Optical Spectroscopy and Microscopy : Fundamentals of Optical Measurements and Instrumentation
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Lecture - 34

Hello and welcome to this lecture series on Optical Spectroscopy and Microscopy. We had in the last class talked about Q-switching and then the practical implementation of a Q-switching using a device called the Pockel cell. It is an electro optic device whose birefringence depends on the electric field that you apply.

During that, in that lecture, I was mentioning or I was talking to you about how we can actually store the energy of this excess energy inside the light radiation in the cavity itself rather than in terms of the population inversion, okay. There is a difference here, right? When you are talking about storing the light energy in terms of the population inversion what you are actually doing is that you have pumped these molecules to the excited state.

Now until you extract they are present in the excited state, they are present in terms of the population at a higher energy. Now they can actually decay through spontaneous emission, thereby you lose your energy and so on and so forth. But more importantly, for you to be able to generate a light pulse out of this it requires some amount of round trips to be performed and the energy gets extracted from this population.

I mean, you need to be able to convert this excess population into the light photons that we are interested in. An alternative way could sometimes can be very, that can be very useful is that to be able to store this energy in terms of the light energy itself in the cavity and then dump it out when the energy reaches its peak.

See the trouble with the previous method, the Q-switching or the one of the things that we may face difficulty in doing the Q-switching is that how often can you actually keep operating this Pockel cell, right or the switch. While the population dynamics constricts my pulse to the short, along with the pumping constricts my pulse to a very short pulse I mean very short duration how often can I keep doing this.

I mean, is there a limit on which at what times I mean can I actually operate this like can I keep operating it at kilohertz, hertz this switch.

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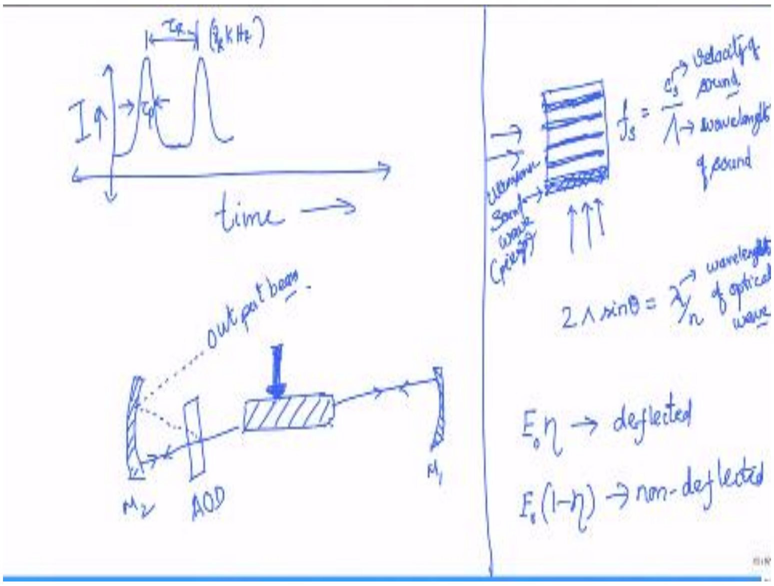

So in other words, we talked about one aspect of the light which is the intensity of the light and its duration, right. Now we want this tau to be as small as possible so that we can pack in the light photons with the high very high density so that a very intense light can be generated in very short times. But the question that we are posing now is that how fast can I expect to generate a second pulse? Is there a limit?

Okay, so this also is tau. So let us differentiate this and this as tau r. This is so called the repetition rate and the inverse of that is the tau r and tau p is the pulse width. So how often can I keep generating this light? Is there a limit on to it?

Clearly yes, because we are actually so if we are to think in terms of the Q-switching, what we are doing is that we have built up this pulse and then reached to the maximum amount that we can actual to the excited state, given by the lifetime of the system and so on and so forth. But then, once we extract it out, you have to wait till the point in time where you have sufficiently built up the population again.

The pump pulse be able to build up as fast as it can. So that sets a limit on the repetition rate and typically in a Q-switching process using YAG and so forth the speed at which we can keep pumping is of the order of kilohertz, okay. So this is 1 over tau r the repetition rate we can call it as mu r is typically of the order of kilohertz. And if you want to go megahertz range then you realize that it can have serious limitation.

It can it becomes harder because it need you need to have enough time for it to build up this population. So what do we do in such cases? This is where cavity dumping comes in really handy. So what is cavity dumping? In many ways you can think of cavity dumping as exact reverse of the Q-switching. So let us say you have a lasing medium okay? And I mean in fact, this can be applied even to a CW pumped laser, right.

As like a let us take an argon laser and then pump it or let us take the argon laser itself and then do a cavity dumping. So when you do that, what happens is that there is a constant pump that is actually present here, okay. So now there is no pulse dynamics, there is no population dynamics here to come and help. Because it is continuously being present there.

Then you put that inside a cavity, okay. Now if you notice actually, we can put that inside the cavity. If you notice I am actually making a cavity out of not a plain middle but a curved mirror, okay. Let us call it as M 1. And in a cavity dumping laser, the end mirrors are hundred percent reflective as against that of any other laser where one of the mirror is partially reflective so that you can take the light out.

Here what we do is that we let the energy build inside the cavity, light energy keep building inside the cavity while you are actually constantly being pumping the medium. So they keep extracting more and more. So in principle, so the light traverses back and forth and keeps increasing the intensity and it is very confined until a point where you put in another device. This we call this device as acousto-optic deflector or a moderator.

What it does is it makes use of the properties in some of the materials such that when you pass in an sound wave through this medium, so let us say an ultrasonic or an acoustic wave were to travel in this direction. Now we know that that acoustic waves are pressure waves, alright. If this pressure waves were to travel inside this medium, then there are places where there is a compression.

And there are places where there is rarefaction because of the longitudinal mode of traveling and then these are pressure waves. So depending on this change in pressure, what you end up creating is actually and patterned and alternate of dark and light, I mean dense and rare places, spaces in this crystal. The dense spaces where the atoms are larger in number.

As a result the light when the light were to if the light were to travel through this for the light, this whole device now looks as if it is like a grating. Except now this grating because there are dense regions and then light regions and then the grating frequency is given by let us call it as frequency of the sound wave is the speed of the sound wave by the wavelength itself. And this is acoustic wavelength, right.

This wavelength of this is the velocity or the sound that is actually traveling in that medium. So as a result, if we define this frequency, then since it is acting like a grating, we can write down the Bragg corresponding Bragged equation which is 2 lambda in this case the spacing 2d sine theta right. So d is the inter ruling spacing. So here that would be given by the capital lambda sine theta equals lambda by the order n.

So this lambda here is the wavelength of optical wave. n is the diffraction order. So as a result, when you look at the light that is coming out from here, you have different I mean you have a diffraction pattern you have a different orders. The central maxima is zero and then a deflected beam. So we will concentrate on the deflected beam and the central maxima and they have different depending on the efficiency eta they have different intensity.

So let us write down two light waves. So the E 0 eta be the deflected and be non-deflected or the other. If so now if we were to imagine such a system were to be present here okay. And the eta itself is dependent on how intense or how strong is the acoustic wave and this is the amplitude of the wave itself. So if there is a the intensity is high of the intensity of the sound is very high, the change in the, the contrast in the densities are also high.

As a result, you have the eta the efficiency of diffraction is also high. Now nevertheless whatever the efficiency when you have such a system okay. So we are remember we are putting in the sound waves we are transferring the sound waves through here. So let us put let us denote that as sound wave. Oh so it is a generated ultrasonic sound wave, sound or a pressure wave is done through a piezo.

So now when you have this such a kind of a device inside the cavity, what you end up having is that a light as I have drawn here that goes without any deflected. This is the E 0 into 1 minus eta faction. That goes and gets hit I mean it and hits the M 2 mirror. Now you see the in this cavity where of this laser where there is cavity dumping the both the mirrors are highly reflective.

As a result, the entire fraction gets reflected back and then travels through. On the other hand, the moment you turn on, there is this non deflect I mean the deflected faction and that it deflects and then hits this mirror and when it hits this mirror, it presents itself with an alternate path and this is our output beam.

So now by operating this mirror at or operating this device, or acousto-optic device in a certain frequency and turning in a cyclic frequency such that you synchronize with the speed at which the population can be regenerated inside the cavity. The population inversion can be regenerated inside the cavity. Then what you end up having is a beam whose intensity is moderated, okay.

So now here two kinds of there are two kinds of oscillation percent. One is governed by the round trips of the light that is that it is taking inside the cavity and then the whole dynamics associated with the population and then the frequency of the acousto-optic device itself. When you have such kind of one on top superimposition, then what you have is amplitude modulated wave or a light that is emanating from that output beam.

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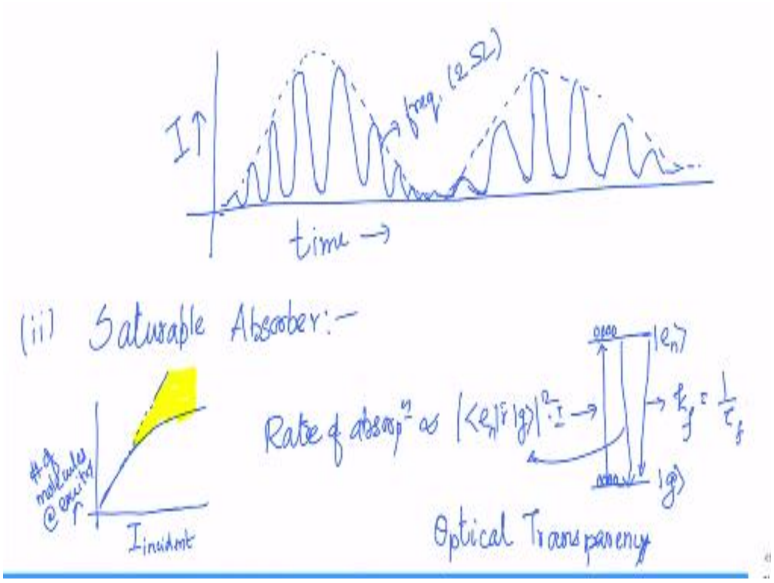

And if you were to plot the output of the laser as a function of time, what you would see is not just a pulse. I am actually I am preferring I mean magnifying the duration of the pulse. Not just a smooth envelope something similar to that, but there will be a carrier frequency. This is the frequency which is it is twice the frequency of the of your this thing as the frequency of such this oscillation and the carrier wave.

Oscillation is twice that of our modulation frequency, okay. And this pattern keeps repeating. You have a wave time. So this is the intensity. You have a wave time that keeps repeating but with whose amplitude is getting modulated. So you wait for sufficient enough time. And then whenever you are operating you are generating another pulse something like that.

Now in this as against a Q-switching, your energy is actually present always inside the cavity right. And you are taking out this energy only, a fraction of this energy at any given instant in time. As a result, the laser can operate at very steady intensity and a very stable situation. Unlike in a Q-switching every time you are actually building up this whole population and then restarting the laser.

It is equivalent to literally turning off and on the whole lasing process. While in here, the laser is continuously operating and then you are taking your, taking a pickoff or a small fraction out of that laser cavity in regular intervals of time. So because of this, you can afford to actually operate this or get this pulses at a very high repetition rate. Tau r’s can go to about a megahertz or so.

And the pulse can also be very small. However, the intensity that you can build up is not as high as that of the Q-switch. Usually a combination of a Q-switch and the cavity dump elevates most of these problems and presents you with a system that is really of a high power and still you are using a cavity dump to throw out the light once the light gets amplified at a certain to a certain degree.

So now that is about another way I mean, that is about the principle of what we can do with an acousto-optic device and then how you can actually generate the light out from the cavity while without having any lossy mirror alright. So the every single photon is used either in one way or the other. And then we also talked about the practical implementation using acousto-optic device.

I told you in the previous lecture, that apart from the cavity dumping, we will also be talking about something called as a proper saturable observer. These are wonderful substances whose property comes in handy when you are actually in either mode locking or whenever you want to generate very high intensity laser. So how does it work? It works on a very simple principle.

Let us take a two level atom and we have a ground state and an excited state, alright. So now in the when we talked about the two state system, we had actually wrote down the rate equations and then showed that when there are only two energy states that are present owing to the insensitivity of the rate of absorption, alright. So the rate of absorption, we said is directly proportional to the square of the matrix element g.

And sorry we I said with the final state, it is actually e n r final state, initial state modulo square times intensity and so on so forth. But then moving to this modulus square the light can equally take the molecule from the ground state to the excited state or from the excited state to the ground state. As a result of this when you have a two level system and then shine the light and increase the intensity of the light.

As we increase the intensity of the light the rate of absorption as a result, the number of molecules going from the ground state to the excited state slowly increases. And if you plot that number okay, as a function of the incident intensity. This is the number of molecules at the excited state. If you plot this as a function of incident intensity, you will see that initially it is a straight line.

But as you keep increasing the incident intensity, slowly the, it will start deviating from the linearity and then we will see it will plateau out. This is because of the fact that the excitation intensity has reached its maximum ability to drive the ground state atoms differentially, which means in simple terms now the population of these two states are such that the rate at which you are actually causing the excitation, right is equivalent to the rate at which the light causes the de-excitation.

That is the stimulated emission, okay. Apart from this, there is also a spontaneous emission. We represent it by a cross arrow. So now initially when your intensity is very low you are actually building up the rate of excitation is such that the de-excitation by this spontaneous process, I mean brings the molecule from the excited state to the ground state.

But then if the rate or the incident light intensity is increased, then if you actually look at the population distribution, there will be a state at which you have equal number or almost equal number of or a comparable number of the ground state and the excited state molecules coming in. Because the forward rate, right this is what this rate is, right. This is totally driven by us and so is this.

But this is fixed for a molecule, right and this is given by the k f which is 1 over tau f. Since as we increase this I, now what you can do is you can actually increase this rate faster than that of the rate at which the fluorescence decay happens. The result being accumulation of the population at the excited state. Now this can happen only if there is a differential, I mean if as it starts happening, the differential between the ground state and the excited state population starts to go down.

Because before even the molecule can come to the ground state, you start exciting the next molecule. So it keeps going down, the fraction of the molecules in the ground state and the excited state becomes more or less equal. At that point, the light that you are shining or the increase that you increased number of photons in this region, specifically in this region, right.

You have increased the number of photons, but they do not result in any absorption. They simply get transmitted. Then you say that the absorption process is saturated now and the media has attained optical transparency alright. Now you see, if you carefully devise a material like this, they can act like an optical self-limiting optical switch. That is to say, when the intensity is very low that intensity is absorbed by this small chromophore and is just keeps getting absorbed.

And until a point where you are right about here in this yellow region is reached where you start to see the no absorption or complete transparency of this excess photon through this media. Now these can actually act as a very well-orchestrated switch all by itself in a passive way. You do not need to have any electrical device or to turn it off and on.

All you need is to design or device this molecule material with proper case. And then you can actually achieve this feat of optical switching or what you call it as a saturable absorber. You can put such material, typically if it is liquid then you actually put it in a acquit inside the lasing, laser cavity itself or nowadays you also get these solid state materials whose optical saturation can be modulated.

By then these are typically a semiconductor device whose optical saturation can be modulated by the electric field. That is convenient when it comes to actually use the optical when the saturation property or optical transparency in response to electrical device. But then you can also think of such devices being present in front of a mirror, in which case the reflection coming out of this can be modulated by the optical saturation.

So using any one of this, typically the dye that I was talking to about it is used in a laser to generate saturable absorber Q-switching based Q-switching lasers. So that kind of brings to an end our analysis of generating a class of pulses that is in the range of nanoseconds. And you typically do it with either a Q-switching and then cavity dumping is a slight modification of that, but we still dealt with in terms of one of its variants, variation is the sub topic.

In the next class, what we will do is that we will go into another way of generating optical pulses which provides us with even higher constricted time profile. I mean even shorter duration pulses constructed in time called mode locked lasers. We will look into the basics of what this mode locked lasers are and then how I mean to I mean there are different ways of achieving this mode locking.

Specifically here we will be talking about two different broad classification of this mode locking, active and passive mode locking and how do we do that, okay. We will use many of these devices acousto-optic modulators, Pockel cells and saturable absorber there but then the, I do not have to describe this devices again there. But I can tell you, I can give you or motivate you how this can be useful for generating the mode locked pulses. I will see you in the next class. Thank you.