Laser: Fundamentals and Applications
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Lecture - 13
Properties of Laser Coherence and Monochromaticity

Hello and welcome. So, today is the third day of this week. So, we have been looking at the properties of a laser light and their origin as well as their applications. So, in the last class we will looked into a couple of a properties one was the intensity, and we you know said that the intensity is probably the most important property of laser that has been utilized by a commercial establishment industry. So, today we will take it from there.

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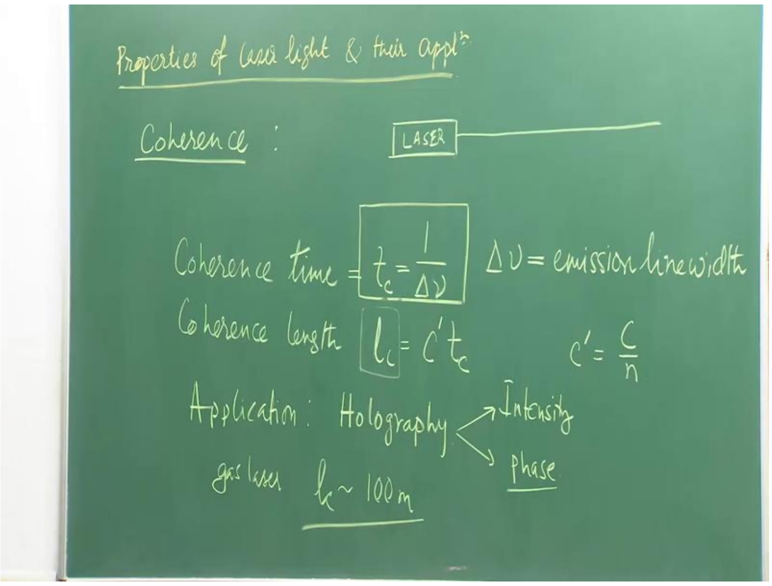

And we will look at another one and properties of laser light and their applications.

So, the first thing that we will consider today is the coherence. So, this is the property which we differentiate a laser light from a conventional light source. In conventional light sources what are the main you know source of a photons it is basically spontaneous emission in most of the cases. So, the spontaneous emission by their own nature they are not related by any phase relationship.

So, you know first place they are scattered in various direction and you know they have different phases and all. So, in laser light we have all the photons having same phase. So, they are related by phase. Now if I take a device which is laser and then we allow the light to come out and propagate; we say that when it generates it is coherent at the beginning. Now we have looked at a one property that is a directionality and a beam width right.

So, there we you know said that they are more or less parallel and after certain a distance they you know become you know broader the beam width become larger, that is because of a property called divergence. So, you know the beam does not remain collimated beyond a certain distance. That distance may be you know really long and that distance can be short also. Here also in case of this property coherence do we have this coherence intact? At infinite distance or not; so is there something like coherence time that is if I start here at time t equals to 0 then if I look at the beam the same beam at some t equals to t prime then will there still be coherence intact or not.

So, is there a coherence time and related to that I can also ask is there a coherence length. So, we will see what are you know these 2. So, what is coherence length and what is coherent time. So, coherence time this is given by this term tc and is. So, where this delta nu is my emission line width? So, from upper layer to the ground level or the lower level when the transition takes place due to a stimulated emission, that emission frequency will be associated with a line width ok.

So, the spectra of that you know emission will be associated with a width which is known as line width. So, this is the expression for coherence time. So, when I write this expression; that means, that I am telling that it will not we infinitely coherent after certain time period which is tc it will lose the coherence nature. And the photons will not be any longer correlated in terms of phase. So, if there is a coherence time then definitely there will be a coherence length, because you know up to tc if the beam is coherent then the length or distance covered by photons in that period of time tc it will have it is coherent property intact.

So therefore, that particular length scale lc is known as coherent length, and you know we can very easily figure that out this is multiplied by the speed of light. So, to be you know proper if we consider the medium then I can write c prime instead of c where c prime equals to c by n we have seen this earlier. So, what does that mean? That this is the you know a length scale such that any distance shorter than this lc we will have the photons correlated in terms of their phases. So, these are the 2 terms that we will you know need to know. So, that is why I am you know mentioning them.

Now, these you know property coherence what are the applications of that property. So, this is one property which finds a tremendous application in fundamental science. So, fundamental research you know, people use this you know a coherent beams for several reasons. But when it comes to actual a commercial applications, the applicability of these property is quite low let us be honest about that. But there are still few places where the phase information is vital therefore, this property coherence is also of importance in those applications where. So, we have heard about ok.

So now So, we have heard about holography right. So, most of us have come across this term you know many times. And also we have the seen a holographic images. So, in this particular case when the holographic images are formed it not only depends on the intensity of light. So, there are you know information stored in the holographic images it is like a kind of a 3D image formation right. So, there it contains the information regarding the intensity, but also contains the information about the phase, which is not there for conventional photography. They regularly the photography that we do even using our you know cell phone camera.

So, there we do not require any phase information. In case of holography we need this phase information. So, in this particular case we have the application of the coherent nature of laser light. So now, if I want to give you certain numbers like, how long this lc can be? This can be fairly long. Like if I take a gas laser this lc value can very easily be 100 meter. So, this is this is quite a big thing. You know, getting a coherent source is a big thing at the beginning and then you can maintain the phase relationship between you know among the photons for a length scale as large as 100 meter ok.

So, particularly for like you know gas lasers you can get this length scale. So, this is just for your information and to get an idea about this scale. And knowing this one you can easily find out what is the length scale a time scale over which the coherence sustained.

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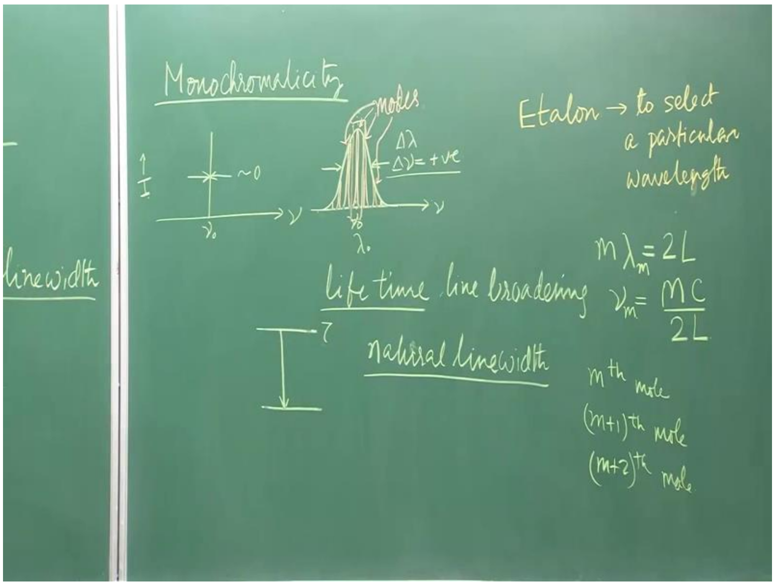

So now let us look at another one another property that is that is monochromaticity. So, from the name itself you can understand what is monochromaticity, we have also said this one earlier, but let me just you know reiterate it once more.

So, mono means single chrome means color. So, the property of having a single color that is a single frequency is known as monochromaticity. So, at the beginning of this course we have said that you know laser has a property that it can be monochromatic; so most of the lasers at monochromatic in a nature. So, what does that mean that you have while the intensity goes in this direction and frequency or the wavelength goes in the along the x axis. And then this is the corresponding frequency of the laser and this is almost like a line.

So, this property is probably most important in chemistry and physics, particularly in chemistry it is very, very important. Now I drew this in a spectra as like a line, now do we really have a line? No, we do not have. Just few minutes back we have mentioned something like line width. So, this one though it seems like this width is like nearly 0, but actually there is a finite line width. So, if I actually look at this one. So, it will look like, And so you can see around this nu 0 you have us positive line width right.

So, this line width can be fairly narrow that we can say this is monochromatic. Nevertheless you know it is not a single line, but there is a width. Now if you ask what is the reason behind having a width then I will very briefly tell you that there are several factors which causes this you know line to spread. There are things like homogeneous line width and heterogeneous line width. So, those reasons which you know which effects all the you know atoms or molecules in the laser active medium here in this context in a same or identical way that will lead to a line broadening which is known as homogeneous line broadening. And the other causes which you know affect different atoms or different molecules in a different fashion that will lead to heterogeneous line broadening ok.

So, what are the different reasons that you can have? You can have a line broadening due to pressure in homogeneity, you can have due to the velocities of you know molecules in a system. So, there are other mechanisms also. The most important cause behind a line broadening which is inevitable; that means, you cannot get rid of it at any cost, is what is called natural line width or the broadening is called life time line broadening. So, from the name you can understand that this is related to the lifetime of energy state.

So, for example, if you are dealing with a an emission spectrum. So, the molecule jumps from the upper state to the lower state to release photon and you can get the corresponding spectrum. And if it is involved between this 2 state I expect the spectra to be this, but it is not, now why because this state has a definite lifetime. And if you have heard about heisenberg uncertainty principle then you can understand that this will incorporate uncertainty in measuring the frequency, because frequency and time they are related by uncertainty principle ok.

So, if we cannot measure the frequency exactly; that means, there is an uncertainty and how this uncertainty is reflected in the spectrum? Uncertainty is reflected in this way by having a width of the spectrum. So, this lifetime of a state is it is intrinsic property right under a given condition. So, this I cannot get rid of therefore, the life you know line broadening due to lifetime of a state is very, very natural to any system. And this corresponding line width is known as natural line width. You can possibly get rid of all the other sources of line broadening, but you cannot get rid of natural line width.

So, the bottom line of the story is that no matter what I will definitely have a line width for my emission spectrum. And thereby does not matter how narrow that be there is a positive delta nu always present. Now why I have been reiterating on this one? We have looked into the longitudinal modes right. So, when you consider a cavity we have seen that you know there are you know different frequency modes that can be supported by the by this cavity formed by the mirrors are those which form standing waves. And we have also seen that there is a condition that is this.

So, for different value of m we get different modes. So, we get first second third 4th m th you know q th different modes. And the corresponding you know frequency also we can calculate right. So, this is for a particular mode. So, if I keep the same it will be MC all right and I can also specify this one as lambda m and nu m. Now I can find out you know say one particular mode corresponding to one particular wavelength and then say I find m th mod then I can have m plus 1 mode and so on all right.

Now, I have a definite nu 0 or definite lambda 0 and then I have a definite delta nu right. So, it is possible depending on the delta nu value or delta lambda I can express that in either way I can have many such modes all right. So, my picture will look like this if I use a different color. So, these are different modes, which modes this a longitudinal modes. So, this one, this one, all these are different different modes. Each mode is associated with a particular color particular wavelength or particular frequency. So, say over on this envelope if there are 1 2 3 4 5 6 6 modes that can be accommodated then there are 6 distinct frequencies or distinct wavelengths are possible ok.

And we cannot separate them just like that. We have to do something in order to you know select one of them. How it is done? That is done by so, if I want to select say this particular mode. I can do that by using something called etalon. To select a particular mode that is particular wavelength or frequency. So, this is done within the laser itself. So, we will not go into the detail of the mechanism of etalon, but what I can tell you very, very simply is this particular optics etalon, it works pretty similar to a cavity itself. And cavity they support particular modes. So, thereby if this cavity is inserted into the laser cavity in a proper way then it will select only one mode say if it does So and then that particular mode is being oscillating inside the cavity and getting amplified.

So, I get a particular mode. So, we can choose the etalon in such a way that I can get the particular wavelength that I want all right. So, I can see that I can ultimately get a light output which is a having very, very narrow line width. You can easily see that you know these modes are associated with the line width which are really narrow. So, we can call that is as monochromatic they are fairly monochromatic. Now So, I told you that there are you know several different mode and we need to have an idea that you know how much is the distance in terms of frequency or wavelength between these modes.

So, let us take some numbers and try to estimate that.

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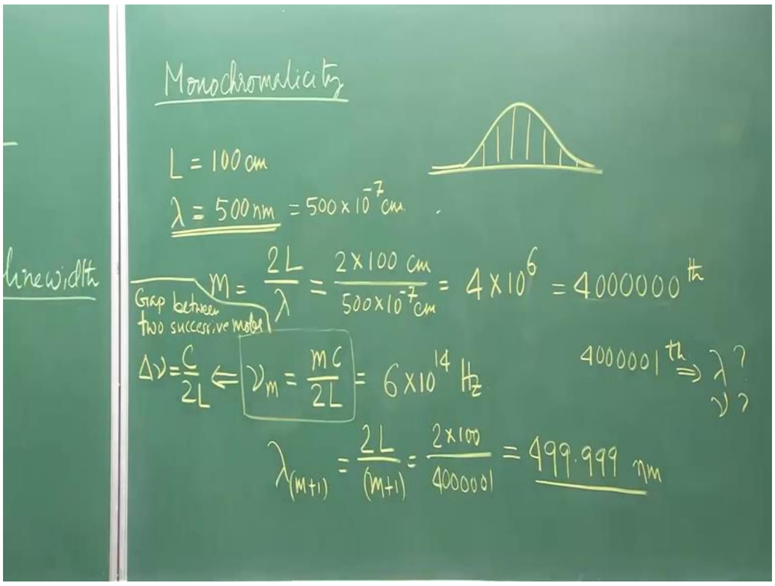

So, if I take a cavity length l 100 centimeter, and the wavelength output of the laser of that particular one particular mode as 500 nanometer which is in centimeter unit I have this value. So now if this is my output then can I find out which mode it is. So, what is the value of m that we used earlier right. So, if I have to find m then what is the value it is because m lambda equals to 2 l that we have seen just few minutes back.

So, here 2 into 100 centimeter and here you have the ratio becomes just a number and if I directly give you the value. So, so that particular mode is this mode. So, you have you know so many modes before that and many modes after this. So, right now what will be the corresponding frequency. So, that we have seen earlier, that is MC by 2 l we have all the values with us. And if we put that you can calculate I am giving you the final result as this.

So, my m th mode has the number this 4 n to the power 6, now if I want to find what is the wavelength or frequency of the m plus 1 mode. That is I am looking for a mode which is all right. So, what is the wavelength or frequency that I need to know. So, if I have to do that. So, I am writing as n plus 1 instead of writing that big number. So, what

I have we have again 2 l correct by the number of that particular mode. So, in our case this is m plus 1 and what is this m plus 1 m plus 1 is this number correct. So, again 2 into 100 and then you get 4 this 1. And if I do this division what do I get I get in terms of nanometer ok.

So, you can verify this one by yourself. So now, you see the m th mode has a wavelength of 500 nanometer and the m plus 1 has wavelength 499.999. So, they are very, very closely spaced right. So, in this way you can estimate any mode right. And also you can figure it out by yourself or you can you know estimate what will be the distance between 2 modes; so the distance between 2 modes in frequency. So, this is the frequency right. So, if I take nu m and nu m plus 1 we can easily figure out that delta nu. So, from here we can figure out delta nu equals to c by 2 l. So, this is the you know gap between 2 successive modes or adjacent modes. And I am talking about frequency gap all right.

So, you can also if you are given you know the particular characteristics of the laser you should be able to also tell what is the gap between 2 particular modes. And why is it that important? That I was you know showing this that I have a spectra and then several modes can occur here. So, how many number of modes are there that we can predict? And you know for different, different laser system you should be able to estimate these things right, for your own understanding.

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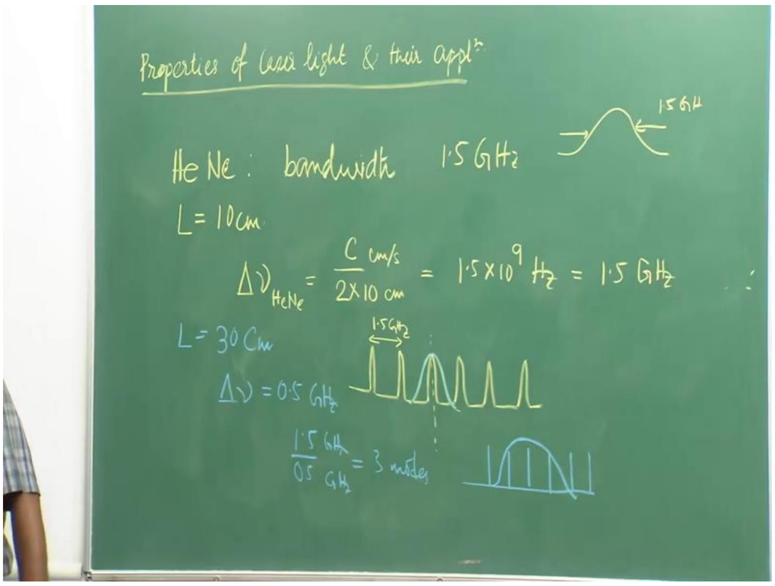

So, if I take a small example if I take the case of He Ne laser. So, for He Ne laser bandwidth is 1.5 gigahertz. So, this is that line width of this whole envelope. So, this is my 1.5 gigahertz giga means 10 power 9 all right. So, approximately this He Ne has a cavity size of approximately 10 centimeter. So, what is the gap between 2 successive modes. So, if I call that as delta nu for He Ne what is the value? That is c by 2 into 10 in centimeter. So, you can also find out this one as centimeter per second and you get it in hertz unit.

So, what will be the value that you will find it is which is 1.5 gigahertz perfect; so, essentially what does that mean that if I have several modes. Several modes are possible right I can keep going in both the direction. So, this gap is 1.5 gigahertz right. Now once I figured this one out I can tell you how many will be there. So, what is the bandwidth of this one this is 1.5 gigahertz and that this gap is also 1.5 gigahertz. So, if this one is the central wavelength of any laser then this is essentially the bandwidth let me reiterate this one. So, you can easily understand that per bandwidth in He Ne laser there is only one mode for this given configuration suppose I would have another case l equals to 30 centimeter ok.

So, if l it with 30 centimeter what would be the case? Here it would be divided by 3. So, in case of 30 centimeter my delta nu would be 0.5 gigahertz So that means, this distance is now 0.5 gigahertz. So, for a given bandwidth of 1.5 gigahertz. I can easily figure out that there will be 3 modes right because 1.5 by 0.5 gigahertz 3 modes. So, if I want to show separately. So, it is like that. So, it will contain. So, 3 different modes ok.

So, in this way I can you know easily figure out how many modes will be there and all, all right. And one more thing I would like to tell you before I finish today is a quantity which is known as quality factor.

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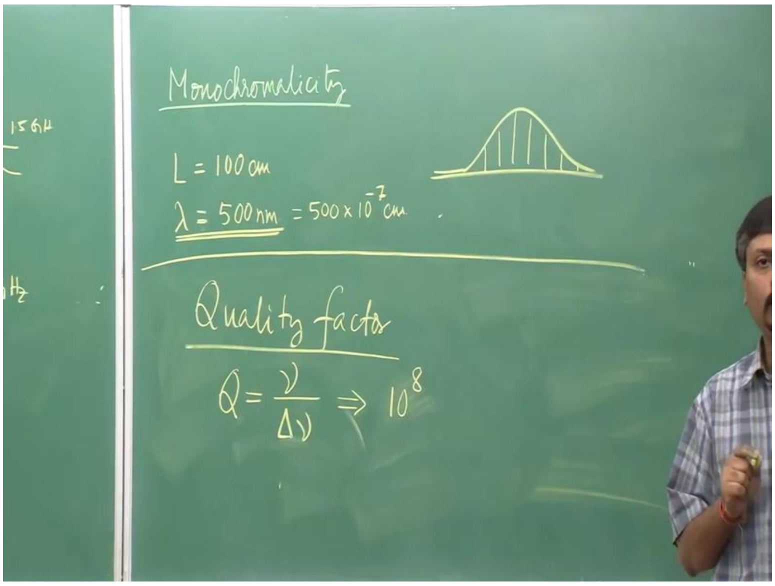

You will hear this particular term whenever you try to look into a particular specific laser. So, if you look at the brush here you will see what is the quality factor of the laser. So, this quality factor is written by this symbol q and it is given as this value.

So, narrower the beam narrower the frequency sincerely what I mean is, then the corresponding quality factor is very high right. Now it is very commonly you can get a quality factor of 10 power 8 if you take those values that I said you can get a value of 10 power 8 or even more than that. And having a high quality factor for a laser is very, very essential particularly in certain cases like spectroscopy and it is precisely high resolution spectroscopy.

So, this monochromatic property of laser is you know something which spectroscopist really laugh, in industrial scale what where do you use this one to separate isotopes. So, the isotopes have very similar absorption, now if you have very, very narrow line with laser light then you can specifically excite one isotope to excited state and then use another mean to separate it from there, otherwise it is really difficult to separate isotopes. So, particularly in the nuclear industry, this high narrow line with a lasers are routinely used to do isotopes you know separation.

So, we will stop here today and again we will start tomorrow.

Thank you very much.