Laser Beam Machining (LBM)

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Laser Beam Machining – An Introduction

- LASER stands for Light Amplification by Stimulated Emission of Radiation.
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- The underline working principle of laser was first put forward by Albert Einstein in 1917 though the first industrial laser for experimentation was developed around 1960s.
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- Laser beam can very easily be focused using optical lenses as their wavelength ranges from half micron to around 70 microns.
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- Focussed laser beam can have power density in excess of 1 MW/mm^2.
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- Laser Beam Machining or more broadly laser material processing deals with machining and material processing like heat treatment, alloying, cladding, sheet metal bending etc.
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- Such processing is carried out utilizing the energy of coherent photons or laser beam, which is mostly converted into thermal energy upon interaction with most of the materials.
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- As laser interacts with the material, the energy of the photon is absorbed by the work material leading to rapid substantial rise in local temperature. This in turn results in melting and vaporisation of the work material and finally material removal.
- Nowadays, laser is also finding application in regenerative machining or rapid prototyping as in processes like stereo-lithography, selective laser sintering etc.

Laser Beam Machining – The Lasing Process

- Lasing process describes the basic operation of laser, i.e. generation of coherent beam of light by “light amplification” using “stimulated emission”.
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- In the model of atom, negatively charged electrons rotate around the positively charged nucleus in some specified orbital paths.
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- The geometry and radii of such orbital paths depend on a variety of parameters like number of electrons, presence of neighbouring atoms and their electron structure, presence of electromagnetic field etc. Each of the orbital electrons is associated with unique energy levels.
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- At absolute zero temperature an atom is considered to be at ground level, when all the electrons occupy their respective lowest potential energy.
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- The electrons at ground state can be excited to higher state of energy by absorbing energy from external sources like increase in electronic vibration at elevated temperature, through chemical reaction as well as via absorbing energy of the photon.
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- Fig. 1 depicts schematically the absorption of a photon by an electron. The electron moves from a lower energy level to a higher energy level.

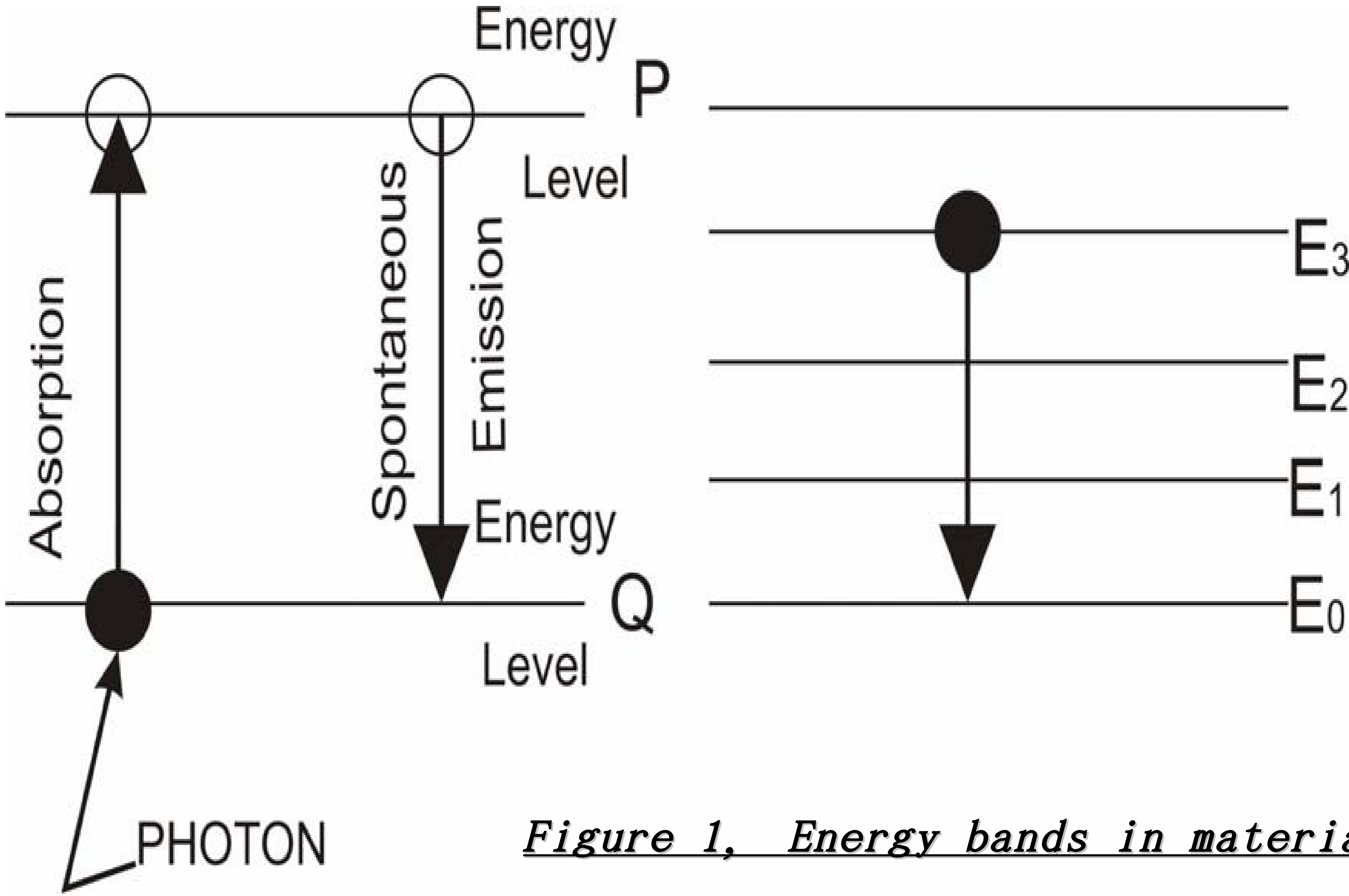

Figure 1, Energy bands in materials

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- On reaching the higher energy level, the electron reaches an unstable energy band. And it comes back to its ground state within a very small time by releasing a photon. This is called **spontaneous emission**.
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- Schematically the same is shown in Fig. 1 and Fig. 2. The spontaneously emitted photon would have the same frequency as that of the “exciting” photon.

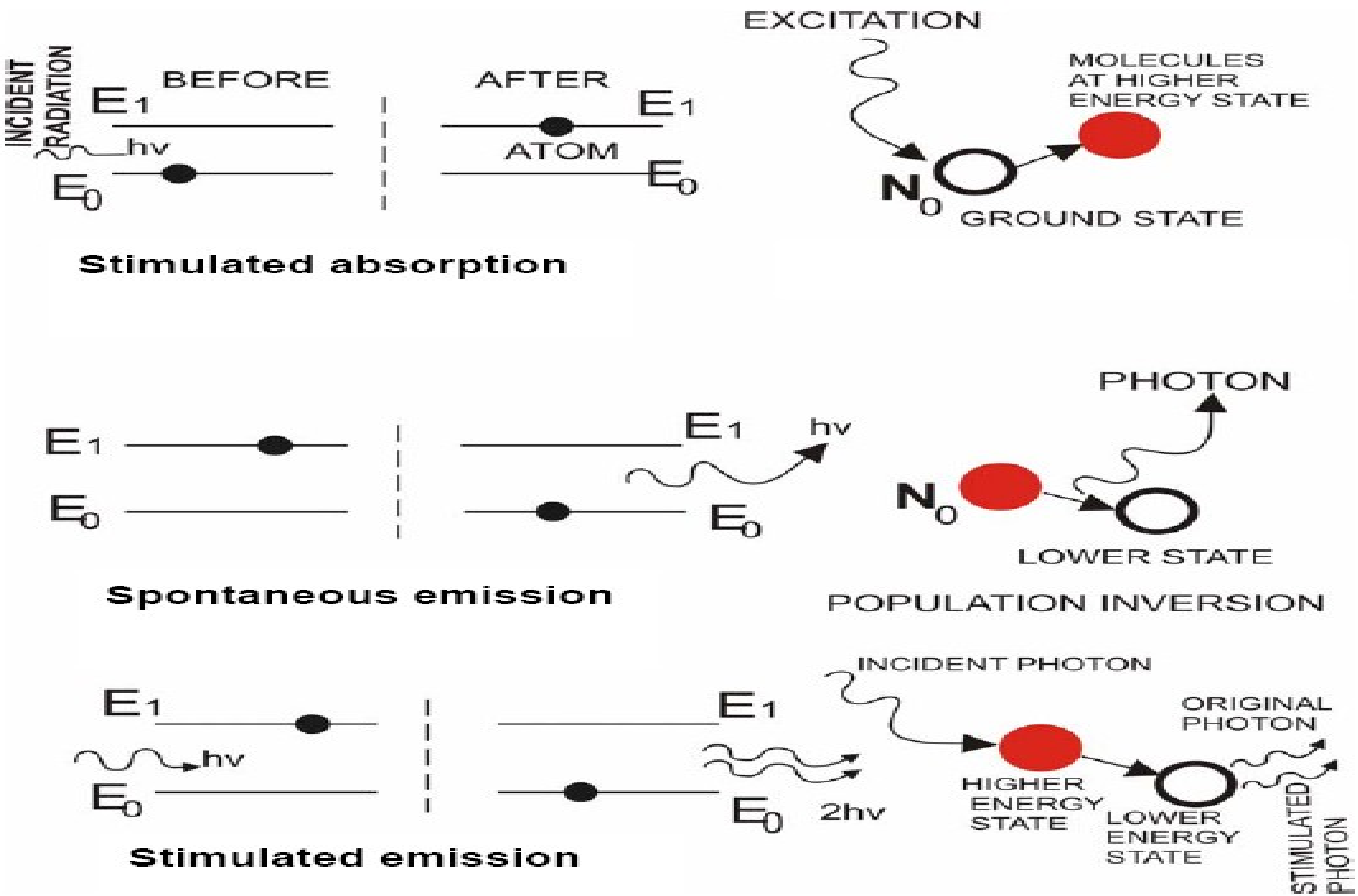

Fig. 2 Spontaneous and Stimulated emissions

- Sometimes such change of energy state puts the electrons in a meta-stable energy band. Instead of coming back to its ground state immediately it stays at the elevated energy state for micro to milliseconds.
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- In a material, if more number of electrons can be somehow pumped to the higher meta-stable energy state as compared to number of electrons at ground state, then it is called “population inversion”.
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- Such electrons, at higher energy meta-stable state, can return to the ground state in the form of an avalanche provided stimulated by a photon of suitable frequency or energy. This is called **stimulated emission**. Fig.2 shows one such higher state electron in meta-stable orbit.

- If it is stimulated by a photon of suitable energy then the electron will come down to the lower energy state and in turn one original photon will be produced. In this way **coherent laser beam can be produced**.
- Fig. 3 schematically shows working of a laser.

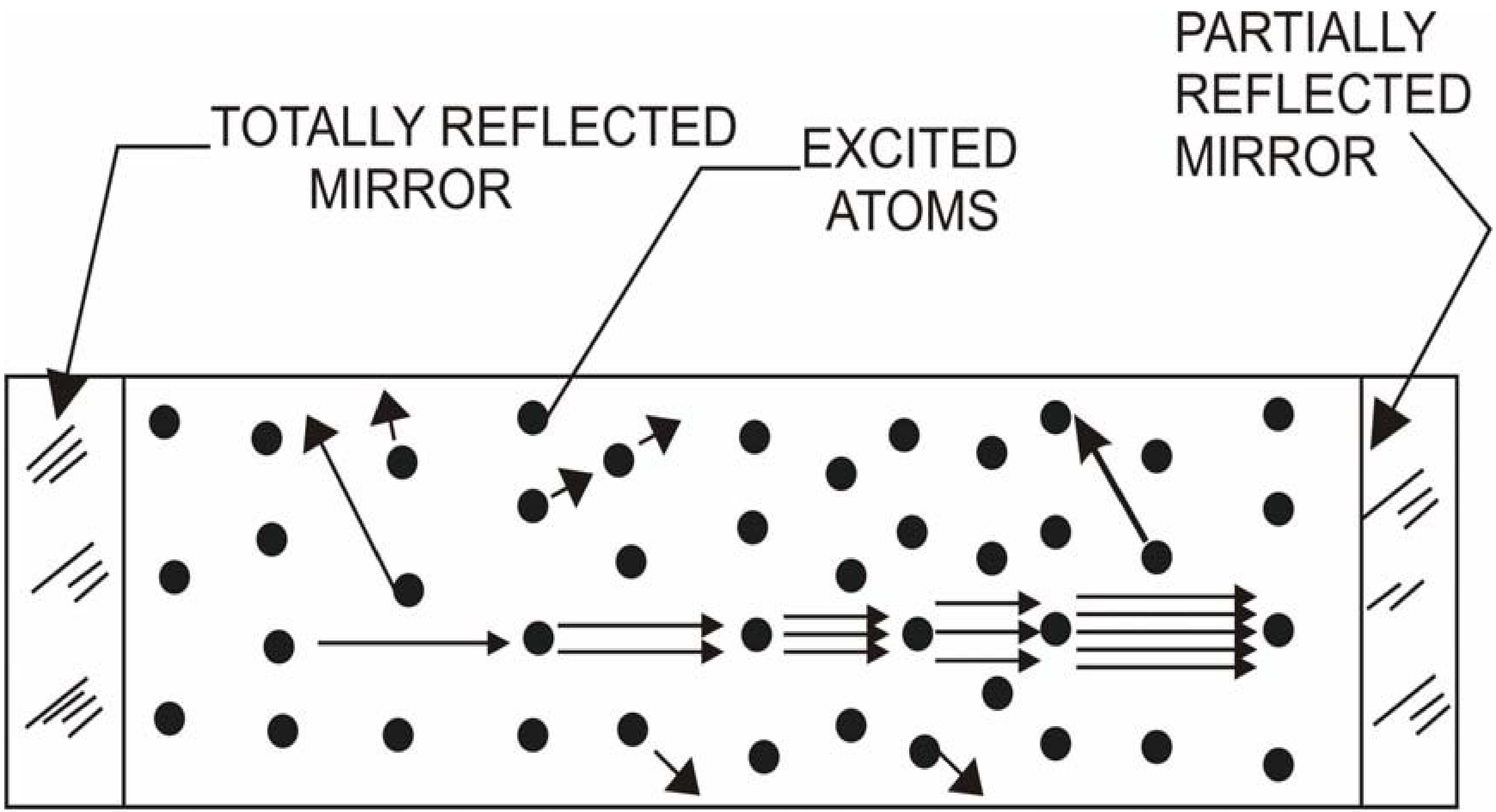

Fig. 3 Lasing Action

- There is a gas in a cylindrical glass vessel. This gas is called the lasing medium.
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- One end of the glass is blocked with a 100% reflective mirror and the other end is having a partially reflective mirror. Population inversion can be carried out by exciting the gas atoms or molecules by pumping it with flash lamps.
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- Then stimulated emission would initiate lasing action. Stimulated emission of photons could be in all directions.
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- Most of the stimulated photons, not along the longitudinal direction would be lost and generate waste heat. The photons in the longitudinal direction would form coherent, highly directional,

Lasing Medium- Heart Of LASER

- Many materials can be used as the heart of the laser. Depending on the lasing medium lasers are classified as solid state and gas laser.
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- Solid-state lasers are commonly of the following type
  - Ruby which is a chromium – alumina alloy having a wavelength of 0.7 μm
  - Nd-glass lasers having a wavelength of 1.64 μm.
  - Nd-YAG laser having a wavelength of 1.06 μm.
- **(Nd-YAG stands for neodymium-doped yttrium aluminium garnet**; **Nd:$Y_3Al_5O_{12}$**)
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- These solid-state lasers are generally used in material processing.
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- The generally used gas lasers are:
  - Helium – Neon
  - Argon
  - CO_2 etc.
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- Lasers can be operated in continuous mode or pulsed mode. Typically CO_2 gas laser is operated in continuous mode and Nd – YAG laser is operated in pulsed mode.

Schematic diagram of Laser Beam Machine

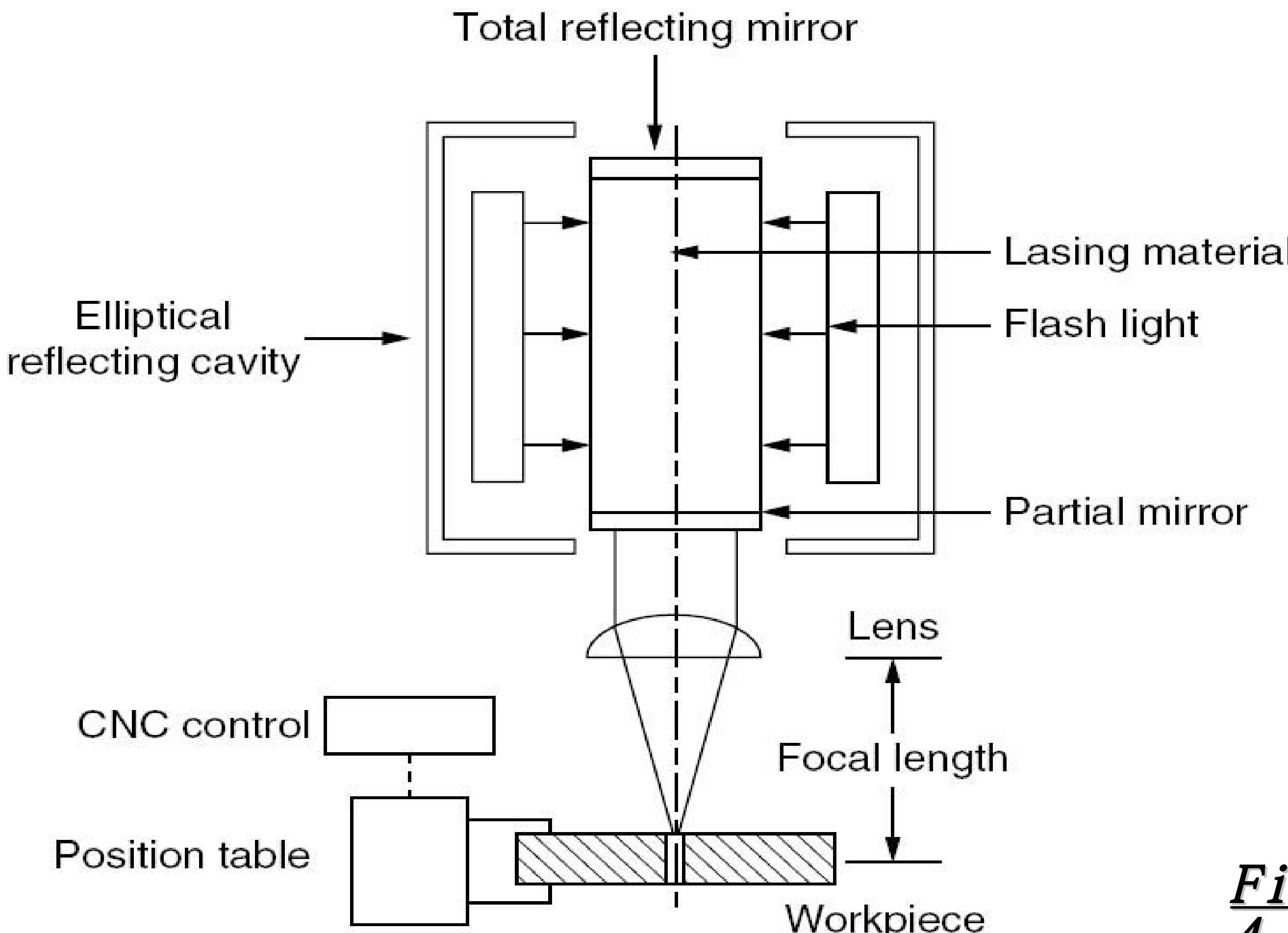

Figure 4

Material Removal Mechanism In LBM

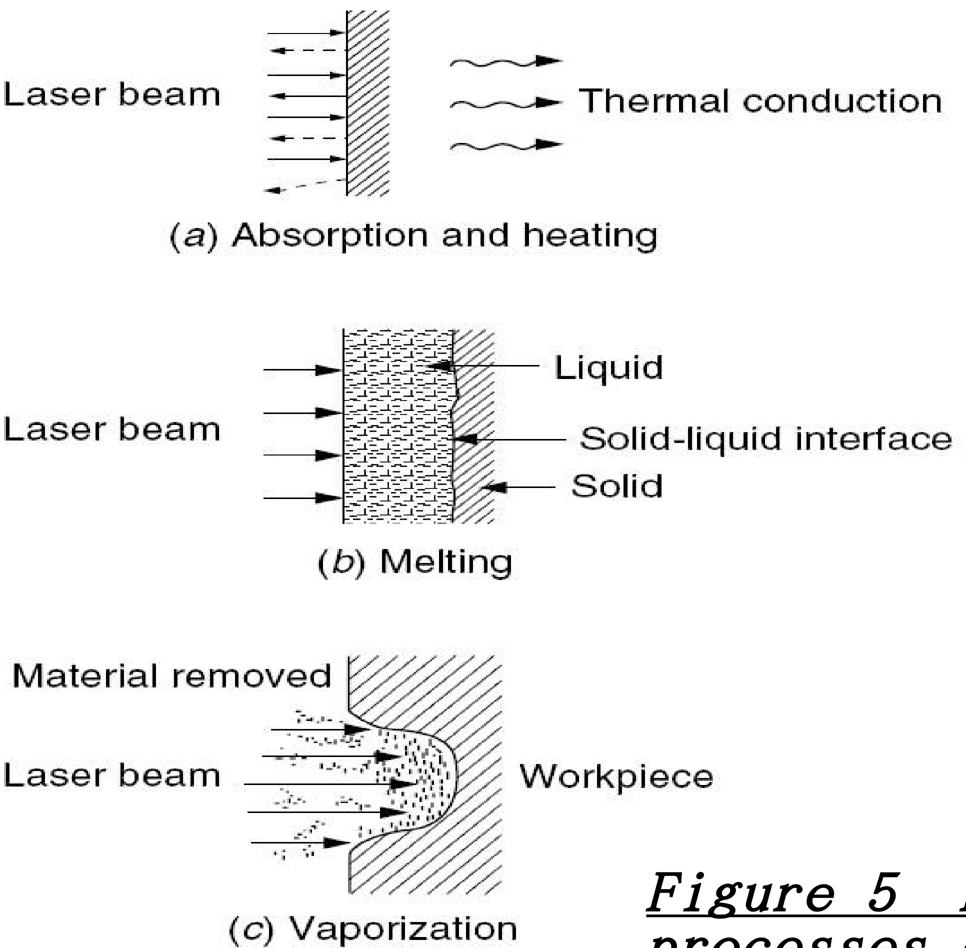

Figure 5 Physical processes occurring during LBM

- As presented in Fig. 5, the unreflected light is absorbed, thus heating the surface of the workpiece.
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- On sufficient heat the workpiece starts to melt and evaporates.
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- The physics of laser machining is very complex due mainly to scattering and reflection losses at the machined surface. Additionally, heat diffusion into the bulk material causes phase change, melting, and/or vaporization.
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- Depending on the power density and time of beam interaction, the mechanism progresses from one of heat absorption and conduction to one of melting and then vaporization.

- Machining by laser occurs when the power density of the beam is greater than what is lost by conduction, convection, and radiation, and moreover, the radiation must penetrate and be absorbed into the material.
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- The power density of the laser beam, P_d, *is given by*

$$P_d = \frac{4L_p}{\pi F_l^2 \alpha^2 \Delta T}$$

- The size of the spot diameter d_s *is*

$$d_s = F_l \alpha$$

- The machining rate φ (mm/min) can be described as follows:

$$\varphi = \frac{C_l L_P}{E_v A_b h}$$

Where A_b = area of laser beam at focal point, mm^2

$$A_b = \frac{\pi}{4}\left(F_l \alpha\right)^2$$

Therefore,

$$\varphi = \frac{4 C_l L_P}{\pi E_v \left(F_l \alpha\right)^2 h}$$

- The volumetric removal rate (VRR) (mm^3/min) can be calculated as follows:

$$VRR = \frac{C_l L_p}{E_v h}$$

- where P_d = power density, W/cm^2
- L_p = laser power, W
- F_l = focal length of lens, cm
- ΔT = pulse duration of laser, s
- α = beam divergence, rad
- C_l = constant depending on the material and conversion efficiency
- E_v = vaporization energy of the material, W/mm^3
- A_b = area of laser beam at focal point, mm^2
- h = thickness of material, mm
- d_s = spot size diameter, mm

LASER Beam Machining – Application

- Laser can be used in wide range of manufacturing applications
  - Material removal – drilling, cutting and tre-panning
  - Welding
  - Cladding
  - Alloying

- Drilling micro-sized holes using laser in difficult – to – machine materials is the most dominant application in industry. In laser drilling the laser beam is focused over the desired spot size. For thin sheets pulse laser can be used. For thicker ones continuous laser may be used.

Parameters Affecting LBM

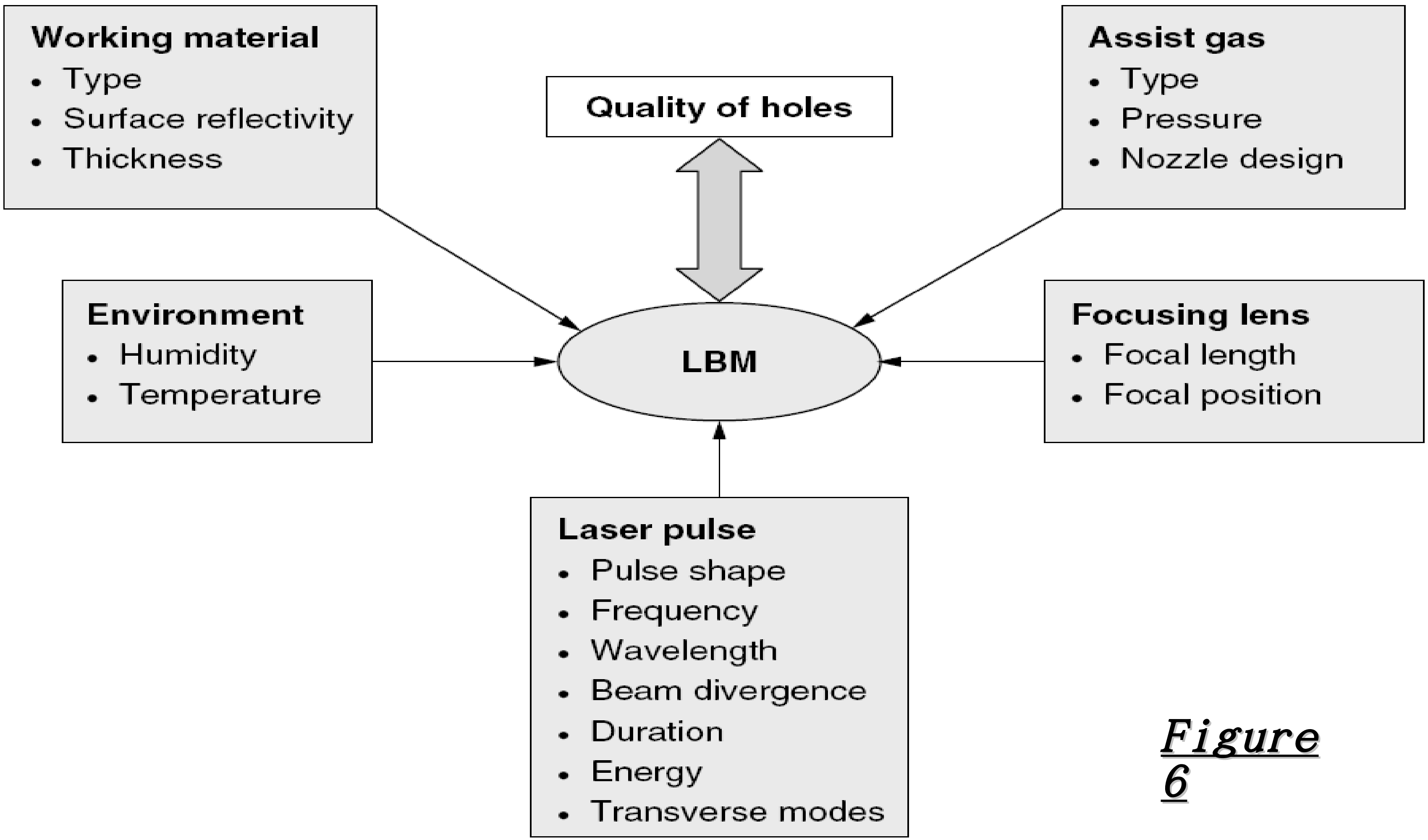

Figure 6

- Fig. 6 presents the factors which affect the LBM process. The factors can be related to LBM Drilling process and are discussed below:
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- Pulse Energy: It is recommended that the required peak power should be obtained by increasing the pulse energy while keeping the pulse duration constant. Drilling of holes with longer pulses causes enlargement of the hole entrance.
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- Pulse Duration: The range of pulse durations suitable for hole drilling is found to be from 0.1 to 2.5 millisecond. High pulse energy (20J) and short pulse duration are found suitable for deep hole drilling in aerospace materials.
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- <u>Assist Gases:</u> The gas jet is normally directed with the laser beam into the interaction region to remove the molten material from the machining region and obtain a clean cut. Assist gases also shield the lens from the expelled material by setting up a high-pressure barrier at the nozzle opening. Pure oxygen causes rapid oxidation and exothermic reactions, causing better process efficiency. The selection of air, oxygen, or an inert gas depends on the workpiece material and thickness.
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- <u>Material Properties and Environment:</u> These include the surface characteristics such as reflectivity and absorption coefficient of the bulk material. Additionally, thermal conductivity and diffusivity, density, specific heat, and latent heat are also considered.

Laser Beam Selection Guide

Application		Laser type
Drilling	Small holes, 0.25 mm	Ruby, Nd-Glass, Nd-YAG
	Large holes, 1.52 mm	Ruby, Nd-Glass, Nd-YAG
	Large holes, trepanned	Nd-YAG, CO_2
	Drilling, percussion	Ruby, Nd-YAG
Cutting	Thick cutting	CO_2 + gas assistance
	Thin slitting, metals	Nd-YAG
	Thin slitting, plastics	CO_2
	Plastics	CO_2
Materials	Metals	Ruby, Nd-Glass, Nd-YAG
	Organics and nonmetals	Pulsed CO_2
	Ceramics	Pulsed CO_2 , Nd-YAG

Laser Beam Machining: New Developments

- In 1994 Lau et al., introduced the ultrasonic assisted laser machining technique not only to increase the hole depth but also to improve the quality of holes produced in aluminium-based metal matrix composites (MMC). Using such a method, the hole depth was increased by 20 percent in addition to the reduced degree of hole tapering.
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- In 1995 Hsu and Molian, developed a laser machining technique that employs dual gas jets to remove the viscous stage in the molten cutting front and, thereby, allowing stainless steel to be cut faster, cleaner, and thicker.

- In 1997, Todd and Copley developed a prototype laser processing system for shaping advanced ceramic materials. This prototype is a fully automated, five-axis, closed-loop controlled laser shaping system that accurately and cost effectively produces complex shapes in the above-mentioned material.
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- **<u>Laser Assisted EDM:</u>** In 1997, Allen and Huang developed a novel combination of machining processes to fabricate small holes. Before the micro-EDM of holes, copper vapour laser radiation was used to obtain an array of small holes first. These holes were then finished by micro-EDM. Their method showed that the machining speed of micro-EDM had been increased and electrode tool wear was markedly reduced while the surface quality remained unchanged.

Laser Beam Machining – Advantages

- Tool wear and breakage are not encountered.
- Holes can be located accurately by using an optical laser system for alignment.
- Very small holes with a large aspect ratio can be produced.
- A wide variety of hard and difficult-to-machine materials can be tackled.
- Machining is extremely rapid and the setup times are economical.
- Holes can be drilled at difficult entrance angles (10° to the surface).
- Because of its flexibility, the process can be automated easily such as the on-the-fly operation for thin gauge material, which requires one shot to produce a hole.
- The operating cost is low.

Laser Beam Machining – Limitations

- High equipment cost.
- Tapers are normally encountered in the direct drilling of holes.
- A blind hole of precise depth is difficult to achieve with a laser.
- The thickness of the material that can be laser drilled is restricted to 50 mm.
- Adherent materials, which are found normally at the exit holes, need to be removed.
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References:

- Advanced Machining Processes By Hassan Abdel-Gawad El-Hofy
- Non Conventional Machining By P.K. Mishra


THANK YOU