Laser: Fundamentals and Applications
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Lecture - 23
Passive Mode - locking and Types of LASERs

Hello everyone, we have been discussing about a mode locking, mode locking techniques and all and in the last class we looked at one of the techniques that is that can actively mode lock a laser continuous laser. Before I proceed further I must tell you something this point, that concept of mode locking is extremely interpret and in this course what we are doing we are looking at the basic concepts of this particular technique, if you want to learn a bit further particularly we did not you know go through the detail mathematical you know derivation of you know the conditions for mode locking and all this things. But these are all there in you know the differences that I suggested and also these are available in literature.

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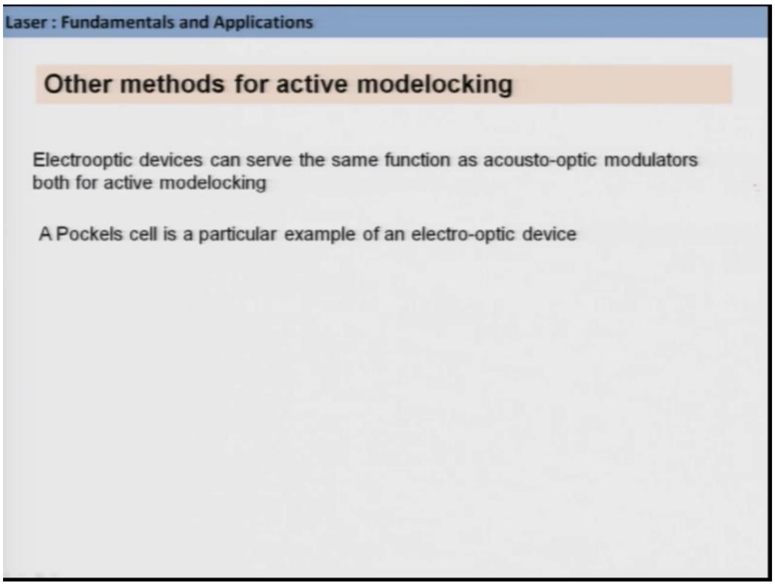

So, if you want to go through the detail of this technique, please go through those differences. So, as we said we will keep it to a you know a basic fundamental level only in this particular course alright. So, let us come back to what we are discussing. So, we showed by using acoustic transducers one can achieve mode locking and that is an active mode locking. Why because you are actively controlling the modulation in center laser cavity modulation of the amplitude or frequency whatever you are doing. So, are they are other kinds of active mode locking? The answer is yes it is not only that acoustic optic modulator has to be used or only acoustic optic modulator can generate a mode locking of a continuous with lasers, but electro optic modulators also can do the chop.

For example a pockel cells, a pockel cell can do the job of modulating the you know amplitude of the laser light and thereby give rise to mode lock pulses. And both are these techniques acoustic modulation as well as this electro optic modulation are used in you know real life.

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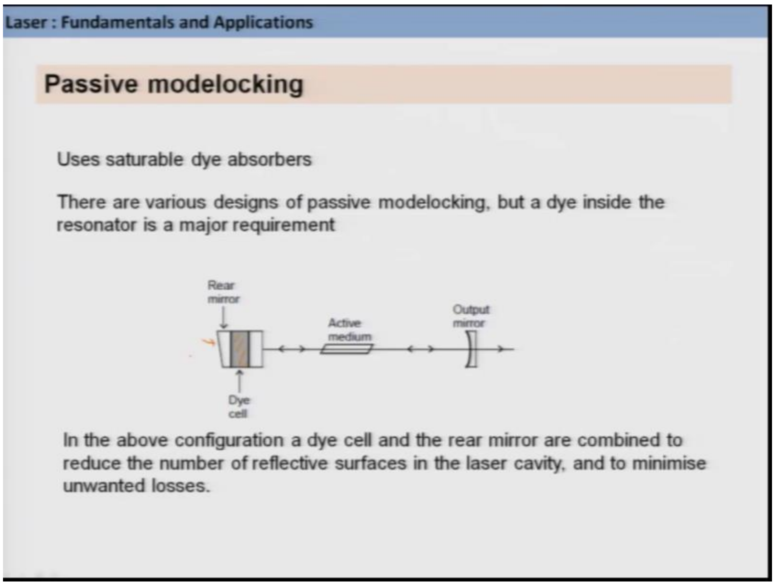

Now other than this active mode locking what else to we have. So, we have also something called passive mode locking, we have seen another passive pulsing technique called passive Q-switching, and what did we do there? We just used at dye solution or any other thin film which contains some material which as known as saturable absorbers. Here also in case of passive mode locking the technique uses saturable absorber; which are mostly some dyes like we mentioned about sinide dyes in the earlier cases. So, there are you know different materials available for which are good saturable absorber.

So, let me remind you what is saturable absorption is if you take this material which we call as saturable absorber and send in light. So, it absorbs all the you know light going through as long as a intensity is low. As the intensity of light is increasing that is I am increasing the number of photons coming in, then it will reach a condition of saturation which means the population of the excited and the ground state will become equal that is n 2 equals to n 1. And at that condition there will be no further absorption of light in practical since, thereby the system will be called a blissed system. So, in this blissed system the light will just pass through. So, light will the media will behave like transparent medium to the light. So, once earlier at the low photon intensity that this dye is kopek at a sufficiently high intensity beyond the threshold, this becomes transparent. So, that is what is the function of the saturable absorber and in the passive mode locking also we use a saturable observer, absorber dye

Now, how you can implement this you know saturable absorber to do the mode locking? There are various different designs of doing this are available, but whatever be the case this saturable absorber which is a dye is definitely a part of the resonator. So, it has to be within the resonator and that is why, we put the resonator this you know dye inside the resonator and I forget about it, and the dye will do the work do that job by itself. So, I am not going to do anything and that is why this method is known as a passive method just like passive Q-switching.

So, here I have shown one you know picture of cavity involving this saturable absorber. So, the dye cell is it here, so this is my dye cell and this output mirror and this is the high reflector and then you have the active medium. So, this is this dye is within the resonator cavity. So, in this particular configuration, this saturable absorber which is the dye along with this real mirror that is this guy, they are combined to reduce the number of reflective surfaces in the laser cavity and to minimize the unwanted losses right. Because if there are you know like you know gaps and all there will be multiple reflection between the you know the container surfaces and all this things. So, we will have unwanted losses which we you know really do not want. So, they are kind of all most coupled together fine.

So, the end of the you know, if I came I can imagine it in a way like you know I have a container, whose inner wall is high reflecting mirror and then I have this dye solution inside. So, I minimize the loss in that case. Now let us look into the detail of this passive mode locking how it works.

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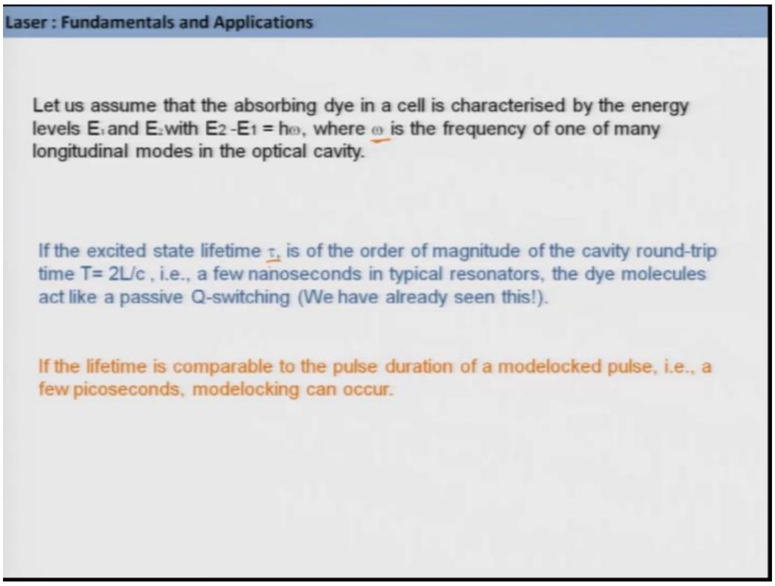

So, first let us assume that I have an absorbing dye and it has you know let us assume it like you know two states system given by energy is E 2 and E 1, and let us take small omega is the frequency of one of the longitudinal modes of the optical cavity. There maybe n number of modes let us take one mode which has a frequency small omega. So, this is I know this we assume now.

Now, suppose the excited state of this saturable absorber dye has a lifetime tau given here and this tau is of the order of the magnitude of the cavity round trip time. So, what is the cavity round trip time that is given by the period capital T given by 2 L by C. So, if I have such a system for which tau is you know having similar value as that of capital T, then what will happen a few nanoseconds in a typical resonators the dye molecule will just act like a passive Q-switch and we have seen this one in case of Q-switching. On the other hand if this dye lifetime excited state lifetime tau is comfortable to the say I means if it is very short, how short if it is comparable to the you know pulse width of the mode lock laser output so; that means, that I want to achieve short pulse say 100 femtosecond or say like you know 1 picosecond, and I am saying that if this excited state of this saturable absorber dye has a lifetime of say like 1 picosecond then I can achieve mode locking.

You try to read between these lines here, here I am imposing a condition which will you know which deals with some time scale which is equal to few femtosecond to picoseconds, which can be the also the gap between the two modes.

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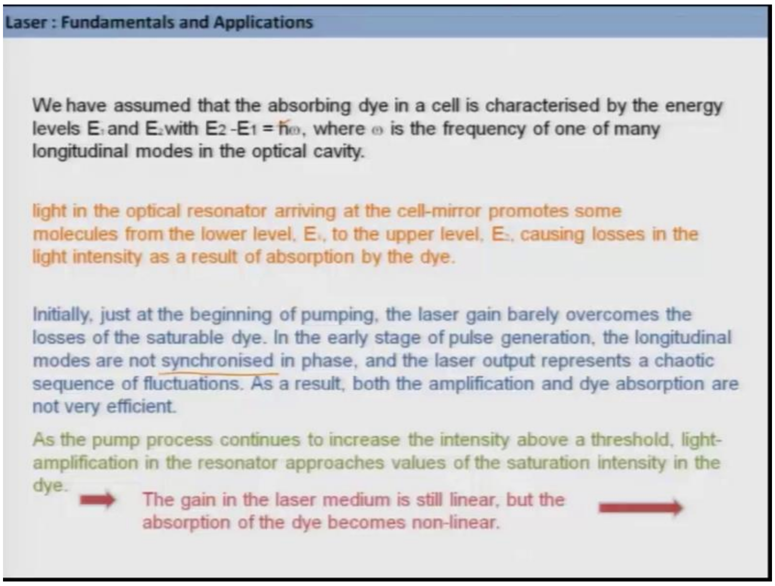

Now, as we have already assume that we have two state systems. So, this E 2 minus E 1 essentially if I write it in terms of omega then I must have each cart omega. Now this light in the optical resonator which is arriving at the you know cell mirror, cell mirror is that I said that dyes taken in a you know say rectangular container, inner side of which one of the inner sides of this container is a mirror. And this cell mirror promote some molecules from the lower level E 1 to the upper level E 2 causing the losses in the light intensity as a result of absorption by the dye fine.

Now, this is at the beginning. So, at just point like a beginning when the you know pumping just starts and you start you know getting some photons coming down due to you know spontaneousemission on may be little simulated emission, till the time I have not achieved gain so the intensity of light coming is very very small. So, if the laser gain cannot overcome the loss that is in curd at this you know dye, because dye observe and goes from E 1 to E 2. So, till that point when I do not have the condition where gain is more than the loss at the dye I have no phase relation between the different modes oscillating. So, the result is again aquatic output. So, there will be random you know interferences and I will have a very low intensity light and they are totally uncorrelated in terms of phase they are not synchronized. So, that is what we will get.

Now, this will not remain the case for ever, after sometime there be will more and more photon coming in and slowly the gain will overcome these losses. Now beyond this threshold the light amplification in the resonator it will you know approach the saturation intensity in the dye. What does that mean? You now this you know two states 1 and 2 in the dye. So, from E 1 to E 2 it is continuously going more and more lights are coming from that medium. So, there will be a condition when this population here in N 1 will be equal to the population here N 2. So, N 1 equals to N 2 and this is situation we have just mentioned it.

So, when this happens, the gain in the laser medium is still not increasing very rapidly. So, this is still within in a linear rising that is slowly increasing, the gain is slowly getting up, but still not in a very abrupt way like non-linear way, but the absorption of the dye it becomes non-linear. Then what happens?

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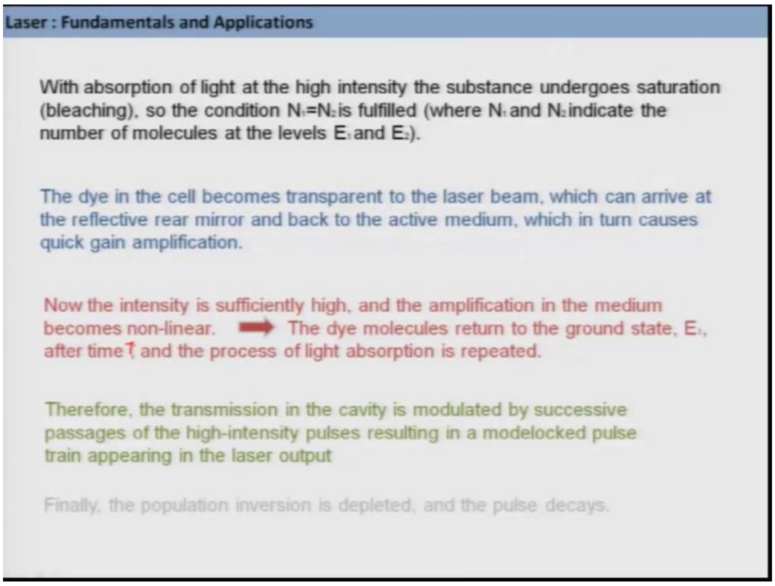

More and more photon coming in that is intensity is higher and higher, the substance that is the saturable adoption absorber undergoes saturation. So, we which is the condition of preaching and once this happens the dye becomes transparent to the incoming light. So, once it becomes transparent, it will no longer in curve loss to my cavity rather it will allow the you know light to propagate through the along the axis of the laser cavity, and it will create the amplification of the gain and the you know laser gain which was following linear relation with time now it will become non-linear. So, it will rapidly increase.

So, now the intensity is extremely high and the amplification in the medium becomes non-linear right we explained that and the dye molecules now returned to the ground state after time tau sorry we will miss that. So, its lifetime it comes back to the ground state and then we repeat the same process. So, what we do we first you know make it kopeck and then at a particular threshold value it becomes transparent, and I have extremely high you know gain and I get a laser output. And after you know its lifetime the you know excited dye molecules will come back to the ground state, again it will opect to the incoming light and again after sometime it will be transparent. So, this process will keep going. So, I will get a repetition of pulses and these pulses will be short and short and short.

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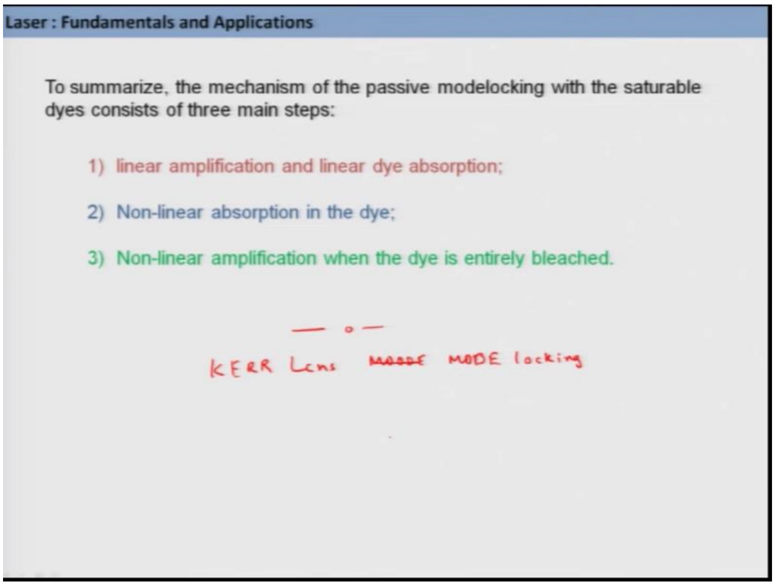

So, we will summarize this you know process of this passive mode locking. So, essentially this has three min steps. The first one is the linear amplification and linear dye absorption. So, linear amplification in a sense that active medium will generate photos and that will you know be a you know linear function of time and at that particular condition dye also will keep on absorbing in a very linear way. So, that is my first step. In a second step the dye starting starts absorbing more and more photon. So, that is in non-linear fashion; and in the third step the dye gets totally bleached and my amplification becomes highly non-linear. So, the amplification is you know extremely high and then I get the pulsed output from the cavity, and then this you know whole three steps again repeat. So, they are again repeated and you get more you know pulses after a certain time, and which is more or less governed by this lifetime of this dye.

So, these are the main techniques that are involved in you know mode locking. Apart from this one there are other type of techniques one of the important thing is called KERR Lens Mode Locking. So, that also is used quite a lot in the practical system, where you know this phenomenon of KERR lensing is used to modulate this you know amplitudes of the you know laser longitudinal modes, and ultimately make a you know a single pulse oscillating in the cavity and getting a very short pulse. So, I think we have covered the pretty much basic of all the pulsing techniques that are existing, and with this knowledge what we will do we will go and learn about some specific lasers right.

So, what are the different types of lasers that we can come across or what are the existing different types of laser. The number is really huge, now this lasers can be categorized in a different sections.

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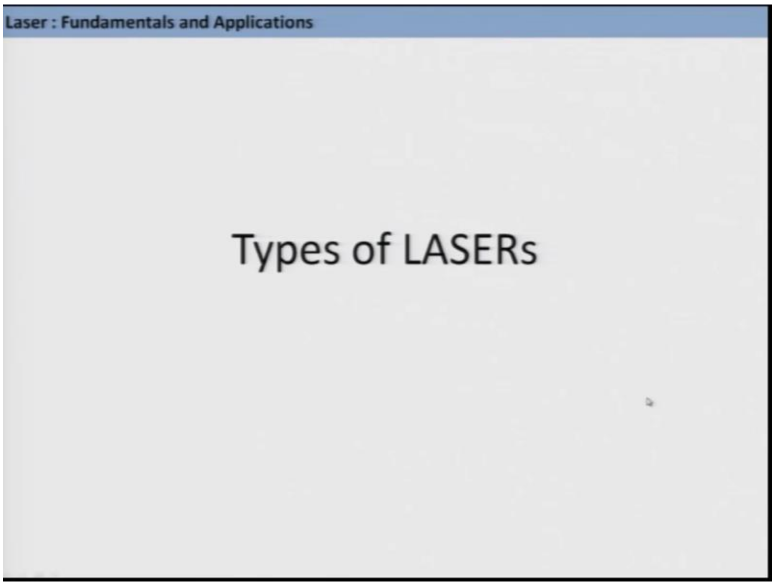

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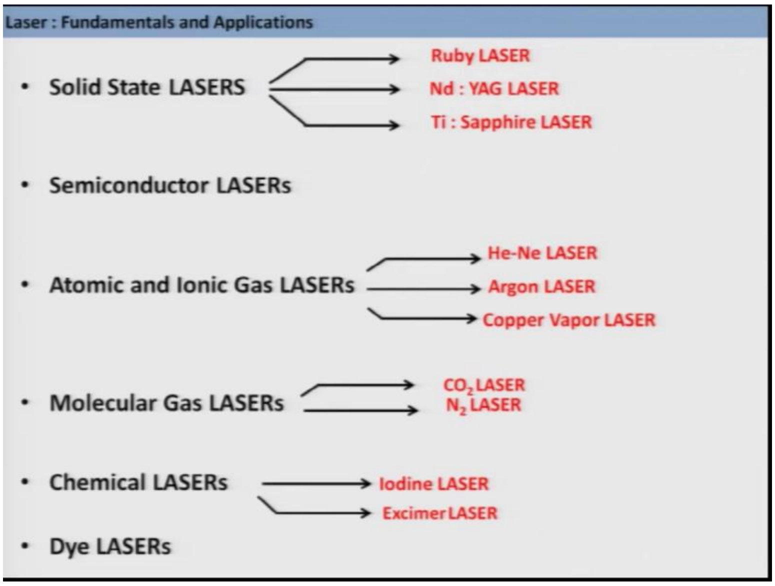

I have tried to categories them in the following manners; there are the lasers where active medium is essentially some solid state materials. There are specific materials which are semi conducted in by nature, so we can have semiconductor lasers. They are lasers whose active medium you know consists of you know atoms or you know basis ions. So, when we are having just atoms they are of course, in the gaseous medium because you know non interacting atoms will be always in the gaseous phase.

So, we can also make lasers out of gaseous molecules acting as the active medium, we can form lasers utilizing a chemical reaction. So, a chemical reaction mixture can act as the active medium and thick responding chemical lasers we can get. And there are certain lasers which are operated in the so called liquid states for example, like dye laser it is not very fair to tell it like you know liquid medium, but since the you know host medium for this dye molecules which provides the states for laser action are dissolved in some solvent which are liquid. So, these are the basic categories of lasers that I have you know put together, but no way this is limited by the categories categorization that we have done here.

Now certain lasers under these categories we will look at. For example, we will look at ruby laser and Nd-YAG laser and tie safari laser, under the solid state laser category. We will look at certain semiconductor lasers and among the atomic and ionic gas lasers we will look at helium neon laser which is like you know one of the most widely used continues wave laser, we will look at organ on laser, we will look at a cover vapor laser. Under the molecular gas lasers head we will look at carbon dioxide and nitrogen lasers, under the chemical lasers we will talk about iodine lasers and one of the you know very unique kind of laser which is known as excimer laser and of course, we will talk about detail regarding the dye laser configuration.

Now before going further into the detail of this thing can I pick any given material and use it as a laser active medium. The answer is no, it has to fulfill certain criteria. So, if you recall the you know very first week of or second week of classes with dealt in detail about the requirement of like you know three state system or four states system, which can give laser action, but not a silly I have a three level or four level system it will always give laser action. It has to also fulfill the criteria of that you know that lifetime the excited state lifetime, it should be extremely suitable so that ultimately one can achieve population inversion.

For example like when you say Nd-YAG laser. So, YAG means yttrium aluminum garnet. So, it is a substance now this yttrium aluminum garnet as such cannot give a laser actions. So, you try you know how much you can, but you cannot achieve laser action at any frequency of that meet here. It is the niobium ion which gives the necessary electronics states, that can give rise to population inversion and their way you can get the lasers. So, it is very much essential to find out which particular material or molecule or atom or ions has the required electronic states, that ultimately can give rise to population inversion and hence laser action.

So, in the following class we will go through different types of lasers we will look and the electronics structures which particular electronic states are involved in lasing why some little bit in details for certain lasers and on. So, we will stop here today.

Thank you for your attention.