Optical Spectroscopy and Microscopy : Fundamentals of Optical Measurements and Instrumentation

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Lecture - 38

Hello and welcome to the lecture series on Optical Spectroscopy and Microscopy. In the last lecture we were looking at the generation of the femtosecond pulses from using a mode locked laser. And we were talking about how to compensate for the intra cavity dispersion induced by the crystal itself, right. We were talking about the frequency content of the pulse.

And how these different frequencies undergo different amount of delay because of the each of them have different refractive index and when such a pulse passes through a piece of glass or in this case the crystal present inside the laser cavity, then the pulse undergoes stretching or development of frequency order inside the pulse train and called chirp.

And this chirp widens the pulse and how we can compensate for this chirp using four prisms and we saw that by changing the spacing between the two prisms, I mean or by introducing more or less amount of glass or the prism, you can actually change differentially the amount of delay experienced by the red and the blue components of this light.

So and then towards the end I did show you an open cutout version, the image of a laser and we would see in the lab session and equate the opened out version of this laser and then various different components present there. So now let us start from this opened version and then I will move to the schematic explaining to you in detail what happens to the laser or the light as it goes through this whole system.

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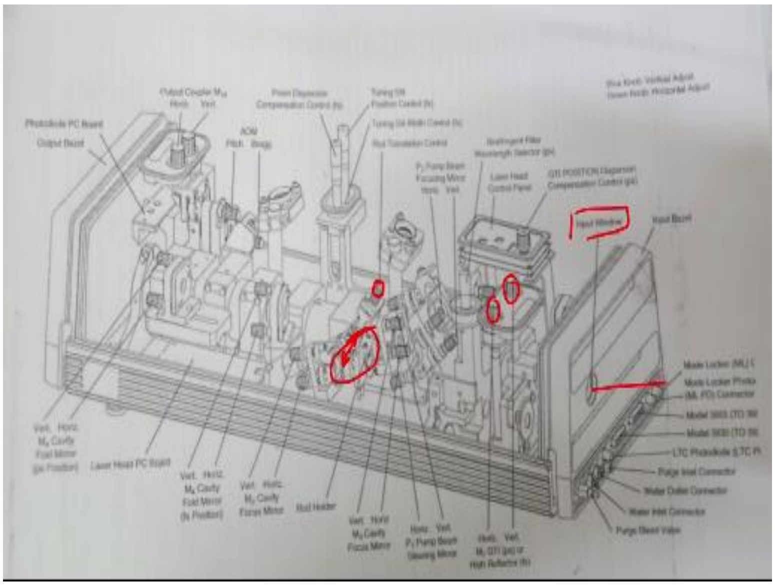

Now the image that we see on the screen is that of the laser as I was telling you in the last class. What you see is only the titanium sapphire component, okay. And we are not so the this titanium sapphire laser in turn requires a pump laser beam. So it does not have to, it does not have any other mechanism to excite itself. So the pump laser beam, we will talk about the whole system in a bit.

But just to put things in perspective, the pump laser beam per se enters this through this hole marked as the input window. Now marked as an input window. The light enters and then the light once it enters, hits a set of mirrors called as a pump optics and pump beam optics before it is before it actually goes on to excite a crystal that is located right about here, okay.

So now the adjustment knob that you see here if you adjust it, it moves the crystal up and down along this direction. So we will see when it will become very nice and clear when you look at the schematic. I am just showing you this picture just to illustrate the optical path inside the cavity. In a real system it is pretty intricate and involved though each one of this component exist for a good reason.

Now let us look at the schematic to understand the light path a little bit. Then, we will go ahead and look at the how do we generate the input beam so on and so forth. So all in the perspective of what we will be seeing in the lab and how do we go about understanding that, okay alright.

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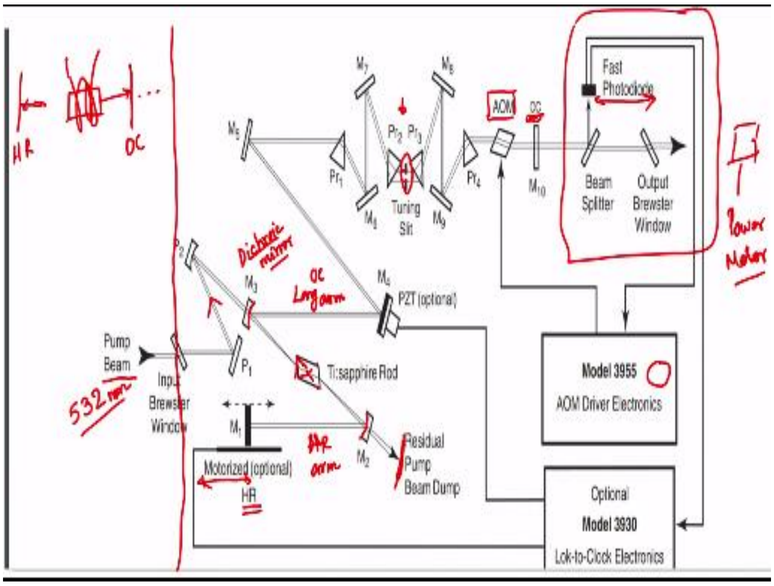

So the input beam, so now this is so if you go between this and this what we have done is that we have flipped meaning the input side was on the right hand side now and here what you see the input side is flipped now. The light enters, the pump beam enters from the left hand side. So the pump beam enters from the left hand side as you can see. And so this is the input window Brewster.

The whole set up is enclosed and it is so and it is airtight so that it can be maintained at moisture free environment. We will see in a minute why it is important or we will see that in the lab why it is important. So now this pump beam, laser beam actually goes inside the cavity. So you can think of this being one end of the laser system. The titanium sapphire laser system hits the pump beam and after it and then following which it goes up and so that is the direction of the light beam.

So titanium sapphire gets excited in the visible light region. In the lab, we will be using 532 nanometer laser light. It is a green laser and that comes in and hits the first curved surface okay the pump mirror two, which focuses the pump beam into the titanium sapphire crystal through this dichroic mirror. This mirror M marked here is actually a dichroic mirror. I will walk you through in the real system.

I may not be able to we may not be able to have the luxury of being able to completely explain why we are having these things during that point. But I will indicate to you what these different schematics in real system, okay. So the M 3, dichroic mirror M 3 separates the excitation, lets the green light pass through, okay and excite the titanium sapphire crystal, alright.

So now the titanium sapphire crystal then the remaining green light actually gets the, it is please note the focus point here that is right at the center. And the remaining green light actually goes and gets dumped in a black dump present, the light dump present inside the cavity. The crystal in turn now generates infrared I mean infrared fluorescence, red to infrared fluorescence, which is collected by these two curved surfaces.

Now this remember I told you this is a dichroic mirror M 3 and M 2. So they will let the green light pass, but they will reflect the red light. Now this curved surface serves to collect the light originating at the focus, right. The full florescence is in 4 pi directions. And of course, the part of the solid angle that is defined by this crystal center entrance aperture to along with the focal point of this curved mirror determines the fraction of the light that is actually collected by this as well as this.

Once it gets collected, that is sent to mirror M 4. That is one arm of the fluorescence light. So let us call this as a long arm because it goes through many different optical elements and it is a, many different optical elements. I really do not know the length, path length. But then, let us call it because simply mainly because it is going through many other optical elements.

And then there is a other arm and that other arm is very simple where the light collected by the curved surface M 2 gets reflected to one end of the laser cavity, okay. So since it is one end, we know and this is the end where there is no output. This is the HR end, the high reflector, right.

So remember in a laser cavity, we have seen right that we have approximated all along the course, that the laser cavity as 2 end mirrors, lasing medium and a source for taking the molecules in the lasing medium from the ground state to the excited state. Could be a flash lamp or in this case, like in this case, it could be another laser another light source that actually pumps this medium.

And then the light emanating from them is actually reflected back and forth inside the cavity by two end mirrors and one of the end mirror is output coupler through which the light leaks out. While the other end is a high reflector, where the lights the incoming light gets reflected back. So now in this model the high reflector reflects the infrared light radiation back.

And once it does then what we see is that this light radiation that comes out all again goes through this titanium sapphire, extracts more energy and then might decide and goes forward in this direction and goes into this long arm. So we will call this as a short arm or the better we could call this as the output coupler end or output coupler arm or the HR high reflector arm.

So this arm is pretty is really simple and you have a way of adjusting its angle with respect to the incoming beam from outside of the box itself. If you look at the cavity here, you see the light is entering from the right hand side. And these two knobs present here are the provides you the ability to adjust the angle of the mirror, okay.

Thereby the incident angle of the incoming beam at the HR, this is the higher end HR end, high reflector end. And so you can see that by adjusting that you could make the beam take a path that is that allows you to actually make alignments to the beam path or adjustments to the beam path.

Similarly, the light getting collected from in the long arm what it happens what happens is that after it hits the MR it goes to the MR M 5, M 7, M 8 or all regular mirrors and what you see and what you see is that the now this mirrors take the beam into a set of prisms as we have discussed in the class right. These mirrors are there to compact, make the whole prism pair compressor compact.

So that it does not have to go through in a different space and all that. So you can essentially you can think of these mirrors as nonexistent except for the fact that they take, they allow you to take the beam through this prisms. And these prisms as we said by adjusting here only one thing that we need to adjust is the amount of glass that we have to put in because the other is the other length is fixed and given the refractive index of the prism.

So by adjusting the amount of the prism that you put in you would not be able to adjust alter the amount of dispersion that or the amount of this the dispersion that you need to compensate for. The one of the beautiful part of the titanium sapphire laser is its ability to generate ultra fast pulses or the hundred sub hundred femtosecond pulses very easily and across a wide range starting from 800 all nanometer to all the way up to thousand 1100 nanometers.

So which means the tunability, right how do we get the tunability. The band why one is that the laser medium itself has enough bandwidth to accommodate all of this lights. Second thing is to be able to choose a wavelength of your choice. The way you do that is by adjusting a slit, a horizontal aperture that is located here in between the two prisms, okay.

So while these prisms while the first prism makes a angular dispersion so that the angle taken by a longer wavelength is lesser than the higher I mean a longer wavelength is lesser than the lower wavelength. And these prism make them as beat the spread spatial spread of this different wavelength linear so the at in this region you one can the d lambda by dx where x is the space, when you move, is constant.

So when you move this slit across this in this space you get to choose. Because the redder would be on the top while the blue would be at the bottom. So you get to choose which of this wavelength is going to go through while blocking the rest of the other light. Thus you get to choose which wavelength survives in this cavity.

So once it goes through then it reaches this acousto-optic modulator which is there to enable or to maintain a stable generation of the stable generation of ultra-fast pulses as we will see as we will see in the lab. You really do not require this to initiate a mode locking. And in fact, we do not turn off this AOM during far reaching mode locking. But with the help of a AOM you might be able to maintain it for a longer period of time in a stable condition.

And once it goes through this acousto-optic modulator you have a n next n mirror, which is M 10 or the output coupler, which is a which lets the part of the laser pulse out while the rest of it gets reflected back. So while you are aligning the laser, the job of you is to be able to do quite a few things. One is to be able to overlap the light coming from the HR end with that of OC end not at one point.

But you need to overlap the entire path which means the path is defined by overlap at more than one point. We will see it in the lab and the theory of the lab sessions where to make an alignment you need to ensure that the two beams are if you are aligning one or I mean a beam with another beam you typically align two beams or more than two beams. All of them need to be collinear to be able to say that they are taking in the same path.

And to ensure that you have to make sure that the beam coming from originating from M 1 and the beam coming out at M 10 are originating from M 10 are aligned are at the same space and at the same time the bean originating from M 10 takes the same path as it was coming in. So that is called us a retro reflection. So the incoming beam and the outgoing beam take the same path, right.

So we can there are quite a few easy ways to check it. We will probably see that in the lab. But the key point here is that you will after this output coupler, there is a beam splitter, which is for some, this whole setup is for beam diagnostics, which allows you to or which gives you a real time feedback of if the light if the laser light if the laser is operating in a pulsed regime or is mode locked.

And also it gives you a feedback of how much is the laser power, mostly in a relative sense not to measure the absolute power you need to put up power meter outside of this cavity and measure it. But this diagnostics, what it allows what it does is that it samples a small portion of the beam and sends it to a fast photodiode. Photodiode is to sense the if there is a light.

It is fast photodiode because if you add to the response time of this photodiode is faster than the round trip time of the pulse, okay. If the photodiode were to respond slower than the round trip time, then you will not be able to differentiate between a light that is pulsed versus a light that is CW and the whole point of this beam diagnostics is to be able to tell you whether it is pulsed or not.

So a portion of the beam is reflected onto the fast photodiode which is then amplified and then detected by some electronics mixture of acousto-optic modulator as well as lock-to-clock electronics okay. So the idea here is that the way of achieving stability, right. So the acousto-optic modulator we have seen previously in the class is nothing but a crystal a nonlinear crystal whose refractive index or the material property is such that the density of the material can be altered by passing sound waves.

Sound waves, the longitudinal waves, pressure waves inside the on the two sides of the crystal. So now here what we do is that we pass the ultrasonic waves and set up nodes and antinodes which correspond to a high refractive and low refractive index or in terms of an optical component it reflects an grating as optical grating inside the crystal.

As a result by turning it off and on you can deflect the beam of light that this incident on this grating. And you can use this as a shutter by deflecting and not deflecting at different instance in time. It can be pretty fast. Now that shutter requires a controller and that is operated by the AOM.

And you will typically have small control here, control unit that allows you to set the phase delay between the or alter the phase delay of the shutter on and off cycle and the round trip time, okay. So you need to I mean both of them need to be in phase. The light pulse that is coming and making a round trip should be in phase with the acousto-optic modulator's operating frequency.

When you do that you have a very stable output, pulsed output. And that clearly depends on one is the phase of the signal that is going into the on and off wave that is going into the acousto-optic modulator. And the other is the round trip time that the light takes inside, light takes to go from output coupler all the way to the HR and then back again.

So now this end if you notice is you can get it to have it as motorized especially if you are to like the laser to be very have a stable operating condition at longer wavelengths. So then you would need this motorized mirror so that you can adjust the cavity length by moving it bringing it back and forth you can actually adjust the time taken by the for the light pulse to come back to the AOM.

So now whenever the light pulse comes back you actually want to have the AOM on so that that the rest every time off so that the mode lock is continuously maintained. So now that brings us to the end of the description of mode locked laser pulse and laser and its operation inside of this system. Now let us go back and look at the whole system because I am going to, when I show this laser system in the lab, we need to know where, how do we generate the laser.

Ultimately, in the lab what we have is a power source, right? You need to take a power source and plug it into the wall supply and from there you need to be able to generate the whole set of this light. And that is what you will see there. So just let me give you an little brief on how we generate this 532 nanometer light itself and it is a commercial system and that is what I am describing.

So commonly you will see one I mean one of the two systems that are more prevalent. And nowadays you do get few other systems but I am going to be talking about the one that we have in the lab since the, I can actually simply open it up and show it to you and describe to you here. Otherwise the other system the equivalent system is pretty much the same in terms of operation and the basic principles.

Here and there are few differences but roughly the operation is more or less the same, okay. So now there are differences in terms of where the prism pair compensator is present and in one it is present between the lasing medium and the output coupler, thereby the light pulse that is coming out from that would not have would not experience the chirp caused by the dice of crystal just before it comes out of the laser.

On the other hand in the other system the mode locking itself is done through Kerr lens mode locking. So it is pretty simple and we to achieve the mode locking where you just have a slit and bring down the slit and to match the focal spot and you get mode locking and the though even though the prism pair is on the other side, the power that you get out from the laser is high. So both of them have their more or less equivalent.

There are differences in their specs, but nevertheless the mode of operation is essentially the same. So you can we either of them when you have in the lab you should be able to go back and see these principles in operation, okay. So generation of the pump pulse itself, right.

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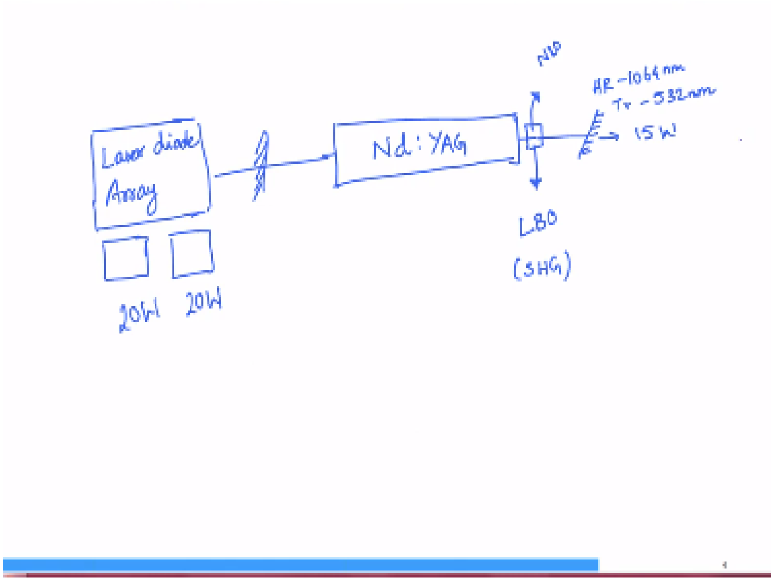

So that is through a set of different lasing systems. The first one being a wall power supply where you have a laser diode array okay. It is a bank of laser diodes two of them. All sending in very all sending in about I think about each one of them is about 20 watts of CW infrared beam focused onto the fiber. And that is fiber coupled. The laser output from here, right from this two banks through these two fibers come in and then excite neodymium yttrium aluminum garnet, okay.

One of them I mean, either YAG or a variation of this crystal. So when you pump the YAG using this semiconductor lasers, the output is 1064 nanometer light. And this light per se cannot be used for a titanium sapphire. So what happens is that I am just drawing in the cavity here. Inside of this cavity, there is another nonlinear crystal which does okay, so there is a output coupler here.

And this is essentially a very high reflector. It is a dichroic again for 1065 nanometer while it is transmitting 532 nanometer The 532 comes because of this crystal. It is called as a LBO crystal. We will see all of this in the, I mean we will not be able to see the crystal, but we will see the existence of that and various different aspects of this and how do we operate this and so on.

This is called as a second-harmonic crystal or second-harmonic generation, the process is called second-harmonic generation, wherein the wavelength gets halved or the frequency gets doubled. And this is a special nonlinear property of this crystal okay. We will time permits we will see this in the course, in terms of coming out from one of the NLO property nonlinear optics properties.

And during this because of this second-harmonic generation, that 1064 nanometer light becomes 532 nanometer. Usually this process is not very efficient. However, when you keep it inside of this cavity of a laser, the efficiency is very high, that the best that you can get. And this is called as intracavity second-harmonic generation.

And that light is 532 nanometer light that gets generated and in our lab we can generate about 15 watts of that 532 nanometer light which then we use to pump the titanium sapphire laser. So again there are multiple stages in this ultrafast femtosecond light generation. The first stage is the conversion of the wall power supply into the light using two banks of diode array.

Each pretty powerful about 20 watts output which infrared output, which goes and gets into the Nd:YAG laser which has an intracavity doubler crystal or second-harmonic generation crystal in the form of LBO and this system generates 532 nanometer green light to about 10 to 15 watts. You can use anywhere between 5 to 15 watts or even 18 watts to pump the titanium sapphire crystal, or titanium sapphire laser.

And in the titanium sapphire laser we have seen the how the light, infrared light that is generated from the inside of the laser goes through. I hope this gives you a overall idea about how a femtosecond system in the lab operates and I will see in the next lecture. Bye. Thank you.