(7) It is used to drill minute holes in cell walls without damaging the cell itself.

3.8 LASERS IN MATERIAL PROCESSING

Laser has widespread nature of material processing. In this section few important examples of laser in material processing are discussed in brief.

Laser in material processing represent a small fraction of growing list of applications that take advantages of unique properties of light produced from many different types of laser. The different types of lasers that are used in material processing depends on the following factors.

1. Their active medium (solid, liquid and gas).
2. Wavelength, power and energy.
3. Mode of operation (continuous wave mode (cw) or pulsed mode).
4. The variety of materials to be treated. Like metals, alloys, ceramics, glasses, polymers and composites.
5. The mechanism of thermal processing. Like heating, melting and vapourisation.
6. The material interaction. Like thermal (induced by heat transfer) and athermal (induced by changes in the atomic scales).

3.8.1 Laser Instrumentation for Material Processing

The assembly of instruments for laser material processing is shown in Figure . .9. The laser setup shown is used for welding, cutting, drilling and surface modifications.

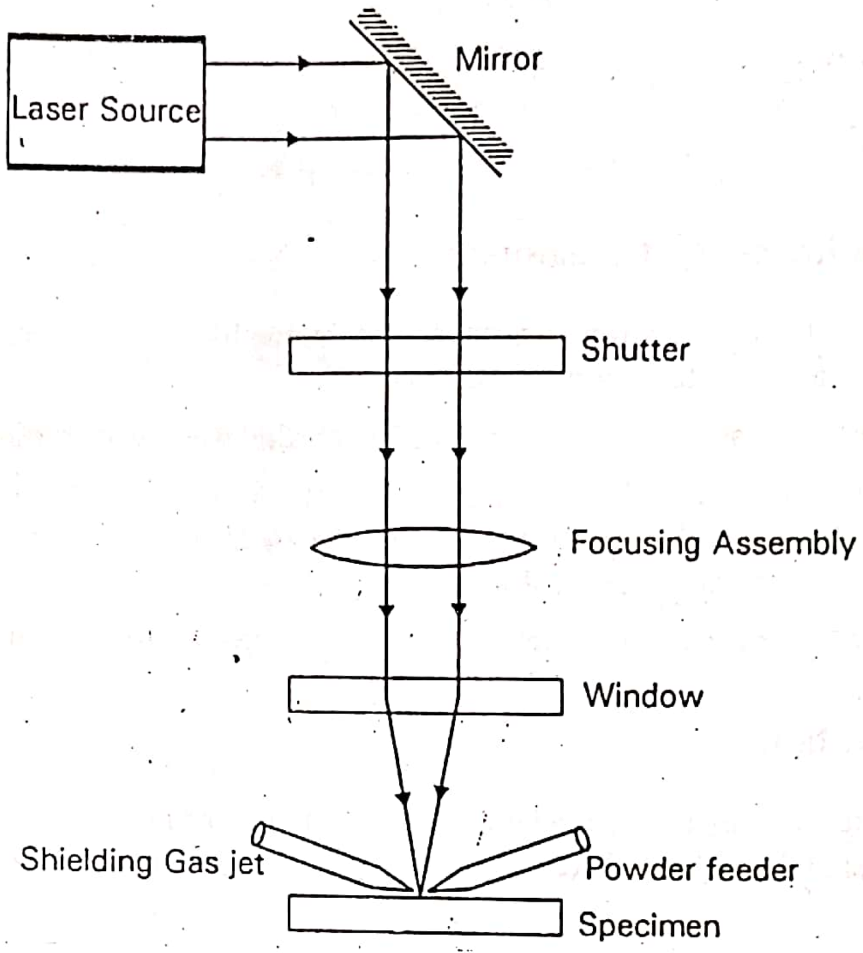

Figure 3.9: Schematic diagram of laser instrumentation for material processing

Instrument Description

The assembly consists of a laser source to produce laser beam, a shutter to control its intensity and there is a focussing assembly (assembly of lenses) to get a fine beam and there is a window to effectively focus the laser on to the specimen.

In addition to the above components, there is a shielding gas jet and a powder feeder. The shielding gas jet is used to (i) remove the molten material (ii) provide cooling effect (iii) protect the focussing optical arrangements against smoke and fumes and (iv) increase the absorbtion of energy by the specimen and to favour vapourisation. For different materials different gases are used. The gases used include air, N_2, O_2, Ar, etc. The powder feeder is used to feed the metal powder whenever necessary.

Working

When the laser source is switched on, the light reflected by the plane mirror passes through the shutter. The shutter controls the intensity of the laser beam and allows it to fall on the focussing lens assembly. This lens assembly focusses the light effectively onto the window and is made to incident on the specimen.

When the specimen gets exposed to the laser beam, it gets heated up giving rise to smokes and fumes and also gets melted. By blowing the gas from the shielding gas jet, the smokes, fumes and molten materials are removed. But as the laser beam is continuously falling onto the specimen the material can be drilled, cut or welded.

Powder spray is used to spray the metal powder on to the substrate for alloying or cladding. There are various other arrangements to monitor and to control the flow of powder and shielding gas.

Advantages

1. Time consumption is less.
2. There is no damage to the materials.
3. There is no need of machining after the processing.
4. Compared to electron beam of material processing there is no need of vacuum.

3.8.2 Lasers in Microelectronics

In electronics industry lasers are widely used in processing microelectronic components and integrated circuits. Few applications of laser in the field of microelectronics are listed below.

1. It is used for trimming of components of the IC's with higher accuracy.
2. Lasers are used in cutting touch pads for cell phones.
3. Using laser, battery cathodes can be cut from aluminum foil and also to cut dielectric from paper for use in cardiac pacemaker implants.
4. Other applications of lasers in the microelectronics field include;high speed printing (laser printers), laser pointers (an eye catching pointing device used in presentations and visual demonstration), all thin film circuit fabrication, as a source in LAN's (Local Area Network), laser evaporation, bar code scanners etc.

3.8.3 Laser Welding

Process

Welding is the process of joining two or more pieces (of same type or different type) into a single unit. In laser welding laser beam is focussed on to the spot to be welded as shown in Figure : 10.

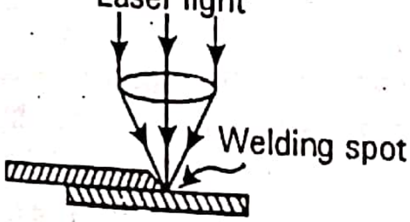

Figure 10: Laser welding

Due to high heat generated by the laser, the material melts over a tiny area on which the beam is focussed. Since the heat produced by the beam is so intense, the impurities in the materials such as oxides float upon the surface, and upon cooling the material within becomes homogeneous solid structure which makes it as a stronger joint.

The Nd : YAG and CO_2 lasers are the two important kinds of lasers that find wide range of applications in welding.

Applications of Laser in Welding

1. CO_2 lasers are used for welding thin sheets and foils where the weld region is wider than its depth.
2. In laser welding of two wires, one may have an effective weld even without the removal of the insulation.
3. Using laser, welding of two dissimilar metals can also be performed. For example measuring probes can be attached to transistors, turbine blades, etc.
4. Laser welding can be done in otherwise inaccesible areas like inside a glass envelope.

Advantages of Laser Welding

Laser welding offers many supermacy advantages over traditional welding techniques. Advantages of laser welding over traditional welding are,

1. Laser welding is a contact less process and thus no foreign material has a chance to get into the welded joint.
2. The result of welding is consistent and reliable.
3. Narrow welds with a controlled bead size are possible, because only a small area of metal is melted.
4. Distortion is minimum because less metal is melted in a shorter time and the heat affected zone (HAZ) is smaller.
5. Faster welding and high production rates can be achieved.

The above features allow welding near heat sensitive or distortion critical parts.

Note:

The laser source used in welding should not have too high power. This is because, a high laser power may evaporate the material and such removal in general lead to bad welds.

3.8.4 Laser Heat Treatment

Heat treatment is the process which consists of heating metals and certain other materials for some time to harden them. The high heat energy produced by a laser beam is ideal for surface modification. Laser heating produces local changes at the surface of material while leaving the properties of the material component unchanged. The laser heat treatment process can be divided into three broad areas.

1. *Heating without melting*: This is generally known as heat treating. In this process, surface of the metal is not melted, but it involves a solid state transformation. As a result of the metallurgical reactions produced during these heating and cooling cycles both mechanical (resistance, hardness, etc.) and chemical properties (corrosion resistance etc) greatly get enhanced.

2. *Heating with melting*: (Laser glazing, surface homogenization and remelting) This method involves very rapid heating, melting and cooling to modify the surface properties.
3. *Melting with addition of material*: This method involves melting of the surface plus addition of another material to form a modified surface laser.

In general CO_2, Nd : YAG lasers are used for laser processing.

Advantages of Laser Heat Treatment

1. Surface hardening increases wear resistance and fatigue life through microstructural changes in the metal surface during processing.
2. As the efficiency of laser processing is very high it resulted in low distortion.
3. As the output beam can easily be shaped by optical components into square, circle, lines or into more complex axi symmetric shapes it makes it easy to heat treat machine parts such as bearing races, gears, shafts, cylinders, camshaft, etc.
4. Heat treatment over a very small portion of a larger system is also possible.

3.8.5 Laser Cutting

Laser cutting is a technology that uses a laser to cut materials. The most popular lasers for cutting materials are CO_2 and Nd : YAG.

Process

Laser cutting of metals is generally done with the help of gas, like air, oxygen, nitrogen or argon which is directed into the cut through a nozzle.

When a high power laser beam is focussed at the surface of the material to be cut it melts the material. The melted material can be removed by making use of a gas jet coaxial with the laser as shown in Figure 11.

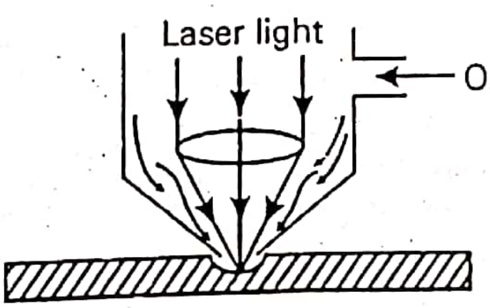

Figure 11: Laser cutting

The laser focussing part is surrounded by a nozzle into which oxygen gas is passed. When laser heats up the material, it interacts with the gas and the gas gets combustion. The combustion of the gas burns the metal thus reducing the laser power requirement for cutting.

The tiny splinters along with the molten part of the metal will be blown away by the oxygen jet. The gas jet also help in removing the molten material. It is the laser and not the burning gas which controls the accuracy of cutting. Thus, the cut edges will be of very high quality.

oxygen is used in cases where oxidation of the edge is allowable. The cutting rate gets increased when oxygen is used for cutting metals due to the reaction between the oxygen and molten metal.

To cut materials that are oxide free, like wood, paper, plastic etc., instead of oxygen inert gases like nitrogen or argon is used.

Applications of Laser in Cutting

1. Laser cutting is used to cut all types of metals including carbon, stainless and zinc coated steel, super alloys, aluminium, titanium etc.
2. Laser cutting is also used for cutting plastics and ceramics.
3. Laser cutting can also be used to cut materials coated with enamel, porcelain or ceramics without causing any damage to the outer coating.
4. Laser are also used in garment industry to cut dozens to hundreds of thickness of cloth.
5. Laser cutting of stainless steel nickel alloys and other metals find widespread application in the aircraft and automobile industries.

Advantages of Laser Cutting

The advantages of laser cutting are,

1. *Flexibility*: The range of materials to which laser cutting can be applied.
2. *Edge quality*: The laser cutting results in high quality edges which can be painted without additional finishing.
3. *Easy automation:* Can easily automated to limited operator involvement and even "light out" operation.
4. *Distortion free*: There is no physical contact between the workpiece and the cutting tool.
5. High precision.

3.9 HOLOGRAPHY

Introduction

In a conventional photography when an object is photographed by a camera, it records only the intensity distribution and hence produces a two-dimensional image of a three-dimensional object.

A new technique known as holography was developed by Gabor in 1947. The Greek term 'holos' mean whole and 'graphos' mean writing. Therefore, holography means a complete recording.

Thus, holography is a technique of recording the amplitude and phase of the light waves reflected from an object. Hence, a three-dimensional image of the object can be obtained. *The recorded photograph is called a hologram.*

Principle of Holography

The principle of holography can be explained in two steps.

1. Recording of hologram or construction of hologram. The recording of hologram is based on interference of coherent light waves.
2. Reconstruction of hologram. This reconstruction of hologram is based on diffraction of light waves.

3.9.1 Recording or Construction of a Hologram

The process of making a hologram is referred to as recording of a hologram or construction of a hologram. This is based on the principle of interference of light.

The light from a laser source is split into two components S and R, as shown in Figure 12.

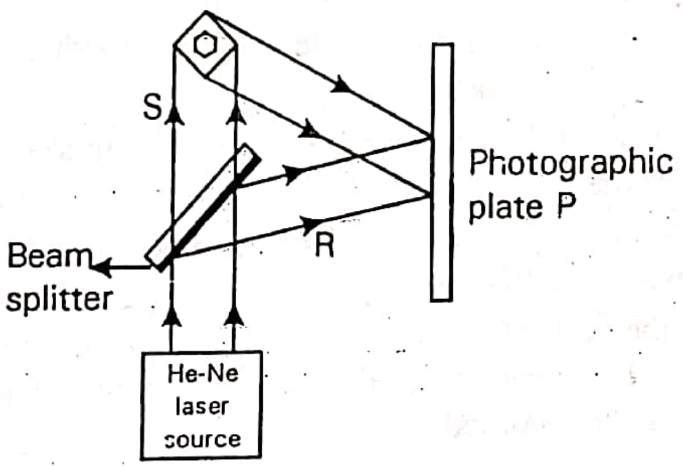

Figure .12: Construction of Hologram

One of the beams, S, is directed towards the object while the other beam R is directed towards the photographic plate. *The wave illuminating the object is called the object wave or signal wave, and the wave directed towards the photographic plate is called the reference wave.*

Since both waves S and R are derived from a single source, they behave as coherent beams. Thus, the two beams interfere with each other producing interference pattern on the photographic plate. Hence, the record of this interference pattern constitutes a hologram.

The developed hologram will look like an ordinary negative. But it contains a complete record of the original object, recorded in the form of an interference fringe pattern.

3.9.2 Reconstruction of a Hologram

Reconstruction of a hologram refers to the method of retrieving the original image from a hologram. This is based on the principle of diffraction of light waves.

Figure 13 shows the method of reproducing the real and virtual image of the object.

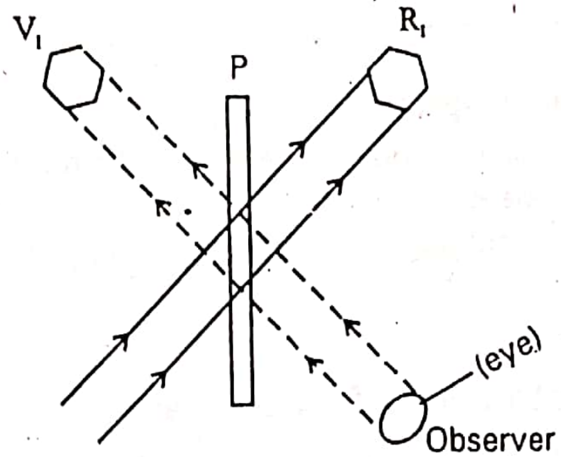

Figure 13: Reconstruction of Hologram

The developed hologram is exposed to a laser beam of the same wavelength, which was used while constructing the hologram. This laser beam called the readout wave or reconstruction wave interacts with the interference pattern on the hologram and gets diffracted to produce two images of the original object.

On looking from the far side of the hologram, an observer can see the virtual image occupying the same position as the original object. This vitrual image V_I is indistinguishable from the object and appears in three-dimensional form. One can observe the different perspectives of the object on moving his eye.

The other image called the real image, R_I, is formed between the observer and the hologram. The real image will appear inverted indepth. This image is also known as pseudoscopic image which can be recorded.

Applications of Holography

1. It is used in data storing system.
2. It is used in producing a 3D image of an object.
3. It is used in studying the distribution of strain in an object subjected to stress.
4. It is used in scanners.
5. It is used in displaying a 3D image.

SUMMARY

- LASER stands for Light Amplification by Stimulated Emission of Radiation.
- A laser beam is coherent and has high intensity, directionality and monochromaticity.
- Einstein's theory is based on quantum theory of light and explains the action of laser beam.
- There are three possible ways through which interaction of radiation and matter occurs. Among these, one is induced absorbtion and the other two are spontaneous emission and stimulated emission.
- Relation between Einstein's coefficients is given by $A_{21}/B_{21}=8\pi h\nu^3/c^3$.
- Population inversion is a state of achieving more number of atoms in excited state compared to the ground state and is achieved by the process of pumping.