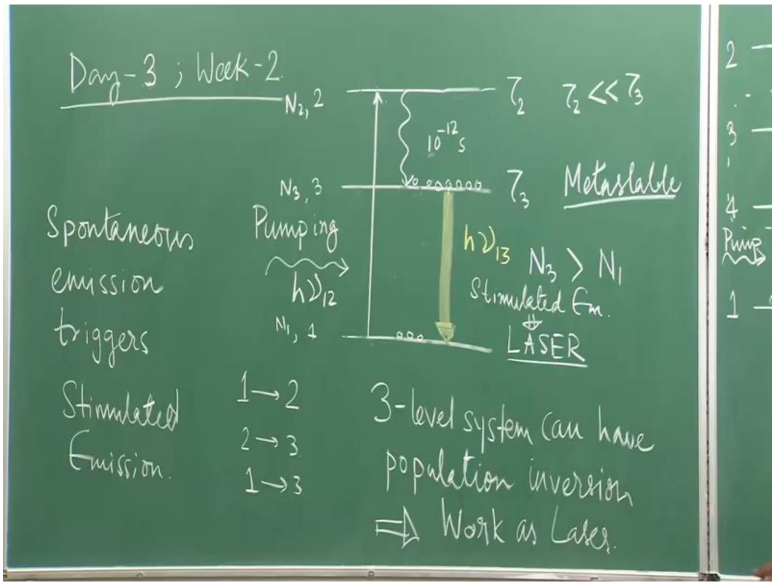
Laser: Fundamentals and Applications
Prof. Manabendra Chandra
Department of Chemistry
Indian Institute of Technology, Kanpur

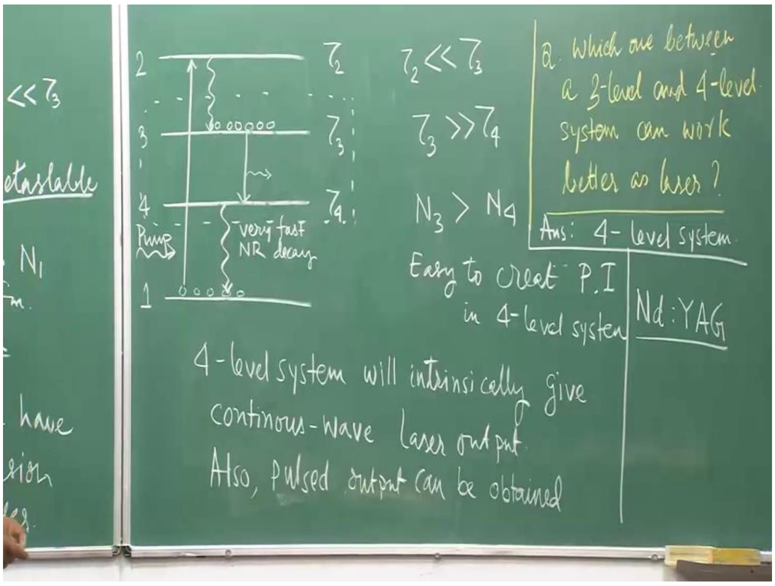
Lecture – 08
Components of LASERS

Hello and welcome back. So, we will start from where we left in the last class. So, we left with a question that is which one between the 2 level system and 3 sorry, between a 3 level system and a 4 level system which one is better in terms of laser action or a more efficient system. So, I hope that most of you have figured out what is the answer, in case you have not then the answer is here.

(Refer Slide Time: 00:52)



(Refer Slide Time: 00:58)



So, it is; obviously, the 4 level system right. So, here we had the question and here I have the answer that is 4 level system. So, 4 level system will work better, why? The answer is actually hidden here. When I have to create population inversion in 3 level system I need to pump it really hard; that means, I have to pump in lot of energy right. So, if I have more number of photons going as a pump; that means, I am putting more energy. On the other hand because this state is not the ground state; so it is population is 0 or very near to 0 at the beginning.

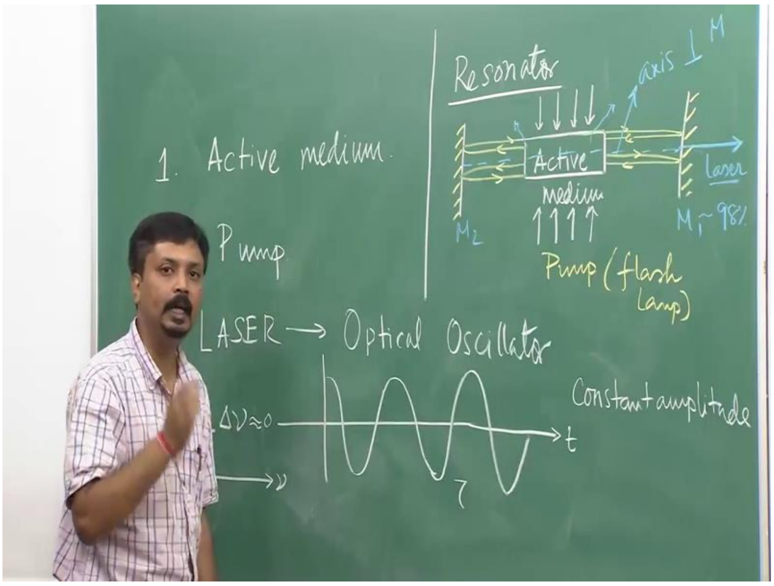
So, as soon as the first you know first transition takes place from here and then quickly comes down here I have a population inversion. So, I have to really you know use low energy, if I want to just get a laser output, which is comparable to this one. Only because this state is not the ground state and it is empty to start with ok.

So, I do not have to compete with a ground state population. That is why the 4 level system is much more efficient much more energy efficient than 3 level system. And also the 2 reasons that we discussed that it can be operated both as continuous wave as well as passed source. So, because of these 2 4 level system is always better an, example of 4 level system. The most famous one I will mention here we will talk about many more in the days to come neodymium yttrium aluminum garnet. Or in short it is called Nd YAG laser and even in a shorter term for this one is just YAG laser ok

So, the 4 level system is very common and this is one of the most common laser that is used industrially and you know in scientific laboratories are everywhere, and we will talk about this in quite detail enough you know one of the following classes when we discuss about different types of lasers. So, I think we have enough fundamental and theoretical background about laser and laser action by now with which we can start considering the actual you know practical depiction of a laser. So, how practically we can get a laser ok.

So, that we can start considering. So, if I ask what do you need to form a laser. So, what will be the answer? If you are following the lectures then you should be able to answer this. So, the most important thing that you need, so is an active medium ok.

(Refer Slide Time: 05:11)



I mentioned about active medium in the first class of this week. So, just to remind you this is the material that you are using where you can have say a 3 level system or 4 level system which you know has those characteristics that is needed for showing laser action ok.

So, not each and every material in the world can you know provide you all the characteristics. So, certain materials which can give you the you know the characteristics that is needed for you know lazing action showing glazing action, and you can suitably manipulate that you can use that as the active medium example, ruby is an active medium ok.

So, if you take a ruby crystal and then you start pumping it essentially you are creating the population inversion there and x after some time it will give you simulated emission. And you can you know try amplifying that stimulated emission and you can get it amplified output. And what do you need? You need a pump, because you have to create the initial excitation correct.

So, you have molecules in the ground state or atoms in the ground state you have to pump them to the excited state and then let them decay to a particular state from where they will lace. So, you need a pump source and that you know can we various type of sources you can have like a you know flashlight or flash lamp like what mimen used in his ruby laser. So, he used flash lamp which was a broadband like various different you know photon energies are there different frequencies were there and then pump it. So, the you know particular energy that is required to pump it from you know state one to the highest energy level is taken from that broadband flashlight.

In certain other active medium safer you know gas laser. So, we will learn about this argon ion laser. So, in those gas lasers you use electrical discharge you know as pump. So, that this discharge provides you the energy to pump it. So, you need these 2, now what are the other things that you will need to you know get a device which will give you laser output.

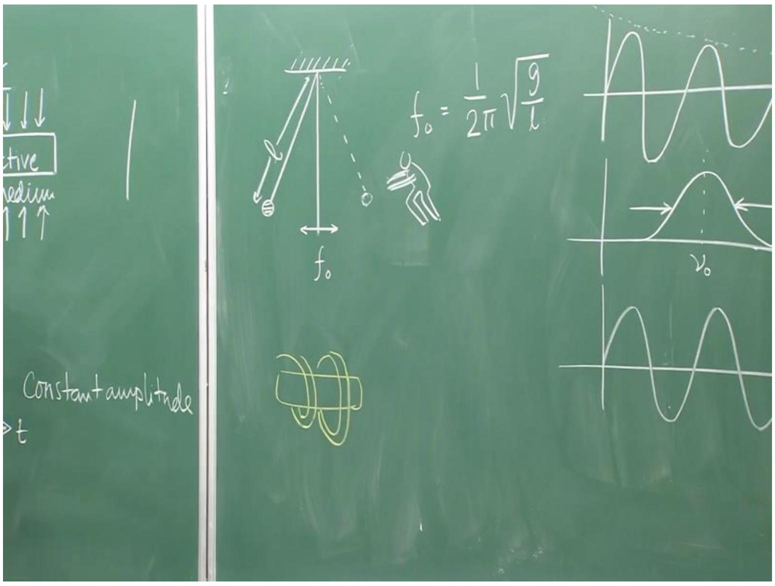
So, let us think about it now let us let us try to do that. So, when we say that you know laser is and a optical oscillators a laser is an optical oscillator. So, what does that mean; that means, that it will have a continuous amplitude. So, my drawing may not be that good, but just what I wanted to mean here is this amplitude is same ok.

So, you have constant amplitude over any given period of time. So that means, this axis is my time and this is associated with a time period say let us call tau, all right? Now this is in the time domain if I look the same thing in the frequency domain how do I how do as it look let me draw it over here. So, if this is my frequency axis and this is the amplitude then, if I Fourier transform it into the frequency domain then what I will see is this, corresponding to particular frequency let me call it as nu 0.

So, this constant amplitude you know oscillation will look like this in frequency domain. So, the width of this spectrum which is also known as line width is really small, it is very close to 0. So, this is what we expect from laser and actually it gives this.

Now let us consider a practical system, because we are talking about oscillators. So, the oscillator that comes to our mind.

(Refer Slide Time: 11:20)



If we start talking about any oscillator is simple pendulum right. So, something tied to the roof. And so, and you take a small string and put a mass here and leave it here. So, bring it here and leave it. So, what it will happen it will start oscillating right back and forth. So, right fine so it will go here also in this direction it will start oscillating.

So, this is a classical example of oscillator. And suppose this is the length of this rope or thread whatever you have or wire, then it will be associated with a frequency. So, this frequency that we know from our high school physics it will be fine. Now how will it behave as a function of time? So, if I look at the amplitude of this oscillation as a function of time, what we will see is something like this like this. If we add this tips we will see an exponential decay ok.

So, if you keep looking at further you will see it is an exponential decay, which scales as e to the power minus t by tau where tau is the period. So, this keeps going down and down and down. And if I look at the corresponding frequency domain picture very similar to these case, I will see a spectrum like this when I see it in the frequency domain. So, this is new 0 earlier what we had we had a line spectrum having line with close to 0, almost like a delta function. On the other hand here I have the central frequency is the same while there is a huge spread.

So, the line width is much larger. So, I have a broadband thing, so what I have? I have a tremendous loss of the amplitude with time and then I have a spectral broadening. So, this is because of the friction right. So, it is it is happening in the air. So, it is having friction and slowly the amplitude is decaying.

Now if I could somehow prevent the friction or reduce the friction and prevent the loss what will happen? This decay will be slight lower and if I can completely make up for the losses here by something I do not know what, but suppose there is a person here and suppose he is you know standing there and just you know it is coming and going back. And so, he is compensating for the energy loss there. If you somehow can do that then what will happen? So, you can come back to the situation where you have continuous constant amplitude and again a spectrum having nearly 0 line width.

So, the question is how do I compensate for this losses, or how do I minimize the losses. So, we do it very cleverly. So, in order to get a final laser I need to overcome the loss and get my output laser output. So, that is done in a resonator, in a cavity which is you know formed by which is formed by 2 barriers. So now, if I put my active medium, say you know neodymium doped YAG (Refer Time: 17:25) ethium yttrium aluminum garnet, or say ruby.

So, this is essentially my active medium. So, this is my active medium. And then suppose I have kept a flashlight here. So, flashlight is such that it is sending pump photons, if you remember the picture that I showed in I think the second class where you had this you know picture of the components of the ruby laser made by mimen. So, how was it was like let me draw it over here. So, you have a rod which is like the ruby crystal, and then you have a flashlight which is like a spiral, right.

So, this is the flashlight which is like you know like a spiral like you have seen those you know led bulbs in your houses which has this nice spiral kind of thing. So, suppose you are putting you know active medium say a duty crystal inside that one and then turn on this you know the spiral lamp, then essentially that is you know all the photons coming out of that you know spiral flashlight it excites this ruby laser all the light goes to the ruby crystal ok.

So, you excite the active medium by some photon source that is my pump. So, this is pump and this is optical pump. So, say a flash lamp. Now what will happen? This will create a excitation in this active medium and if there is you know a stimulated emission suppose I have a 4 level system right. Now suppose this is a YAG active medium. So, it will create the population inversion and then it will also create stimulated emission from there. So, the stimulated emission will keep coming now if I just allow the stimulated emission to you know go away then some amount of energy will go, but that will be very low.

Now, what will happen if I trap them in this cavity which is formed by 2 mirrors 2 mirrors such that both the mirror has 100 percent you know reflectivity, that is whatever light goes here it is reflecting back. So, nothing is going out. So, it is totally closed kind of system here. So now, what will happen? This system after pumping it will at some point of time give you emission that stimulated emitted the photons coming out of the stimulated emission will be coherent. And they will be a directional and because of this directionality whatever the photons that are going out in this direction they will be all reflected back. So, this will again reflect back go through this system and again hit it, and again it will come back. So, there will be roundtrips right.

So, the photons that are coming out as a stimulated emission they will keep going. So now, how it will work? So, this spontaneous emission that is actually triggering this overall you know stimulated emission causing the laser is spontaneous you know emission which are taking place in this direction that is along the you know axis. So, suppose I am calling this one as axis of this whole cavity. So, so this is my axis which is perpendicular to this mirror. So, these are mirror M 1 and say M 2. So, this axis is perpendicular to the plane of this mirror. So, these are suppose flat mirrors.

So, then those spontaneous you know those photons which is coming out of the spontaneous emission which are going in this direction, they will also create spontaneous stimulated emission if they are taking part in triggering the stimulated emission. Then they will lead the you know photon which are coming out of stimulated emission in the same direction and then they will keep going in back and forth between this 2. So, this is developing you know a directionality totally those you know spon photons which are coming out of spontaneous emission, but they are off axis suppose they are going in this direction this direction they are going out of the cavity they are lost.

And we do not really care much about that, maybe a little well talk about that later. So, these off axis spontaneous emissions are going out. So, I am not capturing them and the other photons coming out of the spontaneous emission is triggering stimulated emission and those photons are also going in this direction along this axis alright.

Now, once some stimulated the some photons coming out of a stimulated emission goes and hits here then goes to this mirror through this active medium all right. What they can do? I have already have population inversion if you suppose if it is a 4 level laser I have the population inversion all the time. So, this bunch of photon after reflecting off this mirror it goes and triggers more stimulated emission, which are just going in the same direction. So, these photons are like multiplying. So, they are trapped in this cavity and they are you know traversing back and forth along this axis and every move you know movement through this active medium is creating more and more photon.

So, over a period of time the number of photons within this cavity has built up enormously all right. So, one set of simulated emission when they are making this sound tip creating more again more and more. Now this huge amount of photon density inside this one; if I they will go out if instead of this 100 percent you know reflectivity if I make one of the periods say M 1 say 98 percent reflective; that means, 2 percent it will transmit, what will happen? It will allow 2 percent from this 8, and that is my laser output.

So, I build a huge population and then I allow some amount of light to go through and that some amount is actually quite a large. So, that will have a very high density of photon. So, essentially the intensity of light will be very high they are directional. So, they are not going to scatter. So, they are very very much you know directional they are kind of collimated all the photons have same phase. So, they are coherent ok.

So, they are giving you a coherent collimated high intense laser output. And this what I showed here is a continuous wave operation. I can do something to allow this whole buildup here to go out in a very short period of time suppose I do something and you know once you know a huge number of you know photon density is created here, and allow all of them to go out at a time. So, creating a pulse I can do that as well and actually that is done very regularly since in the Nd YAG laser I can also do this you know I can also get this pulsed output of very high intensity very high power.

So, we will talk about much more details in the coming classes. So, please stay tuned.

Thank you for your attention, see you in the next class.