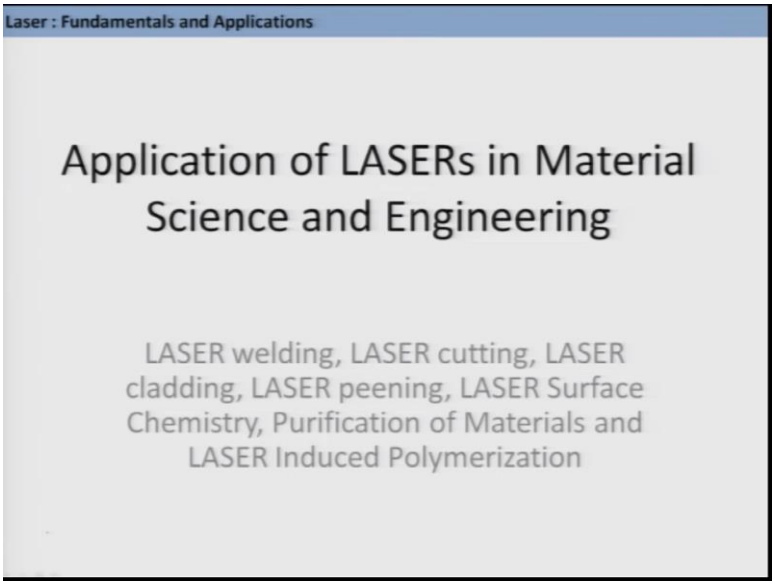
Laser: Fundamentals and Applications
Prof. Manabendra Chandra
Department of Chemistry
Indian Institute of Technology, Kanpur

Lecture – 39
Lasers in Material sciences and engineering and Optical Communications

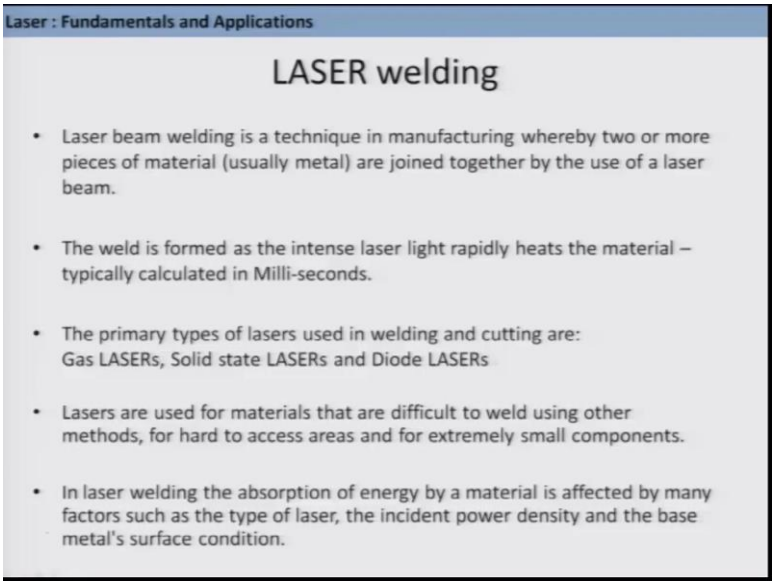
Hello everyone. So, today we will be talking about applications of lasers in a material science and engineering and related fields.

(Refer Slide Time: 00:24)



We will also try to talk about the application of lasers in optical communications. So, the laser is applied in you know various areas of a Material Science and Engineering Metallurgy and these are very much you know important for industries. So, there are several areas that has come up over the years after the since inception of laser like laser welding, laser cutting, laser cladding, laser cleaning laser surface engineering surface chemistry purification of materials and laser induced polymerization to name a few of them.

(Refer Slide Time: 01:11)



So, let us start by talking about laser welding. So, a laser beam welding is a technique in manufacturing where by two or more pieces of material easily they are metals are joined together by the use of a laser beam. So, conventionally what is done you know when you want to join two metals then you come with a very high temperature flame and then you know join them together that is known as conventional welding.

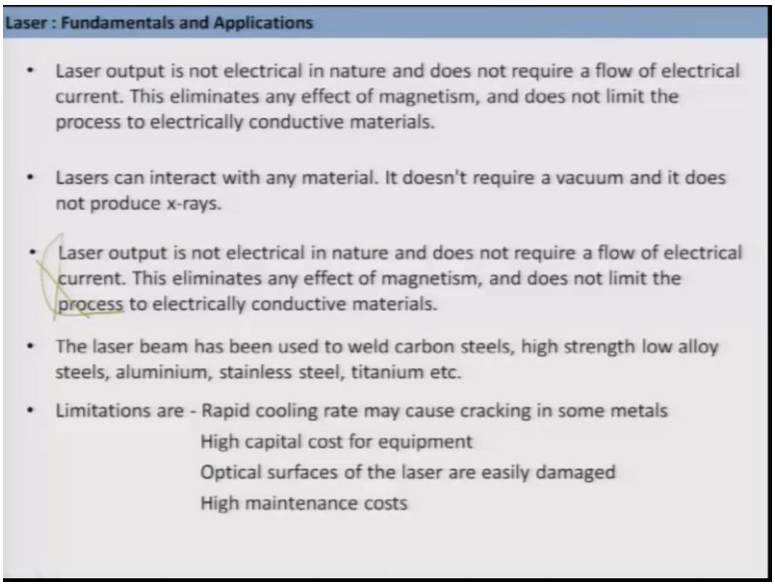
Here instead of that you know high temperature you use laser beam. So, the weld is formed as a intense laser light rapidly heats the material and this happens in short time skill over millisecond second time period the you know main types of a laser that are used in this welding process also in cutting are essentially the gas lasers which can give you really really high power for example, carbon dioxide laser. Also solid state lasers like in the YAG and modern day diode lasers are used for this purposes this lasers are used for materials that are difficult to weld using other methods because some time they may be hard to and also you know access certain areas for the conventional you know welding instrument also in those cases where you need to weld a very very tiny objects. So, in the you know size of say millimetre or micro meter kind of object dimensions there also you cannot use a conventional welding machine and you have to use a laser technique to weld them.

So, these are the advantages of a laser pest welding techniques. So, one if you have a material which really hard to weld, second if you do not have you know access to the

region there you can you have to use laser pest welding and also for you know tiny components say for example, like a in a you know some cheap or you know that kind of a stuff you have to use laser best welding. And in laser welding the absorption of energy by a material is affected by many factors such as the type of laser the incident power density and the surface condition of the base metal depending on that one you know can achieve the efficiency of the welding by using laser.

Now, as we know that the laser output is optical not electrical right and so we do not need to you know have an electric current flow into this metallic system which we need to weld and this eliminates the you know any possible effect of magnetism and also we in this way we do not limit the welding process to only electrically conducting materials which is the case in you know many conventional welding techniques.

(Refer Slide Time: 04:45)



And this lasers can interact with any material and it does not required you know condition like vacuum or it does not you know create some adverse raise also.

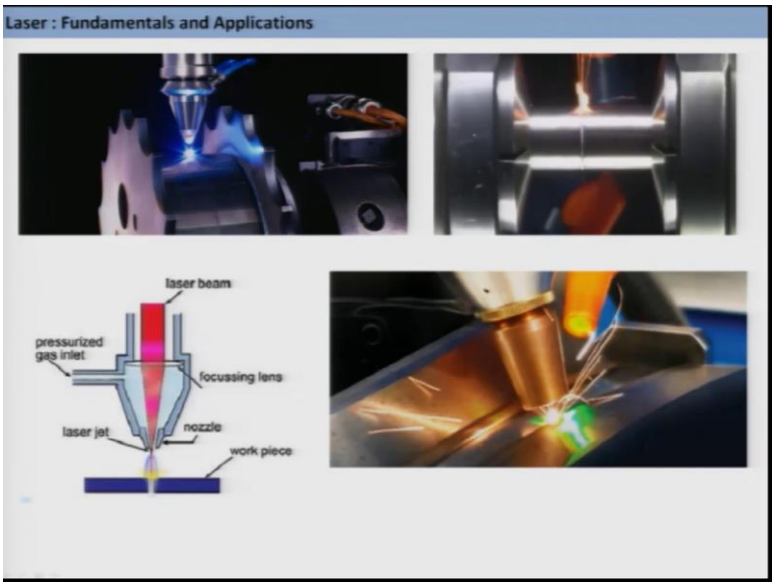
Laser output is not this list sorry this is just repeated by mistake, the laser beam has been used to weld carbon steels you know high strength low alloy steels aluminium, stainless steel titanium and various other materials. Now though they have lot of advantages certain disadvantages are there or limitations are there what are they that is rapid cooling rate may cause cracking in some material because you are using laser for a short period of time. So, you just create that heat in a very short moment and then you withdraw your

laser light the light is off. So, there is no source of heat anymore and then you know this rapid heating and there will be rapid cooling and this can create problem by you know like generating cracks in the material.

Second thing is that conventional compared to conventional welding machine lasers can be expensive so the cost wise it is little bit you know problem. Optical surfaces of the lasers are easily damaged. So, when you at use this laser to weld something so from there you know you many times get lot of you know papers and all those stuff and that can get accumulated in the optical surface of this laser and over the time this optical surface know goes back and you know it is it happens quite often and once the optical surface you know go back the laser performance in welding also determinates. And lastly that you if you are using a laser system for your welding purposes then you need to be at the maintenance cost for this laser system as well.

So, these are some limitation not necessarily that you know big limitations. So, for example, like you know if you have you know enough you know capital to buy and maintain this in the systems they are of you know no problem. Certain figures showing this you know welding and cutting process.

(Refer Slide Time: 07:43)

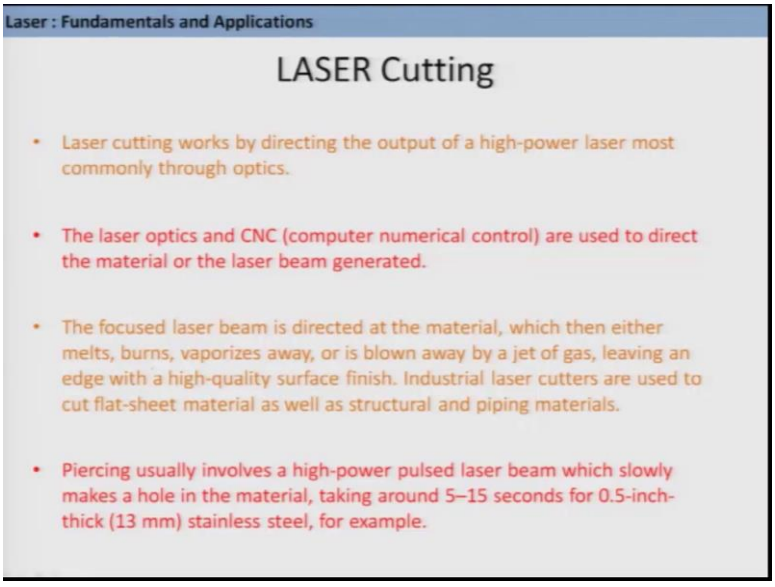


So, here like you know two parts are being you know joined together well together by using the laser same is done on the right side image and this is a schematic of the process where the laser beam is focused using a lens and you know this is passed through nozzle

where through also you send in you know some gas under high pressure. So, that you know you can create the exact environment on the metal surface which you are trying to weld is created.

Next we will be talking about another process called laser cutting. So, laser cutting works by directing the output of a laser essentially very high power laser through optics. So, the arrangement is pretty similar you bring your laser focus it you know focus it really hard on to the surface that you want to cut.

(Refer Slide Time: 08:29)



So, this laser you know optics and the computer numerical control are used to direct the material or the laser beam generators. So, you can either move the material that you are going to cut or you can move the laser head. So, either is fine and you can do that in a computer controlled manner and not only the laser, but are associated optics also can be moved.

This focus laser beam is now directed to the material which then either mails or burns or vaporizes or simply you know you blow away by you know jet of gas like I showed in the just previous slide for welding which leaves an age with the high quality surface finish. So, this is a very big advantage of laser cutting compared to your metallic cutting where you know you have a rough surface edge laser will give you very nice finish of the surface edge. Industrial laser cutters are used to cut flat sheet material as well as structural and piping materials. So, you can do any sort of cutting pretty much using laser

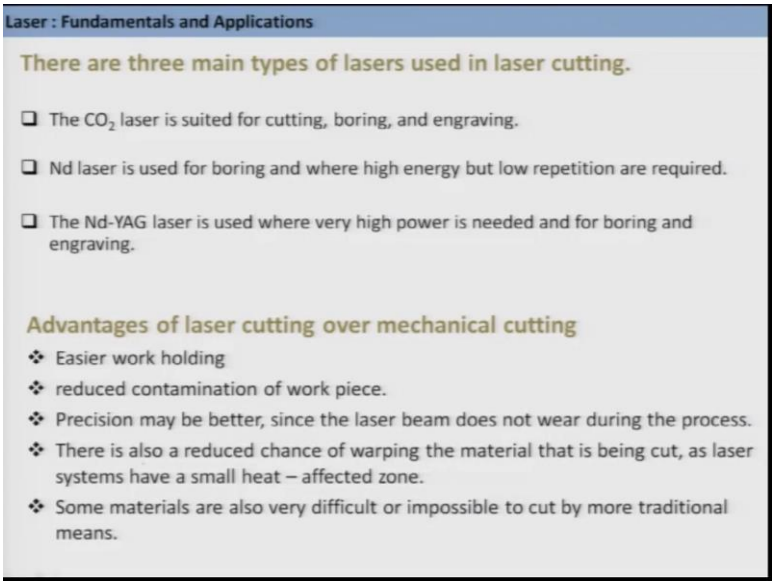
and that is why this is very you know industry is pretty big fan of this laser cutting. You know you can also pierce through material and this piercing usually involves very high power laser pulses which makes a hole in the material and making this whole text like you know anything between 1 to 15 seconds. If you have like you know a half inch thick stainless steel which is amazing right when this is really very short time if you think about it.

(Refer Slide Time: 10:43)

So, here are you know some example shown for this laser cutting and laser drilling. So, here you can see that you know replica structures are being made and this whole laser arm is you know computer controlled and you sincerely what you do you draw the you know structure that you want to make by cutting you know say sheet of metal and then you know essentially you program the motion of the you know laser head along with this optics. And then you know tie it on and then the laser you know follows that program and then it you know cuts the metal and it just replicates everything tito. And you can see that in all these pictures and here this is this image shows the you know laser cutting along with the that you know cleaning of the (Refer Time: 11:46) that are formed during cutting because it can you know a blade it can vaporize it can do you know several things.

So, high flow of a some inert gas at that region we will know blow things away. So, that you get a clean surface of the end.

(Refer Slide Time: 12:14)

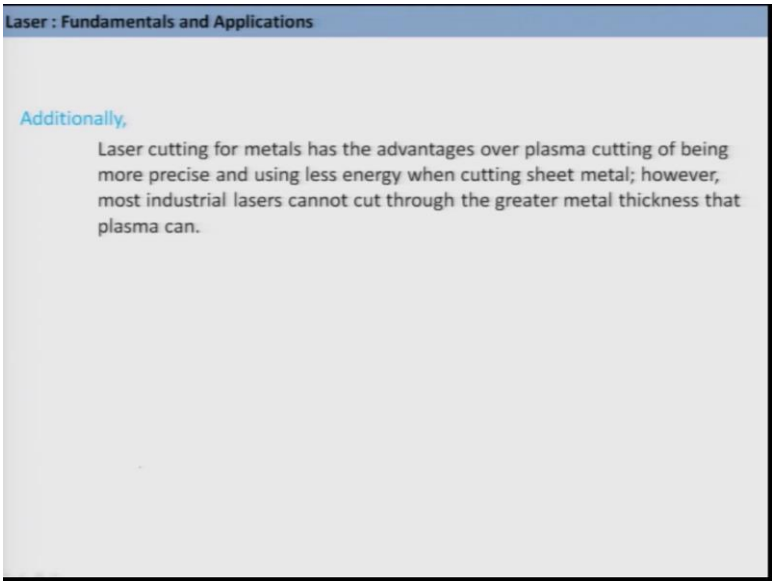


Now what are the lasers that are used for this later laser cutting purposes? There are basically three different types of laser carbon dioxide laser, neodymium laser or neodymium YAG laser that are used you know for either cutting or boring or engraving. Now what are the advantages of the laser cutting over machine cutting? Some of them we have already discussed let us have a look at them again. So, it is you know it is easier to handle you have less contamination in the you know piece of metal that you are working on the precision is may be better because the laser beam does not wear during the process unlike the machines.

So, like if you have a saw which you used to you know use to cut a metal sheet. So, during this process the saw is also getting damaged over the time and this is called wearing process, but a laser light does not have this drawbacks with does not get weared and you know that is the reason you have much precise cutting. There is also a reduced chance of you know warping the material that is being cut as the laser system have a small heat affected zone because you are focusing to a very tiny spots, in the range of you know micron compared to conventional machine this is you know really really small. So, there is you know very very small region where the heat is you know created. So, this is you know restricted to a very narrow region and that is why the warping of material is you know in the chance of having it having a warping is limited.

Some materials are also very difficult or impossible to cut just like we said in case of welding for those materials we can use laser cutting over the traditional say socketing.

(Refer Slide Time: 14:25)

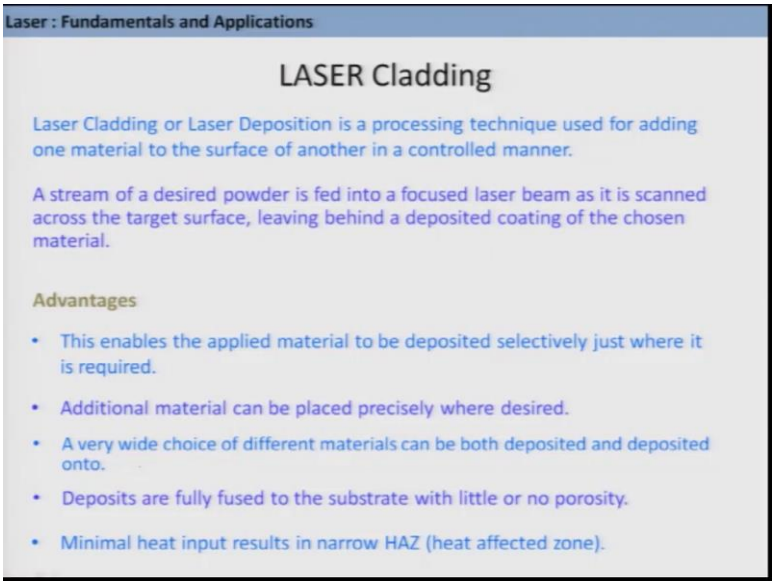


One additional thing I would like to mention here is that the laser cutting for metals has the advantage over plasma cutting of you know because it can be more precise and using less energy when cutting sheet of metal.

However most industrial lasers cannot cut through the greater metal thickness then plasma can. So, if one is interested of cutting really thick you know metal sheets then one may need to use a plasma cutting option, but other than that everywhere laser cutting is superior compared to either plasma cutting or of course, the conventional cutting techniques.

Next we will talk about laser cladding.

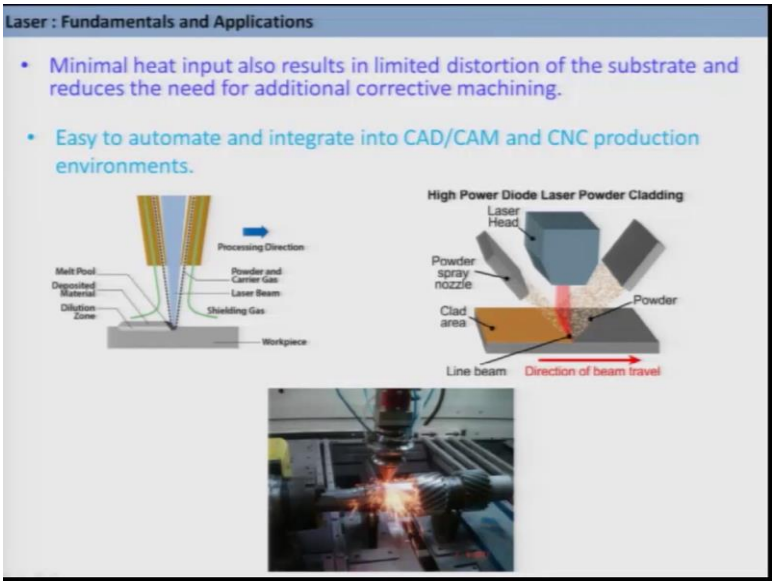
(Refer Slide Time: 15:12)



So, the laser cladding or laser deposition is a processing technique that you know is used for adding one material to the surface of another in a controlled manner and for this a stream of desired powder is fed on to into a focused laser beam as it is scanned across the target surface, leaving behind deposited coating of the chosen material.

So, what it does usually this enables the you know applied material to be deposited onto the sub state surface and not only that you can deposit that in a very selective manage that where ever you want you can deposit it. Additionally you know you can again come with another material and deposit on the top of the first one. So, you can have a very wide choice of different materials that can be deposited or you know deposit on to the previous deposited material where deposits are fully fused to the substrate with little or no porosity which is a big advantage. Minimal heat input results in narrow heat effected zone which we already discussed in the case of laser cutting.

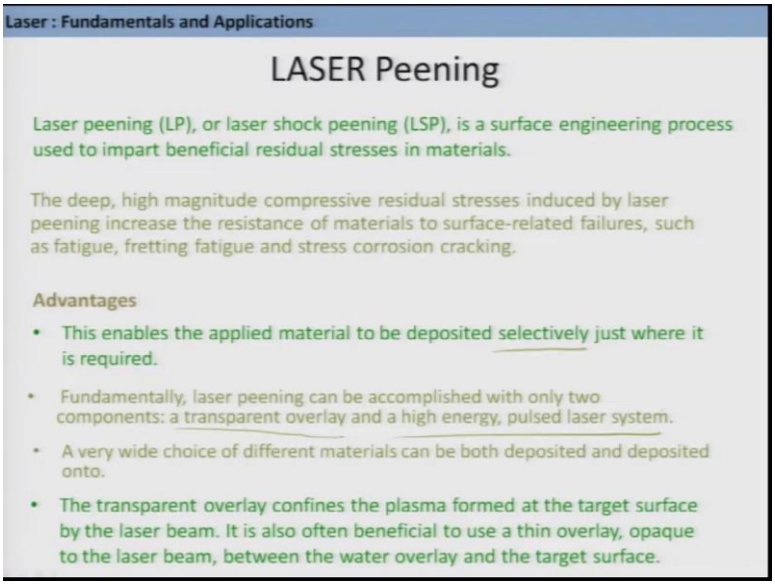
(Refer Slide Time: 16:43)



And this, because of this you know narrow region of the focal spot which in turn in case the minimal heat input that results in limited distortion of the substrate and reduces the need of additional collective machining, certainly a big advantage.

Now, you can you know automate this process you know all together using you know CAD or CAM and you know computer controlled production environment. So, here this you know schematically it is shown how this cladding is done. So, you have supplier you know supplier of powder in terms of in a form of industry which goes to the surface and there it meets the laser beam and gets deposited there. So, you can program where this guys will be getting deposited exactly.

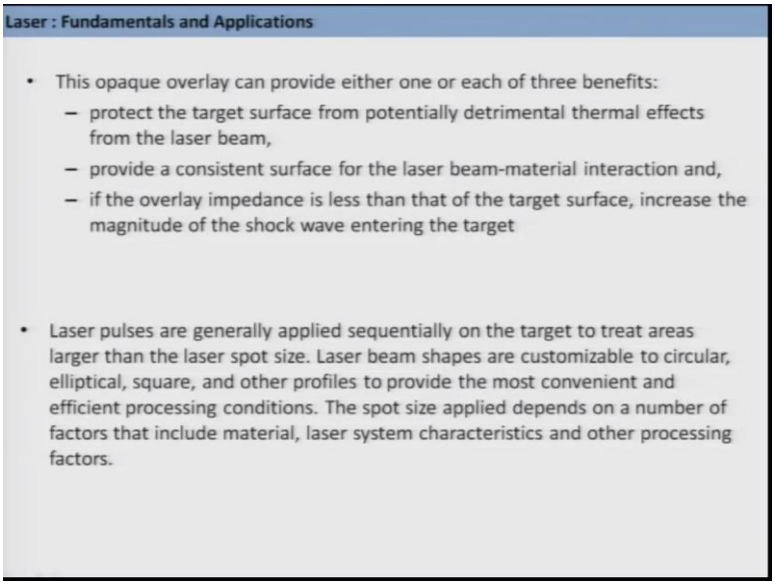
(Refer Slide Time: 17:51)



Next, we will talk about laser peening. Laser peening or laser shock peening is a surface engineering process used to impart beneficial residual stresses in material in certain cases you need some residual stresses within the material and using laser peening you can actually do that. The tip high magnitude compressive residual stresses induced by laser laser peening increase the resistance of material to surface related failures such as fatigue, fretting fatigue and stress corrosion cracking, so this is more like you know you know having impurity in a crystal, it can be in a better in you know for such a system. Here also like you know having some additional stress it can be beneficial as we said just you know minute back. So, you know what are the plus points. So, this laser peening it enables the applied material to be selectively note this just where it is required pretty similar to the cladding that we discussed.

Fundamentally laser peening can be accomplished with the only two components or transparent overlay and high energy pulse laser system. Very white choice of material you can have you know like laser cladding the transparent overlay confines the plasma formed at the target surface by the laser beam and it also often beneficial to use thin overlay opaque to the laser beam between the water overlay and the target surface.

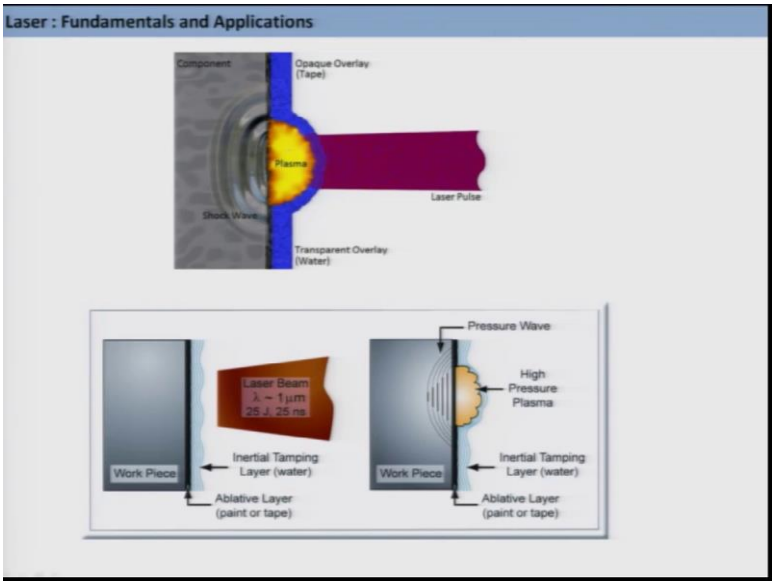
(Refer Slide Time: 19:45)



Now this opaque overlay can provide either one or each of the following benefits. For example it I can protect the target surface from potentially detrimental thermal effects which is; obviously, you can you can expect from laser beam. Second it can provide a consistent surface for the laser beam material interaction and third if the overlay impedance is less than that of the target surface increase in the magnitude of shock wave entering the target.

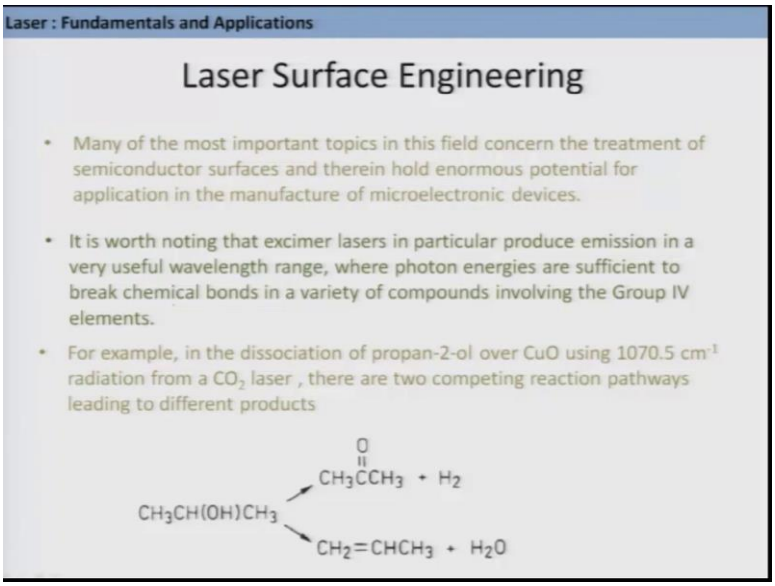
Now laser pulses are generally applied sequentially on the target to treat areas larger than the laser spot size it has to be and the lasers beam shapes are customizable to any shape like circular or elliptical or any other thing like square to provide the most convenient you know efficient processing condition.

(Refer Slide Time: 20:50)



So, here we show schematically how this peening is done. So, the laser pulse it creates the plasma at the surface you know this which is you know opaque overlay and also it creates a shockwave on the other side.

(Refer Slide Time: 21:10)



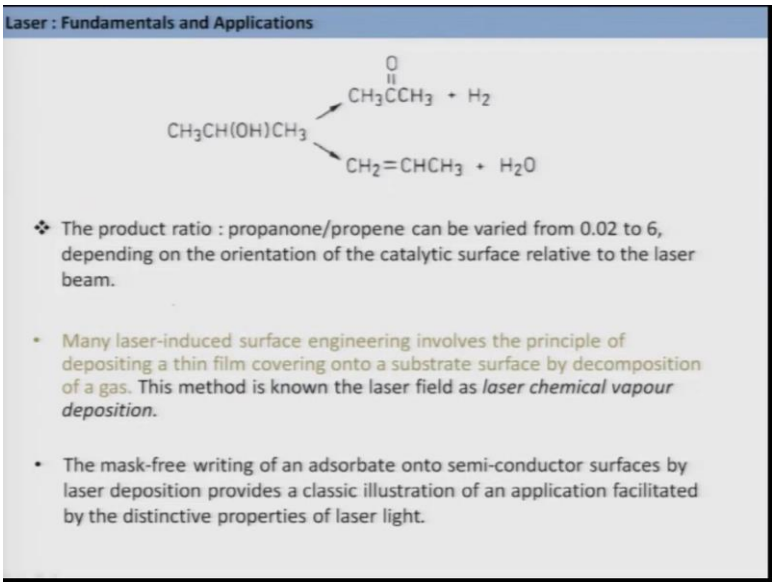
Next we will talk about the laser surface engineering as the last topic in this section. So, many of the most important topics in this field concerned the treatment of semiconductor surfaces and there in hold enormous potential for application in the manufacture of microelectronic devices. You know many of us already that the semi conductor industry

has a you know kind of revolutionized micro electronic device industry and what we were going to talk about actually it you know is of concern in those fields.

So, it is worth noting that excimer lasers in particular produce emission in a very useful wavelength where photon energies are efficient to break chemical bonds we have seen that in earlier case of you know medical application of laser. So, this you know excimer laser fundamental frequencies or their harmonics they can break the chemical bonds in you know different compounds and for us the important compounds are those which involved group 4 elements.

For example the decision of a propan-2-ol over copper oxide using 1070.5 centimeter inverse radiation from a carbon dioxide laser there are two competing reaction pathways leading to different products. So, one is propanone another is propene.

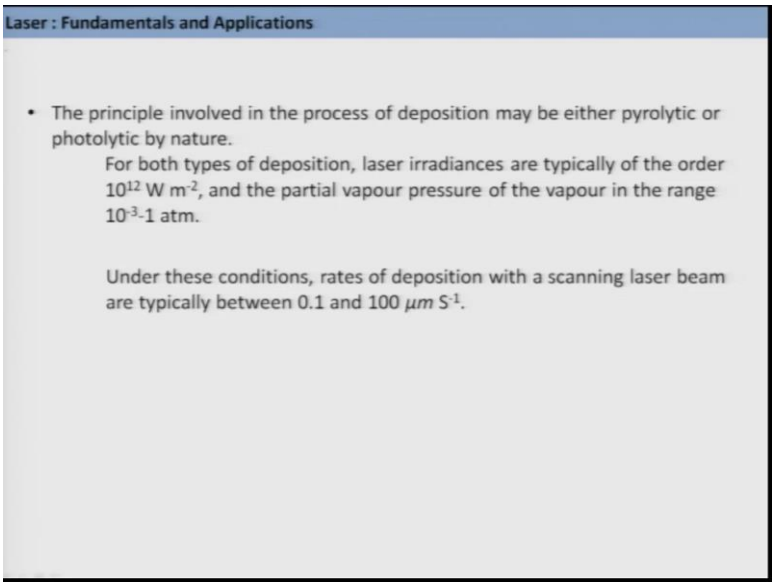
(Refer Slide Time: 22:54)



The product issue of this propanone to propene can be varied from 0.02 to 6 depending on the orientation of the catalytic surface with respect to the laser beam. Many laser induced surface engineering involves a principle of depositing a thin film covering onto a substrate surface by decomposition of a gas and this process is very well known as laser chemical vapour deposition.

The mask free writing of an adsorbate on to semiconductor surfaces by laser deposition provides a classic illustration of an application facilitated by distinctive properties of laser light.

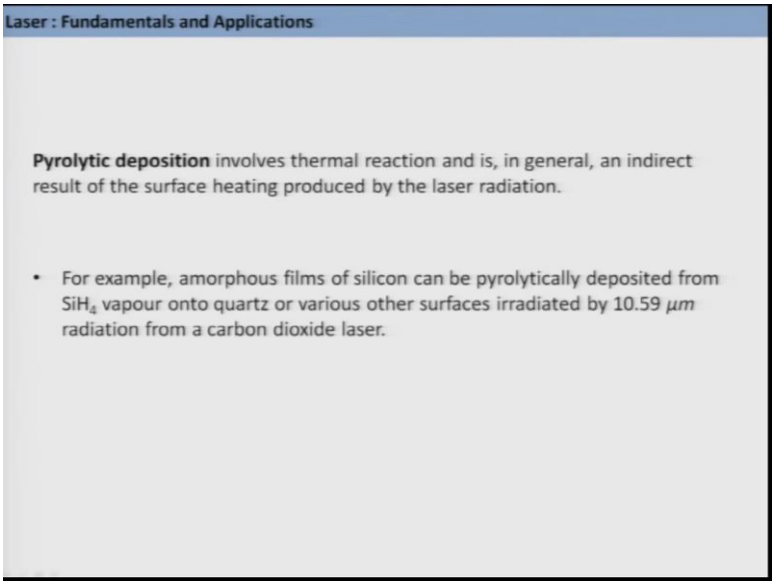
(Refer Slide Time: 23:42)



And the principle involved in the process of deposition in this manner can be either pyrolytic or photolytic by nature. Now both the types either by pyrolytic or photolytics of this deposition the laser irradiance is a typical in the range of 10 power 12 watt per centimetre square and the vapour pressure of the gas is required to be between you know in atmosphere to 1 milli bar ok.

And at this condition the rate of the deposition with the scanning laser system are typically between 0.1 to 100 micro meter per second.

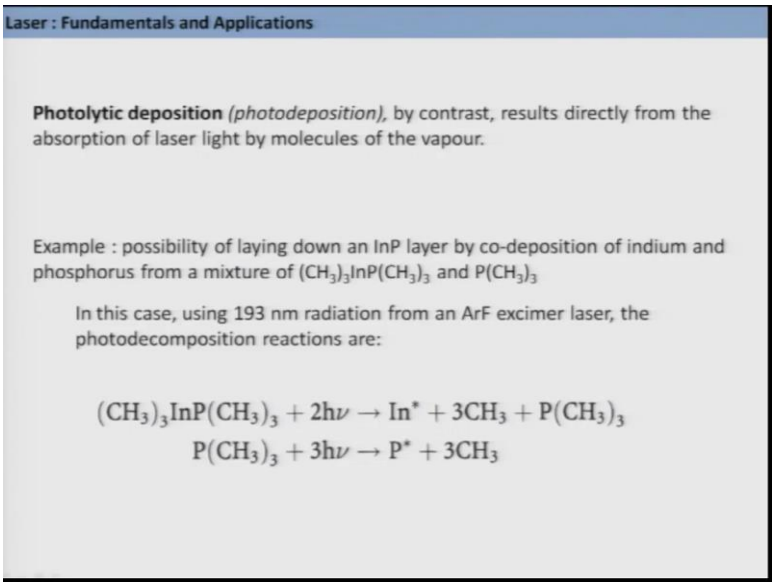
(Refer Slide Time: 24:26)



Now individually if you look at pyrolytic and photolytic decomposition the photolytic decomposition involves thermal reaction and is general and indirect result of the surface heating produced by the laser radiation.

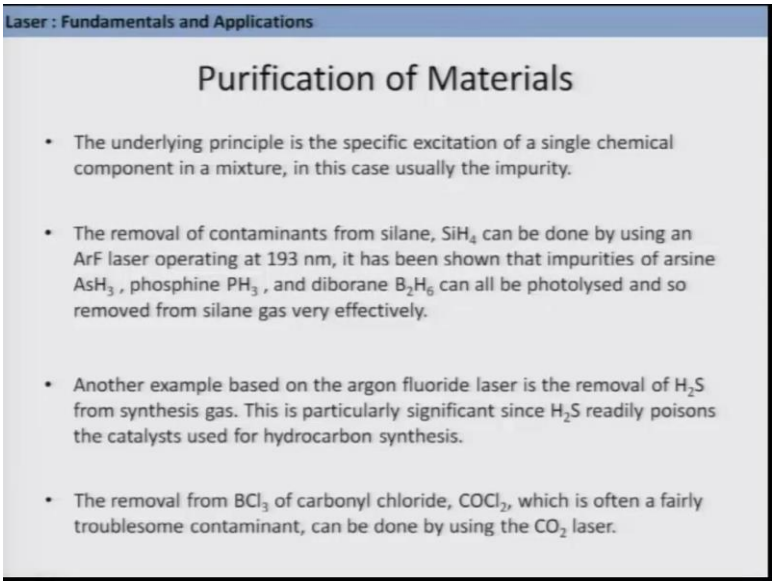
For example amorphous films of silicon can be pyrolytically deposited onto a silicon hydryte vapour from a silicon hydryte vapour onto quartz or various other surfaces irradiated at particular wavelength of 10.59 micrometer from a carbon dioxide laser.

(Refer Slide Time: 24:57)



On the other hand photocatalytic deposit sorry photocatalytic deposition result directly from the absorption of laser light by the molecules of the vapour. So, here we provide another example where this example is you know materialized by using 193 nanometer laser light from excimer laser.

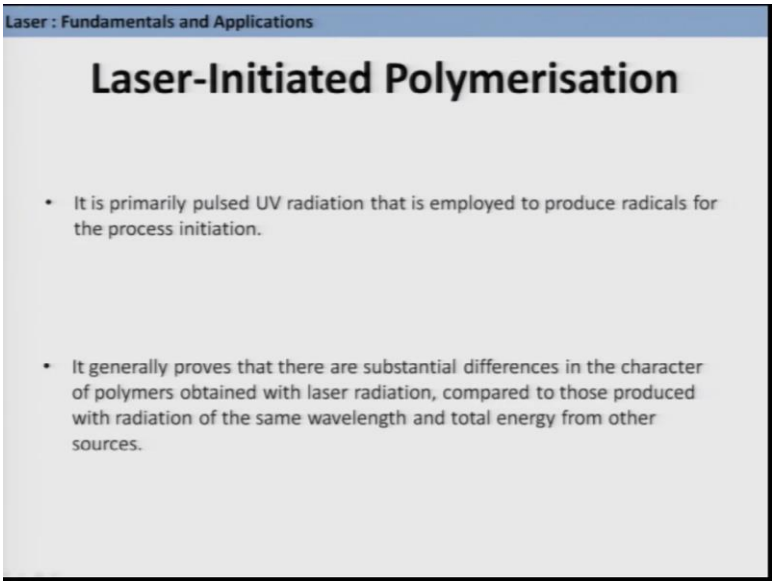
(Refer Slide Time: 25:23)



Also we can use this you know laser radiation for purification material and here the underlying principle is the specific excitation of a single chemical component in a mixture, in this case usually the impurity.

So, we have talked about this very many times we have talked about this when we discussed about the chemical application and also in separation techniques like isotropy separation. So, here also it uses the same principle that monochromatic stuff laser light that can be used to excite selectively one particular component and then you know you get rid of that by some other means. So, essentially we can get rid of the impurities.

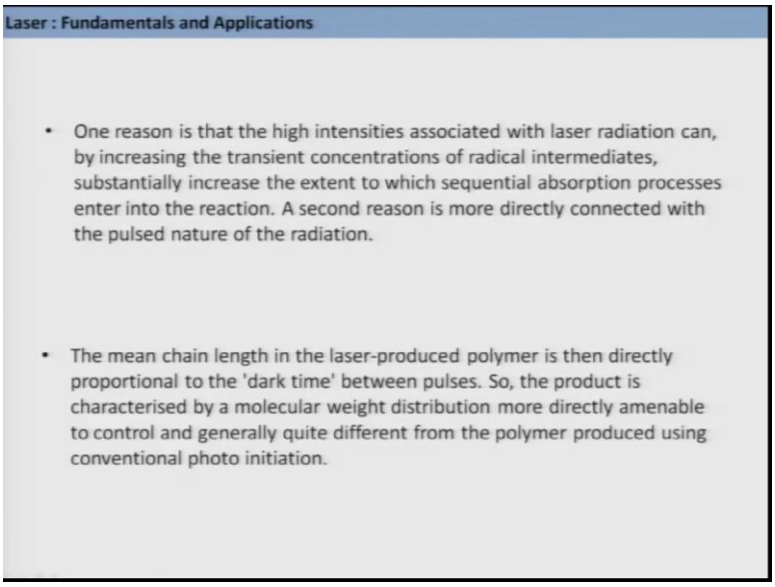
(Refer Slide Time: 26:02)



So, one more thing I will discuss here is the you know preparation of a polymer or in other word the polymerization initiated by lasers.

So, normally pulse UV radiation that is employed to produce radicals for the process initiation generally you know it is generally proves that there are substantial differences in the character of polymers obtained with laser radiation compared to that produced with the radiation of from you know conventional light sources.

(Refer Slide Time: 26:38)



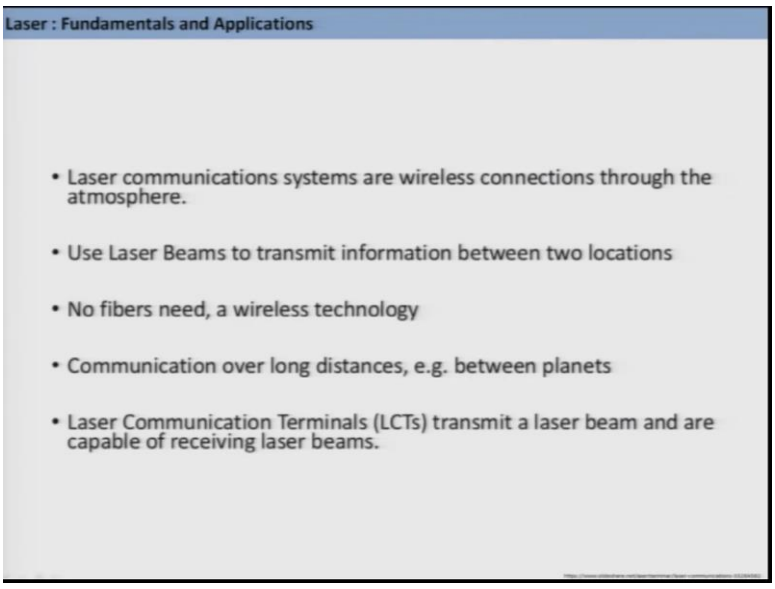
One reason for this is that the high intensity as with laser radiation can be increasing the transient concentration of radical intermediates and substantially increase the extent to which the sequential absorption processes enter into the reaction.

Second reason can be that it is more directly connected to the pulse nature of the radiation and the you know the length of the particularly the mean length of this polymers that are produced by this laser excitation are essentially proportional to the day time or the dark time that is the time between two successive pulses. So, the product is characterized by the molecular weight distribution more directly amenable to control and generally generally quite different from the polymer produced using conventional photo initiation.

So, in a pulsed laser system since the you know day time dictates the polymer chain link so you can actually control the molecular weight of this polymer produced by lasers you know much much better way than what you obtained in case of a normal or conventional source initiated polymerization.

So, with this we will stop this particular section and we will move on to the other application of lasers particularly in the field of laser communications.

(Refer Slide Time: 28:21)

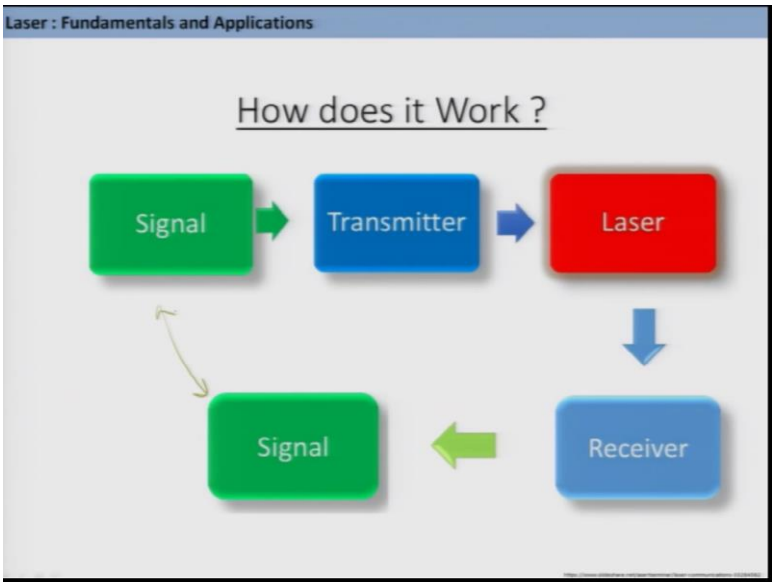


So, the laser communication systems you know are normally wireless systems. So, any communication system we think of they are connected via some sort of a connectors. So,

where you know fibre optic cable etcetera, but laser communication it is like a direct communication without the need of any wired system. So, it is a wireless connections and here the laser beam is used to transmit information between two locations. So, at the source and then you know in the region where signal is received. So, as I said there is no fiber required because it is a wireless technology and you can really achieve communication between you know very large distances and how long the distance can be to give an example it can be communication between two planets.

Now, say for example, we can have a communication from you know earth to mars this laser communication terminals transmit a laser beam and are capable of a receiving laser beam. So, between this terminals we can have the you know talk or communication. Now how does it work?

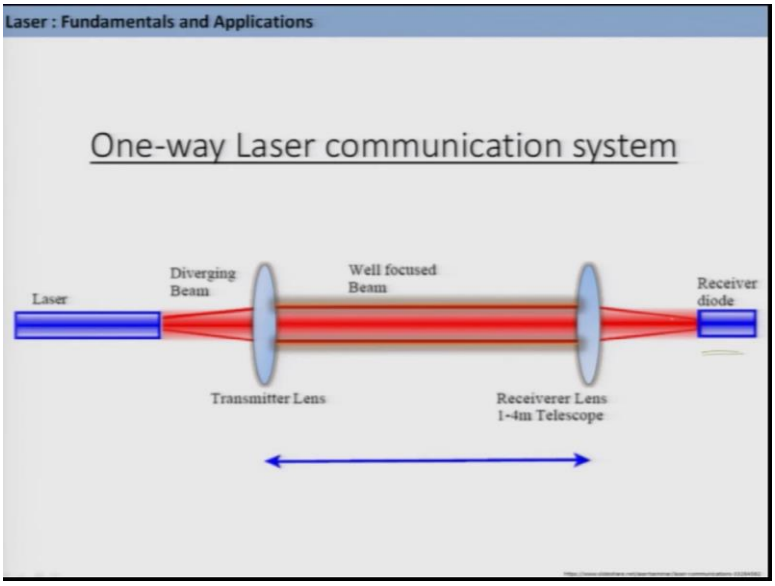
(Refer Slide Time: 30:00)



So, here schematically we (Refer Time: 30:01), you have you know you know some signal are giving to the laser through a transmitter and then you know this laser it sense to the laser beam goes to the receiver on the other hand and which again generates a signal.

So, between the two source we can have you know the communication. So, one signal is send to another place via this laser communication. So, this is exactly how it is done, it is shown here.

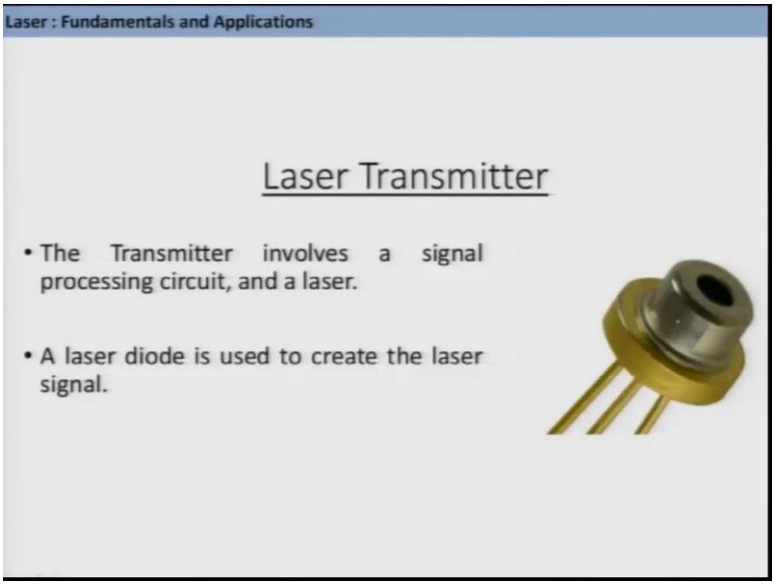
(Refer Slide Time: 30:40)



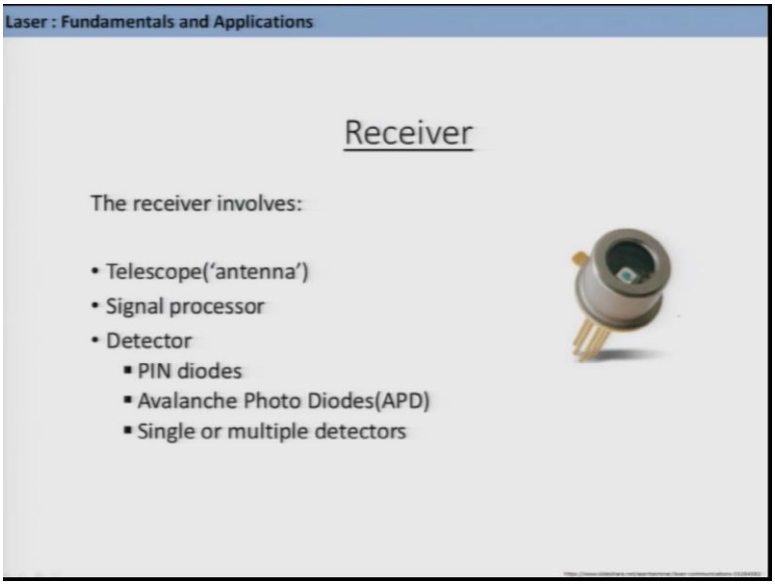
So, you know this is a one way communication system where you are using receiver like which can detect light like a photo diode. So, you take the laser light and you know you calling at the beam and then again second line system which is essentially at telescopic system. We already talked about this one like if you want to collect signal from far distance you have to use a telescopic systems. So, here we use transmitter lens at the beginning and then you have to use a telescopic lens system to collect that signal and then you know detect it so that will act as a receiver all right.

Now, first is the transmitter. So, transmitter is of course, you have to have a laser. So, mostly laser diodes are used for this purpose.

(Refer Slide Time: 31:35)

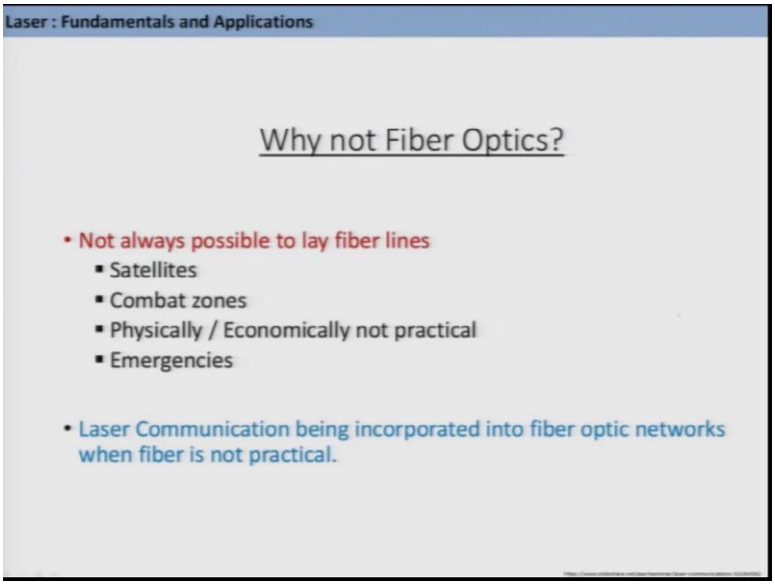


(Refer Slide Time: 31:36)



On the hand you have to receive on the n th and the receiver can be some detector like you know it can be, it can be like an antenna, with a telescope system having a detector like you know PIN diode or avalanche photodiode or you know like you know and you know pmt basic detector or cc based detector they all can act as a receiver of the signal.

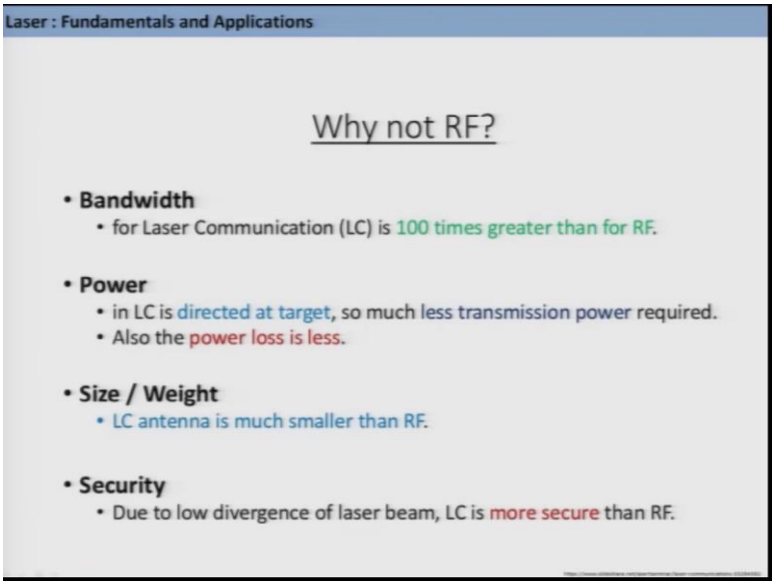
(Refer Slide Time: 32:05)



Now, in this communication system we do not need any fiber. So, you know which way this is better than you know fiber optic communication and why do not you use a fiber optics in the laser communication system. See the problem is that it is not possible to put the fiber optic cable everywhere. So, like you know if you are talking about communication between two planets it is not possible to lay the you know fiber optic cable right. And also if you want to have a communication where is going on I mean you place the you know fiber optic cable and it in know it goes in no time. And if you want to lay this fiber optic cables it can be really really expensive and suppose you need to have a communication on emergency basis. Then you should have a mean to do that and that is where the laser communication come into the play.

So, essentially because the fiber optic cable connectivity may not be possible in certain cases it may be expensive it you know. So, whenever it is not possible to do that and wherever you can avoid having fiber optic cable network you can use laser communication network system.

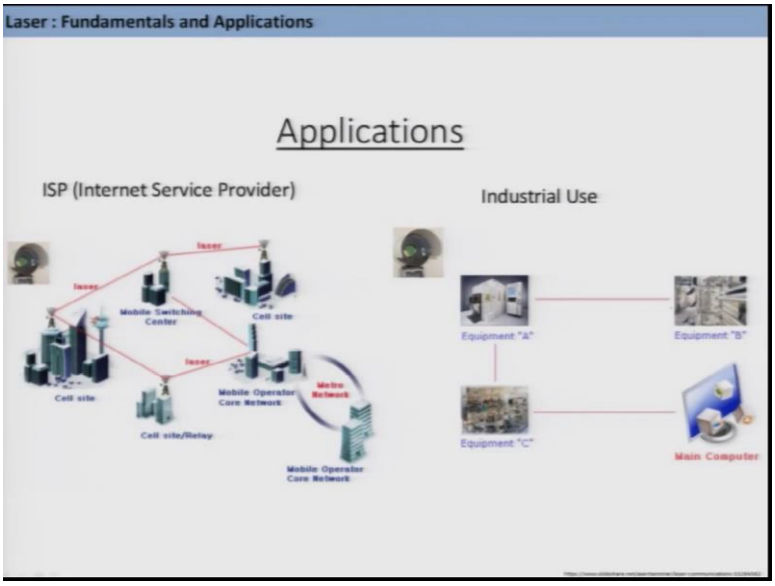
(Refer Slide Time: 33:53)



And if I again ask them fine I understood about the fiber optic network why not then why not radio frequency. So, here is the problem is a bandwidth for laser communication the bandwidth is 100 times better than that for radio frequency in terms of power in laser communication system is you know laser communication system is directed at target. So, so much less transmission power is required and more over because it is a direct communication the loss is also very less.

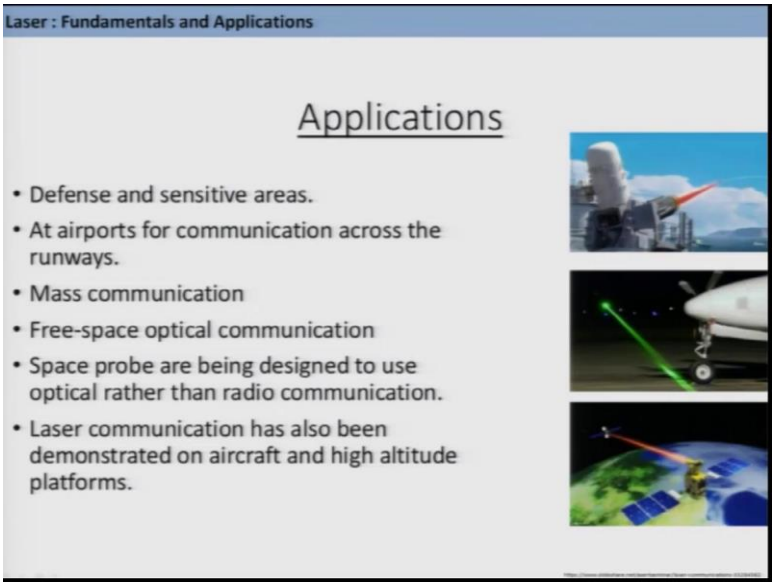
Third the LC antenna which receives is much smaller than radio frequency antenna and fourthly due to low divergence of laser beam laser communication is more secured than RF. So, you know many cases if you want to transmit data which are which you want to keep really really secured you would need a system which does not diverge much so that others cannot you know intercept that one. So, in that regard laser communication is far better option compared to RF communication system all right.

(Refer Slide Time: 35:13)



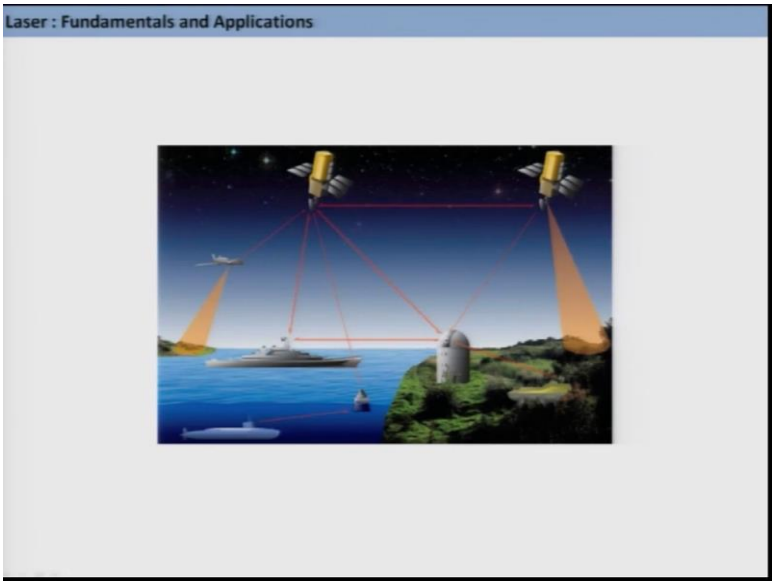
So, what are the different sectors where this laser communication is applied? It is applied in the ISP sector which is the internet service provider. So, there is a huge connectivity between several you know internet provider you know radar system. So, it can be you know also in the mobile systems, mobile networks also. In industry you have the communication between several components several equipments and they are all tethered together one you know main competed that controls all these communications.

(Refer Slide Time: 36:02)



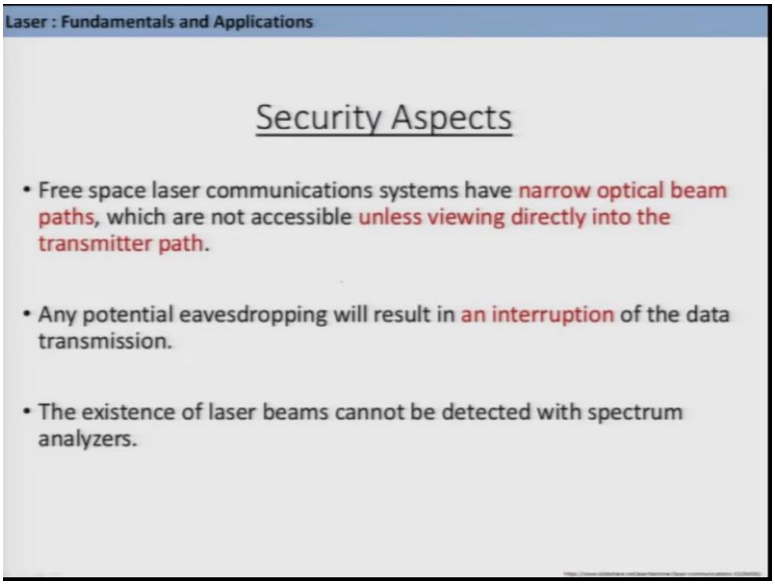
You can also have you know applications of this laser communication in defense or other sensitive areas at airports so far you know communication across the run ways where you would not like to have any kind of interruption for mass communication and of course, free space communication like you know between planets. And a space probes are being designed to use optical rather than radio communications and the laser communication has also been demonstrated on aircraft and high altitude plat form. And not only that you also have communication laser communication system being implemented for you know underwater communications as it shown by this picture like through satellites terminals the air communication is done you know reason given below sea to the submarines.

(Refer Slide Time: 36:42)



So what are the security aspects? Free space laser communication systems have narrow optical beam which are not accessible unless viewing directly onto the transmission, but as what I was saying, so less divergence. So, you know very less chance of interception of that particular information that is being passed.

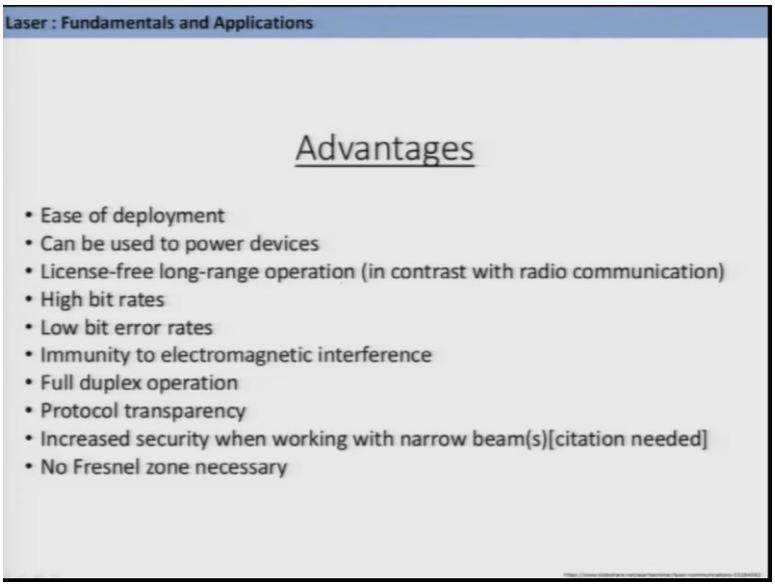
(Refer Slide Time: 37:05)



So, any potential eavesdropping will result in interruption of the data in transmission. So, if there is anything anyone you know tries to see the signal it has to be just come to the beam park and in that case your communication will be immediately gone you will realize that something is problem.

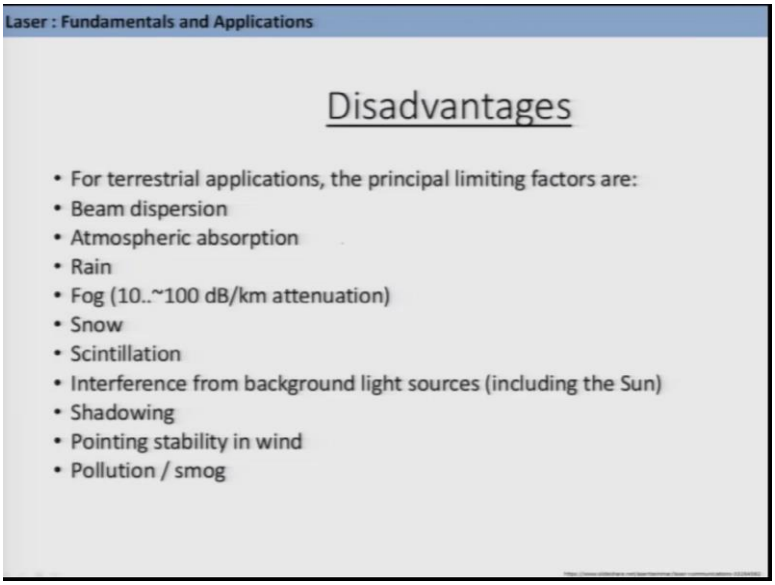
The existence of laser beams cannot be detected with the spectrum analyzer which is a very very you know advantage because it will not you know go and scatter like RF.

(Refer Slide Time: 38:06)



So, what are the advantages? It is easy to deploy your need fiber optic cable or you know big receivers etcetera etcetera, it can be used to power devices and you do not have a problem of you know licensing. So, license free long range operation which is not possible in case of radio communication you can have you know high bit rates low bit error rates you know they are immune to electromagnetic interferences which rather kind of communication techniques are very often you know they suffer from this, you know electromagnetic interference whenever some problems are you know like solar storm happens this communication system just goes hey where which is not the case in case of laser communication. You can duplex the operation fully and you can have many other things like you know you do not need any Fresnel zone.

(Refer Slide Time: 39:07)



No technique is free of disadvantages so is our laser communication process also. So, for you know terrestrial applications the principle limiting factors are like beam dispersion, atmospheric absorption, rain, fogs, snow scintillation interface from background light sources like sunlight, shadowing, pointing stability also pollution, smog all of them with lead to loss of the laser light and hence the communication will be disturbed. But given this disadvantages the advantages seems to be much much higher, much much better for laser communication over any other communication system.

So, today what do we have is that you know lasers have you know applications in various different sectors of medical sciences and also just now we have seen that in

optical communications laser is being used and those optical communication driven by lasers are being used in phase different sector of our life. So, the next class will be the last class that will be having in this course and I will be talking about you know one very important aspect which is laser safety. So, I will see you in the next class.

Thank you very much.