Laser: Fundamentals and Applications

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Lecture – 12
Properties of Laser: Directionality and Intensity

Hello and welcome back today is the second day of this week. So, what are we going to learn today? We will be talking about the properties of laser light and their applications. We have talked about these properties in the first class itself. So, we just mentioned about these properties, we did not talk about the origin of these properties. And we also talked about the applications of laser light, but we did not directly relate the properties of laser light to specific applications.

So, we will try to do that in this class bit briefly. So, we are going to deal with the properties of laser light and their applications.

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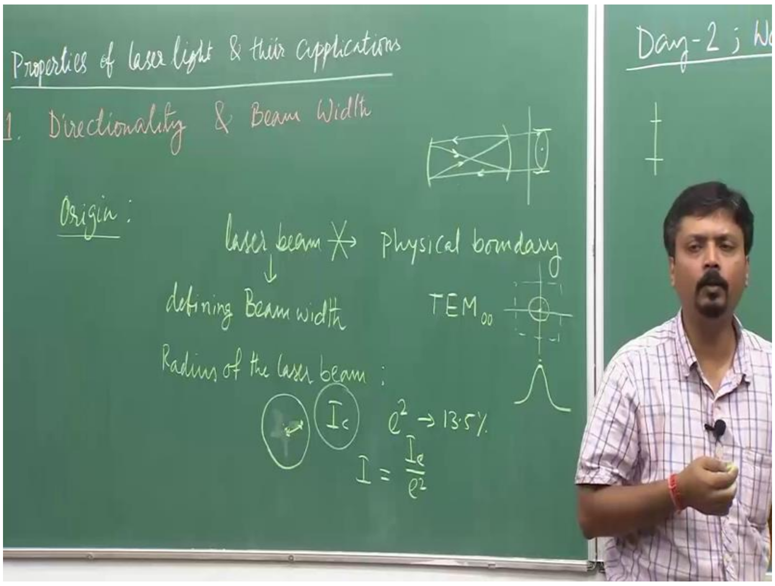

So, the first thing that we will learn today is the directionality and we will also learn about beam width.

So, the first thing that we will talk about is the directionality. So, in the very first class we said that laser light has a very very high directionality. So, it does not you know sprint. So, if you take any light normal conventional light. So, that is isotropic in nature right. So, it goes in every direction. So, if you know are close to the light source the amount of intensity that you will get if you are little away your intensity drops because they are always diverging as they are going in every direction.

So, if you are looking at a conventional light you do not get that directionality which you actually get in case of laser. Now the origin what is the origin? So, I am pretty sure that by now you yourself can figure out why there is a directionality, because we are using a cavity and there is an axis of the cavity and the light, the photons which are getting amplified must fall along this you know they should have their propagation direction along this axis. Or the range that is you know provided by my laser cavity.

So, if I have if I have my cavity like this then it is essentially guided by this you know physical dimension of the spirits. So, as we have shown in the one of the previous classes. So, and ultimately it goes out. So, the you know spontaneous photons which have their k vector lying parallel to this and falls within this width will be amplified and they will be keeping their you know direction in this direction.

So, when they come out they have no other option, but to follow this direction. So, this is the reason when you know that we see that they have a very large directionality right. Now along with this directionality there comes another thing that this laser light it has a width and this is like a real track like ok.

If I take this you know cross section of this beam and then you know. So, if I take a cross section along this is something like this right solid. So, if I take a cross section I will see that you know I if I take a cross section here, and if I take far here I will see there this length is pretty much the same; that means, it is pretty much like a beam we have been talking about beam, but why do I say that this a laser beam, why do not I just say laser light, because it is kind of collimated ok.

So, the photons are coming like a physical beam, what is the difference between say steel beam or say in any other you know metal beam to this photon beam coming out of laser is that in case of metallic beam we have a physical barrier or physical boundary right. So, here in this case we do not have a physical boundary.

So, when you talk about laser beam, we do not have physical boundary, we do not have. So, in a in a metal beam we define the beam width always. In this case also we have to define a beam width which is an very important you know characteristics of a laser light, because that you know gives rise to certain other properties.

So, it dictates like how small you can go in terms of spot diameter when you try to focus the beam using certain optics. So, how do you define a beam width for a laser beam. So, our job is to define beam width for laser light, how do I do that or how what is a normal practice? The normal practice is to start with the center of the laser beam.

So, this is my center of the listening, and I know that there is no physical boundary like I have drawn very nicely here one line here one line here creating a boundary, but you know there is no physical boundary as such. So, no before going into that we must tell that you know this beam properties are also associated with the mode of lasers laser light what which mode it should be the transverse electromagnetic mode.

So, this is related the TEM mode. So, the simplest thing is to look at a mood like TEM 0 0 mode which I showed in one of the previous classes. So, if I look at the beam profiles on a photographic plate it will look like a circle. So, I just mentioned that there. Now what will you find out if you look at the intensity distribution pattern here ok.

So, one thing of course, there is no node going across this. But what you will see is if you take this cross section or if you take this cross section and plot the respective intensity, you will see something like this pretty much like a Gaussian. So, this intensity profile if you look into the 3 dimension. So, you will see a Gaussian profile. So, the central part is the most intense and then it is falling off this ok.

So, in such a beam we can very easily define the beam width by. So, how so the radius of the beam. So, laser beam is defined as follows. We start from the center. So, if this is my say laser beam cross section. So, laser is propagating in this direction I am taking a cross section and I am nicely drawing this line, but we know that there is no physical boundary here.

So, how do I define I start from this center and I go to a distance radially meaning I go in this direction or this direction or this direction or this direction. In this case it is very simple because this symmetric all around right. So, if I go radially and go up to the level up to the distance where the intensity say this I c corresponds to intensity at the center; that means, intensity here.

Now, if I go a distance where the intensity falls off by e square of this intensity; so essentially at a distance where the intensity will be I c by e square. So, that distance say that is as distant is here then I will say this is the radius of my beam and this e square is roughly 13.5 percent.

So, in other word I can say that if I start from this center of the beam and keep going radially until I see that the intensity has fallen down to 13.5 percent of the intensity here. I will define that as the radius of my beam. So, that beam width will be 2 r that is the diameter, correct. So, this is how I define that beam width. Now you know in typical numbers if I look at the lasers can have beam width of a millimeter to a centimeter.

So, knowing that this laser has a beam width and laser has a directionality we can also look into the divergence of the laser beam. Now many lasers they do not diverge pretty much.

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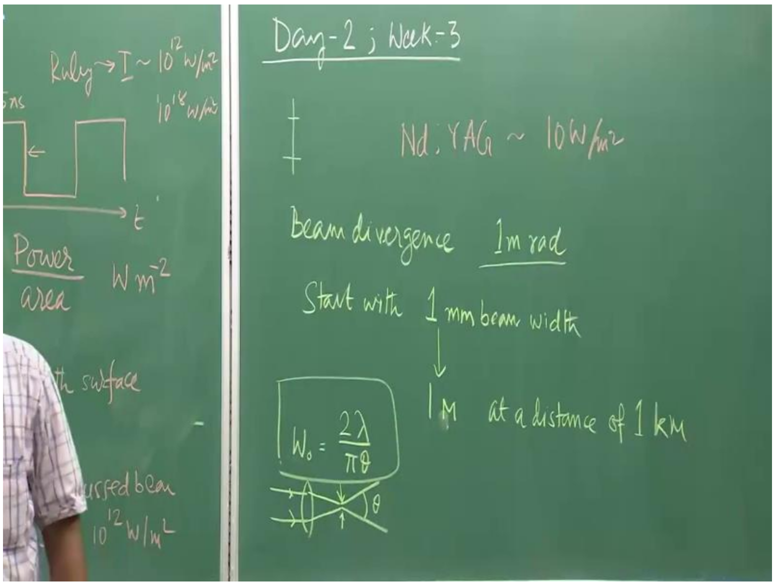

So, say for example, a typical value of beam divergence will be approximately 1 milli rad.

So, when I say a beam has a divergence of one milli rad what does that mean? That means, if I start with a beam width of 1 mm it will appear to be sorry, this is one millimeter, it will appear to be one meter at a distance of 1 kilometer. So, it will if you start from one millimeter we will see the beam to be as 1 meter at a distance of 1 kilometer.

So, you can see that you know the divergence is really little, it is not huge if you take you know a flashlight you will see that if you start with beam diameter of say 10 millimeter within you know few meters it will be like 1 meter right. So, this laser light is you know really good in terms of the divergence. And this divergence can be even smaller.

Now, where do I use these properties that are directionality and having a collimated beam with a very low divergence. In industry people use it for alignment of various different tools or equipments using laser light because of these properties. Of course, in fundamental you know optics spectroscopy people regularly use this one, but apart from that in a industrial scale laser light is always used to do that.

Second thing is that in the environmental studies particularly detecting the pollution these properties are very much needed. So, I sited a particular value of divergence one can have much less divergence. So, if you want to know the condition of environment at say you know troposphere level or beyond then you can use laser light because they are highly directional they are you know low on divergence and they have a definite beam width.

So, you can use laser light to do you know pollution detection and measurement etcetera, and even in astrophysics. Now one more thing is that if we take this kind of beam we can also focus it to a very tiny spot by using a convergence optics like lens. So, for a beam like this TEM 0 0 with the TEM 0 0 mode, we can have a you know spot dimension say omega 0 or w 0 as 2 lambda by pi theta.

So, I am talking about focusing the beam. So, essentially I have a parallel beam going put a convergence optics focus them. Now many of you know that we can focus it up to a certain dimension. We cannot really 0ed on a point. So, there will be a beam waist and then it will diverge. And this is my beam waist ok.

So, and this is my angle of convergence theta is related by this one. So, you can you know get a particular spot diameter. So, this is the beam width. Now we can go to very small value of w 0 the beam waist which is very difficult to do with the conventional light.

Now, what is the application of these property that I can really go to very very small focal spot. In industry you need to achieve really high intensity light to cut or weld or to melt things particularly metals or you know leather various other stuffs. So, there you can get that high intensity by focusing it is well understood that if you start with a large beam and then if you focus it, then all the photons are actually you know falling on that particular small diameter which is denoted by this ok.

So, there you find the application of these properties. Now we will move to another one. Second property is intensity.

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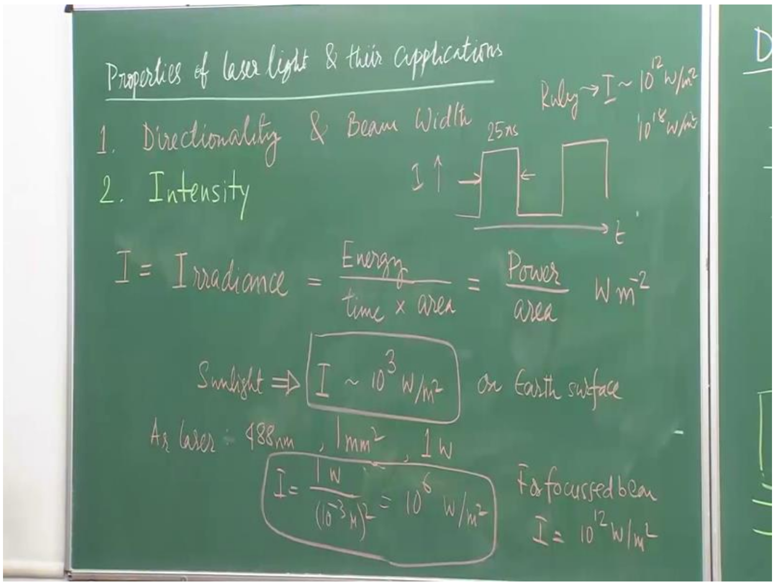

So, this is probably one of the most important aspect of laser which has been utilized in industry. So, just you know 1 minute ago I talked about focusing a beam So that we can you know intensify the beam. And we can use it for you know cutting metals or doing various other processing work in industry.

So, you know how do I define this intensity of laser beam. So, you know this laser beam is collimated. So, they are going in a particular direction it is like a parallel beam. So, in such case we define intensity much better way by utilizing or by using irradiance.

So, what is irradiance? Irradiance is given by energy by time by area. So, energy per time per area. So, this is a lot easier to you know, quantify the intensity of laser because they have a parallel beam going with you know very low divergence. So, this one I can write simply as power this energy per unit time is power by area.

So, essentially this is power per unit area. So, what will be the approximate dimension I can write watt per meter square. So now, we have to look at a irradiance values of lasers now to put things in the right perspective we should also have some reference value. So, what can be the best reference other than the sunlight?

So, for you know sunlight if I consider one meter square area, then the irradiance value; so irradiance is written as I. So, for sunlight I have I value on earth is typically 10 power 3 watt per meter square, this is on earth surface. So, this we should know. So, that we can compare how low or high the laser intensity is in terms of irradiance ok.

So, we will talk about couple of different cases. So, let us say let us take argon laser argon ion laser which can give various different frequency say let us take 480 nanometer output. Now argon ion laser is known to give moderate power, not very high power and it is a gas laser.

Now, at this particular wave length say we have a beam width of one millimeter square, and power of one watt. And this I am talking about an average power what is average power peak power we will learn slow soon. So, we will define those terms. So now, for this system what will be the irradiance? So, irradiance will be power by this one right.

So, 1 watt by 1 millimeter square; so 1 millimeter is equals to 10 power minus 3 meter. So, square. So, essentially sorry this is, so typically it is it can be one watt. So, it will be 10 power 6 watt per meter square. So, a beam of argon ion laser which has an average power of one watt and beam width of one millimeter square has an irradiance of 10 power 6, immediately you can compare these 2 values for the sunlight and for this argon ion laser.

Now, what will happen if you focus this beam. So, if you focus the beam you can go to really really small you know diameter you can calculate that from this. So, if you find out that beam waist you know you can probably you know increase this irradiance by another 10 power 6 times. So, you can easily calculate that one ok.

So, if you take say like you know you know if you talk in terms of the diffraction limit because the beam cannot be focused down to a spot. So, there is a limit, typically this is the diameter of the beam is approximately lambda by 2 lambda is the wave length of light. So, if you consider that and 4 80 nanometer. So, typically say I say like 250 nanometer.

If you convert that you know into area I mean you are assuming a circular beam, then you will see for focused beam you have I equals to 10 power 12 watt per meter square which is really really high, much much higher than the you know irradiance of sunlight on earth surface; if we consider something like a ruby laser which is a pulse laser having a pulse width of 25 nano second ok.

So, you know next class probably we will talking about some of these. So, like pulse width and all. So, say probably I have mentioned it earlier. So, if my light comes in pulses. So, and this is my time axis and this is the intensity. So, this width is my pulse width. So, if for ruby laser it is 25 nano second and if I take you know typical power of you know say 10 watt, then we can find out the irritants by knowing the beam diameter.

So, the beam area of a ruby laser is slightly larger is approximately like a 500 millimeter square. So, if we take that we have to normalize with respect to this time because it is power is per time like in a cheaper time. So, you will see that overall it an unfocused beam that is a collimated beam of ruby laser, it gives an I value of 10 to the power 12 watts per meter square. And when you focus it goes to 10 to the power 18 watt meter square.

So, it is huge amount of intensity, and this have been you know the property which the industry really capitalizes on. Because of this high intensity it can you know cut almost everything and anything and everything. So, for example, if I take you know laser beam of say if I take something like Nd YAG laser and we consider an intensity.

So, if I take Nd YAG laser and consider say 10 watt per meter square, and we can use this to cut a steel plate having a thickness of 3 mm at a rate of one centimeter per second which is really rapid. So, you know these are certain you know unique applications of these lasers because of their properties like high intensity.

So, there are a couple of more properties that we need to quickly discuss, one is the coherence another is the monochromaticity. So, we have to stop today because lack of time. So, in the next class we will start with those 2 properties and looking at their applications. We also learned how to actually estimate you know the number of modes corresponding to one particular gain bandwidth. So, we will talk about all these things in the following class.

Thank you very much.