Laser: Fundamentals and Applications
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Lecture – 10
Transverse Modes of LASER cavity

Hello and welcome back, today is the last lecture of this week it is the second week. So, we finish the last lecture by talking about the modes of the laser. So, we said what is a mode, essentially taking reference from quantum theory of light we say to adequate this is a possible combination of the polarization frequency direction. Now the question that we raised to at the end of the class was are all the modes permitted in a laser in laser cavity. The answer is no, it is not.

So, the only modes so, are which are permitted has to satisfy a condition. So, what is the condition? So, the condition to be satisfied is this ok.

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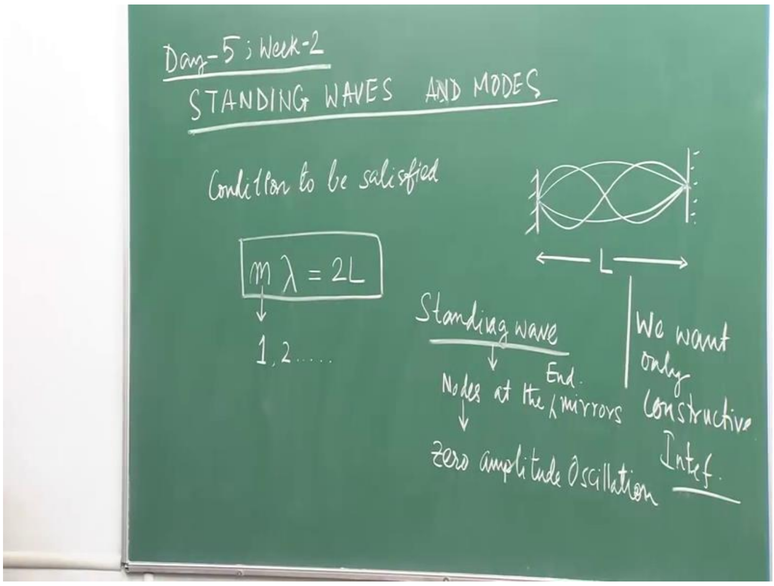

So, what are these? So, we created this cavity right. So, you have the active medium here. So, you are pumping and then your light is you know going and bouncing of between these 2 the length of this cavity is l lambda is the wavelength of the light. So, if I can you know have the information regarding lambda I can very easily get the information for frequency because they are related by the by the speed of light ok.

And what is this M this actually give you the particular mode. So, M can be any integer value 1 2 so on. So, I will say that this is the M th mode. So, what essentially this mode is this if I use this same cavity, then you know this condition actually means that only those modes are permitted that will create standing wave here, this is not very surprising to you right, you have already seen this in your high school physics right. So, for creation of standing wave you have seen earlier using you know like 2 fixed surfaces and making a you know say string or were tied to both ends and then just you know letting it oscillate, there are certain modes that will be actually creating standing mode and you can figure out what is the particular standing mode and the corresponding frequency or wavelength from this.

So, here what does that mean in case of laser. In case of laser it will mean that you know all these modes that will actually form standing wave will have their nodes at the turning points that are at the mirrors 2 end mirrors this mirrors as we have already said are called end mirrors. So, what is a node? So, I said this you know first creation of standing waves there should be you know nodes at the mirrors or actually to be precise at the end mirrors. What is node? Node a node is a point where the amplitude of oscillation is 0. So, this refers to 0 amplitude oscillation, I hope you know this I hope that I am not you know you are not hearing it for the first time.

Now we are just redefining things in the present context that is what I expect. So, you have to have nodes here. So, what is the maximum wavelength that you can see you know have so that that can be counted as a mode meaning that will create a standard standing wave, that is just this one way half wavelength here after reflection fills up another one. So, here is essentially M equals to 1 lambda equals to 2 l very easy to figure out, you can have like this. So, you keep on increasing the M 2 3 4 you go to N number. So, there will be still nodes here and also inside, but my primary requirement is that there should be nodes at the ends in periods.

So, why is this requirement, from where it comes see I would like to have my you know laser to have a large intensity right. So, I would one that since all the stimulated photons are in phase to start with. So now, until unless I have this condition after you know back and forth movement if they are you know random they will interfere destructively and I do not want to have any destructive interference. So, I want only So we want only constructive interference. So, if I have to fulfill this one I have to fulfill this one. So, that is the reason I will get a certain modes like this and these modes that I get here.

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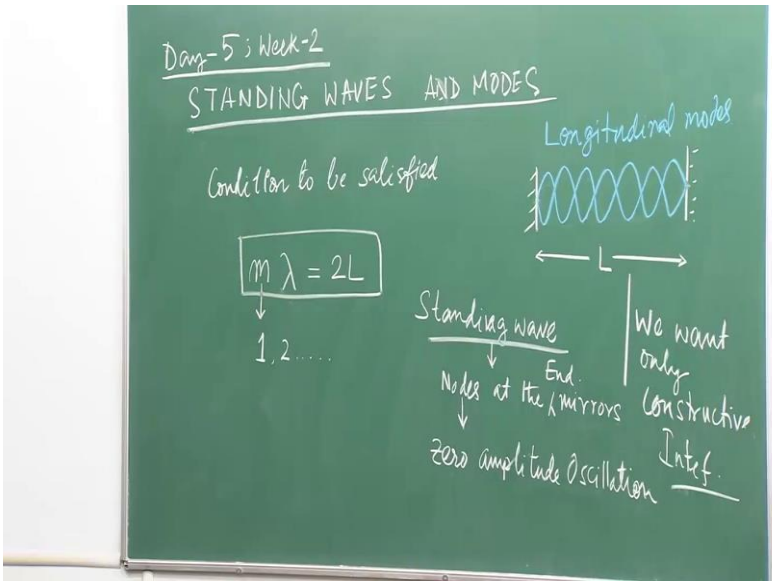

So, if I if I write any general M th mode that would mean that I will have N number of. So, they are you know certain number of oscillation before it you know goes to this 0 amplitude oscillation point that is the 2 nodes.

So, these type of nodes are known as longitudinal modes, these are a longed axis the propagation wave propagation direction is along the axis. So, these are known as longitudinal modes, now how many modes or which particular modes are within the spectral band of my particular active medium that one can estimate and we will see that either the 2 are the end of this class, or in the following class and we would learn how to estimate those things. Now we need to talk about another thing. So, when we say that I have longitudinal mode ok.

So, mode depends on the combination of directions. So, the longitudinal mode is along the axis of the laser cavity. So, immediately you can sense that there is possibly another type of mode actually it is now we have been describing this laser cavity by putting flat mirrors now the flat mirror has a drawback what is the drawback, but it cannot collect the off axis photons. So, the spontaneous emissions which are little bit off excess they will they can trigger the stimulated emission off axis also and if even if it is slightly off axis then they escape the cavity. So, the intensity of light in this particular case is not as great as it could be.

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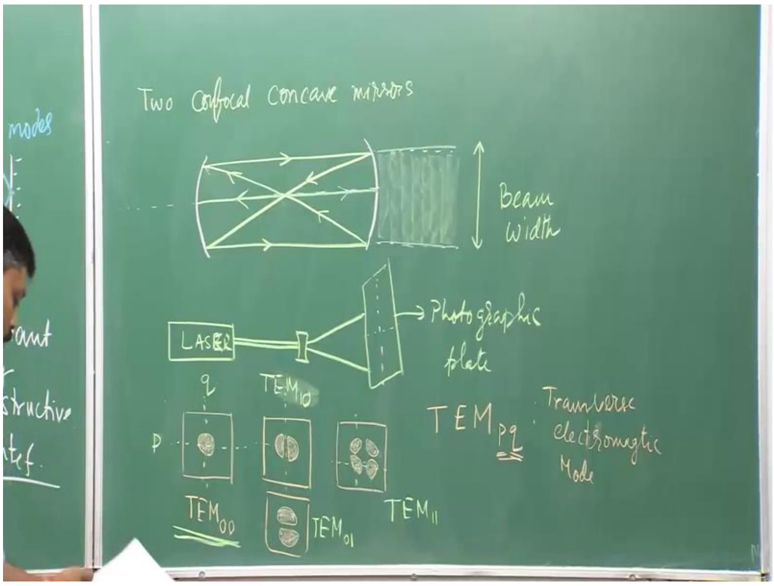

Now this problem can be you know you know arrested if we create the cavity instead of using 2 flat parallel mirrors we use 2 concave confocal mirrors. So, we can use 2 confocal concave mirrors to form the cavity. So, how will that look? So, they will look like this. So, confocal peening that they will have conjugate you know focal lens. So, their focus spot will be here for both of them now if we consider the lights which are moving axially axis will still remain this right this is my axis. So, exactly like in this case my photon will go back and forth ok.

So, I am not losing that characteristic. On the other hand what do I have what do I have extra is the following that if suppose a photon is going in this direction suppose a photon is going in this direction and in this system I will lose that photon. Here what will happen because of it is concave surface and because we have chosen it to be also confocal in this case this will go here. So, suppose this is coming from here let me adequate. So, so it will go here and then again it will pass through the center hit here then it will become parallel to the axis and then again it will follow.

So, it will follow a route like this. So, it is not getting lost. So, slightly off axis photons are also now a part of this amplification process, and you see you know every you know round trip is passing through the active medium, because my active medium will be at this focal point right. So, I am not losing and ultimately what is happening. So, this is happening at this point also this is happening at this point. So, ultimately when it comes out of the laser I essentially have a beam like this. So, depending on my mirror system I will have. So, this is my ultimate laser output. So, it will have it is own beam width.

Now there are several other things that the beam width depend depends on we will talk about that. So, in such kind of cavity with confocal concave mirrors since we are collecting to off axis photon also advantages that the intensity of the you know laser output is much more compared to this system. Now because of it is design I will get some modes in the perpendicular plane perpendicular to this axis. So, what I am saying essentially suppose this is my whole laser, suppose I device this laser. So, everything is inside and all I am getting is an output and suppose I expand this being by a lens what kind of lens I will use to diverts the beam I will use a by concave mirror whereby concave lens.

So, this will expand the beam right this will diverge. So, essentially once it diverges the beam diameter is very large at a distance. And if I put photographic plates, so this is say my photographic plate then I will see how the beam is physically distributed. So, what I can see? I can see some of these following stops. So, let me use a different color. So, in this photographic plate I will see that distribution of the photon in the plane which is perpendicular to this axis. So, this axis is the axis of this laser beam and I am just looking at a plane perpendicular to this axis correct.

So, what I can see in this photographic plate I can see a homogeneous distribution of the beam across a central point. So, this beam is very nicely a circular spot. It can be something like this. So, it essentially has 2 loops in this fashion. I can have like this having 4 loops, or I can have again 2 loops is pattern, but these loops are oriented in a different way. Now what are these? These are called the transverse electromagnetic modes. And they come with some subscript let me call it pq. So, this is if I expand this one this is called transverse electromagnetic mode. That was longitudinal mode this is transverse mode, and you can see the longitudinal mode was along this you know axial direction, here this is actually in the perpendicular plane to the axial direction.

So, how do we get this TEM pq I have shown the experimental design by which you can get it and then how to read these things. So, essentially this pq these are the numbers of nodes number of nodes in this plane that is a perpendicular to the axis of the cavity and in 2 perpendicular relation, because this is a plane right. So, it can have this direction it can have this direction. So, if I look into you know this direction I will get what is the number of nodes that is p, if I look into the other direction I will get the number q. So, here if I look in this direction I see number of nodes 0, this is just a solid circle. So, there is no node. So, 0 node So, TEM So first I am looking at this direction I get or say I started with this one right.

Fine, so in this direction I have no node. So, I get a 0, in this direction the same I get another 0. So, this is called tm 0 0 mode. So, by looking at the beam profile I will be able to tell which kind of transverse electromagnetic mode that the laser beam has. So, for example, if I look into this one what mode this one has. So, this one again I come from this direction. So, I have no mode right, because in this case there is no you know 0 intensity. So, if I look through essentially these there is no 0, but here when I go I have intensity and then there is a 0 mode 0 point sorry point of 0 amplitude oscillation. And then again I have certain oscillation. So, this is essentially you have TEM. So, let us make a convention. So, that we do not have any problem. So, first I will prefer we will choose this direction as p and this one is q ok.

So, if I ask you in assignment or you know exam you should follow this one. So, that you know we are on the same page, or at least one can mention which one is which one. So, in this case if p is my first subscript. So, here if I go I have 1 and in this case I have 0. So, this is tm 1 0 mode. Now what happens in this case say this is you can see this is just you know flipped on the other plane other direction. So, this one will be TEM 0 1. Now this one you should be you know easily figuring out what is this mode. So, you can see this you know if you cross this direction there is one mode node if you cross this diction you have another node correct. So, this is essentially TEM 1 1 mode.

So, you can keep constructing. So, knowing this preliminary few nodes you can keep on constructing you know other types of nodes that are possible, in various cases there are applications of you know higher order modes, but most common is the tm 0 0 mode, most of the comm you know lasers that you will see we will have tm 0 0 mode. Certain cases you will have tm say 0 1 star which looks like a doughnut. So, different types of modes will be there, but most common is this tm 0 0 mode. I will share you know description of various different transmission transverse modes with you. So, please go through them, and you will you will start understanding how to recognize which mode is which one, how to name them. And it will be a good exercise for you as well ok.

So, we have to now with this knowledge that they are longitudinal and transverse modes, which we will use as we progress. Let us now again go back where we were discussing about certain practical concerns or issues involving construction of laser. Where we talked about the concept of loss and gain we mentioned that there must be a threshold beyond which you can get laser action, where your gain will exceed the loss and we will now see that you know how to quantitatively estimate that threshold condition.

So, we need threshold condition. So, this is some condition beyond which we will see laser action, below that we will not see any laser action. So, we have learnt about population inversion earlier, and we also know that the rate of increase of intensity of the stimulated photons. So, what I am saying is that if I say intensity of photon is I intensity of the simulated photons is I then rate of increase of this.

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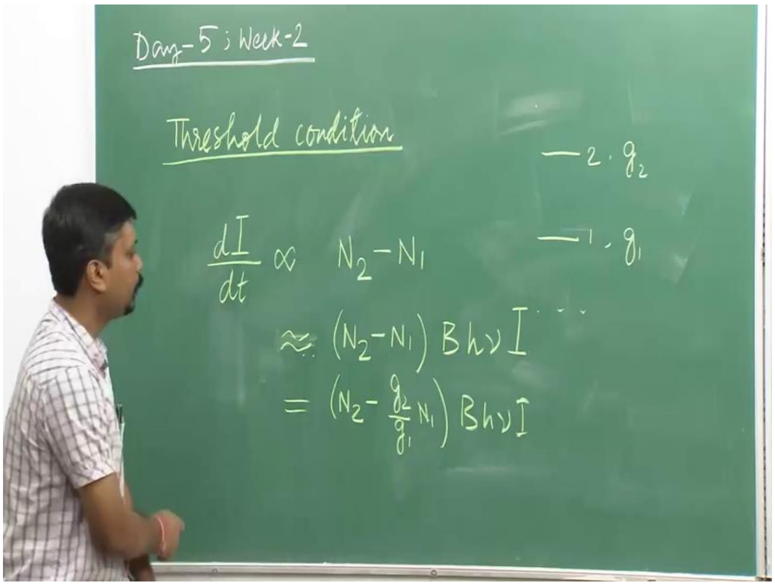

So, when I say rate; that means, there is a time component. This is proportional to the difference in the population of the excited and the ground state; so essentially which is right.

Now if I go to somewhat equality I should be you know writing almost equal 2 into B which is the Einstein coefficient, which is same for absorption as well as stimulated emission. So, I can use B 2 1 equals 2 B 1 2 equals to B as we assumed in one of the previous classes, and we have this ultimately multiplied by this I right. So, this is a actually identical to the equation that we have seen earlier that is just the rate of a transition. Now there we considered about the photon density and or the energy density so as a phi or rho. So, instead of that we are using this so, but both of them are identical.

So, at the end of the day we have seen this one. Now in a practical sense this states that we consider you know, maybe degenerate maybe non degenerate. So, the general idea will be to take the degeneracy into account. So, if I have so these are the 2 levels involved in the lasing action. So, this is level 2 this is level one you can have some other levels here and there I do not care about that, now the degeneracy corresponds to this one if it is g 1 and this is g 2 then I can write this one as N 2 minus g 2 by g 1 N 1, right.

So, we do not have any time left for this class. So, we will start from here in the following class and we will ultimately see; what are the threshold conditions for lasing action.

Thank you very much for your attention.