Advances in Welding and Joining Technologies
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Lecture – 06
Laser and Electron Beam Welding- Part-1

Good morning everybody. Today, I will start the second module of advances in welding and joining technologies.

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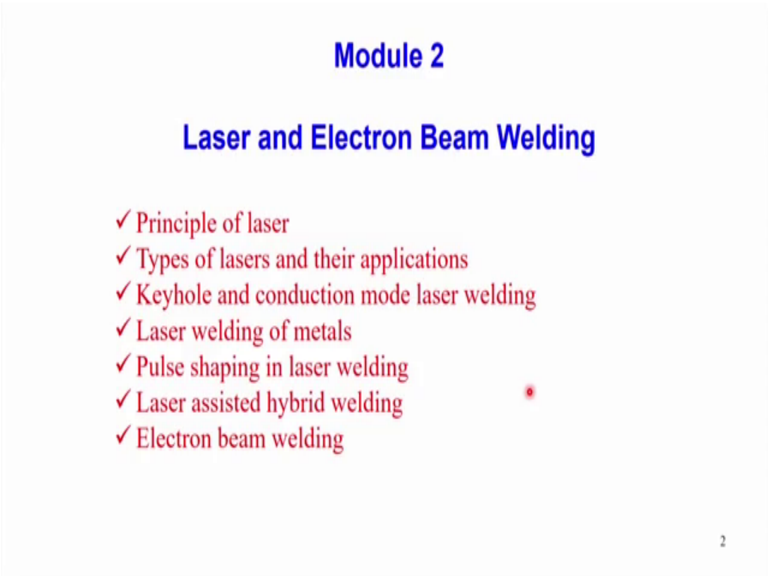

So, in this modules probably, we will try to cover that laser and electron beam welding and these two processes has been widely used in the welding industry and as compared to the other bros other arc welding processes. So, to start with this module first of all, we will try to look back about the principle of lasers and different types of laser and their applications.

So, key hole formation or conduction mode laser welding processes and that laser welding application in the different materials and then related to the laser welding we will finally, look back to that different laser assistant hybrid welding systems and finally, we will cover the electron beam welding process. So, if you when you start with the laser principle of laser.

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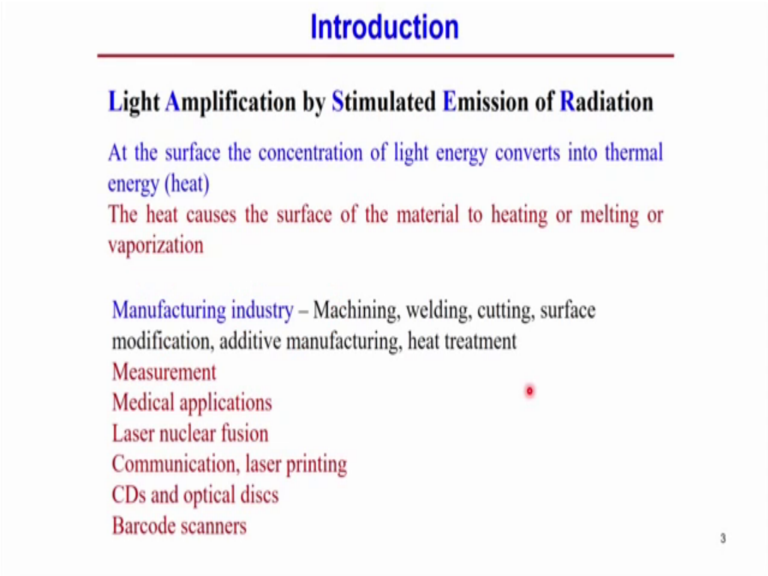

If we can see that some basic things that will try to clear out before application of the lasers in the welding purpose.

So, actually laser stands for the light amplification by stimulated emission of radiation and that radiation has been focused on a specific area, then it is possible to melt that eh material and finally, that its converse to the thermal energy and we can join the two materials, it may be either similar kind of materials or different materials, but when we try to that light energy has been concentrated in a very small zone, the heat causes the surface of the material either simply hitting or melting the material or sometimes it vaporize the material.

So, based on that; we can categorize the laser welding processes, either in the in the terms of keyhole mode laser welding or there may be the conduction mode laser welding process, but we know that there is a huge application of the laser even if you look in to the manufacture industry the all other different manufacturing processes like machining cutting surface modification and additive manufacturing heat treatment there is the huge application of the laser.

So, here the laser has been used in this manufacturing industry as a source and that source can be utilized to heat the surface whenever required either to melt the surface or vaporization of the surfaces apart from the manufacturing industry if you see the laser is used in the other technologies also, for example, the laser beam technology. So, laser based displacement sensor can be used for the verification measurement then huge application of the laser in medical application.

But only different of this laser is the intensity of the light and their concentration or maybe they are focused into a specified area there also laser can be used the nuclear fusion like communication where if you if you see that laser eh printing in the additive manufacturing there is the laser printing technology, but at the normal printing process. So, we can use the laser and if we see the to read the compact disk and there is a there is also application of the laser and. So, many optical diseases there is a huge application of the lasers and some barcodes scanner also we can see there is a application of the laser.

So, laser can be used not only the manufacturing industry rather, it is used for the different other sectors and for the different other technology, but our focus is that how, we can use the laser in the manufacturing and it is very specific to the welding processes now to do that in to the much details of the application of the laser; in the welding industry probably, we can look back that basic structure of the laser eh some facts about the laser.

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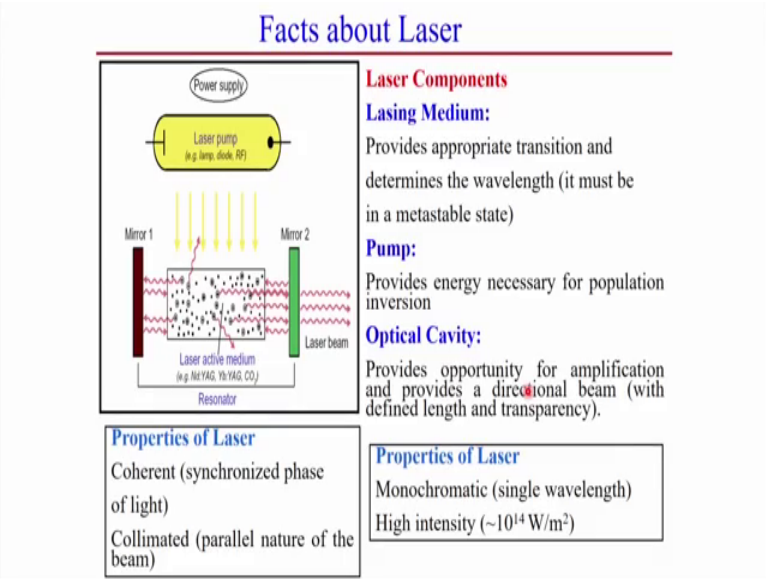

So, if you see that from that there is a from the figure there is a pump that is called laser pump its may be either diode pump or lamp pump. So, the ray can be extracted from pump and then it is focused on the some laser active medium and that active medium may consist of the different solid state or may be in the gaseous state and here the what happens this is a amplification of the ray laser beam and that laser beam has been concentrated or re well controlled laser beam has passed out from the resonator and then and that laser beam can be used using some lengths it can be focused on the specified zone dep depending on the requirement.

So, if you see the basic components of the laser is the first is the lasing medium lasing medium is the provides the appropriate transition and the determines the wavelength of the laser, but of course, it must be a metastable state, but to start before lasing medium it is a energy necessary for the population inversion that comes from the laser pump it may be laser pump it may be diode pump or it may be lamp pump and then the optical cavity; that means, within the optical cavity.

There is a opportunity for amplification of the amplification of the amplification that provides the actually, it creates the directional beam and which define and actually here it is necess the length and the length of wavelength and the transfusion has been defined in this zone and its comes out as a coherent; that means, synchronized phase of the light and collimated; that means, parallel nature of the beams comes out from this lasing medium and; that means, comes from the resonator and then finally, it is focused using some lengths. So, basic properties of the laser if you see the, it is a monochromatic; that means, single wavelength and the high intensity.

So, if you see the high intensity means around 10 to the power 14 watt per meter square. So, when it does this is the from the source can be you see that source can be the different to basic units one is the pump and another is the; they amplification and then creation of the collimated and coherent laser comes out from the system. So, this is the basic system from we can create the laser light and then we can use the several application of the laser light.

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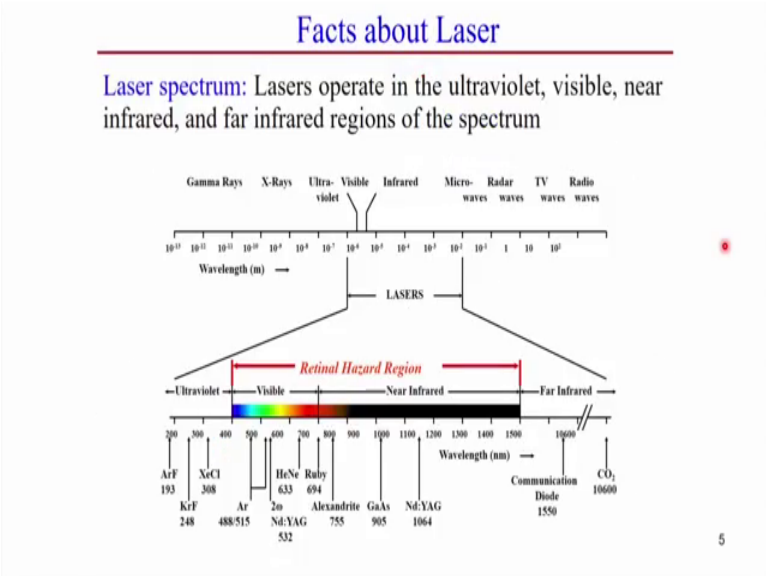

Now, if you see that laser spectrum specifically overall spectrum from the figure it is obvious that there is the overall spectrum that gamma rays X-rays ultraviolet infrared microwaves radio waves all these kind of waves having some specified wavelength, but laser the spectrum of the laser operates in the eh specifically in the ultra violet visible near infrared and the far infrared regions of the spectrum. Now, if we focus on the laser, if you see that laser can be operated at the different wavelength from ultra violet to the far infrared, if you see that first is the visible and visible that ray.

Actually, we can see on the eye and it is not hazardous to the opened eye, but eh the ultraviolet near infrared and the far infrared is may not be the, it may damage the skin or may be the eye, but it is necessary to operate the laser eh within this wavelength. So, I think visible it is a basically visible length is 400 to 700 nanometer and near infrared 700 nanometer to 1400 nanometer wavelength can be created. So, looking into the different laser spectrum there is a wide variability of the laser can be created and the using the different lasing medium or specifically the different lasing medium.

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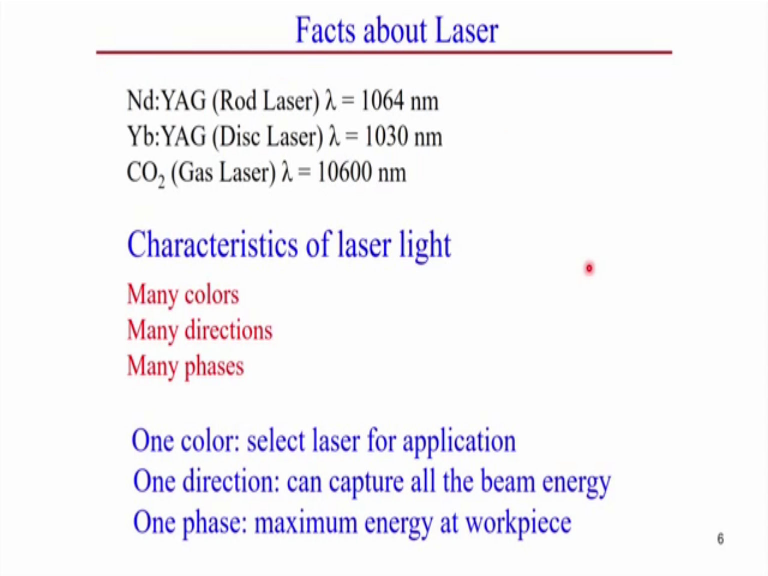

Now, or if you see the mostly use the lasers in specifically in manufacturing process in very specific to do welding process that we generally call the Nd;YAG laser and that is also called the Rod laser and here, here, we can see wavelength is 1064 nanometer similarly Yb:YAG laser that is the Disc type of laser and the wavelength is hundred thirty nanometer.

So, whether we can say the lod Rod laser or the disc laser specifically in the lasing medium what type of the shape actually decides this kinds of name specifically lod, la Rod laser that solid medium in the shape of rod can be used in to create the Nd;YAG laser or Disc type of thing can be used same can be used in case of y Yb:YAG laser similarly carbon dioxide laser also widely used and that that is also in general the gas laser where the wavelength is around 10,600 nanometers. So, if we see. So, there is a huge difference on the Nd;YAG laser and the carbon dioxide laser the in the sense that wavelength is in carbon dioxide laser 10 times more than the Nd;YAG laser.

So, this wavelength variability actually indicates in applicability in terms of the absorption of the laser when it interacted with the material. So, that is very important. So, that how this laser with this different wavelength interact with a substrate material based on that we can find out or the applicability of the different lasers actually comes out now in general if you see characteristic of the laser light we see we can find out there are many colours from in normally green red and some other colours is used then many direction ah. So, it can be focused on the many direction or the laser if we do not control the laser light.

So, it can direct scattered in the different directions then many phases. So, these are the common characteristics of the laser light, but when you try to use the laser in the different application specifically in the manufacturing processes if you see the one colour we choose for a specific application that and that one colour actually decides the applicability of the laser for the different type of materials or different purposes one direction.

So, rather than many direction if it is possible to focus on the laser light into one direction that actually relates to the beam energy of the laser and one phase if we focused on the one phase of the laser light that actually correlates with the maximum energy can be delivered to the work piece. So, among this variability according to our nate. So, we choose one colour one direction and one phase that specify the typical application of the laser in the manufacturing process.

Now, in general if you see that what way the laser works. So, the mechanism of the energy transfer in case of laser welding is completely different from the arc welding process.

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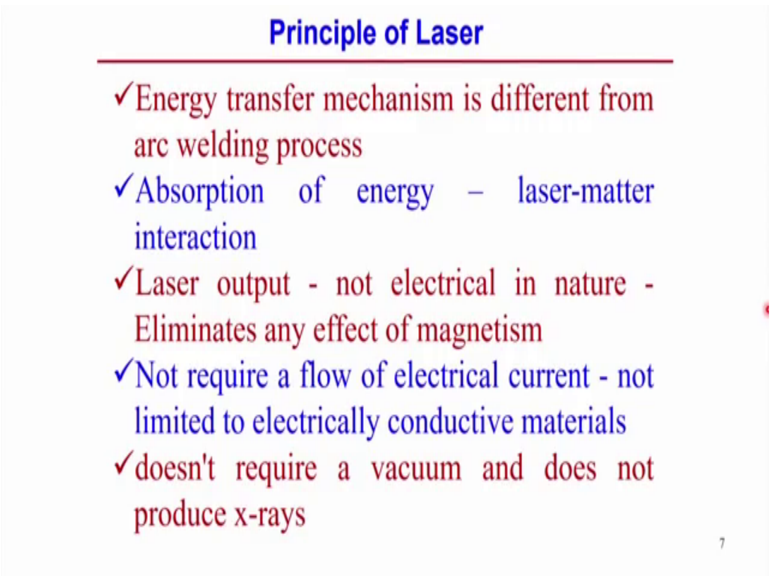

And of course, the absorption of the energy depends on the how laser is interacting with the material; that means, in general we call the laser matter interaction and laser output actually not electrical in nature; that means, it eliminates any effect of the magnetism, but this is not the case in case of arc welding because arc welding normally there is a current flow and it always try to create some electromagnetic field and that arc characteristics or may be creation of the arc mechanism is different from the laser in that sense.

So, here laser is not required any electrical current so; that means, this laser welding process is lo not limited to only electrical conductive material. So, that is why that is the duty or advantage of laser using any kind of materials whether it is electrically conductive or nonconductive so, but that limitation also exist in case of arc welding process hm. So, to create the electric arc the material should be the conductive now other point of the advantage of the laser welding process is that it do not require a vacuum and also it does not produce any X-rays like electron beam welding process.

So, laser welding may be done without a vacuum and, but normally in case of laser welding process we use the shielding gas to protect the molten metal from the outside atmosphere. So, this other two advantages that not required vacuum and the; it does not produce the excess that is the typically advantageous with respect to the electrical electron beam welding eh process.

So, in the with that respect it is advantageous and at the sense it is the cost of the laser welding process is less as compared to the electron beam welding processes, but it is a it sees advantageous with respect to the arc welding process because laser welding the laser beam energy can be focused into a very small area. So, high depth of penetration can be created using the laser which is not which is very difficult by the electric arc welding process. So, in that respect laser welding is advantageous with respect to the arc welding process. Now there are several types of the lasers.

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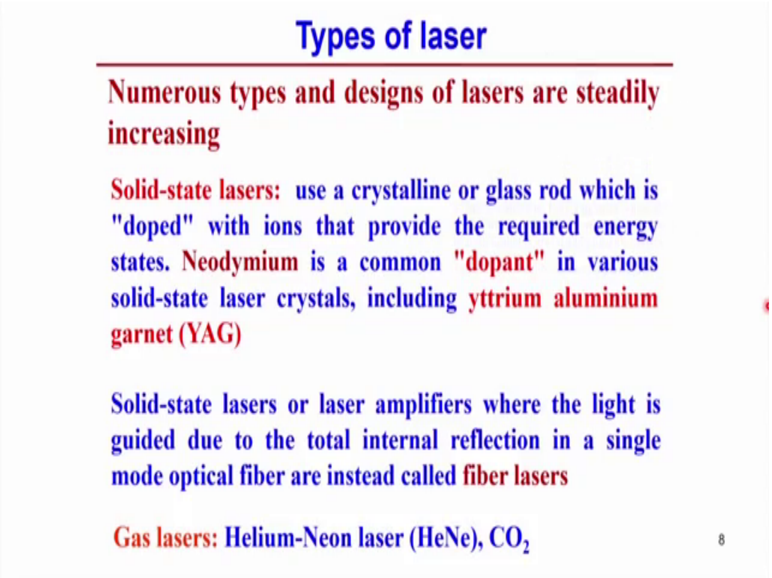

And designs of lasers typically and is day by day the there is increasing use of the lasers and design of the lasers lasers are also come out so, but normally if when we try to use the laser, then categorization in such a way that one is the solid state laser. So, solid state laser basically the crystalline glass or rod in the lasing medium which is doped with the ions and that ion dope dope doped with the ions and actually it provides the required energy state. So, neodymium is the common dopant in various solid state solid state laser crystals including yttrium aluminium garnet that is the full form of the YAG that we use the YAG laser. So, in this case the solid state laser normally we use the dopant material doped with the ions.

So, that that it actually helps to provides the required energy states and that ray can be used by the including yttrium aluminium garnet to produce the rays. So, solid states laser is basically the laser amplifiers where the light is guided due to the total internal reflections that reflections happens within the one single optical fiber means that are called basically the fiber laser of course, fiber laser is a solid state laser by in this case the only the difference in the with respect to other that optical fiber can be used to guide the to conduct the all the internal reflections.

So, in that sense the fiber laser is the with respect to the Nd;YAG laser or with respect to the other solids normally use the solid state laser the concentration of the light can be more in case of fiber laser other type of laser we see the gas laser and we use the commonly ca two gas lasers or helium neon laser. So, here the lasing medium is the gas now apart from the another that if you look into type of the fiber laser here.

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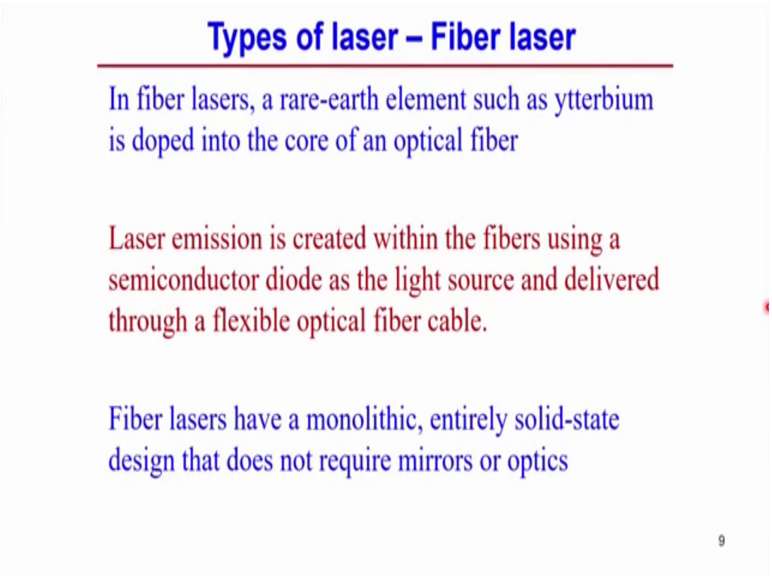

If you see the fiber laser actually rare earth element such as yttir ytterbium is doped into pore open optical fiber. So, in this case the laser emission basically emission of the light actually within the fibers using a semi conducted diode as a light source and delivered through a flexible optical fiber cable.

So, that is the duty of the fiber laser. So, that within the fiber the total internal reflection control and finally, it is delivered also using a fiber cable fiber lasers having monolithic energy entirely solid state designs and that does not require any mirrors or optics. So, like if you see that most of the cases when you try to produce the we needs the mirror to produce the laser beam, but that is not the case in case of fiber laser.

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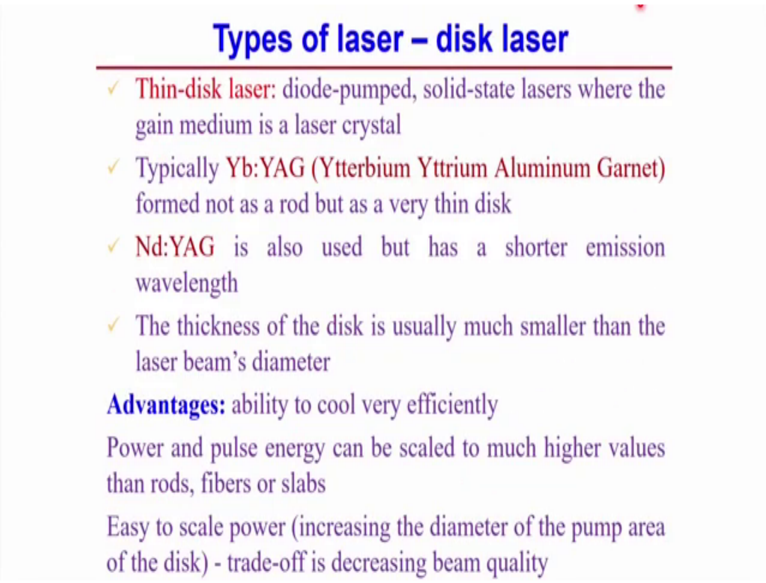

Another type of disk commonly used that is called disk laser. So, thin disk laser actually the pumping we use the diode pump and it is also a solid state laser where the gain medium is a laser crystal. So, in the lasing medium we can use a laser crystal here. So, typically Yb:YAG; that means, ytterbium yttrium aluminium garnet formed here in type form not in the form of a rod rather than that solid that shape is like a thin disk. So, that is why it is called the disk laser. So, of course, Nd;YAG la laser it can be the amplifying medium can also be the disk, but in this case a shorter emission wavelength is generally produce in Nd;YAG laser. So, the shape of this lasing medium; that means, solid state medium is the in the form of the disk that is why it is called as the disk laser and this thickness of the disk usually much smaller with respect to the focused with respect to the laser beams diameter.

So, disk laser is having the considerable advantage in the sense that it is a ability to cool very effectively and power and pulse energy can be controlled or can be scaled up as a very higher values than Rod laser or may be in general we can say the Nd;YAG laser or with respect to the fiber lasers or the with respect to the geometric shape of the solid state medium like slabs. So, this is the typical advantage of the disk laser and of course, easy to scale power increasing the that by simply increasing the diameter of the pump area of the disk and, but in this case the its tradeoff is required to there may be the if you try to scale up of the power there is a decrement of the beam quality.

So, that kind of tradeoff is required either increasing the pump area and decreasing the beam quality. So, apart from the disk laser other type of laser is the diode laser.

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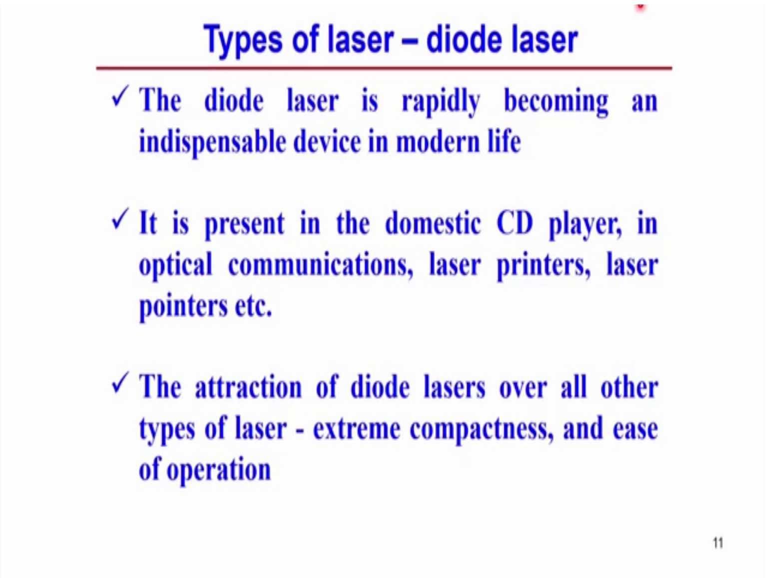

Most commonly used the diode laser if we see, but now a days it can be used readily if we see the several domestic CD player optical communication laser printers laser pointers we can see the application of the diode laser.

So, one advantage is the diode laser it is it can be formed and it is a very compact form, but if commonly, we use the diode diode laser in the CD player optical communication laser printer the intensity of the laser is less, but at the same time, it is possible to use the diode laser, even for metal cutting processes as well as welding processes that is the that is called the high power diode laser.

So, the main advantage or attractive nature of the diode laser as compared to the other laser is that it can be produced the extremely compact form and it is a say to carry and use of operation we can easily apply any local phenomena local manufacturing Loc manufacturing or modification of any locally in that case probably diode laser is a good solution now we look into one typical laser that is called Nd;YAG laser most commonly.

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Nd (Neodymium):YAG (Yttrium Aluminium Garnet) LASER

Type	:	Doped Insulator Laser
Active Medium	:	Yttrium Aluminium Garnet
Active Centre	:	Neodymium
Pumping Method	:	Optical Pumping
Pumping Source	:	Xenon Flash Pump
Optical Resonator	:	Ends of rods silver coated Two mirrors partially and totally reflecting
Power Output	:	20 kW
Nature of Output	:	Pulsed
Wavelength Emitted	:	1.064 μm

We use the laser the several applications now if we try to characterize this type of laser will we can see that type of the laser doped insulator laser; that means, the neodymium is the dopant here and active medium is the medium is the yttrium aluminium garnet that is the also of course, this is the solid state laser then active center neodymium pumping method we use the initial laser light that by using the optical pumping and pumping sources and the flash pump that is called xeon; xenon flash pump generally used for the as a pumping source the optical resonator the ends of the silver coated the rods are silver silver coated and two mirrors partially and totally put the two mirrors partially. So, that as a reflector and finally, the beam is produced beam is directed to a specific direction.

So, typically this Nd;YAG laser having the laser power of output power of around twenty kilo watt maximum and the nature of the output can be produced is a pulse laser. So, pulse laser means not that the variation of the pulse energy with respect to the time and then the final wavelength for this Nd;YAG laser is 1.064 micro meter. So, this all type of critical in information for the Nd;YAG laser which is most commonly used in not only welding this laser can be used for other manufacturing processes processes also, but if you see the laser sources in welding process another mostly used lasers that is ut laser, but apart from that.

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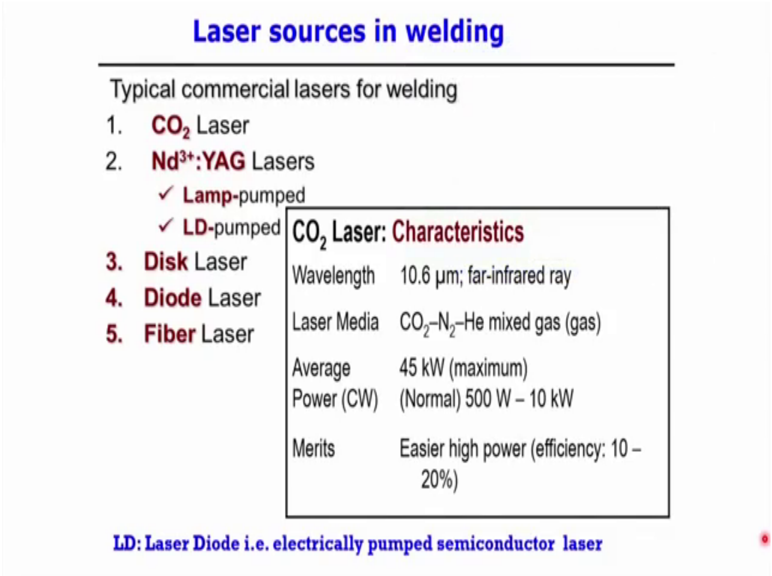

Most commercial lasers that for used for welding welding purposes we can categorize into that first one the CO 2 laser Nd;YAG laser, but Nd;YAG laser either can be lamp pumped or laser diode pump. So, laser diode pump means electrically pumped semiconductor devices so, then disk laser and diode laser and finally, the fiber laser.

So, all this five different types of the lasers is normally used for the welding purposes if you see the typical characteristics of the CO 2 laser that here if you see that wavelength is around 10 point 6 micro meter, but it is in that laser spectrum in that range of the far infrared ray that is the wavelength of this CO 2 laser a las laser media CO 2 N 2 helium mixed gas and average power may can produce the 45 kilo Newton kilo watt maximum power it can produce, but power continuous wave normal power around 500 watt to 10 kilo watt and merits means is the easier higher power.

So, in carbon dioxide laser it is relatively easy to gain the much much power when there is a much power in deduct probably we can use the carbon dioxide laser, but efficiency is very low in this case efficiency is around 10 to 25 percent. So, if you see the overall idea of all this type of laser and then when when it may be applicable in the design welding purposes first one is the carbon dioxide laser of course, carbon dioxide laser when there is a high power requirement is there probably we can use the carbon dioxide laser and since the carbon dioxide laser wave wavelength is 10 times more than the Nd;YAG laser.

So, focused beam diameter and absurdity of this is different from other type of laser in that case Nd;YAG laser is can be useful when more when there is more precision is required in the welding in the welding process or may be very thin sheet it is possible to use the Nd;YAG laser in general because Nd;YAG laser the wavelength is in this case is 10 times less than the carbon dioxide laser and also it is possible to focus Nd;YAG laser in the very small zone there is a small zone compared to the CO 2 laser, but in that respect the disk laser diode laser fiber lasers also having certain advantage.

But now a days if it is possible to high depth of penetration is required if the very narrow heat effected zone then fiber laser is a good solution for that disk laser and diode laser is used some other purposes. So, if you see overall that by knowing the fact about the laser and the different type of laser and the principle of operation of the laser and applicability of this laser in case of the welding we can find out different advantages and disadvantage of the laser when it is applied to the welding process.

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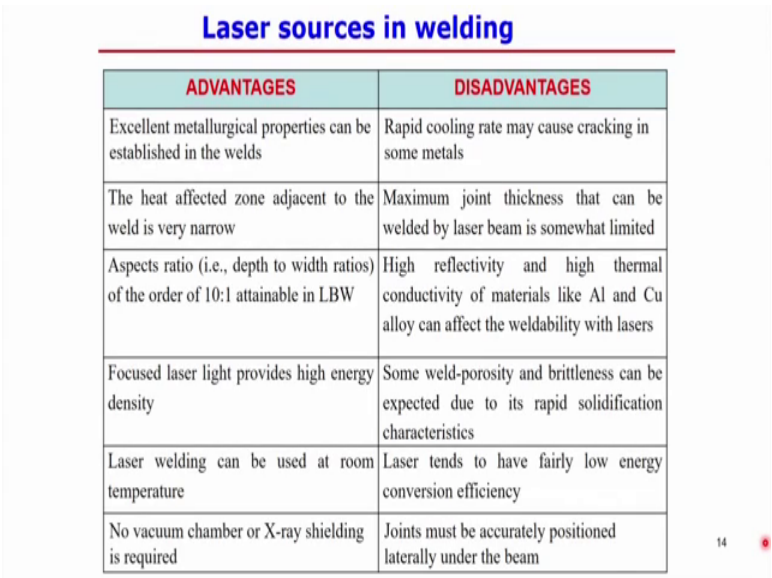

Laser sources in welding

ADVANTAGES	DISADVANTAGES
Excellent metallurgical properties can be established in the welds	Rapid cooling rate may cause cracking in some metals
The heat affected zone adjacent to the weld is very narrow	Maximum joint thickness that can be welded by laser beam is somewhat limited
Aspects ratio (i.e., depth to width ratios) of the order of 10:1 attainable in LBW	High reflectivity and high thermal conductivity of materials like Al and Cu alloy can affect the weldability with lasers
Focused laser light provides high energy density	Some weld-porosity and brittleness can be expected due to its rapid solidification characteristics
Laser welding can be used at room temperature	Laser tends to have fairly low energy conversion efficiency
No vacuum chamber or X-ray shielding is required	Joints must be accurately positioned laterally under the beam

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So, if you see the several points first point is that very good metallurgical properties can be achieved in the weld using the laser welding processes, but this is the very good in the sense that is a relative to as compared to the other typically the electric arc welding processes the heat effected zone is very narrow probably in this case the in laser welding process the heat effected zone is very small as compared to the other arc welding processes aspect ratio; that means, depth to width ratio the weld depth depth of penetration and the width, width of the weld zone that ratio probably it is possible to produce in case of laser welding process it is relatively higher as compared to the other welding processes. So, it can be achieved that as a 10 is to one using the typical for example, if we use the fiber laser probably we can use we can achieve this kind of depth to width ratio another point is that concentration of the laser light in this small zone is very high in this case so; that means, it can produce the high energy density over a small zone. So, that is another advantageous if you want to reduce the heat effected zone by the laser then by any other of the welding processes probably laser is a one of the goods choice or I think laser is the best choice in this case as compared to the other welding processes.

So, and what is another the laser welding can be used even at the room temperature; that means, that may not be necessary to produce mainly the pre heating of the sample to produce the welding next is the no vacuum chamber is required in laser welding processes and it does not produce any X-ray; that means, during the operating of the this laser welding process there is no X-ray shielding is required.

But this two points vacuum chamber and X-ray that is advantageous as compared to the electron beam welding process, but apart from the several advantages of the laser welding processes having some also demerits of all this process these process first thing is that in sense laser is focused in a very small area and most of the cases we use the laser source and at a very high speed when the laser power density is very high or energy density is very high it can be used for welding purposes at very high speed, but to do that there is a negative point here is that rapid cooling normally, we found out in case of laser welding processes that may cause the cracking or may be other metallurgical in incompatibility during the welding process.

So, maximum joint thickness another advantage maximum joint thickness that can be welded by the laser source is somehow limited. So, that actually depend on the that power density of a laser and the focused beam diameter accordingly we can decide the whether we need any conduction mode laser welding process or key hole formation is required in this case, but this disadvantage is, but of course, the depth high depth of penetration can be produced by laser welding processes as compared to the it is advantageous as compared to the other arc welding processes, but if we use the electron beam welding process.

So, we can produce the more height depth of penetration as compared to the laser welding process. So, in that sense the depth of penetration limited in laser welding processes as compared to the only electron beam welding process, but not as compared to the other arc welding processes third point is that high reflectivity and high thermal conductivity of the material of course, like aluminium and copper alloy is very much difficult or to do the welding processes using as a laser of course, in general this welding of the high I can say that difficult weld material like high conductivity and reflectivity material is really difficult using the any not only the laser welding processes in other welding processes also as well.

But still there is a scope of doing the good weld in case of laser welding process when you try to use the pulse welding processes and then when you use the control the shape of the pulse in that case that high reflectivity or difficult to weld material is possible to do weld using the laser welding process we will discuss the effect of the pals shaping for the difficult weld materials later on some weld porosity brittleness can be achieved and it is a the rapid solidification that is the another disadvantage of laser welding process.

But ma main disadvantage of the laser welding process is the normally CO 2 laser or Nd;YAG laser the process eff energy efficiency or energy conversion efficiency is relatively very low may be you can say that around thirty percent or less than thirty percent in this case.

So, apart from the several advantages and disadvantages there is a development of the laser welding processes in the typically the keep in mind in the application of the different type of the materials, but before looking into that we can we can little bit discuss or recap the laser beam optics. So, so that get the idea that how it can be used or how this laser can be used for the welding purpose.

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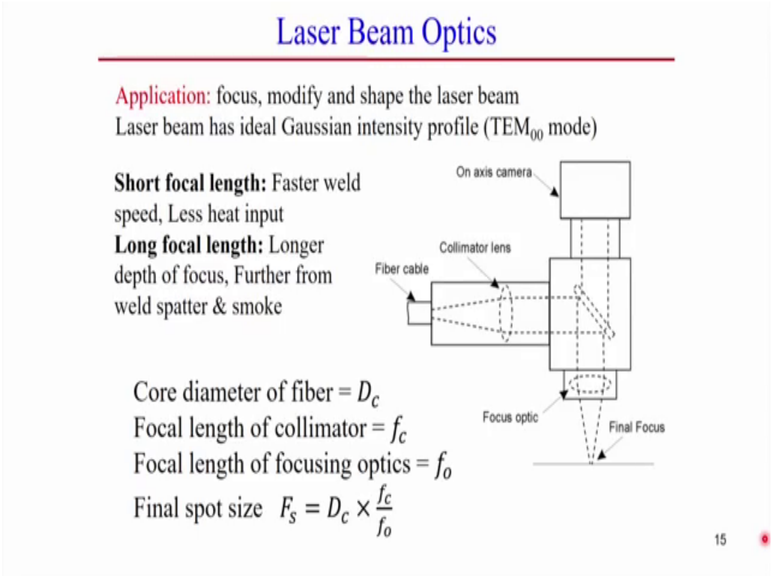

So, first thing is that application of the laser beam is basically focusing modifying and of the laser beam say and, but shape of the beam is laser typically follow the Gaussian distribution and that ideal Gaussian distribution profile can be represented as that is called TEM 0 0 mode so; that means, laser can be represented in different mode. So, ideally represent is that TEM 0 0 mode. So, Gaussian intensity profile means that intensity intensity of the laser energy distribute in such way that when it is focused on the substrate material at the center point the intensity is maximum and that gradually it is decreasing towards a boundary of the focused area.

So, that is called typically represented by the Gaussian distribution now if we see from the figure that there is a collimator lens and the final focus lens is given within the laser. So, laser comes from the fiber cable and the collimator lens is given that is that laser when it comes out and then laser ray becomes parallel reflecting and then optics another lens is there second lens and second lens is second lens is merely used to focus the laser beam on a specified position this is the final focus.

Now, in this case this is the typical laser optics we generally use in the eh laser beam welding process, but if we in general if we see the short focal length; that means, if focal length is the very short when you focusing on the work piece and then laser can be used the faster weld speed; that means, because when do the laser is focused in a very small zone the laser intensity increases.

So, to balance the amount of the energy this laser can be used in the very high speed and other thing is that if laser is focused in settings then short focal length actually can be used the less heat input in the form of a less heat input, but long focal length; that means, the longer depth of focus and that is also actually in other long focal length of course, it decreases the intensity, but if the dis advantage is that it can be safer side when there is a formation of the weld scatter and the smoke; that means, the source is long distance that eh it may not be subjected it may not be get rid of the it may be get rid of the weld scatter and the smoke from the work piece material.

Now, with these laser optics probably we can find out suppose there is a core diameter this is the fiber cable the core diameter is Dc here and the focal length for this lens is fc small fc and the focal length of the focusing optics focusing optics is f 0. So, the final spot size Fs can be estimated as the ratio of the two focus focal length of the fc by f 0 multiplied by the core diameter of the fiber so; that means, that by changing this focal length probably it is possible to estimate the focusing that final spot size of the laser when it is focusing on a specific work piece of the substrate material.

So, this simple calculation shows that that the final spot size can vary depending upon the core diameter and these two focal length of the lens.

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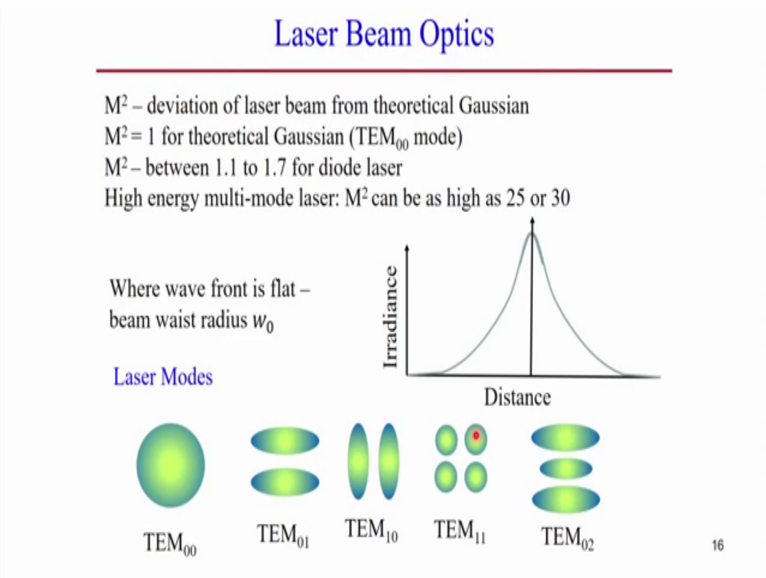

If you see the other critical term which is the laser beam optics that is the m square m square is the represents one parameter that deviation of the laser beam from the theoretical Gaussian. So, theoretical Gaussian module we represent the laser beam in density that is called the TEM 0 0 mode, but the measure of the m square actually decides that how it is deviated from the ideal TEM 0 0 mode. So, m square equal to one that is the that it represents the theoretical Gaussian TEM 0 0 mode, this is the very ideal case and, but m square can vary between 1.1 to 1.7 specifically for the diode laser and for high energy multi mode laser m square can be as high as possible may be 25 or 30. So, m square is the parameter that actually decides how the laser beam is deviated from the Gaussian mode; that means, TEM 0 0 mode.

So, if from the figure if you see the laser radiance and the distance; so, at the center the laser intensity is maximum and gradually the intensity actually decreases with respect to the center now several laser modes can be observed or maybe you can say several modes can be created for the different application if you see the modes that TEM 0 0 mode and the colour contrast TEM 0 0 mode, it indicates that at the center the laser intensity is very high maximum and then towards the outward periphery the intensity is gradually decreasing.

So, so several; so, other modes can be created in several way that TEM 0 1, it is a multimode and TEM 1 0 also the same and the modes are different shape shape are different here and the different other mode TEM 1 1, there are multi mode and TEM 0 2. So, this type of modes can be created depending upon the different application of the laser now if you look into further laser beam optics that the; this is the laser source.

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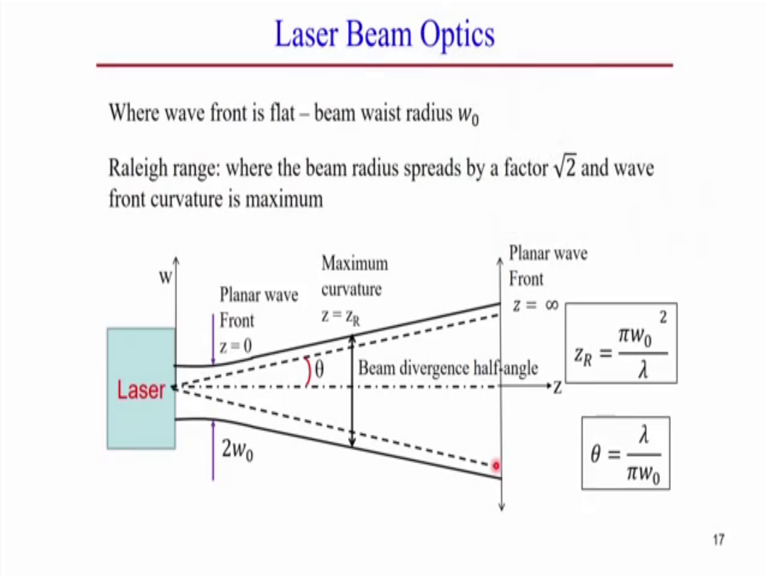

And it is the diverging, but laser source is at actually not is a point source its a sub diameter that planar wave front can be created at a at a specific diameter size that is two w omega w 0 and that is the that is called the where the beam wave front is flat that is called that beam waist radius equal to w 0.

So, here it is w 0 and the Raleigh range means where the beam radius spreads by a factor of root two and wave front curvature is the maximum. So, it is a wave front in this this zone wave front is almost flat, but here the weave front curvature is almost here wave front curvature is the maximum. So, that is called the from Z equal to 0 2 Z equal to Z R that is called Raleigh range. So, waist diameter that is the where wave front are flat then beam waist radius is basically omega 0 or diameter equal to 2 into w 0.

So, similarly here it is the beam waist diameter that is the two w 0 and here we can see the from 0 to Z R that represents the Raleigh range in this case, but here planar wave front Z equal to infinity and theta equal to beam divergent half angle. So, these are the typical typical optics or optical parameter we generally consider for the two analysis of the laser beam. So, here is having the sub relation with the wave length of the laser Z R equal to pi omega w 0 w 0 square by lambda and theta equal to lambda by pi w 0. So, these are the relation between the half half divergence beam and what is the railway range, in this case or railway length in this case, in terms of the wavelength of the laser and the waist beam diameter of the laser.

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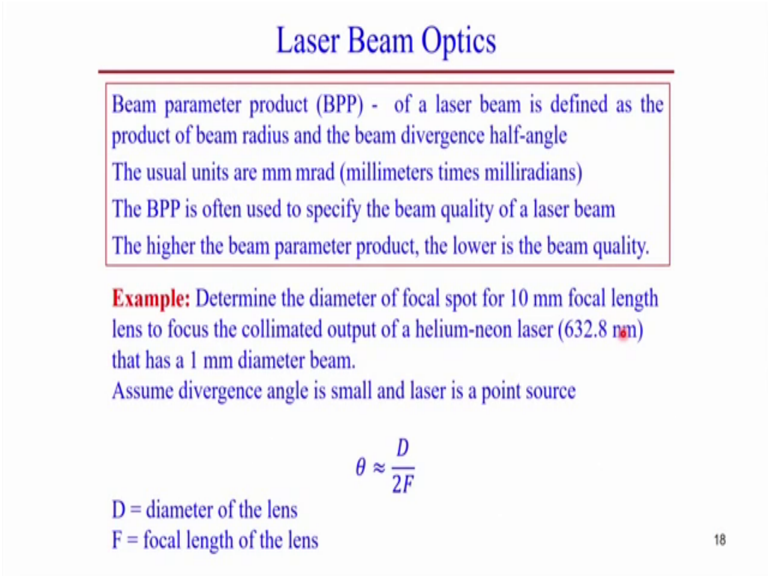

Now, there is a another parameter that actually represent the laser beam quality that is called the beam parameter product or in general we call the BPP.

So, of a laser beam is defined as the product of the beam radius and the beam divergence half angle. So, the usual unit are millimeter times millimeter times mille radium. So, that is called mm m rad. So, this is the unit for the beam product beam parameter product the BPP is basically used to specify the weld beam quality and in general the higher the value of the BPP then lower is the beam quality.

So, apart from this parameter of laser bream quality let us look into one example for the on the laser beam of optics if we see if we try to look into the example that determine the diameter of the local spot for 10 millimeter focal length lens focus collimated output of a helium neon laser having the wavelength is equal to 632.8 nanometer and that has a one millimeter diameter beam.

So, assume the divergence angle is small and them laser is a point source. So, to solve this parameter we can find out the half beam divergence half angle. So, is it is the focal length that is the focal length and the and the value of the that laser beam D is the diameter of the lens. So, D by theta equal to can be estimated D equal to either diameter of the lens and f equal to focal length of the lens.

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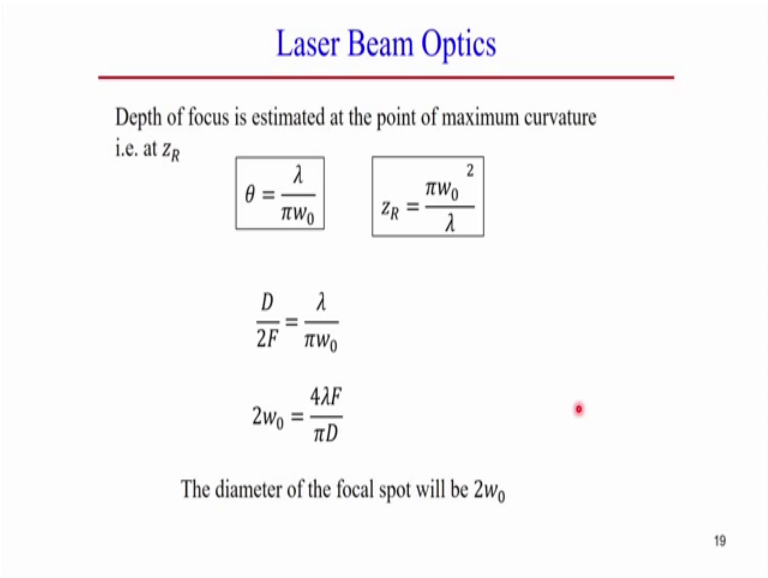

Now, depth of focus is estimated at the point of maximum curvature; that means, at Z equal to Z R. So, in this case theta simply estimated in terms of the laser wavelength lambda by pi into w 0 and from here theta equal to this and plus another equals theta equal to D by two twice f from these two approximation we can find out the relation D by 2 f equal to lambda by pi w 0.

So, from here we can find out the twice w 0 equals to 4 lambda f by pi D. So, all the parameters are given the wavelength and I think f also given and then diameter also given and pi values we know. So, based on that we can find out the diameter of the focal spot should be twice w 0.

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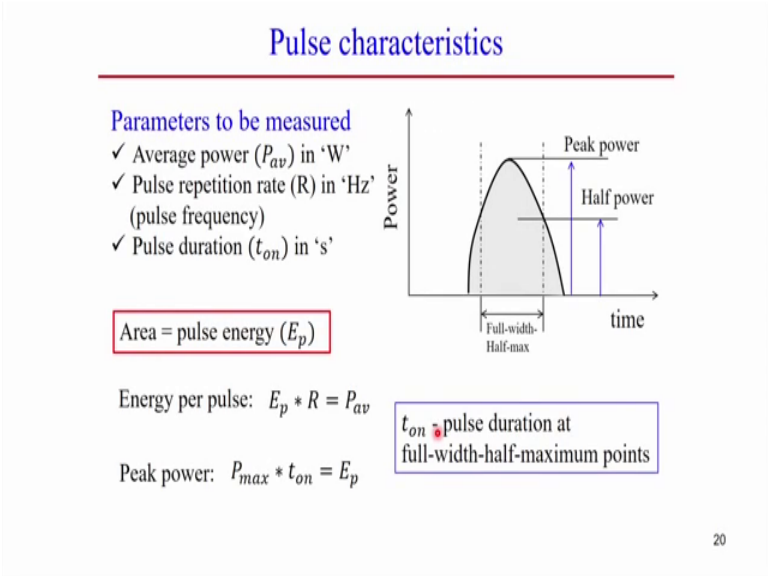

Now, apart from the new optics it is also necessary to know that different pulse characteristics or how we can represent the pulse in case of laser process. So, because there is a huge application of the pulse laser in the welding process; so, pulse characteristics can be represented from the figure if you see there is a single pulse; that means, over a specific in specified length of the time that is pulse on time the total energy of the laser is released, but it is can be repeated over a cycle; that means, cycle time also important to know here and the parameter or we can say that pulse frequency or pulse repetition rate in a in case of laser welding process ah.

So, that parameters in this case if you see the average power pulse repetition rate which is represented in terms of hertz cycles per second or pulse repetition rate and the pulse frequency at the same here and another important parameter of the this is the pulse energy.

So, from the figure if you see that it is not necessary that energy will be released in the that is the shape temperature shape of the pulse. So, that temporal shape of the pulse may not be in kind of rectangular shape, but some we can say that some other kind of maybe consider its a Gaussian kind of shape in this case that it is represents that half width half max full width half max sorry full width half max. So, in this case the half power the center and the peak power. So, in between the half power at the half power point we can find out the; what is the duration of the pulse. So, that total energy can be balanced its represented in terms of if we consider one rectangular pulse. So, in that sense we can find out the full width half max that duration of that time is a basically the pulse duration. So, that pulse duration can be represented t one t on that is the pulse duration at the full width half maximum points that is the pulse duration. So, here we can find out that area of this represe of this temporal pulse is represented is represents basically a pulse energy. So, that is used ep.

So, now energy per pulse can be estimated that multiply by the pulse repetition rate or pulse frequency and that actually indicates the average power. So, average power is basically equivalent to if we assume we say continuous continuous mode of the laser welding process. So, the if you consider the there is a continuously application of the pulse energy over the whole duration that actually represented by the average power, but peak power what is the maximum power for the pulse in this case we can find out the P maximum into laser on time that is equivalent to the pulse energy from that point of view we can find out the what is the maximum power.

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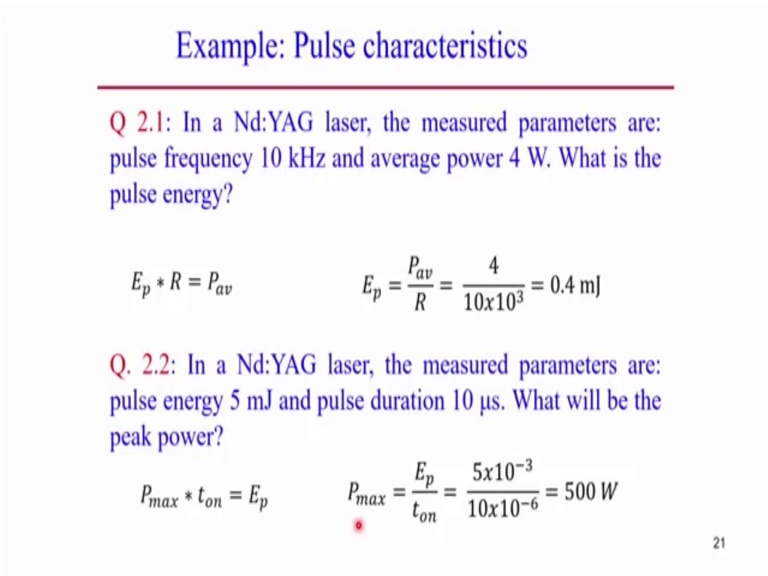

Now, if we will look into two examples that of the pulse characteristics example one that in and Nd;YAG laser the measured parameters are pulse frequency 10 kilo hertz and the average power equal to 4 watt, then what should be the pulse energy. So, in this case simply we use this formula that the energy of a pulse into pulse repetition rate that energy that actually represents the average power.

So, from here we can find out that the pulse energy is equal to average power divided by the pulse frequency or pulse repetition rate that actually coming is out point 4 mille joule in this case now if we see that if the laser measured powers are pulse energy is five mille joule and the pulse duration equal to 10 micro second. So, what will be the peak power. So, in this case we can find out the maximum power into equal to the pulse energy and from here you can come to the maximum power equal to 500 watt.

So, here you can see that if pulse energy is five mille joule in this case it is the maximum power is the 500 watt and if you see the another first example here if you see that actually the average power is 4 watt, but peak power is 500 watt so; that means, if there is a if we assume that if we neglect the effect of the assume that the energy source used as a continuous power of the 4 watt rather we can say energy source can be used at the pulse source where the peak power can be reach up to the 500 watt.

So, there is the huge difference in the average power and the peak power. So, that difference in case of pulse laser peak power and the and the average power difference can impact on the manufacturing process and that will try to see the if we look into the effect of the this pulse shape and the pulse energy specific to the welding processes now if we come to that process parameters for the laser welding process is that in general that is first is the pulse energy.

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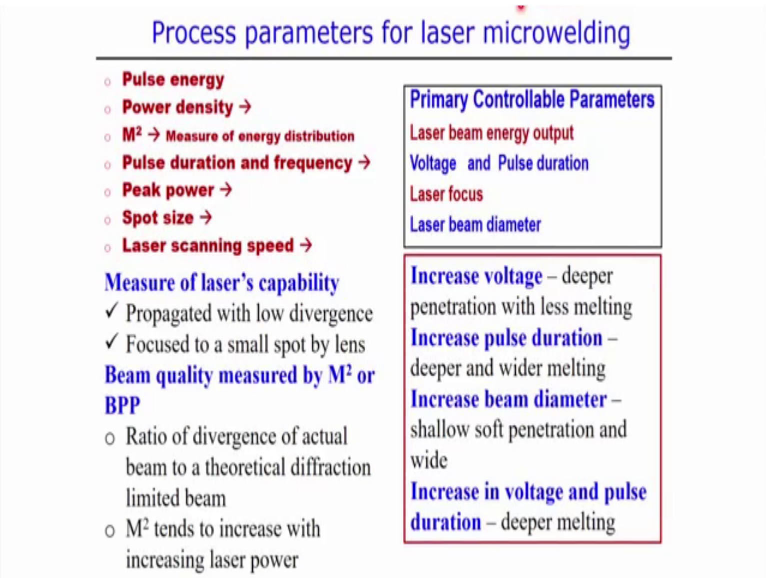

Then power density and then we estimate the m square that is actually defines the measure of the energy distribution. So, what way the energy distribution at the different mode of the laser then pulse duration and the frequency peak power what is the peak power of this laser and a spot size and laser scanning speed; that means, applicable of the when we apply the laser in what velocity the laser has been moved. So, all these are the typical parameters for the in case of any pulse laser welding processes need to define and that all these parameters actually decides the applicability of the of this laser and the to different manufacturing processes and of course, the different size of the work piece now primary controllable parameters main control parameters in case of laser welding is that laser beam energy output.

So, specifically pulse laser welding process the main parameter is the pulse energy output and the duration of the pulse over which this energy has been applied to the substrate material and that is required to define the pulse pulse laser source and second is that laser focus; that means, where the laser has been focused on the surface or the below the certain depth from the top surface accordingly the laser beam radius can be estimated and that actually radius decides the heat effected zone or effected zone or molten zone will be created by application of the laser.

So, that are the two primary controllable parameters in case of pulse welding processes and other parameters increasing voltage; that means, deeper penetration with less melting that is also if the; there is a in there is a deeper penetration with less melting is required they need to increase the voltage of the applied laser then if dip and y dag melting is required then probably duration of the pulse is you can increase the duration of the pulse and if we use the shallow and soft penetration and wide beam is wide shape of the weld zone is required probably.

We can increase the beam diameter beam then; that means, by increasing the beam diameter with the heat effected zone or molted zone can be increased considerably, but with the compensation of the decreasing the depth of penetration, but both increasing the voltage as well as the pulse duration in that case very deep melting or is you got may be in that case the weld pool volume is requirement is very high then we need to operate both the increase increment of the both voltage as well as the pulse duration now apart all these from all these parameters process parameters are need to define in any case of manufacturing process not only in the welding processes, but major lasers beam capability actually depends on the how it is propagated with the as low as low divergence angle and specifically focusing in the very small zone by the lens these are the two parameters that actually indicates that the laser beam quality of course, laser beam quality measured by the m square or either m square value or the BPP value.

So, that ratio of the divergence to the actual beam to the theoretical deflection limited beam that is the measure of the m square and the m square tend to increase with the increasing the laser power. So, basically m square decide the that different mode and the BPP the quality; that means, its BPP measure in terms of the laser divergence angle. So, all this parameters are very much sensitive in any case of manufacturing process when you try to apply the laser as a source.

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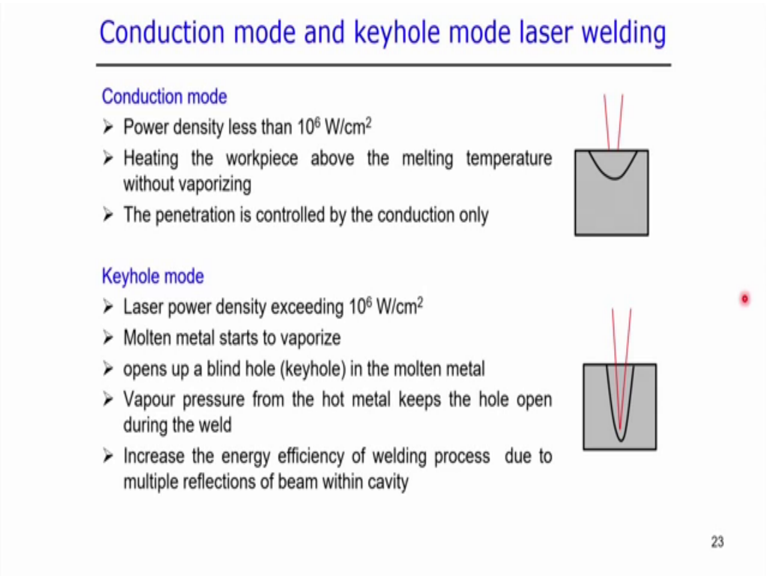

Now, will come to that point mostly used that conduction mode and the keyhole mode laser welding process this is very important part of the laser welding process first is the if you look into the figure you can find the difference what is the conduction mode and what is the key hole laser welding process. So, that figure this figure indicates that here application of the laser on some substitute material there is a it produces the shallow or wider width and the very small penetration and other cases if you see there is a laser beam actually deeply penetrating the substrate material.

So, first case is the conduction mode because there is no vaporization loss of the material and second case the laser beam inserts and there is a definitely there is a vaporization it reaches the maximum temperature in such a way that it vaporize the substrate material and that is why it interact with the material and it forms the one it forms the this kind of key hole formation. So, these two modes depending upon the application or that mainly variation happens into the as in the source in terms of the laser power density. So, if you find out the conduction mode typical characteristic of the conduction mode laser welding process the power density is basically less than 10 to the power 6 watt per centimeter.

So, this is the threshold value decide whether it is conduction mode of the key hole mode laser welding by simply measuring the power density of the laser. So, power density can be estimated by the laser power divided by the area of the prospection overage it is falling. So, in conduction mode simply heating the work piece above the melting temperature, but without vaporizing the material; so, penetration is controlled by the conduction mode only there is a no formation of the any key hole, but key hole mode if you look into other cases the laser power density always exceeding 10 to the power 6 watt per centimeter square then normally produce the key hole.

So, molten metal actually starts to vaporize and actually forms vapor doman their; that means, by opening up a blind hole that is called the keyhole in the molten material and the vapor pressure from the hot metal keeps the molten open the keeps open the molten pool during the welding processes. So, once the moves array the laser source from that point then again that cavity actually filled by the molten pool and afterwards its solidified and gets the welded joint.

So, increasing the energy efficiency that is a another advantage that in keyhole mode laser welding process is that when the there is a deep penetration of the laser beam inside the work piece material the absorptivity of the material actually becomes in absorptivity of the laser by the metal is actually increases so; that means, in this case the energy conversion efficiency that or may be efficiency of the process welding process due to the multiple reflection within the cavity in general it is increases.

So, this two modes are it is a very important to identify the, which modes of welding process is used and when we apply the laser source in the any welding of the any materials. Now apart from; now we come that we see that difference of the two conduction mode laser welding process.

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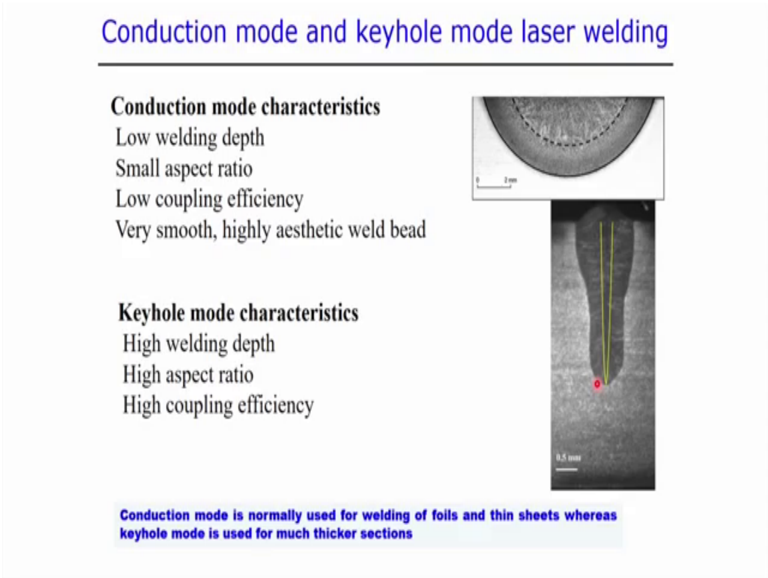

Both the cases that stainless steel has been joined using the laser welding processes.

So, first that if you see the first figure there the dotted line actually indicates the fusion zone and next line indicates the heat effect zone. So, this molten zone it seems the depth that ratio depth of penetration and width is less in this case and second case if you see that there is a high depth of penetration of the weld pool, but with this relativity less in this case. So, first case we can see that from the macro graph itself you can see that it is a its generally conduction mode laser conduction mode laser welding process.

So, what are the typical characteristics is that low welding depth small aspect ratio; that means, penetration and width ratio low coupling efficiency very smooth highly aesthetic and the weld pool can be appeared in case of conduction mode laser welding process these are the typical characteristics of the conduction mode laser welding process now if you look into that next one that key hole mode characteristics in this case that high welding depth you can produce the high welding depth high aspect ratio and the high coupling efficiency.

So, here if you see, but this weld pool has been measured after the after post weld treatment after post weld; that means, after the solidifying the molten zone and then we take the macro graph and we estimate we can visualize the max size of the weld pool during the welding, but it the size of the weld pool does not ensure the size of the key hole key hole probably it was the marked by the yellow color that probably was the size of the keyhole and with that key hole size; that means, we can the key hole size means that was the vapor domain during the welding process and remaining is the is it was the molten zone.

So, there you can see the conduction and the keyhole mode laser welding process there is a wide difference in the weld pool shape and size, but conduction mode is normally used for the very thin shape and foil where the key hole mode can be use the must much high thickness materials is supposed to join in that case.

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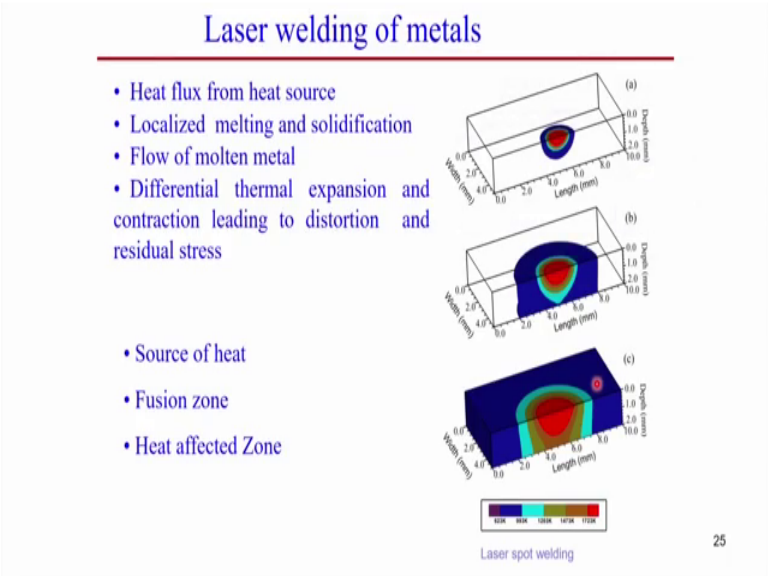

Now, we can see the laser welding of the metals here say what are the typical laser welding metals that heat flux is used from the heat sources, but in this case is the heat flux means in the from the laser source, we can use sources then localized melting of localized melting and solidification occurs of course, localized melting and solidification occurs means when there is a laser is at one point specifically in case of spot welding process then when you switch off the laser source then after that it solidified, but in case of the linear welding process when we use the moving laser source. So, when laser moves at it from the actual focus of on the work piece then after moving as it subsequently the molten material actually solidified.

So, that is point of the joint for a linear welding place that it is subjected to some localized heating and then again solidification of the material, but one point is that of course, when you whether we use the conduction mode key hole mode laser welding processes all the cases there is a the within the small weld pool there is a flow of molten metal may happen it may be either laminar flow or may be the turbulent flow of the material may happen, but most of the cases we find out specifically in laser welding process by its a turbulent flow or it is very difficult to identify a characteristics whether it is a laminar flow or turbulent flow of the material.

So, anyway must there must be some material flow during the welding process so; that means, during the welding process the material is not was not stationary there is a flow it flows on specific direction will discuss later on the flow of material, but finally, happens the after solidification there is a due to the different thermal expansion and contraction that actually finally, produce the some amount of distortion in the welded joint as well as the some amount of the residual stress.

So, this cannot be avoided in any case of the welding processes now if you characterize this the welding processes in general there is a source of the heat; that means, in this case the laser next it creates the fusion zone and as well as the it creates the heat effected zone. So, right hand side figure shows the one typical example of the laser spot welding so that the simulation of the laser spot welding zone.

So, molted the rate colour actually indicates the molten zone. So, initially the initial time was very less. So, it creates a very small weld pool and with the application further time gradually the molten pool size actually increasing the remaining other is the coloured indicates the heat effected zone. So, within the in the simulation process actually the apart from the red colour the other different colour we can produce the contour isotherm and; that means, constant temperature that temperature actually indicates the heat effected zone in case of the laser welding processes.

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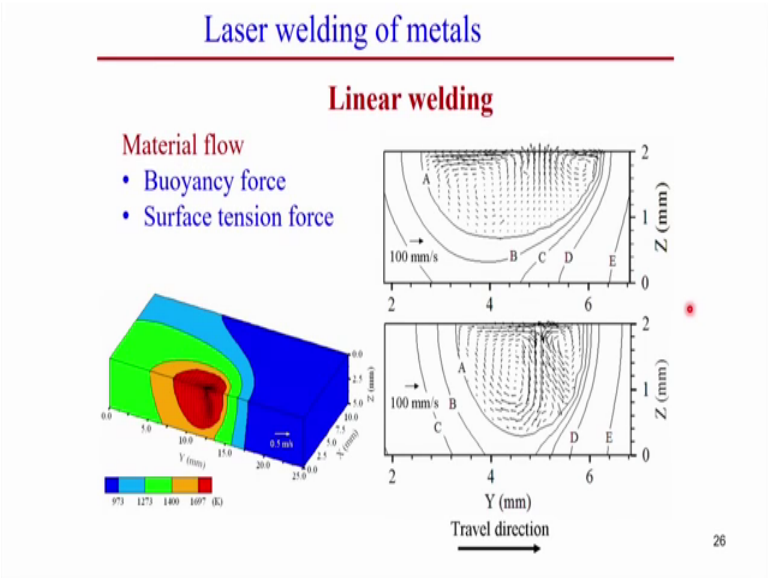

Now, of course, the laser welding process the; it is always subjected to some material flow, but what are the drive driving forces for the material flow in the laser, laser welding processes. So, material flow mainly happens due to the buoyancy force because there is a temperature difference and of course, we takes into account that the density difference through the buoyancy force and another point is that surface tension when the surface of the molten pool is interact with the another medium in between that medium it produce the surface tension force. So, depending upon the material and the next because the molten pool is basically is covered with the shielding gas.

So, that interaction between the molten pool and the shielding gas in that surface there may be the different surface tension force if you create. So, depending upon the composition of the material the surface tension force acting normally from center of the heat source to outward periphery or it may acts the reverse direction from outward periphery to the center it depends on the composition of the material. So, we can do the similar kind of simulation.

So, we can see the colours figure that actually the within this red zone that indicates that molten pool within the molten pool there will be may be some must some heat conduction, but at the same time that there must be some material flow and the arrow actually represents the material flow field within this zone and if you see that there is a non symmetric profile looks like and when the in this case the laser is laser source is moving from one to another direction. So, it creates at a certain instant of time. So, it creates the molten pool certain area, but other part is already solidified during the welding process now further zoom this thing material flow if we see in this case that the material flow creates in such a way that from the center to out that actually driving force the surface tension force is basically acting from center to the outward periphery. So, its it is creates the clockwise material flow field right side and left side we can say the anticlockwise material flow field.

So, in this case the anticlockwise and right hand side clockwise see the depth direction also we can see that see other cases. So, this is the first cases. So, in the second cases if we see the material flow the right the right hand side if the flow field is basically acting in the anti clockwise direction and left hand side it is the clockwise direction. So, with the difference between these two cases the second cases the material flow actually helps to produce the high depth of penetration, but in the first case the weld width is very higher depth of penetration is low as compared to the second case.

So, here the difference is only the nature of the surface tension force and that actually drives the nature of the material flow and finally, the nature of the material flow actually decides the size and shape of the weld pool. So, second cases there is a certain percentage of the or that surface active elements presence of the surface active elements actually revert the surface tension forces and that actually in effect heat actually increases the weld penetration and decreasing the weld width.

So, that is why fluid flow or material flow is important to analyze in the certain cases when there is a presence of the surface active elements and that works adversely adverse effect to increase the depth of penetration and one important point is that of course, the material may happen here is the buoyancy force and on the surface tension force, but in case of arc welding process the driving forces for the materials should be included the electromagnetic force that actually influence the material flow field as compared to the laser welding processes. So, apart from the laser welding process of the different materials may be; now we can look into that pulse shaping in the laser welding process.

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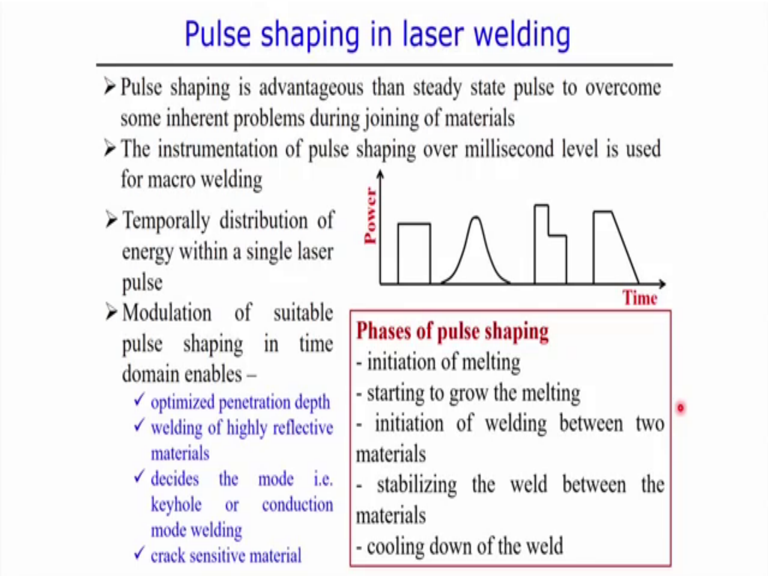

So, pulse shaping is advantageous in the sense that steady state pulse to overcome the some inherent problem during the joining of the material the shaping pulse shaping of the millisecond pulse basically is estimated based on the practical application of this; that means, simply pulse shaping.

So, we understand that temporally distribution of the energy within the single laser pulse, but modulation of the suitable pulse basically if you create the different shape of the pulse from laser source that actually helps to weld of the or to app applicability of the laser for the different purposes fasting then the is the modulation of the pulse can be done with m to that by to optimize the penetration depth welding of the very high reflective materials decides the mode of the welding arc; that means, whether it is keyhole or conduction and the it is effective for the cracks sensitive materials. So, right hand side figure if you see the laser power and this is the time.

So, here you can see the; this is the different temporal shape of the pulse. So, each or having shape of the pulse actually influence to the different welding processes; that means, different welding processes for the different type of materials when there is a some difficulty. So, difficulty in the sense that very difficult to weld material simply shaping of the pulse actually help to get away the good availability of that material, but before do that need to know that what are the different phases of the pulse shaping that shape of the pulse how it helps basically first is the initiation of the melting shape of the pulse it is a very high energy for the reflectivity material.

So, initiation of the pulse actually initiation of the melting for the shape of the pulse then starting to grow the melting that can be controlled by the shape of the pulse stabilizing the weld between the materials and finally, cooling down of the weld. So, all this basically the phenomena can be controlled by the different shape of the pulse let us see what are the role what are the different shape of the pulse how it influence to the different welding processes.

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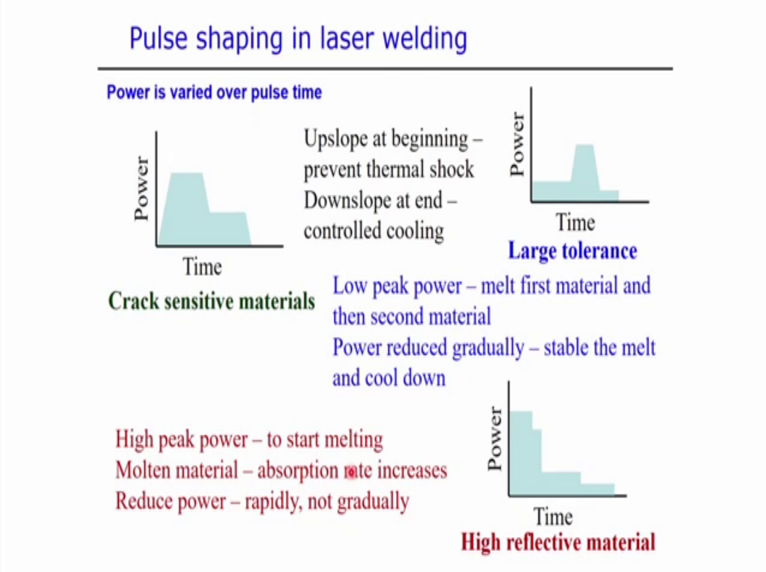

So, in case of pulse shaping laser welding that first if you see the power is varied over the pulse time that is true now first figure the cracks sensitive materials and we have we can design the shape of the pulse like this design the shape of the pulse like this, but how it helps the initially upslope sat the beginning that actually prevent the thermal shock should not actually application of the energy instantaneously laser the gradually or making some slope means that not we are applying the laser ener pulse energy instantaneously.

So, that slope actually prevent the certain thermal shock at the same time down slope at the end that actually control the cooling if there is a slope application of the laser pulse that actually controls the cooling. So, this typical shape of the pulse is helpful for the cracks sensitive material, if we see the large tolerance the gap between the to joint materials if the there is a existence of the large tolerance in that case initially low peak power is followed there from the shape of the pulse that actually helps to melt first material and then the second material and then increment of the pulse increment of the amount of the pulse energy over a certain period and finally, very low amount of the pulse energy. So, that actually reduce the stable the melt pool and the basically cool down of the molten material.

So, this typical shape of the pulse actually is useful for the large toler when there is exist some large tolerance between the two work pieces next is the high peak power that actually to start melting initially the this pulse shape is basically for the high reflective material. So, here the initial the high reflective material we follow without any slope the instantaneously there is a increment of the amount of pulse energy that actually helps to start the melting specifically for the due to the high peak temperature although they are high reflective material.

So, we amount more amount of energy that helps to melt the at the starting then we reduce the power gradually step by step. So, then molten material absorption rate actually increases and then finally, we reduce the power very small, but we reduce the power is rapidly not gradually. So, this specific type of the shape of the pulse is very useful in case of the high reflective material.

So, we can see that al although there is a difficulty of the difficult to weld materials by other welding processes as well as laser welding processes, but laser welding processes advantageous in the sense that it is possible to control different shape of the pulse and we can improve the weld material of the different type of materials like the crack sensitive materials for high reflective materials or sometimes the high conductive materials.

So, in this case, it is necessary to design the specific shape of the pulse thank you for your kind attention. So, next we will start with the laser assisted the hybrid welding processes.