Advanced Manufacturing Processes
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Module - 03
Advanced Machining Processes
Lecture - 12
Laser Beam Machining (LBM)

Welcome to this session on laser beam machining under the course advanced manufacturing processes. In our previous sessions we have discussed about electric discharge machining processes. In this session we will discuss another advanced machining process namely the laser beam machining process. This is one of the process in which there is no conventional tool is used, instead the beam in the form of laser will be used as the cutting head. This will be responsible for non contact cutting or processing of materials unlike the conventional machine tool where contact between the tool and the work piece is necessary.

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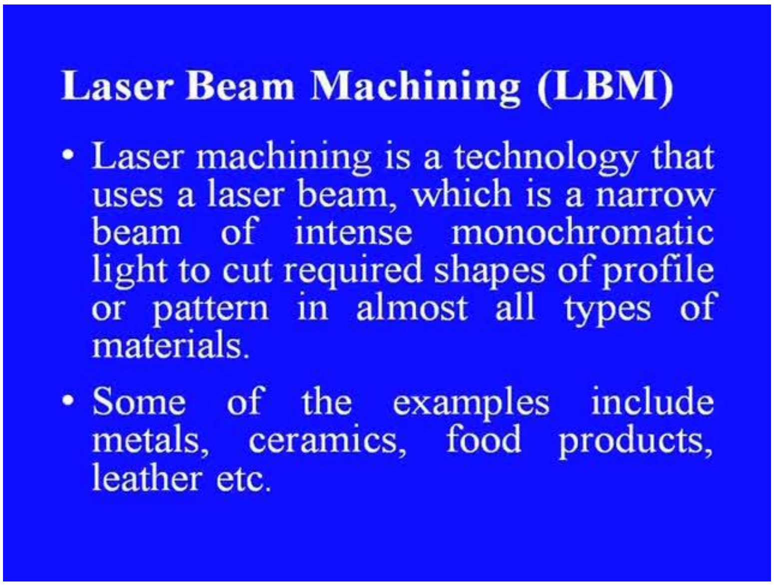

Laser beam machining is a technology that uses a laser beam which is a narrow beam of intense monochromatic light to cut required shapes of profile or pattern in almost all types of materials. This is another striking feature of laser beam machining that this particular process can be used to process any material irrespective of its hardness, irrespective of its melting point. That means from foam to the hardest diamond can be cut using this laser beam machining. Some of the examples of cutting this with this process include metals, ceramics, food products, leather, etcetera. In this process the output of a high power laser beam is directed in a programmed manner towards the material required to be cut. The high amount of heat thus generated either melts or burns or vaporizes away the material at the focused zone.

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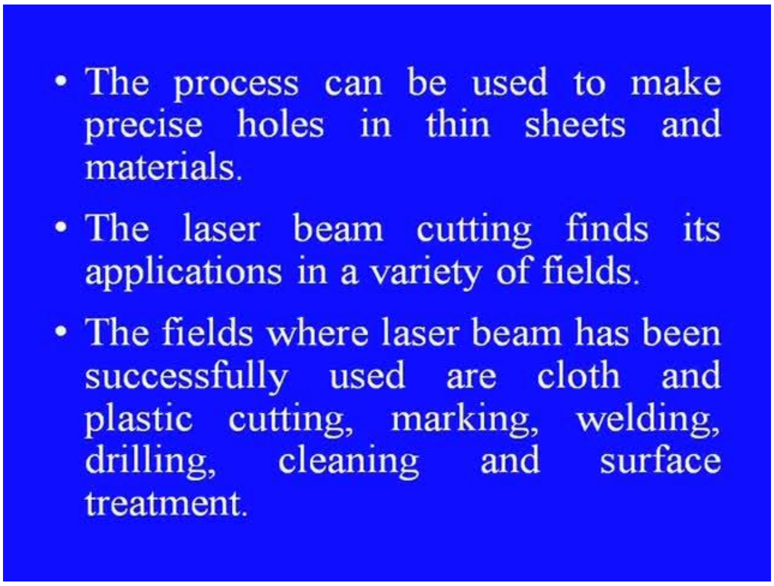

The process can be used to make precise holes in thin sheets and materials. The laser beam cutting finds its applications in a variety of fields. The fields where laser beam has been successfully used are cloth and plastic cutting, marking, welding, drilling, cleaning and surface treatment. As laser 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 vaporization of the work material and finally, the material gets removed.

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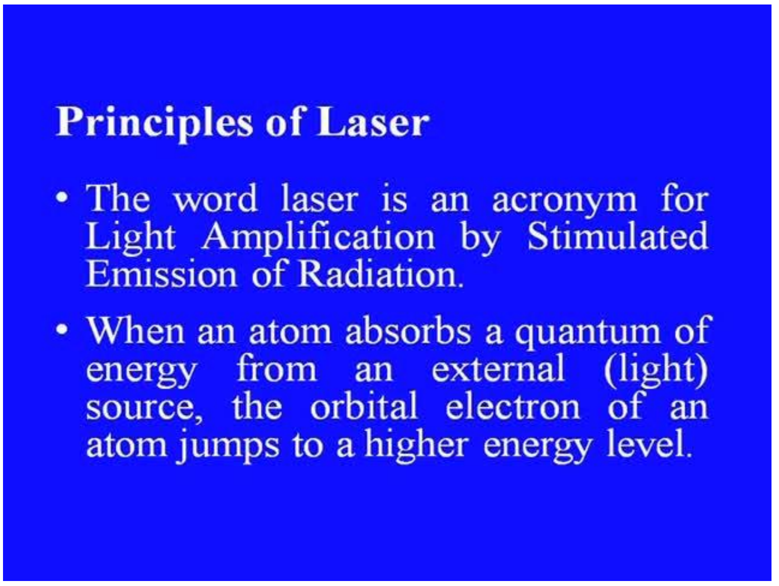

Now, let us look at little bit of principles of laser. How laser is being produced? In fact as everyone knows the word laser is an acronym for Light Amplification by Stimulated Emission of Radiation. So, here when an atom absorbs a quantum of energy from an external source which is usually a light source, the orbital electron of an atom jumps to a higher energy level. The electron later drop to it is original low energy orbit and emits the absorbed energy. If the electron which is already at high energy level absorbs the second quantum of energy, it emits two quanta of energy and after emitting the energy it returns back to its original orbit.

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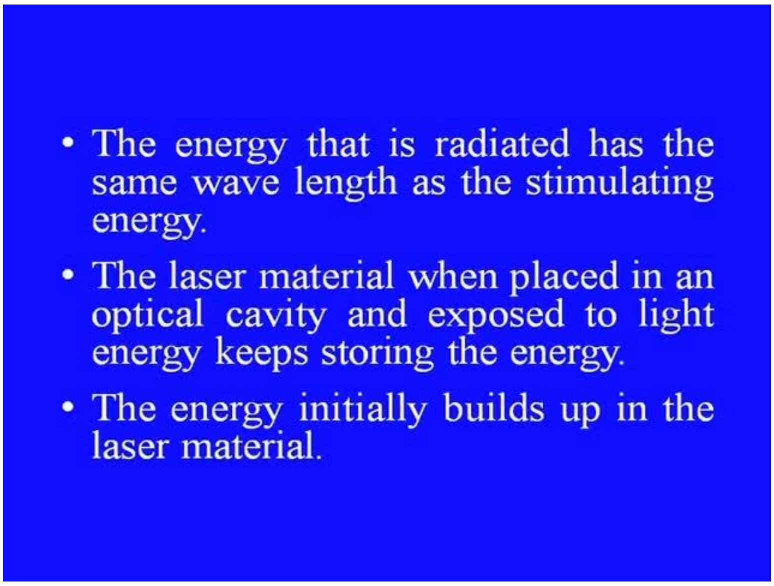

The energy that is radiated has the same wave length as the stimulating energy. The laser material when placed in an optical cavity and exposed to light, it keeps storing the energy. Light is nothing but a form of energy that excites the elements of the material which is called lasing material. The energy initially builds up in the lasing material which is also called lasent. The energy then finally, gets emitted in the form of a highly amplified light beam; this is shown in the figure also. This is like this.

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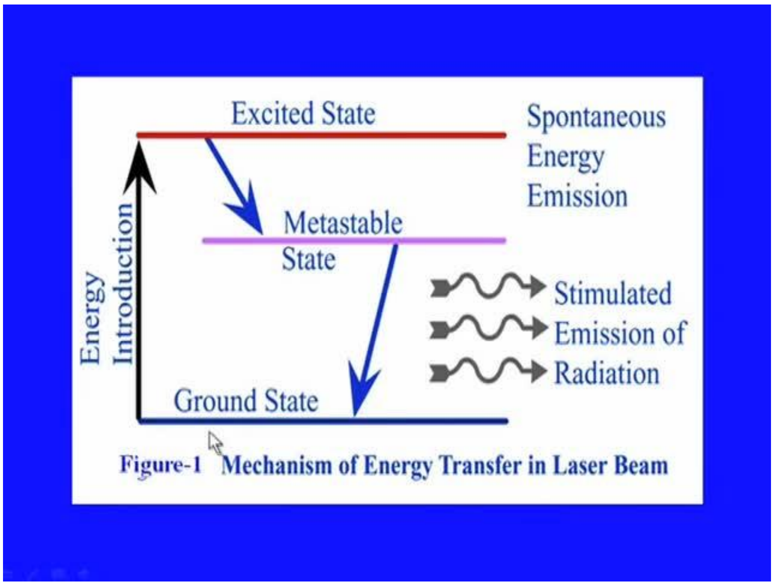

The elements of the lasing material is in the ground state usually before the excitation is employed to it. Then when excited the outer orbital electrons, the the electrons gains energy and it is moved to a further energy level state that is called excited state which has got higher energy, but then this state is an unstable state and it comes down, it always tries to comes down to the lower energy state. And therefore, this jumps to the next energy level which can be a meta stable state and then to the again ground state. However, while in the excited state they have got higher energy and therefore, while coming back to ground state they will have lower energy and this difference in energy is radiated at a particular frequency and this is called the laser emission. This can be also explained like this.

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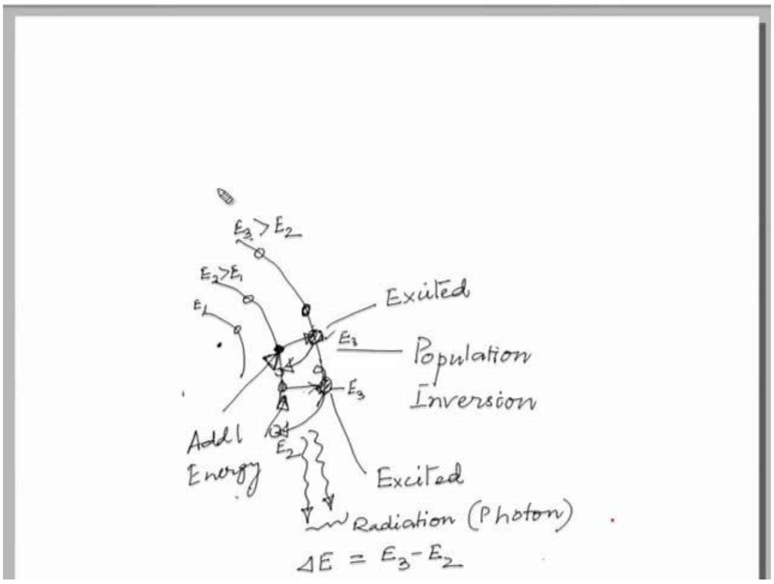

Say for example and in a configuration where electrons are there in different cells. Now, if this electron, this electrons are supplied with some additional energy, additional energy. So, this energy is pumped to this then these electrons from low energies so here this energy level E 1 and this is E 2 which is greater than E 1 and this energy level at this cell is E 3 which is greater than again E 2 that means these electrons at this shell will have the highest energy level.

Now, if by the application of some additional energy electrons in the outer, in the shell having lower energy being pumped to, pushed to the another level where the energy is actually higher than this then this electron at this level will have higher energy which is not natural. And also at this shell there will be an excess of electrons which should have been naturally there. Therefore, at this shell this particular condition is called population inversion.

This population inversion is achieved with the help of additional energy pumped to these electrons which are at the lower energy level to bring them temporarily into the higher energy state level. However, these electrons are very unstable but excited, they are at this state excited level and always they will try to come back to their original original position. Therefore, they will try to jump down to their original shell back here. However, since they are temporarily at E 3 level, energy E 3 level and coming back to E 2 level there will be a difference in energy which is equal to E 3 minus E 2, this delta energy will be emitted at as some radiation. This is also called the radiation or photon. This will be in terms of some energy packets, this is called photon.

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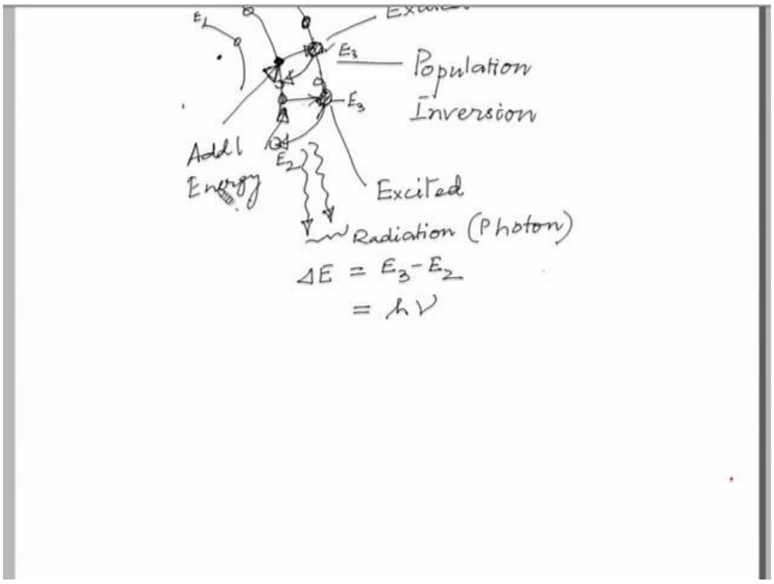

And these photons will be nothing but some waves radiated at a particular wavelength and they are nothing but the laser. Therefore, from this what we have understood is there must be a condition of population inversion for the lasing to take place, and this population inversion is created with the help of some additional energy which will be responsible for pumping the low energy electrons to some higher energy state temporarily.

And these high energy electrons will come back to its low energy original orbits by emitting the additional energy in the form of some radiation that is called laser or photon. And they will have identical frequency and will be highly coherent. Now, let us in brief see different attributes of a laser beam.

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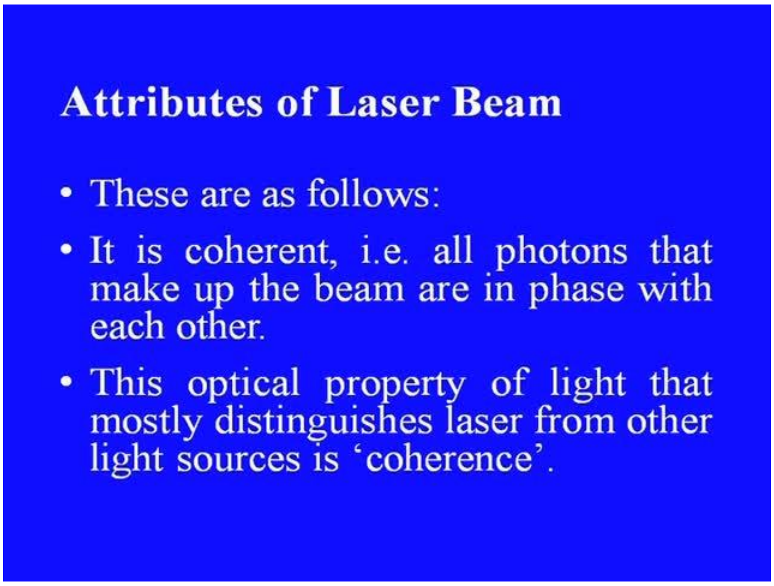

The first and foremost attribute of a laser beam is it is coherent. That is all the photons that just now we have discussed that make up the beam are in phase with each other. This is a significant property or characteristic of the laser beam. This optical property of light that mostly distinguishes laser from other light sources is coherence. The laser is regarded as the first truly coherent light source.

Other light sources such as the sun or a gas discharge lamp are at the best only partially coherent. It is highly collimated that is parallel beam is produced while emitting the photons. The laser rays are almost perfectly parallel, it is monochromatic that means the light is of one color or of one wave length. Different media used to stimulate the photons generate different wavelengths, but each type of laser has specific wavelength.

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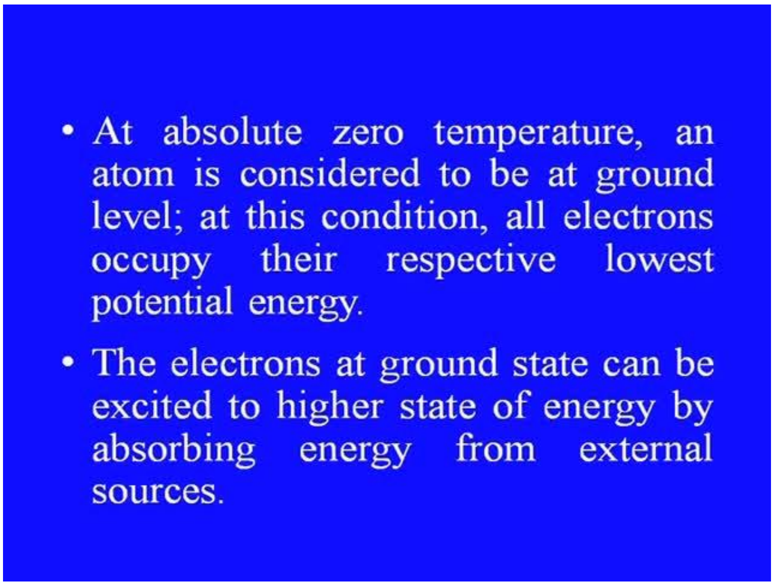

At absolute zero temperature, an atom is considered to be at ground level; at this condition, all electrons occupy their respective lowest potential energy. The electrons at ground state can be excited to higher state of energy by absorbing energy from external sources. The energy absorption takes place through increase in electronic vibration at elevated temperatures through chemical reactions or by absorbing energy of photons.

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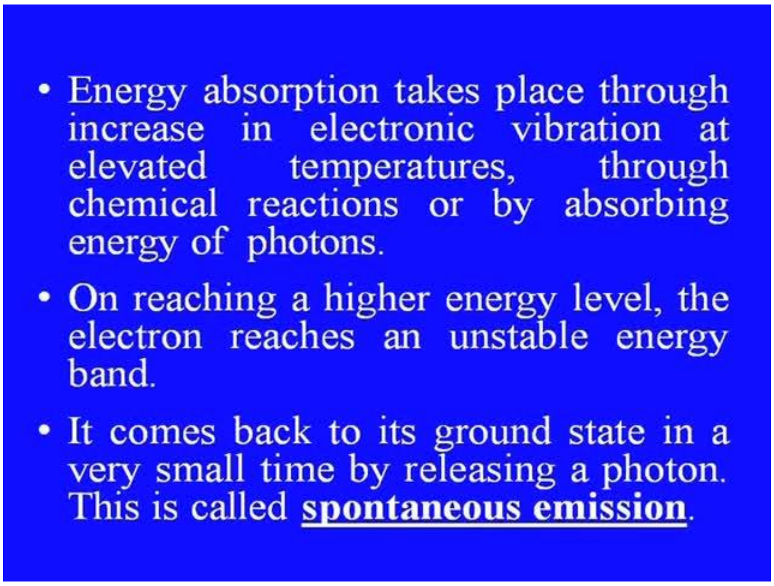

On reaching a higher energy level the electron reaches an unstable energy band. It comes back to its ground state in a very small time by releasing a photon. This is what just now we have discussed. This phenomenon is called spontaneous emission. The spontaneously emitted photon will have the same frequency as that of the exiting photon. 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 for micro to mille seconds, this is what was shown in the figure.

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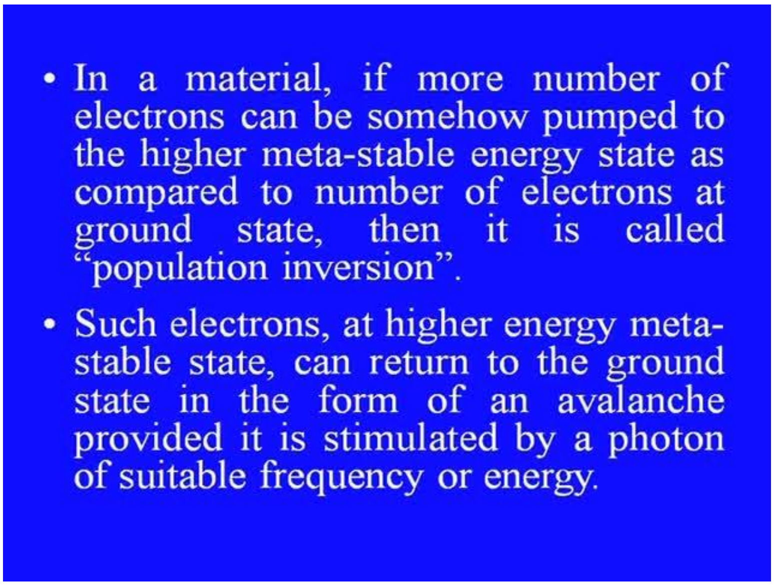

In a material if more number of electrons can be somehow pumped to the higher meta stable energy state as compared to number of electrons at ground state then it is called population inversion. This is what we have already discussed. Such electrons at higher energy meta stable state can return to the ground state in the form of an avalanche provided it is stimulated by a photon of suitable frequency or energy. This is called a stimulated emission. 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 a coherent laser beam can be produced. This is shown in this particular figure.

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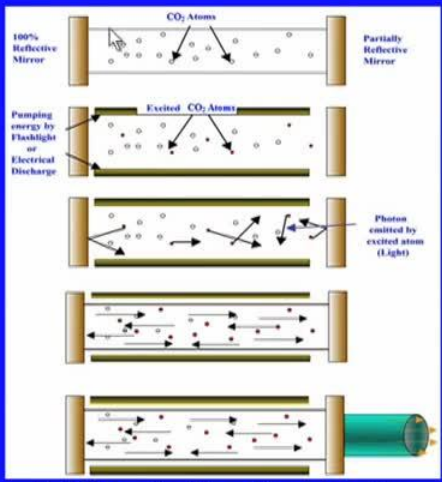

Fig.2 Schematic of Laser Beam generation

This is the lasing medium what we call as lasent. In this case we are we are showing here the carbon dioxide atoms which is a gas as we all know and which is also a very good lasent material. And these carbon dioxide atoms, these small, small atoms are excited by some external energy sources say for example, flash light which will be responsible for increasing the energy level of these CO2 atoms or carbon dioxide atoms. Then these excited atoms at higher energy level will try to come back to its original low energy state and thereby while coming back to its original level it emits some radiation as we have already discussed.

These radiations are successively reflected by a particular mechanism of reflectors which thus amplifies the radiated emission to a particular level. And then it is allowed to pass through a special mechanism of partially reflecting mirror which will allow some of the laser being reflected inside this cavity to outside to be collected as laser beam. This beam will be tapped and will be taken for doing some other work. This is what exactly the principle, how a laser is being produced. Here in this case carbon dioxide is the lasent, not necessarily it should be a gas, there can be a semi conductor, there can be a solid like ruby; we know ruby is a natural material for producing laser.

Then there are several synthetic materials, semi conducting materials which will be used as lasing material or lasing media. Generally, flash lamps will be used as the additional source of energy which will pump in additional energy to excite the atoms inside the lasents. After multiple reflections of these emitted radiations inside the cavity in which a specially arranged set of mirrors will be there. After reflecting for several times the concentrated energy or amplified beam energy will be taken out by some window, specially constructed window for purposes of different use.

Population inversion can be carried out by exciting the gas atoms or molecules by pumping it with flash lamps, then stimulated emission would initiate lasing action. Stimulated emission of photons could be in all directions. 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 intense laser beam.

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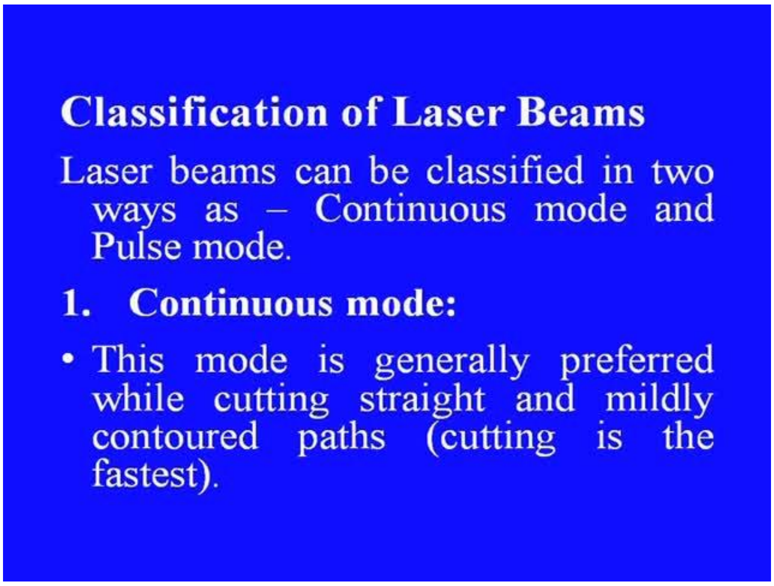

Now, let us look into a classification of laser beams. Laser beams can be classified in two ways continuous mod and pulse mode. Number one continuous mode; this mode is generally preferred while cutting straight and mildly contoured paths, cutting is the fastest.

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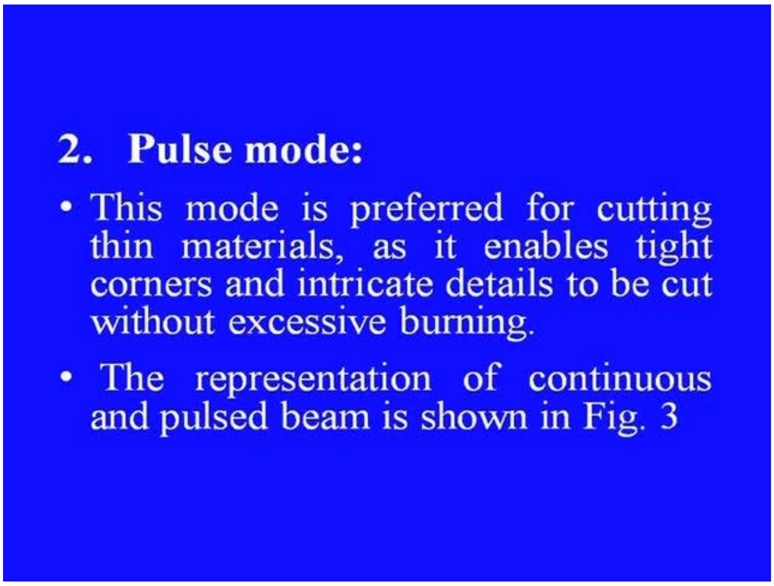

And number two, pulse mode. This pulse mode is preferred for cutting thin materials as it enables tight corners and intricate details to be cut without excessive burning. The representation of continuous and pulse beam is shown in figure three.

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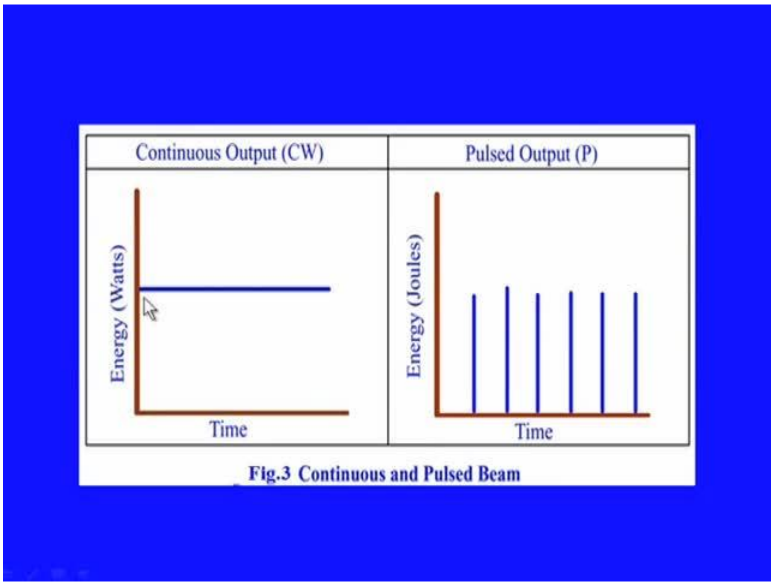

So, this is where the continuous beam looks like that means the meaning is it will have continuously at the same energy output. Whereas in pulse mode there will be a spike or discrete energy pulses as output, means for few microseconds or milliseconds there will be an output of specified energy level say several watts or joules or whatever. And there will be a dead zone in between, gap in between followed by another pulse or spikes of energy. Thus, in the output the energy will be obtained in the form of pulses not continuously. That is why this is called pulsed output laser. There are generally two types of lasers used for cutting, the gas laser and the solid state laser.

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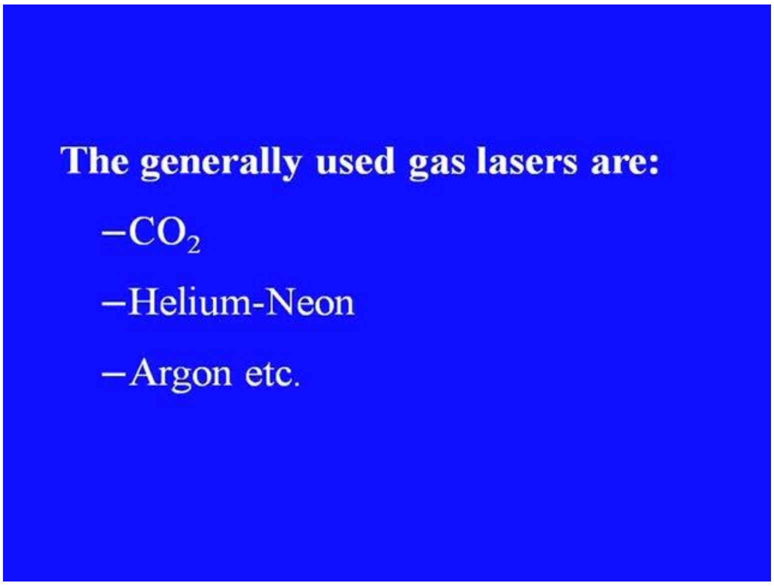

The generally used gas lasers are carbon dioxide laser, helium neon laser and argon laser etcetera. Let us see characteristics of carbon dioxide lasers, these lasers can be operated continuously and on a pulsed basis. Thus, they have wider application in case of continuous mode or in case of pulsed mode.

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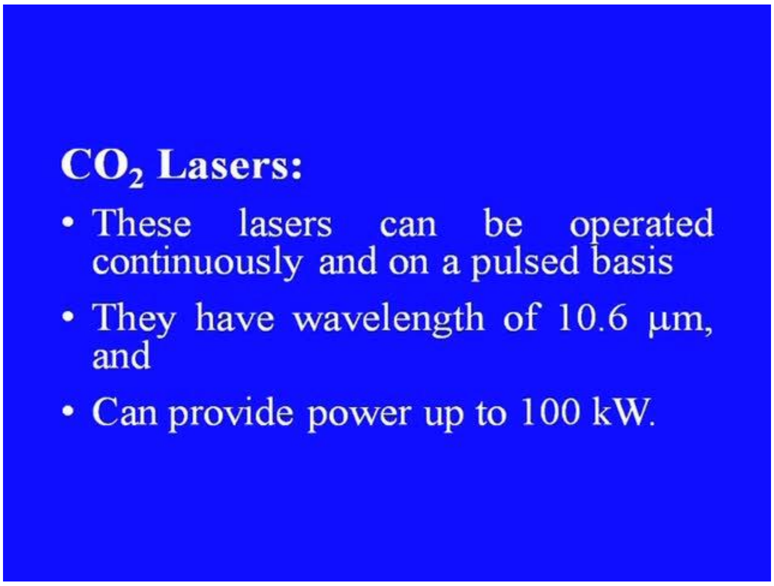

They have wavelength of 10.6 micrometer and they can provide power up to 100 kilowatt. That is why they are preferred in most of the industrial applications where high power is required. The carbon dioxide laser is more powerful among all lasers and is primarily used for cutting and for filing. It is capable of cutting up to 25 millimeter thick carbon sheets. This laser beam because of the spread after its focal point tends to create a tapered cut.

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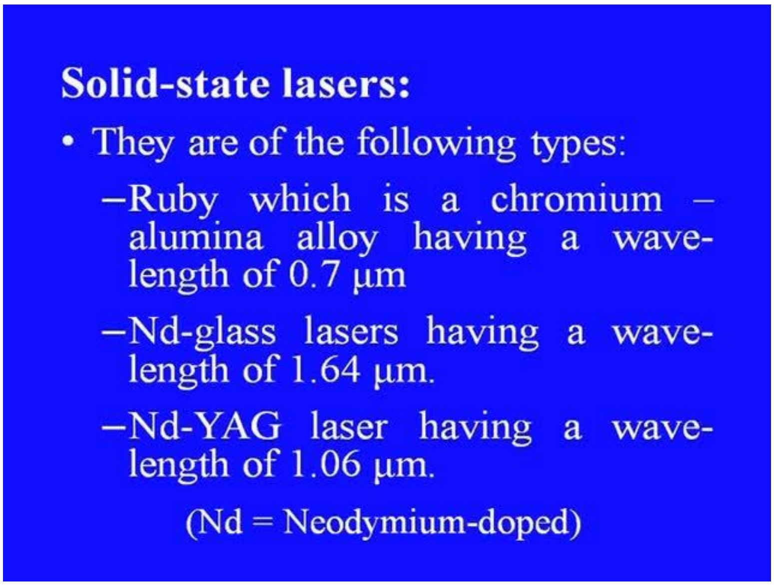

Let us see the attributes of solid state lasers. The solid state lasers are obtained in different forms like ruby lasers. Ruby is nothing but a chromium alumina alloy having a wave, wavelength of 0.7 micrometer. Another form is neodymium glass lasers which has got the wave length of 1.64 micrometer. Another very popular form of solid state laser is Nd YAG lasers also called neodymium yttrium aluminum garnet laser. This lasers have the wavelength of 1.06 micrometer. This Nd YAG laser is another very popular layer in industrial applications. This Nd YAG lasers have wavelengths of 1064 nano meters and it can provide powers up to 5 kilowatts. These lasers can also be obtained both in pulsed as well as continuous mode.

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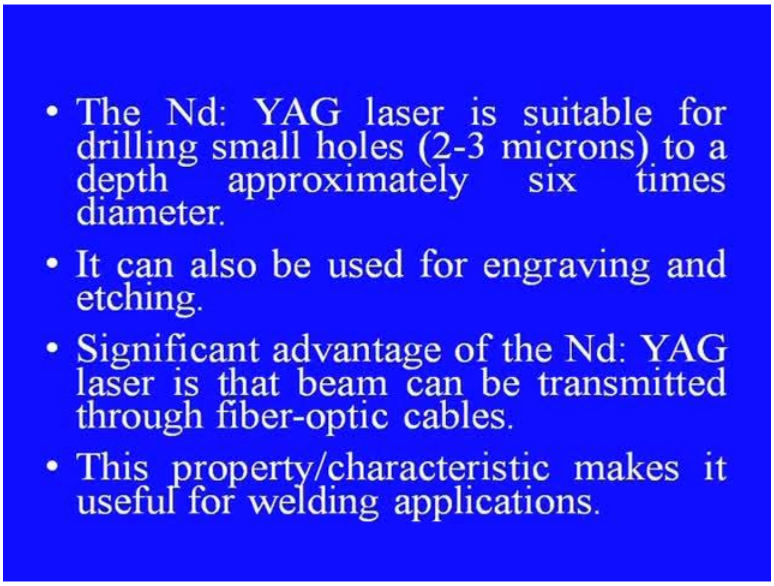

The Nd YAG layer is suitable for drilling small holes say for example, 2 to 3 microns diameters to a depth approximately six times the diameter. It can also be used for engraving and etching. Significant advantage of the need neodymium yttrium aluminum garnet laser is that beam can be transmitted through fiber optic cables. This property or characteristic of this laser makes it popular for welding applications. Now, let us see how the material removal or cutting is taking place using laser beam. The focal point of the laser is intentionally focused on to the surface of the work piece for providing the heat in a concentric manner, means the focal point is the point where we want to make a cut or make a hole in case of drilling.

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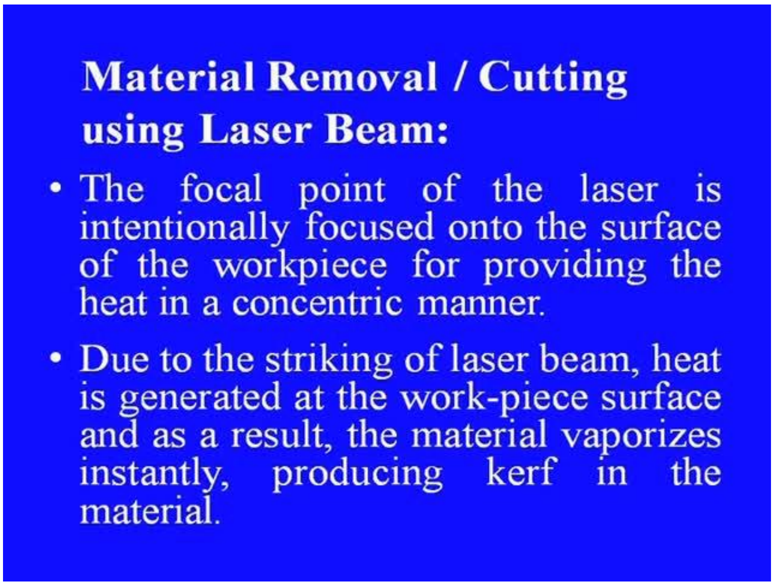

Due to the striking of laser beam heat is generated at the work piece surface, as a result the material vaporizes instantly producing a kerf in the material. The movement of the machine axis is through the computer control which helps to achieve the required profiles on the work piece. Heat affected zone is minimal in laser as compared to flame cutting.

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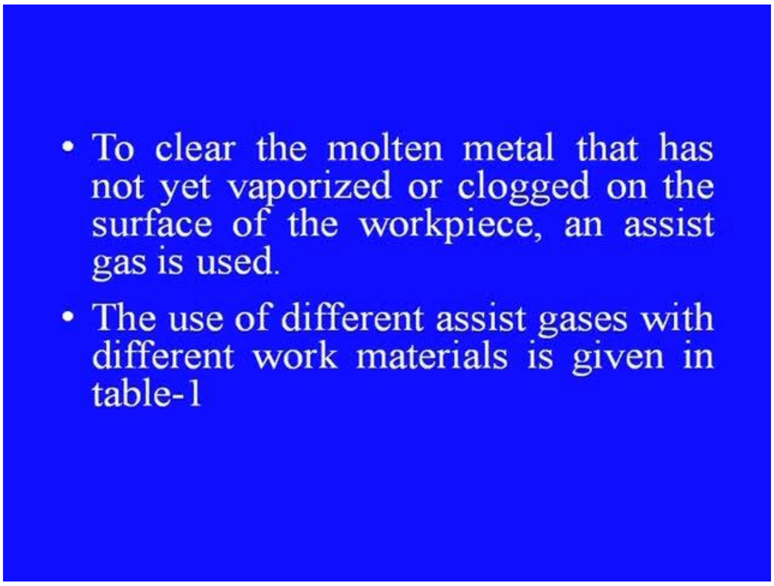

To clear the molten metal that has not yet vaporized or clogged on the surface of the work piece an assist gas is sometimes used. The use of different assist gases with different work materials is given in this table.

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Table-1 Gases used for different materials

Material	**Gases**
Mild steel	Oxygen
Stainless steel	Oxygen or nitrogen (nitrogen leaves an oxide free edge that can improve weldability)
Aluminum	Nitrogen
Titanium	Argon (an inert gas because of its reactivity)
Nonmetals	Air or inert gas

Say for example, mild steel material oxygen is used as an assist gas. Similarly, for stainless steel material, work piece material oxygen or nitrogen is used as assist gas. Nitrogen leaves an oxide free edge that can improve weldability that is another advantage of using nitrogen in this case.

Similarly, for aluminum also nitrogen use is used as an assist gas. For titanium machining on the other hand argon gas is used as an assist gas. For non metals generally air or any inert gas like argon is used as assist gas. The schematics are shown in these figures. In this figure when the power supplied by the pulse forming network an intense pulse of light or photons is released through one end of the crystal rod like this…

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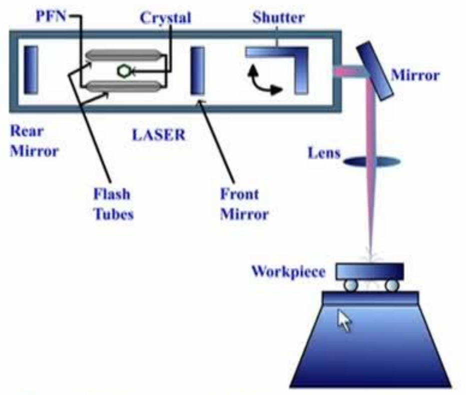

Figure-4 The schematic of Laser Cutting Unit

So, this is the PFN also called pulse forming network in which these are flash tubes which will be supplying the additional energy to the lasing material which is a crystal in this case, shown as crystal. Thus the energy level in this crystal will be increased by this additional energy from this flash tubes system and then the emission from this crystal will take place in the form of laser. These emissions will be continuously reflected by these mirror system, this mirror system which will be responsible for amplifying this radiation to a certain level.

After it attains certain energy or power level they will be taken out by some partial lens arrangement through which the laser will come out like this as shown in this particular figure and can be focused on the work piece with the help of some lens assembly or lens system. This focal point on the work piece can be adjusted with the help of this lens system. And the output of this laser can also be changed by the control mechanisms in this entirely laser producing mechanisms.

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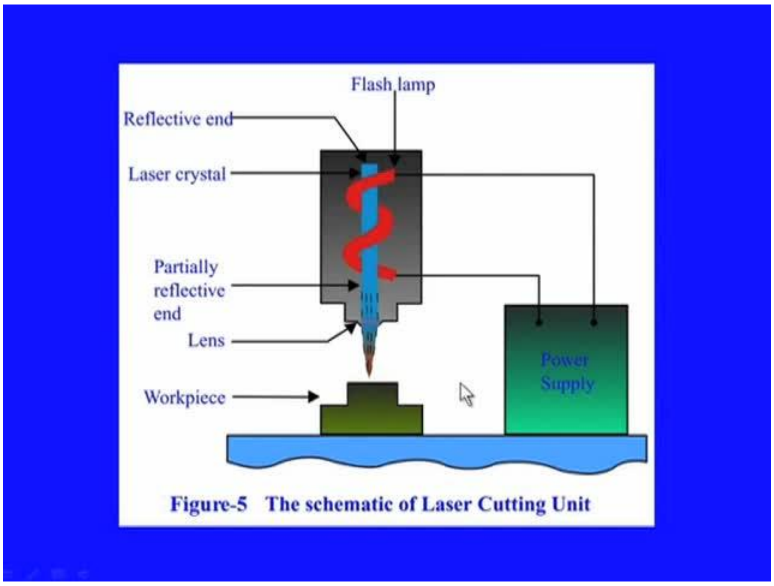

Figure-5 The schematic of Laser Cutting Unit

This is another schematic of how the laser is being produced. So, this is the lasent and then this is here that spiral red element is responsible for the additional energy which is in the form of a flash lamp. And this will supply energy to this lasing material and in one end of this mirror system which is partially reflective, therefore some amount of beam will come out as the laser beam and they will be focused with certain lens system on the work piece.

The power to this additional energy system will be controlled by some other power supply system. If we look at the development of laser then it is way back in 1917 a discovery by Albert Einstein who first gave the principle of laser. But the first industrial laser was developed around the year 1960. The laser beam can be very easily focused using optical lenses as their wavelength ranges from 0.5 micron to around 70 micron.

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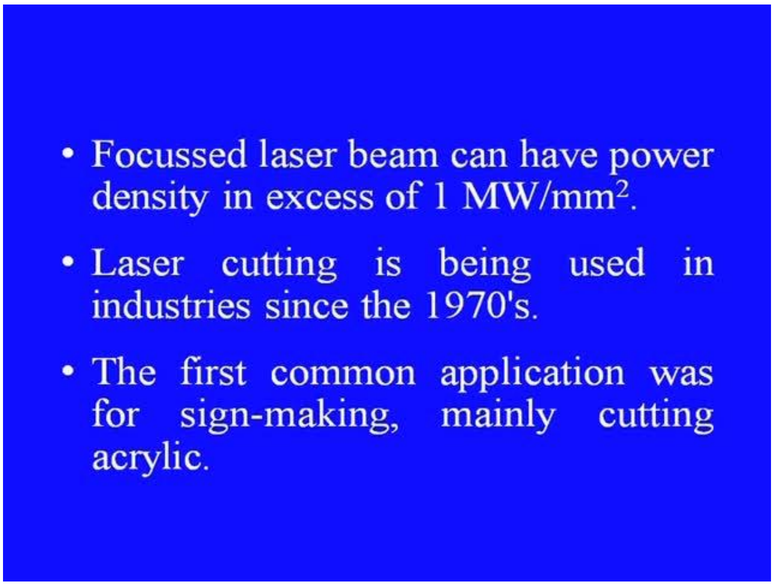

Focused laser beam can have power density in excess of 1 mega watt per millimeter square. Laser cutting is being used in industries since 1970s. Once this high power laser production was possible the application envelop of lasers also got expanded. Thus, once the industrial use started coming say for example, since the year 1970s the lasers got their application in various spheres of industrial cutting, heating or melting, scribing etcetera. The first common application was for sign making, mainly cutting acrylic. It was established as a manufacturing process however, in the late 1980s. It is now a significant process in every manufacturing economy.

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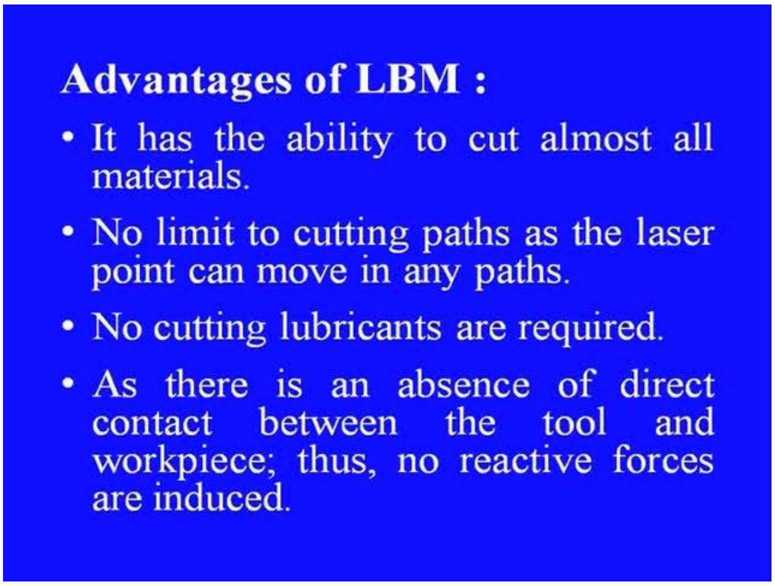

Now, let us look at some of the advantages of laser beam machining. Laser beam machining has the ability to cut almost all materials which is very significant irrespective of its physical property or the hardness. No limit to cutting paths as the laser point can be moved in any path by suitable computer numerical control technology. No cutting lubricants are required as we have already talked about. There is no physical contact between the tool and the work piece. The contact is through electromagnetic radiation or the beam of light.

As there is an absence of direct contact between the tool and the work piece; thus, no reactive forces are induced. As no reactive forces are induced it is not necessary to provide work holding systems. If we can just place the work piece on to the system or the machine setup it is sufficient. Similarly, fragile materials which are otherwise very difficult to hold in conventional machining systems or machine setups are easy to cut using laser material or laser beam as there is no sturdy work holding devices are required. Holes can be located accurately by using an optical laser system for alignment.

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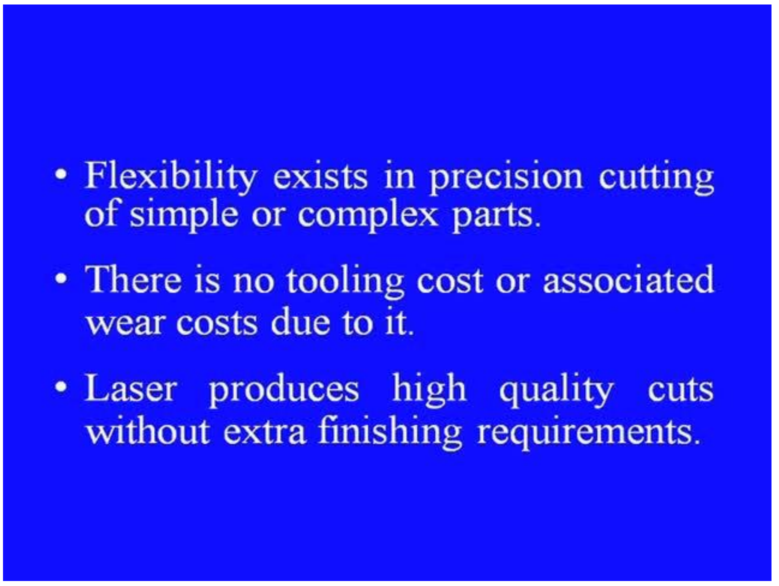

Flexibility exists in precision cutting of simple or complex parts. There is no tooling cost or associated wear cost due to it since there is no physical contact between the tool and the work piece. Laser produces high quality cuts without extra finishing requirements. Very small holes with a large aspect ratio can be produced using laser beam machining. A wide variety of hard and difficult to machine materials can be cut. Machining is extremely rapid and the setup times are economical. Holes can be drilled at a different entrance angles say for example, 10 degree to the surface.

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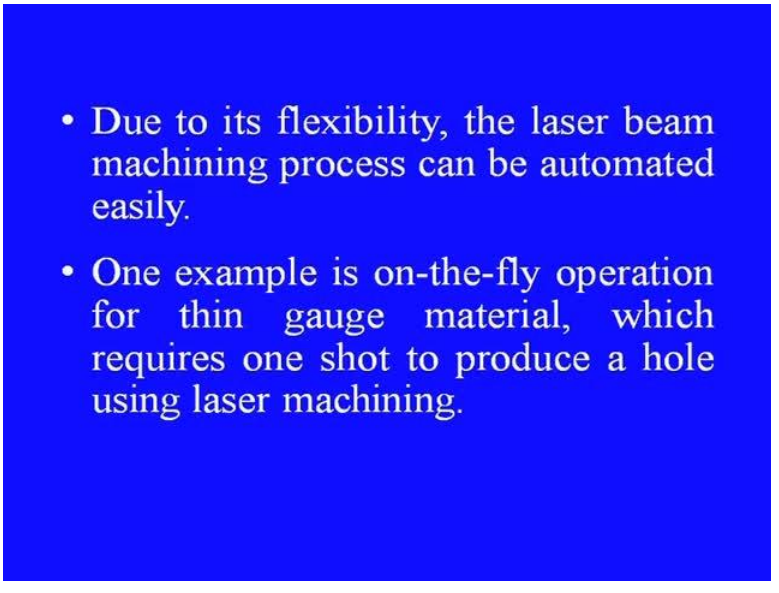

Due to its flexibility the laser beam machining process can be automated easily. One example is on the fly operation for thin gauge materials, which requires one shot to produce a hole using laser machining. Now, let us look into some of the limitations of this process.

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Laser processes involve high capital investments and high operating cost. Laser holes are tapered to some extent, approximately 1 percent of the drill depth. This can be explained like this.

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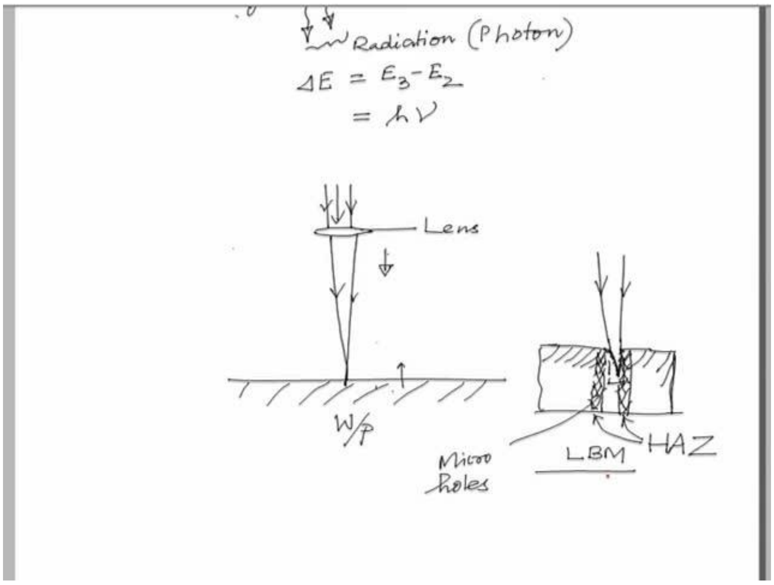

As I have already explained the laser can be, laser can be focused on to the work piece by using suitable lens system. So, this is the lens system, this is the laser and this is say for example, work piece. Now, as this hole will be created here, this either this work piece will be moved up or this laser system, laser head system will be moved down. Now, as it moves up what will happen a different portion of laser will touch the work piece surface something like this, say this is the work piece and therefore, the corresponding drilled portion will be something like this.

Thus, instead of getting a straight hole something like this we will be getting in fact a hole tapered something like this. This is nothing but laser. This possibility is there in case of LBM and therefore, if it is, the application is for a precision products or applications then this may not be a very suitable process to be used for cutting or drilling micro holes. It cannot drill blind holes to precise depths; the thickness of the material that can be drilled is restricted to 50 millimeter or so. Heat affected zones through the lasers may change the mechanical properties of the metallic materials and alloys.

This also I have already told like in this case, this area wherever we are machining so near to this, this area may get affected further or you can say this zone on the either side of the cut can be considered as the heat affected zone where the property of the metal or the alloy can be different. So, this is considered as the heat affected zone. This may not be required or appreciable in certain precision application cases. The processing time in laser holes is slower due to the trapening action or the process involved in it.

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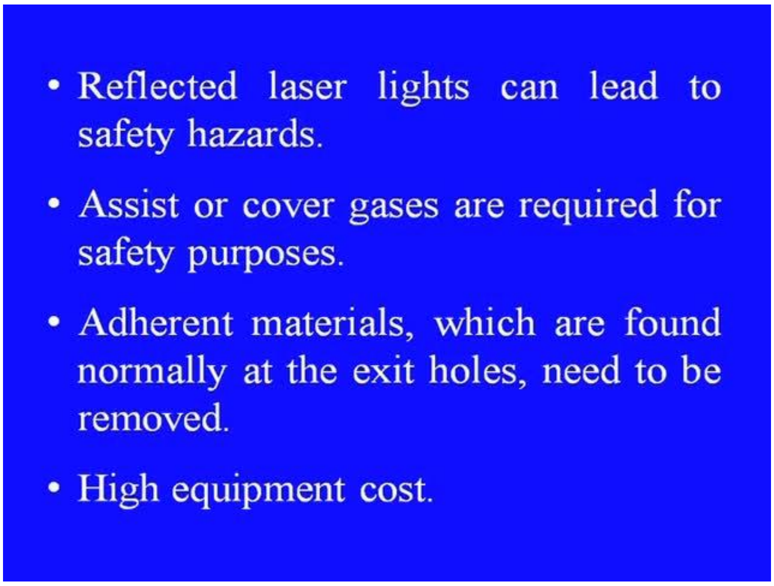

The reflected laser lights can lead to safety hazards. Assist or cover gases are required for safety purposes. Adherent materials, which are found normally at the exit holes need to be removed. This needs additional time and involve cost and the laser producing machines having very high cost. Now, let us summarize what we have discussed in this particular session.

In this session we have discussed about the principles of lasers, different attributes of laser beams, classification of laser beam, the mechanism of laser activation, the types of lasers mainly the gas lasers and the solid state lasers. We have already discussed carbon dioxide lasers, their attributes, solid state lasers like ruby lasers, their attributes. These two are the most common form of laser used in industries. Then some of the developments in laser beam machining process also discussed. In the next session we will discuss some more features about this laser beam machining process and the influencing process parameters in this particular process. We hope in this session the information was useful and fruitful.

Thank you.