Metal Additive Manufacturing

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Lecture 10

Laser Based Processes (Part 2 of 2)

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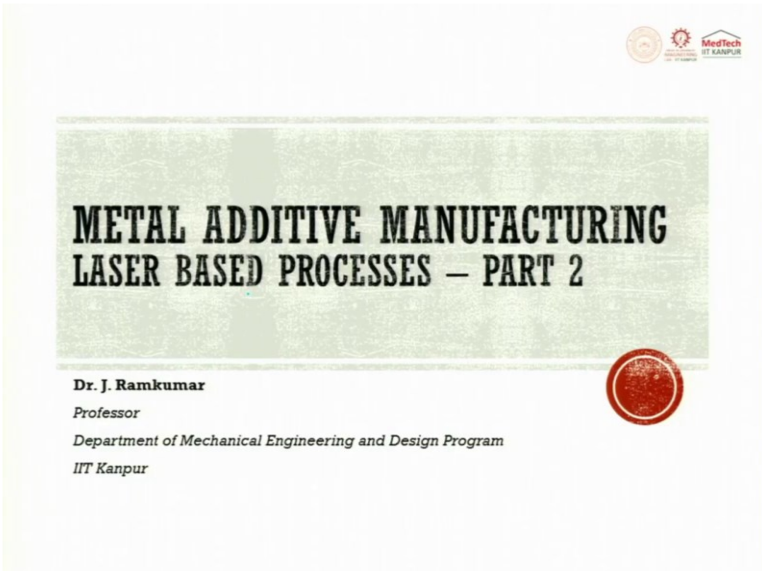

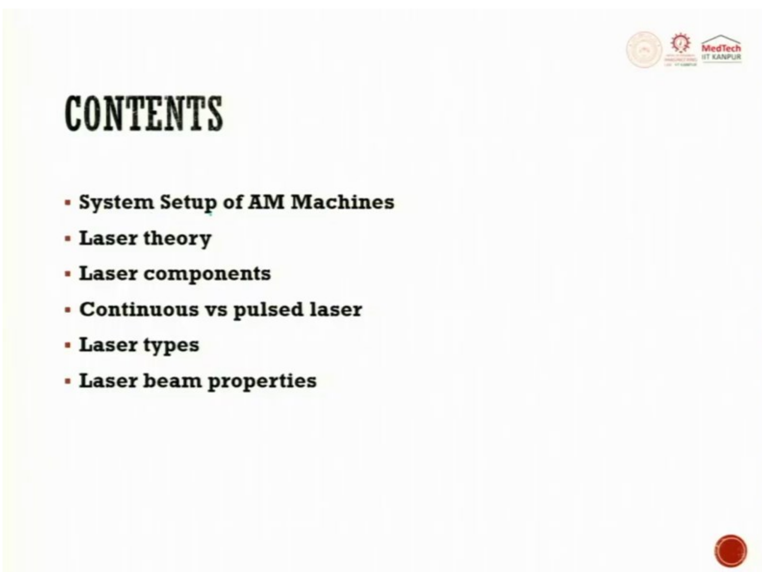

Welcome to the next lecture on laser-based process part 2. In the previous lecture, we have been discussing system setup of AM machine, we saw little bit of fundamentals of laser theory. Then laser components, continuous laser and pulsed laser we saw. Now we will try to see various lasers, in this we will try to see solid state laser, gaseous laser, fiber laser, how does it work.

In this chapter finally we will see some of the laser beam properties. Generally, at IIT Kanpur we offer a full course on laser fundamentals. Since laser is part of this additive manufacturing, we are just superficially brushing through fundamentals of laser which will help you to understand while doing machining or while making prototype or while evaluating prototype or the final product.

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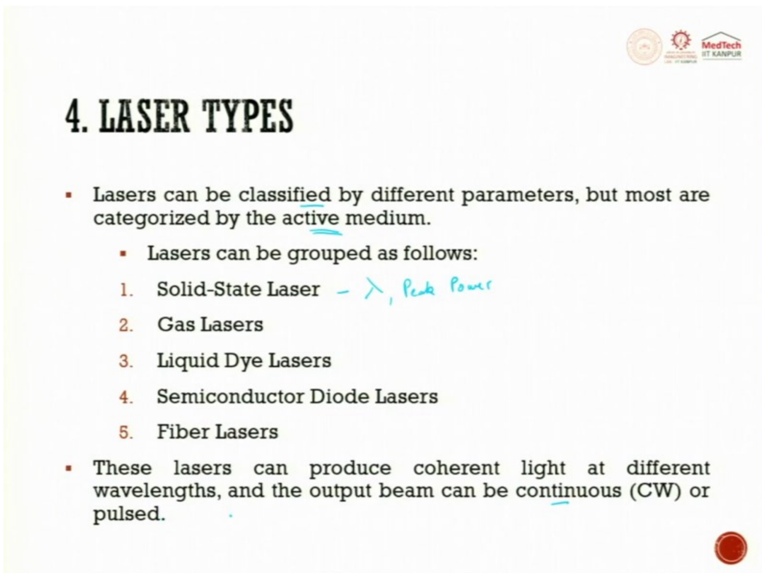

Different types of lasers, lasers are classified by different parameters but most are categorized by the active medium. The laser is grouped under solid state laser, gaseous laser, liquid dye laser, semiconductor laser, and fiber laser. So, the difference if you see it is in the gain medium. So, you can have a solid state, you can have gaseous, you can have liquid dye, you can have semiconductor, and fiber lasers, each one of them have their own particular requirements in terms of lambda and in terms of peak power.

So, what you can get here, you cannot get in the other thing, that is why we have so many different types of lasers. The laser can produce finally a coherent light at different wavelength and the output beam can be either continuous or pulsating. So, this continuous, pulsating will be taken care by q switching and mode locking facilities which are added to the system.

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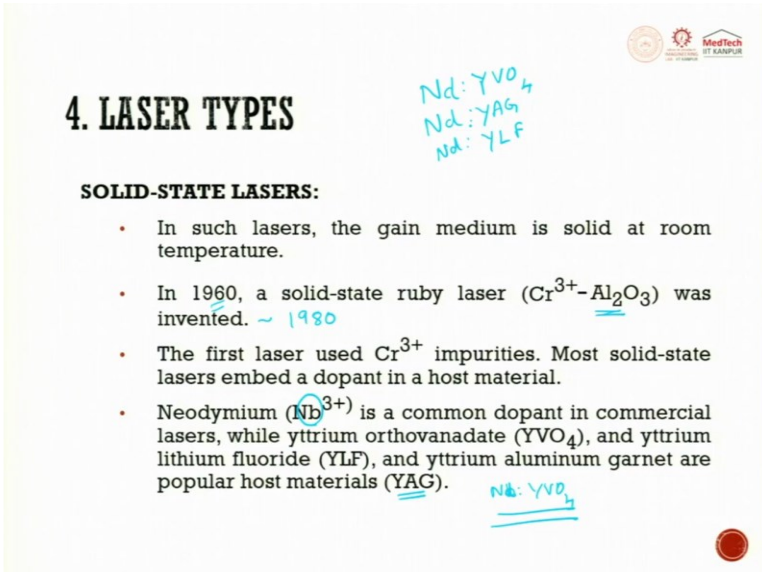

In solid state laser the gain medium is solid at room temperature. It started way back in 1960, but the maturity level started to come into existence after 1980 in various industries. In 1960, the first solid state ruby laser was invented but it came into industry into fullest extent after 1980. So, it is typically only 50 years old.

The first laser used Cr^{3+} impurities. Most solid state laser embedded a dopant in the host material. The host material is Al_2O_3. Neodymium is another common dopant in commercial laser today that is why you have Nb laser with Yttrium. So, we have Nb:YVO_4 laser.

So, neodymium is the common dopant in commercial lasers with Yttrium which is (YVO_4) and lithium fluoride (YLF) and Yttrium aluminum garnet (YAG). So, all these things are pretty common. So, it is Nd YVO_4, Nd YAG, Nd YLF. So, these are some of the commercially available lasers. So, all these things have their own lambda so depending upon the lambda you can try to use it.

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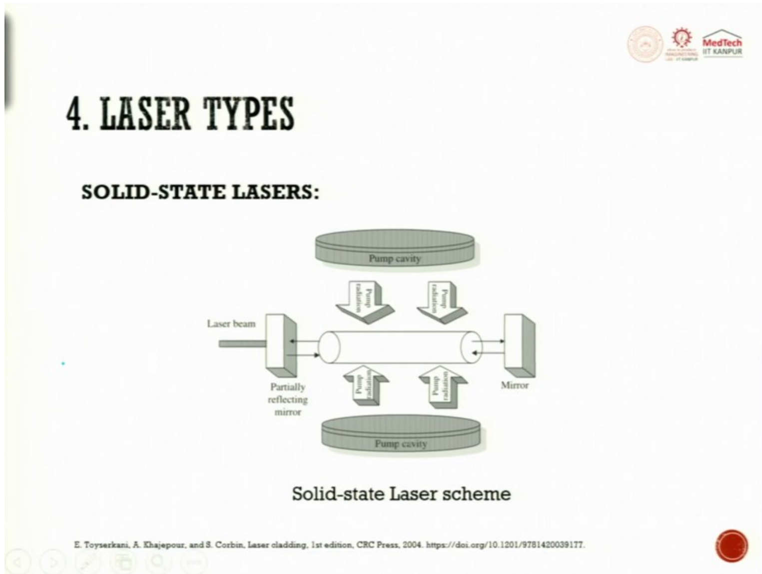

So, here in a solid state laser you will have this as the gain medium. So, you have a pumping cavity it can be light or it can be electric. So, then as I told earlier it has 100% percent reflection, it is partial reflection it goes back and forth and exits a beam out. So, for this type of laser here you have a solid. So, what we had is Nd YVO_4.

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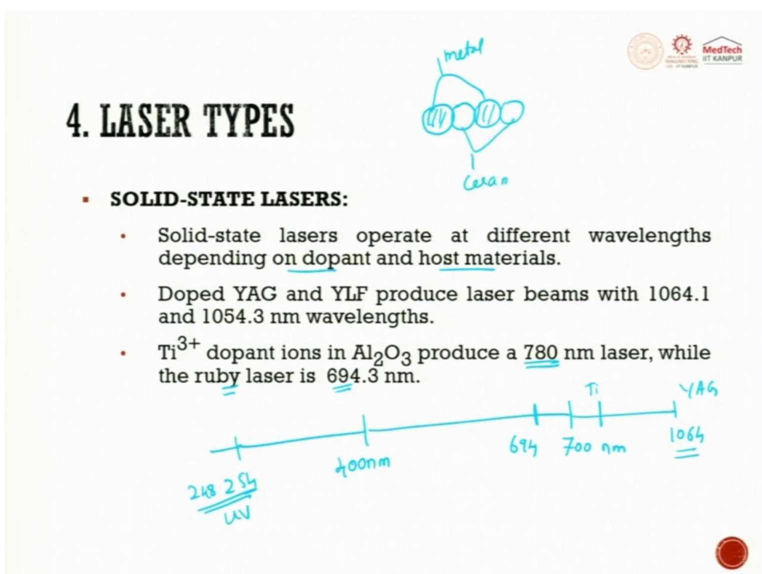

Solid state laser operates at different wavelengths that is why you have different materials depending upon the dopant and host material. So, these two dictates the lambda doped YAG and YLF produce laser beam with 1064 nm and 1054 nm. There are certain applications depending upon the wavelength. Ti^{3+} dopant ions in Al_2O_3 produces 780 nm while ruby laser produces 694 nm.

So, we talk about 400 to 700 nm, this is the visible range. So, now we are talking about 1000 nm is here, 1064 nm is here. When we talk about blue laser they come under 254 nm, 248 nm all these things are UV laser or blue laser. You can have something around this. So, this is 400 nm, 700 nm, this is the working range for the visible range. You are now talking about lasers in this place 1064 nm is YAG, then 1054 nm if you take it this is somewhere around about here which is Ti doped Al_2O_3, when you take ruby it is somewhere around about 694 nm.

So, each of these wavelengths are very important when it starts interacting with the work piece material. So, here it is a powder. So, the other interesting thing is, suppose you have a metal powder you have a ceramic powder which is there. Assuming for discussion sake, these are all metal powder and these are all ceramic powders, if you want to melt only metal powders you can do it depending upon the wavelength.

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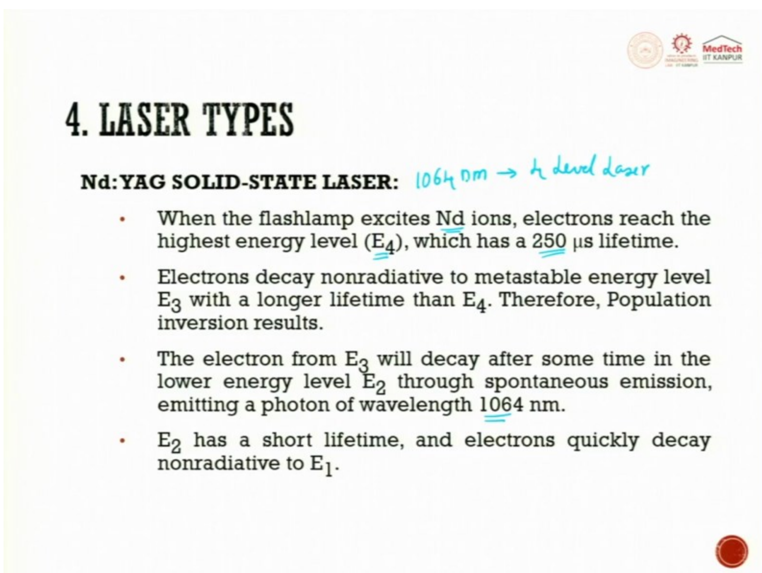

So, Nd YAG solid state laser will have a flash lamp which excites Nd ions, electrons reach the highest energy level of E_4, At 4^{th} level it has a 250 μs lifetime. Electrons decay non radiatively to meta stable energy level E_3 with a longer lifetime than E_4.

Therefore, population inversion results the electron from E_3 to decay. After some time, the lower level E_2 through spontaneous emission emitting a photon of wavelength 1064 nm. So, Nd YAG comes with 1064 nm is 4 level laser used for prototyping. E_2 has a shorter lifetime and the electron quickly decays non-radiative to E_1. So, E_4 to E_3 non radiative, E_2 to E_1 non radiative. So, what thing happens is from E_3 to E_2 only. So, Nd YAG laser is very common solid state laser it uses 1064 or it throws out 1064 nm.

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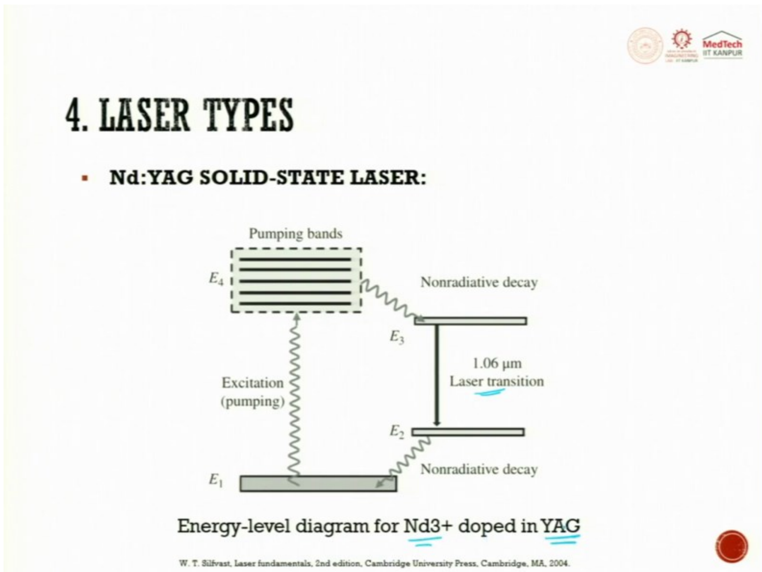

So, this is what is the diagram E_1, E_2, E_3, and E_4, pumping band it comes to E4, pumping action takes place, from here it falls and non-radiative decay happens to E_3, from E_3 to E_2, it falls, emits radiation laser transition and then from here it falls down. Energy level diagram for neodymium doped YAG laser is this. So, when you buy laser you should also look at the type of laser and the wavelength of laser.

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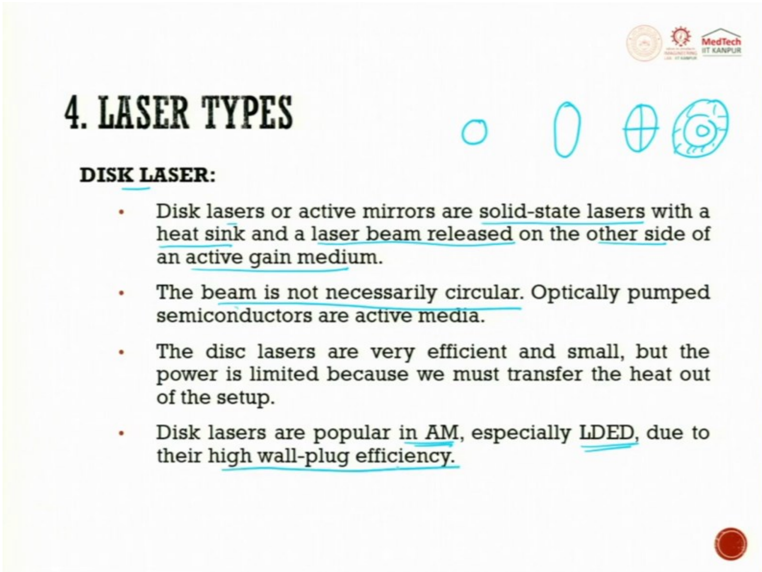

Let us take the other laser which is called as disk laser, disk laser or active mirror are solid state lasers with a heat sink and a laser beam released on the other side of an active gain media, and the beam is not necessary circular.

So, this is another interesting learning you are having now beam need not be circular it can be also oblong, beam can also be split, beam can also be concentric, depending upon your requirements you can change the shape of the beam. Optically pumped semiconductors are active media, the disk lasers are very efficient and small but the power is limited.

Because we must transfer the heat out of the setup. Disk lasers are popular in AM especially LDED (laser directed energy deposition) due to their high wall plug efficiency. It is because of this disk lasers are also effectively used.

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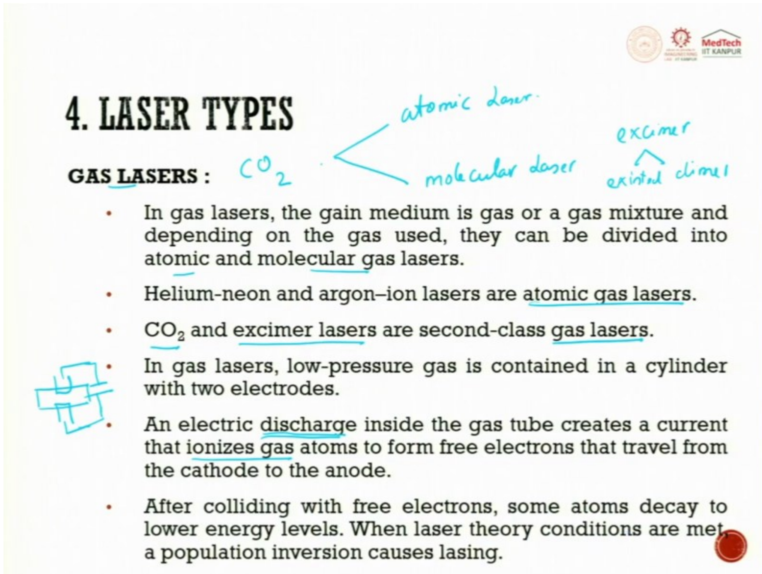

Next laser is gaseous laser we are talking about CO_2 laser. In gaseous laser, the gain media is gas or a gas mixture. Depending on the gas used they can be divided into atomic or molecular gaseous laser. So, CO_2 is one example and then here it can have atomic laser or molecular laser, molecule is big, atomic is small.

Helium neon and argon ion gases are atomic gases whereas CO_2 and excimer laser are gas laser which is molecular laser. The excimer laser is nothing but excited dimer. So, dimer krypton fluoride gas comes, it tries to activate, tries to take you to population inversion and then you try to get it.

So, you have helium neon and argon ion lasers and you have CO_2 and excimer lasers for molecular lasers. In gaseous laser the power will be generally low. Low pressure gas is contained in the cylinder with two electrodes this is what I said. You have a container, you have electrode you pass current and then you try to activate whatever you want.

So, an electric discharge inside the gas tube creates a current that ionizes gas atoms to form free electrons that travel from the cathode to anode. So, discharge means it reaches a stage and it starts discharging that means to say in between the two electrodes you will have air. This dielectric has to be broken. When it breaks, it tries to create a discharge, and electric discharge inside the gas tube creates a current that ionizes the gas.

So, what do you mean by ionization? Ionization of gas is nothing but plasma, ionized gas atoms to form free electrons that travels from the cathode to the anode after colliding with free electrons. Some atoms decay to lower energy level when laser theory conditions are met. The population inversion causes lasing action. This is CO_2 gaseous laser.

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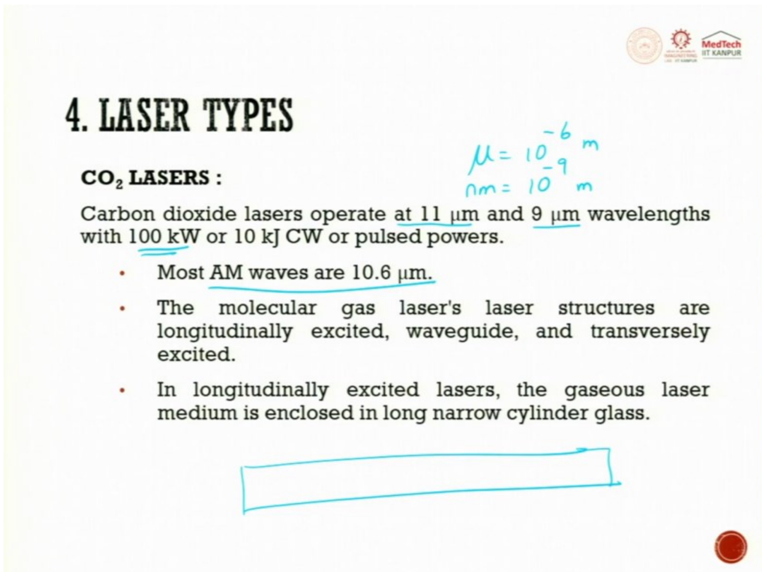

CO_2 lasers are operated at 11 µm and 9 µm wavelength. Micro- So, µ is 10^{-6}, when we say nano it is 10^{-9}. So, try to have this conversion at 11 µm and 9 µm wavelength and with 100 kW or 10 kJ continuous wave or pulsed power supply most of the additive manufacturing machines uses 10.6 µm as wavelength.

The laser structures are longitudinally excited wave guides and transverse excitement happens the longitudinal excited laser and the gaseous laser medium to be enclosed in a long narrow cylinder. So, it is like this long narrow glass cylinder it is that, and then you fill it up with gas you excite it either by light flash lamp or by excitement, this is the glass tube.

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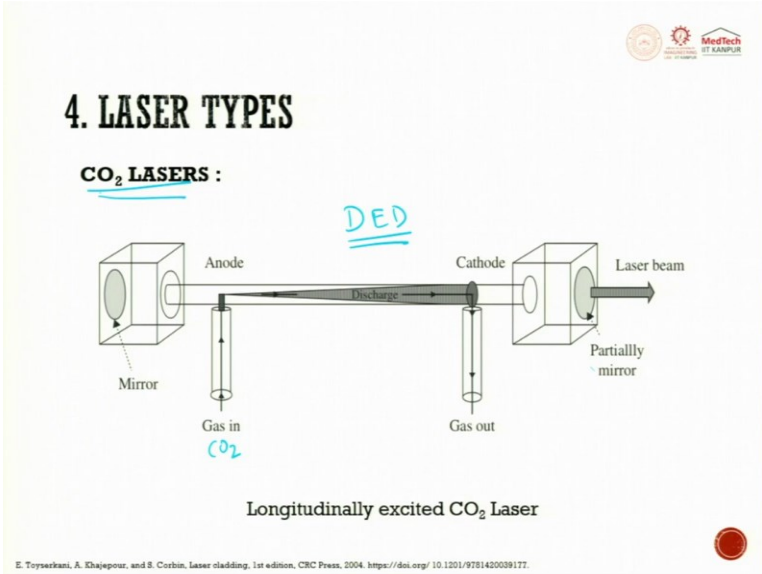

So, this is the glass tube. So, you can see gas in and gas out happening. So, you have anode at one side, cathode at one side this is 100% mirror and this is partial mirror. So, it goes back and forth and then it exits out. So, gas in it can be a CO_2 gas, gas out can be the split gas whatever it is gets dissociated and then it comes out.

So, this is called as CO_2 laser, this is also effectively used in additive manufacturing and in DED process majority of the time they prefer to use CO_2 laser, but the only limitation of CO_2 laser is it occupies a huge space and it is also not very high energy efficient.

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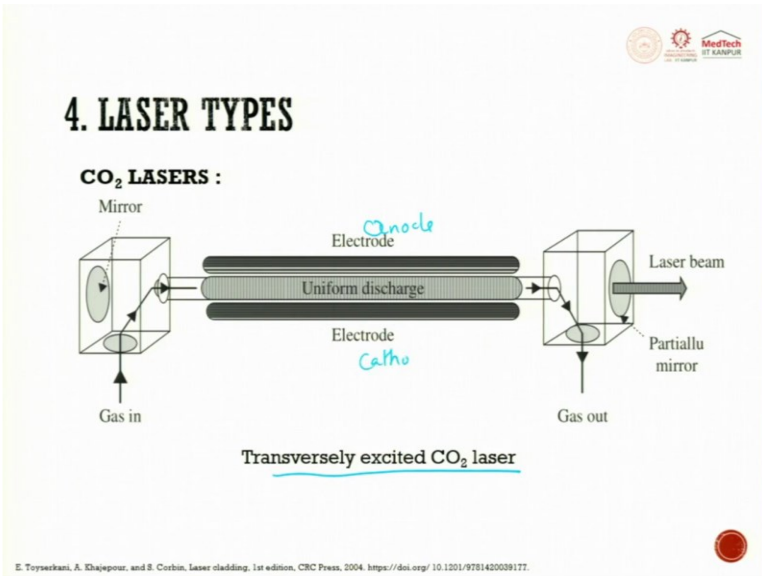

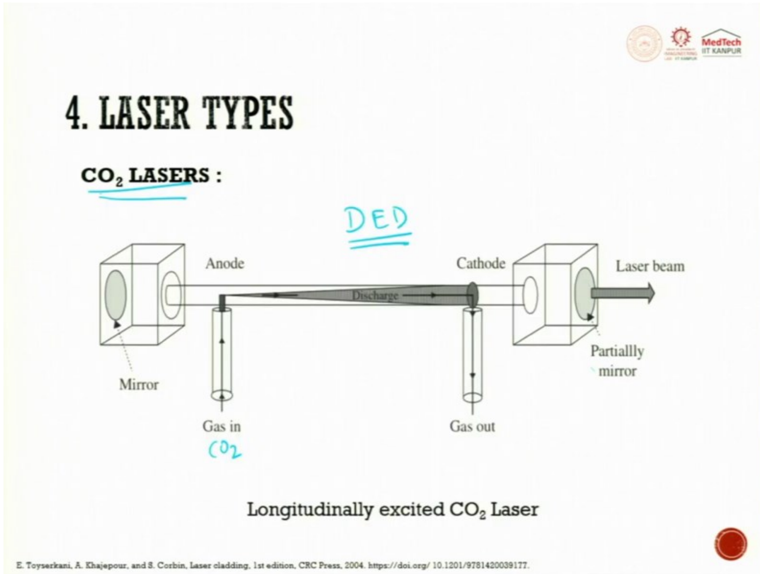

So, the other way around is you can also have transversely excited CO_2 laser. So, you can see here this is a mirror the gas comes in it goes through the uniform chamber and the gas gets out, the electrodes are placed and rest all things are same. So, this is transverse type, this is longitudinal type.

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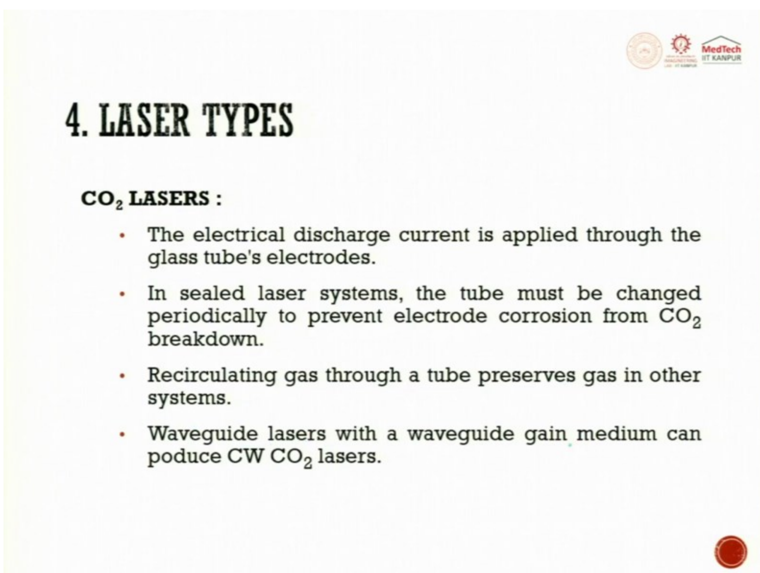

The electric discharge current is applied through the glass tube electrode in sealed laser system. The tube must be changed periodically to prevent electrode corrosion from CO_2 breakdowns. Recirculating gas through the tube preserves gas in another system. The wave guide laser with a waveguide gain media can produce continuous CO_2 laser.

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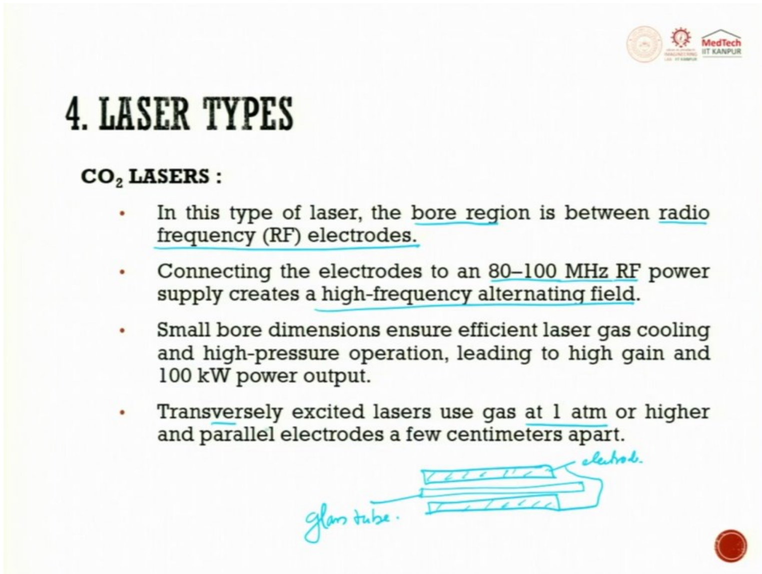

In this type of laser, that means to say CO_2 laser the bore region is between radio frequency electrodes. Connecting the electrodes to an 80-100 MHz RF power supply creates a high frequency alternating field.

So, it tries to generate a high frequency alternating field. Small bore dimensions ensure efficient laser gas cooling and high pressure operations leading to a high gain and 100 kW power output. Transverse excited lasers uses gas at one atmosphere or higher the parallel electrodes are few centimeters apart so this is for transverse. You have glass tube inside. Transversely excited laser use gas at one atmosphere.

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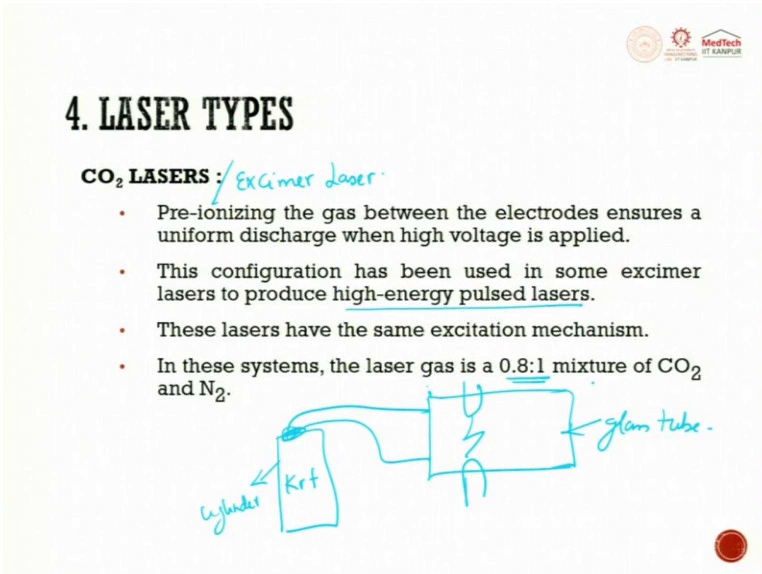

Pre ionized gas between the electrode ensures a uniform discharge when high voltages are applied. This is quite common in CO_2 laser or in excimer laser. So, here what happens you have a cylinder pre mixed krypton fluoride. So, the gas goes into the tube and in the glass tube you have electrodes through which there is a discharge happening. This is a glass tube this is a cylinder and it is pressurized.

So, the tube goes like this. So, pre ionized gas between the electrodes ensures the uniform discharge when high voltages are applied. This configuration has been used in some excimer laser to produce high energy pulsed laser. These lasers have the same excitation mechanism. In this system the laser gas is 0.8:1 mixture for CO_2 and N_2.

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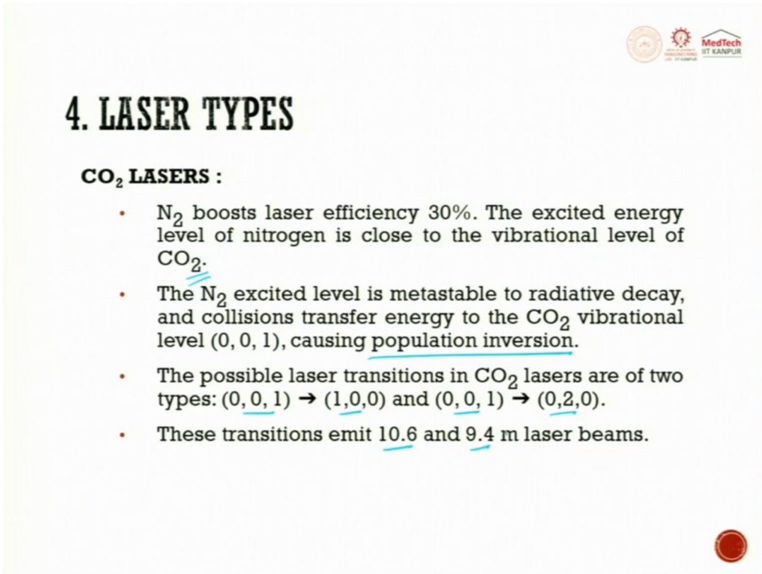

N_2 boosts large efficiency to 30%, the excited energy level of nitrogen is close to the vibrational level of CO_2. So, we use them premix of CO_2 and N_2. N_2 excited level is meta stable to reactivate decay and collision transfer energy to the CO_2 vibrational level 0, 0, 1 causing population inversion. The possible laser transition in CO2 laser are: (0, 0, 1) ➔ (1,0,0) and (0, 0, 1) ➔ (0,2,0). The transmission which is emitted is 10.6 and 9.4 μ laser beam.

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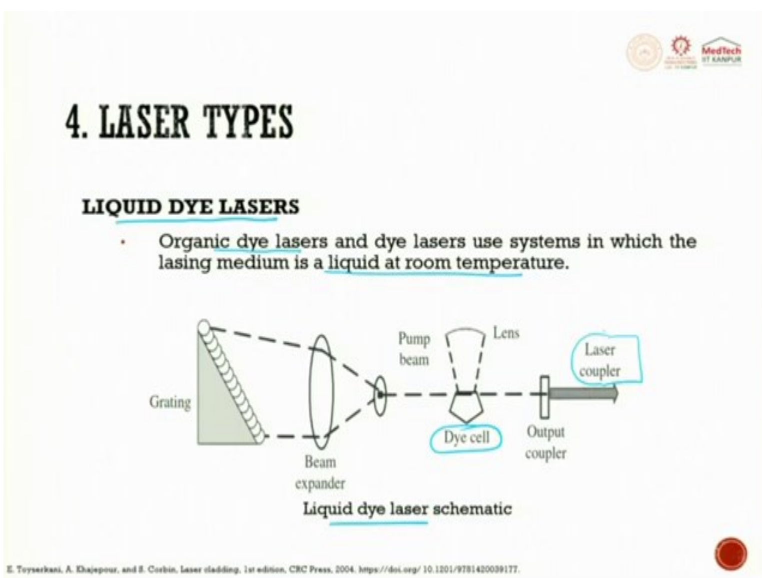

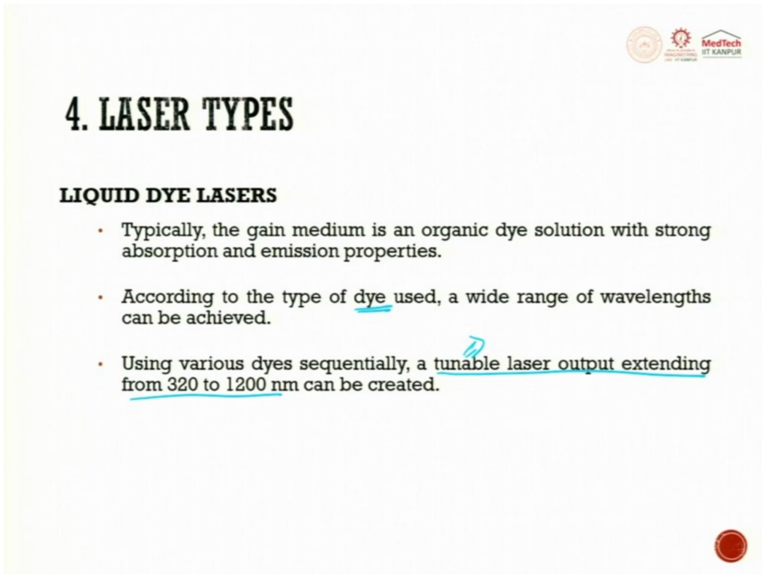

We also have liquid dye laser, we always try to use an organic dye laser, in which the lasing media is liquid at room temperature. So, what we do is we try to have a grating, we try to have a beam expander, then we have pump in the beam which happens, we have a lens.

So, here is the dye cell. This dye cell will be given a light which tries to excite the dye. Here is an organic dye which tries to get excited and when this gets excited, it tries to eject out a laser output from the output coupler.

So, dye lasers are generally used for pumping. Dye laser can pump another laser and this will be a pumping source for getting excited. People use that but generally dye lasers are not very high power and it is used for marking radiation or diffraction patterns, then gratings all these things are done.

Typically, a gain media is an organic dye solution with strong absorption and emission properties. According to the type of the dye used, a wide range of wavelength can be achieved that is the beauty of this. You change the composition, you try to get different wavelength but the only thing is, there will be powers that will be extremely low. Using various dye sequencing, a tunable laser output extended from 320-1200 nm, so this is called as tunable laser.

Tunable laser means you can try to change the wavelength depending upon the dye you use and this is very important because when you are trying to do additive manufacturing you might have to use varying wavelengths to meet out to the requirements. At that point, this type of lasers come handy but the power what is there is very low. People are working on it to try to accelerate or make the power high such that it can be used by a tunable laser output.

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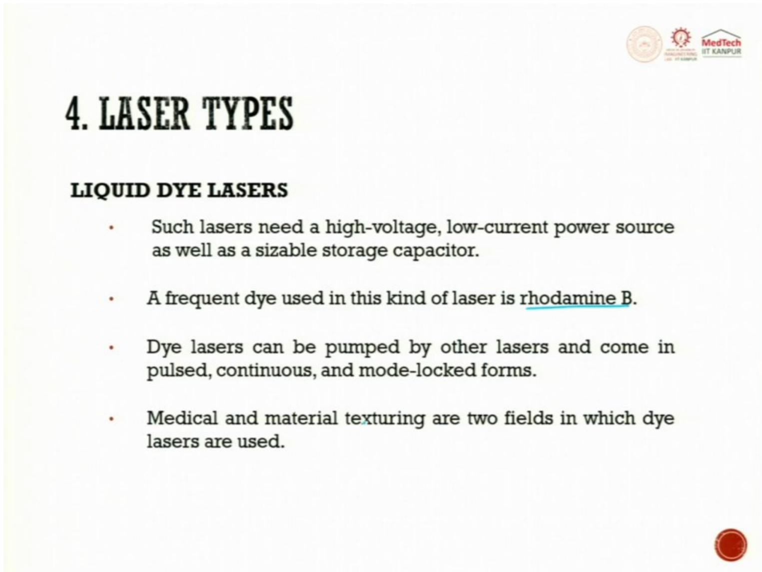

Such lasers need a high voltage, low current power source as well sizeable storage capacitor. The frequent dye used in these lasers are rhodamine B. Dye laser can pump other lasers and come in pulse, continuous or mode locking forms. Medical and material texturing are two big fields in which this dye laser is used.

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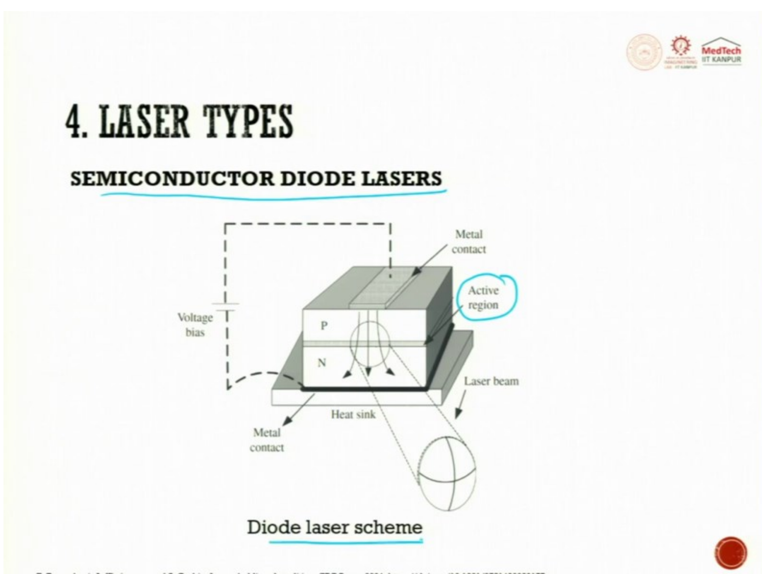

The last one is going to be semiconductor laser which is very common today. In semiconductor, we have a p type we have a n type and in between the p type and n type, we have an active region. So, there is a voltage bias which is passed to the metal contact on the top, and at the bottom you will have metal contact which is taken from n and then you try to pass a voltage which tries to move the electrons from top to bottom.

And this tries to hit at the activation region and what you get is a laser beam which gets out of this activation media. The lasing media which comes from the active region is becoming very popular and this has very high or very good energy efficiency. A lot of new laser additive manufacturing machines are getting attached with diode lasers.

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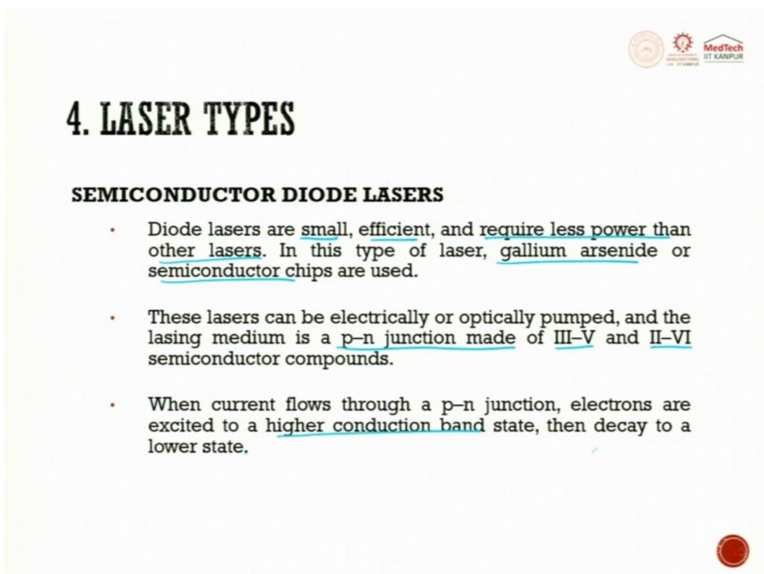

So, it is also called as semiconductor diode lasers. Diode lasers are small, efficient and requires lesser power than the other lasers. In this type of laser, gallium arsenide or semiconductor chip are used.

So, it is very efficient because when we talk about sustainability, we always look for low power lasers. I am talking about in low power what gets out of the machine will be high power. The laser can be electrically or optically pumped, and the lasing medium is a p–n junction made of III–V and II–VI semiconductor compounds. When current flows through a pn junction, electrons are excited to a higher conduction band state then decay to a lower state.

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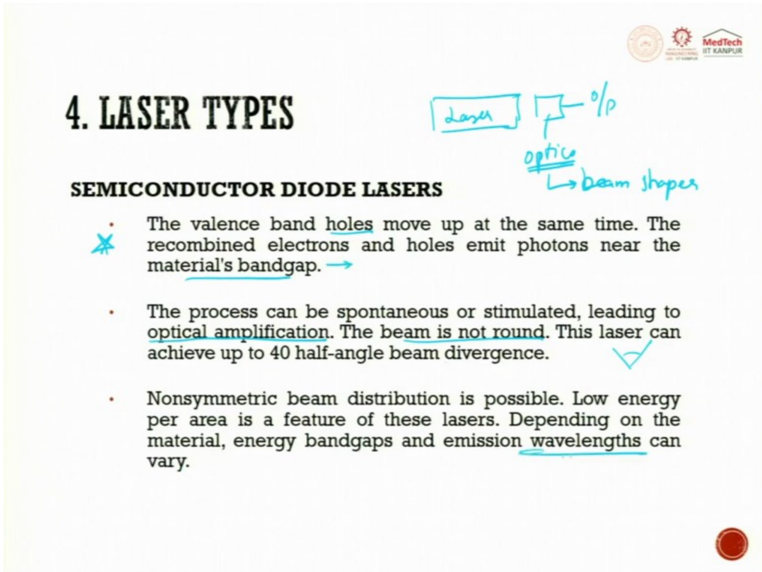

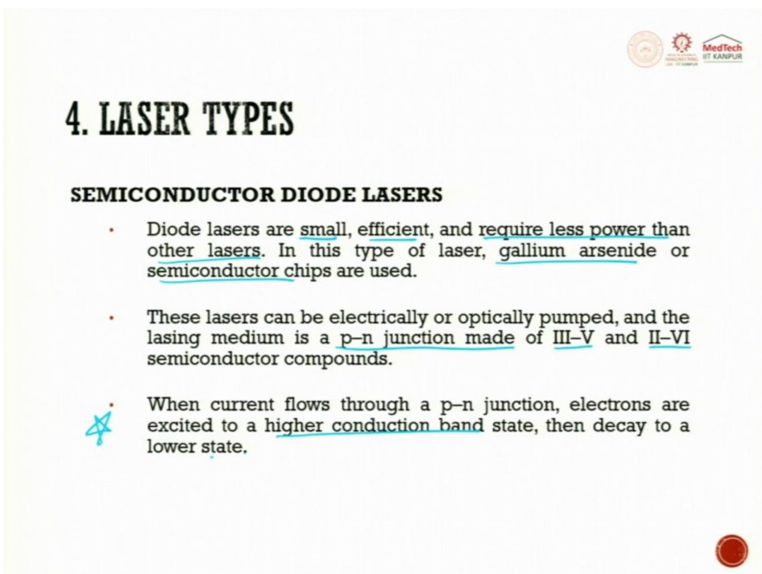

The valence band hole moves up and at the same time the recombined electrons and the holes emits photon near the material band gap. This is an important point, the previous one is also important. When a current flows through a pn junction, electrons are excited to a higher conduction band state, then decay to a lower state.

Next, the valence band holes moves up at the same time. The recombined electrons and holes emit photons near the material band gap. The process can be spontaneous or stimulated leading to an optical amplification. So, optical amplification is very important but the beam is not round the laser is achieved up to 40 half angle beam divergence.

The non-symmetric beam distribution is possible. So, here you should also understand the beam is not round. So, I have to do something to make it round. So, basically in laser, you will try to have optics and then you will try to have an output. So, this optics can be a beam shaper.

Non symmetric beam distribution is also possible. So, that means to say you can convert Gaussian distribution into cowboy hat pattern or you can try to have a skewed distribution also. Non symmetric beam distribution is possible, low energy per area is the feature of this laser. Depending on the material, energy band gap, and emission wavelength can be varied.

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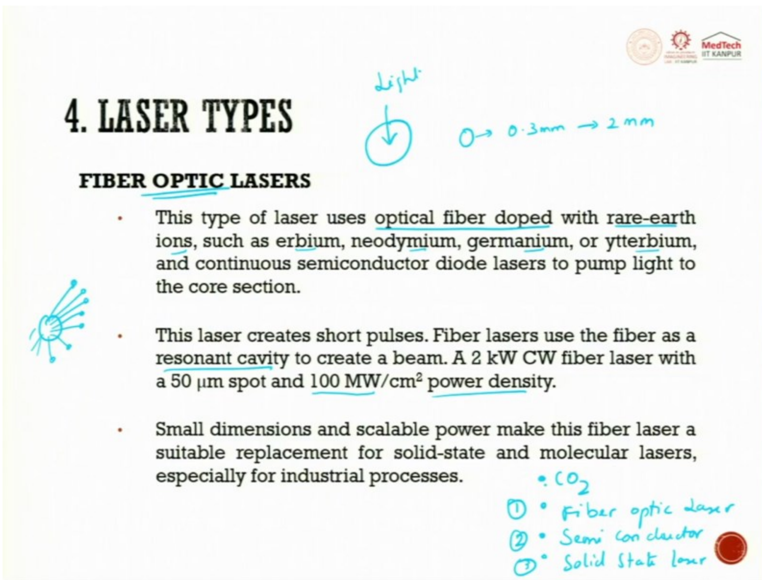

Fiber optic laser- This type of laser uses only a fiber optics. Fiber optics means a glass fiber which is having a diameter of maybe 0.3 mm, it can go up to 2 mm, something like that. So, fiber optic cable, you would have see as a toy also. So, you would have seen there will be a light source, in this light source they will attach it with fiber optic cable. So, you will see at the end of the cable you had as though something like a droplet of light.

So, optical fibers are doped with rare earth ions such as erbium, neodymiun, germanium, ytterbium and other continuous semiconductor diode lasers to pump light to the core section. So, here is light. So, there is a core section, this laser creates short pulse. Fiber lasers can use a fiber as a resonating cable. So, what you saw a long longitudinal cable for CO_2 and transverse here you use a fiber itself as a resonant cavity a 2 kW continuous fiber laser with 50 μ spot with 100 MW/cm^2 power density can be achieved.

So, look at it. This is also now gaining importance in additive manufacturing. Small dimensions and scalable power make this laser a suitable replacement for solid state and molecular laser. So, if you look at it today, we use CO_2 seldom fiber optic laser. This is first of its kind. Next, we try to use semiconductor laser, the last one we try to use is solid state laser.

So, these are the three types which are commonly used in today's additive manufacturing process. For pumping, you use a dye laser, CO_2 laser is also slowly dying because of its efficiency and the huge space required for making the setup. So, these three are going up and down and depending upon the dopant and the gain media, you try to get multiple wavelengths.

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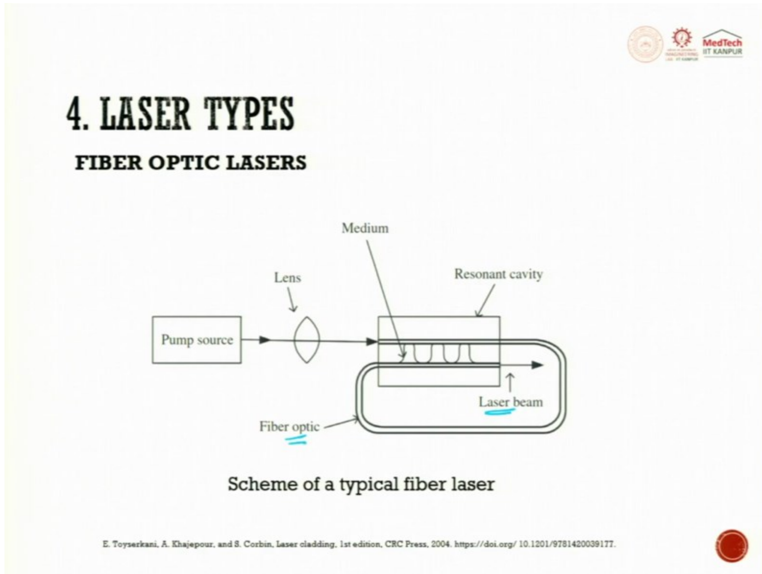

So, this is fiber optics. So, you have a pump source, you have a lens, it passes through the optical fiber, the optical fiber itself is a resonating cavity. So, you have a medium which tries to push. So, it you try to have a lasing action inside and what comes out of this is nothing but a laser beam, this is a fiber optic cable. These fiber optic lasers are gaining more importance on top of solid state laser. Semiconductor laser is also coming up but fiber optic is the outstanding now.

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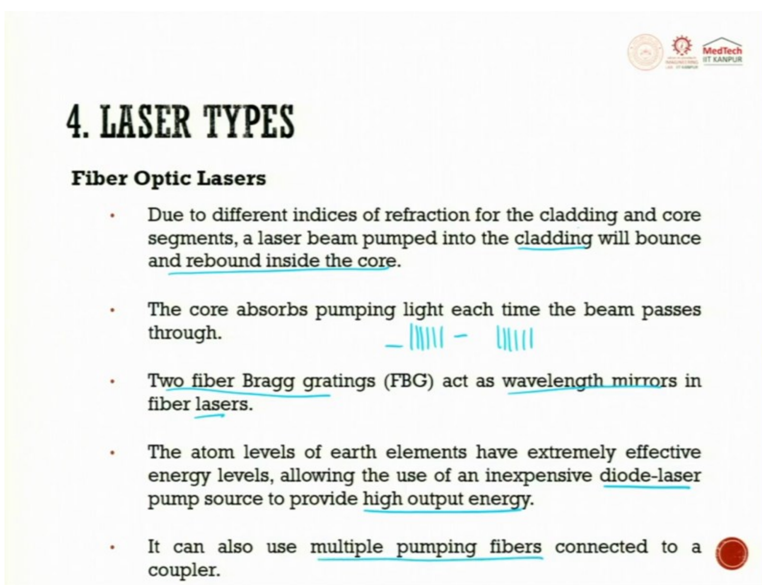

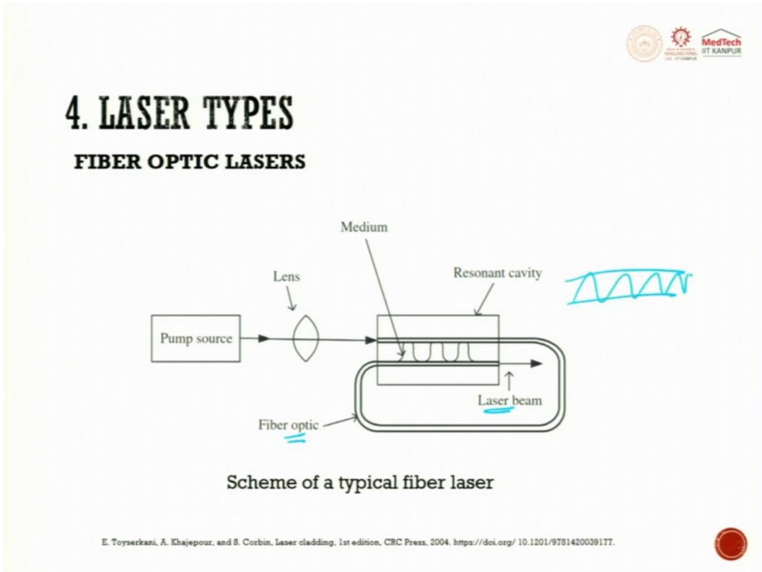

Due to different indices of refraction for the cladding and core segment, a laser beam pumps into the cladding which will bounce and rebounces inside the core. So, what we are trying to say is inside this cable it will bounce and rebounce.

Cladding will bounce and rebounce inside the core, the core absorbs pumping light each time the beam passes through it. You have these two different fiber gratings, gratings are nothing but small lines which are drawn where it will have transparent and opaque when the light passes through it, and hence it creates a diffraction pattern. Two fiber brag gratings act as a wavelength mirror in the fiber laser. The atomic level of earth elements have extremely efficient energy levels allowing the use of inexpensive diode laser pump source to provide high output energy. It can also use multiple pump fibers connected to a coupler.

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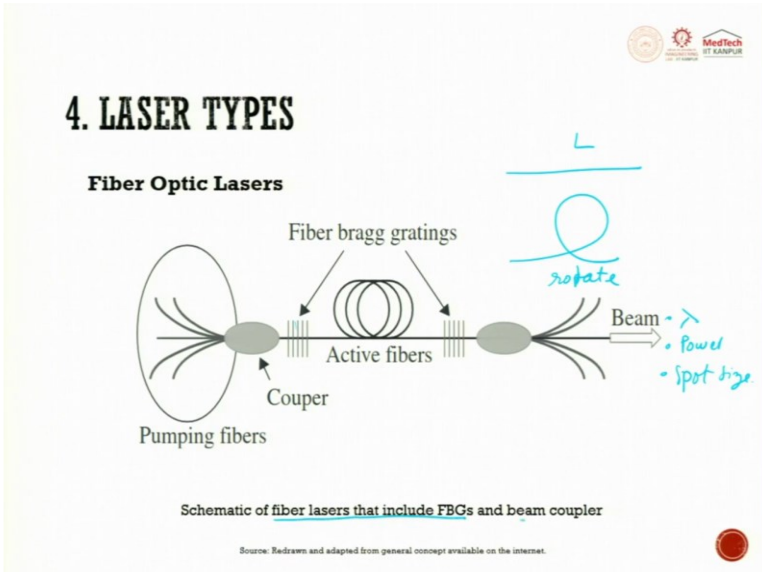

So, this is a coupler. So, these are multiple fibers attached to a coupler you can have gratings and this will try to create a beam. So, this is rotated and kept. So, that, the length is now converted into rotation and occupies a small space. Finally, you get a beam output. So, here λ, power, and of course spot size is very important. So, this is a fiber laser that induces FBGs and beam couplers.

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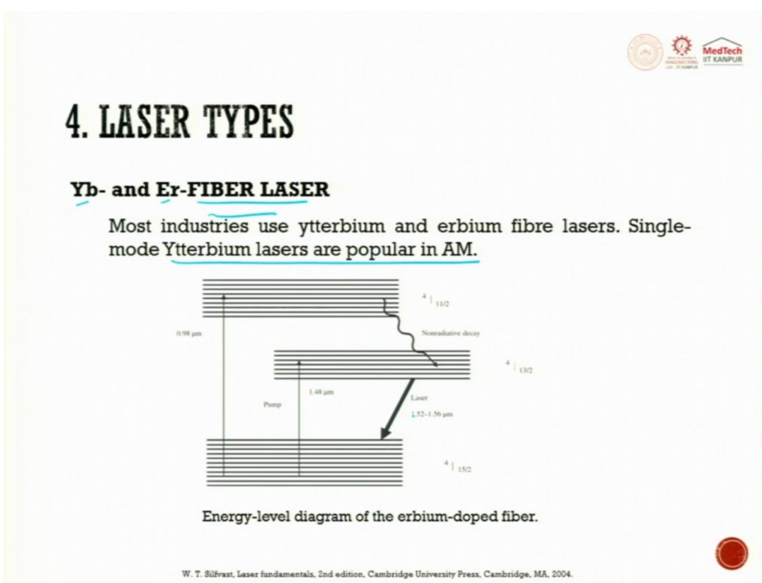

So, the Yb and Er fiber lasers are very common. So, most industries use ytterbium and erbium fiber lasers. Single mode ytterbium lasers are popular in AM. So, as I told you fiber laser in additive manufacturing is going to be there. So, here I have said E_0 or E_1, E_2, E_2. So, this is non-radiative, this is radiative, and you see the wavelength what comes out.

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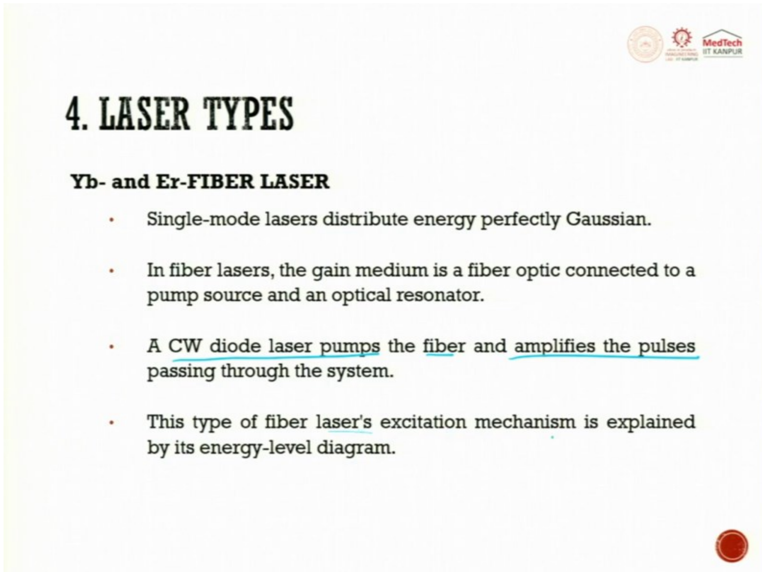

So, single mode laser distribute energy perfectly as Gaussian. In fiber laser, the gain medium is the fiber optic connected to a pump source and an optical resonator. The continuous wave diode laser pumps the fiber and amplifies the pulse through the system. This type of fiber laser excitation mechanism is explained by its energy level diagram.

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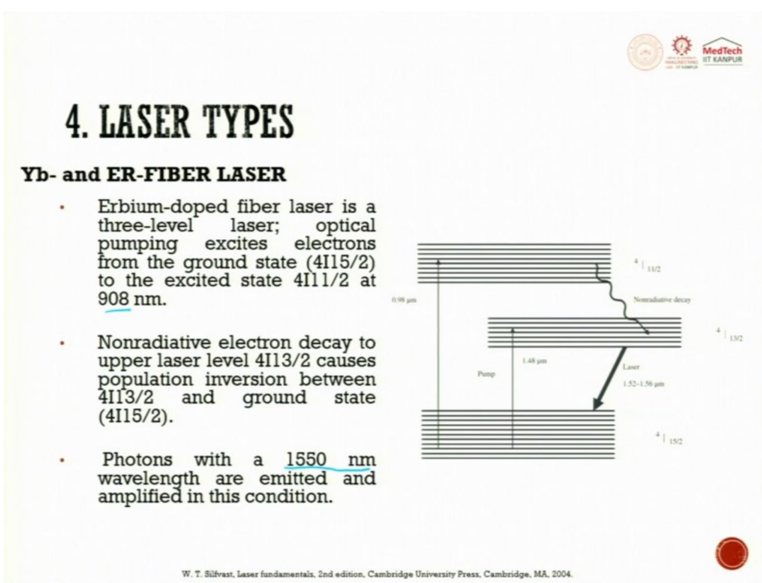

So, this is what it is. So, erbium doped fiber laser is 3 level system, which we have seen; optical pumping excites electrons from the ground state (4I15/2) to the excited state 4I11/2 at 908 nm. Nonradiative electron decay to upper laser level 4I13/2 causes population inversion between 4I13/2 and ground state (4I15/2).The photon with an 1550 nm wavelength are emitted and amplified in this condition for usage.

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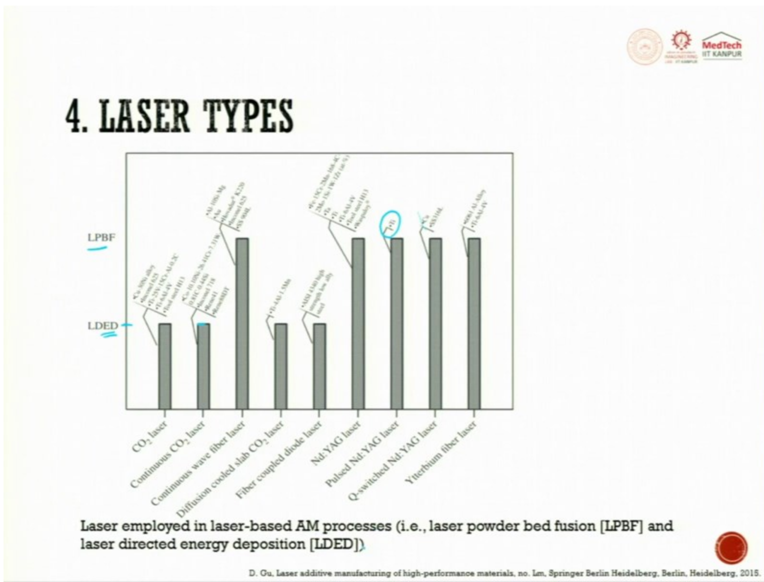

So, if you see the laser type and if you see the two processes, prominent process one is called as laser powder bed fusion and DED. You can see here it is CO_2 laser, which falls here is DED and then you have continuous CO_2 laser, then you have continuous wave fiber laser which falls in powder bed, then you have diffused cooled slab CO_2 laser again in DED.

DED and all is very high power, then you have fiber coupled diode laser for DED, then you have Nd YAG glacier for powder bed fusion, then pulsed Nd YAG glacier for powder bed fusion and I have told you what is the source, the active media, then you have q switched Nd YAG laser which is there for cobalt which is used as the dopant, ytterbium fiber laser which is also used for powder bed fusion. This graph tries to talk about laser employed in laser based additive manufacturing in powder bed fusion and directed energy deposition.

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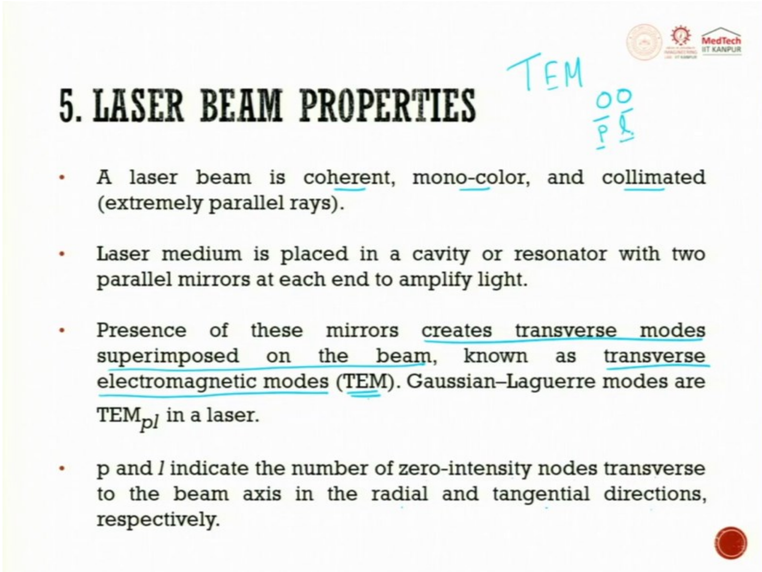

So, now let us see the last part of the lecture which is on laser beam properties. Laser beam is a coherent monochromatic or mono color collimated extremely parallel light which comes out. The lasing media is placed in the cavity or resonator with two parallel mirrors at each end to amplify light. The presence of these mirrors creates transverse electromagnetic mode superimposed on the beam.

So, this is called as the Gaussian Laguerre modes are given as TEM_{pl}. In the laser p and l indicate the number of zero intensity nodes transverse to the beam axis in the radial and tangential direction respectively.

When you buy a laser, there will be in the specification of TEM_{00} mode. So, this TEM is nothing but transverse electromagnetic mode which is caused by transverse modes superimposed on the beam. So, this 00 is nothing but p and l, which indicates the number of zero intensity modes transverse to the beam axis in the radial direction and tangential direction.

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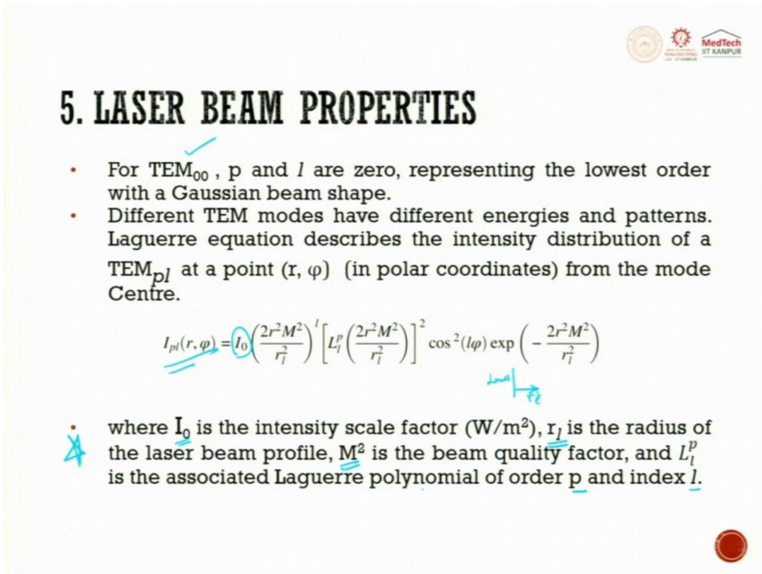

Now let us see some of the modes. So, for TEM_{00}, p and l are 0 representing the lowest order with a Gaussian beam distribution. This is commonly used mode for additive manufacturing with respect to metals. Different TEM modes have different energies and patterns. The Laguerre equation describes the intensity distribution of a TEM_{00} or p l mode at a point (r, φ) (in polar coordinates) from the mode centre.

$$I_{pl}(r,\varphi) = I_0\left(\frac{2r^2M^2}{r_l^2}\right)^l\left[L_l^p\left(\frac{2r^2M^2}{r_l^2}\right)\right]^2\cos^2(l\varphi)\exp\left(-\frac{2r^2M^2}{r_l^2}\right)$$

So, it is represented as this. where I_0 is the intensity scale factor (W/m^2), r_l is the radius of the laser beam profile, M^2 is the beam quality factor, and L_l^p is the associated Laguerre polynomial of order p and index *l*.

When you buy a laser, you always ask for the mode of the laser and then you will try to ask what is the M^2 value of the laser you will try to also ask what is the profile it follows. So, the profile following will be found out by solving this equation or you can ask them they will say it is a Gaussian distribution but $TEM_{11,00}$ mode itself is predominantly dominated by a Gaussian distribution.

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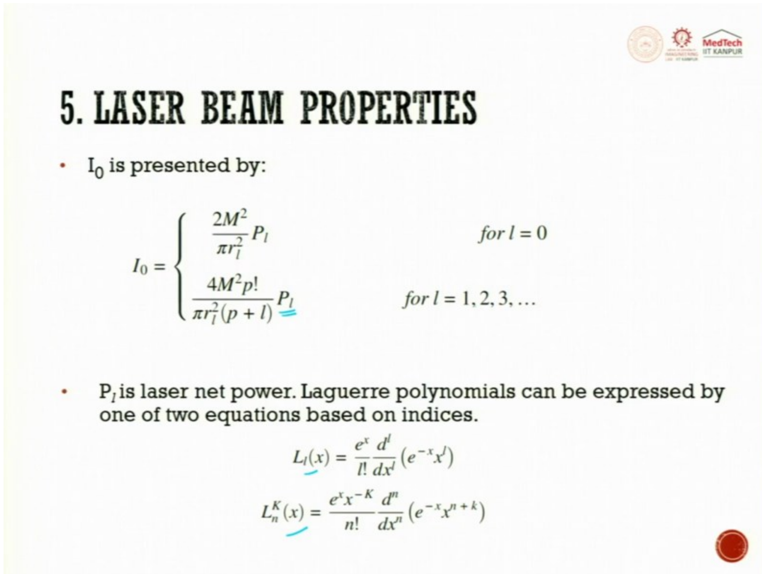

So, I_0 is represented by this way:

$$I_0 = \begin{cases} \frac{2M^2}{\pi r_l^2} P_l & for\ l = 0 \\ \frac{4M^2 p!}{\pi r_l^2 (p+l)} P_l & for\ l = 1, 2, 3, \dots \end{cases}$$

Laguerre polynomial can be expressed by one of the two equations like this. In the examination we will try to have a small math problem to be solved in such a way that you try to figure out what is your I_0.

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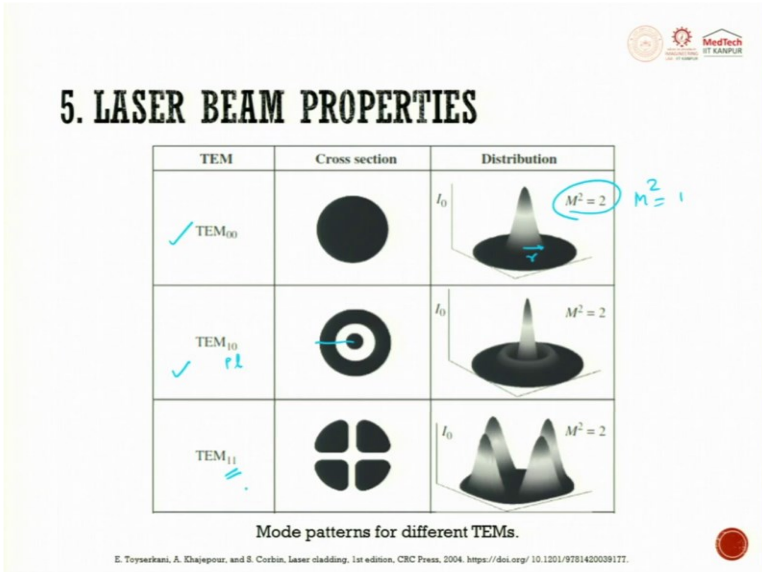

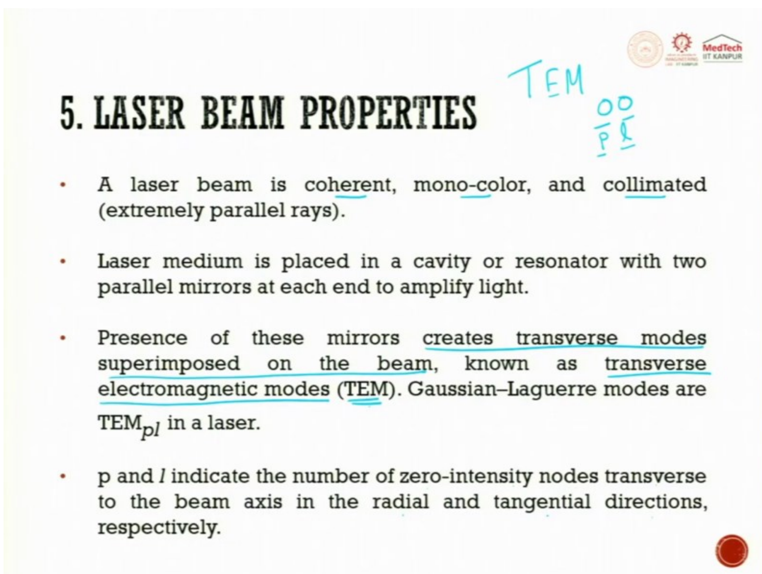

So, out of the various modes which are generally available for laser, the most common one is TEM_{00} mode, the cross section will be like this and the Gaussian distribution will be like this, this is called as I_0 and this is called as the radius r. The M^2 value is 2, generally the M^2 value should be close to 1, 2 means the beam is not going to give you a good result when you finally develop the part.

TEM_{10} mode you have a center one and then I said in the radius this is p and l, if you go back and see what is your p and l this indicates the zero intensity mode transmission of the beam axis in the radial and tangential direction. So, now let us see the TEM_{10}.

So, this is 10 which is you have double circle, you can also have TEM_{11} which is cut into four peaks if you want to have very precisely, then you can have this. So, depending upon the choice of the mode you can also dictate the quality of your output.

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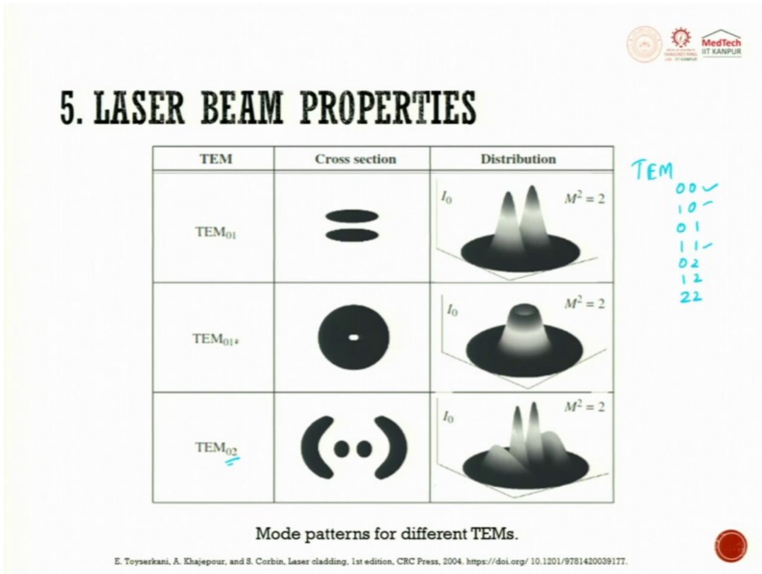

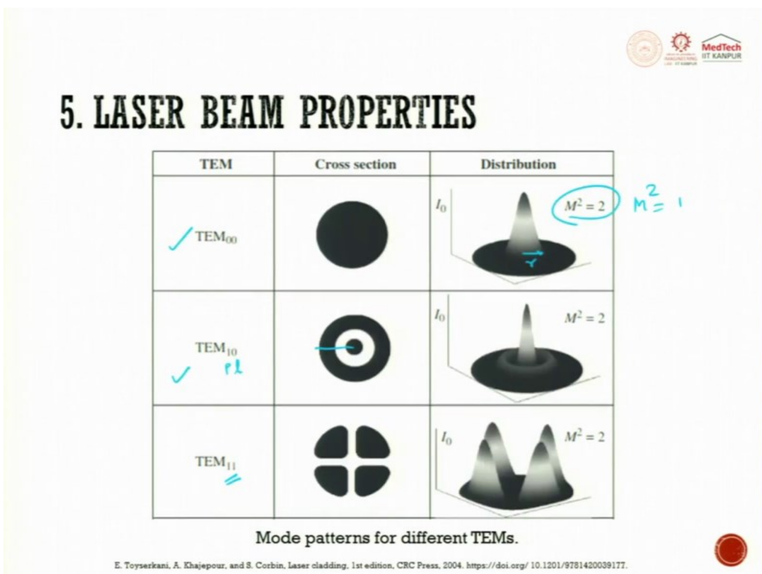

You can see TEM. So, what are the combinations it is very easy 0 0, 1 0, 0 1 ,1 1. So, and then you can have 0 2, 1 2, 2 2. So, you can keep on adding. So, this is what we have seen 0 0 mode, 0 0 mode is very straight forward which is this and 1 0 mode is this, 1 1 is you are cutting it into four, 0 1 is you will have a peak like this.

And if you have TEM $_{01*}$, then you will have a cowboy hat pattern this is something like a cowboy hat pattern and all these things are important because all these things try to dictate the melting or the sintering process when we use the beam.

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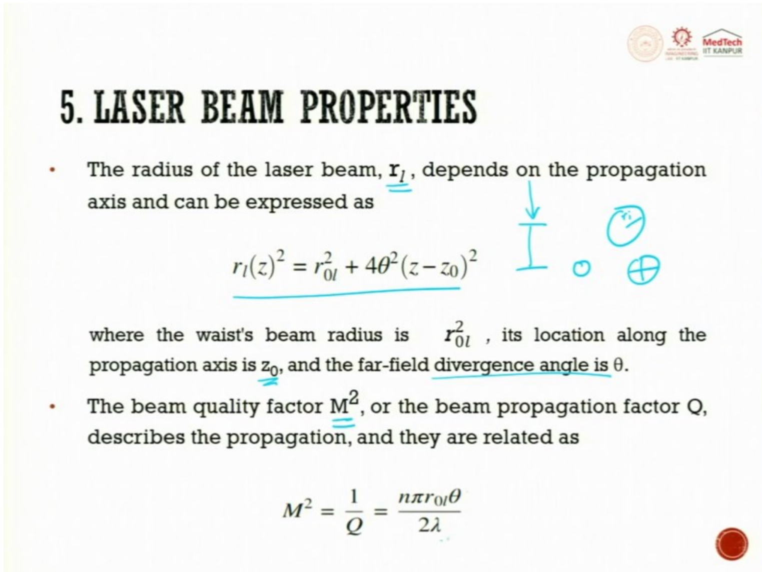

The radius of a laser beam. So, you have a spot the radius of a laser beam is always represented by r_l, depending upon the propagation axis and which can be expressed in this form:

$$r_l(z)^2 = r_{0l}^2 + 4\theta^2(z - z_0)^2$$

where the waist's beam radius is r_{0l}^2, its location along the propagation axis is z_0, and the far-field divergence angle is θ.

because the spot diameter is very important the TEM00 and all is within the spot whatever you are trying to get the profile.

The beam quality which I was kept on repeating M^2 can be written as:

$$M^2 = \frac{1}{Q} = \frac{n\pi r_{0l}\theta}{2\lambda}$$

Q is the beam propagation factor.

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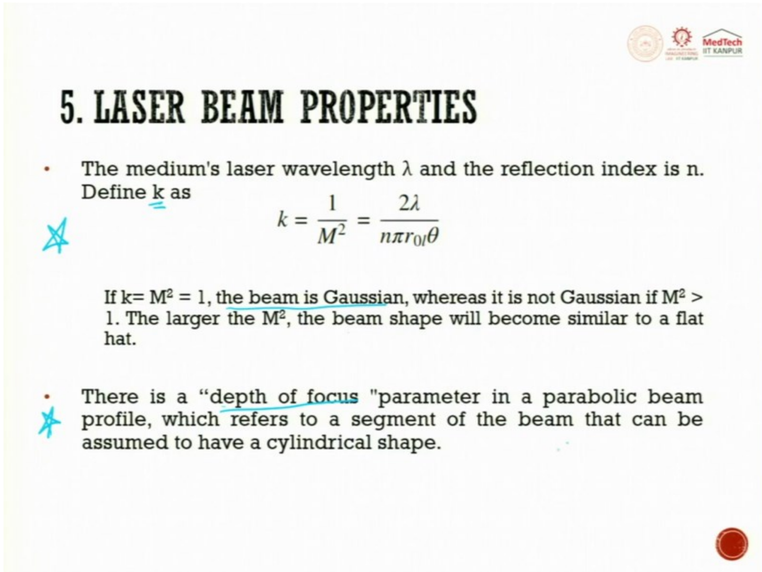

So, the medium's laser wavelength λ and the reflection index is n. The k is defined as:

$$k = \frac{1}{M^2} = \frac{2\lambda}{n\pi r_{0l}\theta}$$

The larger the M square value the beam shape will become similar to a flat hat; therefore the depth of focus parameter in a parabolic beam profile with respect to the segment of the beam that can be assumed to be a cylindrical shape.

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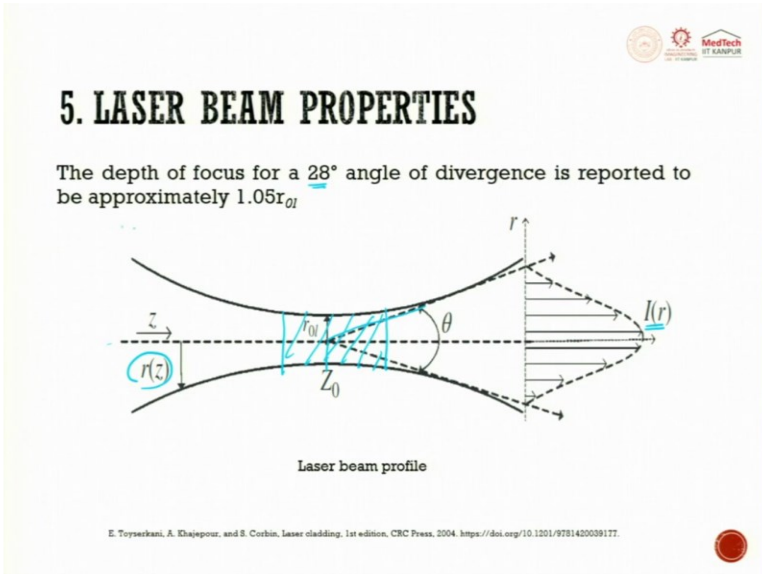

So, this is what is the diagram which we talked the depth of focus for a 28 degree theta. So, this is 28^0 angle. So, this is how you project it, this is the Gaussian distribution we follow. The depth of focus for a 28° angle of divergence is reported to be approximately $1.05r_{01}$

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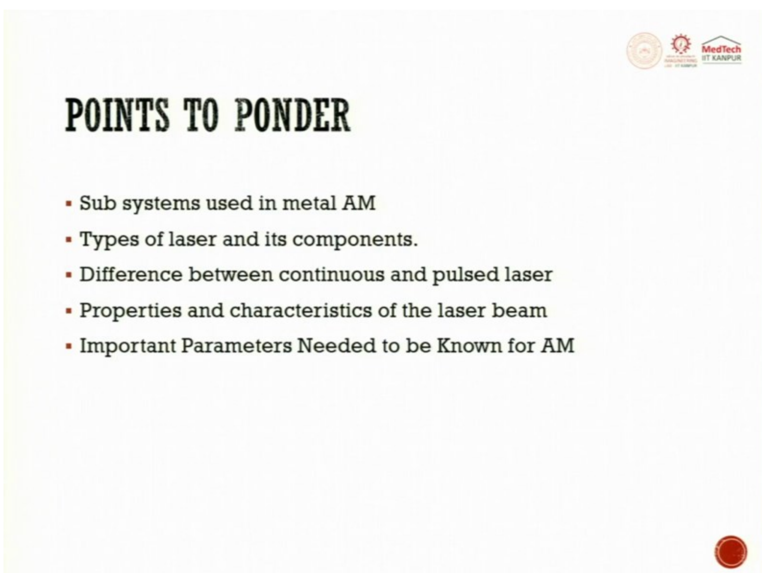

So, to come to a conclusion till now what we saw in the last two lectures. We saw various subsystems, then we saw about types of laser and its component. Then difference between continuous and pulsed laser, today we use exhaustively pulsed lasers, properties and characteristics of laser beam.

So, we also saw different types and here we saw the properties like waist, what is it and important properties which are needed to be known for AM. So, as and when I see through the slides, I kept on saying this parameter is important for AM. So, that is what we are trying to talk about here. So, I am sure you will all now have a little bit of knowledge about laser, laser matter interaction, how is the choice of your laser going to affect the influence of either sintering or melting while the product is developed. When doing DED, the energies are high as compared to that of your powder bed fusion method.

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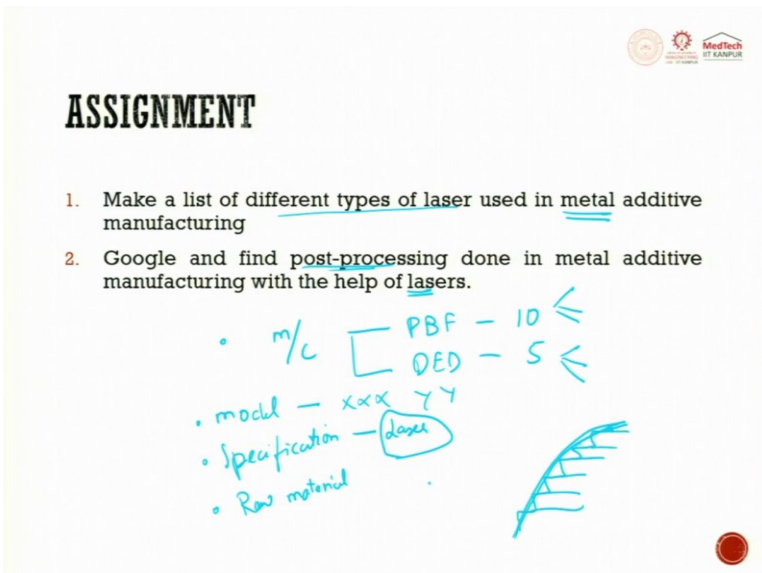

So, now I have two assignments. all these assignments you do not have to submit it is only for you to learn more about the subject. Make a list of different types of laser used in metal additive manufacturing. So, what I am asking you is you start looking at various machines at least in powder bed fusion some 10 machines. 10 machines means 10 different company machines, then DED at least look at 5.

So, now what will happen is each machine manufacturer will have at least three, four variations. So, try to write down all the machine model. So, model number whatever it is xxx yy then you try to write down the specification which is used for the machine and in particular laser start noting it down and then you also try to see what are the possible raw materials which can be used in this process.

When you do so our focus is more towards laser. So, what are the different types of lasers used in metal additive manufacturing, google and find post processing done in this metal additive manufacturing with the help of laser. So, when we start producing all these things layer by layer you will have something called as a stair case effect.

Because you are building it layer by layer, then you have this stair case effect you have to smoothen the surface. So, when you have to smoothen the surface in the post processing nowadays we also have one more laser which tries to move on top of the metal additive manufactured part remove the staircase effect and flow the material such that it gets a very smooth surface.

So, it is worthwhile for you to understand how do we do post finishing operation using laser for additive manufactured parts. If you can also make a small essay about it, understand the process, look into the laser, find out what is the difference between this laser and that laser with respect to all the parameters this will try to give you an overall idea of the process and laser involved in the process. Thank you very much.