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

Lecture – 21
Mode – locking

Hello and welcome today is the first day of the fifth week. So, we started looking at the pulsing technique called mode locking, and there we looked you know at the basic principle of mode locking. So, we what we said in the previous class let us have a quick recap of that.

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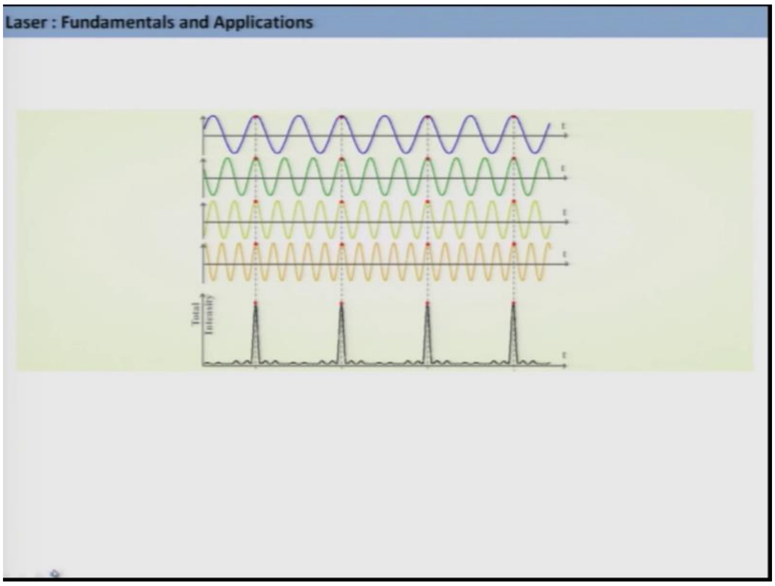

So, we said that a particular gravity can you know host several different frequency modes particularly longitudinal modes, and all these different longitudinal modes can if they are not related in terms of their phases, which generally is true in that case we have a situation where we get you know an output which is totally cavity.

So, only you get you know you know random fluctuation of in intensity, and it appears to be in a continuous laser and with a very low intensity due to distractive interference because their phases are not in you know co related. In case if this these notes are co related in terms of their phases, meaning that you know neighbouring modes are all somehow locked in their phases; that means, you know they are not haphazard they have a particular relation and that relation maintains then you will get you know a single end in single pulse with high intensity, because of constructive interference at that particular region and everywhere else there will be destructive interference.

So, you will have only one you know peak coming out of all these modes, and if you can generate a cavity such that it houses only one such peak.

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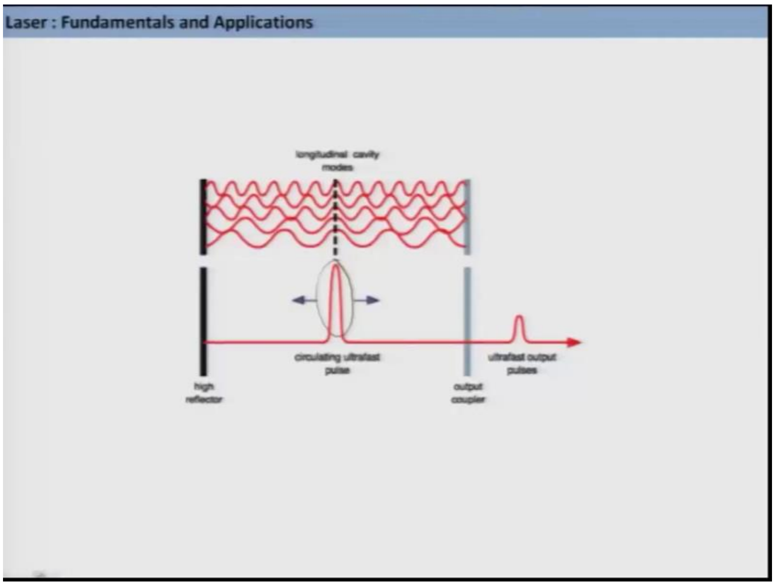

Then that particular pulse will move back and forth between the two impetrates and it will give an output to the end coupler. And we also showed that these type of pulsing technique can yield really really short you know pulses with really short width or short time duration.

And we also estimated like based on a particular active medium, for which we know the bandwidth spectral bandwidth and with a cavity length, how much we can compress the pulse; that means, how short we can go in terms of its width. And we also said that the width of the pulse is related to the number of modes within the cavity. Now if we tell it very explicitly then actually it is dependent on the bandwidth spectral bandwidth of the active medium, because the cavity can support you know infinite number of modes, but how many modes are there corresponding to that given bandwidth of the active medium that is what will ultimately be useful for us. Anything outside the bandwidth of the active medium it is not of our interest. We are interested only on those frequencies corresponding to those certain longitudinal modes, which fall within the envelope of the spectral bandwidth of the active medium.

So, therefore, it is you know the pulse with essentially dependent on the spectral bandwidth of the active medium right that is what we boiled down to. So, now, having said that let me ask you a question, if I take some you know gaseous system as my active medium for my laser say for example, like if I take lactancia laser and I take a dilaser. Say for example, based on say ruled m time which one of them can give extend shock pulse like we calculated in the previous class in the order of few femto second, is it both of them or one of them or none of them. If you think about this question properly then you will understand that the spectral bandwidths are not the same for a gaseous system and a you know a di organic di most likely in some solvent, but is not the medium for dilaser.

There is even in hell difference in terms of their bandwidth. So, for a gaseous laser say for example, heni or nitrogen, their bandwidths are extremely narrow. So, that they can you know support one two three four number of modes. On the hand other this dilaser initial bandwidth that you know di initial bandwidth essentially is so large, that they accommodate 10 to the power 3 to 10 to the power 4 number of modes. So, immediately it is you know clear that a gaseous laser mostly they cannot under any circumstances give rise to ultra shock pulses at max you can get like a nano second pulse. On the other hand this dilasers or some second solstice laser for example, like titanium sapphire laser there you can have a spectral bandwidth which is large enough to acidometer a huge number of modes and we know that more the number of modes more is a possibility of shortening or compressing the pulse.

So, I can achieve extreme short pulses with a solstice sapphire laser or a dilaser say pick a second to pick a second pulse, but not within gaseous laser like helium laser or nitrogen laser for that matter ok.

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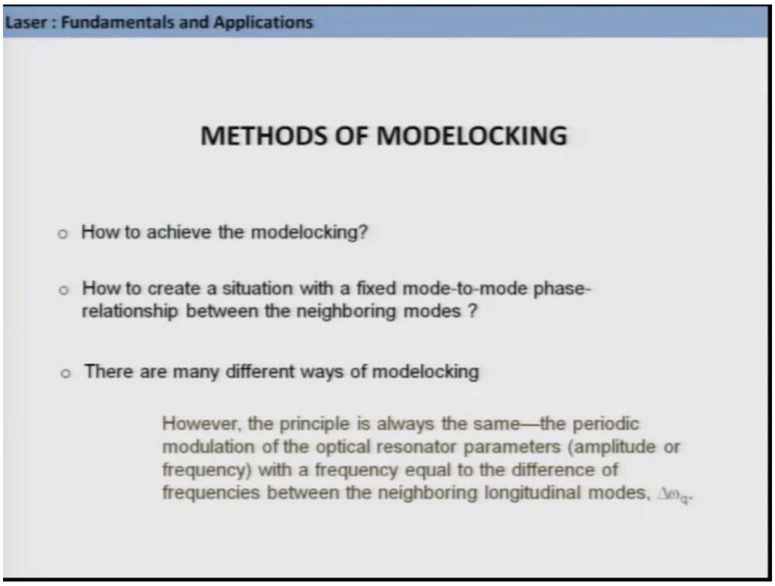

So, we have understood what is the basic principle behind mode locking. So, we need to really lock the phases of the different modes. Now the question that we have to ask now that fine I understand the basic principle, but how to get it how to achieve the mode locking; well in other word if I ask the same question in a different way is that how to create a situation with a fixed mode to mode phase relationship between the neighbouring modes exactly what I was talking about ok.

So, the answer is there are several different you know ways to achieve this mode locking. Now does not matter how many different ways you have the principle the basic principle is going to be the very same it is not going to change. So, what we have to do we have to achieve the periodic modulation of the optical resonated parameters something like amplitude or frequency, with a frequency equal to the difference of the two neighbouring longitudinal modes. If I can achieve that is it I can lock the phases. So, that is my target alright. So, there are two mainly two different types of mode locking that we can achieve one is active mode locking and another is passive mode locking ok.

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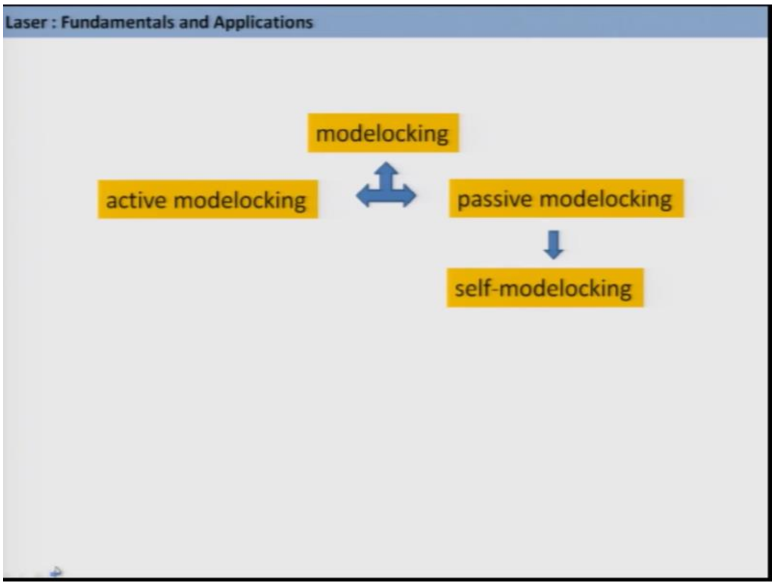

So, we will talk about this things in bit detail we will try to understand how exactly, this is done experimentally just for your information you know within the passive mode locking there is something, also known as self mode locking which happens due to the say focusing of the laser beam in the cavity. So, if time permits we can also touch up on that particular thing. So, in case of active mode locking what you do, you control some parameter from outside. So, you control it in case of passive mode locking, you put something which decides how to get that mode locking and when to do that. So, more control over this mode locking conditions will be you know removed. So, this is known as passive mode locking.

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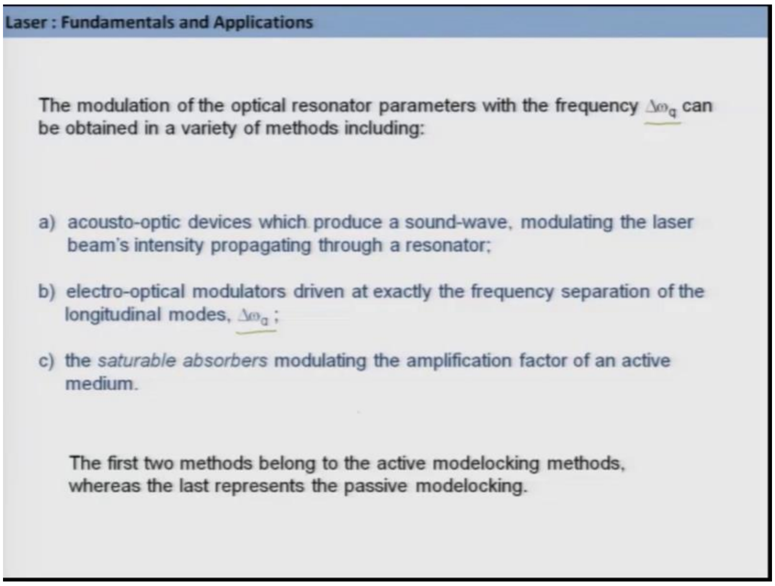

Now, as we said you know in the last slide that ha the modulation of optical resonator parameters will be needed. So, that you can lock the you know frequencies of two neighbouring modes by you know whose gaps are equal to C by 2L. So, the modulation of this optical resonated parameters with a frequency delta omega q, the modulations of the optical resonator parameters with a frequency delta omega q, it can be obtained by varieties of methods. So, what are those methods for example, you can use an acousto optic device which produces sound wave. This is not total new to us we have seen in case of q switching, the acousto cavity dumping how an acousto optic modulator is used.

So, this acousto optic modulator or acousto optic base device can modulate the laser beams intensity providing through a resonator, and in that way we can achieve mode locking. Also we can use instead of acousto optic modulator; we can use electro optic modulator which are driven at exactly the same frequency as that of the separation between two longitudinal modes, which is which we write as delta omega q. So, we know what is that that is c by twice l, l is the cavity length. And also we can use saturable absorber which we have also learnt in case of passive q switching. So, we can use a saturable absorber which can modulate the amplification factor of an active medium. So, the first two that is a and b they belong to the active mode locking whereas, the third one it belongs to passive mode locking ok.

So, these things are not very very surprising to you while discussing about q switching we also said that you know this active and passive techniques to achieve pulse output is there in q switching as well as in mode locking. And the similar kind of devices are used to achieve different type of pulses based on either q switching cavity dumping or mode locking. So, we will see how to do those things.

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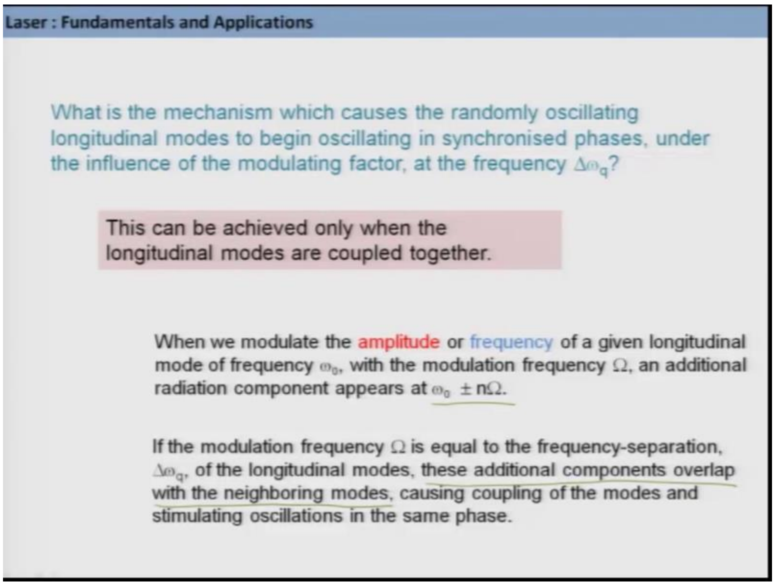

Now, we should ask that what is the mechanism which cases the randomly oscillating longitudinal modes to begin oscillating in synchronised phases under the influence of modulating factor; whatever that may be at particular frequency which is equal to the gap between two neighbouring right. So, what is the mechanism; that we need to understand first. So, we can achieve this this condition only when that is you know phase locked modes, only when we have this modes in a coupled condition. If the modes are not coupled or correlated then the result is acouse we have seen that right at the beginning of the class today when I was you know re capitulating few things thought in the last class, I showed that particular figure when the you know random phases in the longitudinal modes resulted in a total chaotic intensity distribution in the output beam.

So, if we want to avoid that then I must have an you know condition when somehow this modes are coupled together and later on we can you know bring in the condition, where this are so coupled that they will give rise to a constructive interference at a particular place and elsewhere destructive interference as we described in the previous class. So, when we modulate either the amplitude or the frequency of a given longitudinal mode of frequency say omega zero small omega zero, with modulation frequency say capital omega and additional radiation component appears at omega zero plus minus capital omega, multiplied by n' n is an integer it can be one two three anything.

So, if the modulation frequency omega is equal to the frequency gap between these two longitudinal two neighbouring longitudinal modes, that is in our case what we said as delta omega q then this additional components that is this part we are talking about that omega zero plus minus n capital omega, this additional components overlap with the neighbouring modes this is very important. So, you should note this part if I can modulate the you know if we can you know use a modulation frequency such that the you know modulation frequency is equal to the gap between the longitudinal modes.

Then these additional bands or we call it like side bands will exactly overlap the neighbouring modes, because my modulation frequency is capital omega and I am choosing this capital omega to be equal to delta omega q which is equal to C by 2L equal to the gap between the longitudinal mode. And I know that if I modulate with a frequency capital omega then my main frequency which is known as carrier frequency or the incident frequency is going to be shifted by say capital omega or 2 capital omega 3 capital omega so on. In that case this shifted side bands are exactly paused at the position of the neighbouring group; because my neighbouring modes are separated by the same amount C by 2L which is equal to now my capital omega.

So, this point has to very very clearly understand. So, we are going to build the whole story based on this. So, now, in that case when this side bands or this so called additional components they overlap with the neighbouring modes because the coupling of modes and stimulating oscillation in the same phase, this needs to be understood very clearly. I am allowing the creation of the side bands exactly in the positions of neighbouring modes. So, this is mode 1 mode 2, 3, 4 and I am selecting this mode one as my carrier frequency that is small omega 0, then I am creating omega zero plus capital omega which is at a next mode position and if I keep doing that. So, essentially all of my modes are coupled because if I choose this particular mode to be my omega zero then I can create this side band at the position of this one. So, in that way all the modes are now coupled in terms of phases. So, they will if they propagate in the medium they will create you know the same the photons with the same phase. So, they will keep oscillating in the same phase. So, let us now consider in particular mode that we talked about using acoustic device. How an acoustic modulator can bring in this particular condition where creating the side bands at a particular frequencies which are exactly the positions of the different neighbouring mode frequencies, and thereby causing a coupling between the neighbouring modes which will create the you know or which will stimulate the oscillation at a same phase relation exactly that is what we want.

Mode locking is all about creating a phase relation between the modes and maintain, that is all is mode locking about. Now in case of acoustic modulator this particular modulator it generates sound wave we have seen that in case of q switching and this sound wave modulates the amplitude of the laser beam.

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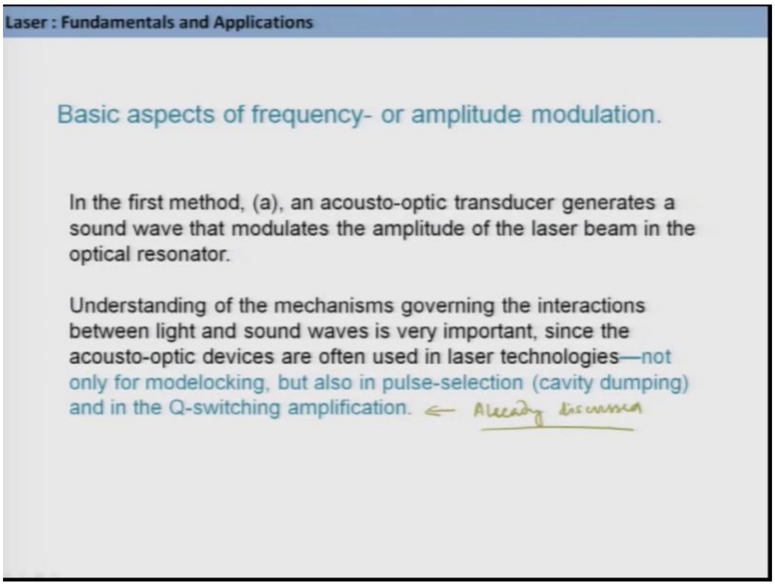

So, what we are talking about here is the particular frequency that we are choosing as the carrier frequency. So, if we target one particular frequency say like you know 800 nano meter, acting as a carrier frequency and I can modulate that within the resonator optical resonator in this particular case. So, you know since we are going to use acoustic modulator and we will be dealing with a sound wave. So, therefore, the understanding of the mechanism governing the interaction between light and sound wave is of utmost important and this acousto optic devices as we have seen is often used in laser technologies and I we have already seen this, we have already discussed in cavity dumping or in q switching we used these things.

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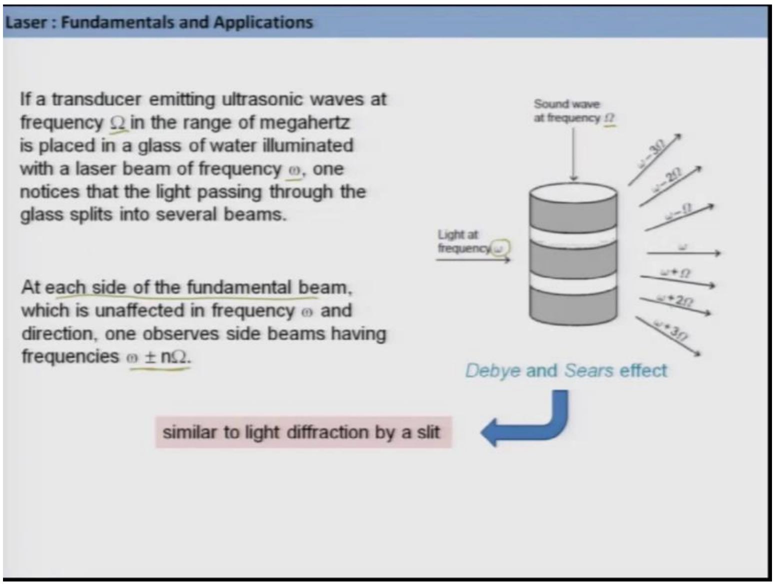

Now, suppose I have a acousto optic transducer, which is emitting ultra sonic wave at a frequency capital omega, may be in a megahertz and if I place that transducer in a glass of water. So, take a glass of water take your transducer which emits acoustic wave in the range of say 10 power 6 hertz and put it there and you bring in. So, suppose this is my glass of water. So, you put your transducer here. So, that it can sync sound wave in this direction downward and you bring your laser light through this one fine. So, laser light is eliminating this whole you know water in the glass. So, we take the laser beam frequency as small omega, now if I do this experiment what will I see. So, this whole experimental thing is shown here you have a glass of water and transducer is kept here which is sending sound wave at frequency capital omega. So, capital omega is for sound frequency which is the modulating frequency and our carrier frequency is the light frequency small omega.

Now at this condition what happens when I start sending the sound wave this light frequency is small omega that gets split into several different beams, and at each side of the fundamental beam they are disposed and not only they are you know separated in space, but they are also separated in frequency.

So, their frequency are either up shifted or down shifted. So, by l amount omega plus minus n capital omega; capital omega is my modulating frequency coming from the acoustic device in terms of in the form of sound wave fine. So, this already we have mentioned that you know when this happens, when I modulate it gets you know up shifted or down shifted and of course, when n equals to 0 you have the un part of incident light passing through the medium [FL]. So, this I can show pictorially like this. So, the un part up part goes as such and in different direction they are split having different different frequencies.

So, this is the down shifted in terms of energy, and in this direction you have the up shifted. This particular effect is known as debye and sears effect. So, this is after then name of the scientist and this particular effect if you think about it, is pretty similar to light diffraction at a slit by a slit. Why? Because in case of light diffraction by a slit if you remember certain experiments using these slits what you see you know one particular intensity at the middle, and then you see that there are you know dark and bright dark and bright you know spots (Refer Time: 25:24) spots you know in both the sides of that I mean spot and they are very much prettier decay in nature.

Here also we are seeing the same thing. Only difference between the diffraction by a slit and this process is that in case of like diffraction know of you know change of energy takes place you just see the intensity variation right. So, you see maximum you know intensity at the middle and then you know smaller intensity in both the directions, which ties down, but there is no change in the frequency, but here when I modulate with an acting you know sound wave we see a definite modulation of the white frequencies too and that is in both the reactions up shifted as well as down shifted. Now we see that this is very similar to diffraction I gave this analogy.

So, why is it so? Sound is a longitudinal wave. So, what it does it just you know you know compressors and dilates compressors and dilates. So, it changes you know in the direction of its prorogation correct.

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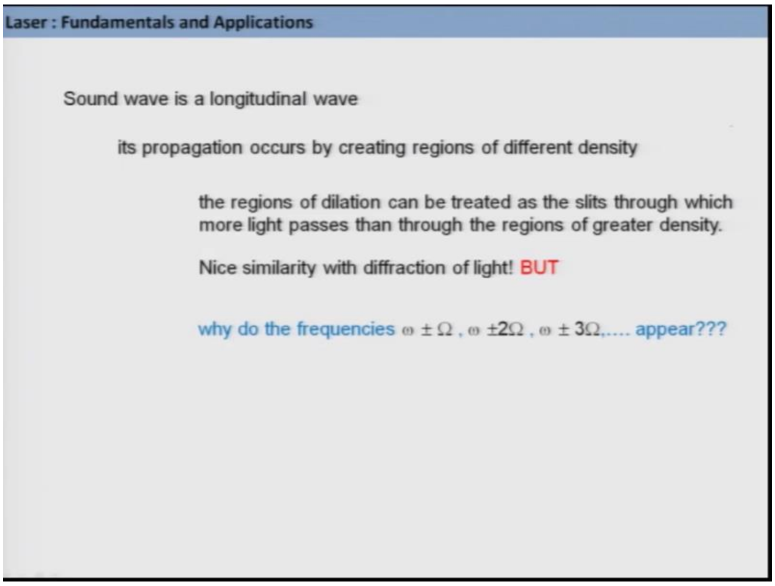

So, it creates different density regions in the medium, and particularly this regions of dilation where it gets you know white split, it can be treated as the slits through which more light passes than through the region of greater density that clearly makes sense. Now this is very good it shows you know nice similarity with diffraction of light we all agree about that point, but the question remains why to the frequencies say small omega plus minus capital omega, small omega plus minus two capital omega and so on why do they appear? That is a question that we need to answer.

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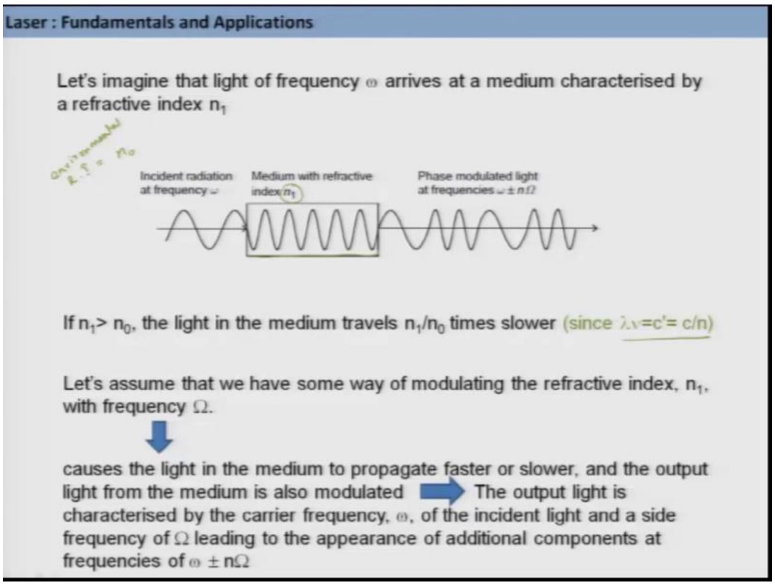

So, let us imagine that you know light of frequency omega it arrives at a medium characterised by a refractive index n 1. So, pictorially it is shown here. So, this is my active medium it is shown here; it has a refractive index of n 1 everywhere else. So, apart from this active medium, everywhere else suppose this refractive index is n 0. So, this is my environmental and refractive index is equals to n 0 right. So, it goes through that active medium faces its refractive index n 1, now if the environmental refractive index n 0is less than that of diffractive in that of the active medium then what will happen? The light in the medium will travel slower by what amount by an amount n 1by n 0 amount.

So, the light will be retorted why it will retorted? We have let us think this equation right. So, if you utilize that you can easily figure out why. Now suppose for the time being we assume that we have some way of modulating the refractive index. So, I have started with n 1I can go to n 1 prime, n 1 double prime and so on. I do not know how, but suppose I can you know assume that I can do that ok.

So, and I can do that with frequency capital omega. Now if I can do that then what will happen it will cause the light in the medium to propagate faster or slower it will make some change in their you know the speed; and the output light from the medium will also be modulated and what this will do? The output light is characterised by the carrier frequency omega small omega that is the incident light frequency at a side frequency of capital omega leading to the appearance of additional components of frequency at omega plus minus n omega. So, this is the reason. So, if I can really vary the refractive indices. So, it will be leading to the creation of the side bands along with the you know along with the carrier frequency, and these side bands will have to be at frequencies shifted by n capital omega because the modulation frequency is capital omega.

So, we will keep discussing this part in the following classes as well. So, in the following we will talk little bit more about this one, and look at and the possibilities of other you know techniques which can also give us mode lock pulses.

Thank you very much.