Chapter – 10

LASER BEAM MACHINING (LBM)

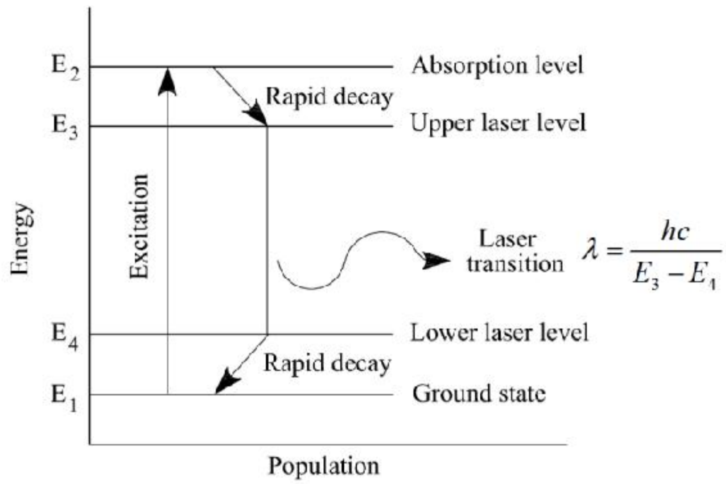

Figure 10.2 Energy transitions in a four-level laser system

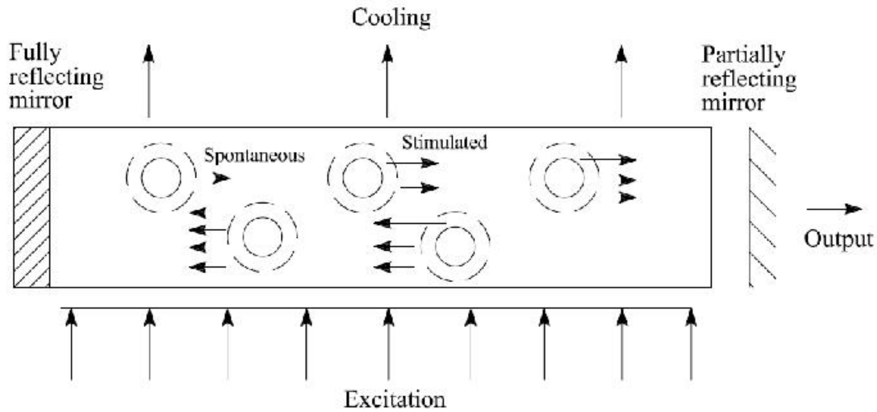

Figure 10.3 Schematic illustration of amplification by stimulated emission

gain. If the loss is greater than the gain then the laser will not produce light. Positive gain is the second requirement for laser light generation - the first being a population inversion.

10.3 MATERIAL REMOVAL MECHANISM

Laser radiation is essentially electromagnetic waves, thus, absorption of light can be explained as the interaction of the electromagnetic radiation (characterized by electric and magnetic vectors) with the electrons (either free or bound) of the material. The absorbed radiation results in the excess energy of the charged particles such as kinetic energy of the free electrons, excitation energy of the bound electrons, etc. Eventually, the degradation of the ordered and localized primary excitation energy through various steps leads to the generation of heat. Hence, the absorption process is sometimes referred to as the secondary "source" of energy inside the material and is used to determine the extent of various effects on the material during laser–material interactions.

Laser light impinging on the surface of a material may be absorbed, reflected, transmitted, or re-radiated. The absorption of laser radiation in the material is generally expressed in terms of the Beer-Lambert law:

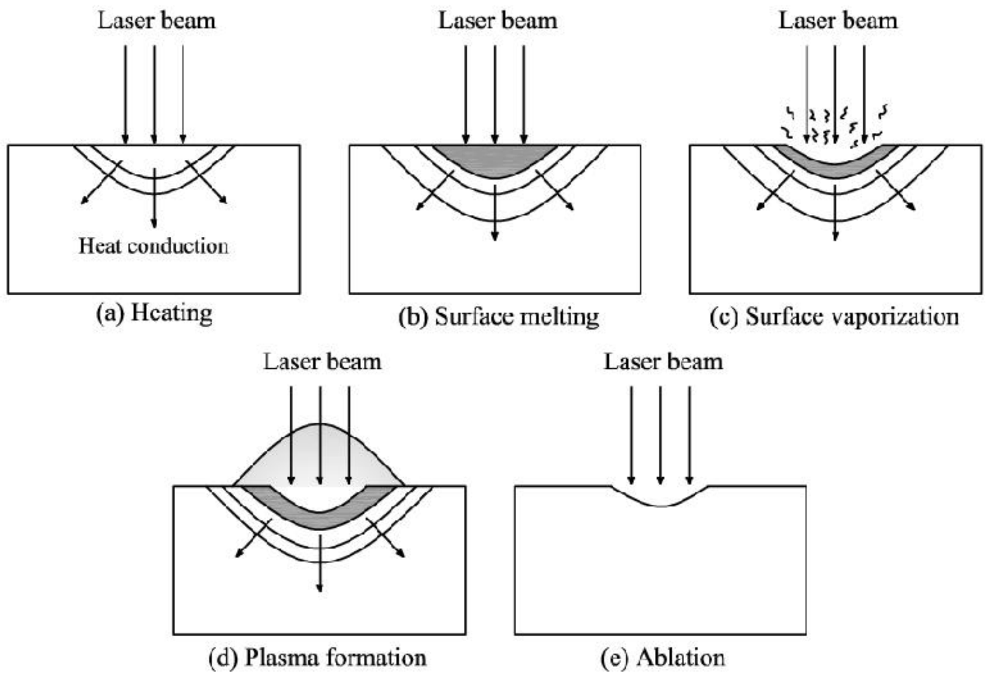

Figure 10.4 Schematic of laser–material interaction through (a) heating, (b) surface melting, (c) surface vaporization, (d) plasma formation and (e) ablation

$$I(z) = I_0 e^{-\beta z}$$

In the above equation, I_0 is the incident intensity, $I(z)$ is the intensity at depth z, and β is the absorption coefficient. Thus, the intensity of the laser radiation is attenuated inside the material. One of the important parameters influencing the effects of laser–material interactions is the absorptivity of the material for laser radiation. It can be defined as the fraction of incident radiation that is absorbed at normal incidence. On the other hand, the reflectivity (and hence the absorptivity) of the material is greatly influenced by the wavelength and temperature. As the temperature of a material changes, the absorptivity of the laser beam can increase or decrease, depending on its optical properties and modifications to the surface, e.g. oxidation reactions or phase transformations. For many metals and alloys in the solid phase, the absorptivity in the infrared range is well approximated by an increase relationship with temperature. A material, which is strongly reflective at low temperature, may become strongly absorbing at high temperature. This is of particular importance in the laser processing of materials where laser–materials interaction results in significant increase in the surface temperatures. Other parameters, which influence the absorptivity of the material, include angle of incidence of the radiation and surface condition of the material.

The laser energy absorbed by the material during laser–material interaction is converted into heat by degradation of the ordered and localized primary excitation energy. The typical overall energy relaxation times are of the order of 10^{-13} s for metals (10^{-12}–10^{-6} s for nonmetals). The conversion of light energy into heat and its subsequent conduction into the material establishes the temperature distributions in the material. Depending on the magnitude of the temperature rise, various physical effects in the material include heating, melting and vaporization of the material. Furthermore, the ionization of vapor during laser irradiation may lead to generation of plasma. In addition to the thermal effects, the laser–material interactions may be associated with photochemical processes such as photo-ablation of the material. These effects of laser–material interactions are schematically presented in Figure 10.4. All of these effects play important roles during laser materials processing. There exist distinct combinations of laser intensities and interaction times where specific effect of laser–material interaction dominates.

10.4 TYPES OF LASERS

According to the laser medium used for generation of laser beam, the lasers are classified into followings:

(i) Solid state lasers: Ruby laser, Nd:YAG laser, Nd:glass laser
(ii) Gas lasers: Argon laser, Krypton laser, Helium-Neon laser, CO_2 laser
(iii) Metal vapour laser: Copper, Gold
(iv) Excimer laser: Argon-Fluorine, Krypton-Fluorine, Xenon-Chlorine
(v) Dye laser: Polymethene dye, Courmarine dye, Rhodamine laser
(vi) Diode laser: Homojunction (Ga As laser), Heterojunction (GaAlAs laser)

According to power of laser beam, lasers are classified into four classes as follow:

(i) Class I laser: Low power lasers usually less than 0.4mW, examples: laser printers, CD/DVD players and diode lasers
(ii) Class II laser: Low power lasers, power range 0.4 to 1 mW, examples: laser pointers, range finders
(iii) Class III laser: Class IIIa – Intermediate power lasers, power range – 1 to 5 mW, example: laser scanner, Class IIIb - Intermediate power lasers, (i) Continuous Wave (CW) laser, power range – 5 to 500 mW (ii) Pulsed laser, energy density is less than $10J/cm^2$, example: Dye lasers.
(iv) Class IV laser: High power lasers, (i) Continuous Wave (CW) laser, power is more than 500 mW (ii) Pulsed laser, energy density is more than $10J/cm^2$, Examples: Argon laser, Nd:YAG laser, CO_2 laser, etc.

10.5 WORKING PRINCIPLE OF Nd:YAG LASER

Nd:YAG laser is a neodymium element (rare earth) based laser. YAG stands for Yttrium Aluminum Garnet ($Y_3Al_5O_{12}$), which exist in the form of crystal. Nd:YAG laser is a four level solid state laser. Figure 10.5 shows the energy level diagram for Neodymium (Nd3+) ions. When the krypton flash lamp is switched on, by the absorption of light radiation of wavelength 0.73 μm and 0.8 μm, the Neodymium (Nd^{3+}) atoms are raised from ground level E_0 to upper levels E_3 and E_4 (Pump bands). The Neodymium ions atoms make a transition from these energy levels E_2 by non-radiative transition. Energy level E_2 is a metastable state. The Neodymium ions are collected in the level E_2 and the population inversion is achieved between E_2 and E_1. An ion makes a spontaneous transition from E_2 to E_1, emitting a photon of energy $h\nu$. This emitted photon will trigger a chain of stimulated photons between E_2 and E_1. The photons thus generated travel back and forth between two mirrors and grow in strength. After some time, the photon number multiplies more rapidly. After enough strength is attained (condition for laser being satisfied), an intense laser light of wavelength 1.064 μm is emitted through the partial reflector. It corresponds to the transition from E_2 to E_1.

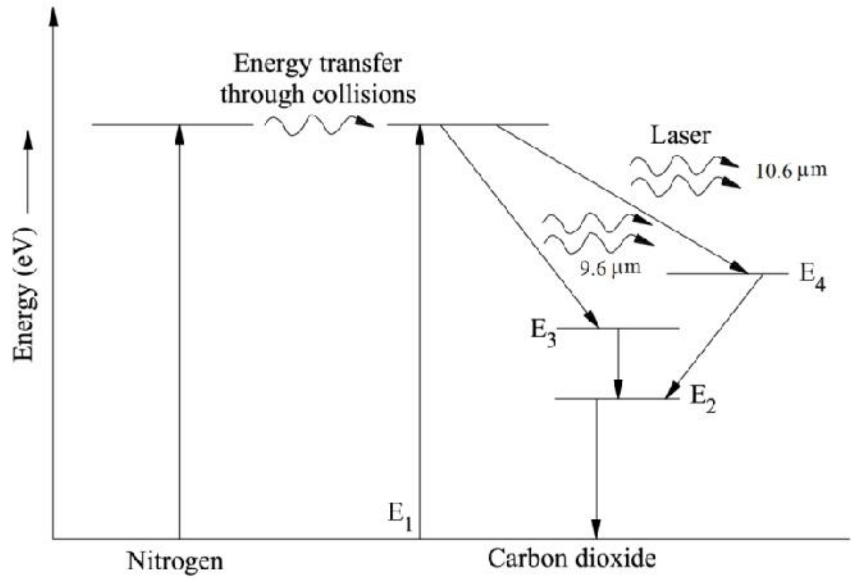

Figure 10.9 Schematic showing the energy levels of nitrogen and carbon dioxide molecules

Figure 10.9 shows the energy levels of nitrogen and carbon dioxide molecules. When an electric discharge occurs in the gas, the electrons collide with nitrogen molecules and they are raised to excited states. This process is represented by the equation (10.1).

$$N_2 + e^* = N_2{}^* + e \qquad (10.1)$$

Here, N_2 is nitrogen molecule in ground state, e^* is electron with kinetic energy, $N_2{}^*$ is nitrogen molecule in excited state and e is same electron with lesser energy. Now N2 molecules in the excited state collide with CO_2 atoms in ground state and excite to higher electronic, vibrational and rotational levels. The representing equation for this process is

$$N_2{}^* + CO_2 = CO_2{}^* + N_2 \qquad (10.2)$$

Here, CO_2 is carbon dioxide atom in ground state, $CO_2{}^*$ is carbon dioxide atom in excited state and N_2 is nitrogen molecule in ground state. Since, the excited level of nitrogen is very close to the E5 level of CO_2 atom, population in E5 level increases. As soon as population inversion is reached, any of the spontaneously emitted photon will trigger laser action in the tube. There are two types of laser transition possible. In first type of transition from level E5 to E4, laser beam of wavelength 10.6 μm is produced. However, in another type of transition from level E5 to E3, laser beam of wavelength 9.6 μm is produced.

10.7 PROCESS PARAMETERS IN LBM

Laser beam machining process has several predominant process parameters upon which the machining characteristics are depending upon. These process parameters are discussed hereunder.

(a) Laser power: This parameter directly influence the amount of material removed from workpiece. In most of the laser beam setup, the power of laser beam is controlled by lamp current if there is flash lamp or by semiconductor diode if the laser system is diode pumped. The power of the beam should be such that the material gets enough thermal energy to melt and vaporize and the unwanted phenomena such as heat-affected zone, recast layer formation and generation of micro-cracks can be minimized.

(b) Pulse frequency: The pulse frequency or pulse repetition rate determines the number of times the 'burst' of photons strike the workpiece surface per unit time duration. The high peak power pulses at low frequencies will increase the surface temperature very rapidly resulting in material vaporization and minimal heat conduction into the work material. At higher repetition rates, the lower peak power will produce less energy to vaporize the material but will result in significantly more heat conduction.

(c) Pulse width: Pulse width is expressed as the % of duty cycle. Required pulse width depends on the time needed to vaporize the material for micro-machining operation. It should not be shorter than the penetration time of laser beam. High quality beam is produced by precisely controlling this parameter..

(d) Cutting speed: In LBM, cutting speed plays very significant role for the quality of machining. The displacement of work piece during pulse cycle should be smaller than the diameter of the focused spot to achieve smooth machining surface. For effective cutting by laser beam, the spot overlap play significant role. The amount of overlap between two consecutive laser spots is high when the cutting speed is low. However, for high cutting speed, the quality and geometrical accuracy of machined surface is much less due to reduced overlapping between laser spots. In addition, the amount of heat affected zone increases at low speed cutting.

(e) Rotational speed: This process parameter is used when machining of cylindrical shaped job. Cutting, grooving or marking on cylindrical surface of workpiece can be carried out by proper controlling the rotating speed of job and by proper ON/OFF of laser beam by Q-switch.

(f) Assist air pressure: Assist air pressure plays important role for quality and accuracies of machined parts. Also, for achieving high aspect ratio features, assist air pressure becomes a significant parameter because it helps to eject the molten materials from bottom of the machining holes or respective feature. Apart from using air, many times, different type of compressed gas is also used to avoid oxidation of workpiece when machining of highly oxidized material is done. The primary propose of air pressure is to remove the melted or vaporized portion of material from the machining zone and to protect the focusing optics against vapor or spatter emitted due to high intense beam.

(g) Axial feed rate: When machining is carried out on cylindrical shaped workpiece, axial feed rate play important role. Depending upon the value of axial feed rate and rotating speed of workpiece, the cutting features on the workpiece is generated. The axial feed rate along with rotational speed of workpiece not only controls the amount of spot overlap, but it also governs the circumferential overlap (overlap between two consecutive cutting features at axial direction) on workpiece surface.

(h) Transverse mode: Transverse mode of electromagnetic radiation is a particular electromagnetic field pattern of radiation measured in a plane perpendicular (i.e., transverse) to the propagation direction of the beam. Generally, lasers are operated in Gaussian Mode. This mode is further divided into (i) Hermite-Gaussian Mode and (ii) Laguerre-Gaussian Mode. Gaussian beams are usually the preferred output of most lasers, since they are easy to manipulate, are circularly symmetric, and usually

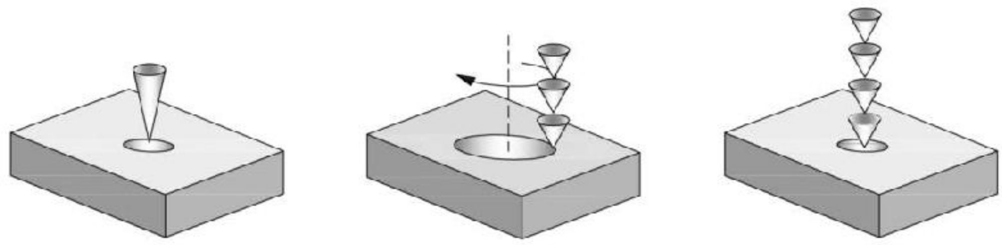

Figure 10.10 Schematic of laser drilling procedures

have the greatest overall and concentrated intensity of all the transverse modes. They are stable as well, which means they retain their shape as they propagate.

(i) Spot size: Depending upon the beam focusing ability of focusing lens, the laser spot size at focal plane is varied. In addition, the focal spot size of laser beam play significant role in obtaining the output feature size and accuracy on workpiece surface. Moreover, the spot size of laser beam is varied by moving the focusing lens in Z direction in respect of workpiece surface for machining at defocusing condition, where the laser power intensity is less compared to focused condition.

10.8 VARIETIES OF LASER BEAM MACHINING

Due to several extraordinary features in laser beam machining process, the demand of lasers in manufacturing sectors is increasing continuously. Depending on the relative movement of laser beam with respect to the workpiece to be machined, various laser beam machining processes have been developed for obtaining various output features in LBM. These LBM processes are discussed briefly hereunder.

(a) Laser drilling: In laser material processing, laser drilling is one of the applications of lasers. Laser drilling is most extensively used in the aerospace, aircraft, and automotive industries. Laser drilling is a precise noncontact type and reproducible manufacturing method in which small diameter (less than 100 µm) and high-aspect ratio holes is produced in a wide variety of materials ranging from metals, superalloys, ceramics and composites. This process has no tool wear rate, which is normally associated with conventional machining processes. In laser drilling process, high intense and stationary beam is focused onto the workpiece surface and the beam intensity is such that sufficient heat is produced to melt and vaporize the materials and the compressed air supplied is able to eject the materials in liquid and vapour phases. The design of co-axial nozzle is made such that while laser drilling, the laser optics can be shielded from ejected debris.

There are three categories of laser drilling process, (i) single pulse drilling, (ii) trepanning drilling and (iii) percussion drilling. Figure 10.10 shows the schematic of these three types of laser drilling processes. In single pulse drilling, narrow holes (diameter in micron ranges) are produced in thin sheets (thickness of less than 1 mm). Due to single pulse nature of this drilling process, the intensity of laser beam should be such that the laser beam can vaporize the material in single shot. In trepanning laser drilling, moderate size of hole (diameter in the range of 1 to 3 mm) is produced by carrying out laser drilling of series of overlapping holes in the circumference of a contouring circle as shown in Figure 10.10. During trepanning, either the workpiece or focusing optic is translated. Both the pulse modes i.e. continuous wave (CW) and

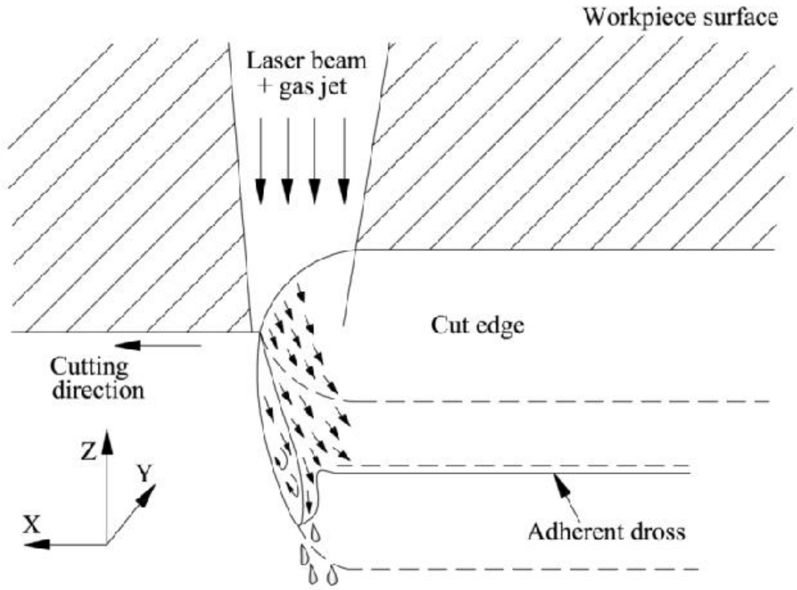

Figure 10.11 Schematic of laser cutting process

pulsed modes can be employed in trepanning. In percussion laser drilling process, a series of short pulses (pulse duration is in the range of 10^{-12} to 10^{-3} s) are irradiated on the same spot to produce a through drilled hole. Each of the pulses removes certain amount of material from irradiated surface. This type of laser drilling process is applicable for producing through holes in thick materials (thickness upto 25 mm). This process is applied for generating series of holes in combustion chambers, turbine blades, etc.

(b) Laser cutting: Laser cutting is considered to be in the category of two-dimensional machining process. This process is a high speed, reliable and repeatable cutting method applied to process wide range of materials (steels, superalloys, copper, aluminum, and brass, and nonmetallic materials such as ceramic, quartz, plastic, rubber, wood, and cloth) and thickness. In this process, cutting operation is carried out by moving high intense laser beam onto the workpiece surface. The high intense laser supplies sufficient energy on the focused spot on workpiece and the temperature generated at this zone is more than material's melting / vaporization temperature. Depending on the thickness of material, laser cutting operation is carried out creating a cutting front. The molten portion of material is expelled from cutting front by highly pressurized gas. In addition, some chemical reactions also take place due to which additional amount of material is also removed from laser focused zone. Laser cutting can be executed by either moving the workpiece in different profiles using CNC stage or by moving the laser beam using XY galvano-system. There are mainly four types of laser cutting approaches, (i) evaporative laser cutting, (ii) fusion cutting, (iii) reactive fusion cutting and (iv) controlled fracture technique. The selection of optimum technique and operation condition depends on the thermo-physical properties of the material, the thickness of the workpiece, and the type of laser employed. In Figure 10.11, the schematic shows the laser beam cutting process.

(c) Laser grooving: Laser grooving process is carried out by scanning the irradiated laser beam over path of surface when the groove is to be generated. There are two

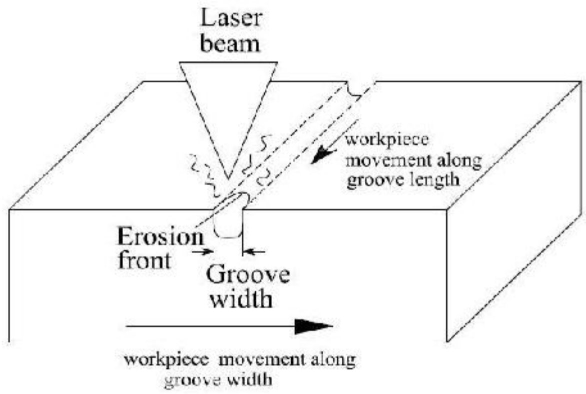

Figure 10.12 Schematic of laser grooving process

methods of laser grooving process, (i) using a single laser beam and (ii) using two laser beams. In case of single laser beam, the desired width of groove is machined by producing multiple grooves side-by-side causing overlap between two adjacent groove widths. This process produces trapezoidal or rectangular shaped groove on desired workpiece surface. However, when two intersecting laser beams are used simultaneously, each of the laser generate cutting surface and the desired shaped groove is formed by removing a certain volume of material in bulk form. The mechanism of laser grooving is similar to laser cutting process; only the difference is that laser grooving process does not produce a through cut upto the thickness of work material. A typical laser grooving processes is shown in Figure 10.12. The groove depth defines the boundary of the volume of material removed. The quality of the machined surface is related to heat affected zone and the formation of recast layer at the groove walls or surfaces. Dimensional accuracy is one of the important criteria for laser grooving process.

(d) Laser turning: Laser turning process is applied to machine engineering material for removing material from the surface of cylindrical shaped workpiece. For removal of bulk form (like a ring shape or tapered groove) of material from workpiece, laser turning process is applied by using two intersecting laser beams. However, when single laser beam is used for laser turning, laser beam is irradiated onto the machining surface of rotating workpiece through the desired length of turn along the axis of work sample. Figure 10.13 shows schematic view of laser turning process using single beam and two intersecting beams while rotating cylindrical workpiece and moving it along axial direction. Using laser turning process, material removal from cylindrical surface of workpiece can be removed by controlling the rotational speed as well as axial feed rate of workpiece. In addition, pocket milling and laser grooving can be carried out on cylindrical surface of work sample by special arrangement of workpiece movement. To accomplish the laser turning process, special attachment and precision fixture for rotating and feeding the workpiece are needed to develop.

(e) Laser texturing: One of the key technologies for manufacturing of defined and patterned surface microstructures is laser surface texturing (LST). This process renders tribological characteristics on the surface of work material to improve load capacity, wear rate as well as to reduce coefficient of friction of the surface. In this process, relative movements between the laser beam and work surface is given at different pattern to create patterned microstructures such as crossed grooves, linear

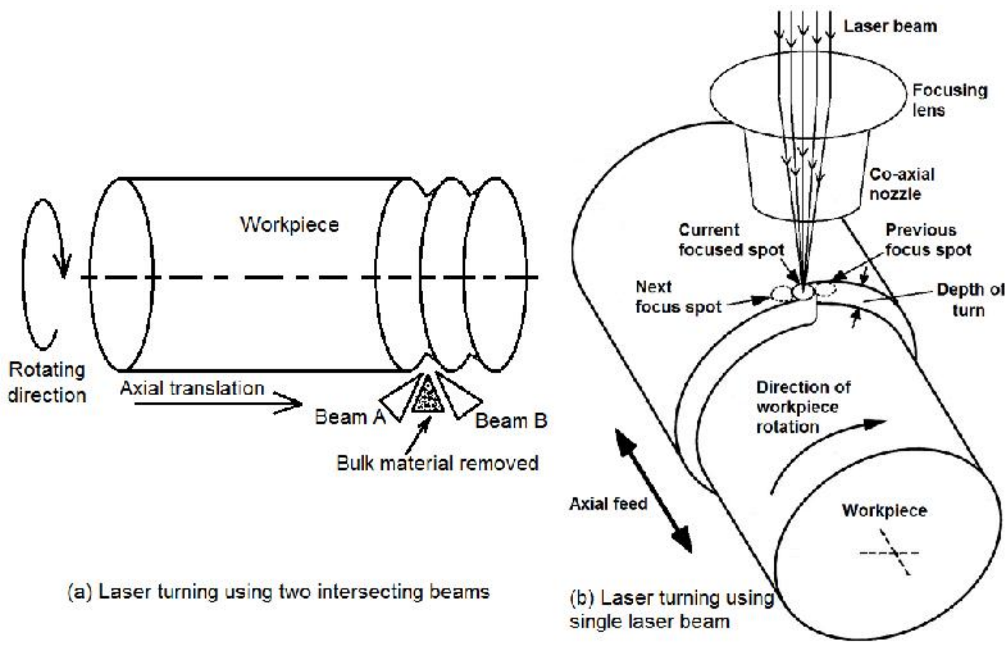

Figure 10.13 Schematic view of laser turning process using single beam and two intersecting beams

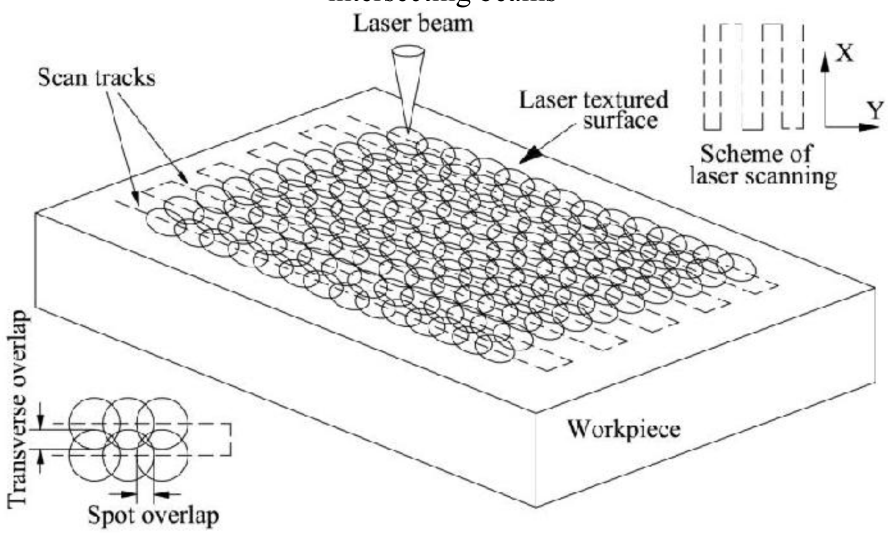

Figure 10.14 Schematic of laser surface texturing process

grooves, dimple shaped impressions. In laser texturing process, laser beam is focused and exposed on the workpiece surface with defined patterns by relatively moving the workpiece in X and Y directions. Thus, laser beam scanning was applied on the surface with overlaps between two consecutive laser scan tracks. The amount of this overlap is controlled by the value of transverse feed. In this way, laser surface texturing is carried out on workpiece surface to obtain square or rectangular type scan area. With the change in the number of scan passes during laser surface texturing process, a specific depth as well as surface features can be achieved. In Figure 10.14, the schematic view of laser surface texturing process is depicted along with laser scanning strategy and overlap factors.

(f) Laser milling: Laser milling is one of the laser material processing techniques in which desired shape of cavity with specific depth and dimensional accuracy is

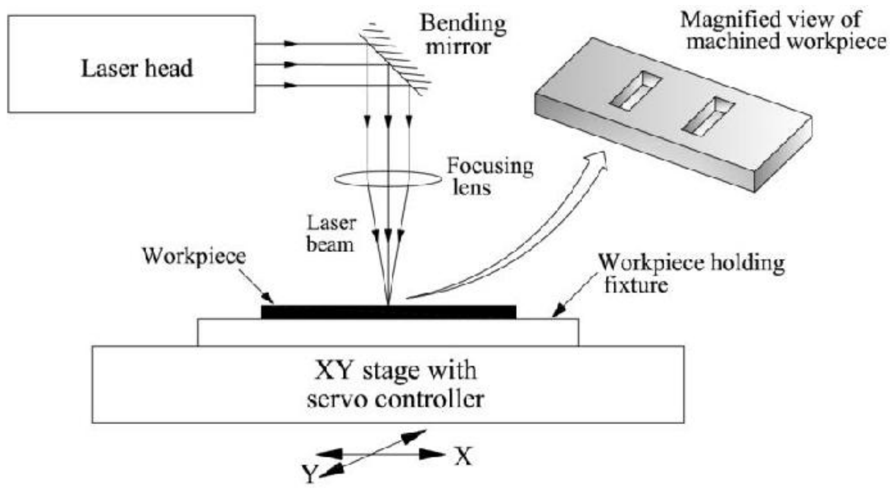

Figure 10.15 Schematic of laser milling arrangement

achieved by proper controlling the beam scanning parameters and other laser process parameters. In this process, very less amount of material in the form of micro and nano-sized particles (melt and vapour forms) are removed from laser scanning areas in layer-by-layer fashion after every scanning pass of laser beam. Depending upon the number of scanning passes, the depth of milling is varied. The quality as well as accuracy of milling cavity depends on several predominant process parameters such as laser power, pulse energy, laser fluence, pulse frequency, pulse duration, laser lamp current, scanning speed, hatching scheme and overlapping of hatch tracks. The schematic view of laser milling process is represented in Figure 10.15.

(g) Laser welding: Laser welding is achieved by using the heat from laser beam to melt the materials to be joined which upon solidification produces a strong weld. The heat input in laser welding is relatively low when compared to the conventional welding processes such as arc welding. High power density can be achieved by simply focusing the beam into a very small spot size. At a very high power density the beam forms what is called a keyhole weld below the point of contact of the laser and the workpiece. The keyhole aids the laser absorption into the material and allows a low heat input to be sufficient in melting the workpiece material. The low heat input ensures that minimal distortion is produced even in delicate workpiece. The depth of penetration in laser welding depends on the available laser power and the location of the focal point. The laser beam is focused on the surface of the workpiece to be welded. The laser beam is engaged with the workpiece material where some of the beams are reflected and the other beams interact with material which in turn leads to the conversion of light energy into thermal energy. The heat energy melts the surface of the material and the heat is further transferred through conduction to the bulk of material. In Figure 10.16, the schematic view of laser welding process is depicted. In laser welding, material vaporisation is not desired and this has to be prevented through proper control of the operating energy density that kept the working temperature below the vaporisation temperature of the materials being welded. The laser can be operated in pulsed and continuous mode for welding. Pulse laser can be operated at a low timescale and as low as milliseconds especially when thin materials are being welded. Continuous mode operation of laser can be used for deep welding in thick materials.

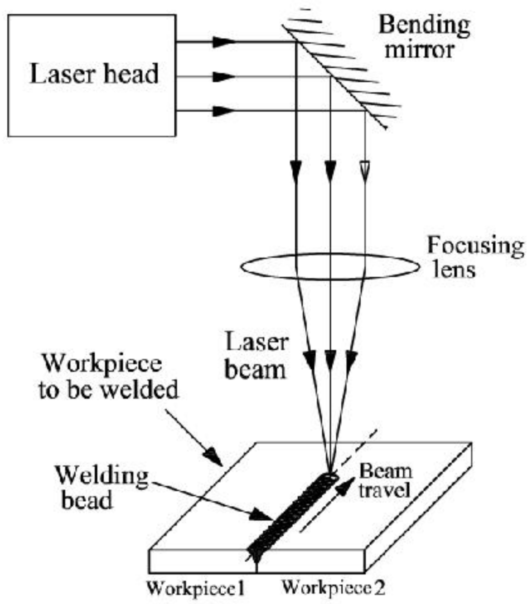

Figure 10.16 Schematic representation of laser welding process

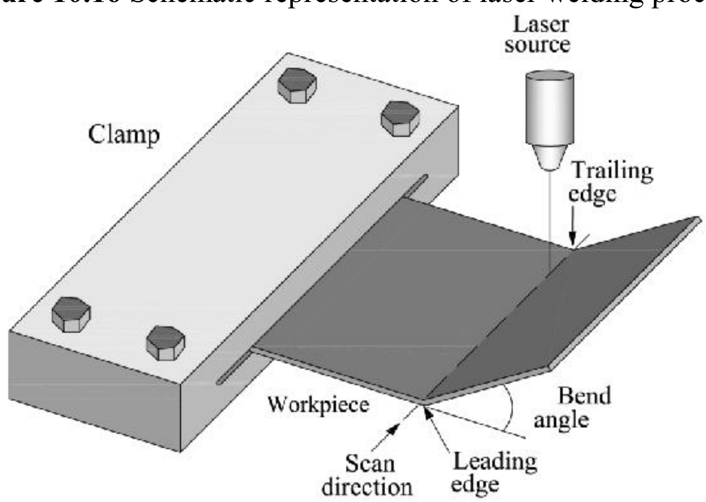

Figure 10.17 Schematic representation of laser bending process

(h) Laser bending: Laser bending process is considered to be in the category of laser forming processes. In this process, bending of workpiece is carried out by controlled energy of laser beam. The workpiece get enough thermal stress through a specified path to shape the sample. In this technique, the work sample is fixed in one side and laser scanning of the top surface parallel to the fixed side is carried out at some specific laser power and laser scanning speed. The heating of the material causes the expansion of the material in a confined region. Due to continuity of the heated region with the surrounding material, the free expansion of the hot region is resisted, resulting in bending of the part. In Figure 10.17, the schematic of laser bending process of sheet metals is represented.

(i) Laser heat treatment: Laser heat treating is a surface modification process designed to change the microstructure of metals through controlled heating and cooling. An advantage that lasers offer in this process is the ability to heat treat localized areas without affecting the entire workpiece. The enhanced mechanical

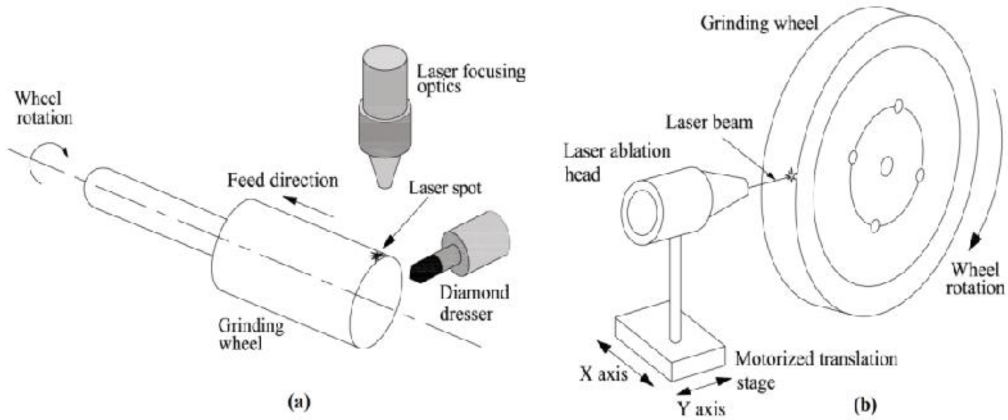

Figure 10.18 Schematic representation of laser dressing mechanism (a) laser

properties resulting from laser heat treating depend upon the specific composition of the metal or alloy. CO_2 lasers, Diode lasers, Fiber lasers and Nd:YAG lasers are commonly used for laser heat treating.

(j) Laser cladding: During laser powder cladding, the high energy output from the laser is used to adhere metallic powder fed from the outside to the base material of a workpiece in a metallurgic process, thus reconditioning the surface structure of workpiece or improving the surface quality and protecting the workpiece against wear and/or corrosion. During this process, the laser energy welds a powdery welding consumable onto an existing component. This provides a pore- and crack-free layer with low dilution and a small heat-affected zone. This strengthens resistance in components and increases load capacities. Wear and corrosion are considerable cost factors in almost all production processes.

(k) Laser dressing: Dressing of grinding wheels refers to the re-sharpening operation designed to generate a specific topography on the cutting surface of the grinding wheel. Recently, significant interests have been attracted toward the development of laser-based technologies either to assist the conventional mechanical dressing operations or to use lasers for selectively modifying the wheel surfaces for efficient grinding performance. In laser assisted dressing, a focused laser beam is used to locally heat the surface of the rotating grinding wheel ahead of the dressing tool, typically a single-point diamond dresser. The main objectives behind such processes is to reduce the wear of dressing tool and improve the surface quality by locally changing the material removal mode of hard ceramics from brittle fracture to ductile flow by laser heating. Direct laser dressing is based on the ability of the high-power lasers to locally modify the surface of the grinding wheel to generate/expose the sharp cutting edges which can play an important role in efficient material removal during subsequent machining of the material. Figure 10.18 shows these two mechanisms of laser dressing process of grinding wheels.

(l) Laser deburring: Deburring is the process of removal of undesirable projections of material beyond the edge of the workpiece due to plastic deformation during machining. In other way, deburring is an edge finishing process of precision parts for rectifying additional dimensional errors. Laser beam can be used to remove these burrs from manufactured components or parts by selective material removal process. Figure 10.19 shows the schematic view of laser deburring process.

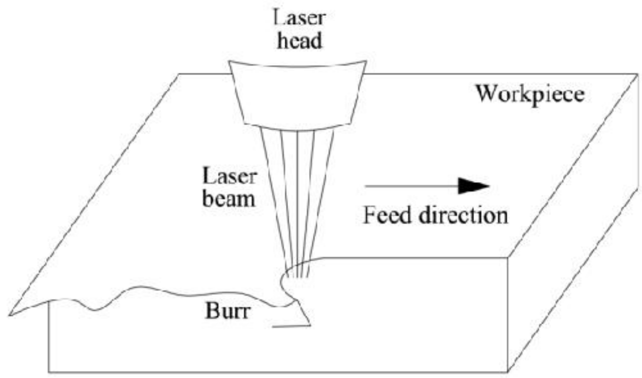

Figure 10.19 Schematic view of laser deburring process

10.9 ADVANTAGES AND LIMITATIONS OF LBM

Advantages

LBM process has various advantages which are mentioned below.

(i) The process is employed for machining wide range of materials ranging from metal, non-metals, ceramics, glass, composites etc.

(ii) In this process, no physical tool is required and therefore, no tool wear occurs.

(iii) LBM is successfully applied for generating micro-hole, micro-slots, micro-turning, micro-milling and other surface generation processes (texturing, scribing, etc) very precisely and accurately.

(iv) Complicated shape with accurate geometry and surface finish can be machined efficiently in LBM.

(v) The process can be easily automated with highly flexible robotic manipulators.

(vi) In Laser beam Machining (LBM) process there is no direct contact between the tool and the workpiece, hence there is no issue of tool wear.

(vii) LBM can be carried out in normal machining environment. Here, there is no need to special machining chamber (dielectric or vacuum).

(viii) Refractory materials can be easily worked.

(ix) Employing several work / laser head moving arrangements, LBM can be used for number of machining techniques such as drilling, cutting, milling, welding, surface hardening, dressing, deburring etc.

(x) The process is faster compared to other machining advanced machining processes like EDM, ECM or USM.

(xi) The process has small heat affected zone (HAZ) and thermal damage to parent materials is negligible.

(xii) The size as well as power density of laser beam can be controlled by moving focusing lens in respect to workpiece surface.

Limitations

The process has several limitations such as

(i) Energy efficiency of the process is very low. Laser beam energy is only 1 to 2% of the total input energy to the machine.

(ii) The process involves high capital and maintenance cost.
(iii) Laser beam can leads to safety and health hazards.
(iv) Drilled hole size and shape is not accurate and straight. Tapering of holes or slots is a major limitation.
(v) Durability and reliability of the machining system is limited.
(vi) Experienced and skilled operators are required.
(vii) The laser system is quite troublesome since the life of the flash lamp is short.

10.10 APPLICATIONS OF LBM

Some of the important applications of LBM process are mentioned below.

(i) LBM is applicable to wide range of materials ranging from hard, brittle, metals, hard-to-machine alloys, ceramics, composites, etc.
(ii) It is used for micromachining processes such as micro-drilling, micro-grooving and micro-cutting in several engineering materials like tungsten, titanium and its alloys, structural ceramics, etc.
(iii) Cutting complicated profiles on thin films for making Integrated Circuits, engraving patterns on suitable thin films or sheets.
(iv) The process is very efficient in machining of refractory and hard-to-machine ceramic materials.
(v) The process is extensively used in electronic and automotive industries for making holes and slots in various components.
(vi) It is mostly used in aerospace and nuclear industries for producing small sized components.

10.11 SUMMARY

LBM (laser beam machining) is one of the mostly used advanced machining processes. In this process, a highly focused laser beam is irradiated on the selected region of workpiece surface. Upon interaction, due to rise of huge temperature, the material melts and vaporizes. With the assist of highly pressurized air / gas jet, melted and vaporized portion of material is removed from laser irradiated zone. The process has several influencing process parameters such as laser power, pulse frequency, pulse duration, duty ratio, gas / air pressure, beam scanning speed, etc. By implementing several translation arrangements of workpiece in respect of laser beam, several machining processes such as drilling, cutting, milling, grooving, turning, scribing, bending, dressing, etc has been applied for producing different cutting features in the manufactured components. The process has several advantages such as able to machine wide variety of materials, non-contact type machining, selective material removal, no mechanical stresses rendered, faster process, etc. The process can play significant role in manufacturing MEMS devices, drug delivery systems, optical switches, micro-motors, medical surgery parts, etc.

Multiple choice questions

1. What is the wavelength value of Nd-YAG and Nd-glass lasers used in LBM?
   (a) 633 nm (b) 694 nm
   (c) 856 nm (d) 1064 nm