Ultrafast Processes in Chemistry
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Lecture No. 27
Sapphire Laser (Lab visit)

So today we have come to our lab once again and we are going to show you what we have done is we have opened up our older version titanium Sapphire laser for you and we will show you what is inside and not be able to show you the laser beam because it is 800 nanometer and if you block it of course there will be no lasing, but at least you will see what is there inside the laser. Earlier we have visited the other lab where we have a one box MaiTai Sapphire laser, which is essentially a black box here we can make the black box a little grayer for us by taking the lid off before showing you the laser. Let us go through the schematics once again.

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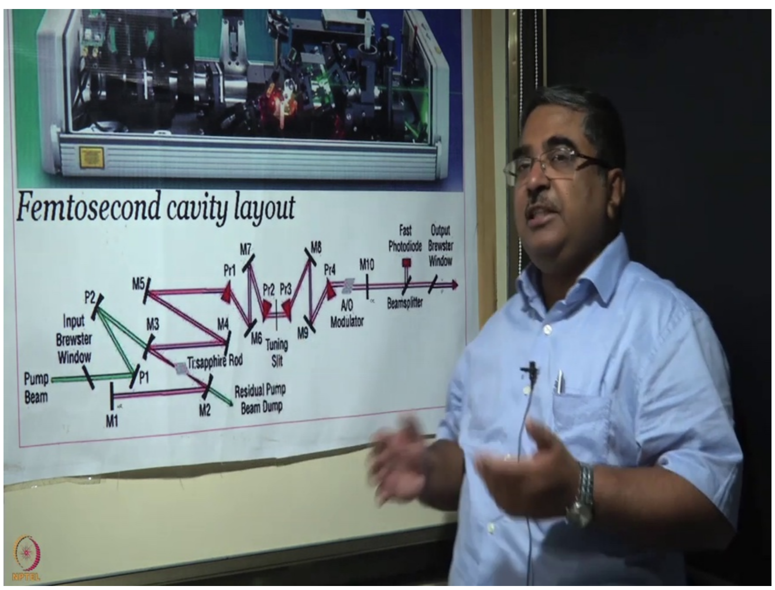

What we have in this laser is first of all, we have a pump laser, the laser is a diode pumped solid state laser giving 532 nanometer. The laser we have is millennia in principle it can go up to 5 watt of green power. So this green light comes in, hits pump mirror 1 which is a plain mirror goes to pump to P2, which is a curved mirror. And because of this curve pump mirror, it gets focused onto a titanium Sapphire rod.

What is interesting here is that the pump actually goes through one of the mirrors in the titanium sapphire laser cavity M3. So, this M3 is a dichroic mirror that transmits green light and reflects red light. So, this thru mirror pump beam gets focused onto the titanium Sapphire rod and then the emerging beam goes through another curve mirror M2 and then it gets dumped. Now, what M2 and M3 do is that they are curved mirrors.

So, they capture the fluorescence from the Ti sapphire rod, and then let us go to this arm first then we will go to the other one. Let is look at M2 titanium sapphire rod rod is at the focus of M2. So, the fluorescence from the titanium sapphire rod is captured by M2 and is collimated the collimated fluorescence hits M1 at normal incident and so is made to retrace its path for a second time it gets focused on Ti sapphire rod and then it goes to M3. So why it is focused on the Ti sapphire rod is that it is retracing its cavity.

And any case you want this fluorescence light to generate stimulated emission that is why this kind of design of path length is there. Then once again, let is not forget that the Ti sapphire rod is at the focal point of M3 as well so the first beam from M3, once again is collimated, it hits a plane mirror M4, it is directed to another plane mirror M5. And then from there, it goes into the rest of the cavity. We will come back to this part a little later let us just ignore it for the moment

and let us say that from M5, it goes straight and then it goes to M10, which is the output coupler, the partial reflecting mirror, through the output coupler, we get the laser after output coupler, there is another beam splitter, which takes a small part of the beam to a fast photodiode for diagnostic purposes, to understand whether it is pulsed or what is the repetition rate of the pulse and so on and so forth.

And then this is the beam that we finally get that goes through an output brewster window which ensures that a vertical polarization is maintained. Now, let us see what is there inside between M5 and M10. What happens here is that from M5, the parallel beam goes through a prism PR1 into M6 into himself these are all plain mirrors, you do not want any more focusing defocusing to happen there.

So, only these two are curved mirrors, all the rest of the mirrors are plane mirrors, then from M7, PR2 to PR3, M8, M9, PR4 and then it goes to an acuosto optic modulators, which actually is not really required as we studied earlier. Titanium Sapphire laser gets mode locked by itself. You do not have to do active mode locking, it might help stabilize the operation. That is why it is there. But to be honest, even if you switch off the acousto optic modulator, once the laser is pulsed, there will be no difference.

Now why do we have these 1 prism pairs here there are 4 prisms for this I will refer to what we have discussed in the class. But remember that we said within the cavity itself, the laser beam gets chirped. Red light and blue light have different velocities. And so they traveled different distances over the same time. And this chirping is going to lead to a broadening of pulse. And not only that, this pulse will be such that at different times of the pulse, you are going to get different colors.

This is completely unwanted to eliminate chirp what one does is one introduces these prism pairs, which sort of make up for the chirp that is accounted for already. So if there is positive chirp that is already there in the cavity, the prisms in introduced negative chirp, so that net chirp is 0. So this is what ensures that the pulse width remains 100 femtosecond or whatever it is supposed to be for that particular laser.

There is one more advantage in principle it could have accounted for chirp by 2 mirrors the reason why we have 4 mirrors is that if you do it using 4 mirrors, then in this part, the beam is completely horizontal. However, let us not forget that this beam is chirped. So spatially, it is dispersed in space and chirped in time. So since it is dispersed in space, so at the top, maybe there is a red light at the top at the bottom, maybe there is blue light.

So what you have here is what is called the tuning slit. So the slit, let us say, this is the laser beam, and each of my fingers represents a different color. You put in a slit here, and the slit is put in such a way that it cuts the top color and the bottom, then this will be the color of the light that gets through. If you move the slit down here, then this will be the color of the light that gets through. Of course let is not forget that when we say that this is the color of the light that get through. We are only talking about the spectral maximum.

There is always going to be a bandwidth but this is how Ti sapphire laser is tuned very conveniently by moving the slit across this this particular horizontal beam, which is not only chirped in time, but also dispersed in space. So, that is the design. Now, let us just show you the actual laser itself.

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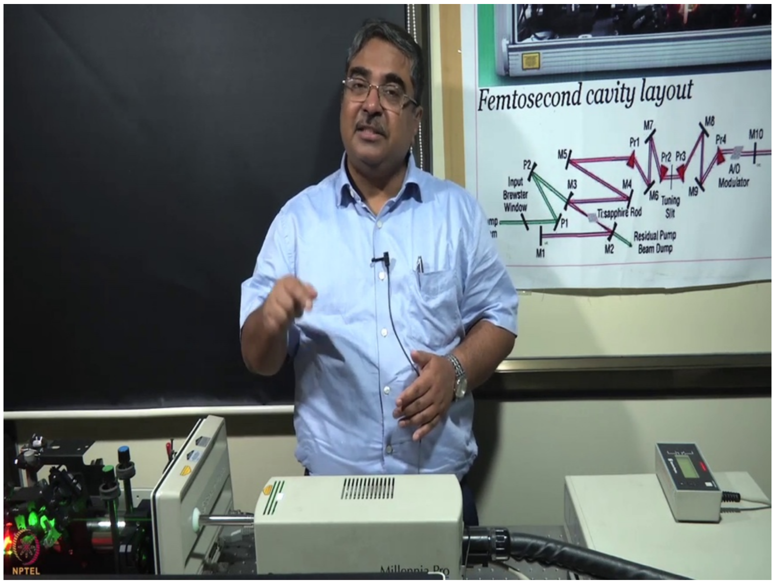

This is the pump mirror, as you said it is a diode pump solid state laser. The way it works is that under the table we have this diode banks, which have pigtail. Pigtail means there is an optical fiber that comes out from the end of the diodes themselves and that is what takes the light on to the active medium of the laser that is kept here. It is NDLF in our case, NDLF, like Nd YAG uses about 1064 nanometer which is IR light and this is the cavity of the laser.

Then what we have is we have an interactivity second harmonic generation crystal, nonlinear optical crystal is inside the cavity itself. So, what happens is in every round trip, the IR light passes through it and generates green light, the green light comes out through this aperture. Now, since it is a little high energy light, we have for the reason of safety kept this green light within this aluminum tubing, but you will be able to see it once we go on to Ti sapphire laser.

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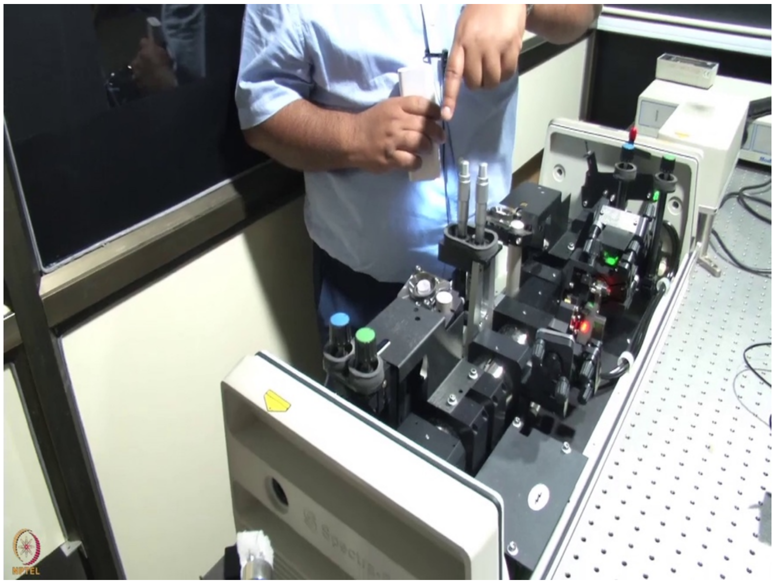

So, this is what the action is. This is the titanium Sapphire laser that gives us 100 femtosecond pulses tunable in principle from 700 nanometer to 950 or 1000 nanometers in practice, in this laser we have never gone beyond say 875 nanometer because once you go beyond 900 nanometer, then the moisture in the air starts creating a problem. And so you need to keep this entire laser cavity parsed in nitrogen and that nitrogen would better we dry nitrogen that is too much of a trouble.

So, you really have not gone beyond 875 nanometer using this laser. Now, let us try to look at the parts one by one, you can see this green light coming in that is the pump light. Well, in an ideal scenario, you should not be able to see that green light you see it because our lab is really not as perfectly clean as we had like it to be there is there are some dust particles wherever this beam is very strong, that means dust is too much.

You should not in a very good lab; where you can maintain absolute dust free condition you would not even see the beam because unless something scatters the light it will not reach your eyes. So, but here it is a little bit of an advantage. So it comes here hits this is mirror, this is a first mirror it hits then it goes on to the pump focusing mirror P2 and then it is focused on to this here is the titanium sapphire crystal, it gets focused through this mirror M2 and goes through this mirror M3 this is where the residual pump beam is dumped.

So, the lower mirror this one is actually M2, this is M3. So, this is the part that brings the pump laser into the Ti sapphire cavity and pumps the Ti sapphire crystal. Remember, this is where the titanium sapphire crystal is and you might be able to see a little bit of the orange glow that is there from Ti sapphire crystal. So, there is a fluorescence, what happens to the fluorescence this here is 1 curve mirror, M2 and this is the other curve mirror M3.

The Ti sapphire crystal is kept at the focal point of both. So, M2 captures it since the collimated beam straight to this is M1 with M1 because this is the beginning of the cavity. And the only controls that we usually do here, you see there are controls here, if I touch this, then the beam position will be position of the pump will move. Generally for this laser, you do not have to do anything everything is calibrated, what we generally touch is these two knobs, if we turn this, then the P 1 mirror, the first mirror in the laser cavity will move horizontally.

If we touch this, then it will move vertically, you might see the color code green, green for land, horizontal and blue for sky vertical. So, this is M1, M2 and M3. And these are the pump mirrors. Then from M3 it goes to M4. From there it comes this side and it is on this side that we have that those prism pairs we are going to show you now. So, we have discussed this part already. This is M4 the fourth mirror this here is M5, from M5, where does the light go? It goes to the first prism.

From first prism, the light goes here, this is M6, the horizontal mirror at the bottom from there it gets reflected vertically up to M7, the 7th mirror, from 7th mirror it goes to the second prism. This is the third prism and this is the portion where the beam is horizontal spectrally dispersed and chirped in time from the third prism, it goes to this mirror here, again gets diffracted vertically up here, and finally goes to the fourth prism from where it goes to the output coupler.

These are the controls of the output coupler once again, blue means vertical. These are the controls of the output coupler. Blue means vertical and green means horizontal. By turning these knobs, one can play around with the path of the beam. But generally, we like to play around with only one side. So, just so that the alignment is not destroyed. Let is come back to this portion here. First prism, second prism, third prism, fourth prism.

This black thing that you see here in between the 2 prisms actually contains the slit. And this is where by moving this back and forth you can see it is moving. That is a slit moving across the spectral dispersed beam and that is how one selects the modal color and this micrometer gauge, what it does is that you can see what happens here. Look at the prism pairs very carefully to see the prism pairs are getting closer or further apart.

So what this decides is that, I will try that once again. If I move it this way, the prism pairs get further apart. If I move this way, the prism pair gets closer together. So what this decides is how much of glass your laser light goes through within the cavity and that is what decides the pulse width as well. And in order to get the laser pulse, all you have to do is you have to just turn this all of a sudden, and generally that disturbance is enough to get the laser mode locked.

So, this is what we have seen so far. The beam, the pump beam comes from here, hits the pump mirror here and gets focused onto the Ti sapphire crystal here. This is mirror 2, this is mirror 3, these 2 mirrors collect the fluorescence from here it goes to the first mirror M1 then retraces paths. From mirror 3, it goes to mirror 4. From mirror 4, it comes to mirror 5. Then we have the prism pairs here and the 4 mirrors. Finally, this here is output coupler, and this is the port from which the laser comes out.

So, that is it, we have opened up the laser for you and we have shown you the optics inside. And I hope now all of us have an understanding of what the light path is inside a typical titanium Sapphire laser. You might remember that you saw another compact Ti sapphire laser earlier there what happens is that in a much smaller space, the cavity is folded further and usually those lasers cannot be opened up like what we have done here.

Now the last question, how do we know whether our operation of the laser is pulsed or whether it is continuous waves? Now again, going back to our theory classes, we know that when it is pulsed there is a broad bandwidth, a CW laser can be monochromatic, but a pulsed laser can never be monochromatic, there is always a spectrum with some full width half maximum that will be associated with pulsed operation and we know how to calculate it for pulses of different shapes. So, what we do here very simply is that.

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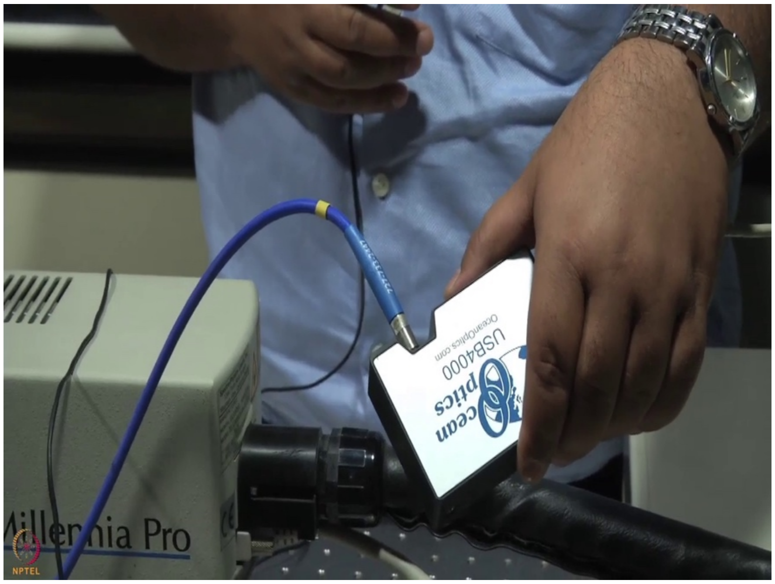

We use this kind of a device this is a very simple compact handheld spectrometer. What you see here is an optical fiber, the optical fiber here captures a part of the laser light scattered by some scattered are placed in the path and this inside contains a grating and an ray detector. So, we get the emission spectrum or we can say we can get the spectrum of the laser. And what we do is while playing around with the micrometer that I showed you a few minutes earlier, we keep disturbing it until the outputs of this spectrometer turns from a highly monochromatic one to a little broader spectral one in the laser that I have shown you. Typically, we have a spectral width of about 12 nanometer when the central wavelength is 800 nanometer. So that is all for today is module. Next day, we go back to the theory classes and take our discussion further. Thank you.