Laser: Fundamentals and Applications
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Lecture - 28
Introduction to Non Linear Optics

Hello and welcome back today is the third day of the 6th week of this course. So, in the last few lectures we learned about different types of lasers and you know laser, laser mediums and certain properties of those. So now, we are in a condition that with those basic knowledge that we occurred in last few classes. We can now look at the applications of lasers. And in this case in this particular section we will learn a few applications in detail. And some other you know in a brief manner.

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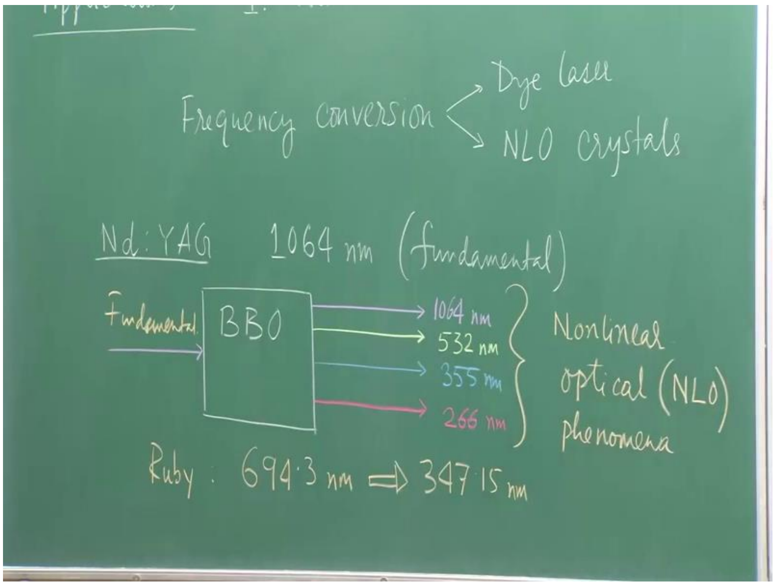

Applications we mentioned about several applications. So, one of the you know finest application of laser lies in the field of non-linear optics.

And that will be our first topic of discussion. So, during the days when laser was being developed. In those days people needed to use several different colors different frequencies for various you know research work or applications other kind of you know commercial applications. Now converting the you know frequencies was not so easy. What I mean is like developing a laser source having the particular wavelength of interest was not so straightforward. So, in those days the frequency conversion used to earlier be done in a window where a dye could be operative; that means, using dye laser.

So, if we consider one was using dye laser, but that was also quite limited based on the you know dyes available and the characterization of the dyes at that particular time, but one most use frequency conversion method was based up on using some material which are called non-linear optical material and particularly the crystals made up of certain material which are known as non-linear optical materials. Now I will give you one particular example to make it little clearer to you.

So suppose we have one Nd YAG laser. So, let us consider Nd YAG laser. So, the fundamental frequency which is the most common fundamental frequency of Nd YAG laser as we know is 1064 nanometer that is the fundamental. Why we are calling it fundamental and all these things it you know it will be pretty much clear. So, essentially whenever we deal with any laser frequency directly count coming out of the laser cavity is called it is fundamental wavelength ok.

So, that is you know directly related to the active medium and it is properties. So now, what people used to do they used to take the output of Nd YAG laser which is say given by this particular color. And then you put a transparent crystal of something like beta barium borate. So now when the light is to pass through this one under certain condition under certain you know angle and all, one can get several different frequencies right. So, one of course, if you are passing the light through the medium then it can just pass through as it is. So, one will get back the 1064 nanometer light unperturbed. But there were several other wavelengths and these wavelengths which used to come out of this crystal is not arbitrary. So, one mean wavelength that used to come out was at 532 nanometer then there was light at 355 nanometer and also some light at 266 nanometer. So, all these different wavelengths that used to be obtained, I mean it will always give rise to these different sets of wavelength and also beyond when an intense laser light passes through this kind of crystal which we took as beta barium borate.

Now, this conversion is not arbitrary if you look at you can see that this 532 nanometer is exactly the half of this wavelength 10 64 266 nanometer is half of 532, 355 is roughly one third of this 10 64. So, these are not at all arbitrary there is a very finite you know relation between starting wavelength and the wavelength that you can obtain when you pass through some material which we know as non-linear optical media. And this type of frequency conversion is obtained from non-linear optics, and this frequency conversion phenomena is known as non-linear optical phenomena. We write this non-linear optics on non-linear optical term in short as NLO and very often we will use this term NLO. The first observation of this kind of non-linear optical frequency conversion was obtained in ruby laser. So, the first wavelength that one got was like ruby laser has a fundamental wavelength of 694.3 nanometer and it was converted using a non-linear optical crystal to 347.15 nanometer.

So, this is just an historical fact the first frequency conversion through non-linear optics was obtained at 347.15 for ruby laser and it converted the fundamental frequency of 694 to 347. Now whenever these kind of frequency or conversion takes place now what is the advantage like I mean one can easily think about having just a fluorescence you know I choose a dye I get a fluorescence and fluorescence is rate shifted compared to the excitation wavelength. So, I could easily get that frequency conversion rate choosing a particular dye. So, what is the advantage of this kind of frequency conversion?

The advantage lies here is that the properties of a laser light is intact in this particular case. What I mean is the light that comes out from this non-linear optical medium is coherent. It has the directionality and still it has high intensity. So, it pauses all the properties of a laser light. So, this is the fundamental, and whatever the output that may be harmonic or some other wavelengths they will be just like laser. So, even though I do not have an active medium which can directly give me this laser wavelength, I can use another laser and use this non-linear optical material and frequency convert them to achieve just like a another laser at another frequency. Now we will try to learn rather briefly what is non-linear optics. So, the question is what is non-linear optics ok.

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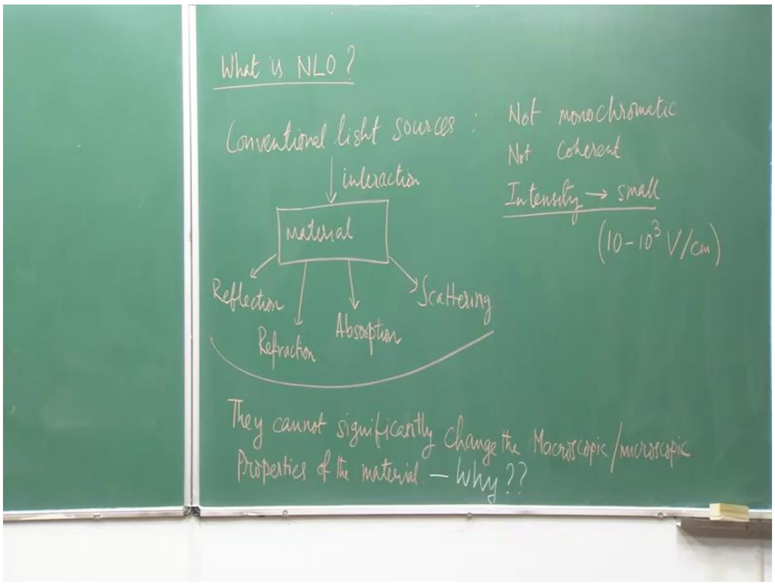

So, to answer this one let us first consider what are the properties of a conventional light source, because this non-linear optics it is related to the intensity of incident light as well also the particular type of material that we are considering. So, if we consider conventional light sources what are the properties that we have first place they are not monochromatic fine. Also they are not coherent right also the intensity is fairly small how small. We have seen it earlier in one of the earlier classes that the electric field amplitude is something like between 10 to 1000 volt per centimeters, this is fairly a small number. Now if this intensity of light for a moment I forget about the other thing you know wavelength or the you know phase. So, if I just consider the intensity of light, this amount of electric field if it is allowed to interact with some materials. So, this is a material which you can take as a as an dielectric. For example, so what will happen? So, it can give rise to reflection.

It can give rise to refraction, it can also give rise to absorption it can give scattering. Now these weak field of this conventional light sources can give rise to these kind of properties, but they can hardly alter the macroscopic or microscopic properties of material. So, this interaction, so this is interaction, so these interaction. So, they cannot significantly change the micro say let us macroscopic or microscopic properties of the material fine. So, this is true for this conventional light sources which has a very small intensity in the order of 10 to 1004 per centimeter. Now at this point if I ask you fine I said that they cannot significantly alter the macroscopic or microscopic properties, but why?

So, I am asking why it can cannot change the macroscopic or microscopic properties. So, if it has to if a light source has to alter the macroscopic or microscopic properties of the material that is interacting with, then it should the electric field of the light should have an intensity at least comparable to the intensity of the electric field in the matter itself. So, so answer if I say is that the intensity That is 10 to 1000 volt per centimeter the typical value is still you know several orders of magnitude less than the intensity of the electric field within the material.

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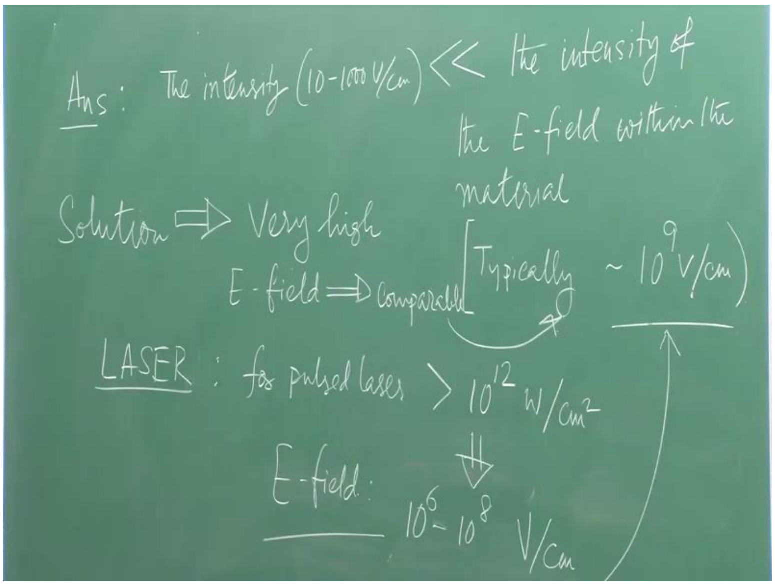

What is the typical order of the electric field within the matter? It is typically around 10 power 9 volt per centimeter and this is 10 to 1000. So, of course, this is like you know 10 to the power 8 to 10 to the power 6 order of magnitude less, now if I have to alter any macroscopic or microscopic property of the matter itself then I must be able to you know impart enough electric field to disturb the equilibrium position of the electrons within the matter.

The you know the electrons are bound to the nucleus and you have the associated electric field intensity of this sort. Now until unless I can you know give an input of you know the order of this number I cannot change any property of the matter. Now if you think about the solution. So, solution of course, you need to use very high electric field. When

I say very high; that means, comparable to this number. Now if I consider a laser what is the typical intensity of a laser? So, if I consider particularly pulse laser. So, for pulse laser the intensity of the laser beam can be much greater than a kilowatt per centimeter square. We have done some problems associated to this and we have seen that you know I can go much more than this one. No these numbers will transform in to an electric field intensity. So, this number will be approximately 10 power 6 to 10 power 8 volt per centimeter when I consider the electric field amplitude of the same beam. And I can increase it much more at least we can focus it and we can increase the intensity. So, I can achieve an electric field amplitude what is comparable to this number. So, with the laser beam we are in a condition to you know perturb the equilibrium positions of the subatomic particles within the matter basically electrons. And that is the key to achieve some responses which are non-linear functions of the input radiation intensity.

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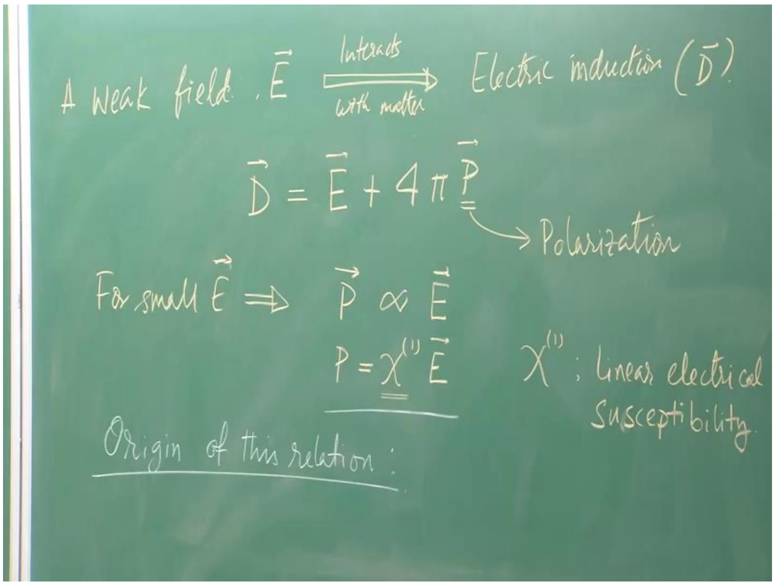

So now let us consider a weak field say we call it E. So, this weak field when it interacts with matter what it will do? It will create an electric induction. So, when it interacts with matter it will create electric induction. Or it will induce some electric field in other word. So, this electric induction if I call it as d then this d is equal to the given input E plus the quantity 4 pi in to p.

Now, there is a new term this p which is known as polarization, that is created in the material by this incoming light field E alright. Now if it is really a weak field; that means, the E is small what we have this the polarization. So, for small E this polarization p is proportional to the input electric field intensity E. And I can write equality as this; this constant chi is known as. So, let us call chi 1 this is linear electrical susceptibility fine. This is a very important quantity, we will talk about this one little bit in a while ok.

Now, this is a nice expression that polarization is related to the electric field, now from where does it arise? So, the origin of this relation that we need to discuss a little bit in order to understand the basics of non-linear optics. Because this polarization and the susceptibility they are the heart of the non-linear optics.

So, we will stop here today and in the next class we will start from here discuss further about non-linear optics and different orders of non-linear optics.

Thank you very much for your attention.