Laser: Fundamentals and Applications
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Lecture - 14
Continuous and Pulsed Laser

Hello and welcome. So, today is the fourth day of this third week of this lecture series. So, what we will learn today. Today we will talk about few terms that you will very often come across whenever you will till with laser or related stuffs. So, we will start with power.

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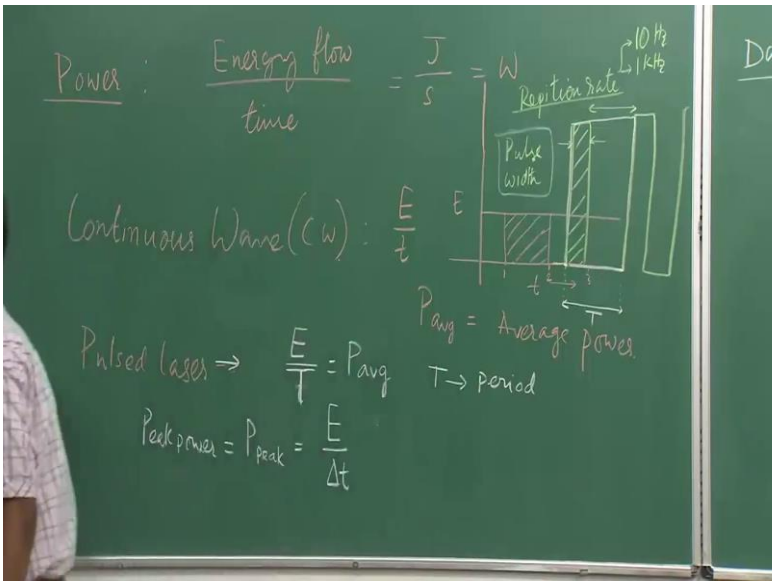

So, whenever we talk about you know power, the main thing that we notice is the energy flow at a given you know per unit time. So, if I specifically write energy flow per time and we normally can write in terms of you are familiar with this terminologies. So, it is joule per second, so we call it watt.

Now in case of laser, there are two different types of laser one is continuous wave another is pulsed. So, let us first see what happens in case of continuous wave or in short we call it CW. So, for CW laser you know power that we talk about is essentially the same thing that you just wrote is E by t and this is you know in a continuous wave laser will give you light always.

So, it is not like some time it is off some time it is on its not like that it is always on. So, if you look at the look at the energy of the light as a function of time then you will see a plot like this and if you look at the energy overall, how will you do that? So, if you say this is time 1, this is time 2 3 and so on in seconds. So, this will give you the power and this is mostly known as average power or so this is the case in this is what we find in case of continuous wave laser now when we have another type of laser that is pulsed laser what do we have.

So, there also I can have an average power, but apart from that we also get something called peak power. So, in case of pulse laser we have average power as well as peak power. Now in case of pulsed laser what do we actually see if we go for that let me just draw the same in the same plot with a different colour. So, in case of pulsed what we generally have let me start from here. So, that it is clear in this way it will keep going and for this amount of time the light is on and this amount of time that is this one this is off. For this particular type of laser we have to define what is average power and what is peak power. So, let us first look at what is average power.

So, this pulses will come and go come and go and you know it will repeat itself several times you know in a one second duration. So, let me introduce another term here. So, this is called repetition rate this is applied applicable for pulse laser. So, what does this repetition rate means that is how many times this pulse will appear in a second. So, if suppose there are you know 10 times you know there are if the pulse is on 10 times in a second then the repetition rate will be 10 sorry hertz suppose it flashes 1000 times then the pulse repetition rate will be 1 kilo hertz similarly if it flashes million times it will be 1 megahertz and so on all right.

So, now this is on for only this time and this has a particular width for the time width for the time being let us call this time width as pulse width. We will look at this pulse width this term pulse width a little bit more closely you know in a while. So, for the time being let us take this width as my pulse width that is for the duration of time when the light is on.

So, if the laser has a repetition rate say you know in one second then if you put a detector in front of the laser you know laser and it detects overall energy emitted by the laser in one second then the total energy for this one. So, the total energy will be say E and this is measured over suppose t second then this will be my P average and this t essentially for pulse laser is given by the period t is time period.

What is t let us look at in this figure. So, if I start from this point where the pulse is just turning on and then keep going till it reaches an equivalent point here then this period is called capital T all right. So, for a pulse laser this is the average power and then what is the peak power then. So, let us called P peak this peak power is the total energy over a period of time given by this pulse width. So, if I call the pulse width as delta t then this is my peak power. So, we have defined the average power as the energy part time period which is this time and peak power as the energy over this pulse width time.

So, if you think about it that over this total time period the amount of energy that you know a detector will measure will be the same, only thing is that certain amount of time there is no light all right. So, essentially both the energies will be same in this particular case right I hope this is clear. So, therefore, using this equality in the energy of the laser output for when we quantify P average or peak power for a pulse laser we can get a relation between these two different types of powers. So, what we you know essentially mean is that from average power we get E equals to correct and this is from P average.

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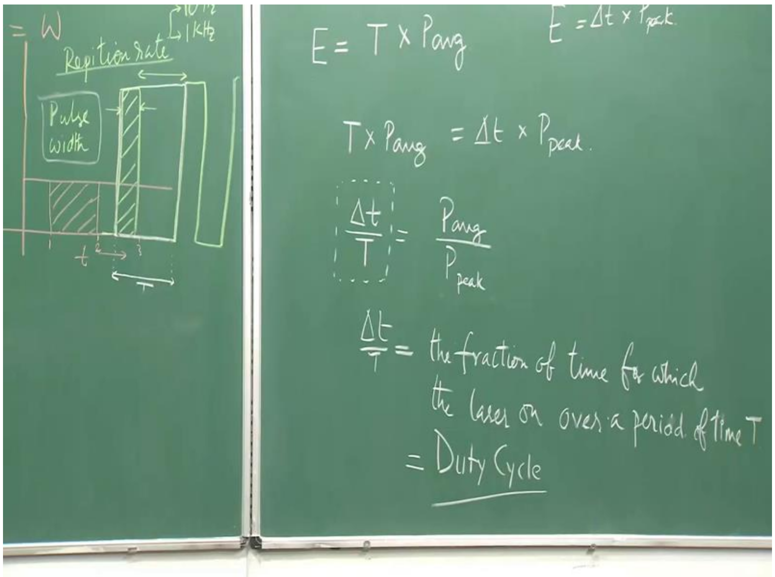

And from P peak we get E equals to delta t multiply it by P peak. Now as I said just a couple of minutes back that for a pulse laser I can see that over a period of time t if I measure the energy that will be exactly equal to the energy if I measure it over this delta t time period because this much amount of time there is no light. So, then I can equate this two E's. So, essentially I can write.

Now, I can rearrange this in a way so that I can write delta t over capital T is equal to average power divided by peak power. So, this quantity delta t by capital T has a special name. So, what is this delta t by T? Delta t by T is essentially the fraction of time for which the pulse is or laser is on over a period of time correct and this is known as duty cycle of a laser. So, this is very important term whenever you deal with a laser it will come with a particular number for that laser. Now what advantage do you we have that if we know the duty cycle for any given pulse laser and if we know the average power then we can very easily find out the peak power what the other way around if we knew one of them we can easily find the other one.

Now, I talked about this peak power I will try to explain it once more because this is somewhere people get bit confused at what are the differences between a peak power and an average power. So, for peak power essentially you assume that whatever the energy flow is here if the laser would not be turned off for a given period of time which is this time then that would be the power of the laser that is average power of laser right. So, this is what actually the case. In a pulse laser the light is turned off for certain period of time which is equal to this amount. But what I am saying is if the laser would not be turned off for this period of time; that means, if it would behave like a continuous wave then whatever the average power that you would get or whatever the power that we would get that is my peak power.

While the average power means that it does not matter you know for how long it is on or off for a given period of time how much energy which is producing right and that will define my average power. So, you can understand the value of peak power and average power they will be quite different. So, let us have a look at that let us take an example.

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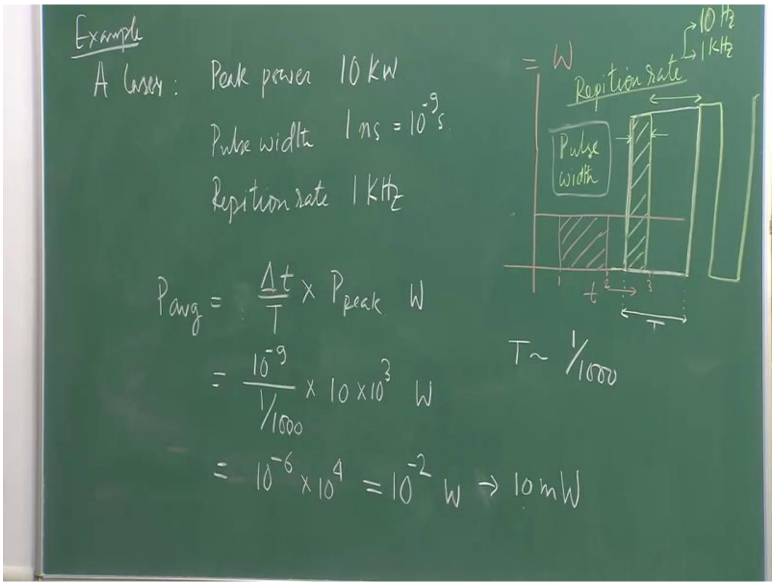

So, if I take a laser, this is an example a laser having an output let us take some recent number. So, for this laser I have a peak power of 10 kilowatt and have a pulse width of say 1 nanosecond which is equal to 10 power minus 9 second and it has say repetition rate of 1 kilo hertz; that means, there are 1000 pulses per second.

So, if I have this one then what is my P average I need to figure that out. So, how do I find out what is the P average, if we recall this equation here that is the duty cycle is equal to the ratio of average power to the peak power then what I have - I have correct therefore, how much is my delta t - delta t is 10 power minus nine second.

Now, what is my t what is the period. So, how do I calculate the period? So, I have such thousand pulses coming in and that will be you know one second wide and I need to find out what is my this T. So, easily what I can find out neglecting this width of 10 of a nanosecond I can roughly assume that this gap sorry this gap is at essentially 1 upon 1000 second right.

So, this what I am saying is this t is roughly 1 by 1000 because there are 1000 pulses coming in 1 second. So, if I put that by 10 kilowatt; that means, correct. So, therefore, I have 10 power minus 6 into 10 power 4 that is equal to 10 power 2 and if we look at the dimensionality then this is time this is time and this is watt. So, ultimately my dimension will be always watt, this is I can write. So, 10 power minus 2 watt right.

So, essentially this is nothing, but 10 milliwatt. So, you can see if a pulsed laser has 10 kilowatt peak power it gives a 10 milliwatt of average power so that much is the difference and the difference will depend on what is the repetition rate what is the pulse width and so on. So, a peak power can be much much higher than average power and this peak power is of tremendous importance in certain cases when we talk about certain applications of laser in detail that time you will see why this peak power is so important all right.

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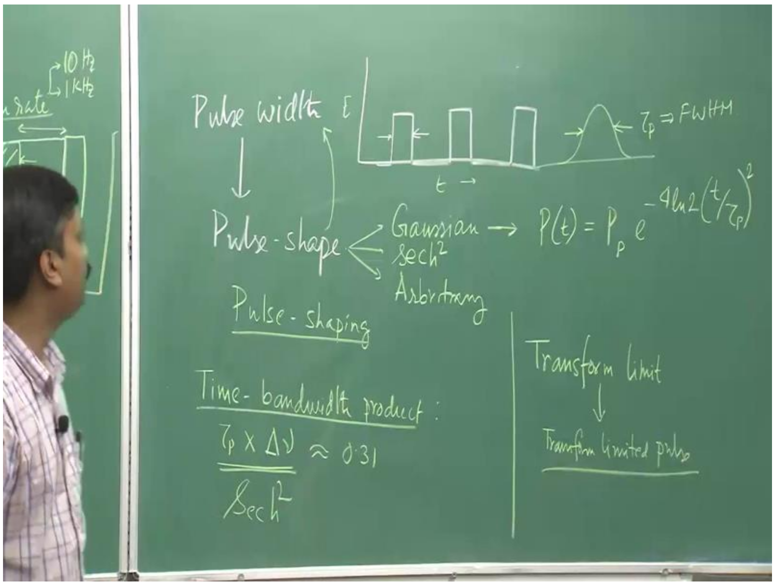

Now, we have talked about the pulse width. So, essentially we have used this term pulse width just now. So, normally what we you know did we said that if the light is on and off and we took it like here like squares or rectangles of light envelope where the light is on otherwise its off and we said that this time period is my pulse width. So, this is a very very simplistic view. As a matter of fact when we talked a talk about laser pulses this pulses can have a particular shape.

So, we need to know what is pulse shape or shape of the pulse because the pulse shape will determine what is the pulse width. So, they are very very related now mostly we show like the square or rectangular pulses, but the pulse can have different temporal profile. So, what is pulse shape essentially? So, if you look at these things. So, this is nothing, but energy and this is time. So, this is a temporal profile or the shape of this energy distribution over time. So, this can be of different type.

So, in general when I talk about pulse shape I know that this is a shape of the temporal profile of a laser pulse which can be fitted to a particular function at least approximately. What kind of function? It can be our very well known Gaussian, it can be a high per second or it can be various other some arbitrary functions. So, some function should fit the pulse and accordingly I will have a pulse shape and that will dictate what will be my pulse width.

So, for example, I can fit a pulse with a Gaussian say for example, I will take a one particular example of a Gaussian function which is a function of time where this tau P is my width of the pulse. So, if I can fit it with a Gaussian nicely then I will call this as a Gaussian pulse and then I will I can get this width of the pulse. So, normally say for example, if we have a Gaussian pulse nominally we can take the full width half maxima. So, normally what we can do if we have a pulse of say like this then the full width at half maxima we can take as my pulse width. So, this is.

But this can be incorrect for in case I you know take a full width half maxima for say high per second you know pulse. So, there are certain factors which has to be multiplied with that full width half maxima value. So, that we get the actual pulse width. So, so you know now that you know there are many things regarding the pulse ship and there is actually a total different topics of research which deals with the temporal shapes of the pulse is known as pulse shaping. So, it is good to know this and different shapes of pulse can do different jobs that is why people are interested about this pulse shaping all right. So, now we discussed about this pulse width because we have used this pulse width in finding out what is the you know peak power.

Now couple of more things I will introduce today they are say time bandwidth product, you will come across this term very often. So, simply this is a product of the pulse width which refers to this time pulse width always refers to the time because I am looking at the time profile or the temporal profile of a pulse and taking its width. So, this time refers to pulse width and multiplied to the spectral bandwidth. So, we have talked about the spectral bandwidth quite rigorously in last few classes, so we call it like delta nu or delta lambda if you talk in terms of wavelength. So, this quantity is of tremendous importance.

So, these values also depend on what kind of pulse that you are using. If suppose I have a high per second pulse. So, if we consider high per second pulse then this value is approximately 0.31 issue all right. So, what does that mean this puts a limit this kind of relation actually puts a limit to the you know minimum spectral width for a given fixed temporal width or minimum temporal width for a given spectral bandwidth which is known as transform limit.

So, you can understand that if I have a particular width bandwidth for the spectra say delta nu equals to say 100 hertz arbitrarily. Then my pulse width can or cannot be you know minimized or compressed beyond a certain limit and that is the transform limit the moment I reach that particular limit my pulse is known as transformed limited pulse and these terms are extremely important when we particularly deal with ultra short pulses.

What is ultra short? We discussed about a nanosecond pulse, so this is short pulse, but an ultra short pulse is something like a fem to second that is 10 power minus 9 second and beyond. So, like attosecond 10 power minus 18 second of on the order of 10 power minus eighteen second. So, in those cases this time bandwidth product and this transform limit is of extreme importance so that we can you know be sure that I cannot squeeze the pulse width further or you I cannot squeeze the spectral width further and I have reached that limit.

So, these are the few terms that we discussed today we will be you should you know learned about this one a little bit more from the books that I have suggested and this will definitely help you when you start reading about laser and we go to the next in a section of this particular course when you hear these terms quite often so that you do not you know feel that I do not know this terms. So, that is why I thought of introducing this terms today.

So, we will talk about you know certain important aspects like what are the ways we can make a laser pulsed, what are the pulsing techniques. We will discuss that in the next class and beyond.

Thank you very much.