Manufacturing Process II
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Lecture No.40
EMB+LBM

Good morning! Welcome to the NPTEL sponsored series on Manufacturing Processes – II. Today we are going to do the lecture number 9.6, that is module number 9 non-traditional manufacturing and this is the concluding lecture of this particular module.

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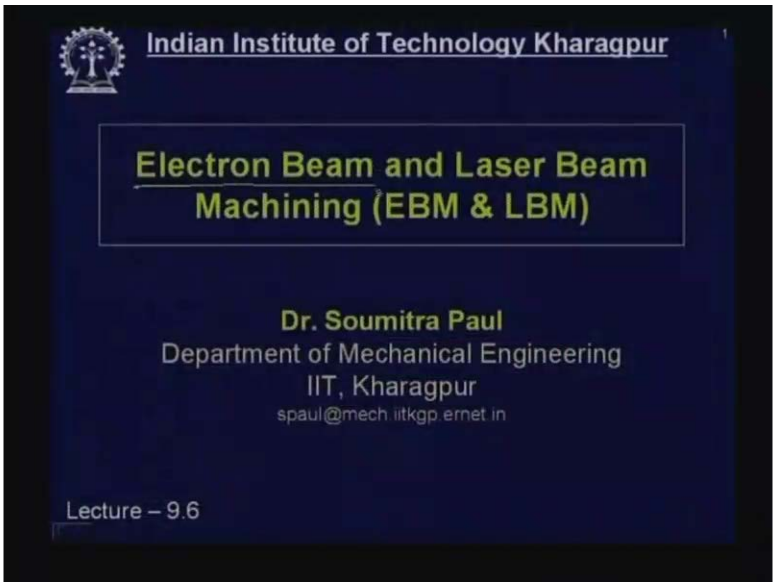

as well as this particular lecture series on Manufacturing Processes II. Today we are going to study electron beam and laser beam machining. They are called in short EBM and LBM. Before starting any lecture, thus for we have gone through the instructional objectives that is what you are going to learn after going through this particular lecture.

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In any non-traditional manufacturing process, mechanism of material removal is very very important. Whatever we have studied in this module generally we cover what is the basic mechanism of material removal and that also we are going to study today specifically for today's topic electron beam and laser beam welding, electron beam and laser beam welding laser beam machining for carrying out that we need equipments. So we have to study what are the major components of those equipments in electron beam machining and laser beam machining, then we are going to concentrate on the working principle of electron beam machining and laser beam machining, then once we have studied the working principle, we will try to schematically represents the EBM and LBM equipments.

In any nontraditional manufacturing process be it EBM or LBM or for that matter electrochemical machining, electro discharge machining, identification of process parameters are very very important. So today also we are going to see what are the process parameters and we are going to study to some extent what is the effect of those process parameters on the machining characteristics of EBM and LBM. Like all other machining processes non-traditional machining processes, here also we are going to see what are the applications advantages and limitations.

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Now let us very briefly go through the classification of non-traditional machining processes. They are mechanical processes, electrochemical processes, electro thermal processes, chemical processes. Already we have studied quite a few mechanical processes under this lecture series. We have for example studied, abrasive jet machining, ultrasonic machining, water jet machining as well as abrasive water jet machining. Within electrochemical processes, we have studied in detail electrochemical machining processes. Today our process is under the category electro thermal processes.

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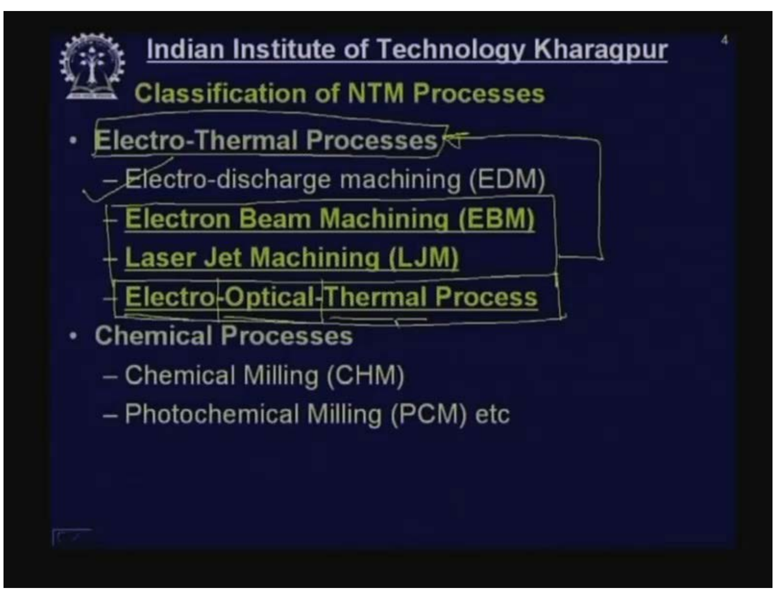

Even within electro thermal processes, already we have studied electro discharge machining. Today we are going to concentrate on electron beam machining and laser beam machining. These two processes though belong to electro thermal process they can also be described as electro optico thermal processes. Why? Because both in electron beam and laser beam welding, ultimately we generate a beam of electron, high velocity, high energy or in case of laser beam machining, a beam of photons. Thus it is also can be classified as Electro-Optico or Optical-Thermal process.

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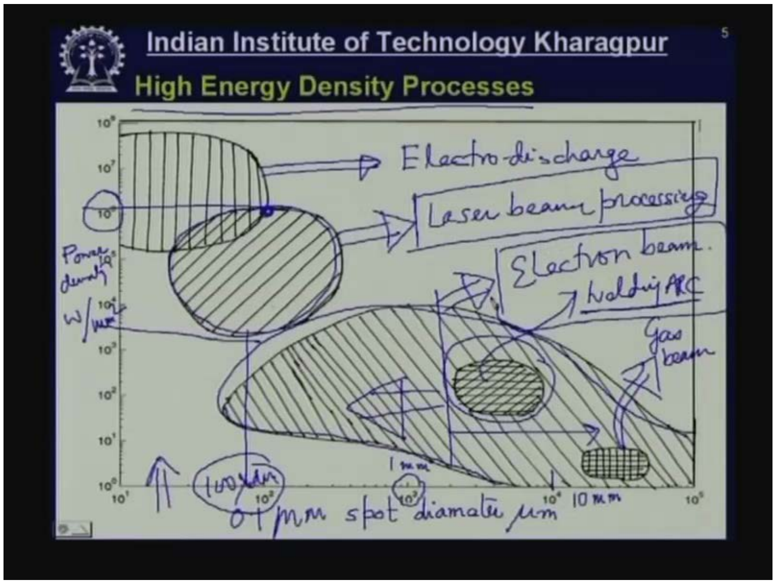

Now these two processes, they are basically like other non-traditional processes, they are basically high energy density process. What do you mean by high energy density process? In this particular graph, this is my spot diameter in micron that means, wherever is 10 to the power 3 is written. This is around one millimeter, this is around ten millimeter and this is the power density of the process in question what per millimeter square. There are five different zones shown in this. Already some of the processes we have studied. Say for example, this particular process is called electro discharge process. So as in case of electro discharge process, the spot size is really very less. The power density is very very high. This one is of interest to us. Today this particular sector belongs to laser beam processing or laser beam machining.

I would rather use the word processing because other than machining, as we go through the lecture we will find out laser beam can also be used for kind of processing. Here as you can see the typical spot size is around 0.1 millimeter or hundred micron. Both of them are same and the power density is rather high. It can be as high as ten to the power six watt per millimeter square or one megawatt per millimeter square. The total energy involved is not high but as because the spot size as because the spot size is less the power density becomes very very large. This very large domain, that is shown here. This belongs to electron beam processes and that is of interest to us. When electron beam machining is done, typically we do not go towards this we concentrate towards a millimeter or sub millimetric spot size.

So that a very large power density can be obtained. This one here is for gas beam say for example; oxyacetylene beams and this one here is corresponding to welding arcs. So this is the basic classification or characteristic of high energy density processes and out of those high energy density processes, two of them we are going to study today. One is laser beam machining, another one is electron beam machining. Now as I said earlier both laser beam machining and electron beam machining they are equipment intensive processes. The equipment is the heart of the process and we need to study those equipments in electron beam machining. The electron beam gun which generates the beam of electron is the heart of the equipment. Let us see how it is fabricated:

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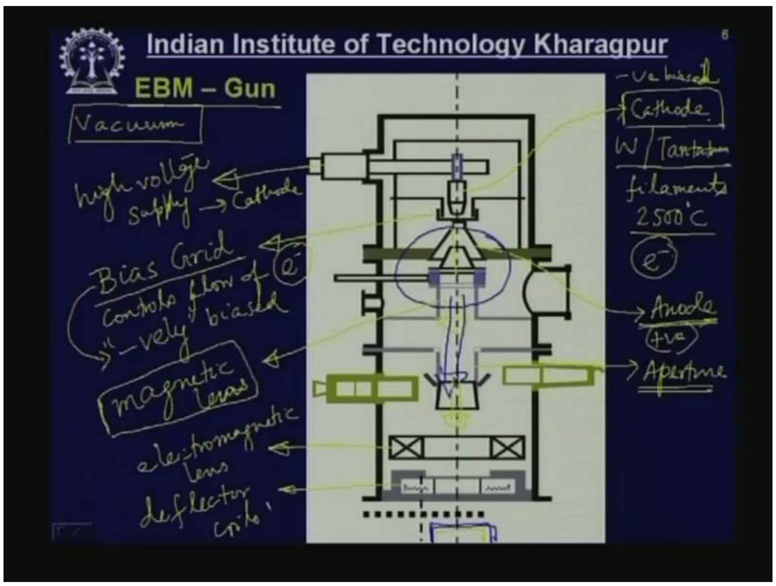

Now electron beam gun first and foremost operates under vacuum. So this whole structure whatever has been shown this whole structure is under vacuum. This particular part is my cathode. This cathode is made of either tungsten or tantalum. These are filament type cathodes. Potential difference is applied across this filament. So that the filament temperature goes around 2500 degree centigrade at such high temperature and moreover under vacuum, there would be emission of thermo-ionic electrons. Moreover this particular cathode is highly negatively biased. This is negativity biased and this is your high voltage supply to your cathode. So through this section, the high voltage supply comes. So once this filament goes to this temperature, electrons are emitted thermionically as the cathode is negativity bias, they are repelled from the cathode.

Just after the cathode you have once again a bias grid, this bias grid is very very important in construction of the electron beam gun because it controls the flow of electron it controls the flow of electron. This bias grid typically is negatively biased so that, electrons do not get collected on it or rather there are concentrated. Just following the bias grid, you have a positively biased anode this is my anode. So this is positively biased so what happens electrons are negative anode is there. So anode because of the potential difference between the anode and the cathode, the electrons are accelerated. As they pass as the electron pass through this particular section, the anode section they achieve a velocity which is almost half of the velocity of light. So, when they are passing through this particular section, they are highly energetic. Just following the anode, you have two more things. One is called magnetic lenses, these are magnets and these are magnetic lenses.

What is the function of magnetic lenses? They serve the same function as that of any lens which is to concentrate or focus a beam of light but we do not have a beam of light here, we have a beam of electron. So these magnetic lenses they would focus or concentrate beam of the electron. So gradually the electron beam would be very concentrated and they will start moving through this particular section. But, some of the electrons may diverge for whatever reason. So, just after the magnetic lenses we have an aperture. It is just like an aperture of an optical camera. But, the purpose of this one is bit different. Whatever stray electrons are available here, the aperture will capture those stray electrons so that the electron beam which emerges from this section, there are very very concentrated and focus. There are no stray electrons.

Further down the line, you have an electromagnetic lens which ultimately focuses the electron beam on to your work piece. Your workpiece will be somewhere here. Your workpiece would be somewhere here which will be explaining once again in a later slide. your workpiece will be somewhere here. So that electromagnetic lens would basically be concentrating the electron beam or focusing the electron beam on the electrode. This particular piece of small coil is known as deflector coils. These deflectors coils can deflect the electron beam by small amount so that you can correct, if there is if you are not getting a proper hole shape, two more instruments we have not mentioned here, possibly I can a take a fresh slate and these are this two.

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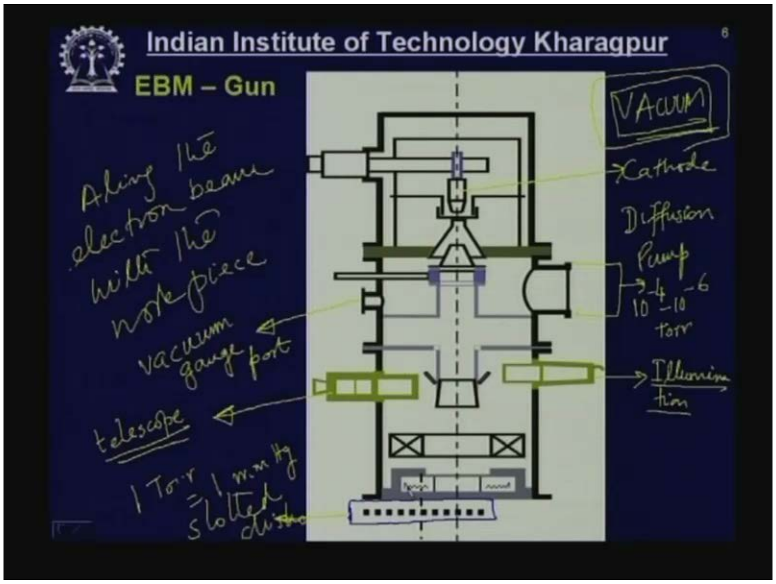

This one as well as this one. This is called illumination system and this is a telescope. This illumination system and telescope they are used simultaneously. Why they are used? To align the electron beam with the work piece. So this is the requirement of the illumination system and the telescope. What else do you have here? Here we have a port. As I said earlier, electron beam gun operates under back vacuum. So this particular port is for measuring the pressure or monitoring the pressure. So this is vacuum gauge port from mounting my vacuum gauge. There is another port as can be seen here. This is my diffusion pump. Diffusion pump is a vacuum pump which maintains vacuum within the electron beam chamber.

What is the level of vacuum level of vacuum is 10 to the power minus 4 to 10 to the power minus 6 torque. I hope you must be knowing that one torque is equivalent to one mm Hg pressure, that means the pressure of one millimeter of mercury is one torque and we are maintaining ten to the power minus four to ten to the power minus six torque within the electron beam gun. So this is the construction of the EB gun. Always I am saying electron beam guns are operated under vacuum. Why they are operated under vacuum? If they are not operated under vacuum, first and foremost from the cathode if you remember this is my cathode. We would not have thermo-ionic emission and even if we have thermo-ionic emission, those electrons will collide with the air molecules and they would be accelerated to that extent.

There would be so many numbers of collusions with air molecules and they will lose their energy that is the reason electron beam guns or electron beam machining as such is carried out under vacuum. There is another small piece of equipment that we have not yet mentioned this one. This is the slotted disk; what is it? This is slotted disk. What is the purpose of slotted disk? Whenever we are machining with the electron beam material removal occurs because of vaporization and melting. Those vapours should not enter my electron beam or should not obstruct the optical windows of the electron beam gun. So there is a slotted disk and they are synchronized with the electron beam and always it will allow the electron beam to interact with the workpiece but it would not allow any vapor of the workpiece to obstruct the windows of the electron beam gun. There is another piece of information which is very very essential. In electron beam machining, the gun is operated in pulse mode unlike in electron beam welding where it is operated on continuous mode. So how is it operated in pulse mode that can also be explained from this diagram.

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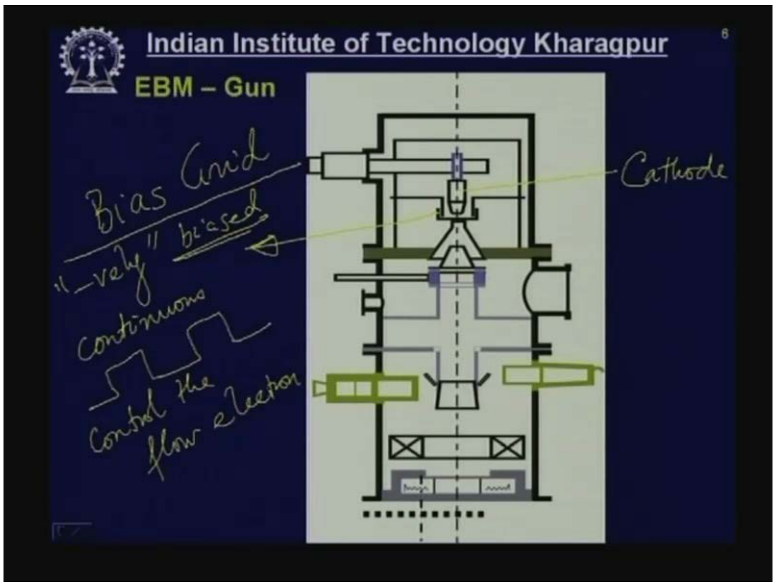

If you remember this one was your cathode, this one was your bias grid, we have already mentioned, this is a negatively bias grid. But this negative bias is not continuous. It is in pulse mode. As this bias is in pulse mode, this bias grid controls the flow of electron. So whenever there is a bias, appropriate bias it will allow the flow of electron. In other time, when it is not appropriately bias it would not flow of electrons and in that way, we can operate almost similar electron beam gun. In continuous mode which is required in electron beam welding or in pulse mode which is the topic of today electron beam machining which is requiring electron beam machining.

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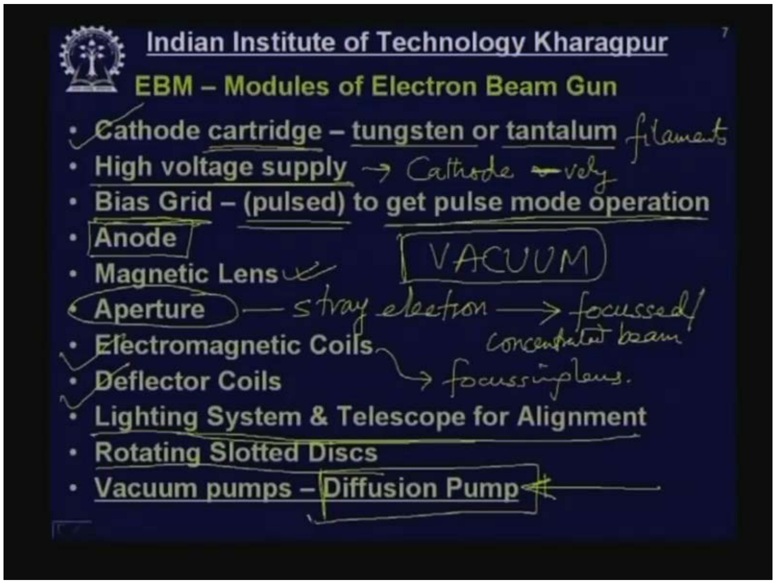

Now already we have discussed the different modules of electron beam gun, just in the previous slide just to summarize that let us identify them once again. We require as we have mentioned earlier a cathode it is typically in the form of a cartridge we have also mentioned the cathode is made of tungsten or tantalum. These are in the form of filaments. There has to be a high voltage power supply, so that the cathode is negatively biased. So that whatever thermo-ionic emission of electron takes place, they are repelled from the cathode. There is a bias grid. Mostly it is supplied with a pulsed bias, so that we can operate the instrument in pulse mode following the bias grid.

There is an anode magnetic lenses which concentrate the beam, aperture which captures the stray electrons. It captures the stray electrons. Why do they capture? So that we get a focused beam or a concentrated, focused and concentrated beam. Then you have electromagnetic coils, which actually works as a focusing lens. Then we have deflector coils which can deflect the beam by small amount. We require a lightening lighting system or illumination system and telescope for alignment. We also require rotation slotted disks so that electron beam gun does not get damaged because of production of vapor during machining and as it has been mentioned number of times, the whole system has to be under vacuum and who maintains that vacuum within the gauge within the electron beam gun that is maintain by rotary pump and diffusion pump. That means diffusion pump becomes a very very important module in electron beam machining or in the electron beam construction of the electron beam gun. So we need to study what is this diffusion pump and how it works?

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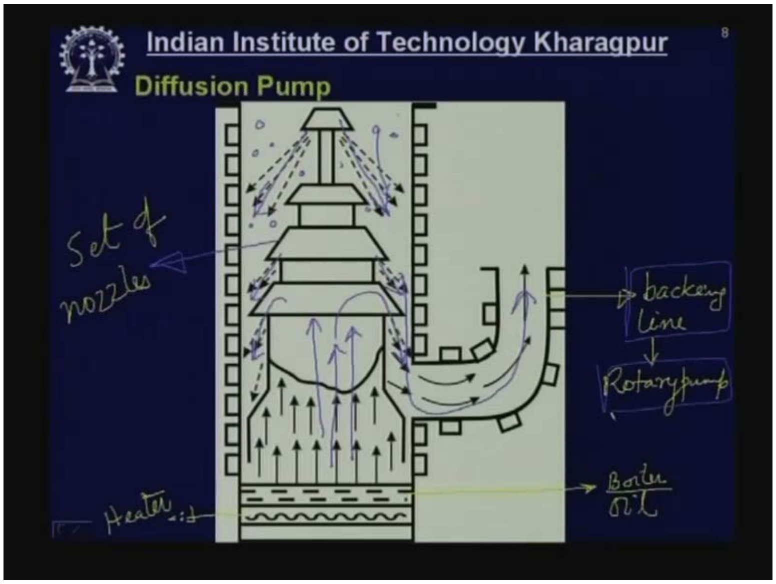

So this is the slide depicting the construction and working principle of diffusion pump. What do I have here? Here we have a boiler. Is it a boiler like a steam, steam thing. No it is a small boiler containing oil. Just below that, we have a heater. So as we are heating the oil, oil vapor should be produced and those oil vapors would start going up just above those oil vapors we have a structure which is called a set of nozzles and further a part of the diffusion pump is connected to something which is called backing line which is in turn connected to a rotary pump. Rotary pump is also a vacuum pump, but it can maintain vacuum which is not so high.

So what happens when we heat the oil? The oil vapors starts going up. As they reach this particular section their momentum is reversed and they come out as a high velocity jet through this part. Similarly, they come out from this section. They come out this section they also come out from this section. This side of the diffusion pump is connected to my electron beam gun. So if there is any residual air molecule because of the momentum of this oil jet these air molecules should be entrained in the jet and gradually everything would be removed through this backing line via the rotary pump and in this way within the electron beam chamber which was here. Within the electron beam chamber, this is the connection for diffusion pump. So within this chamber, we will be getting vacuum in tune of ten to the power minus four to ten to the power minus six torque.

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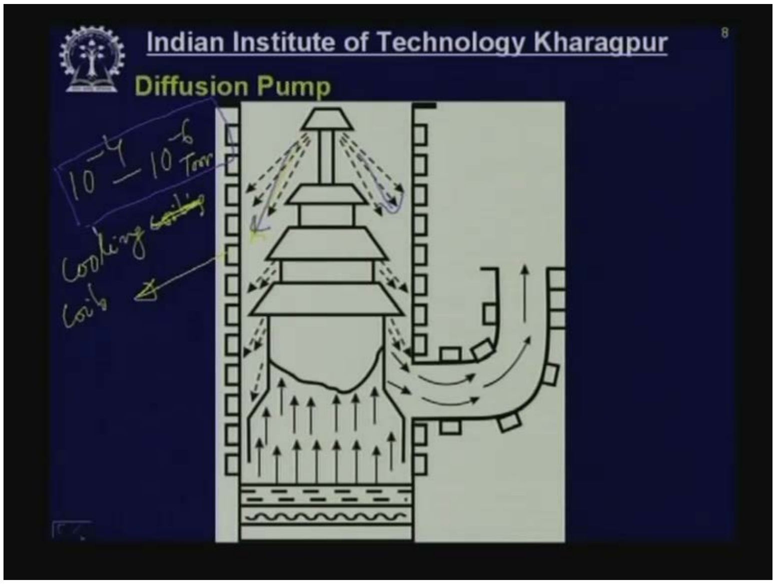

To help proper working of the diffusion pump we have a series of cooling coils which helps which helps in condensation of this oil vapors in a very nice manner and entrainment of any residual air and this cooling coils through this cooling coils cold water would be passed continuously. So diffusion pump is also another very important part of electron beam gun which maintains appropriate vacuum within the chamber. Now let us have a look at the mechanism of material removal in electron beam machine.

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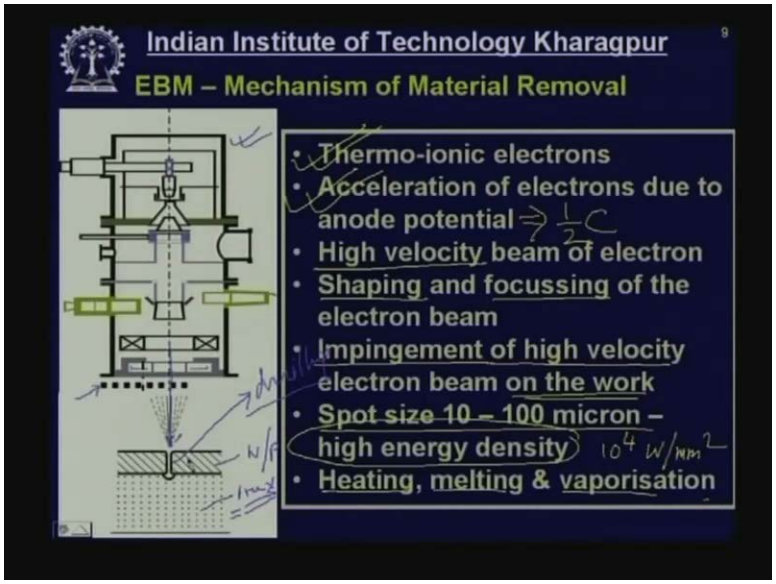

So what we have till now? Till now we have a gun. This is the gun we have already described its fabrication as well as how it produces electron beam. This if you remember is the slotted disk and the electron beam comes and impinges on my work piece. So this is my work piece. Just below the work piece you require auxiliary material. This requirement of auxiliary material would be explained in the next slide. So how does it machine? As we apply high voltage to the cathode as well as to the filament, we get an emission of thermo-ionic electrons.

These thermo-ionic electrons are repelled by the cathode and attracted by the anode through the bias gird. So, they are accelerated and they are accelerated almost to half the velocity of light. So you get a high velocity, high energy beam of electrons. These electrons beam is shaped and focused by a series of magnetic and electromagnetic lenses and finally this electron beam impinges with high velocity and high energy on the work piece. Typically the spot size would be around 10 to 100 micron. So the density could be very high. The density could be as high as ten to the power four watt per millimeter square. It could be as high as on impingement the electrons the kinetic energy of the electrons would be absorbed by the work piece which will lead to heating, melting and finally vaporization leading to as you can see in this small schematic, leading to drilling has been schematically shown here. This has been explained in a better manner in the next slide.

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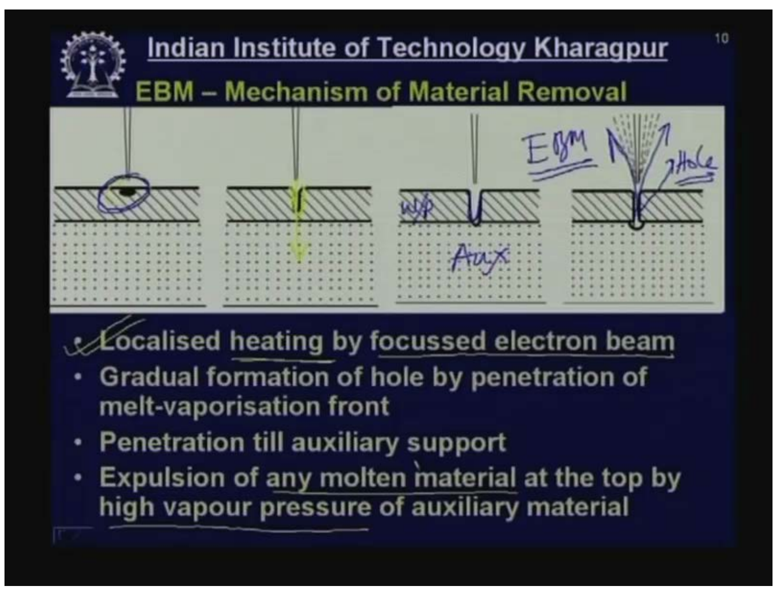

So once the electrons are impinging what happens because of the kinetic energy being transferred into the thermal energy, we have localized heating by the focused electron beam. So this is my localized heating, this is my localized heating, then what happens? Then gradual formation of the hole because of penetration of your melt vaporization front as localize heating takes place the melt vaporization front develops here and it gets start to penetrate and finally it penetrates till the auxiliary material this is your auxiliary material and this is your workpiece material here severe melting and vaporization is taking place. Auxiliary material melts very fast and produces vapor.

So if there is any molten metal in the path, it ejects that molten metal forming a proper hole leading to electron beam machining or electron beam drilling. So because of the presence of auxiliary material, there will be tremendous high vapor pressure which removes any molten material, molten workpiece material leading to formation of the hole. Now let us have a look at the process parameters in electron beam machining.

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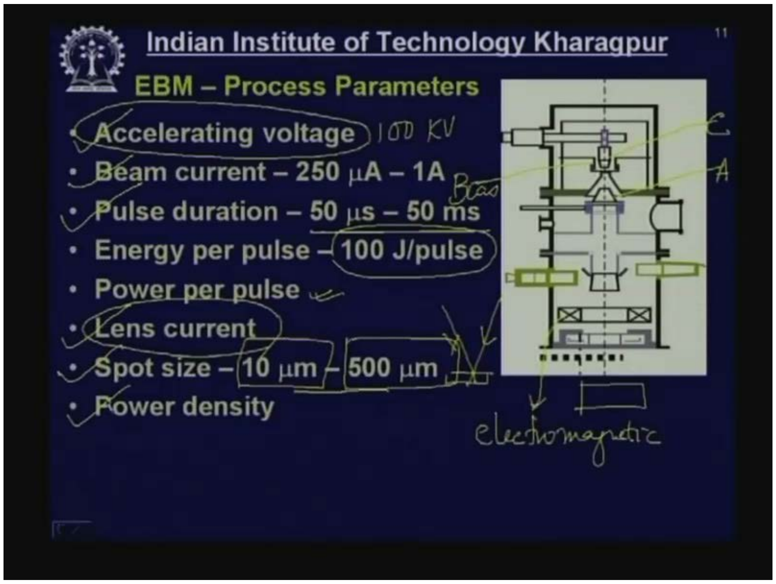

First process parameter is the accelerating voltage where is that accelerating voltage? Between my anode and my cathode, I have an accelerating voltage. How much could be the accelerating voltage? It could be hundreds of kilovolts, then you have beam current that is the current flowing between the cathode and your workpiece here, that is your beam current, then you have the pulse duration that is how often or for what duration you put a pulsed bias on the bias grid that is very important because only during that phase you are allowing your electron beam to impinge on the work piece.

Now if someone multiplies these two you will get an energy per pulse in the range of hundred joule per pulse. So power per pulse is also important as energy per pulse is important. Next comes the lens current. This lens current will determine to what extent the electron beam is focused. It has to be focused this is my electron beam this has to be focus. For focusing this I need pass large amount of lens currents to the electromagnetic lenses. This is my electromagnetic lens that determines my spot size. Spot size is typically from 10 micron to 100 micron or even 500 micron. This spot size ultimately you determine my power density. So what is my power density?

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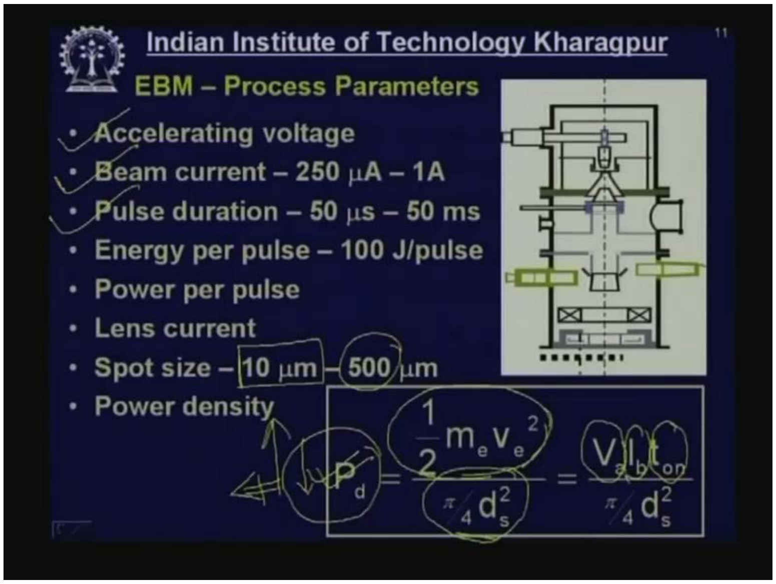

This is my power density. This is a derived variable which basically indicates how fast can I machine. Power density is nothing but the kinetic energy or kinetic power of the electron beam because this is mass flow rate of the electrons over divided by the spot size area. If my spot size is larger power density would be less. If my spot size is higher power density would be high. In other words, as far as the in terms of process parameters, how come the power is decided? Power is decided by accelerating voltage, beam current and pulse duration. See this is my accelerating voltage, beam current and pulse duration. This is my total power in a particular pulse and this is my spot size that is the area that gives me the power density. This power density is the most important parameter, a derived parameter which governs the rate of material removal in electron beam machining.

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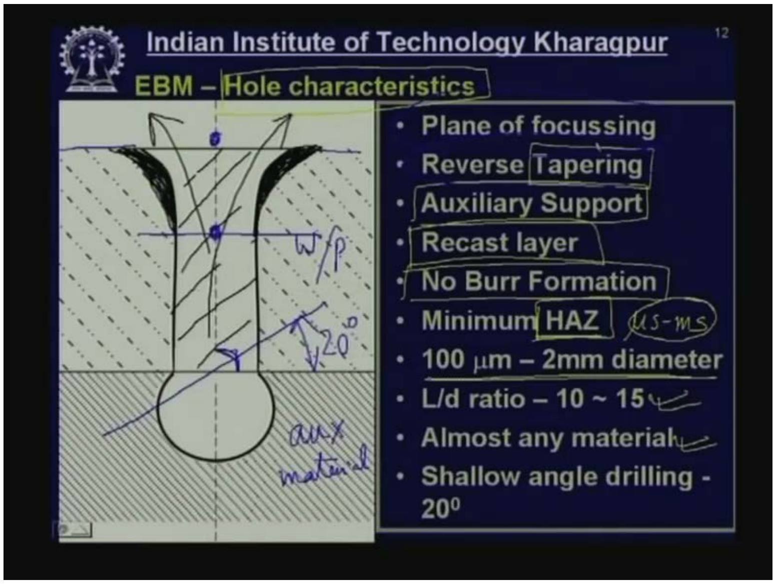

Now let us come to machining characteristics: In any nontraditional machining process there are machining characteristics. In electron beam machining, the shape of the hole is the machining characteristics. So what is there to study? This is my workpiece that is supported on auxiliary material. Typically what happens? Typically the problem in electron beam machining the main characteristics is this formation of what is called what you can see here, recast layer at the entry. Formation of recast or resolidified layer at the entry. In electron machining, electron beam machining we are getting this hole. How we are getting this hole?

We are getting this hole because of melting and vaporization of the material. As because there is melting at the entry through this port, the vapor and the molten material are being expelled in the process. When there is no pulse, there is no heat input. There can be solidification, re-solidification at the entry. So what are the issues here? Issues are these. There could be tapering. As it has been seen in this particular diagram, there is requirement of auxiliary support material. There could be recast layer at the entry. Generally in electron beam machining, there is no bar formation as electron beam machining is done, the pulse duration already we have mentioned microsecond to millisecond over that small duration of time, there is minimum amount of heat affected zone. This is what heat affected zone.

This amount could be hardly very very less. It is in ten sub microns. Now electron beam machining as I have already indicated is mainly used for drilling operation. So in electron beam machining, you can get a diameter of 100 micron to 2 millimeter. L by d ratio achievable is ten to fifteenth. So it is very good. Almost any material can be machined in electron beam machining. Here we have shown that the angle is ninety degrees. Is it not? This angle we have shown as ninety degrees. But, this can drilling can be done at a shallow angle at small angle of twenty degrees. Plain of focusing generally is here at the top of the material but the plain of focusing can also be inside the material and that can affect your tapering leading to reverse taper.

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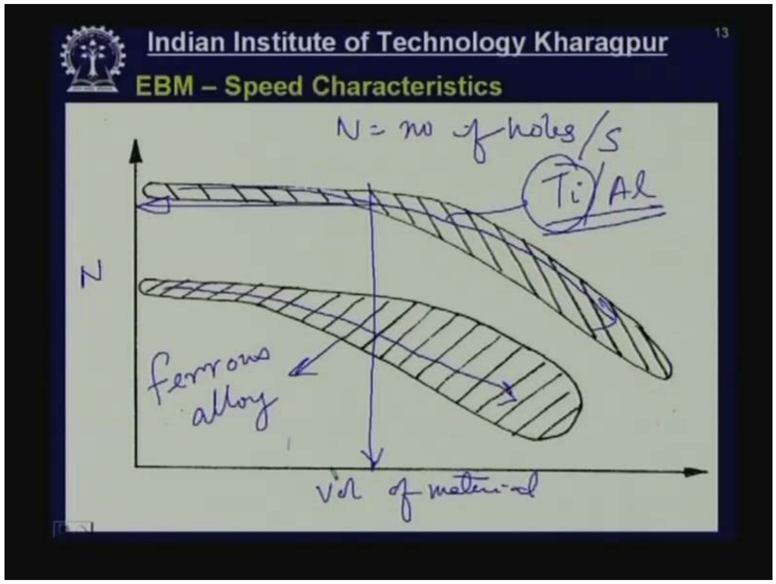

Now let us come to electron beam speed characteristics: How fast we can machine? This is your volume of material removal or volume of hole and this is how fast you can machine. Number of holes per second. So as the volume increases, it is expected you can machine less number of holes but there are two different zone shown. This is typically for ferrous alloys and this is for titanium and as well as aluminum alloys. Meaning thereby for the same material removal I can machine faster in case of titanium and aluminum, definitely aluminum melts much faster at a much lower temperature. So it requires less energy. In case of titanium however, its thermal conductivity is poor. So the energy is concentrated is not defused. So once again, we can machine at a faster rate for the same volume of material removal. Now let us come to the advantages of EBM processes.

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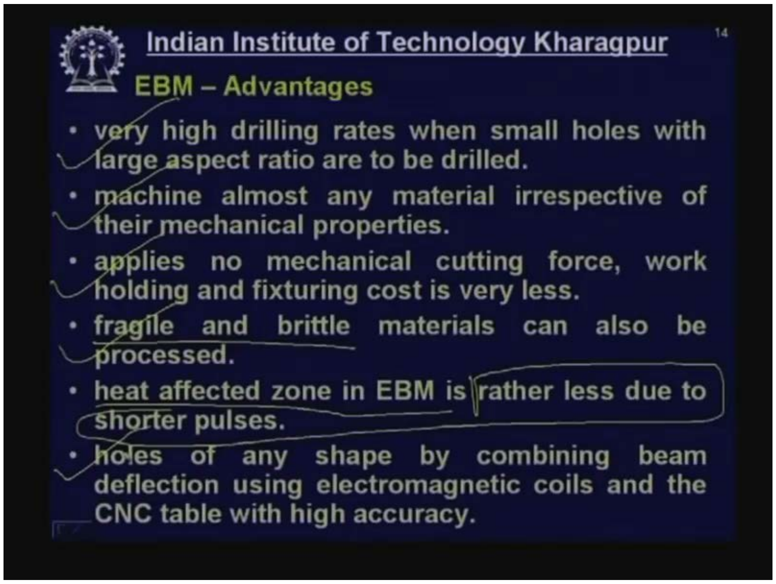

What are the advantages? Very high rate of drilling; It can machine almost any material there is no mechanical force. So fixturing is very easy as because there is no mechanical force, it can machine fragile and brittle materials. Heat affected zone in electron beam machining is very very small. Why? Because we are using very short pulses, it is not a continuous machining process. Holes of almost any shape can be drilled how? By using that deflector coils and the CNC table just below the EBM.

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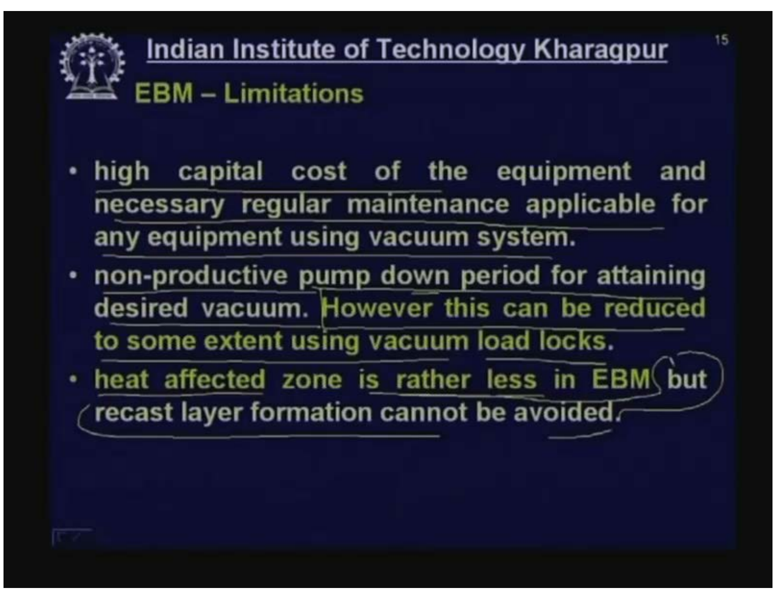

What are the limitations of EBM? One of the major limitations is the high capital cost and there is another limitation. What is that? Any vacuum system requires maintenance and here also we have a vacuum system and once again you have non-productive pump down times because of the presence of vacuum system. This can be to some extent reduced by using load locks. Heat affected zone though it is rather less, but there is some amount of resolidified material formation at the entry. If you remember which quite often, is taken as the limitation of electron beam machining.

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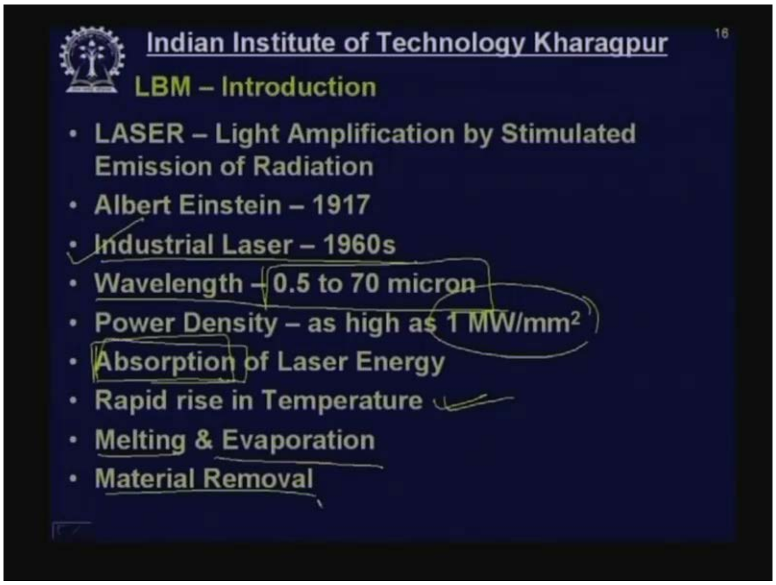

Now let us come to laser beam. Today we are going to cover two processes. One is electron beam machining and another one laser beam machining. Now let us go into the laser beam machining. What is laser? Laser is known as Light Amplification by Stimulated Emission of radiation that is laser. When laser was conceived not actually made but when people understood that laser can be made. In 1917, Einstein understood the basic working principle of laser. However only in 1960 industrials lasers were manufactured and they were put to use. Wavelength of the laser is in this region. It is sub micronic to 10 sub microns, power density it is a high energy density process could be as high as, as we have indicated earlier one megawatt per millimeter square.

It is very interesting that laser has to be used on materials where it absorbs laser energy. Upon absorption of the laser energy, there is rapid rise in the temperature leading once again to melting and vaporization and material removal. So the material removal process in laser beam machining is very similar to electron beam machining in the sense, once the laser energy is absorbed, there would be rapid rise in temperature melting and evaporation and material removal.

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Now what is the working principle of laser? Working principle of laser depends on stimulated emission. Generally an atom may absorb energy that is called spontaneous absorption, followed by spontaneous emission. This spontaneous absorption and emission process the time duration is in nanoseconds. However there is something called stimulated absorption leading to metastable state of electron, population inversion and stimulated emission. This gives phase coherent laser or beam of photon. They are coherent, not only in temporal mode but also in spatial mode. We will go into this in detail in next few slides.

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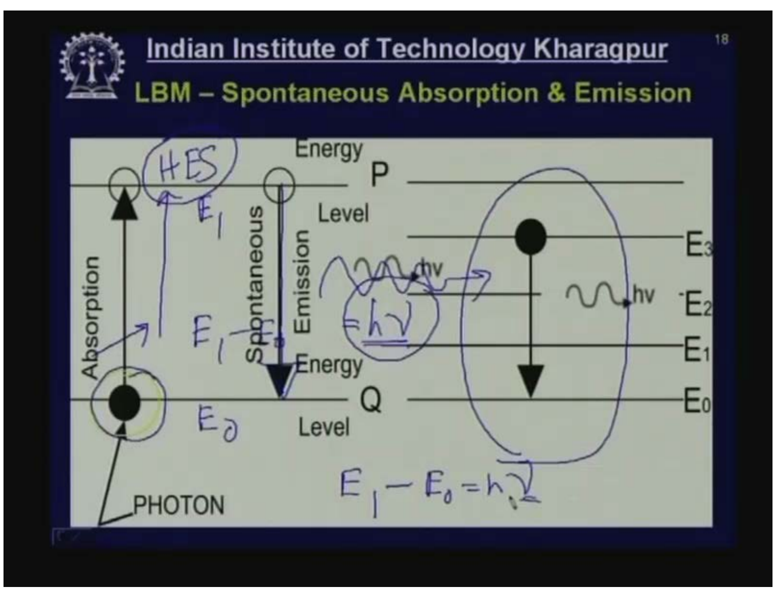

This one shows what we have mentioned earlier. Spontaneous absorption and emission: This is a particular electron in the ground state. This particular electron is in the ground state. It absorbs energy spontaneously and goes into a higher energy state. But it does not stay in the higher energy state for a long time. It comes back to the ground state and in the process emits a photon the same thing has been explained by energy bands. So this photon would be having an energy of h nu and that energy is equivalent to the energy gap between ground state and the higher energy state. So E 1 minus E 0. So if I can write it here E 1 minus E 0 equal to h nu, where 'nu' is the frequency of that particular electron. This process takes nanosecond. However, you can also put electrons in the higher energy state by something which is called stimulated absorption.

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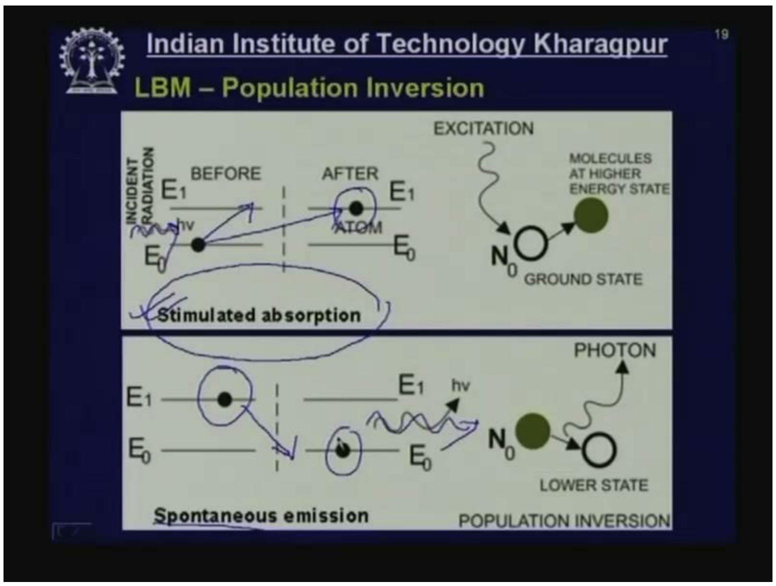

If photon is radiating a particular material, the energy of the photon goes to the electron and it moves from ground state to the higher energy state and then this material is having electrons at higher energy state. This energy, this electron can come down once again to the low energy and there would be a mission of photon. This is called spontaneous emission but before that there is a stimulated absorption, then what is stimulated emission.

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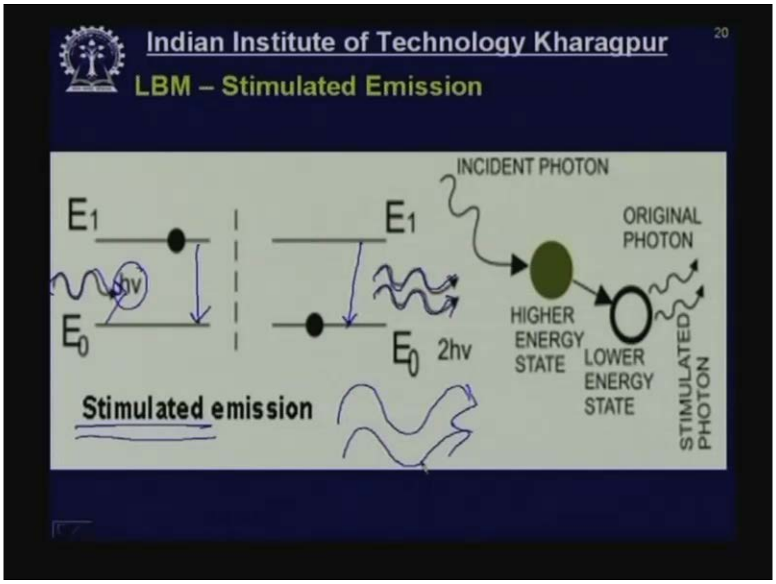

Already in the material, you have lot many electrons in the higher energy state.

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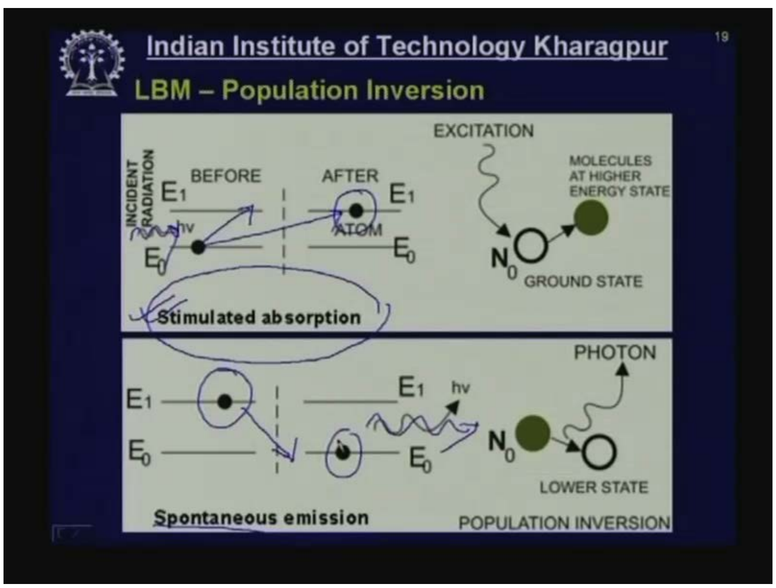

This is called population inversion. Generally, electrons are not in higher energy state. Somehow by doing stimulated absorption, you have put lot of electrons in the higher energy state, then what are you doing? That material you are radiating with a photon. This photon energy if it matches with this energy gap would stimulate. This is very very important this electron to come down to the ground state and at the end of that, you would have two photons having same temporal and special coherence. This is the emission or stimulated emission which is leading to formation of laser beam.

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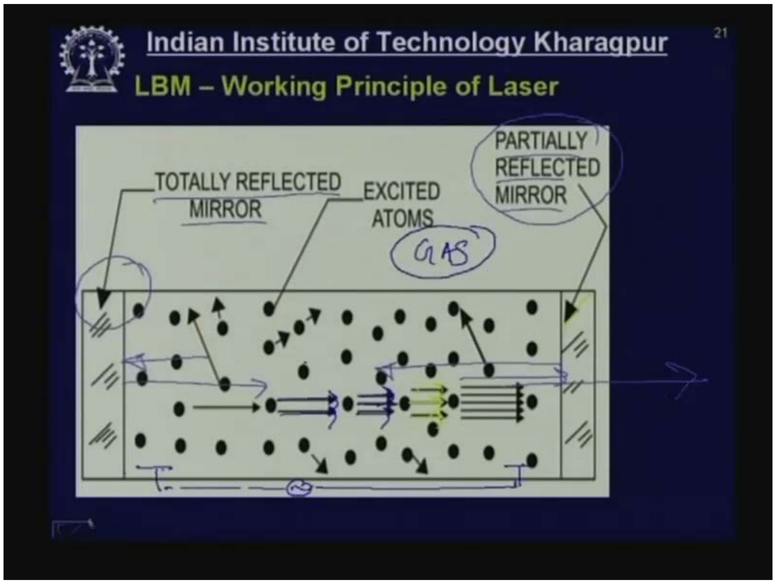

How is it done? Actually this has been explained in the gas laser mode. Here, you have a gas laser or a gas inside a tube that is excited by electrical discharge. There is an electric two and one cathode and one anode electrical discharge is established in the rarefied gas. What happens? They would be going to the higher energy state and they would come down in process. Gradually you would have lot of coherent photons coming out one by one and number of photons will increase. In this side you have, on the other side what you have is a fifty percent or partially reflected mirror and on this side, you have a totally reflected mirror.

So a photon when it goes there may get reflected back and it once again can stimulate another photon to come out from the higher energy electron. Once it reaches here, there a they get reflected back into the chamber as because this is partially reflected mirror. After sometime, you would have a coherent beam of laser, a coherent beam of laser coming out. Now let us see what are the different types of lasers and the lasing medium that is what is used as a laser.

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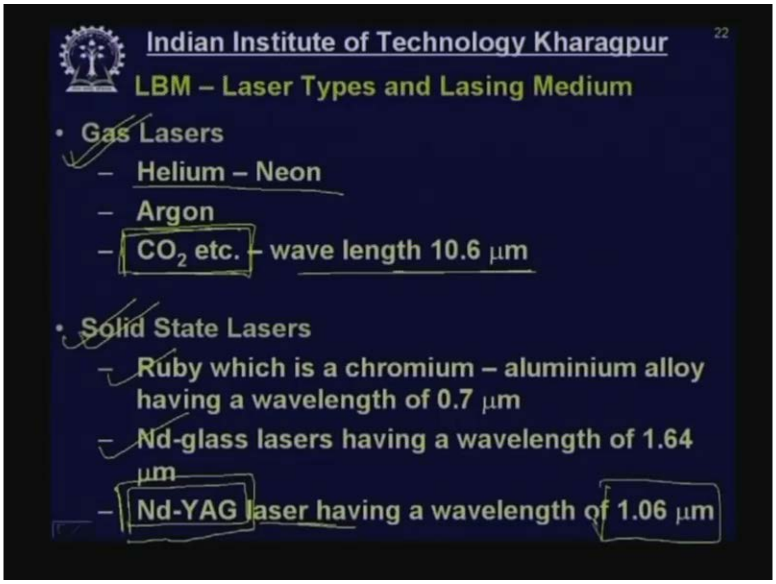

There are two different kind lasing medium: One is called gas laser, the other one is called solid state laser. Typically Helium, Neon, Argon and carbon dioxide laser are used, carbon dioxide laser is the most industrially used laser having a wavelength of 10.6 micron as far as solid state lasers are used, you have ruby laser Nd glass laser and Nd YAG laser. This Nd yttrium aluminum garnet laser this is once again another very popular laser having a wavelength of 10.06 micron. So they are exactly one tenth of that.

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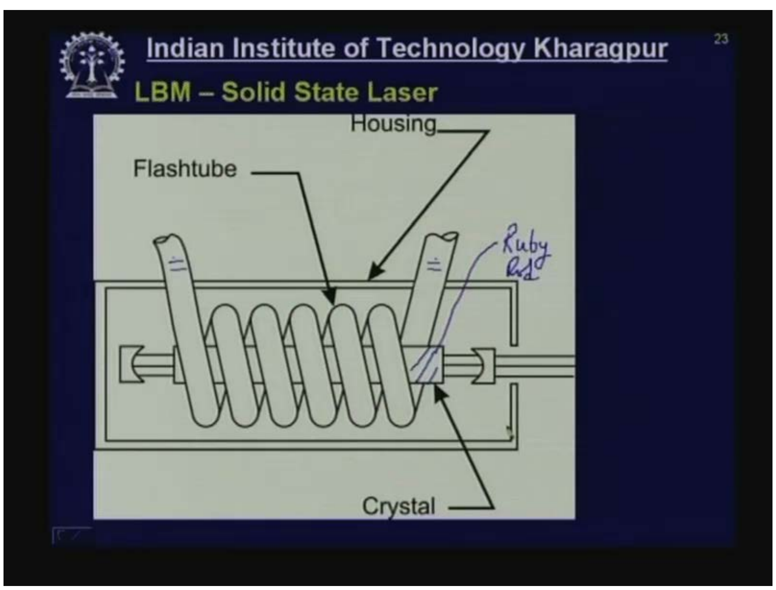

Now how a solid state laser works? Say for example, what we have here is a solid state schematic of a solid state laser. This particular part say is my ruby rod. So that is my lasing medium around that I have a flash tube. This is my flash tube. This flash tube pumps optically pumps energy within the ruby rod. So that electrons which are at ground state can be put to the higher energy state and this is the housing. How it works?

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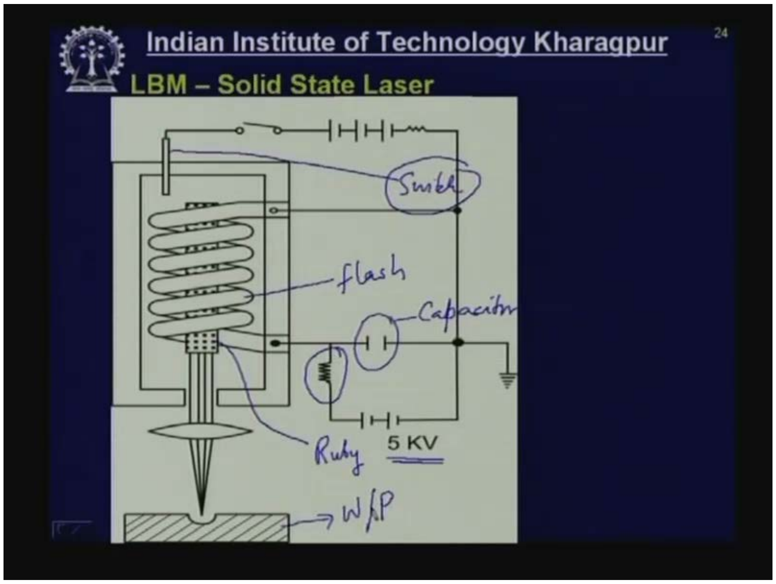

Once again, this is my flash tube, this is my ruby rod. This flash tube pumps energy within the ruby rod to create the population inversion. How it is done? There is a capacitor from a supply, this capacitor is charged and discharged. The charging time and discharging time is determined by this register and there is a switch. This switch initiates the first emission and you get a laser beam which interacts with your work piece.

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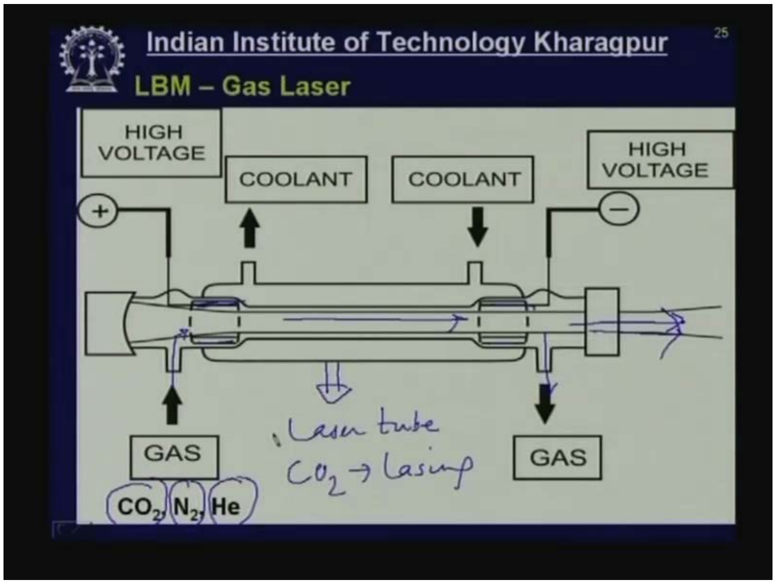

How it is done in a gas laser? In gas laser also we need to do the population inversion. So this is my laser tube through which continuously carbon dioxide, nitrogen and helium is used. What for carbondioxide is used? Carbon dioxide is my lasing medium. This is my lasing medium. Nitrogen and helium are used as a coolant gas and support gases. So you have carbon dioxide. Mixture of carbon dioxide nitrogen and helium are going through this particular port and coming out through this particular port. What else do you have here? You have an anode and here you have a cathode where you apply high energy sorry high voltage to the anode and the cathode. So that an electrical discharge is established between these two electrodes. This energy of the electrical discharge pumps the gas molecules from the ground state to the higher energy state and as they come out, it leads to stimulated emission leading to the formation of the laser beam. This is the typical working principle of carbon dioxide laser. As you can see, there would be lot many especially in the previous diagram, it was very clear.

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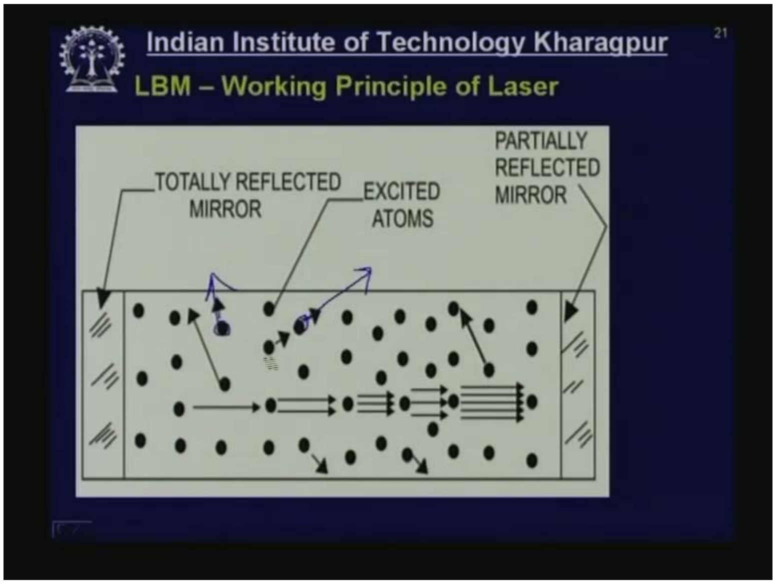

There would be lot many photons which are going in haywire direction. They do not have the coherency because they need not be emitted in the same direction. These photons as they interact with the medium or the glass tube thus produce lot of heat.

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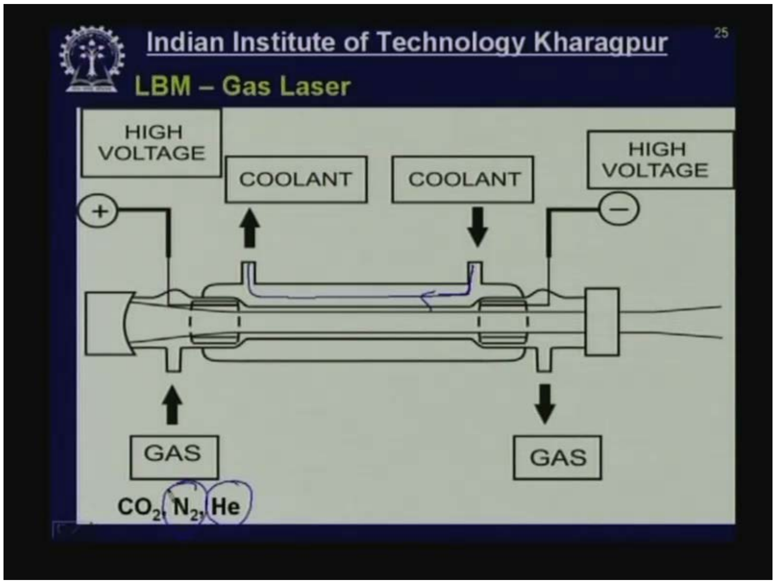

The heat is taken out by flowing coolant. Through this helium and nitrogen also provides some amount of internal cooling to the gas. Now carbon dioxide laser maintenance as well as use is very easy, but there is one problem.

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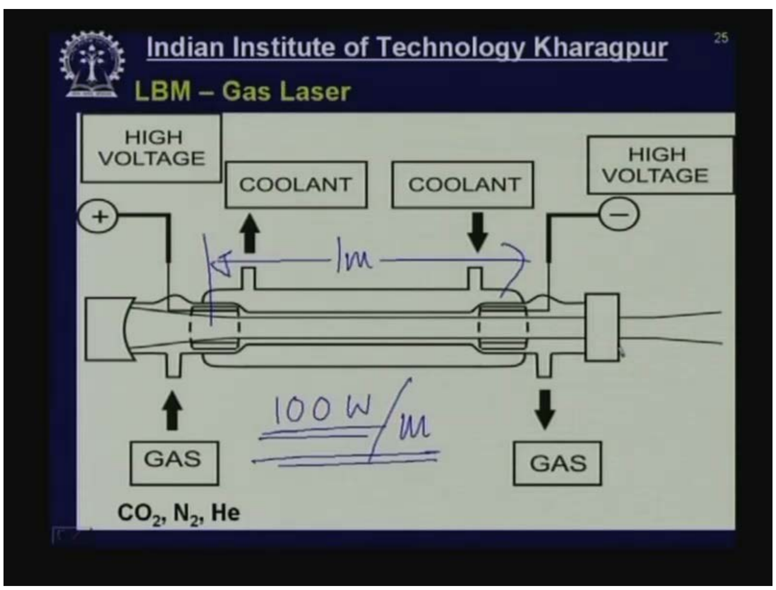

What is that problem? Typically, for hundred watt of power, this length is around one meter. So, it is 100 watt per meter is the length of the tube. If that is the situation what can you do? If you have to make a carbon dioxide laser which is 10 kilowatt, what would be this length? This length would be 100 meters. So that is not at all expectable. So we have to develop a design where we can get the benefit of high power carbon dioxide laser without going into hundred meters. That is done by something which is called folded gas laser.

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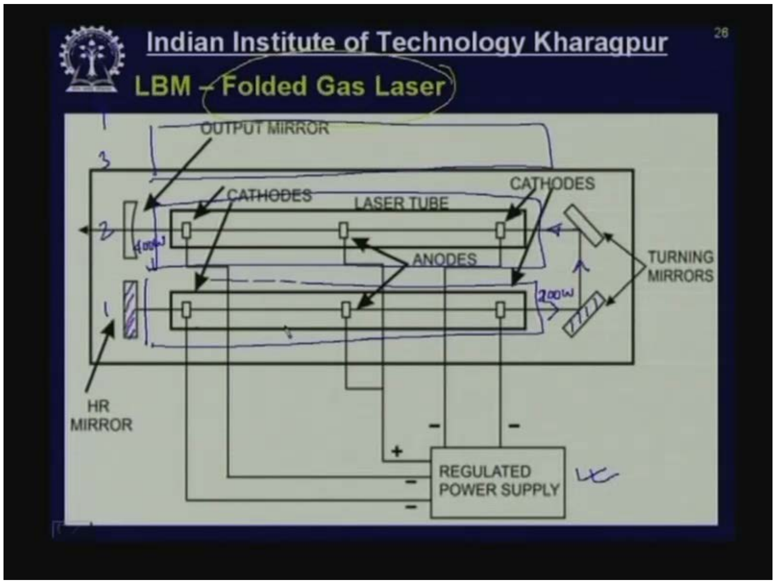

So we have a series of individual gas laser tube. This is one laser tube, this is another laser tube. Possibly here also there could be a laser tube. What happens? This is the first one. This one is a hundred percent mirror. This is a turning mirror. So laser coming out of this. This particular tube is feed back into the next one. So this possibly produces hundred watt or two hundred watt. This one gets that particular beam and passes through this one. So ultimately four hundred watt comes out. So what is the basic principle? We have series of one two three four. One upon one after another laser tubes so this is called folded gas laser. Once again, here also we have a power supply. Here will the gas flow lines have not been shown but we have gas flow as well and ultimately you have an output mirror here only two fold has been shown but here you can build lasers which are five fold six fold and increase the total power from the gas laser. Now what is the mechanism of material removal?

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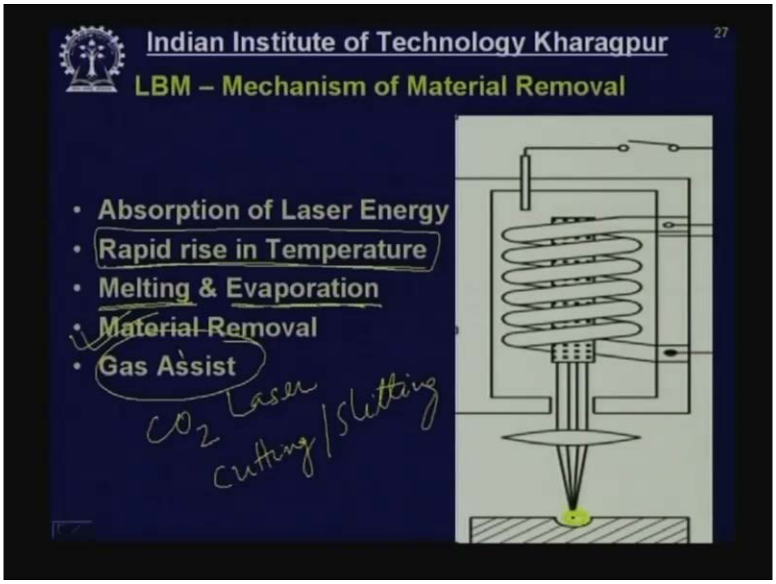

As we have already told earlier, the mechanism of material removal in laser machining is very similar to electron beam machining. In electron beam machining, what we have is a high energy beam of electron that interacts with the work material, the kinetic energy of the electrons gets transferred in to the heat energy. Here also the energy of the photons or the laser beam has to be absorbed by the work material. Once the energy of the beam is absorbed by the work material, what would happen? We would have increase in the, we would have increase in the temperature because the energy of the laser beam is converted into heat energy and this is my workpiece material where we would have increase in temperature. This increase in temperature will lead to melting as well as evaporation depending on what is your material leading to material removal. In case of carbondioxide laser, which is mainly used for cutting action which can also be called slitting option, slitting action. We can also use gas assist for enhancing the material removal. So, material removal mechanism in LBM is similar to electron beam machining.

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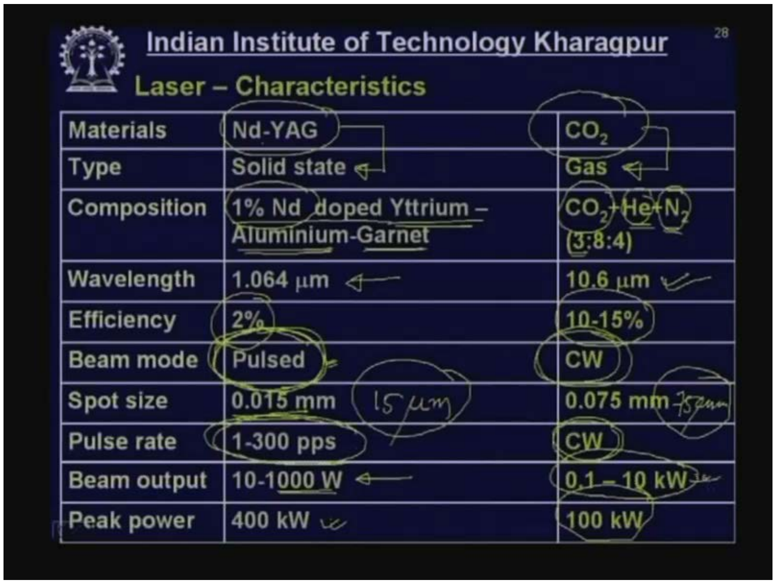

Now let us come to some common characteristic of laser beam or different types of laser. As it has been said, the most common laser is Nd-YAG laser and carbon dioxide laser is Nd-YAG laser is a solid state laser. Carbon dioxide laser is a gas laser. What is there in Nd-YAG? It is basically a doped laser. You have yttrium, garn aluminum and garnet and that is doped to it one percent Nd. Carbon dioxide laser is also not full hundred percent carbon dioxide. You have carbon dioxide, helium and nitrogen. The lasing medium is carbon dioxide. But helium and nitrogen acts as a support gas as well as internal cooling. How they are different from each other? This is having a wavelength of 1.06 micron where this is just ten times 10.6 micron. However efficiency of carbon dioxide laser is bit better than the efficiency of Nd-YAG laser.

Generally Nd-YAG lasers are used in pulse mode. This work generally is very very important. They can also be used in other modes, but generally they are used in pulse mode and carbon dioxide laser is used in continuous mode that is continuous eradiation spot size is this one. In better other words, it is around 15 microns. So it is very very less. In case of carbon dioxide laser, it is around 75 microns. So almost 0.1 millimeter and this is almost 0.01 micron, 0.01 millimeter it is very very less as because this is used in pulse mode, the pulse repetition rate is 1 hertz that once per second to even 300 pulses per second, carbon dioxide as we have already told is used in continuous mode.

Now let us come to the beam output. Beam power output is around maximum 10 to 1 kilowatt, whereas in case of carbon dioxide, it is around 100 watt to 10 kilowatts. There are carbon dioxide lasers which are even larger. Peak power available is around 400 kilowatt. This is bit different. This is beam output and this is peak power because the output as because it is work and as because it is used in pulse mode, you get lot of peak power. In case of carbon dioxide peak power is around 100 kilowatt. But normally they are in this range.

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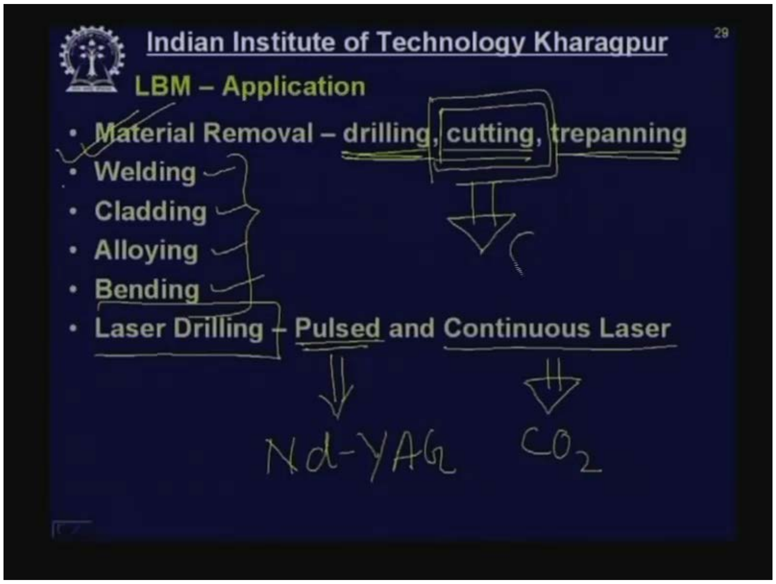

Now let us come to the applications of laser beam: Laser beam can be used for a host of purposes as far as machining is concerned, it can be use for material removal. It can be used for drilling. It can be used for trepanning. It can be used for cutting. It can be used for other material processing as well. For example, welding, cladding, alloying and bending laser drilling can be done using continuous laser that means what using carbon dioxide laser, pulse laser can also be used that means primarily use of Nd-YAG laser.

Now this drilling as far as the cutting is concerned or even trepanning is concerned, this should be done by carbon dioxide laser. With gas assist that is with flow of oxygen or without gas assist. Both of them are possible. Whenever we are cutting, we are not very bothered about we have to cut very fast. Rather than very without any heat effected zone and all and that require the gas assist which enhances the cutting speed. Now let us come to the applications. As I said, different types of laser can be used for thick cutting. Typically carbondioxide is used for thin slitting of materials. Nd-YAG is used for thin sitting of plastics carbon dioxide is used.

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Indian Institute of Technology Kharagpur

LBM – Application

Application	Type of Laser
Holes upto 1.5 mm dia.	Ruby, Nd-Glass, Nd-YAG
Trepanned Holes	Nd-YAG, CO_2
Holes – dia. less than 0.25 mm	Ruby, Nd-Glass, Nd-YAG
Drilling – punching	Nd-YAG, Ruby
Thick cutting	CO_2 with gas assist
Thin slitting of metals	Nd-YAG
Thin slitting of plastics	CO_2
Plastics	CO_2
Metals	Nd-YAG, ruby, Nd-glass
Organics, Non-metal	Pulsed CO_2
Ceramics	Pulsed CO_2, Nd-YAG

So in this way different types of applications can be undertaken with laser. Now let us come to the advantages of laser beam machining.

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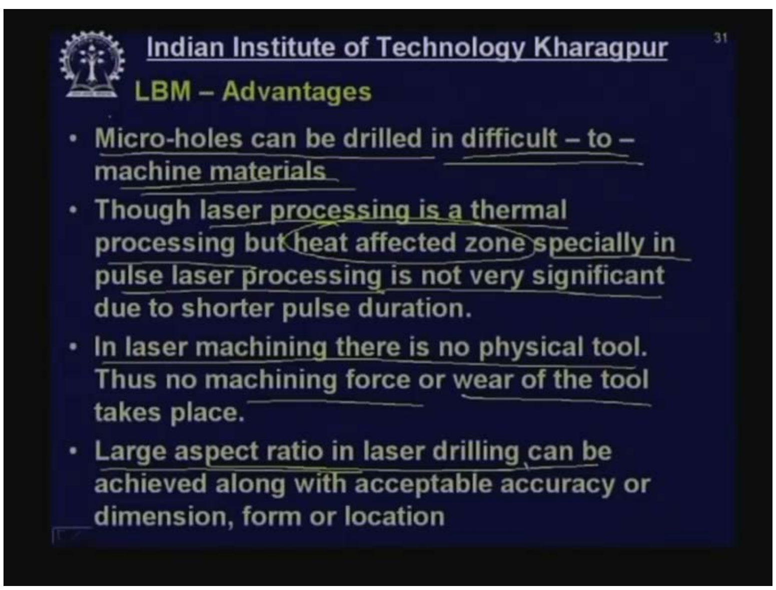

What are the advantages of laser beam machining? Micro holes can be drilled not only in easy to machine materials but also in difficult to machine materials. That is very important. Though laser processing is a thermal processing but heat affected zone special in pulse laser processing is not very significant. This particular point is very very important. In case of continuous machining, using continuous laser like carbon dioxide, you would have significant amount of heat affected zone. But using Nd-YAG type of lasers which are used in pulse mode due to duration of the pulse, very short duration of the pulse, you would not have that much of heat affected zone. In laser machining, there is no physical tool. Say for example; in electrochemical machining, electro discharge machining, though they are non-traditional machining process, you have physical tools as because there is no physical tools. There is no machining force or wear taking place on the tool. It not only can produce micro holes, but it can also produce holes where aspect ratio is very very large. With acceptable accuracy, both dimensional form and location can be done by laser beam machining. Now is there any limitation in laser beam machining?

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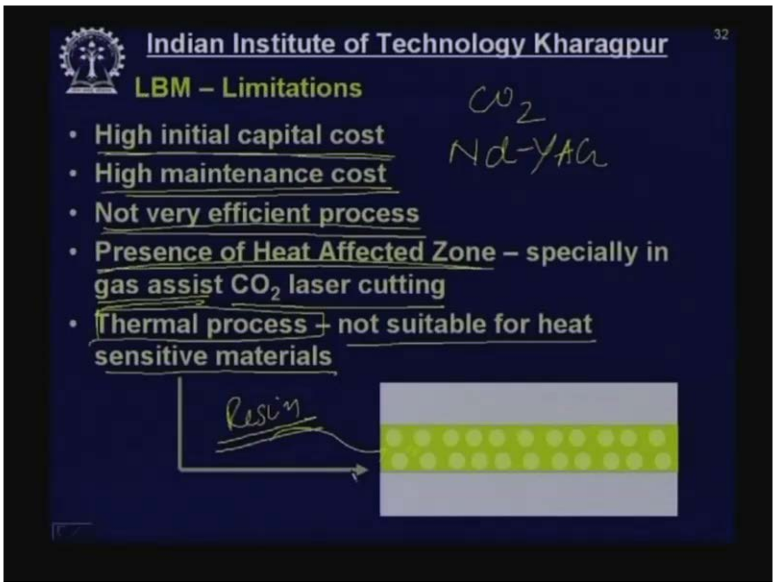

Yes there are limitations. First and foremost, there is high capital cost. Be it carbon dioxide laser, Nd-YAG laser, you have a high capital cost, not only that you have a high maintenance cost as well in laser beam machining. From the energy point of view, unfortunately, it is not very efficient. Its advantages are it can machine almost any material, but from energy point of view it is not very very efficient. As far as carbon dioxide laser cutting is concerned, especially with oxygen gas assist, there would be presence of heat affected zone. One of the major limitation of laser beam machining is its characteristic and its limitation that it is a thermal process. Such that, it is as because it is a thermal process, it cannot be use for machining heat sensitive materials. Say for example, here you have a heat sensitive material where this particular color represents raisin. This is a laminated structure. If this has to be machined by laser, then this raisin would be eaten away by the heat of the laser and it is not acceptable. So though it has got it advantages, but it is also being a thermal process. It is not suitable for heat sensitive materials.

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Now let us come to the summary: We have already discussed the major components of electron beam and laser beam equipment. We have discussed working principle. After going through this lecture, you can draw the EBM and LBM equipments. We have identified the process parameters. We know the basic mechanism of material removal and most important you know application, advantages and limitations.

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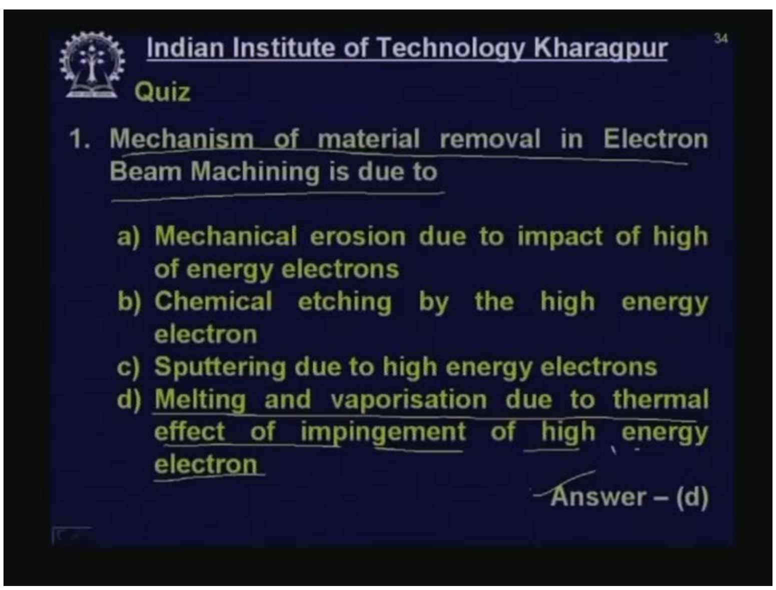

Before concluding, let us go to a through a quick quiz. Mechanism of material removal in electron beam machining is due to what? We all know it is because of melting and vaporization due to thermal effect of impingement of high energy electron so answer is d).

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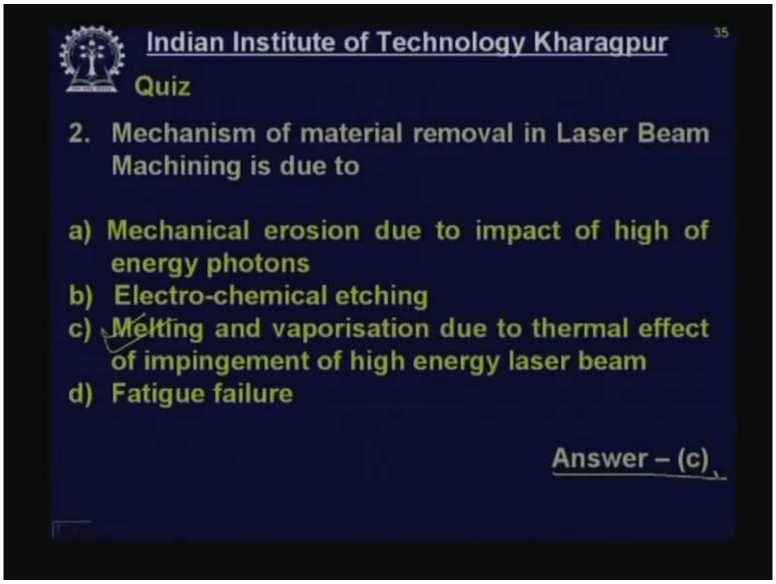

Mechanism of material in laser beam machining we have said numbers of times. Once again, it is because of melting and vaporization. So this is my answer. Answer is c).

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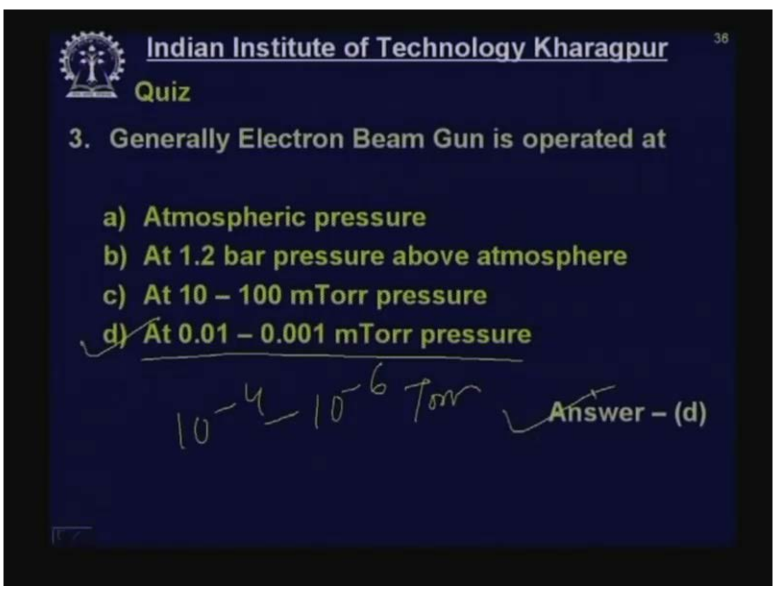

then comes the third question. Generally, electron beam gun is operated. We all said that it is operated under vacuum and this is my level of vacuum. 10 to the power minus 4 to

10 to the power minus 6 torque which is nothing but, this milli-Torr. So answer is d). Laser beam is produced due to what?

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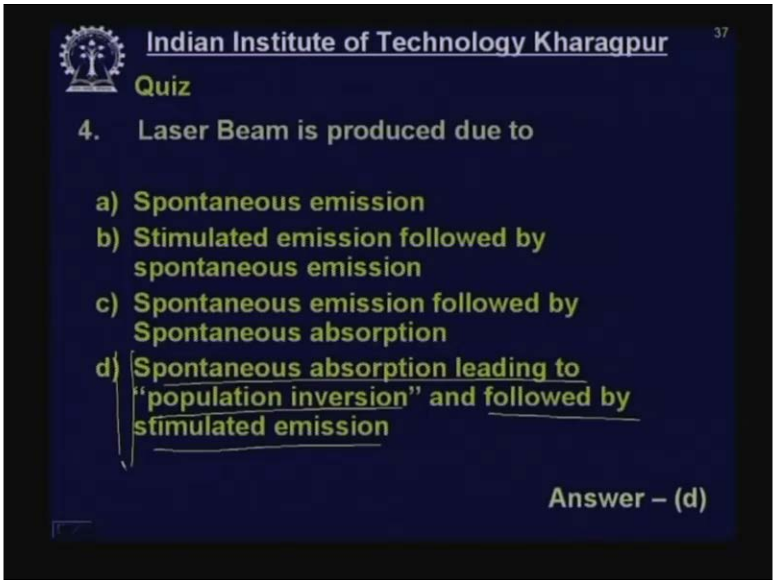

It is produced due to population inversion and stimulated emission. So, spontaneous absorption leading to population inversion followed by stimulated emission. This is the mechanism of production of laser beam. Today, we are coming to an end of this module. Not only that, this is the last lecture of NPTEL sponsored Manufacturing Processes- II. Within this module, we have learnt about non-traditional manufacturing processes. While starting this particular module, initially I tried to make the difference between conventional and non-traditional manufacturing, the characteristics difference and then we have studied the major non-traditional processes. We have studied abrasive jet process.

If you remember this was a mechanical process, ultrasonic process machining this was mechanical. Water jet and abrasive both of them they are mechanical processes. Then we went into electrochemical followed by electro discharge and today we have completed electron beam and laser beam process. This is not the end of non-traditional manufacturing. This should be the beginning of non-traditional manufacturing as far as you are concerned. There are other non-traditional machining process hopefully, jointly, we have made a good progress in the area of non-traditional manufacturing and we will keep on learning from other sources regarding the other process.

Thank you so much.