Optical Spectroscopy and Microscopy : Fundamentals of Optical Measurements and Instrumentation
Prof. Balaji Jayaprakash
Centre for Neuroscience
Indian Institute of Science-Bangalore

Lecture - 33

Hello and welcome to the lecture series on the Optical Spectroscopy and Microscopy. So far what we have seen is that we can generate lights of a special kind called the laser light or the light I mean stimulated emitted light and amplified to a good extent, and even more specialized are the lights that we were just talking about in the last few lectures about the pulsed light, flashes of light, very short duration of light pulses.

And how they are originating naturally from the dynamics of the population that is involved in the laser light generation itself. We took the example of a Ruby laser, the first laser that was invented and then zoom in to the very beginnings of the light generation. And when you look at that what we call it as a transient behavior, when you looked at that, what we see what we saw was not a monotonous increase of the light intensity but rather a brief bursts of pulses.

And then we went ahead and try to understand in terms of the population dynamics of the excited state, right. You are having a ground state system, the Ruby in this specific case is the chromium ions and when they go from the ground state to the excited state, and then you put this media into the cavity together, how the dynamics originates such that or interplay such that you generate these pulses of light.

This is true even in India or in any of the subsequent lasers if you would like to think about ahead in time. But then what we will see now is a specific example of how to actually implement, right. We, we kind of took a laser media such as a Ruby and then said, imagine if there were to be a shutter inside, alright. And then in I mean, the equivalence of the shutter we said it is equivalent to the cavity losses.

And then we can actually manipulate these pulses or manipulate the light the disk emerging out from this laser into occurring in terms of the bursts or the light flashes. And just to briefly give you the extent of the flash light flash that we are talking about, or the magnitude of how short can we actually get this just to give a real world comparison. If you looked at a photo flash, any normal photo flash typical photo flash is anywhere between 1 over 60 to 1 over 100 seconds.

That is the light intensity reaches its peak and comes down in less than 1 by 60th of a second, okay or 1 by 100th of a second depending on I mean if you want to be really fast flash. You can improve that, you can spend more money and get even faster flashes, okay and to freeze events in time okay.

Imagine a very, imagine a dark room and then you want to capture a fast moving event then the speed at which you can capture or freeze your event is determined by the x I mean the time extent for which the light is actually shining on it. Now the laser lights here we are talking about or that we are planning to generate here or of the order of hundreds of femtoseconds and particularly in the Q-switching and stuff that we had talked about, it can go from microseconds to nanoseconds.

And that itself is like several orders of magnitude larger than the I mean several orders of magnitude smaller in pulse width, then the flashlight itself. It is so much so that if you actually calculate how much of the distance that the central wave, wavelength of this pulse would travel, you almost come to about just confining your light to one single wavelength, okay.

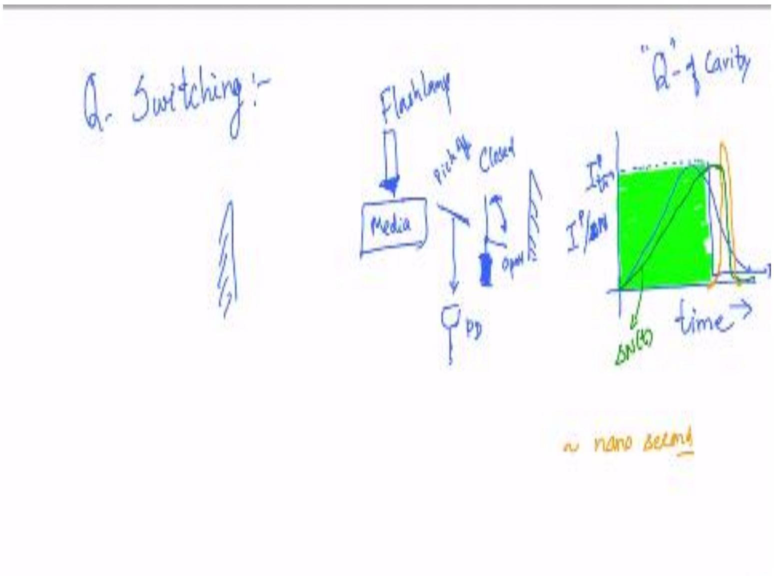
That is how short in time we can actually construct these light pulses. And that is why we are taking this special efforts to learn this methods. And this allows us to achieve few things. One, being able to study processes that are happening in a really fast timescale. Typically, in a chemical dynamics or in a chemical reaction systems that is something that you want to follow.

In a biological system, which is much more profoundly used application involves a brief but a very high intense light, often you require this right because very high intense light shone for a sustained period of time can damage a living system. So what you want to do is you want to restrict this to as brief a time as possible.

And that is why this femtoseconds becomes really attractive and you can actually give pretty high intensity of pulse, big shock. And it is extremely useful to have such kind of light sources. With that spirit now let us look at how we can actually put to use the Q-switching phenomena that we have seen in theory, and then in practice, when we have to implement that in a real laser system, what do we need in terms of the parts that go in and then the analysis that follows, okay?

This would be like a semi quantitative approach. The emphasis here is on to drive you the motivation and the intuition rather than really going into the in-depth description of this laser systems, okay. So now let us look into look at the Q-switch laser themselves.

(Refer Slide Time: 07:36)

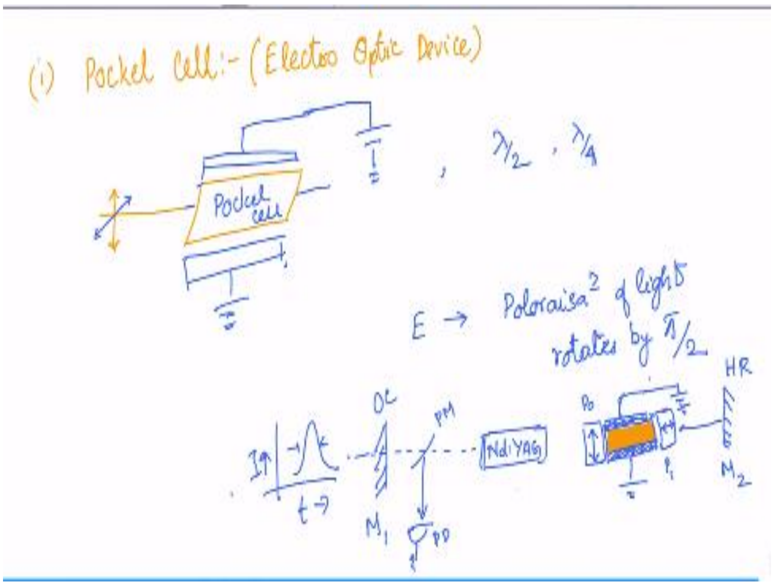


What we saw in the Q-switch description, Q-switching description is that there is a media and then we talked about a shutter that closes and opens right? The idea is that when you close it, the loss incurred in the cavity is very high, and then when you open it, the loss is going down. As a result, the threshold falls down. So that is the whole crux of the entire setup, optical setup. So how do we implement this?

Because of the requirement of turning this off and on, the shutter going between closed and the open state really fast because the flash lamps act fast. On top of it, what we are talking about is generating the light pulses that are limited by the lifetime of the excited state, right. If the we can actually build a population inversion, but if you do not extract it before they all come down then it is of no use.

So you are actually wasting that energy in terms of fluorescence and that is not useful. So what do we want to do is that we want to be able to turn on or turn off or operate the shutter in the as close to that of the light, timescales of the lifetime. So if you are to do that purely mechanical shutters are not of much use. So we are going to be using special kind of shutters okay.

(Refer Slide Time: 09:23)



And the shutters that we will be specifically we will be using in here and we will be talking about is called as is based on an optical device called as a Pockel cell. These are electro optic devices that can modulate what is called as a birefringence, okay. So these are electro optic devices that can modulate birefringence. What is birefringence? Essentially, if you take this in a crystal that exhibits this property, so when you impinge light okay light photon.

When you impinge the crystal with a light photon whose polarization is vertical as shown here versus light whose polarization is horizontal. The extent to which the crystal will allow the light to go through, right I mean the path delay the refractive index shown by this device for this two lights are different, okay.

So the refractive index here is dependent on the polarization and you quantify the birefringence by the difference in the maximum and the minimum refractive index that material exhibits. What Pockel cell is special about is that you can modulate this birefringence of a crystal by sending in by putting the by turning it turning keeping the crystal in an electric field or not.

Proportional to the electric field that the crystal sees it can actually modulate the its birefringence property. The net result is you can modulate the refractive index okay or as a refractive index between these two polarization of the lights thereby, by cleverly choosing the field that they are existing in, what you can actually do is, so if you put them inside an electric field, what you can actually do is that you will be able to differentially rotate the polarization of the plane polarized light that is impinging on this.

So what we what you what we do is that we measure this phase difference that is imparted by this Pockel cell for this to polarization, and then we depending on the phase difference, we measure the phase difference in terms of the lambda of the wavelength. So if we were to say the Pockel cell is operating at lambda by 2 phase difference what it means is that the path difference or the retardation suffered by one of the polarization is half the wavelength, corresponding to half the wavelength.

If you are and it slows down such that, while the if you measure the path difference between these two lights, they will have a lambda by 2 part difference and lambda by 4 so on and so forth. Thus in principle, what it allows you to do is it allows you to rotate the plane of polarization of the light, okay that is coming out as a function of the electric field that we impinge.

So let us say if we were to, if I were to plot the transmission of the polarized light, you can actually see that I mean polarization of the transmitter light you will see that at some theta it has the maximum, I mean some theta has a maximum transmittance and then the other two I mean around that it actually falls down. So by coupling this such kind of electro optic device, together with that of a polarizer, right.

We have seen talked about this polarizers before. We can actually effectively shutter the light from going through or not going through. Let us take one specific example where we are going to apply an electric field turn off and turn on this electric field, such that the path difference incurred by this Pockel cell is lambda by 2.

Which effectively means if you are sending in a polarization, a light of vertical polarization you can actually rotate I mean it ends up rotating and becoming horizontal polarization. So in that configuration so we are operating the electric field such that the E is such that the polarization of the light incurs a polarization rotates by pi by 2, okay.

So then what we can actually do is that we can actually put integrate that into the cavity as follows to generate a nice Q-switching laser. So the design of that would be these are the end mirrors, let us call them as M 1and you have your media. So okay, laser medium, we can call it as you can take it as Nd:YAG. Then usually these mirrors are Brewster at Brewster angle and there is a Brewster kept at Brewster angle.

So there are usually polarization sensitive components inside the cavity starting from the crystal phase to the end mirrors and the windows that couple the light to the outside. Even that can actually associate a polarization to the laser light. Even if it were not to be there, let us specifically put in a plate or we call let us call that as a polarizer with a vertical polarization and then P 0 polarizer P 0.

And then we have our Pockel cell alright. So this is our Pockel cell, right. So that is our Pockel cell and then the electrode is what we have represented here. So the electrode it is really a high voltage, when I am just drawing it here as. So now at the end, we also have another polarizer but in a different orientation. So these are basically crossed polarizer.

Normally, if nothing were to happen in the Pockel cell, the light that is coming through here would be polarized in the vertical direction and then it will not be able to go through the other polarizer at all. As a result, you will get a very feeble light to no light at all coming out from the other end of the polarizer which is let us say P 1. So we have here a situation which is and M 2 be the other mirror.

Let us call that as a higher reflector and this be the output couplers. So this we have a situation where there is a very high loss in the cavity. So the every light that is going through does not come out and it just gets absorbed by the medium or the by the polarizers that are present here. So what we end up having is that a very high threshold because of the heavy losses we have a very high threshold.

And the energy gets built up in terms of the population inversion in the YAG crystal. The moment and we would have our pickoff mirror. Remember we will have our pickoff mirror which is taking in a small fraction of the light that is coming out means present inside the cavity and then putting it to the photodiode.

We can monitor the amount of population inversion that is happening in the crystal by monitoring the intensity of the fluorescence that is emanating from the Nd:YAG picked up by this pickup mirror and putting into the photodiode PD. As soon as you reach a point where you think is the peak inversion that the crystal can sustain. So you the E field E with the magnitude E is applied to the Pockel cell.

When you apply and when you turn on this E field, what is happening is that the polarization of the light that is coming through here is rotated by thus by 90 degrees which means the vertical polarization becomes horizontal which easily goes through comes back again in getting reflector and comes back again. And since this is a much shorter distance and by you will keep this Pockel cell on until the point that the light pulse come travels through back.

It will incur the same amount of 90 degree rotation so that it can pass through this Pockel cell and then keeps amplifying the crystal by keeps getting amplified in the lasing medium. I am sorry. It incurs the same amount of polarization shift and then it passes through. Now it gets amplified because there is no loss and then your threshold has fallen down.

So effectively it extracts all the stored energy in terms of the population inversion from the YAG crystal. What you get out is a huge amplified pulse. It gets self-limiting. It falls down because of the self-limiting nature of the light pulse that we discussed in the previous class, remember. So light intensity as a function of time. So the light that comes through is going to be of a pulse that is something like that has a very short pulse duration and very high intensity.

Thus by operating this electrical electro optic device, you could actually turn off and on pretty much like what we had discussed in the previous lecture. You can actually gain, you can moderate the gain inside the cavity and then generate light pulses. There are other equivalent configuration for the Pockel cells.

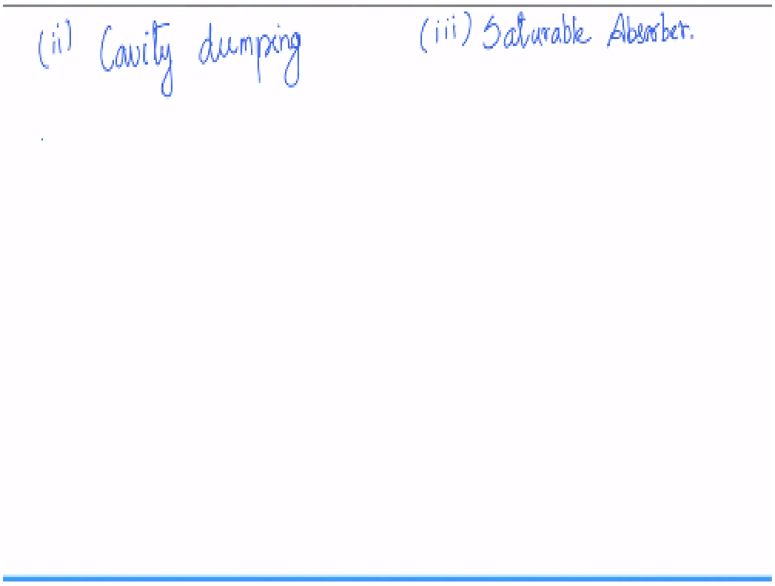
One cool way which minimizes the number of optical elements that need to be inside the cavity by removing this one of the other polarizer is by using the Pockel cell in not in not in a lambda by 2 configuration, but as a lambda by 4 configuration wherein the light that is passing through gets only quarter wave retardation while per pass through.

So if you do not have this polarizer so it is the vertically polarized light going through here gets a quarter wave retardation hits this mirror, while it comes back, coming back, it suffers another quarter wave which is half wave retardation, and then it cannot go through because it is the vertical polarized light after one complete round trip it becomes lambda I mean equivalent of a lambda by 2.

Which is polarization that is rotated by in the to the horizontal direction which this polarizer will not get through. So it is a high loss situation. And the moment you turn off alright, now turn off the Pockel cell, there is no lambda by 4. As a result, the vertically polarized light goes and hits the end mirror, comes back without suffering any rotation. As a result, it extracts out the energy that is stored in the YAG lasing medium in terms of the population inversion.

So these two are different configuration with which you can operate the Q-switch laser using a Pockel cell. And there are also other methods of generating this kind of Q-switched pulses or an intense pulse.

(Refer Slide Time: 26:24)



So one other method which is also useful in other forms of pulsing is called as cavity dumping. And then we will also talk about saturable absorber. And then we will also be talking about saturable absorber. Sorry, absorber. So one of the biggest limitations of the Q-switch laser is that, that you are actually storing this energy in terms of population inversion in the lasing medium itself.

Which means, if you for you to actually I mean when the pulse comes out it is largely driven by the dynamics of the population inside this media and it takes its own time to actually gain its extract its energy through many, many round trips. So it is not so much just the one other way of generating Q-switching, but as an alternate one can also do something called as a cavity dumping.

We will talk about this in the coming lecture, what this cavity dumping is and how it avoids this problem of having to rely on the population dynamics of the lasing medium to generate this laser pulses, but rather you store it in the cavity itself okay. We will again take a qualitative approach to understanding the phenomena of cavity dumping before we going into phenomenon of saturable absorption or saturable absorber.

This really is another way of having a switch inside the cavity. This will be used later in generating pulses in a different means as mode locks, mode locking and so on, okay. In the next class we will talk about cavity dumping and saturable absorber. Thank you and see you in the next class.