Ultrafast Processes in Chemistry
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Lecture No. 15 Part I
Gated Detectors and Streak Camera

When in last lecture we said that next we are going to go on to discuss basics of lasers. I thought I would pull it off for one more module, which might be a little longer than other modules or maybe this can become 2 models we will see.

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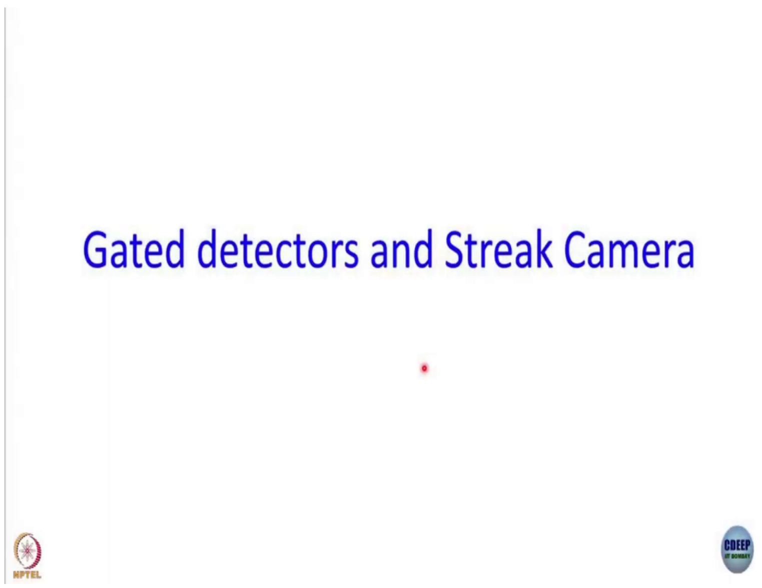

Because there is one more issue that I would like to address about instruments, instruments as they are used without getting into the math of it, before we start talking about laser basics. So all this time, we have talked about various techniques. We did a very brief sketchy this discussion of pump probe spectroscopy, then went on to talk a little bit about time correlated single photon counting and then we have done a discussion on femtosecond optical gating or femtosecond fluorescence upconversion technique.

So before taking a holiday from the instrumentation part of it, let us discuss one more thing. Unfortunately, we do not have it in our lab. But this is an important instrument to know. And you will see why because use of these instruments like this is actually on the rise it is going up. I will tell you why they are not as popular as they should have been, given the appeal that they have. And they will also tell you why they are becoming more and more popular now. So today we talk about gated detectors and streak camera. Remember this entire course is about time domain measurements, you want to look at dynamics, and we want to see how spectra evolve over time.

So this, gated detectors often play a very important role. Now what is the meaning of getting so even before getting into the instrument? As such, it is not very difficult to understand if you use a real life analogy, let us say there is a marathon 20,000 people are running the marathon or something of course, the end there is the end line at the finishing line at very different times. So, now, suppose what you do is, you put a gate at the finishing line and keep the gate closed and open periodically.

What will happen? First time you open it for say 2 minutes. First you open it for 2 minutes. The first 2, 3 runners who have reached they will get through and then you close the gate and you count that 3 people have reached if required you say these three people at least then you keep the road closed for some more time. So, whoever reaches that gate actually waits. And then after a few minutes you open again for 2 minutes. Whoever is there gets in close the gate.

Now you count the 10 people have gone in and then you keep on doing it how will the distribution change? What do you think? Initially, there are very few winners. So maybe 2 people will go in then three 5, 10, 20, 30, 40, then we will come to the level right then hundreds of people will start getting in for every instance when the gate is open. And let us say, I am opening the gate for a small time at periodic delays, and then what will happen, then we start tapering again. So towards the end, people who are lagging behind they will reach so now if I keep on counting the number of persons getting through the gate.

And plot as a function of time, what kind of plot will I get, not necessarily Gaussian it will go up and then it will fall off. So maybe a gaussian, but what I would like to think here is that it look maybe like an exponential function, provided there are many who reach at the same time at the beginning. In a distribution, will go up and go down. So this is basically the idea and this is what is used. And to do this the first thing that we need to know a little sketchily is about 2 dimensional detectors.

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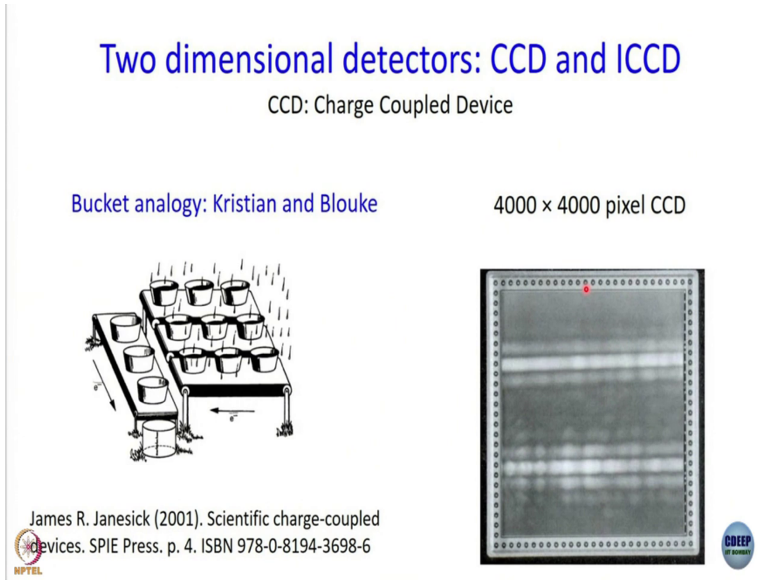

So we will not get into the electronics of charge coupled device because afterall charge coupled device camera as chips, you cannot really do anything with them. If something goes wrong, you have to send it back to the factory. So it does not make much sense to know about the intricate electronics of it for our purpose. But we should know how it works. At least a 2 dimensional detectors now are not as mysterious as they used to be well, 20 years ago.

Has anybody seen a 2 dimensional detector outside the lab? Mobile phone camera. So with the advent of digital photography, everybody uses this 2d detector, and everybody is familiar with the term pixel, so what do you have your array of detectors. A matrix of detectors and typically, you would have like 3000, 4000 by 3000,4000 or something like that. And the way CCD works is a little more complicated. For that CCD this is not something new, by the way.

It was, I think, introduced sometime in 1969 or so. But then the technology has evolved. And to understand how CCD works without going into the math, there is this bucket analogy that Christian and Luke had proposed very early on. This is suppose there is a field and you and this raining and let us say the field is large enough that the amount of rain at different points of the field is significantly different.

How do I know how much it has rained? In at any given point of the field, I put in an array of buckets, and I collect rainwater. And then when I am done measuring, what I do is this is a conveyor belt. Pour the water of the first row of buckets into this fixed buckets, and measure the volume, then maybe throw then the second row of buckets goes there. So, basically you are collecting information here and you are transmitting to a storage location. That is essentially how a CCD works.

And the way it works is by changing voltages that are given to the pixels. For our purpose, all we need to know is that it is a 2 dimensional array detector. If you look, you could look at a CCD, this is what it would look like, and you can see these lines can't you? And if you look a little more carefully, you can see that each of these is actually something like a square. So, array can be along x direction as well as y direction. So, this is quite an old picture.

This one is actually an actual photograph of a 4000 by 4000 pixels is, you might have a better seat in your mobile phone now. You have megapixel and so on and so forth. So, more than number of pixels, better is a resolution. So of course, what do we use it for? We use it for imaging to detectors are actually very good for imaging purpose. So when you talk about microscopy, which is where these become extremely useful, because you can capture the entire image right away. If you use single point detectors like what we do in our lab, then you have to scan.

But if you use an array detector, then you can actually capture the image like taking a photograph. So that is where as the real application is, and CCDs are used in many different ways. They are actually with you test your CCTV cameras, for example, use the CCDs and in astronomy, plenty of applications or there is just our spectroscopy. But then if you want to do time domain spectroscopy, what is more important is not CCD. What CCD and ICCD remains intensified CCD. So that is where the action is as far as we are concerned.

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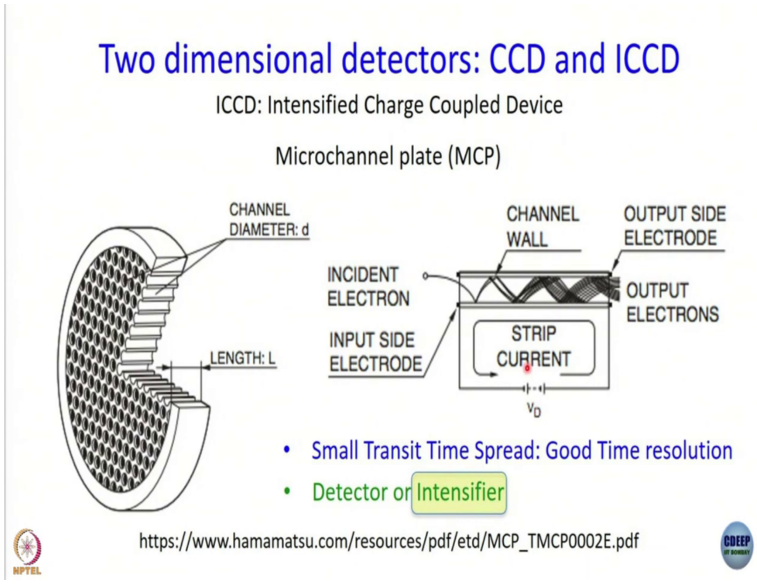

So what you have in ICCD is that you have something that intensifies the image or intensifies, whatever it is that you are looking at. So before CCD, there is something that increases the signal, you can think if I put it in very simple terms, and there is something almost always is a microchannel plate that does this ring a bell microchannel plate have you heard of this somewhere? In some other context, it is TCSPC microchannel plate actual detector will come to that so this is what microchannel plate cross section would look like.

So what you have there is that you have millions of capillaries that are fused together. And well it is called microchannel plate.why microchannel? you can see the plenty of channels and why micro because the length is in microns, how good our micro channel plate is, is determined by the ratio of the length of the capillaries and their diameter, and of course, this is a coating of something, the way microchannel plate works is this, so on, suppose that this is the front face that we can see here, and that is where your incident electron falls or maybe even light falls and an electron is generated this primary electron.

Next what you have is you have this voltage ramp. So, now this primary electron since it is a capillary it is very difficult for it to just go straight. It will hit a wall and then when it hits a wall, and what is happening here is that if you see carefully look at the circuit, the thing is strip current, so you see this side is negative this side is positive. So the actually being accelerated as it travels to the capillary. So, it is getting energized since energy is electron hits the wall then it gives rise to secondary electrons.

So, this is what is depicted here 1 electron gives rise to 2 electrons to give rise to 4 gives rise to 8 and so on and so forth. By the time it comes out of the capillary, you get a large number of electrons for every input electron. So, what is it doing here? It is sort of acting as a photomultiplier is not it? It is multiplying the signal it is acting as an amplifier or an intensifier. So, you can use it as a photo detecter.

If you have a photo cathode here, all you need is you need a photo cathode here then, light falls on it electronic digital that is primary electron it generates a large number of secondary electrons and that is all the signal gets amplified. So, typical amount of Application amplification of course, depends on what kind of CCD you use something like 10,000 or 40,000 something like that, very large level of amplification can be observed here.

The reason why MCPs are very attractive is that to start with the very small transit time spread, what is the meaning of transit time spread if you have read about photo multipliers, there are dinodes, there are plates at different varying voltages and then your electrons have to go from here to there that will the next one, so on and so forth. So, the time taken by an electron to get go through the detector that is called transit time.

Now, they can many different paths. If there are many different paths, then the transit time can also be very different depending on what path the electrons take. The how wide the distribution of transit time is, is called transit time spread and greater the transit time spread, worse is the time resolution? If transit time is very small, then time resolution is better And here the good thing is that you are working with a capillary that is only a few microns long, you are not working with a photomultiplier tube which is 2 inches long.

So, transit time spread is actually small in MCP. So, time resolution is good. That is why until very recently, even in something like time correlated single photon counting experiment, the best detector you could use was MCP you could get instrument response function of about 30, 40 picosecond, only if you used MCP PMT that you made by MCP microchannel.

So, obviously, one application of it is as we said already detector the other application which is have more relevance here is that of intensifiers. We already discussed how it can act as an intensifier you can see the number of electron is going up. So, suppose you do not use it as a detector your photo cathode, you have this and then you have some detector here. Suppose you have a CCD here, if you do not have MCP, 1 electron will hit that pixel of CCD, if you have a MCP in between the photo cathode and the CCD then 40,000 electrons will reach.

So, that is why MCP can act as a good intensifier and that is what is important in our context. And before going head further, let me say once again let's not forgotten this investigation is going to happen only when you apply a high voltage between the faces of MCP are clear about that as we know photomultiplier tube works only when high voltage is applied, you know, so you have to apply high voltage 900 volt, 1000 volt, 2000 volt whatever it is, depending on what kind of MCP you are using, have we understood that MCP we can act as an intensifier.

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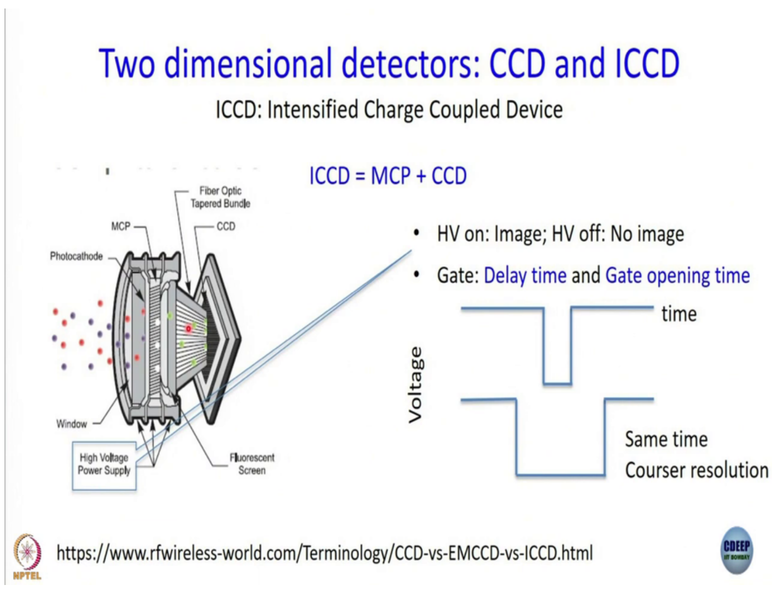

This is a schematic of an ICCD so, I hope you can see what we have written here. So, he has first of all have a window, what window something which protects whatever is there inside but allows light to go in. So, you the small dots are photons, you can think then first of all there is a photo cathode as is shown in the diagram. And by the way, this photograph reveal this schematic is taken from RF wireless world.com I think that is about your CCTV camera.

So, they said this is not confined to the lab use of this. So photo cathode then, this is your MCP microchannel plate and that is where you apply the high voltage from the microchannel plate typically what you do is in earlier models, one would use lenses, but nowadays are most of the optics for the purpose of complexion and lesser loss on all lenses and all have been all replaced and people use fiber optics. So typically you would find fiber optic bundle that takes the information to different pixels of the CCD that is kept here.

So, I hope it is not very difficult to understand that suppose this is my MCP. There is a photo cathode ray of light falls here, the signal goes through gets amplified, and then it is taken by a an optical fiber to a particular pixel of the CCD that is kept here another layer which is infringes on another point is amplified and guided to another pixel. And that is how one can obtain an image and that is really the more general application. So, ICCD in short is basically MCP intensifier coupled with CCD.

And once again, let us not forget that this intensifier can work only when you apply high voltage. And that is what allows this device to be used for time resolved measurement. Why? Because when the high voltage is on, that is not, that is when you get an image, that high voltage is off, you get no image. As we said earlier, you can think that there is one primary electron if there is no high voltage, maybe that one electron reaches the CCD maybe does not but when high voltage is on that one electronic replacement for 40000 volt so that is why when high voltage is on images on image is obtained.

And when high voltage is off image is not obtained on the CCD, instead of image if you say signal, I am fine for the moment. So now you can use this high voltage as a gate. Remember, we discussed this getting business where you had 20,000 runners and you are opening the gate at periodic intervals for a certain amount of time and you are measuring how many runners get through that is exactly what you can do by applying the voltage as a square pulse at regular intervals.

So, essentially something like this. Let us say I apply voltage in this way this is voltage versus time plot. So, the voltage is off for all this time, then it opens all of a sudden, I mean, it is applied all of a sudden, it remains at a constant value, then gets back to 0 and remains off for some time. Then again after some interval the voltage goes on once again and the reason why I shown it like this is that the voltage applied is actually negative on this side you need high negative voltage and then this time for which the time after which the voltage is switched on that is called the delay time.

Suppose, you shoot a laser and then after 1 nanosecond turn the voltage on this 1 nanosecond is delay time if you turn the voltage on after 2 nanoseconds delay time and the time for which the gate is on the voltage is applied this time this is called the gate time. In fact, this technology is nothing very new or anything even when you want to measure say phosphorescence on a regular fluorimeter not a regular parameter with the pulsed source of light, you use this kind of gate delay technique.

The only difference is that there you are giving the high voltage to the photomultiplier tube. Here you are giving high voltage to the MCP which acts here not as a detector as such, but as an intensifier. So what is crucial here? But even before getting there, I want to record a fluorescence decay, how will I get it? Hit a sample with a pulse. And wait for whatever amount of time you want, open the gate for something, and then close it again you make a measurement in the next short the laser pulse, wait for some more time, open the gate for equal amount of time.

In the same experiment, if you open the gate for different amounts of time, then it is going to be completely messed up. So you have to define your gate time and you have to define the delays. You have to define the range of delays. So basically, I consider this is a gate. What I am doing is that for different experiments and just moving this gate along and if this is the starting point, the now delay 0 gate is whatever it is now, I keep increasing the delay for every measurement that is how I can get time resolved data what is crucial here, what are the things that are important first of all this how sharp this fall is that is very important.

You need a good square pass kind of thing. If it is not square, then of course, you are not going to be able to make a good measurement and you have to have the electronic control to be able to change delay with the accuracy that you need and apply this voltage with the accuracy you need all this is important. So, this is an example of what I had said already. Here. If you compare this with this, what have I done? I have used the same resolution, why am I saying same resolution, because the on time is same, but I have used a different delay right, different delay is what I should have written here different delay, same resolution.

But then if I open the delay more, then I hope you can see that you get time resolution here, because you cannot differentiate between this time and this time. Here you can differentiate between the times in this day. So whatever time for which this voltage is applied, that defines your picosecond per channel. Now, earlier, when I said earlier, maybe 20 to 25 years ago, the best one could do is nanosecond.

But sometime towards the beginning of 21st century, these cameras like 4 picos and picostar introduced well you could change the delay with picosecond change the resolution and you could apply this gate times off say 50 picosecond or 20 picosecond now I think you can do 20 picosecond also. So with the improved electronics that is available now, this is becoming a better technique to do time resolved measurements.

Where it is it really used it is used in applications like Fluorescence lifetime imaging microscopy. In our lab, we do FLIM using this TCSPC this is another way of doing it. So what you can do is so these are all called cameras CCTV camera. So what you can do is you can take this ICCD and you can connect it directly to the microscope so you will see the image. Now what you do is you keep on changing the delay, and you define your gate time, you will keep getting images and the entire device will be grabbed at the same time at different delays for whatever time resolution was given.

So from there, you can actually get time resolved images. So that is the real application. Hardly anybody records just florescence decay or just a time resolved absorption using an ICCD camera. ICCD cameras are typically used to image I mean, that is why they were made. But time dissolved image is a good application? In fact, many times people do not even care about time, they just want to see the image they cannot see it unless it is intensified. So it is often used for steady state measurement.

But in high end applications, one can play around with this delay and get time and record time resolved images as well. Of course, you do not have to image all the time, you could do something else. We said that you can couple the ICCD with , With a microscope and get anyways, suppose I am not really into microscopy, but in our discussion earlier also very often, we want to know about time resolved emission spectra, like this 2d detectors. That is something that is that you can do very easily, maybe I will just draw a schematic.

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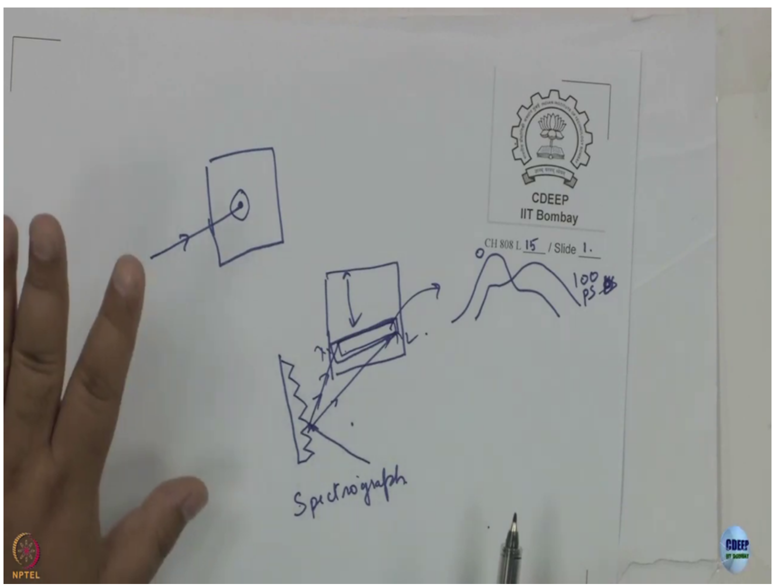

Now see, let us say this is my ICCD and I couple it with A, I put a greeting in front of it. So typically what you would use here is a spectrograph. A spectrograph is sort of like a monochromator with an input straight but without an output slate. So light falls on it let us say this is a mission from something. So it gets it gets broken down into different wavelengths, this is lambda 1, this is lambda 2.

So now if you look at the images in each slice, what you could do is you can get the spectrum. So from here in your computer you can easily get the spectrum. Now suppose this is the spectrum that you get for 0 time to get the spectrum after say, 100 picosecond, and let us it looks something like this handwriting is getting worse every year. So what am I doing here? I am getting the time resolved emission spectrum directly. That is one advantage of using something like this, of course, even here, we are really using only one part of the 2d detector.

I am not using this most of the 2d vector is actually wasted if I work in this mode, but I have at least shown you the advantage is not 0 at least from the discussion that we had earlier. What do we generally use to use for our measure, we use a point detector. So if you do not even have a spectrograph, then what we are saying is the entire lights, this is your ICCD or CCD, the light goes and falls on 1 point. And he just said that you are things like 4000 by 4000 pixels.

Out of this 4000 how much of that 16 into 10 to the power of 6. Out of this 16 into 10 to the power 6 you are using maybe 10 every exactly 1 pixel. So at least this is better. We are using 1 horizontal row of the detector. And that is where we can get time resolved emission spectra using gated ICCDc and what I am telling you is that now you can get, it is not really as good as this TCSPC time resolution is not so much but 20picosecond, 30picosecond interval,20 picosecond gate time,that is now doable.

And the good thing is the speed the entire spectrum gets captured at one shot right, but then still see we are as you said, already, we are wasting almost all of this CCD. We are not using most of the pixel is this some way of using those pixels? Let us see.