Ultrafast Processes in Chemistry
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Lecture No. 30
Q Switching

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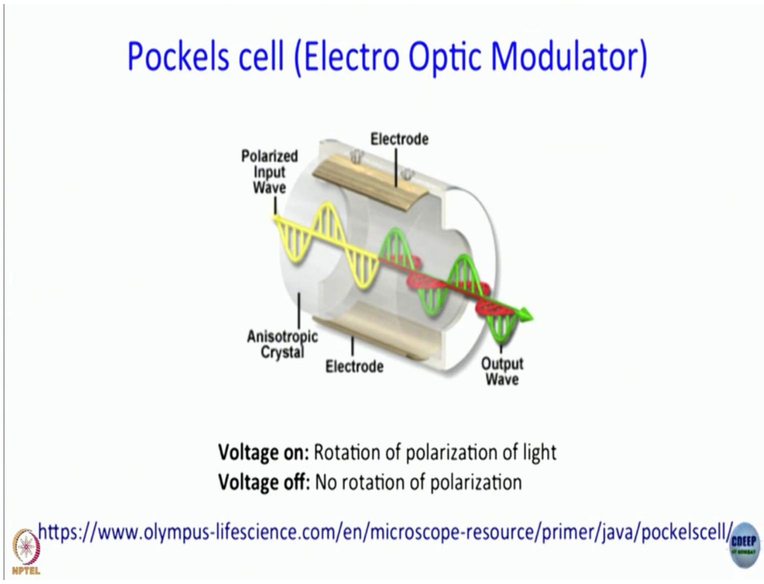

This is where we have stopped, we have introduced pockels cell, which is an Electro optic modulator. Remember earlier we have talked about acousto optic modulators, AOM as they are called in short, these are called EOM. So hence forth, you should not get scared or confused if people throw these acronyms at you AOM, EOM, you know what they are now we know how it works.

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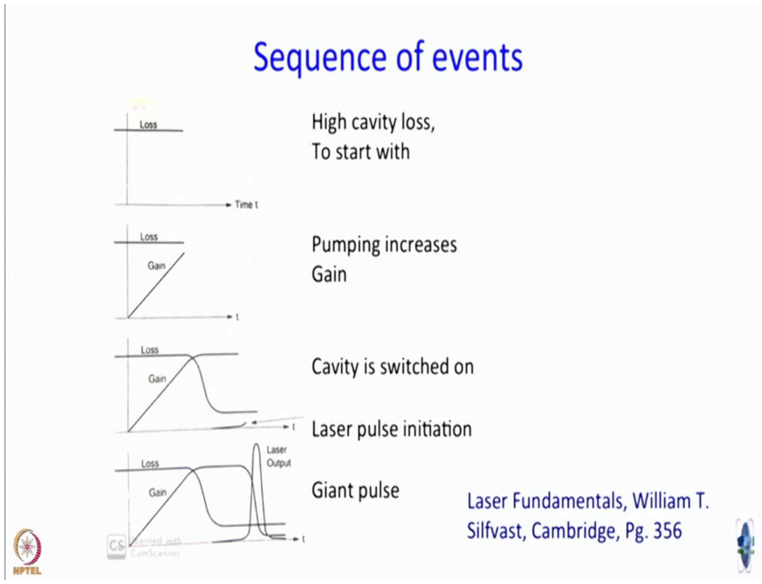

And we know that our ultimate goal is to obtain queue switching by using a Pockels cell. If you understood these 2, the rest is not very difficult to understand.

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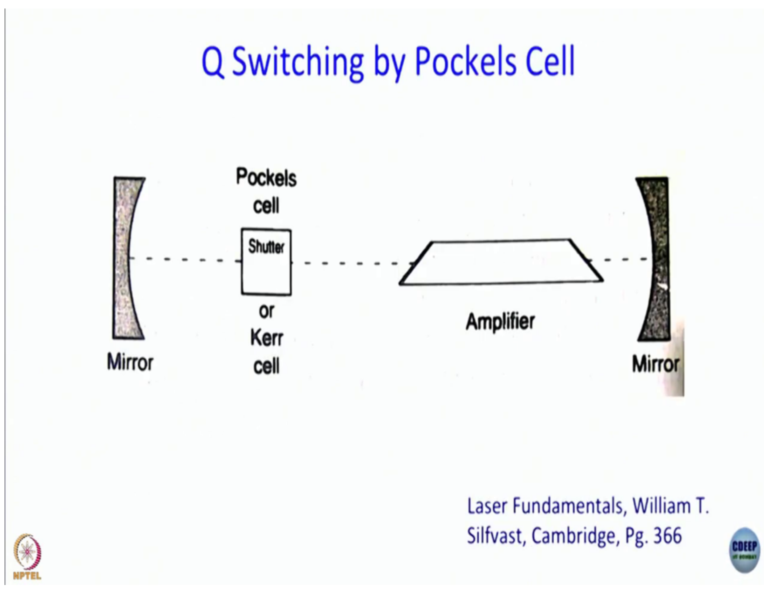

We will just introduce one more term, there is brewster angle. Again, this discussion is completely from Silfvast book, the book that we have been using. So far I find that discussion of Pockels cell is a little easier and qualitative in Silfvast book. In fact, right after this discussion in the same book, you do have a detailed mathematical discussion of the theory. If you are interested, you are welcome to study.

But, we can develop a qualitative understanding at least from what we are seeing. So, this here is a cavity I forgotten to write which one is output coupler. So I will tell you the mirror that is blacker. We are saying that is the high reflector. This one that is less black, that is an output coupler. So if you can ignore this pockels cell in between for now, you can think it is a very simple laser cavity.

You have a gain medium which they have written as amplifier did not get confused with this between this amplifier and the amplifier using in our lab is just gain medium. And you might see that this gain medium is shown a little strange shape. It is not the cross section is not a square it is a trapezium. That is because in fact all gain medium are kept or cut in this case at what is called Brewster angle, Brewster angle is such that if the surfaces at Brewster angle then a particular polarization will be sustained, everything else will be reflected.

And you will see in a minute, a few minutes how that becomes useful. Are we clear about the cavity? And in the middle of it, we have introduced a Pockels cell. So let us see how Q switching is done in this case, for the moment, let us think this is a CW laser. At the end of the discussion, we will also mention unfortunately are not drawn the diagram but as you will be able to understand. We will see what happens if this is a mode lock laser.

I can put in a mode locker here, can’t I, or it can be if this amplifier gain medium that can be Ti sapphire crystal and it would be. So, it can be CW can be mode lock does not matter. To start with let us say this is a CW laser. Now, the way it works is this you apply the voltage to pockels cell. And you use a pockels cell and use a voltage in such a way that polarization of light going in is rotated by 45 degrees this is a very nice trick that is used ubiquitously in especially ultra-fast spectroscopy.

So, the moment a beam of light passes through if it is linearly polarized the pain of polarization will be rotated not by 90 degrees but by 45 degrees. So, let us say we have plane polarized light like this vertically polarized light. And pockels cell is powered, voltage is on. So now, when this light passes through when it emerges what will be the polarization? It will be rotated by 45 degrees. So, well it is not so easy to draw the 3 dimensional diagram on 2 dimensional surface.

So, please imagine that this tilted arrow means 45 degree rotation of polarization. Now this goes, and hits the output coupler comes back and passes through pockels cell again. I hope you agree with me that when it passes to pockels cell again, once again it will be rotated by 45 degrees. And the light that now emerges is at 90 degrees? You started with vertical polarization after a round trip, through the pockels cell polarization is now horizontal.

This meaning of this donut is that this arrow one of the arrow heads is pointing towards you. In the later diagrams I have used a different kind of donut. Now do not forget that this amplifier again medium surface is cut at the Brewster angle. And what did we say? It is only going to sustain one kind of polarization In this case vertical polarization. So, what happens when this horizontally polarized light goes further and impinges upon the surface of the amplifier or gain medium it will not be allowed to enter it will get reflected so it is no longer there.

So, as long as the voltage is on the cavity is not there, so, we have been able to satisfy the initial part in the scheme that we had drawn a little earlier, there is a high loss cavity and you can actually have control loss in this medium, maintain it has high low and then start pumping. As you pump, the population of the higher energy level keeps increasing. Then what you do is after an appropriate time, switch the voltage off the moment you switch the voltage off.

Pockels cell is now, if I can borrow terminology from our eminent inorganic chemistry colleagues, it is an innocent piece of optic until now, it was not innocent, it was doing things to the polarization of the light. Now, it is not so, since it is now innocent, what will happen is, vertically polarized light will pass through without changing polarization hit the mirror come back, pass again nothing happens goes to the amplifier.

Now, the cavity is on and after a few round trips, what will happen is threshold will be exceeded and light comes out like as a pulse, this is Q switching operation and at that moment you are so engrossed at looking at the colorful light pulse. You did not notice that there was another arrow that came up voltages switched on, which means the cavities not there again. So, you understand there is a lot of electronics involved here precise timing is required.

And that is what limits the kind of pulse that you can get by using Q switching as we have discussed when we talked about Q switching earlier electronic all electronic components have their response time. So, you will, it will be impossible for you to keep this cavity on only for a few femtosecond. It was based on nanosecond actually 100 picoseconds maybe yes, anything less than that if you want to really 10 picosecond, 10s of picoseconds laser use mode locking, not Q switching femtosecond laser, forget about it.

But you will see how Q switching is important in femtosecond laser technology as well. We will come to that but this is how you can produce a giant pulse of light using pockels cell as a Q switching you understood? Now, let me ask a question. Well, let me remind you the question we asked all this time we were saying that this is a CW laser. Suppose this is a mode locked laser, then what will happen? Pockels cell voltages off for say 100 nanoseconds or something and let us say this is a titanium sapphire laser.

So, some pulses will come in the 100 of nanoseconds, what is the separation in time between 2 successive pulses of Ti sapphire laser is, 12.2 nanosecond. So, if this pockels cell is open for 100 nanosecond, there is something like 10 pulses is there. So, the output will be a giant pulse made up of small pulses, short pulses will it be a square pulse Or will it be something like a Gaussian envelop , you understand what I am saying right.

When the light goes out, what goes out is whatever number of pulses are produced in that 100 nanosecond? Pulses are several femtosecond or smaller. What will the output look like? Will it be if it is a CW pulse output as a function of time is Gaussian is just that full width half maximum is nanosecond and not femtosecond. But if you have a mode lock Ti sapphire laser or some such a laser, which is in any case producing femtosecond pulses at 80 megahertz.

Then within that 100 nanosecond 10 pulses will come. What I am asking is will the pulses be all the same intensity? Or will it be something like going up and going down? It would not be same. Because, what happens is when it is coming even then it is doing round trips. So there will be an increase in energy and then eventually loss will take over, then intensity will fall.

This is something that is important in what we are going to discuss next chirp pulse amplification. And this is something that we have seen in our lab also so, if you look at that oscilloscope, you see some pulses? And then when you switch it off, you did not see half of it that is what it is train of pulses. And then one can think about applications like pulse shaping, if you understand this so far so good. Now to our pockels cell, the only things that can we use for Q switching.

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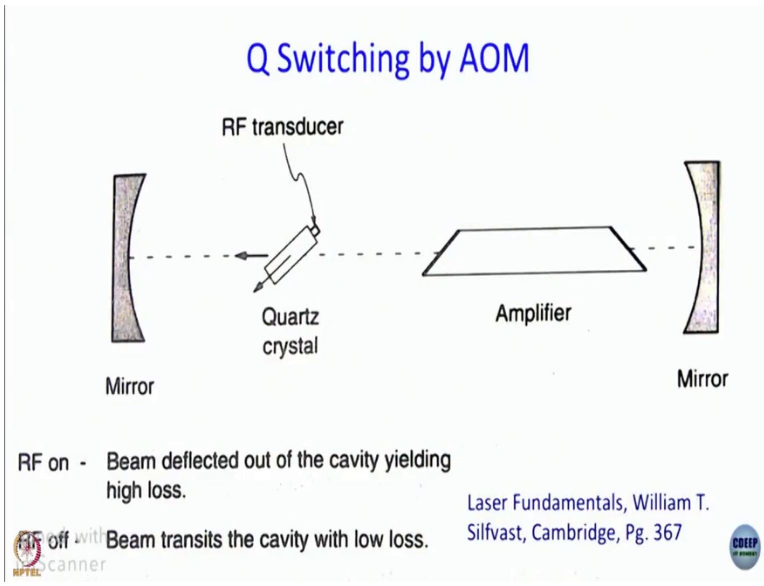

No, you can use our old friend acousto optic modulators as well. Not very difficult to understand use a Bragg cell any emission that comes will be sent off access by the Bragg cell most of the time. And then you can use a suitable frequency of sound, whenever it is favorable, the cavity will be switched on. So, you can do Q switching by AOM as well. EOM are more popular actually.

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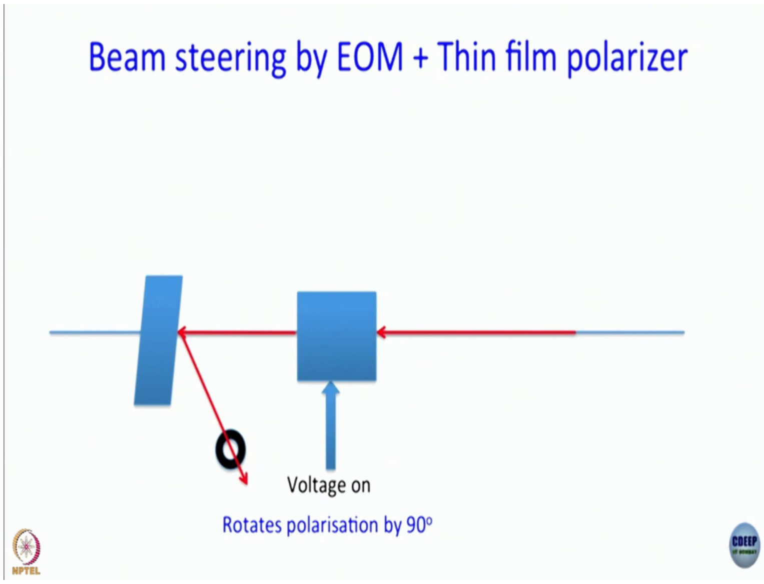

Since we are talking about you are an EOM, let us not stop only at Q switching. Let us talk about another application which might sound very similar after all, I mean since our basic principles are the same, it is what kind of linear combination of things you take that determines what your application is. So, far we have seen how a pockels cell can be used for Q switching getting giant pulse out of laser.

Now, let us discuss very briefly how a pockels cell and a thin film polarizer combination can be used to switch or steer a beam in direction that we want once again, this is going to come useful in the next discussion and the discussion we are going to have in the next module chirped pulse amplification. Here, remember earlier what was if it was only a pockels cell, it would not have worked. Pockels cell could act as Q switch because along with it.

You also used a gain medium at Brewster angle. So, which a dye laser so we talked about dye jets the other day. The dye jets were never like this. If this is a mirror, always at Brewster angle, Brewster angle is extremely important in all kinds of laser application because you are dealing with polarized light. So, here what you do is you use a combination of a Pockels cell and a thin film polarizer. Has anybody ever seen a thin film polarizer?

Is anybody into photography at all? Somebody has a good camera? How good a camera I mean, camera is as good as it is. But how enthusiastic are you? Do you use external filters and all of your camera? So if you are more of an enthusiast what you will do is you will like to get the best possible picture. And very often you will see photographs in which the sky is blue sounds foolish but it is blue like it is usually not to our naked eyes.

Some filter has been used? Very often you will see cameraman using filters which are colorless. Sometimes they have UV filters sometimes they are polarizers. Whenever we say polarizer, especially chemists, we think of that Canada balsam and whatever it is we think of a nice cube which has been cut from cut diagonally and glued together on all that. It is not necessary that always you have to have cube polarizers you are going to have plate polarizers as well. So, thin plates, they are called thin film polarizers.

In fact, the polarizers that we use in our TCSPC, they are basically plates, is not it? So, something like that. So, what you do is right now we are not bothered about where exactly the end mirrors are and all. Here we have a pockels cell and here we have a polarizer and voltages is off. If you have a polarizer then it will allow either vertically polarized light to go through it or horizontally polarized light to it and like to go through it depending on what kind of orientation of polarizer you have taken.

Let us say we work with vertically polarized light voltages off it goes through and then your polarizer is aligned. So, without any hassle light goes through. And very typically it will this will apparatus will be inside the cavity of a laser we will discuss in the next modules in a little more detail. So do you understand if the voltage is off, then a vertically polarized light will go through this and well, one thing I should say is that this thin film polarizer is kept at an angle to the direction of propagation of the laser.

Very typically it is kept at 45 degrees. So we already shown you what happens with this combination of pockel cell and TFP capped at 45 degrees or whatever degrees for vertically polarized light, it goes through it depends on our requirement, I am only taking an example, you might want the horizontally polarized light to go through then you choose the orientation or polarizer accordingly.

Now, what happens when without changing this apparatus which means, thin film polarizer is set so, that vertically polarized light will go through. I apply a voltage now this time I apply a voltage in such a way that polarization is rotated not by 45 degrees, but by 90 degrees it is in my hand for a given pockels cell you can do actually whatever you want. Now what will happen vertically polarized light comes, when it goes through it becomes horizontally polarized hits this and gets reflected.

So, whenever I want the light to come in this direction, as far as the voltage on for whatever duration I want. Whenever I do want it to go straight, I would switch it off? So, this is a very efficient way in which you can switch an external beam into another laser cavity or switch the output from there. Now, let us think a little bit, we had said, that we get a giant pulses out of Q switch lasers right.

That is because we keep it on for some time at least some 10 of nanoseconds or something. Let us say I have a good pockel cell which I can accurately control with a precision of say 5 nanosecond, not impossible 3 nanosecond, let us say 5 nanaosecond which means I can have a fairly square pulse in that timescale. And let us say that this vertically polarized light that we are talking about that is from a femtosecond laser.

So, femtosecond laser gives a train of pulses all same intensity, and there is an oscillator, your separation between 2 pulses is 12.2 nanoseconds. What I say is, I will switch on the voltage only for 5, nanosecond and then switch it off for some time, understood what I am saying. What kind of output will I get in that direction? In this direction, yes but, let us go in steps, you will get a pulse, will the pulse width change? No, but repetition rate will change?

And in fact, if I want, I can switch out 1 single pulse. I keep it on for 5, nanosecond again I mean, and then switch it off. So anything that comes up in 5, nanosecond how many pulses can come? If you are dealing with a Ti sapphire oscillators, only one because the next pulse is 12 nanosecond so it is like a gate that opens for some time. But the timing is such that when one person walks through so in Q switch, what we had is it is like opening the gate of some office building at the beginning of office hour or end of office hour for that matter.

A lot of people rush through and this one is like you open in the middle of the night, one person is there he walks out. So, beam steering and beam switching in and out of cavity. That is where Q switches actually find application. We might think that why are we even talking about Q switches because we are interested in ultra-fast. This is not ultra-fast. It does have application as we will see.

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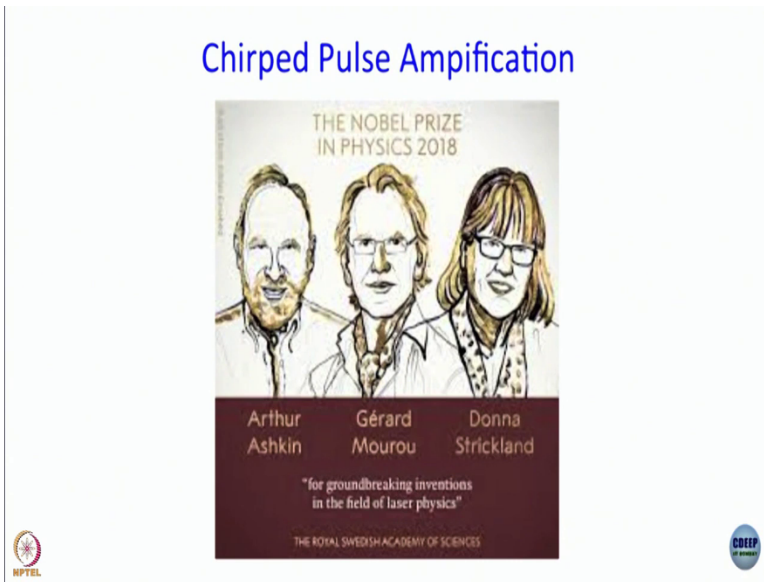

And the application is in something called chirped pulse amplification. Notice people Arthur Ashkin, Gerard Mourou, Donna Strickland. The names ring a bell. Who are they? They got the Nobel Prize? When? Last year 2018 Nobel Prize in Physics. It was split into 2. Half of it went to Arthur Ashkin good. What did Ashkin get it for? He got it for something called laser tweezers, micro manipulation and Mourou and Strickland got it for chirped pulse amplification, a technology that is used in all ultra-fast labs worldwide.

And that is based on what we have discussed so far. So, what we have done is we have talked about how to produce short pulses from ultra-short to not so ultra-short, we have talked about how to modulate the repetition rate of the output by cavity dumping and then by Q switching. And then now we are going back to a domain of ultra-fast lasers, where we learn how to amplify a pulse using all this and maybe a little more. That is what we will do in the next module. This is how you do it.

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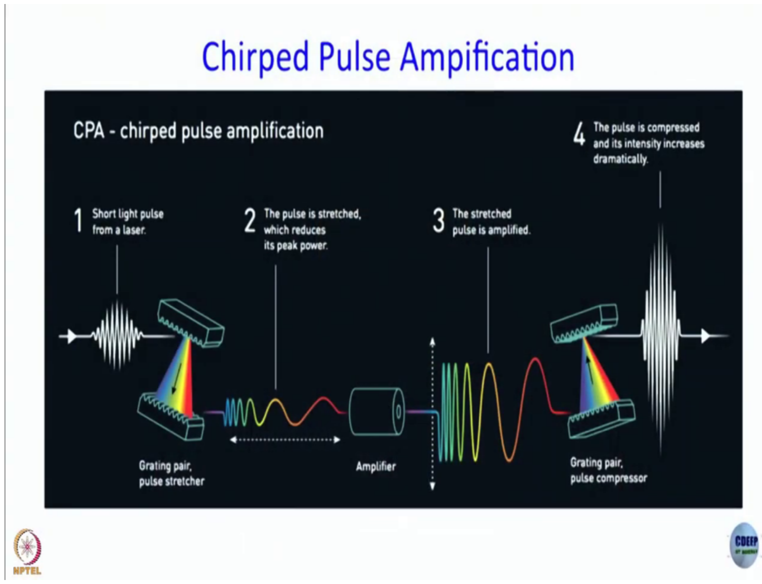

Of course, we will discuss it in detail in the next one. But today, let us at least give you a preview. What happens is, I hope this is something that you know now what this means it is electric field data field versus time plot for a pulse and you have a pulse from an oscillator. And you want to amplify it, you amplified by switching the pulse in using a Q switch into the cavity of another laser. Again the second laser has no output coupler only 2 high reflectors.

And there it gets amplified how it gets amplified. We will learn in the next module. But the problem is this, you people calculated few weeks ago, how much of energy there is per pulse, if you are talking about is really small pulse. So, much of light introduced into another laser is going to destroy the optics and then use a very neat trick. And the trick is converting a difficulty into an advantage. When we talked about construction of a Ti sapphire laser, we talked about chirping.

When goes through some medium red light goes ahead and blue light rays behind or the other way around. That causes a broadening of pulses. And all that happens, because remember we are working with a multimode laser remember longitudinal modes that we talked about, lots of modes are actually here what is done is before introduction of the ultra-short pulse into the cavity of the second laser, which is called an amplifier.

It is made incident on a couple of prisms or a couple of gratings which disperse the light and we introduced chirp intentionally. You make red light go forward blue light trail behind. So what you do is you expand the pulse from say 15 femtosecond or 25 femtosecond into whatever it is you make the pulse wide make it a 20 picoseconds or 2 picosecond or something broad pulse. So then the energy that would have been incident on the optics in 20 femtosecond gets spread over maybe 10 times to 20 times 100 times that time.

So that is why it is not so hard on the optics, then it gets amplified comes out. The problem is the output is also chirped, but you did not want it then you use a compressor again, another pair of gratings in a different orientation, which compensate for the chirp that you are introduced. So while stretching the pulse, you make different frequencies travel different paths. Let is say you have given a smaller path length for red larger path length for blue.

In the compressor after the pulse has been amplified. In the compressor, you do exactly the opposite. You give now a longer path length for read a shorter path length for blue. And then the spread that had taken place there is offset and they come together. So once again, you have ultrashort pulse. The difference is the amplitude has increased from what it was by several orders of magnitude. In the laser that we use, we get from nanojoule to millijoule.

So, that is what happens here. So, one thing I forgot to say is that in Q switch lasers, the energy that you get is the power that you get is sunlight peta watt. Sometimes if you want, you can get peta or what is the meaning of peta? We are very good with Femto, Nano, Micro, Giga what is Giga? Giga is 10 to the power; what is; Giga is 9. Then after Giga that is tera 10 to the power 12 peta is 10 to the power of 15 not - 15 the other way around. So you get petawatt output if you use I mean you can get you did not always get petawatt lasers using your Q switch.

But the thing is the giant pulses very wide. Here, you pack all the energy in a small time so you actually you have seen what kind of energy is per purples, power per pulse you can get. So that is what we are going to take up in the next module.