Laser: Fundamentals and Applications
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Lecture – 09
Modes of LASER cavity and standing waves

Hello and welcome back. So, we started looking at the practical issues that you know involves the construction of laser. So, in the last class we said that there are certain requirements for making or constructing a laser.

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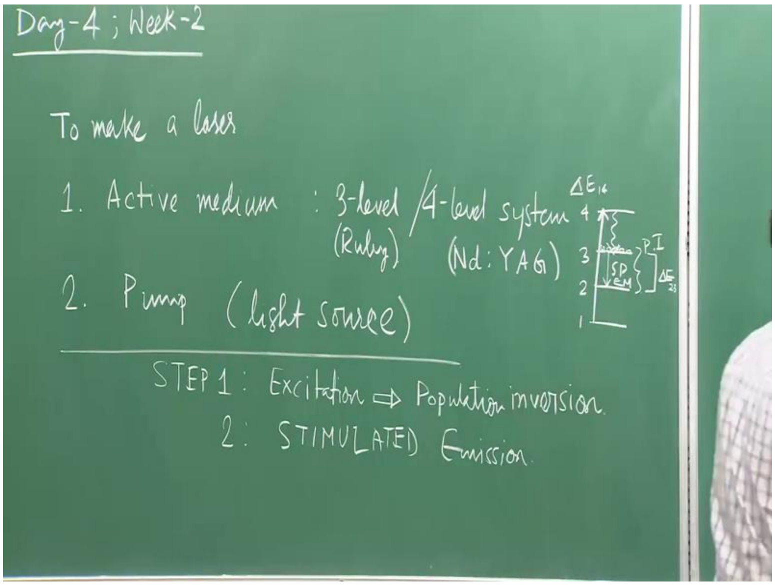

So, what are those things that we need in order to construct a laser. So, to make a laser or construct a laser, we need most important thing is the active medium. So, your active medium is the one that can give rise to population inversion and hence laser action. So, the material that will have electronic states that can give rise to population inversion can work as an active medium.

So, you can choose the you know particular type of material system that you want based on the you know the kind of laser that you want, based on the type of frequency that you want, based on the type of power that you want. So, you can choose systems which are like you know may be a 3 level system or 4 level system and when we talk about this particular material as we mentioned. So, an example of 3 level system is a ruby. So, and a 4 level system is neodymium doped yttrium aluminum garnet or YAG.

So, this is the most important thing to choose first. And the second is the source of light that will excite the atoms to higher excited state from there it will lays. So, we said that this is known as pump. So, we need to have a pump alright. So, this is nothing but some light source, which can be a flash lamp which can be electric discharge system depending on your medium and requirement. So, these are the 2 primary things and with this we can, we can start constructing a laser.

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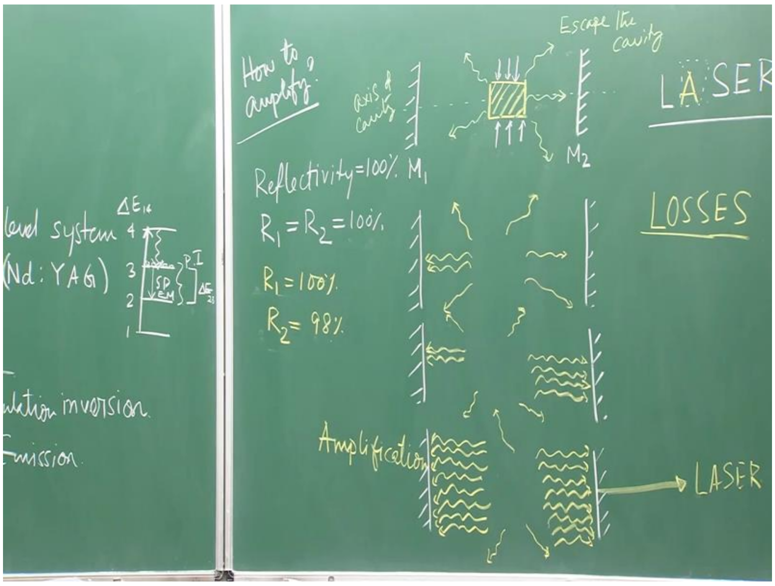

So, let me show you. So, first what we will do we will take our active medium it can be a small crystal of that particular medium it can be you know gas if you are talking about gaseous laser system.

So, whatever that is So, I have that active medium. So, next we pump it using some light source. So, this yellow one is my active medium, and these white arrows just signify photons coming from the pump source. So, once we get these then what will I get I can excite the you know atoms within the active medium to the respectives you know state which can ultimately give rise to population inversion. So, I can create the population inversion. So, in the first step; so step one is excitation which will lead to population inversion. These things we have already you know learnt I am just reiterating again and again. So, that we are absolutely clear about the whole mechanism ok.

So, once the population inversion is created I need to create stimulated emission right. So, second step will be stimulated emission. Now the question is how the stimulated emission will be created. Say for example, I am taking a 4 level laser 4 level system suppose I take something like this. So, then what is my system my system is like this. So, first excitation will take this system over here.

And then it will come back by non radiative transition and here population inversion will be created between these 2 step. So, atoms are here. So, up to this point I have created. Now I have to create the stimulated emission how it will be happening because my source is such that it is energy corresponds to this gap. So, this arrow corresponds to the gap between the level step 4 one. So, I have said in this way suppose I write which may be different from the last class, but you understand this ok.

So, this energy gap is much more than this energy gap right. So, this delta E say I say delta E 2 3 and this delta E is delta E 1 4. So, delta E is 1 4 is much higher than delta 2 3, now in order to create a stimulated emission I have to give photon of the energy delta E 2 3. So, how we can do that? We do not need to supply any light from outside, why? Because these 4 atoms sitting at level 3 will at some point of time relax back to here by spontaneous emission right. So, it will have spontaneous emission.

So, we are showing it by a straight arrow. So, this spontaneous emission will give me a photon which has this energy gap. Now this photon if it interacts with this active medium meaning that it will interact with these atoms sitting at level 3, and it will trigger a stimulated emission. So, this spontaneous emission will create a stimulated emission. So, I will get 2 photons out of you know due to this one spontaneously emitted photon. Now those 2 stimulated photons if they interact with the active medium again before leaving this medium totally then they can trigger again stimulated emission, but if they leave this active medium. Then of course, we lose them then we have to again wait for another photon coming through spontaneous emission to cause another set of stimulated emission.

So, although we are getting a you know stimulated emission, but we are not in a condition to create a laser. So, in this picture what we get we get light out of stimulated emission of radiation true. So, in this I get this one, but there is something missing here right a is missing meaning the amplification that is another criteria right that is the main criteria to get a laser output. So, the question is how do I amplify right. So, question is how to amplify. It is clear this in this condition this you know stimulated photons are not you know going to create a huge amount of farther stimulated emission or the you know only spontaneous you know emission is not going to trigger huge amount of simulated emission and thereby know amplification. In order to get the amplification what we need is to put this system within a resonator to be precise within a resonator cavity.

So, what is that resonator cavity that we are going to deal with, we are going to create a resonator cavity by placing 2 mirrors. So, we put this system in a resonator cavity which is created out of 2 flat mirrors M 1 and M 2. What are the characteristics of this mirrors? M 1 and M 2 will be extremely flat whether we can make it or not we will see later, but at least to start with we do not see much you know problem in having a extremely flat mirror, with reflectivity of 100 percent; that means, these guys are 100 percent reflective. So, if the reflectivities are R 1 and R 2 for M 1 and M 2 that is 100 percent that is what we should ok.

So, we create a cavity by making this 2 putting this 2 in parallel configuration and then put this active medium along with the you know pump source in the middle. So now, what will happen? Let us see that you know in an elaborate way pictorially. So, that it becomes very clear to you. So now, what I have after this expectation creates a population inversion first thing is that it will start emitting photons spontaneously. So, the spontaneous emission will have it is own frequency, and all the spontaneously emitted photon we will have same frequency. Because the spontaneous emission is going to take place from this level to this level not from here to here directly that is my design.

So, spontaneous emission will take place randomly. So, it can go in this direction it can also go in the direction which is along the axis of this cavity which means the axis which is perpendicular to the mirror planes all right. So, this is my axis right. So, if I so, this is my axis of the cavity all right. So now, the spontaneous emission will go in every possible direction, because they are very random. So, some of them will be going in this direction.

So, what will happen now? So, these photons which are going in a direction other than the axial direction; they will not go and hit this mirror and return rather they will escape. So, this photon will escape the cavity, it is very easy to understand. So, they are not falling on the mirror even if they fall on the mirror then they will again go out right, but these photon which is moving along the axis that will be reflected back here and then reach here passing through the active medium.

So, it will start bouncing off between these 2 mirrors and every time it will go through the active medium causing more and more stimulated emission make sense absolutely right. So, if I look at that this problem in a stepwise manner. I am not bothered about the active medium we know that it is there. So, I am just drawing these photons. So, there will be spontaneous emission all the time. So, this photon so, this photon will now bounced back and hit here. So, what will happen when it will go here it will create 2 photons right. And in the meantime there may be another spontaneous you know photon which is along this axis fine. So, in the very next step what I will see is I will see these 2 bouncing back and making 4 photons while this one will bounce back and it will pass through active medium create 2 more photons.

So, I will see and then the spontaneous emitted photons are always there. Now what I am seeing is with every round trip there are more and more stimulated emission and they are increasing right, 2 to 4 4 to 8 and so on. So, after certain time what I will see is this I will see exactly this picture. So, these are all stimulated photons and then as usual there will be some random spontaneous photons right. Now coming from this one to this one we can easily, see the ratio of the number of stimulated photons to the spontaneously emitted photons are becoming higher and higher and higher. So, the number of simulated photon or in other word they have you know stimulated photon density exceeds the spontaneous photons by a huge number ok.

And that is what we want and this is what is called amplification right. I started with one spontaneous photon going in there and then I am getting more and more. So, every round trip is getting multiplied that is what is called amplification. So, this is the so, in some way we can say this place we are having kind of a seeding. So, we are you know planting a seed and ultimately this is getting amplified. So, billions and billions and billions of photons are created within no time right. Because this cavities if we have a practical sense it will be if it few tens of centimeter maybe 100 centimeter or so that is traversed by light how many times you can very easily calculate that by knowing the speed of light right.

So, you will see billions of times they are coming back and forth. So, the numbers of photons are also getting multiplied. So, stimulated photons are the predominant species within this one. Now by you know by design stimulated emission have the same property as that of this spontaneous photon. When I say it has the same property I mean actually identical. So, it will have the same direction that the spontaneous photon was moving it will have the same phase it will have the same energy that is same frequency same color same polarization. So, everything is identical to this spontaneous photon and when I amplify them all of them have the same property. So, that is wonderful thing right. And that is why one needs a light source like laser instead of a conventional light source all right, excellent.

So, this is my resonator cavity right. So, I can see having a resonator cavity we can amplify the stimulated emission fine. So, we have got the stimulated emission amplified, but what about the output I have chosen these mirrors to start with to have 100 percent reflectivity; that means, no light can escape here all right. So, if I want to take an output then I have to make that provision here all right. So, next step is to essentially replace one of these mirrors by a partially transmissive mirror. So, instead of this condition I can have now R 1 equals 100 percent and R 2 say I make it 98 percent say.

So, 2 percent of light will pass through this mirror. So, every time it you know bounces of this mirror 2 percent of the light will go out that is what it means. So, this is this is completely reflective and this one is partially transmissive. So, once I have that I can have and output alright. So, this is more or less what you know how you will construct a laser. So, this is my laser. So, I have found out a way to fill this blank by putting the active medium in a resonative and we also got the output by in instead of putting 100 percent reflective mirror on both the ends make one of them partially transmission.

So, we get a output now there are you know this is a very basic concept there are so many things there right. Which one needs to consider and we will learn some of them, say I will give you one example I have been saying that 100 percent reflective mirrors, but actually getting a 100 percent reflectivity is very very tough. Second I said I will be using a flat mirror all right. So, this flatness of the surface that also may not be you know as you expected it can be a little rough even at a very very you know small dimension, but getting absolutely flat surface is a big deal. So, that will give rise to some loss of photons right I assume that all the photons are going and hitting and coming back going and hitting and coming back, but if suppose the mirror is not flat. So, what will happen it will deflect the moment it deflects from this axial direction it will escape the cavity right.

So, a roughness of the surface or you know a little bit faulty mirror when it is a faulty; that means, it is it has a reflectivity which is less than 100 percent for one of the end periods. Not the one that is that is purposefully or intentionally made you know transmissive, the other one which is supposed to be 100 percent reflective if it does not have 100 percent reflectivity then we are going to lose photons.

So, this is generally called loss. So, there are several different types of reasons that will give rise to loss of photon, and these are some you know we will talk about certain losses. Now if we have to really get you know laser output which is like really amplified signal one help one has to amplify it. So much that that is you know capable of overcoming the losses and we get a net output. So, what we have to have we have to create again over the losses right.

So, there will be certain conditions which will be called threshold conditions we will talk about that you know maybe the following class. So, we will know how quantitatively we can figure out how we can reach the threshold condition and then beyond and go and get laser output. So, we have seen that this resonator cavity can give us you know it is it is extremely helpful and actually this is very crucial in order to get the laser output fine. So, we will come back to you know this discussion of this practical issues involving the construction of laser in the meantime let us look at certain other things which will be you know essential in order to move forward.

So, for example, we will now talk about certain concepts like modes of laser and standing wave.

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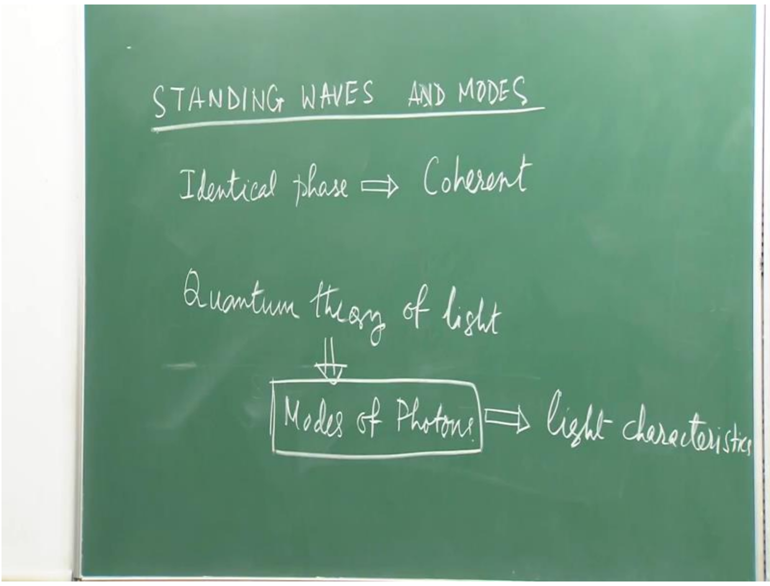

So, we will talk about standing modes sorry, standing waves and modes. We will see you know how it is relevant to this case. So, as we said just few minutes back that by design my stimulated emissions or stimulated photons have all the characteristics same as that of the spontaneous photon. And one of these criteria is the phase correct. So, identical phase for all the photons and because of which we called the output ultimately as coherent right.

So, this concept of coherence comes from this you know having identical phase as that of the spontaneous photons which triggers the stimulated emission in our laser construct. Now if we you know talk about the quantum theory of light. So, in quantum theory of light you know it is very common it is very usual to refer to the modes of light or modes of photon modes of photons modes of light to characterize the photon. So, normally we say this beam is coherent. So, it refers to that this has the same phase now in quantum theory of light when you say that this is the mode of the photon of this is the mode of the light this actually tells you some characteristics off the light right, So light characteristics.

Now what is meant by these modes of photons this is extremely relevant to our context. So, modes essentially it represent the possible combinations of frequency polarization direction of light. So, what kind of combination that I have will dictate what mode I have. Now whether all the modes that are possible in principle can actually be sustained in a laser cavity that is the question. So, what we will do in the next class is to find out whether you know all the modes that are possible in principle can be there in this cavity, if yes how? If not why not and then what are the modes that we can actually generate alright.

So, we will meet again in the following class till then have a good day and or good night whatever it is.

Thank you very much for your attention.