Microsystem Fabrication With Advance Manufacturing Techniques
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Lecture – 27

Hello, and welcome back to this lecture 27 of microsystems fabrication by advanced manufacturing processes, quick recap of the last days lecture. We were talking exclusively about e b m processes e b m machining, and as you have already discussed details before it is about beam of electrons which are accelerated at a very high kilo electron volts of kilo, I mean thousands of electrone volts of potential, and which results in stream of electrons at a very high velocity interfering with the work piece, and there is a conversion of energy from the striking electrons to feonanic vibration on the surface of the could results in local temparature increse there by sublimating the material as usual.

There is a beam transferent layer while interfearing with a sample surface the beam does not see the layer for some small delta value before it goes in to the dept, and his a certain region at the bottom of this layer, and in in that region it creates a small waper pocket which can come out, and this is responsible for all the machining a operation we excusively discussed about can be rastered, and the surface, and how it is a high resolution process of writing, because of the fewly small wave length wave length, and limited difraction which should happen to the beam, and then we talked about certain modalities about the machining parameters, and have the process can modeling in terms of the requirements of power, and other the parameters of being like a diameter the velocity of raster of the beam the work piece material properties like thermal conductivity so on so forth.

We found out that the actual velocity of the rastering is mauch faster in comparision to the the velocities that is beining taken over i mean taken over is being offered if you just use a simplistic model of power eqaul to c q, where c is the coefficient of vn determined experimentally from material removal rates in the power of the beam today we will be slightly changing here, and going diffirent process of laser beam machining system here the system of machiningis driwen by intensity laser which is focused on to a surface creating some obsorption of material of the surfaceand this objaption agian govern by b s low, and ther is convertion form photon to pholan in this particular case there is a photon to phononic vibration ah convation, and that phisycs of this process phononic viberation is tempature incring, and local tempature incring is, and ther is the big issue of reflact hence in the laser machiningin pross, because extremely reflective surfaces smooth surfaces are have a lot a power loss factors induced by the reflectivity which results in effectively utilizing very small percentage of the laser been. So, in order to investigte ah the the leser beeing order in machiningprocess one needs to the realy looking to fundametals, and the basics of laser laser.

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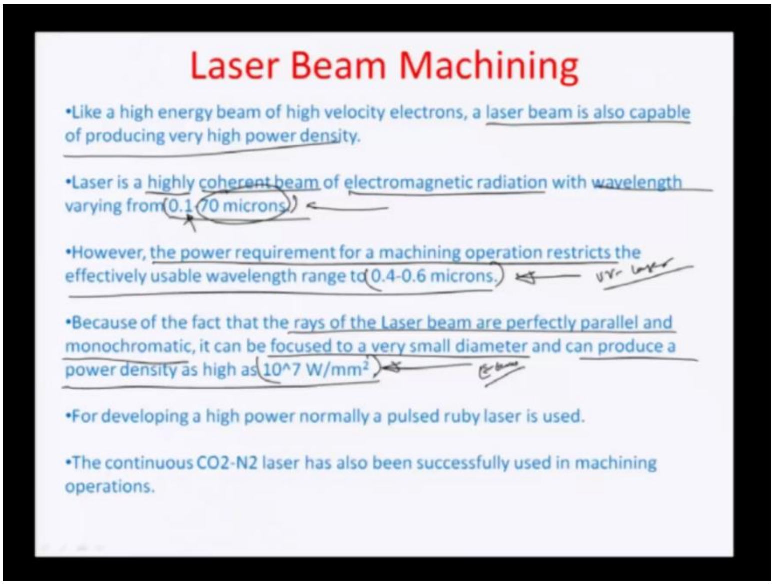

We all the know is light amplification by stimilated ambition of deviation, and let us look at the some at the property of what laser beam is capable of, just like a high energy beam of high velocity electronas a be laser beam is also capable of producing very high power density local density very high surface it is highly coherent beam as most of no leser to me as electro maganetic radiation, and it has wavelength varies about 1.1 to 70 microns. So, this is realy the range of how much wavelength can be achived as high as 70 microns wave length can also being achieved by a lasing source, and as low as about 0.1 micron about hundred nano meters wave length can also be achieved.

So, the lasers happen in almost all parts of the spectrum including the u v laser to the visible laser to even the infored region, and because of this unit property laser beam machining can be can be used for a variety of application of this photon to phonanic process which really results in machining a range of materials, one instance you can machine human bones for example, using laser in other instance you can just machine tissues, and other examples machine can be hard metals or some time plastics and...

So, different wavelength different energy of the laser beam can a suitaibility tailor ed by creating a plusation affect of a being could actually give you a lot of different surface finishes, and there is wast materials to the wast range of finishes that you can cover using laser beam machining, and the power requirement for a laser beam machining operation restricts the effective usable wavelength 0.4 to 0.6 microns all though these days a recordability of u v laser which actually operate less than four hundred nano meters region of wave length as well, and because of the fact that rays of laser beam are perfectly parallel, and monochromatic in nature can be focused to a very very small diameter, and can produce a power density as high as about ten to the power of seven watts per milimeters square. You can compare the this with the e beam process discuss before, and see the littles actually quit comparable to the power densities that are achieved by the electron beam. So, for developing a high power laser normally u v laser is used is there there is also also a energy laser u v laser which is very often used, and then there are continous c o two carbon die oxideneitrozen laser lasers which have been very sucess fully used for all kind of machining operations.

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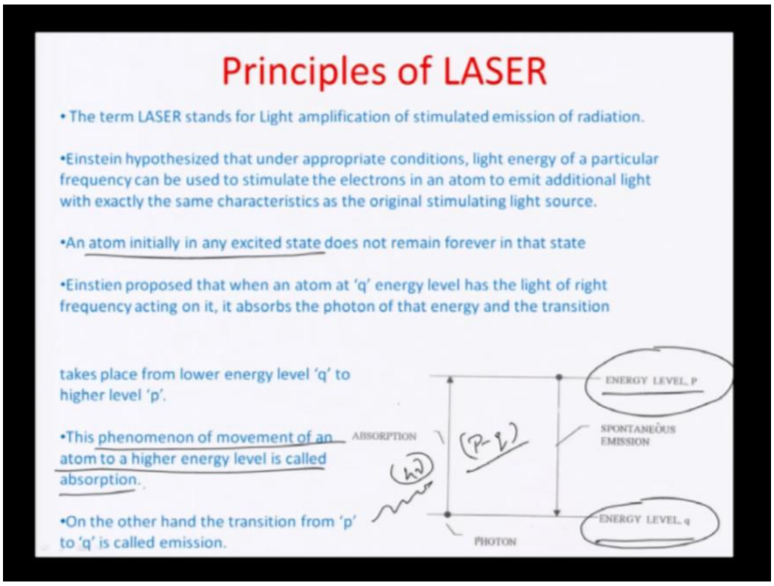

Let us talk little about the principle of laser machine laser or as already defined laser to be light amplification by stimulated emmision of rediation ash the really what is important phinominally important this laser ambition is this the stimulated part of the ammisition. And we have to understand the physics little bit, and what this stimulated emmisions are, and basically it comes from einstien‘s quantum theory which talks about there under apropriate conditions light energy of a particular frequency can be used to stimulate the electrons within an atom to emit additional light with exactly the same characteristics as the original stimulating light source. So, so lets say states herethat an atom is initiaaly than excited states, and we know that at all typically states a very short lasting in nature they are not really very long lasting states may be a couple of from to second over which the transaction happens the electron changes its orbital, and the there is some kind of h new or rediation with emmited, because of that...

So, let us suppose in this particular case you have two different enegy levels of an atom energy level q, and energy level p there is spontaneous emission of electron, because of the absorption of the photon from energy level q to a higher energy p where the total amount of h new or the energy or the energy with which is added here to the electron is actually only the difference of the two energy of p, and q and. So, there is a phenomena of movement as all of us know to atom to a higher energy level know this principle is actually the absorption of life. So, phisically the physics behalf absorption is nothing, but that there is a incident radiation on to an atom, and there is a change in the electronic state from a lower level to a higher level as absorving the energy, and after small amount of time breif amount of time the electron decides to come back emit the same amount of energy back, and this is called the emission.

So the absorption pats of the light energy comes into makes this transaction happen from a lower lwvel to higher level emission part to when the electron decides to electron s return back to the ground states or another lower level, and emmites a energy which is equal to the two states to the electron. So, what is important is process following that step for once this emission as happened they would be another process can stimulation which would happen at joint, and we going to learned about the stimulation after the electron transists back to its ground ststes on the emission is made of the particular enegy what next what happens which causes stimulation of several different happens with in a leasing media. So, that all of them emate radiation to gether.

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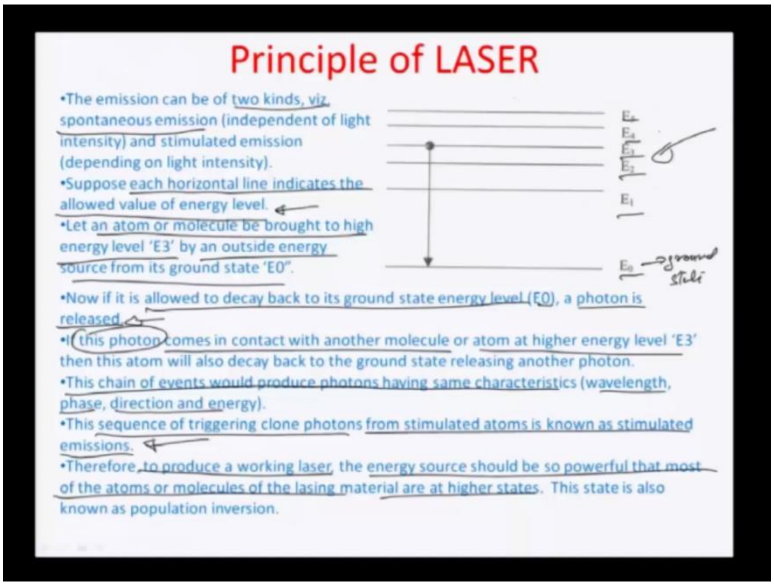

So, lets talk about this here lets a this is a complex model different energy levels of of an atom ground state of on the ground energy level, and these are different higher energy level varying from even to E 5. So, therefore, there are two different kinds of emissions which can happen the emission of invoice the return back of electron higher over level. So, one emission is actually called a aa spontaneous emission it means that its independent of the ah intencity of the light its happens to spontaneously, and the other depending on the light intensing stimulated others. So, there are two different cathegiries one in which depending on the ambiant light ah, and and it is independents. So, its constimulated on the independent life, and it is dependent on the anbient light, and it is independent of the light, it is called contanious supposing each horizontal line here indicates the loud value level of energy level an atom or molecure be brought to high energy level E3 by an outside energy sourc e from its ground stste E0.

So, if it is allowed to decay back to its ground state energy level E0 a photon is released, and this photon now comes into contact with another molecule or atom which is already existing at a higher level E3 this is what this spontanity of stimulated emission is would mean that supposing that already a electron transiting back from a level E3, which creates photon, and this photon, and this photon, and his instead of fully emited by the data goes on strikes another on which is already in the energy level E3, and this phenomina of all the atoms going to the silversion level at higher energy level by the by the absorption of the ambian radiation is also called the the population inversion.

So, all of them are now high energy state there is another atom which this photon which comes uot spaces ah at higher energy level E3 what could happen essentially is that the electron from that E3 a higher excited state atom would as well transit back to the lower level the on additional to the photon which which as already beam. So, therefore, this increases the the amount of photons the amount of light which is emitted, and there are. So, therefore, there exactly at the same face angles same wave length same characteristics everything togother they all emit together, and it creates a situation which is called stimulated emissions of higher energy state of the atom by an already emitted photon from a ah atom which is already transated back to a lower energy state.

So, chain of events would produce photons having same characteristics that is wavelength phase direction, and energy this is that we mean by really coherance, and this sequence of triggering clone photons from stimulated atoms is actually known as stimulated emission therefore, produce a working laser this energy source should be. So, powerful almost of the atoms or molecules of the lasing material are at higher states therefore, all the lasing system essentially would have aah aa an ambient light source which would be responsible for making the population inversion happen go to higher levele three as ndicated here in this particular diagram, and this population inversion is all done by a source which the which typically as a very high power or a high energy, and this is the power of a laser.

So, how many atoms or what is the density of the atoms which would all achieve higher energy state, and inwarded state a population whole population of atoms getting inwarded in what a goal of a lasing medium or or laser source or laser tarches.

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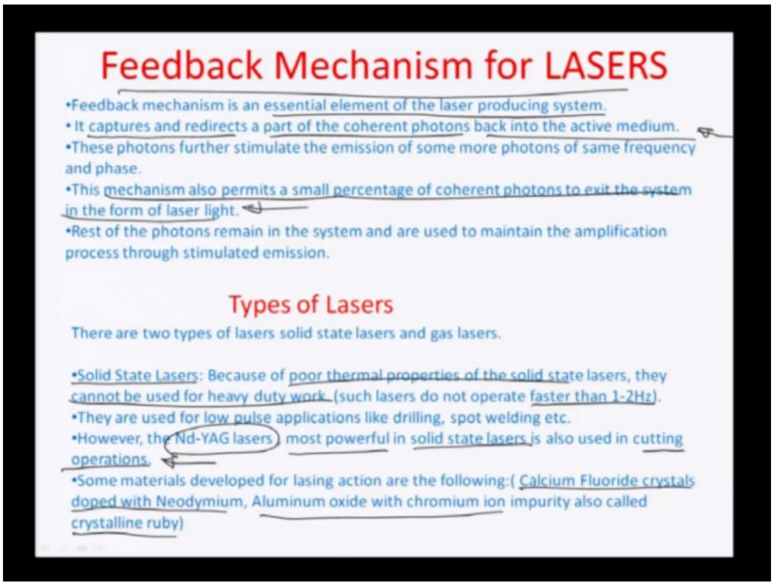

So, there are certain aspects of a laser which are which are very important now once it has been stimulated stimulated ambitions happen, and thre is an amplification, and there is a amplification, and the stimulation amplification, because of stimulated ambition which is happening from the media thats why laser feedback mechanism of lasers are important property of laser to understand. Once we talk about laser machining. So, feedback mechanism is an essentially the element of the laser producing system, and it will not let the minimizes the lasers the laser of the lacing system essentially. So, one of the rows that feedback mechanism has that it captured, and redirects a part of the coherent photons back into the active medium as if these photon emission of there captured put back into the medium would be responsible for a all this stimulation. So, they can stimulate for the higher energy state atoms, and all of them stimulate together the emission as many you can safegetting lost the more energy intensive these stimulated states would be in terms of no of photons.

So, the machanism also percents a permits of small coherent photons to exit the system this is responsible for the laser light. So, we have to develop a. May be syncronus anochronus i am sorry time base d different points of time system where there is a gating of the light of the post to known gating and. So, there are different ah switches associated with a laser light of a output some of them are called switches which pauses very at a very high frequency thus gating the light back n, and lossing some of the photons which have been stimulates emission back, and fourth into the light source, and laser source, and into the medium therefore, there is a retention of those photons into the medium another, and there is a slow ah of the photons laser swhich actually are the laser light. So, most of the photons which are generated by the stimulated emissions are captured, and retained in the sytems. So, that can you have more amplification, more stimulated ambition, and part of it thus deactive machining or deactive processes, and comes out of the laser torch which we can normally see or that can be impacted on to a work piece to have machining process. So, let us look at some of the varieties of types of laser which are available there are solid staster gas based laser each of them have there own limitations, and short comings next start about solid states. So, solid state lasers, because of poorthermal properties cannot be used for heavy duty work, and also not there very high frequency. So, they can operate typically laser than or with the speed laser than 1 to 2 hards. So, thats about how much solid state laser can delivered.

So, how they are used. So, in some situationa machining you do need a continous type process we are like for example, operations like driling operation like spark welding we are you need to deliver a continously the beam radiation. So, that absorption can be created locally, and it it results in continously removal of the material, and in case of spark welding it it creates a tag by melting both the material, and fusing them. So, in such applications the solid states laser can be very wel used, because of their poor termal propertiescan lower frequency of operation. So you can increase the plus to very high value we are some times even up to the level of about nano seconds or pico seconds pluses can be generated by any system, and ah the most important examples of such solid states lasers which as lightly more powerfull than what other i mean systems are these n d yag kind of lasers.

So, these are used in cutting operaters other like for example, ah were completely large size she is have to be cut into small pieces there is a lastering of a laser which would take place, there be continous addition of power there be take place. So, heavy duty leases are used their n d yag forms one of those varieties in the solid states where the deliver enough power for such complete cutting action to power some materials which are developed for leasing action are calcium fluoride crystals doped with neodymium aluminum oxide with chromium ion impurities also called crysalline ruby, so on. These materials are actually ah the typically the lasing medium which would do all these population inversion stimulated emission and so on so for.

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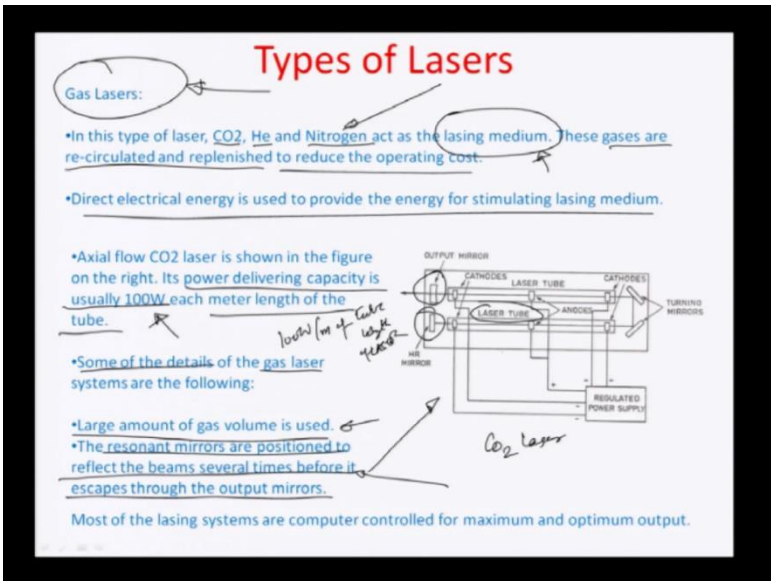

Lets start gas lasers now. So, solid state lasers a kind of outdated, because of their slow speeds ah the next generation lasers for actually where the medium was instead of solid like a ruby syatem of a gas several types of laser exists in the category there are carbon oxide laser helium nitrogen lasers, and all these gases typically act as a lasing medium meaning thereby stimulating emission fundamentals that we discussed about the in the last to slides are instead of solid medium gases medium that is a courses are recirculated, and replenished, and this reduces the operating cost of a laser in some of the cases direct eletrical energy is used the provide the energy stimulating lasing medium for example, this write here shows a c o 2 laser were how you can see that lasin c o, and there are these electrodes the cathod, and anode which are actually produces the discharge which actually ah produces the further population inversion as well as the stimulated version. So, the power delivered capacity of c o 2 laser about 100 wats, and ah this is about per meter of the length of the tubes that have high it is about 100 wats of per meter of the tube length of the laser.

So, there are some details which are needed to be understood for gase lasers particularly one is that large volume of gas used resonant mirrors are positioned to reflect the beams several times. So, basically put the same light which is coming out to the medium back into the medium again to have more, and more stimulated emission till its cross over a certain intencity k, and it escapes through the output mirrors which are these mirrors write here. So, most of the basing systems are kind of computer control these days are the designed from the optimum output. So, that fundamentaly lasing system would do whether it solid system for a gas lasers solid understood a fundamentals have lasing happens.

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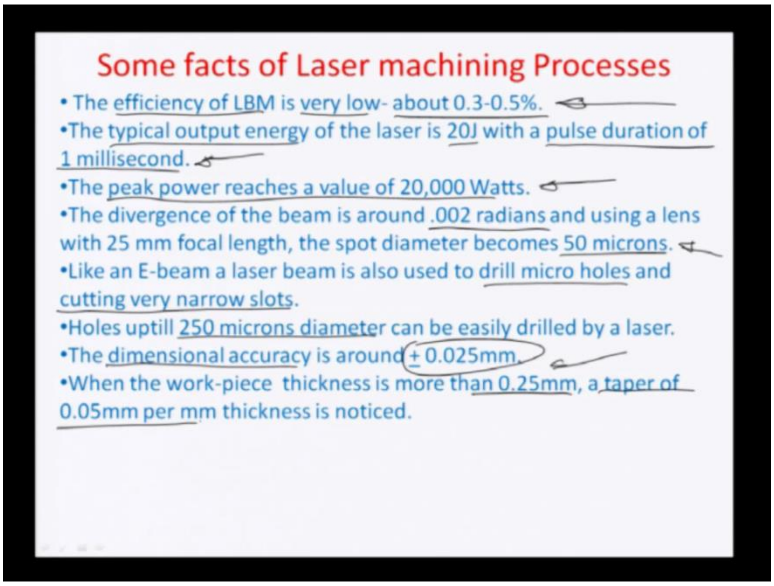

Lets actually looking to some other facts based on the machining processes of this laser systems. So, very important fact which needs to be mentioned here is that effeciency of the LBM is very very low in the range of about 0.3 to 0.5 percentage meaning there by the most of energy whih is coming out of the lasing process is actually either reflected or a doesnot do anything other important aspect of such lasers thus the output typical output energy of laser like about 20 june, and that was the plus duration of almost 1 milisecond noe this has to ah fast. So, many decates of research in laser tyechnology, and these days get we can get front to second laser based on which are extremely high frequency, and and loading to cycle or the peak power lasers reach typically to a value of about 20,000 watts paticularly when machining is an material removal is an watt, and in such asituation the divergence of the laser beam is only about 0.002 radians.

So, there are very disfraction effects that the laser would have, and you can easily laser a focus to a spot of almost 50 microns these days the limit have been pushed incase of systems to close two to three microns thats have low you can get this with technology in the optical technology getting parallely developed. So, like an e beam a laser beam is also used to drill micro holes, and cutting very narrow slots resolutions of the systems are having same mode of minus as e beam system, and holes typically up to about 250 microns diameters can be easily drilled by a laser with a dimensional; accuracy of around twenty five microns a point zero two milimeters plus minus. So, when a work piece thickness, and is more than about 0.25 milimeter a there is a taper which is produced which is almost about fifty microns per milimeter thickness is noticed. So, thats have laser machining processes parameter related to that can be understood.

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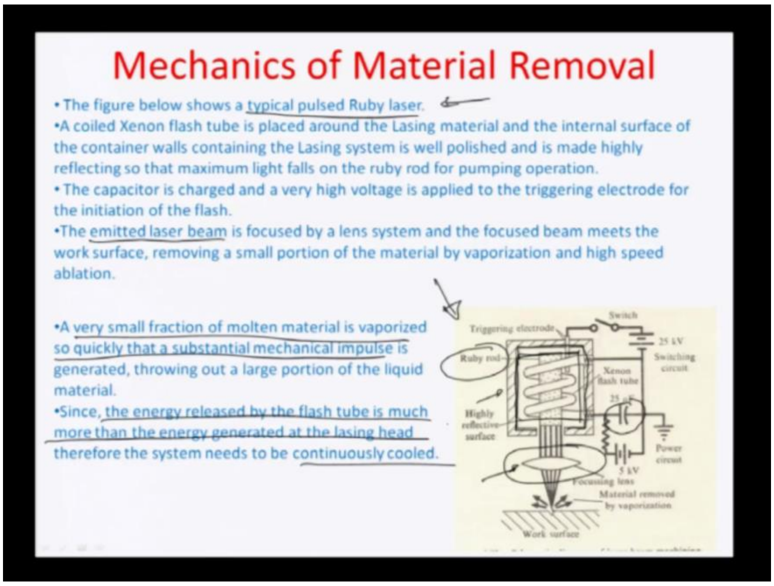

Lets talk about machanics of material removal in a in a laser. So, this figure right here shows typically a plus ruby laser you can see that there is a ruby load which is the lasing medium in this particular set up here there a there is a colied zenom flash tube which is this region coiling the ruby medium the xenon flash tube is responsible for all the primary emission which results in the population in the ruby medium, and the whole set up is housed with in a highly reflective surface meaning thereby the meaning of surface here inside which this whole lasing system is placed is highly highly reflective. So, there are hardly any photon losses either from the xenon flash tube or the ruby laserand the capacitor write here its charge to a very high voltage, and that isto a triggering electrode which actually leeds to create this primary extension in the xenon flash tube, and once this the xenon flash tube flashes sends photons have have it creates a population inversion in the ruby medium.

So, emited laser have being focus now and so there is there is of course, this whole principle of amplification, and emission which happening, and there is a occasionally loss of photons, and most of the photons are retained with in the medium for the amplification purpose, but ocassion in the loss of photons which formulate the cutting deam, and its comes out of the optical system its this length right about here, and then get focussed very narrowly on to a small spot near the work piece. So, you have to really focus the lasing system with respect to the work piece very closely before you start all the melting, and vaporisation process. So, immediately with this aa laser light getting on to the work piece a very small fraction of the molten materials a quickly vaporised, and there is a substantial machanical implus which is generated, because of this certain vaporisation. So, it is sort of a submilation.

Process absorption of that local region, because of that the high intensity that is a power per unit area area the spot beam very small those up to a level wayer the sonanic vibration, and the the sonanic energy which is delivered is. So, high that material all together to absorbs ah the photons, and gets up canatic energy increases, and molic user almost net losers gases or wapers ans. So, momet this waperfor machines completed there is a sudden escape of that waper out of the work piece which creates a secondary machanical impact absorbs in the energy released by the flash tube is much more in the energy generated at the lasing head you have to continously cooled this system otherwise a hit may as well hit the melting point of some of the materials involved in developing this leasing torch. So, all the lasing mediums typically need to be continously cooled for proper.

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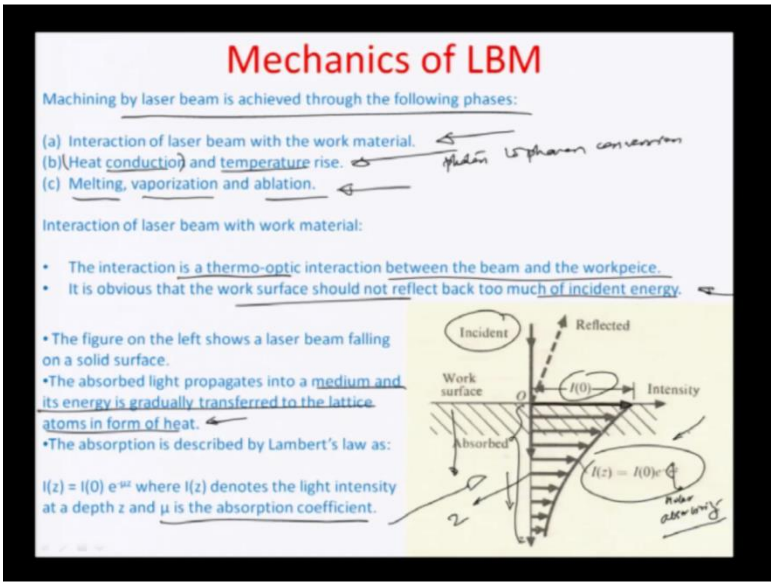

So, machining by laser beam is typically achieved by the following phases phase one is interaction of laser beam with the work material there is a photon to phonon conversion which rises the local temparature, and energy, and there is of course, heat conduction beacause of a sudden temparature gradian which is produced from the central of the beam to the side of the beam, and sudden rise of the central of the beam temparature, and there as of course, there is melting viporisation.

And ablation which takes place, because of such an intraction of photon to the phonon at the vibration of the particular laters with wish the photons interacting the interaction is thermo optic in nature between the beam in the work piece it is obvious the work surface should not reflect back too much of incident energy, because that is a last, and the thatah how the that how the absorption happens is reflected in this figure here were the incident intencity one side false on to the surface in question, and there is a gradual absortion, and the shortening of intensity has one goes into a certain dept which is given by bs law I 0 is the intensity certain distance z from the surface death of z from the surface I 0 is the intensity towards the surface that is the intensity of the incident being and. So, I Z computed to domain the looking at the I 0 is to per minus newzy actualy the more of absorvity and. So, it is also known as the absorbtion coefficent. So, the absorbed eneregy propegates into the medium, and energies gradually transferred to the lattice atoms in form of heat, and vibrations, and that whats the beam its law says about absorption, and how the energy is disperable in the mediumlets.

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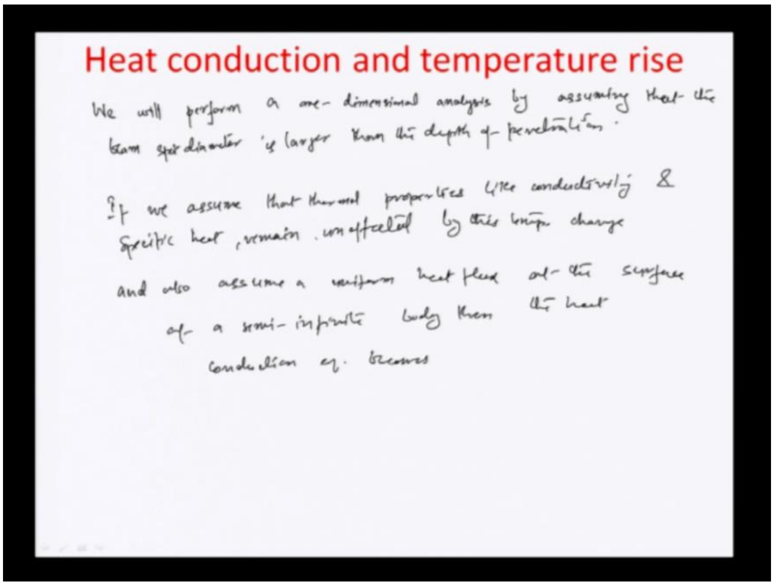

Look at heat conduction equation, and effective tempaturised based on the theory. So, you well a form a wonder mentional an all by assuming that spot diameter is larger than the dept, if assume the thermal properties like conductivity, and specificate remain unaffected by this temparature change in also resume acertain uniform hit flucks surface of a semi finanied body.

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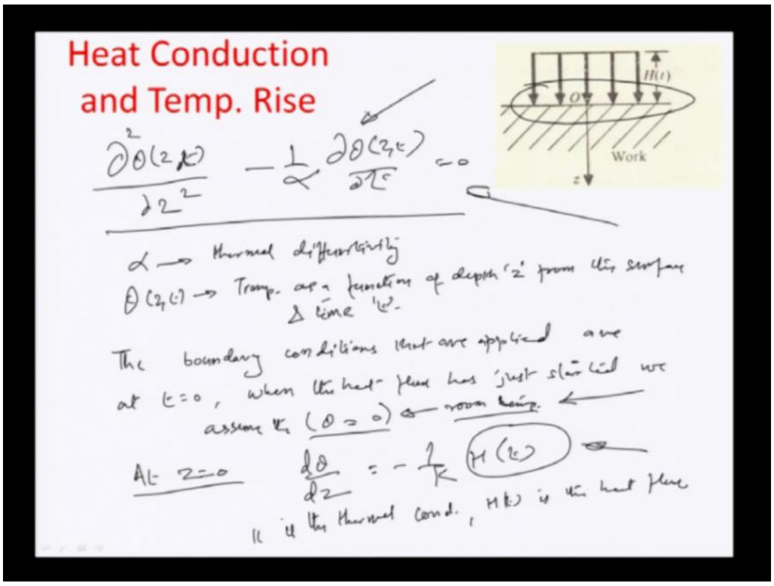

Then the heat conduction equation becomes del to theta function of dept, and time by desi two minus one by thermal deasisity alpha del theata time delti equal zero alpha is we all know thermal depusivity theata is temparature as a function of depth zee on the surface, and we are try to boundry conditions or estimating this equation on this beam work piece interface zooming that there is a constantate flucks. We just coming to the laser beam into surface of the work material. So, the bomby condition there are the applied up there are time t is equal to specially one the heat flucks us just started.

We assume that theata to be called zero this is actually room temparature now you assume assume room temparature with the base line. So, you can consider theata to be zero here. So, everthing kepts develop over the base line. So, at the surface with depth z is equal to zero the detitha by dici is actually minus one by k h t there are t basically the the temparal flucks hit fluckso just sent with in the work piece k is thermal conductivity of materials.

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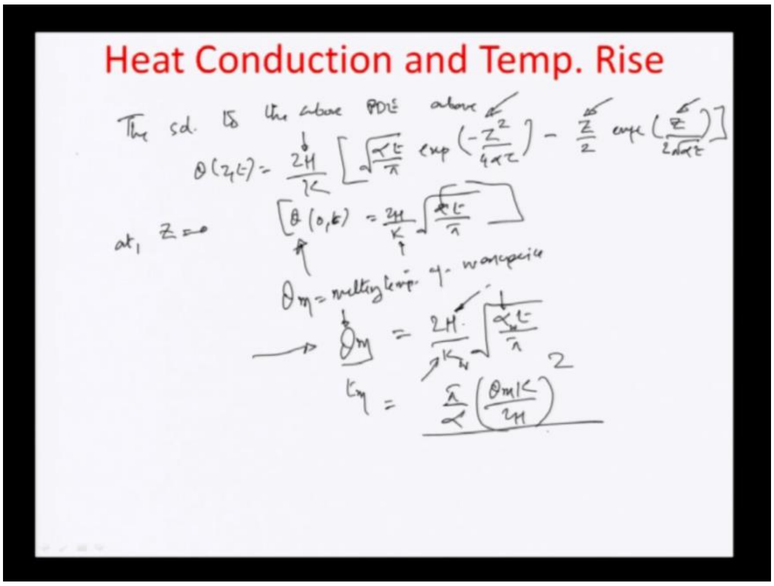

So, if we really ah fly these to boubdry conditions anolyed to slove the this partial differential equition on the solution to the, and we can actually used any method like variable separation may be or pamatric method of solution of the p d. So, pd about the solution is theata g t equal twice at by k h is the constantly flucks times of route of alpha t by pai explanation to the power minus square of depth before alpha 2 minus z by 2 the first kind of the question z ny twice route of alpha t lets evaluated what happens at z is equal to 0 we are already mentioned about this is before there are z is equal to 0, and that is a surface theata zero at any point of time tis actually given by this twice H by alpha route of alpha t pai put the z value zero here sorry this is k. So, the total amount of theata at distance z equal to to zero on the surface if any point of time in is actually twice h by k route of alpha t by pai were hobiously case thermal conductivity other material material with which is machine to alpha is the thermal depusivity is time of the whole machining process, and h is total amount of heat flucks which come xen are the system you cantalk about the heat flucks are as the amount of power per unit area that is coupled to the surface the work surface the units are whats per milimeters square.

So, sh why does happen in labour machining or how does melting happen the surface of the machine ah surface of the work piece which is being heat upon by the incident laser is reaching the multing point of the material. So, this theata essentially here zero is nothing but the melting point or the melting temparature of the work piece or work material. So, you can have a very good formulation here on first on first principles that theata 2 m is related to the incident power twice of the incident power by thermal conductivity of the work piece of twice route of alpha t by pai alpha t in the thermaltime of machining.

So, another words we do know what is beata m, and property from the properties of the material you do know what is the beam power that you are using impact gets very critical to a estimate the beam power considering all the reflecting losses which are there from the surface, because most of the power gets of from this coupling mode by the essential evil by reflection particularly for smooth, and shiny surfaces. So, once together estimated that, and a sure that what is the power density the flucks which is coming into the surface in terms of whts per milimeters square we can find out machining time here t m by plugging in the various values of these are material properties of the work piece ah or this is the power this write here there is the melting temparature. So, t m is basically hold to pai by alpha times of thedam k by twice h whole square thats have melting temparature t m.

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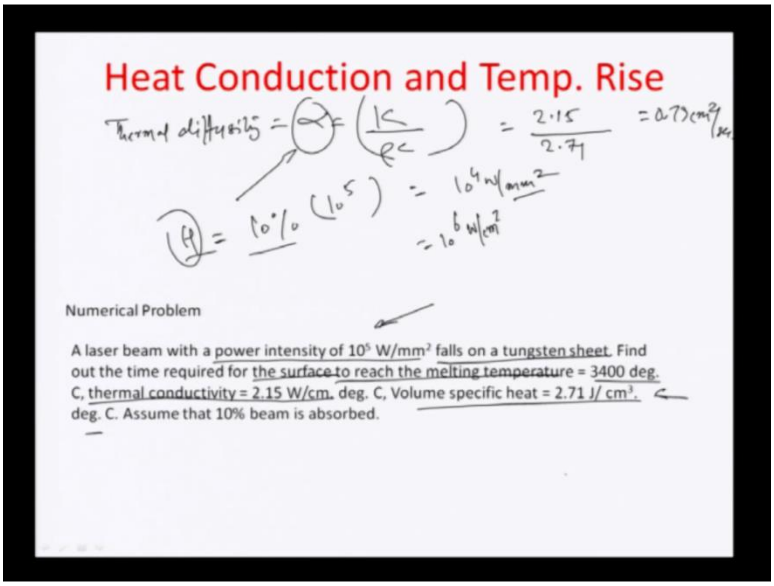

Let us do a small problem here that is the laser being, and we have a power intensity being coupled of about at the power of 5 watt milimeter square falls on a tungsten sheet, and find out the time required for the surface to reach the melting temparature which is 3400 degree celcius we have the following parameter c thermal conductivity is 2.15 watt per centimeter degree celcius volumes specific heat row time is a c, and you have to assume that ten percent beam is absorbed on the word surface. So, lets say lets look at thermal defuse very fast lets calculate termal defusivity alphais given by thermal conductivity by volume specify k by rossy, and this happens to 2.15 by 2.71 about 0.79.

The units aresemi meters square per second. So, alpha is calculated now, and we how know that we are couple beam power h which is about 10 percent of the actual power beam coupled actual power beam, then rest to the power five square. So, this happens would be about 10 to the power 4 what from the. So, thats how how much the beam power is coupled to the surface in in question, and if you change the sightly from to a convenient unit just, because of everthing else in centimeters the samples to be 10 the power of 7 sorry it is no 6 watt per centimeter square.

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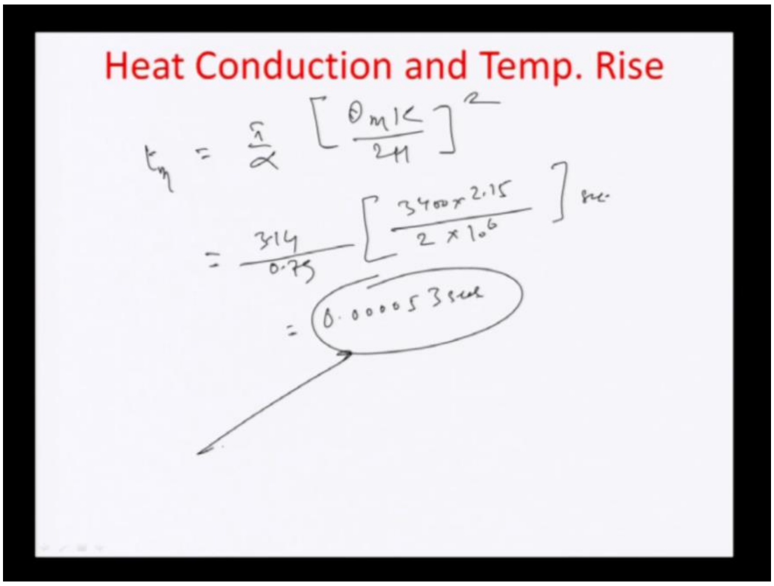

So, thats how much power gets coupled, and we can find out machining time t m by very easily here by using its expression herely attarived pai bt alpha theta m K by twice h whole square is 3.14 divided by 0.79, and three diam is basically 3400 times of 2.15 by twice 10 three power of 6. So, many seconds comes zero point almost 0.000053 seconds. So, that is how small a time it takes for laser to heats the surface of a melting temparature of almost about thirty four hundred degree celcious. So you can think of the amount of laser power which is been utilised just an ten percent of the laser power. So, how much amount of power is really a important for a changing material properties taking into the waper state is very much very small percentage of how much power is generated with in the rubby medium of the crystal or even gas laser.

So, that shows a the difference in the power levels between what is incide the laser actually get delivered from the laser torch. So, the next ah lactured towards end the particular lacture we would actually try to make a little more complex model by assuming instead of a ah study stay problem transian problem, and try to see a evaluate have a temparature varies in that particular case by making model a little more complex, and changing also the system from a sami final plate to a circular beam over a small region.

Thank You.