Ultrafast Processes in Chemistry
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Module No # 08
Lecture No # 43
OPA in our lab: TOPAS C (part 1)

Today we are going to talk about the optical parametric amplifier that we have in our lab the purpose of this is we were in their lab they should know what is there inside the well the black box that is white in color. And for those who are not in the lab we want to give you the little bit of an idea of how complex it is and at first look it might look completely baffling you do not know what is going on inside and you do not even know what is what? But after this module black box will not remain so black after all right so the OPA that we have in our lab is called TOPAS C before going into that.

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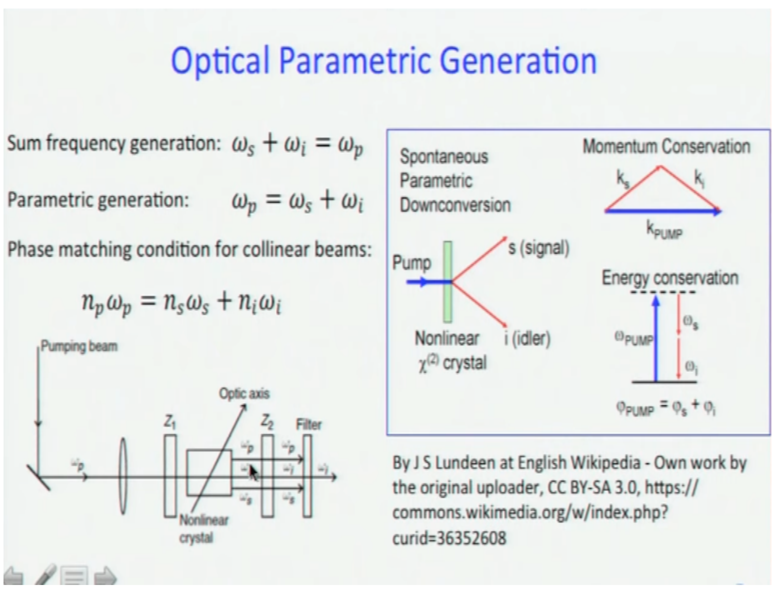

Let us quickly revise what we had said about optical parametric generation and amplification in the previous module we said that some frequency generation is something that we have studied earlier where 2 photons of smaller energy join up in an non-linear optical medium to produce a photon of higher energy. Optical parametric generation is exactly the opposite where a photon gets split into 2 consequent photons obviously of smaller energies up after going through a non-linear optical medium.

And then what we said is that when we write something like this that omega p = omega s + omega i the problem is that there can in principle be infinite number of omega s and omega i combinations that would add up to be give omega p that nobody said is omega to a integer or non-integer even integer nothing right. So in principle infinite number of combinations can be there but in practice the number is limited so this is somewhat like the boundary condition that we have encountered in quantum mechanics.

It is limited because not only does the energy have to conserved energy conservation is given by omega p = omega s + omega i which is said that is not the only condition a very important condition is that momentum also has to be conserved. So now you see the moment we say momentum has to be conserved you have only certain values that omega s and omega i can take. And then if you are going to do it in a collinear geometry for collinear beams the momentum conservation condition reduces to np into omega p = ns into omega s + ni into omega i.

So that gives us not only a limited number of omega n and omega s that we can handle that can get but also we get way of determining what is going to be omega s what is going to be omega i because one can in principle play around with the refractive index by change in temperature as will see there are other factors as well of course angle tuning is an issue temperature is an issue that can be something else that we will see it today right.

So this typically would be the geometry of optical parametric generation were a pumping beam is focused on to a non-linear crystal to generate idler signal and residual pump will be there the residual pump is removed and the depending on what you want the idler can also removed to give you only the signal. Now this can be done in 2 ways one is by using filters of appropriate energy band pass filter or long pass filter, short pass filters and like that well typically long pass filter.

But polarization also has a role to play because depending on what kind of non-linear optical crystal we take and depending on what is the polarization of the pumping beam we will have different polarization of this signal. So if it is oe then it is very simple to understand that by setting a polarizer perpendicular to the polarization of the input beam the pump beam you can separate out this signal without much hassle.

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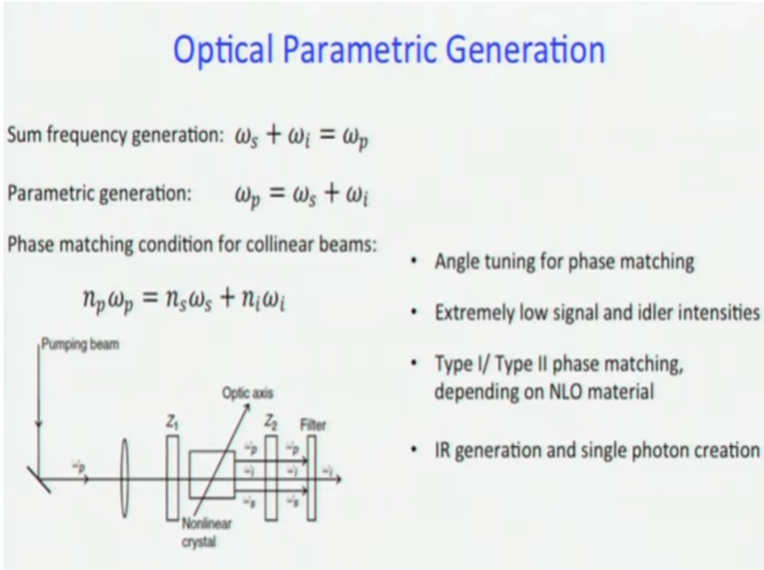

So polarization is also a key factor now the problem with optical parametric generation well not problem the let us say the different points that one needs to keep in mind during optical parametric generation is that one can do angle tuning to get phase matching like in other non-linear optical processes the signal and the idler intensities are very low because we are going splitting the photon is less probable then combining 2 photons you can get type 1 or type 2 phase matching depending on the NLO material.

And then this is very useful for IR generation and single photon creation so the problem here that comes out is extremely low signal and idler intensities. How do you work around that one way of working around that is put this entire thing in a cavity? If there is resonance signal beam then automatically it is going to get amplified sort of like a laser that is what gives you an OPO optical parametric oscillator.

Typically optical parametric oscillators have repetition rates of tens of megahertz and it gives you reasonably strong signal beam. So when you want to do some kind of photon counting application TCSPC or femtosecond optical gating OPO would be the preferred light source if you have resources to get it OPO is actually extremely expensive okay pumping the energy that you get are not really in milli joule it is more or less comparable to what you get out of a titanium sapphire or oscillator a little less on that.

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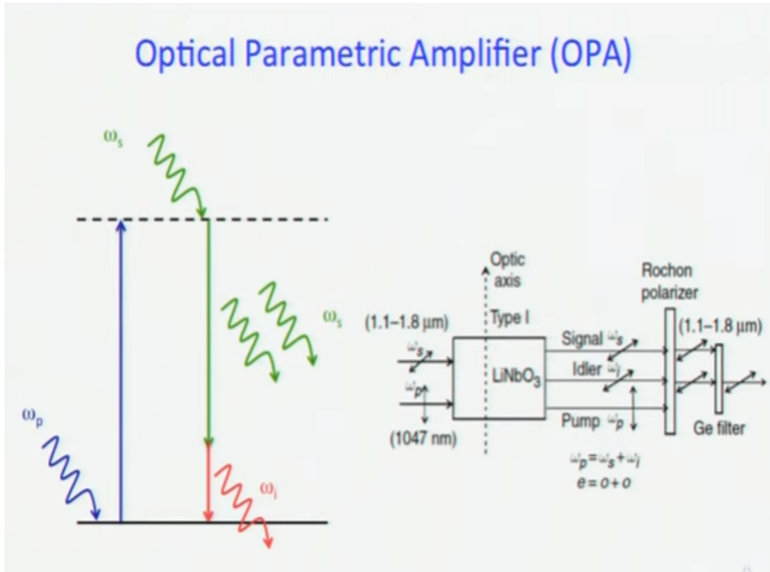

The other way to do it is to do the optical parametric amplification and that we what we have in our lab and that is what is useful for pump probe kind of applications so what you do here is that using the pump photons the system is promoted to some virtual state and then omega s these signal photon is made available that some intensity low intensity. That causes the generation of another omega s so here you get an amplification you have 1 omega s photon you get 2 coming out of it then of course since energy has to be conserved omega i the frequency of the idler is also generated.

And here what we show here a typical set layout of a optical parametric amplifier whether the pump and the signal photons are perpendicular in polarization to each other we are using LiNbO3 which gives you eo kind of phase matching. So what you get is you get the signal and the idler to be horizontal in this era pump remains vertical. So next thing is put in a polarizer and cut out the pump insert the polarizer to horizontal polarization and then the signal and the idler goes out.

Now if you put it in a filter which is going to cut out ir then the idler is cut and you get the signal coming out. Or if you want the idler to come out instead of the signal then what you want to do is if you want to use long pass filter we should allow ir to go through and cut the visible okay. So this is what we have studied already.

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And this is what our white color black box looks like TOPAS C this is where we do optical parametric generation. So what we will do in the next 20 minutes or so is that we will try to open the lid and see what is there inside. So first of all TOPAS C needs a pumping right and the pump beam that we typically feed into it in our lab is the 1 milli joule typically 1 milli joule or 1.3 milli joule from the output of our regenerative amplifier.

Our regen actually produces 4 milli joule but then TOPAS cannot take so much of energy the optic will burn and it is not required also. I will show you at least in 1 slide what is the problem if you have too much pump in case of spectroscopy any kind of spectroscopy basic working principle I do not know if I said it already is too good is no good sometimes you might think that you focus tightly and then perfect focus is going to get you the perfect output that is not correct because if you focus too tightly then your optics might burn.

Or you in case of white light generation you might get what is called filamentation okay so one needs to optimize conditions rather than maximize anything. So 1.3 milli joule of energy is fed into TOPAS and the way it goes in is by this all mirror telescope.

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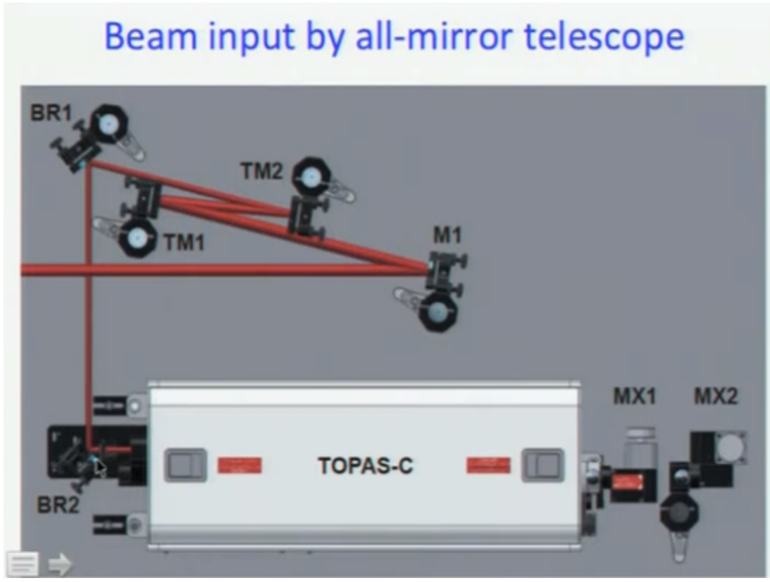

When I deal with femto second pulses what is the preferred optics that I want to use lenses or mirrors. Suppose I want to focus on femto second pulse should I use lens or should I use concave mirror, convex lens or concave mirror yeah mirror why yeah because when femto second pulse passes through any medium especially solid medium then it broadens chirped it is something we have studied earlier in the course but as you see inside TOPAS feeding of the beam is by all mirror telescope understandably later on we do use lenses and we use lenses for a reason.

It is okay to use lens TOPAS we will see why okay so this is what happens light comes in hits mirror 1 then TM1, TM2, BR1 and BR2 and that is what feeds the light into to TOPAS.

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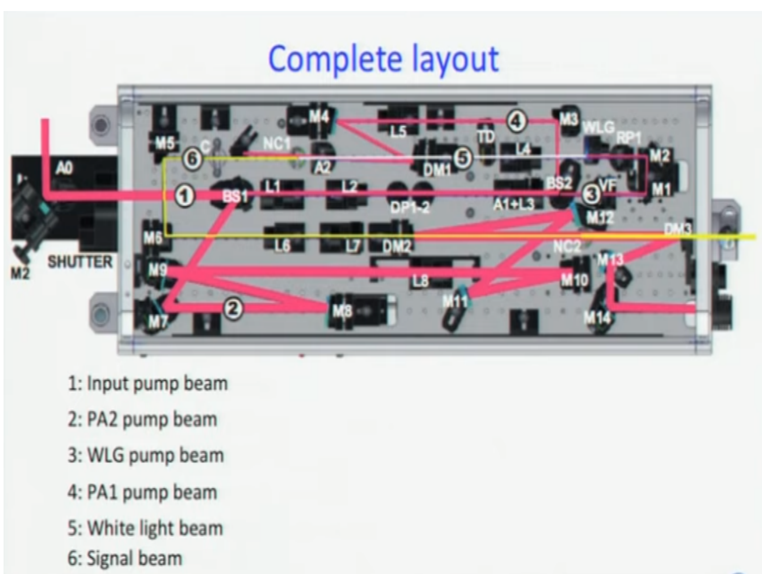

And what happens inside this is the layout that you have inside TOPAS so what you see is a lot of pieces of optics and first you open the lid and look inside you do not know what is what? You do know which one is mirror which one is the beams meter which one is sapphire plate which one is a non-linear crystal which one is lens? So let us see will go slowly and if we can understand.

But to start with let me give you an overview what you have is you have this input pump beam that is labeled 1 okay it goes to a beam splitter BS1 and we will do this all over again in the next slide. This beam splitter 1 reflects almost 80 to 98% of the beam depending on how much power you put in to this direction towards M7 what it does? It does so that branch is called the PA2 power amplifier PM is power amplifier.

So 80 to 90% of the input beam is used as a pump for the second stage when you generates strong signal right. So second stage of power amplifier or sometimes it is just called the power amplifier and the remaining 2 to 20% of light goes to beam splitter split up by this 2 lens L1 and L2 convex lenses. See we are using lenses here what is the role of this convex lenses we will discuss in the next slide but the crux of the matter is that the second path which is denoted no sorry third path which is denoted 3 here that is for generation of white light.

So that beam is called WLG pump beam WLG means white light generation why do we need white light here because the purpose of using this piece of equipment is that we want to generate different colors and we want to generate as many colors has possible at will. So now if you want to do that since you know how an OPO works anyway you understand that we have to make available little small amounts of signal beam of as many colors as possible.

If I have monochromatic signal beam then I can only amplify that color right but that is not what we want? We want wide tunability and the widest possible tunability one can get in this situation is by generating white light okay. So white light is going to provide the signal that is going to be amplified later on okay. So this path 3 is for white light generation pump beam that what it does is it goes and it produces the white light I do not know if it is very easy to easy for you to see here but we will see it later on so do not worry.

Fourth one is PA1 pump beam what does it mean okay you generate white light here you see that WLG written in white and you see this beam that is in do you see the white beam that white beam number 5 is the white light beam. So, white light generation takes place here on a sapphire plate very much like what you do in your pump probe experiment. Then this white light goes straight on to this NC1 can you read NC1 written in white.

So this NC1 is the first non-linear crystal there white light goes in as a signal and then path 4 is your PA1 pump beam PA1 PA here is once again PM is power amplifier but PA1 is also called pre amplifier. So what do you do here is that in this NC1 you generate the first pre amplify the signal beam for the first time okay and see what has happen. So the reason why it is drawn in yellow is that what it means is you select which component of white light you want to amplify okay how you select will come to that okay.

One of the components of white light so this component color is the optical parameter we are amplifying optical parameter right the optical parameter amplifying is a particular color or frequency. So that signal is amplified first then it goes here so this is path 6 is the signal beam goes here comes straight and here you see there is another non-linear crystal NC2. That is your amplifier so already once amplified signal is amplified for second time in this NC2 and how is it amplified?

Here now what you do is one thing I want to do is on this NC you see this white light and the pump are actually collinear from this diagram it might look like that they are little non collinear they are not they are perfectly collinear okay. And here in the second stage what you have is you have to this 88 80 to 98% of the light that was there in path 2 PA2 pump beam that is also made incident on that I made a little bit of mistake here it is non collinear sorry on NC1 it is non collinear.

Because you want to separate the pump from the signal in the second part in NC2 it is collinear okay right. And then you have some dichroic mirror here which lets the signal go through and reflects the pump beam so pump beam can come out from this port okay. Of course what you could do is that this pump beam itself is going through nonlinear crystal. If you want you can block the signal beam and tune this nonlinear crystal so that you will get second harmonic of the pump beam. That is a very easy way of generating 400 nanometer light bypassing the OPA right.

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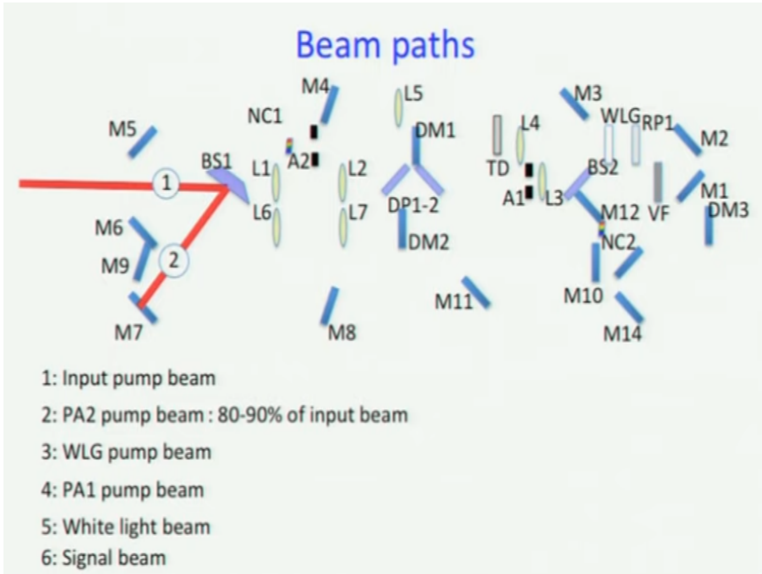

So now let us see what the beam path is and to do that I feel it is easier if you just draw the schematics like this and this is a cartoon of what you would see when you open the lid and if you do not know what is what it is a perfect hotch-potch impossible to understand what is going on here. So we will do is that is why animation is required we will step by step what this beam paths are right? So here is your pump beam 800 nanometer 1 milli joule what is the repetition rate? 1 kilohertz, the first piece of optic it hits is a beam splitter not a dichroic beam splitter just regular beam splitter which reflects A beam splitter is just a partially reflecting mirror right like the output coupler of the beam laser that you may think off. So it reflects as we said earlier 80 to 90% of the beam of the light and sends it towards M7 that is your path 2 PA2 pump beam we will come back to it later.

Even through it is called path 2 will not discuss it to start we will come back to it little later there are other things we want to talk about. Now what happens to the remaining 2 to 20% of the beam it would propagate straight right. And then you have this L1 and L2 what is we take a rain check on the question why is it okay to use lenses you will understand why it is okay shortly but can you tell I have 2 lenses one after the other what is that arrangement called optics class 8, class 9, class 10 have ever seen anything any device as a toy which has 2 lenses one behind the other telescope.

Binocular is a I mean modification of telescope it as 2 telescope join together right so telescope right and what happens when you have 2 lenses you have parallel beam coming in the first lens focuses right and after the focal point it is diverging beam both are convex lens remember.

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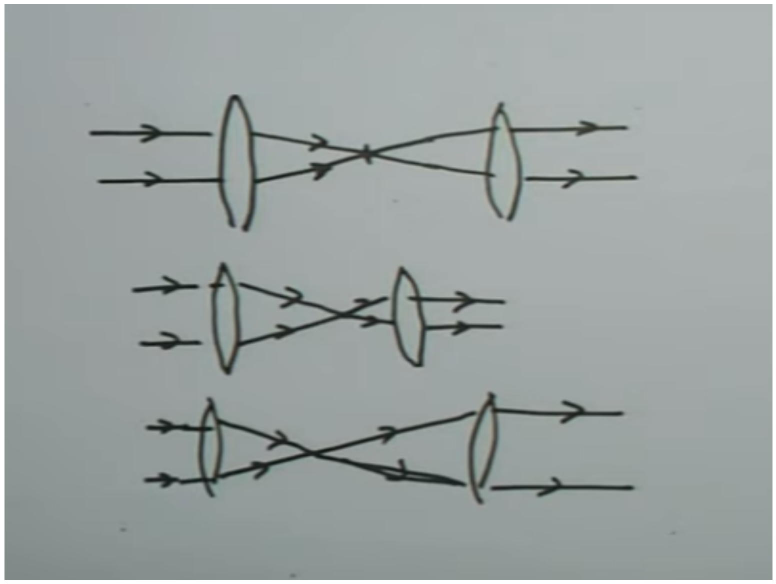

So second lens picks up this diverging beam right is that what I am saying you have this parallel beam we have lens like this it gets focused and after the focal point it is a diverging beam is very simple actually is sure you know it I mean doing it as a revision. Now when I put the second lens I want to put second lens in such a way that the focal length of the first beam is also the focal length of the second beam okay.

But then need not be a 2 lenses of equal focal length okay let us say that the focal length are equal then what will happen we will generate the same collimated beam okay right but makes no sense why put the lenses in between unnecessarily. But if you have a situation like this where the second lens as a smaller focal lens than the first one then what will happen? Then the output beam will have a smaller beam diameter right.

Conversely if the second lens has a longer focal length then the output after the telescope is going to have a larger diameter right. So the reason why one uses a telescope is in case you want to change the beam diameter want to make it shorter want to make it longer you use a telescope comprises 2 convex lenses where 2 convex lenses with different focal lengths depending on whether you want to expand the beam or whether you want to well I do not to use what contact de-expand the beam may be contract the beam the you are going to use the lens with focal length first or second.

In this case the case that we are discussing we use a focal length we use a longer focal length first so what I am saying is L1 has a longer focal length L2 as a shorter focal length. So what will it be will be the beam get expanded or contacted right? So the purpose of using this telescope is that we want to make the beam diameter a little smaller because after this stage it has to go through some iris you do not want the beam to be too large. Of course you get put an iris and cut out part of the beam but then you are losing on energy that is why you need arrangement like this.

So this telescopic arrangement is very common in optical instruments especially if you want to do microscopy and all they are ubiquitous, they are everywhere alright. So what we have learnt so far is the beam comes in hits BS1 almost all of its gets reflected a small part of it gets transmitted and the size of the beam is decreased by using a telescope comprising of L1 and L2 okay. What happens after that we study in the next module.