Ultrafast Processes in Chemistry
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Module No # 07
Lecture No # 34
Oscillators And Amplification: Designs And Materials

We are nearing the end of our discussion of amplifiers so the next couple of modules we will first talk about the different designs of amplifiers that are there. And of course this discussion will be incomplete because really there are many designs. If we try to discuss all of those it will become very boring. So I will give an idea of some just to understand there is several techniques can be used and then in the next module we are going to briefly talk about the amplifier that we have. So right now we are discussing the different designs and material that can be used to make oscillators and amplifiers.

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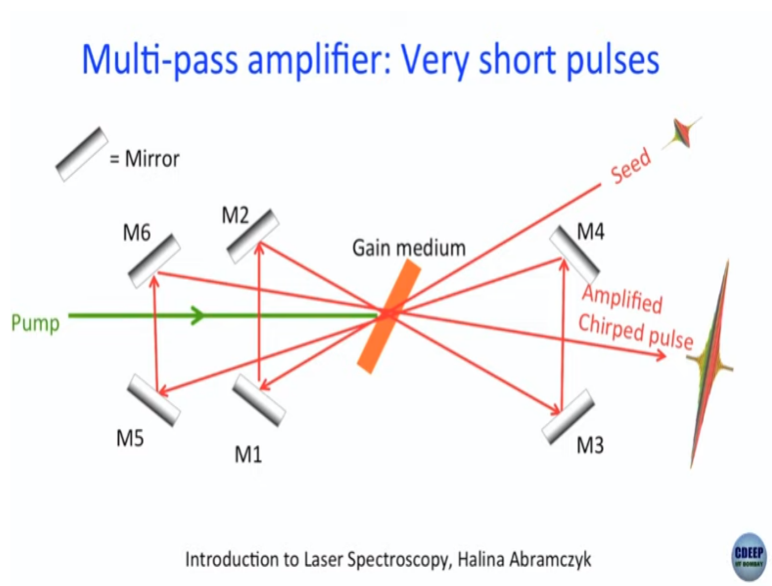

And as a recap we have discussed this already we have discussed 2 kinds of amplifiers 1 is multi pass amplifier in which this seed goes to the gain medium multiple times. And this is used for very short pulses no extra EOM or anything is used so the pulses can remain short but the power that you get the energy that you get per pulse extend of amplification is not as much as one can get using a regenerative amplifier.

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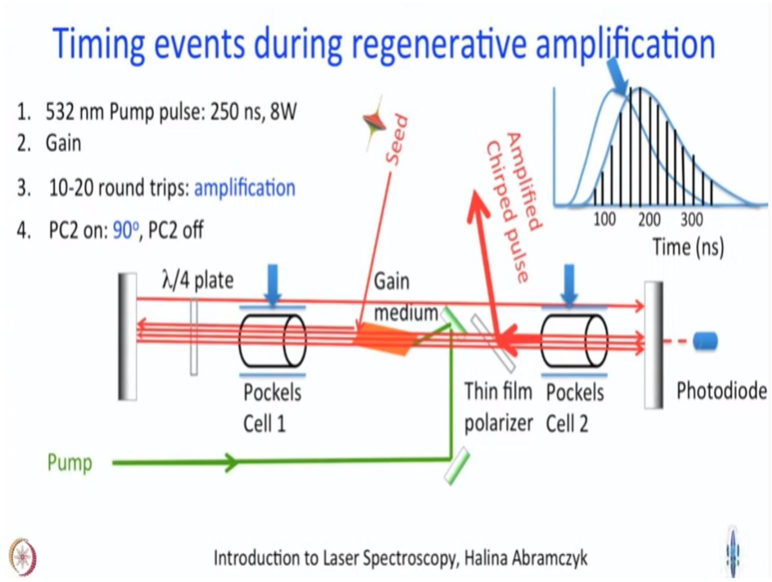

And in the last couple of modules we have discussed in as much detail as you could without getting into too much of instrumentation the timing events that are there during regenerative amplification. And this is the one design that we have talked about the design where the gain medium is in a cavity and then this seed is switched in to the cavity by using a lambda by 4 plate it is kept in the cavity via combination of the same lambda by 4 plate and a Pockels cell.

And then after the required number of round trips it is switched out of the cavity by this second pockels cell 2 design of regenerative amplifier where we have 2 pockel cells but this is not the only possible cell there can be more.

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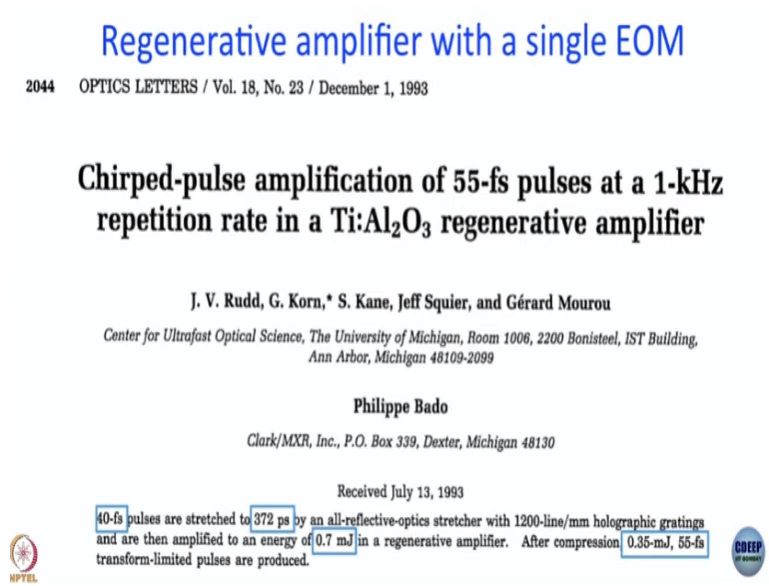

This is once again now see in this discussion of today we are going to refer to optics journals very frequently optic letters and all. So this is an example of a regenerative amplifier design from 1993 that was the time when all this was being done even now it is being done but we will see what is being done today. But whatever the design we use now even that sort of got defined this 20, 25 years ago. So here you see there this paper where Mourou is there Korn is also there.

Then interesting thing about this paper I mean there are many interesting things one thing I like to draw your attention into is that. This is the collaboration between the academia and industry so most of the authors including Squier to whom several designs are ascribed are from university of Michigan Ann Arbor. But then is one other who is from Clark MXR incorporator and that is the company that actually makes an market lasers.

And we briefly talk about what kind of laser Clark MXR is focusing on right now but here this is an early report of an amplifier reputation rate is still 1 kilo hertz. And what they had been able to do us they had taken 40 femtosecond pulses as seed so I like to give you the feel of the number as well this 40 femtosecond pulses were stretched to 372 Picosecond. And then the specification of grating is also given and it was amplified to 0.7 milliJoule energy.

What is the energy we get out of our amplifier? 4 milli Joules so this is not really as much as what we get today and after compression you get 0.35 milli Joule 55 femtosecond transform limited pulses. So it is not even 0.7 milli joule is what you get out of the regen before it goes into the amplifier. There is always some loss at every stage during stretching during well during amplification of course it gets amplified but may be not to this extend that you would expect in the ideal case and during compression also some loss is there.

So you see before and after amplification 0.7 milli joule to 0.35 milli joule half the power is actually so before and after compression. After compression half the power is gone and if you look at the full width half max of the seed and that of the output 40 femtosecond pulses were put in as seed and you get 55 femtosecond pulses. So not only have you lost energy per pulse little after compression you have in the entire process you not been able to get back the entire you have not been able to get back to the pulse width that was there in the seed.

So I just like to draw your attention to this because when we do discussion without doing experiments many times we are here to think of the ideal case scenario. But ideal case scenario is very difficult to achieve is always some loss or the other the challenge of course is to minimize the loss and get to near perfect near ideal situations.

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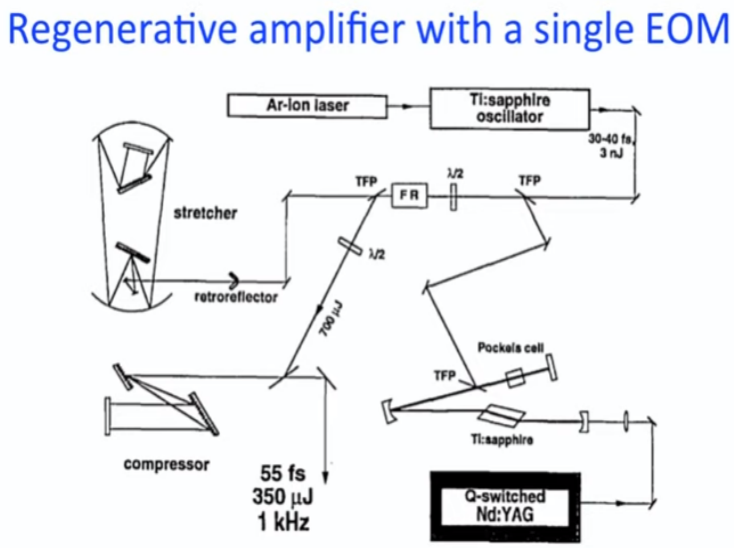

So let me show you the design and here I would like you to I have not animated the whole thing not because it would take a long time but because now that we have seen all this pulses passing and the polarization getting flipped and all that I think we should now be able to work out what happens at every state. So I will start I will get you started on how it works but then let us see if you can do the rest of the path together.

To start with see what is there I hope everybody can read can you read what is there so first of all you have this Ar-lon laser in 1993 Ar-lon laser was the state of the art DPSS lasers were just about coming mostly people use Ar-lon laser. And even now there are people who work in imaging and all sometimes they prefer Ar-lon laser because it has very sharp lines but then it is very difficult to maintain it goes back it change the tube which is very expensive.

And then when you changed what you do with the old tube it take us space in the lab. It is not easy to through away a laser tube it will burst, its hazardous.So anyway that Ar-lon laser was used to pump the Ti-sapphire oscillator output of the oscillator is 30 to 40 femtosecond 3 nano joule can you read this numbers 3 nano joules okay. Then it comes here and I have not really read whether the polarization was vertical or horizontal but demonstrate the phenomenon I have drawn it to be a vertical okay vertical polarization.

What is next in line? Thin film polarizer TFP what would happen when the vertically polarized light goes through the thin film polarizer? No, it is a polarizer it is not a polarization rotator so it will go through provided it has a component that is allowed by the polarizer it will not go through if there is no component. So here the thin film polarizer is set so that it can pass vertically polarized light. So this is an important thing to understand and remember polarizers sort of act as gates then do not rotate the polarization right do not get confuse between a polarizer and Pockels cell.

And today we are going to talk about something else as well okay after TFP there is a lambda by 2 plate would rotate the polarization by 90 degrees. After that we have something called a faraday rotator. Well the name sort of at least a second word is self-explanatory it will rotate what will it rotate? It will rotate the polarization of the laser okay and what is the faraday rotator what it is the difference between faraday rotator and Pockel cell? They use 2 different effects pockel cell uses pockels effect and faraday rotator obviously utilizes faraday effect.

Pockel cells faraday in the names are very eminent scientist so we have already discussed pockel cells where you apply a electric field and that causes rotation of polarization. In a faraday rotator you apply a magnetic field you still apply an electric field which causes an magnetic field and it is a magnetic field that causes the rotation. Right now you do not need to get into to the knitty gritty of whether they are inter changeable or whether you want to use this or you want to use that.

Right now let us just take it like that there is a magnetic field as long as the power is on like it is now it is going to rotate the polarization and in this case by 90 degrees. So what happens when the vertically polarized light reaches the thin film polarizer which is set to vertical polarization it will pass through. Then when it goes to lambda by 2 then what happens it will be rotated by 90 degrees so vertical polarization becomes horizontal polarization.

Then when it goes to the faraday rotator it is turned back to vertical polarization why we are doing this we will understand in a while. Then what happens is it goes through the thin film polarizer so see the design is such that you use the same path until a point and then there is a branching. From the second thin film polarizer that is there the light beam as a choice it can either go straight and enter the stretcher or it can get reflected and go into the compressor okay that will be determined by the polarization.

This thin film polarizer is once again set to vertical okay so vertical polarization will go through and if it goes through then it goes through the stretcher and then get stretched. However if this was horizontally polarized it would be reflected by this thin film polarizer and would go into the compressor that is what happens after amplification okay. For now go straight and I have not drawn its path all the way to the stretcher but you can understand it goes in this is the mirror from the mirror it goes to the grating first grating get dispersed goes to the concave mirror which sort of focuses it on to a second grating plane mirror then retraces its path comes back here.

And then goes back all the way okay so here there is an alignment where it is retracing its path and this alignment is actually more difficult than what we have discussed for the amplifier earlier. Because now you have 2 parameters not only do you have to take care of the beam going in 1 direction the beam coming back should actually go to the same path. Of course people working with lasers for them it is not so unusual because when you have a laser you have 2 mirrors and the gain medium to and fro beams have to have the same path.

So I do not know whether that was the reason why it was designed this way but that this was what it is in most early amplifiers and may be even some modern ones because one thing it does is that it can use the same pieces of optics multiple times for doing multi different things okay. So it comes back when it comes back it still retains the vertical polarization so it will go through and when it goes through sorry it was so fast when it goes through what will happen thin film polarization polarizer lets it through faraday rotator is now off.

So faraday rotator was on at the beginning right after the beam passes through it is turned off so now it is going to rotate the polarization any more so if we does not rotate the polarization any more what will happen? At lambda by 2 plate it comes as a vertically polarized light and turns polarization is turned by 90 degrees it will come horizontally polarized. Now what will happen when the beam retraces its path to this thin film polarizer will it get through no because that polarizer as we discussed earlier is said to vertical right.

So now it will come to the thin film polarizer it will be reflected and after this I have not drawn the path let us see without the aid of those arose and donuts we can figure out what is going on in the rest of the cavity okay. So this is how the beam is stretched and injected into the cavity and we have to remember the polarization now what is the polarization? Vertical horizontal? Horizontal right? So horizontally polarized light goes from thin film polarizer first plane mirror, second plane mirror thin film polarizer again and then it has to be reflected.

So if this is to be reflected what is the polarization that this TFP allows to go through vertical understood? So horizontal polarization is going to be reflected into the pockel cell okay pockel cell is on so while coming back it will become vertically polarized so now it will pass through thin film polarizer. And then it hits this curve mirror which focuses this on to the gain medium through the gain medium onto the high reflector here and this entire arrangement is pumped by a Q switch NdYAG laser as we have discussed yesterday 100, 200 nanosecond full width of the maximum; big pulses understood.

So vertical polarization all the way now it does whatever number of trips it has to do and you see there are only 3 mirrors. So after the required number of the trips then this pockels cell is turned on again so vertical goes in turns by 45 degrees while coming back turn by 45 degrees again. So now when it reaches this thin film polarizer once again it is horizontal so it will not get through. So horizontally polarized beam comes back to this thin film polarizer okay.

What will happen? Does this thin film polarizer allow the horizontally polarized light to go through does it reflect? This is what we need to remember okay go back to the it will reflect right remember we started with vertical polarization and that light went through. So horizontally polarized light will be reflected turns by 90 degrees okay. Now do you want the faraday rotator on or off because now what is the next step it should go in this direction is not it? It should go in this direction into this compressor so should we turn the faraday rotator on or off or should it remain off should I turn it on should it remain off?

Remember happen the first time when the faraday rotator was on it became vertical once again and pass through this thin film polarizer went to stretcher. Do you want that to happen no so you do not switch on the faraday rotator at this stage. So then what will happen it will still remain horizontally polarized hit this thin film polarizer gets reflected into the compressor gets compressed 55 femtosecond 350 micro joule pulses come out at the rate of 1 kilo hertz.

What is it that determines that the repetition rate is 1 kilohertz where it the 1 kilohertz come from? Yes this Q switch NdYAG laser is operated at 1 kilo hertz. So see the way it works is that you need a timing circuit. A timing circuit is some electronic board that takes input from the YAG laser from the oscillator and can drive all this Pockel cell and your faraday rotator okay. So it is very important to do a precise time that is where electronic comes in big time.

So of course nowadays up to this stage nobody uilds an amplifier to be very honest because amplifier with as short pulse as you wanted available in the market but you might have to fix one. We have an amplifier in our lab in many places I do not think it is any better abroad service engineer always take a lot of time to come does not matter which country you are in unless may be you are in Saudi Arabia or on somewhere in space.

So sometimes you might we require to fix a laser when you have a post doc of when you are in lab sometimes in some labs the old homemade oscillators and amplifiers are still working. So if you happen to land in one such lab in a lab like that you might have to use it so it is better that you know okay. So this is the design of a regenerative amplifier with a single EOM but then when I say single EOM I am cheating a little bit because sort of not telling you that this is also faraday rotator with that right.

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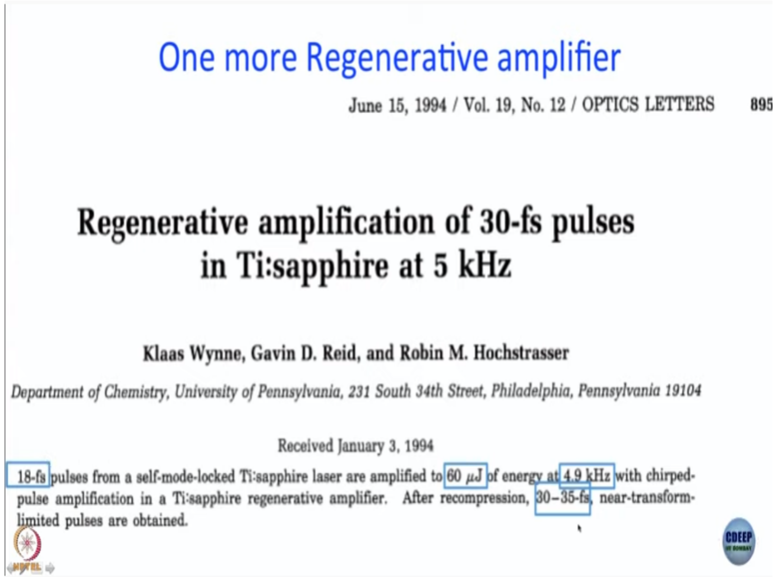

Next one more design and we will do little quicker now I wanted to show this primarily because all this time we were talking about people who are laser switches engineers and all. This laser is made was built in the lab of a true blue physical chemist Robin Hochstrasser okay and just look at the parameters 18 femtosecond shorter pulse 18 femtosecond pulses from a self-mode locked Ti sapphire laser were amplified to 60 micro joule amplification is not so much right of energy at 4.9 kilo hertz.

So the laser they used to pump the region the reputation rate of 4.9 kilo hertz with chirped pulse amplification at Ti sapphire regenerative system. After compression 30 to 35 femtosecond near transform limited pulses are obtained. So once again you see you start with 18 femtoseconds seed you end up with 30 35 femtosecond amplified pulses. So that is why whenever you get an amplifier you want the oscillator associated with it to have as short pulse width as possible okay right. And this is the design I will not discuss it more detail but I encourage you to try and work out the path of the beam in this one yourself let this be the homework okay.

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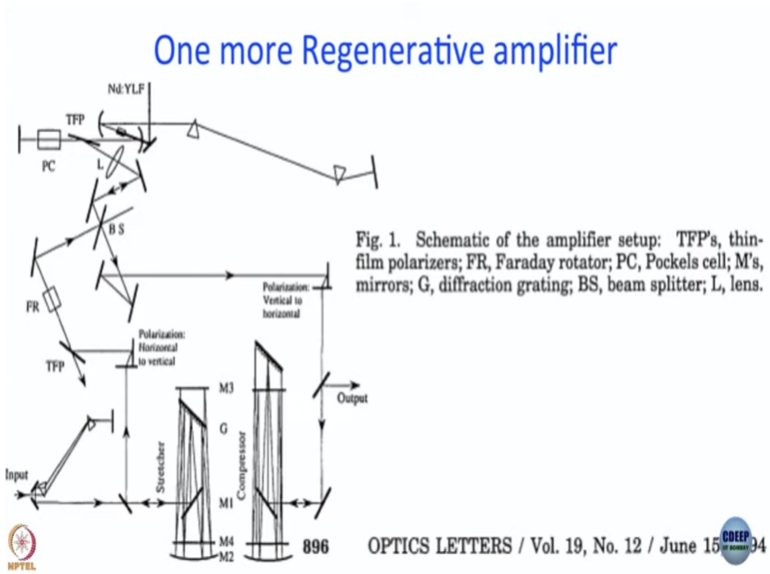

And I just like to draw your attention to this fact that here they are using a prism pair to add some more of compression to so that the smallest pulse can be obtained and sometimes even this is not enough you might have to use extra cavity prism pairs okay. Now let us move to another kind of system all this time we have been talking about titanium sapphire and titanium sapphire alone. Say might have given the idea that there is nothing in the world other than Ti sapphire with which your ultrafast lasers are made that is not the case.

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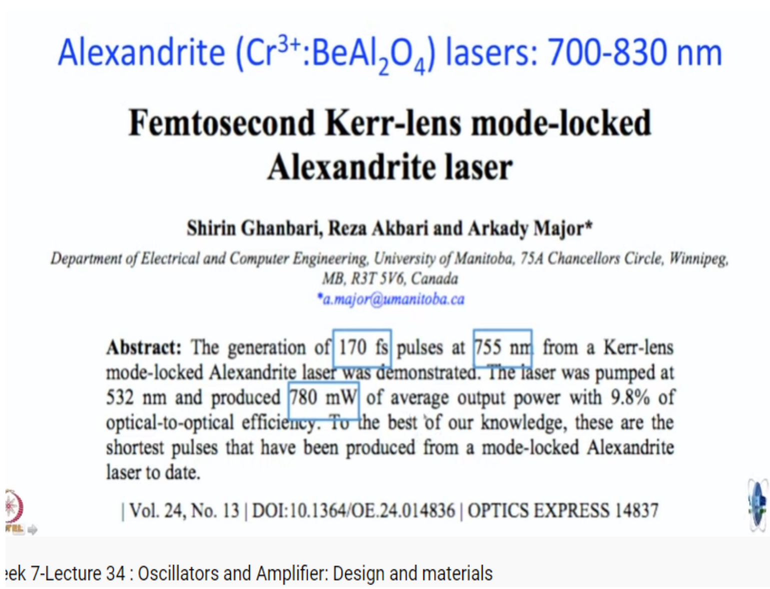

Another material that is used is called Alexandrite is chromium dope Bal2O4 the range of tunability the range of emission is 700 to 830 nanometer. In fact I think in 1979 or so the first tunable laser solid state was made using Alexandrite so it is been there in the market for long time but why is it that Ti sapphire is so popular Alexandrite is not so popular the answer is sort of there on this slide just see the bottom line this paper we are discussing by Major and coworkers was published in optic express which year? The year is not even there I think 2012 if I am not much mistaken the DOI is given 2012 even in 2012 read the first line generation of 170 femtosecond pulses at 755 nanometer from a Kerr lens mode locked Alexandra laser was demonstrated.

Output power is 780 mill watt more or less like what we have in our setup. Actually less than that and to the best of our knowledge these are the shortest pulses that have been produced from a model lock Alexandrite laser to date. So, even to go down to 170 femtosecond which is not a big deal with the Ti sapphire at all that has been achieved only 3, 4 years ago. So that is why Ti sapphire is much more popular but Alexandrite is also used for several reasons. And I want to discuss Alexandrite especially because I want to talk about interesting architecture.

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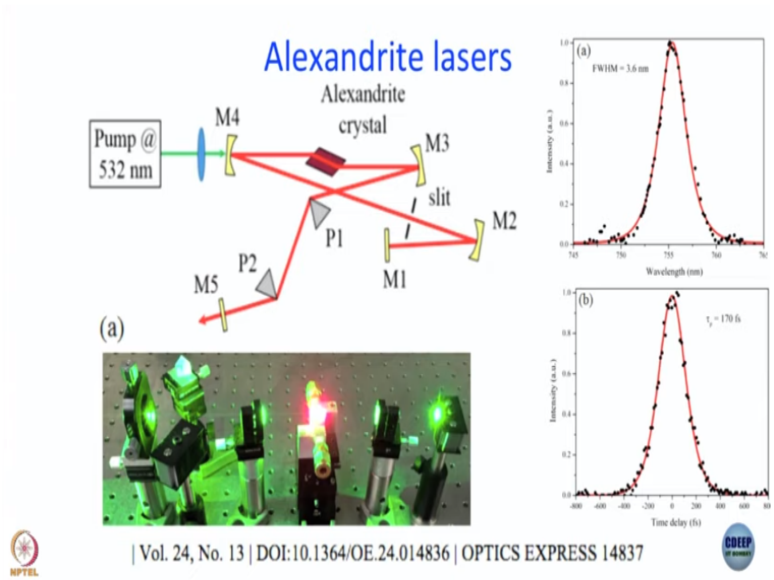

But before we go there this is your well since this paper was published in this millennium the figures are in color okay. So as you see even this people like what hofster group did in 1993 they have used inter cavity prism pair in fact in the photograph this is the Alexandrite rod. And here you can see this prism you cannot see the other one but you can see one. Now what do you get? This is the spectrum of the pulse what is the full width half maximum 3.6 nanometer actually very narrow sort of light or diode lasers.

And full width half maximum of pulse how much is it 175 femtosecond and there is a best one can do using an Alexandrite laser. But you think of it this would be a interesting or useful laser if you want to do TCSPC is not it spectral width is narrow. The problem with using Ti sapphire laser for excitation or doing microscopy is that it is a broad band laser. Many times if your laser is spectrally very narrow you can and if it is tunable then you can excite molecules in different environments with Ti sapphire that I mean shorter the pulse that advantage is compromised to a greater extent.

Because spectral spectrum is very wide here the spectrum is narrow so that is actually an advantage disadvantage is cannot go less than 175 femtosecond okay. So this is Alexandrite laser and then I want to show you something interesting here. Then what will discuss next couple of minutes is actually little bit of digression in the sense that it is not ultrafast laser is a CW laser but I still wanted to talk about it because it is an interesting design. I think that this could perhaps be one of the important designs for future where one people might be able to make ultrafast lasers using the design and you will see why that design is fascinating.

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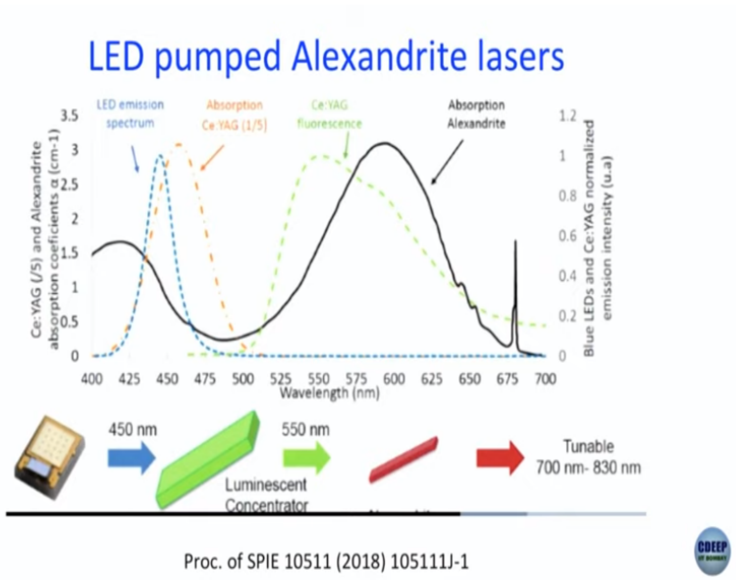

So here this paper is from last year and this is actually a conference proceedings are SPI's has this photonic press conference in San Francisco every year in the month of February a several smaller conferences is in it so this one I think was part of LAC which is a laser conference. So there LED pumped Alexandrite lasers were demonstrated. So see until now we have been talking about DPSS pumped lasers right.

If you can use LED the cost as well as operational issues go down by orders of magnitude right and now LEDs are so common place these is the LEDs the light we have in this room okay. Everybody is familiar with LED they are everywhere. So what they have done is they have taken this is the LED right here I have forgotten the size I think it is 1 centimeter by 1 centimeter they have taken LEDs that give out emission which peaked at 450 nanometer that emission was concentrated by using something called a luminescent concentrator I will discuss how it works and this concentrators are very much topic of contemporary research.

Only yesterday we had visit by an inorganic chemist who talked a little bit about how this try to make concentrates will come to that now this concentrator material that is used is Ce:YAG and emission of Ce:YAG is at 550 nanometer. Emission of LED is peaked at 450 nanometer and it overlaps very strongly with the absorptions spectrum of this Ce:YAG which as a maximum at 460 or some somewhere like that.

Then emission of the Ce:YAG is that is a very broad emission 550 or so and this emission spectrum has a very strong overlap with the absorptions spectrum of Alexandrite. So the idea is use an LED excite Ce:YAG it will emit somehow concentrate that emission and deliver it to Alexandrite now Alexandrite can emit okay. So we will take a break now and will come back and will start our discussion from how luminescent concentrated works.