Ultrafast Processes in Chemistry
Prof. Anindya Dutta
Department of Chemistry
Indian Institute of Technology-Bombay

Lecture No. 33
Chirped Pulsed Amplification

We continue our discussion on chirped pulsed amplification as we have said already, this is how it is done, output of oscillator is stretched goes into an amplifier gets amplified but remains chirp and then you compress to remove the chirp to get the desired amplified unchirp output. In the last couple of modules, we discussed the stretching and compressing bit. Now, we are going to talk about what happens inside the amplifier. The general introduction to this is this.

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The way you do amplification is first you do seeding. Seeding means introduce a chirped pulse into a pumped gain medium and a gain medium is typically the same as the one that you have used to generate the ultra-short pulse in the first place. So, if you are using a Ti sapphire laser, typically you use a Ti sapphire gain medium but it is not compulsory, you do have ultra-fast fiber lasers, which are used to seed Ti sapphire amplifiers.

For now, since we use Ti sapphire oscillator, Ti sapphire amplifier does not just stick to that so, essentially what you do is you introduce the chirped pulse medium into a pump gain medium as a

Ti sapphire laser, then what will happen the pulse when it goes to the pump gain medium will find a lot of ions molecules whatever it is in the excited state. So it is going to cause stimulated emission and that will resulting amplification.

Now you make this, go back into the gain medium again, you will further amplification and so on and so forth, so you do a number of round trips in order to amplify the light that you are seeded in what is the number of round trips? Is it better to have 5? Is it better to have 500? Is it better if we keep increasing maximum is the best? Actually not, I am going to demonstrate maximum is not the best. We will see what that means and then when you have reached amplification to a sufficient level, switch the pulse out of the amplifier and into the compressor.

How do you switch the pulse out of the amplifier? We will see, but this is the general way in which amplification of an ultrashort pulse is done after being stretched.

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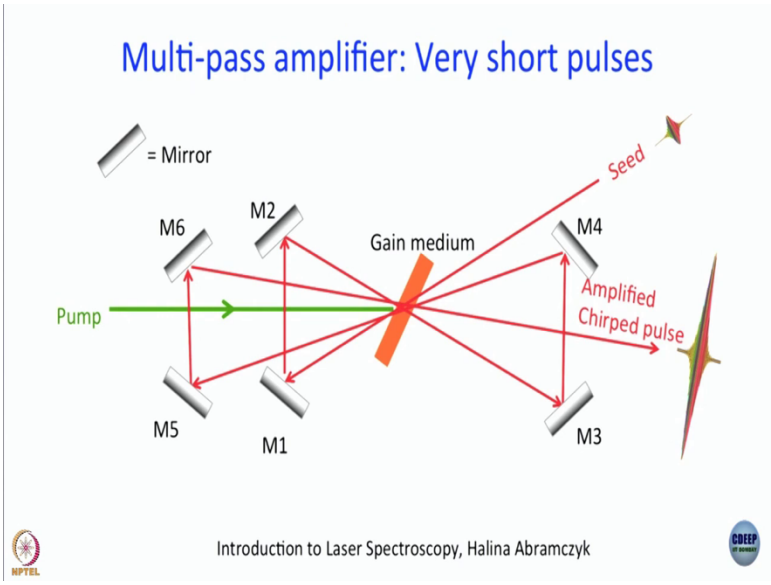

So we are going to discuss 2 different kinds of amplifiers, one, the multi-pass amplifier and second regenerative amplifier. In our lab, we have a regenerative amplifier. When do you choose which one? You choose a multi pass amplifier when your pulses a really very short 6 femtosecond, 10 femtosecond, but then the output generally does not have as much of power as you can get in regen. Regen means regenerative amplifier.

Sometimes if you want an ultra, really ultrashort pulse, as well as high power, you might have to use multi-pass as well as regenerative amplifier. So there are systems in which both combination of both are there so, let us see how a multi-pass amplifier works. So, I hope it is not very difficult to understand what we have drawn here, you drawn a gain medium and we have drawn a lot of mirrors M1, M2, M3, M4 and M5, M6.

Now, there is no guarantee that there will be 6 mirrors they can be more there can be less and the geometric can be such that M2 can be used as M2 as well as M4. It all depends on how efficiently one can design it, so, to start with you pump the gain medium and as we have discussed, you will find a lot of excited state population in that case. Then, the chirped output of the stretcher is fed into the gain medium and this is called the seed.

I hope you are familiar with this can you see the chirp here? Or is it too small, seed goes through. So in the first pass itself, I hope you will agree that there will be some amplification because it is already pumped? So if it is a Ti sapphire crystal, there is a gain medium, then you will typically pump it with some Nd-YAG laser or something like that? We will talk about this pumping laser and all in a little more detail when we talk about regenerative amplification.

So now the mirrors are arranged in such a way that after hitting M1, the beam goes to M2 and then M2 sends it to the gain medium once again, on M3. So now this is a second pulse to the gain medium, so there will be further amplification. Next step M3 sends the beam to M4 from M4 again it goes to the gain medium to M5 third pass. From M5 it goes to M6 and from M6, it makes the fourth pass through the gain medium and goes out and what goes out is the amplified chirped pulse.

Good thing about multi pass amplifier is that the only medium through which the beam travels is a gain medium everything else is reflective. That is why it gives you very short pulses. Problem is amplification is not so much because and how many mirrors can you put in it all depends on that you can put in 50 mirrors and make that number of passes then perhaps it will be very large but typically this is used so that the pulse does not become too broad.

And it is useful in applications where you need a really short pulse and you can afford to compromise on the energy a little bit.

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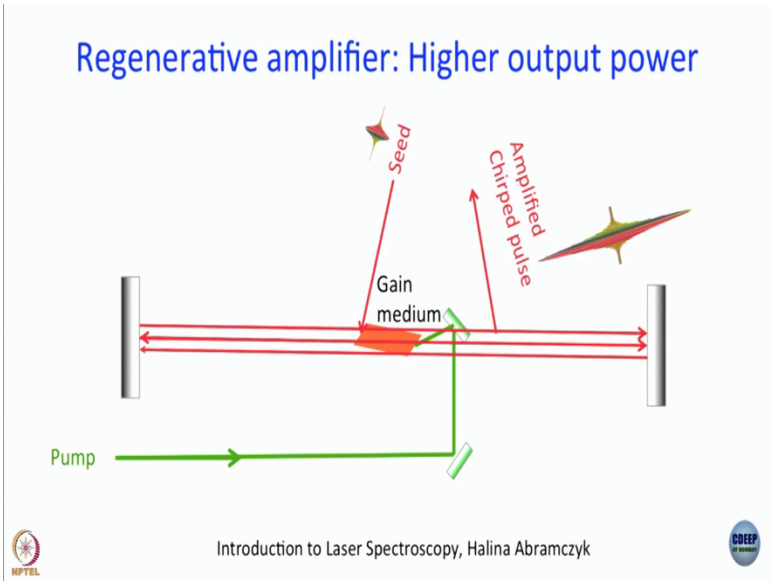

Now let is come to the design we have in our lab, it is called regenerative amplifier here you have higher output power. The difference between multi-pass amplifier and regenerative amplifier is that in a region the gain medium is actually inside a cavity. So, it is a laser by itself so, what you do is, these green mirrors are the pump mirrors. The black mirrors are the 2 mirrors of the laser. The point is both are high reflector mirrors there is no output coupler we have encountered this.

When we discuss cavity dumper we are said there is no output coupler by the acousto optic modulator Bragg cell you get the beam out. So here it is something like that both are high reflectors, you cannot afford to have an output coupler when you are talking about when you are trying to amplify because before the sufficient number of passes is made, your beam is going to exceed the threshold and you go out. So, you have to use something else we will see what, so first of all, pump the gain medium.

Then, first, I will show you a schematic. Then I show you another schematic let us take a schematic we will be a little more detailed than the first. So you pump it and then the excitation population is built for some time now. And then you have put the seed in and typically and we are going we

elaborate upon this in the next slide, put the seed in. And typically what you do is in this video, I forgot one slide anyway, I can just tell you about it, it hits the gain medium itself.

And this gain medium, of course is end are at brewster angle. So it is the gain medium, and then does multiple round trips in the laser cavity itself. Now all these arrows that I have drawn are displaced with respect to each other. Please do not take that seriously. They are all actually the same axis. But then if I try to do that, he will not be able to see anything except some arrowheads coming up here in there which you might miss. So this is what happens.

So it goes around in the cavity and as you would have understood by now, in every round trip, the beam gains energy or in other words gets amplified. And then after the required number of round trips, you have some way of switching it out. What is switched out is once again the amplified chirped pulse, how do you do the switching in how do you do switching out? The answer to that comes from what we had learned maybe 3 or 4 modules ago.

Remember we talked about acousto optic modulators, electro optic modulators, Q switch. So, the answer here is Q switch.

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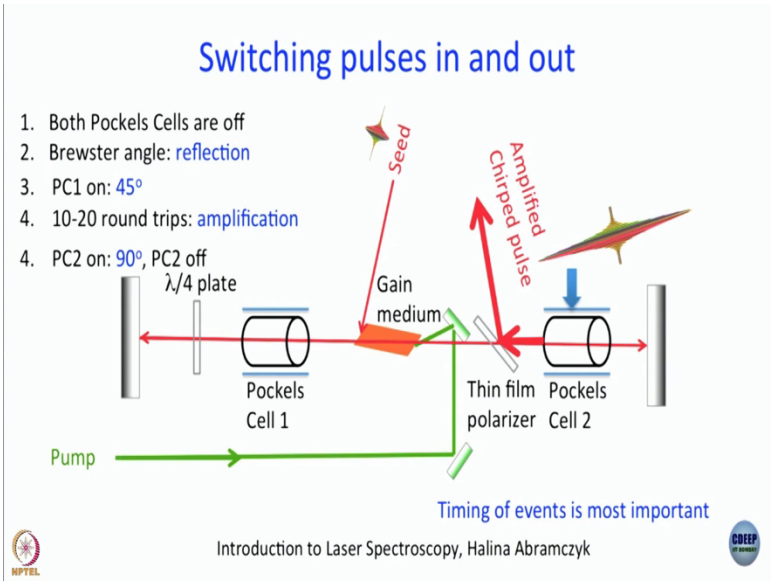

And the way it is done is not difficult to understand, but you have to do actually a lot of things to make this happen. So, in the setup that we are going to talk about now, this is what is discussed in

this introduction to laser spectroscopy book and this is more or less the arrangement that we have in our laser, our amplifier. So, we are going to discuss this where you use 2 Pockels cells, a quarter wave plate and a thin film polarizer.

Now, unfortunately, the slide I forgot this is a simpler to see design when you do not use two Pockels cell use, you use only one. simpler to see difficult to implement, very difficult to implement. So, if you ever make if you ever have to build your own amplifier, please use 2 Pockels cells. Otherwise this alignment becomes a complete nightmare. So they use something called a Faraday rotator and all.

So when it is not at all easy, maybe next day in later model we will start with at least the schematic of that design. But this is something that is much more popular now, it is placed in such a way that this brewster angle supports one kind of polarization, either horizontal or vertical. The way I have drawn it is that I have said that horizontal polarization from the direction we are looking, goes through the gate medium.

That is how the brewster angle is and this thin film polarizer is also such that it transmits that polarization which is sustained in a gain medium that is what you need to do remember of course, if we cross this polarizer then no beam will ever get through. So, this thin film polarizer allows the same polarization to pass through as the one that is allowed by the gain medium by virtue of its brewster angle. So, now, let us see how this happens? These will this is something that we should definitely know.

So, first of all start from a condition where both pockels cells are off, remember what pockels cells do? If they are powered, what do they do? They apply high voltage to pockels cell. What does it do? This is a pockels cell light passes through this is basically a window of some optical material and it has electrodes on 2 sides, if you apply high voltage the pockels cell turns the polarization of the light.

And what we have said is that depending on how much voltage you apply, you can make this polarization turn by 45 degrees or 90 degrees or whatever angle you want and you can do it at

different extents. So if you want you can even generate circularly polarized politically polarized light. So to start with pockels cells are off that is they are just pieces of glass. And see this is why you cannot use this if you want a 6 femtosecond laser.

Because in addition to your gain medium, the beam is passing through significant amount of glass. 50 femtosecond is fine. Now, first both pockels cells are off, now then you pump it typically you pump not by a CW laser, but by a pulsed laser. But it is not an ultrashort pulse. It is by our standards ultra-long pulse, something like 250 nanoseconds. There are advantages of using pulse pump.

First advantage I think we all know by now if you use CW light versus if you use pulse light in pulse in pulsed operation, we pack the energy in some small amount of time. Since we are so used to femtosecond we are being to 250 nanosecond is a long time. But 250 nanosecond we will try counting on counting using some stopwatch, you know how difficult it is.

So, 250 nanosecond is also a small time, so you pack all the energy in that time that helps and secondly, as we are going to discuss later timing is very important in this kind of amplification process. If you use pulses, it becomes easier to time we will discuss this not only in this module or the next one, but also in the module where we actually show you photographs of the amplifier and discuss. So, it is pumped, by a pulsed laser.

So, in the gain medium excitation population has grown in that condition introduced the seed and here comes the effect of polarization. So, let us say this vertical polarization is what cannot go through the gain medium and the polarizer then what will happen? The seed will be reflected by the game medium will come this way. Are we clear so it will go towards your left whether lambda by 4 is it goes in that direction Pockel cell is switched off nothing will happen.

But then the moment it reaches the lambda by 4 plate, it will turn by 45 degrees. Then it goes and hits the other mirror then when it comes back and passes to the lambda by 4 plate again what will happen? Will it go back to its original position or will it turn by 45 degrees more thankfully, it will turn by 45 degrees more otherwise this would not have worked comes back turns by 45 degrees more and now you have horizontal polarization.

Horizontally polarized light is what can go through the gain medium as well as the thin film polarizer. So, it goes what do we need to do now, we need to make it oscillate in the cavity may make it do round trips. So, that will get amplified. But see now there is a problem. The problem is if it goes back in this condition once again at lambda by 4 plate it will turn by 45 while coming back it will turn away 45 more, it will become vertically polarized.

So, it will not come back, that round trip will not take place. And then when it comes from the high reflector side and hits the brewster window, it will actually go out in the same direction from which the seed came. It is not as if it will go back and make another round trip it would not you understand the problem. So, you have to do something and there is something is that is why the pockels cell is here.

Now what you do is you switch on the pockel cell and you switch on the pockels cell and apply voltage in such a way that it is going to introduce 45 degree rotation of polarization. Now, let us see what happens when this horizontal horizontally polarized light comes back after reflection in this mirror comes back goes to gain medium pockels cell turns by 45 degrees then what will happen when it goes through lambda by 4 plate turn by 45 degrees more.

So, it will become vertically polarized then lambda by 4 plate vertical polarization that will go hit the mirror come back turn by 45 degrees again. Now, when it goes to pockels cell once again it turns by 45 degrees becomes horizontally polarized all over again. Now, it can do the round trip as long as pockels cell 1 is forward. have we understood. So, you cannot do this by using passive optics alone.

You have to do something actively and that is where the pockels cell plays a role. So, it can go here and then it can do round trips. Typically you make it do 10 to 20 round trips, why not more, we will see shortly, after that after it has done 10 or 20 round trips, what will happen? Amplification will happen? When you reach the required amplification level, then what we will do now is I am going to switch it out is not it? So to do that, now, pockels cell 2 is switched on pockels cell 1 is switched off.

So it is not necessary to switch off pockels cell 1, just because you want to take the beam out, pockels cell 1 is switched off because it is it no longer has to be switched on and also you have to prepared the amplifier for the next seed pulse. So, this pockel cell is switched on in such a way that it turns the polarization by 90 degrees. So now what will happen? Horizontally polarized light comes back from the mirror turns by 90 degrees, we will go through the thin film polarizer.

Now, thin film polarizer is set so that horizontal fully polarized light will go through vertically polarized light will be reflected. So that is what will happen. It becomes vertically polarized here is thin film polarizer. And then it goes out and it goes out as once again the Amplified chirped pulse. So, this is what happens in the laser we use, is there any question it is very important that we know the sequence of events here.

And it is also very important that we understand that timing is key that is where all the electronics comes in here all the timing circuits all this has to be precisely timed. Otherwise it will not happen, let us calculate something, what is the round trip time? Let us say, how, how wide is our laser? I think we know that it is kept like that how wide is our laser? 2, feet so round trip is 4 feet. So 4 feet means what? 4 into 30, 120 centimeter.

So how much time what will be the roundtrip? Actually, it is easier if we keep it in feet 4 nanosecond. So, every round trip takes 4, nanosecond. And we have said the pulse that we used to pump is a 250 nanosecond pulse. How many round trips can you do? While the gain is on say 250 by what is the round trip I said 4, nanosecond 250 by 4 is almost 240 by 4, 60 is this, in principle you can do 60 round trips.

And when should the next seed coming? The next seed should come in only after the Amplified chirped pulse has left. And the next pulse from the pump laser has come. There is a periodic process. So, how frequently can we get an amplified chirped pulse out of the system? Who will determine that? So, what we see is that the game begins with pumping and we are pumping by a pulsed laser that would have some repetition rate.

So, each pumping event initiates the process that leads to amplification. So, for each pump pulse, I can get 1 amplified chirped pulse. So, what I am trying to say is that the output of this amplifier is going to be determined the repetition rate of the output of this kind of an amplifier will be determined by the reputation rate of the pulse pump laser is that right? It can never be more than that actually it is exactly equal to it.

So, now tell me what is the output that we have? What is the repetition rate of our amplifier is 1 kilohertz where does that 1 kilohertz come from the oscillator is 80 megahertz. Why is the output 1 kilohertz because the evolution lasers that is used to pump the gain medium of the amplifier operates at 10 kilohertz. What is the meaning of 10 kilohertz what is the time separation between 2 pulses. 10 kilohertz is 10 to the power 4 times per second one way that is 10 to the -4 second which means 0.1 millisecond which means 100 microsecond.

So, pulses are separated by 100 microsecond and their pulse width full width half max is 250 nanosecond that is what happens. So, timing is of utmost importance in this kind of pulsed operation. That is what we need to know. I think we will stop here today even though I do have one more slide. It is better that we go back understand this completely. Come back next day. Do a quick revision of this thing and then go on to talk about timing. And then what is there inside our amplifier? That is what we will do in the next module.