Laser: Fundamentals and Applications

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Lecture - 33
Application of LASER: LIDAR

Hello and welcome back, we have been talking about the Applications of Lasers, and for last few days, we were discussing about one of the finest applications of laser technology in the field of non-linear optics.

So, we had some brief discussion about that now next we will move on to other types of applications that actually, the invent of laser has pioneered and we will be talking about one such field, which not only helped to advance the fundamental knowledge in the field of science you know physics, chemistry, biology and you know atmospheric science, environmental science, you know in various different sections, but also you know it has enabled us to develops several, you know sensing or detection I mean devices based on which can provide you know since seeing and detection of several analyte of interest, so we are going to talk about spectroscopy and specifically we are going to talk about laser spectroscopy.

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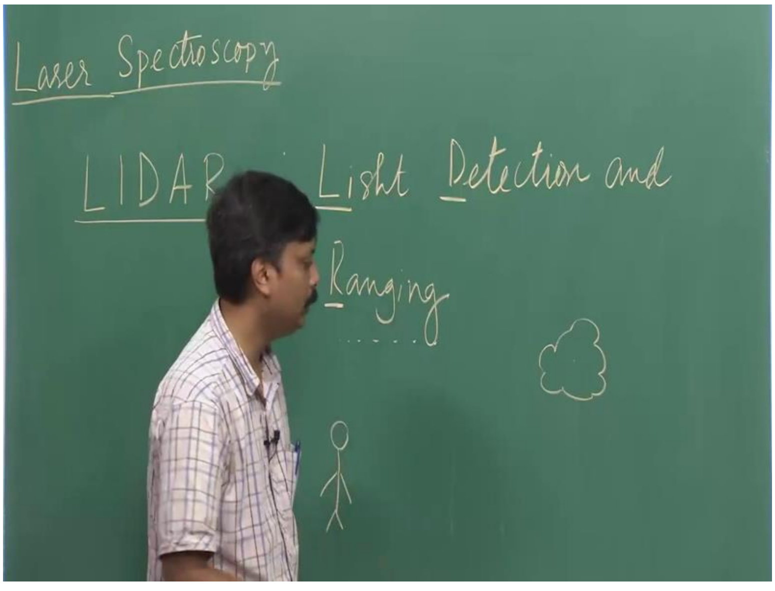

So, in the field of spectroscopy wherever, the laser is used we will call it as a laser spectroscopy, now what is spectroscopy first, spectroscopy is essentially the study of the wavelength or frequency dependence of optical responses from any substance, which gains or releases energy when it interacts with light.

So, you know light matter interaction can give rise to some detectable signal, which falls in the regime of spectroscopy. And as I said this spectroscopy not only helps us to understand, you know several aspect of you know light matter interaction or for that matter you know structure, property of material for fundamental interest, but also it can provide us a way to device tools for practical purposes.

So, what are the different you know applications that we can think of using spectroscopy and mainly driven by the laser. So, we will start with one such in technique, which is known as LIDAR. So, what is the full form of LIDAR, this is light detection and ranging. So, this is how this term LIDAR is so, what is the purpose of this technology LIDAR, the main purpose of having this particular technology is to measure the distance at which one particular analyte is present and also why what amount.

So, that is why this term ranging is there. So, this you know gives you an idea like how far is my analyte present from me. So, suppose some observe is you know standing here and for away in the cloud, there are certain analytes present and you would like to know and you can see that you know this can be really, really at for distance it can be you know few kilometers to 10s of kilometers away from you and you would like to know suppose, what is the amount of sulphur dioxide in that particular cloud, or in that particular region of interest.

So, there you use this particular technique LIDAR. So, how it actually works, so let us talk about that one a little bit, so this technology it works.

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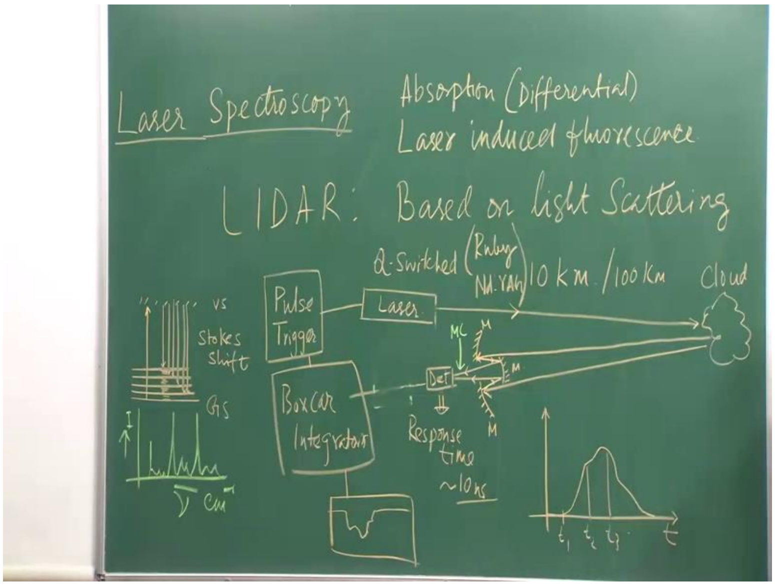

Primarily based on light scattering, but is does not mean that there are no other techniques or which can provide you the LIDAR based detection capabilities, it can be other things like you know florescence, it can be Raman scattering, it can be absorption, various other things are possible.

But it started with you know detecting the scattering of light from your analyte. So, first let us have a look at the so, let it with here, so first let us look at the way the experiment is done. So, we will talk about the experimental setup. So, before going to the experimental setup, you can you know ask this question that why do I need laser to do this one? Why cannot I use conventional light source. So, the answer we will come if you look at the experimental arrangement immediately. So, first as light source you use a laser, and then what about the analyte is there suppose it is end at say again cloud suppose, this is cloud and I am looking for a particular type of molecule there or a particular type of airs all there ok.

So, whatever we may analyte is there and I have selected my wavelength accordingly and after the scattering, what will happen it will scatter back, fine now if I can use a telescopic set up, because it is coming from a very far distance. So, I mentioned particularly is cloud and if you are standing on the earth surface and measuring string to measure something in the cloud you are at a for differed distance and then if you want to detect light you have to have a telescopic arrangement right.

So, if you so, these are mirrors, particularly curve mirrors and this is your detector. So, this particular arrangement is a telescopic arrangement. So, instead of using a lens we are using curve mirror. So, that can do the same functionality as it can do the same function as that of the lenses.

So, what I am doing, I am in allowing the laser light to go and interact with some material at a far distance, and then the scattered light from that light matter interaction is now detected by a telescope and 10 centi to detector for generating signal. Now you see if suppose this distance is 10 kilometer, I am giving you an arbitrary number, suppose this distance is 10 kilometer or say 100 kilometer, and if you use a conventional light source will the light reach there.

The answer is no because it is, so divergent and the intensity of the conventional light sources. So, low that before even reaching there it will be lost. So, you need some light which is highly intense and which has a very high directionality, high collimation and laser provides you with all those properties and that is why you use a laser instead of commercial light source in the LIDAR technique ok.

So, now so this is how the you know detection will be done, but how will it give me actually my information that I need, that is the distance and the amount of my analyte present, there and if I can I would need the you know concentration of that analyte as a function of distance also at in a different, different distances how they are distributed in terms of their concentration. So, for that what I need to do I first I need to synchronize my laser and my detector.

So, what is done here, you use the pulse trigger technique to couple the laser and also the detector through an integrator, which is known as boxcar integrator, we are not going to into the details of these parts . So, the you know signal coming from the detector is fade into the boxcar and this boxcar and the laser both are synchronized by this pulse triggered unit ok.

So; that means, I have an way to know that after how long, I detect a signal after you know what time after the laser light is coming out from this box I detect my signal. So, I can exactly I have an idea about the time of travel for the light from here to back here. So, if I know the time then, I can have also information about the distance, because I am dealing with the particular wavelength of light and I know the light frequency in a certain medium.

So, thereby I can easily figure out the distance at which my analyte is present. So, once you know this detection is done then my recorder will give me some signal. So, the signal will be a drop of the intensity, so I will see something like this as a function of time. So, essentially if I can use this signal properly, what I will get? I will get as a function of time some signal. So, I drew it in a positive way that hardly matters. So, this time is the time gap between the laser emission and this detection.

So, if I see that, this much amount of signal I am getting for say time t 1, this much at time t 2, this much at t 3 and so on. What do I have, I can find out the corresponding distance and then I can find out that how much light is collected at that particular time and; that means, it is coming due to the scattering. So, how many of that particular analyte is there that is also possible to calculate. So, I get both of the information fine, now at this point I should also know that this is a fantastic thing, but what is the limitation ok.

So, the limitation is hidden here at this point so, this detector is the source of the limitation, so every detector has a particular response time. So, it takes certain amount of time to you know give you the signal and if suppose this response time of this detector sometime it is also called rise time, if suppose it is like say 10 nanosecond. So, what does it mean; that means, that I will have an error in my time measurement by this much amount of time roughly.

So, I also know that how much is the distance that light travels in that particular time. So, thereby I can calculate the error in the distance that I am measuring. So, suppose this distance is like say 10 kilometers or 50 kilometers or you know 100 meters, whatever that is I will have an error corresponding to this time ok.

So; that means, a distance of few meters. So, if I use a detector which is having a response time of few nanoseconds that will always limit my detection or say I should say that will have an error in measurement by few a meters. Now you imagine if I am trying to deal with something like at that distance of 100 kilo meters few meter is nothing.

So, in that way this ranging technique is you know really amazing and this has revolutionized you know environmental science and you know different aspects of chemistry and also physics, where you know people and also you know like other areas of sciences where people want to know about a particular analyte which is important to us I will give you examples immediately.

Say for example, I want to know how much is the amount of ozone in upper atmosphere and how this ozone is distributed as a function of distance from the ground level, why do we need that first place say for example, ozone is very, very crucial for you know our life how, because there is a ozone layer in the stratosphere which blocks all the u v light which are harmful for us from entering right.

So, sunlight has u v light also and the ozone actually blocks those u v lights from entering the atmosphere. So, we are safe now because of several reasons, ozone layer is getting depilated because of the emission of the factories and you know there are use of certain molecules, which produces radial which drastically destroys the ozone layer and that creates trouble for the human life.

So, we need to know at different parts of the atmosphere around the globe, how the ozone is distributed in the atmosphere, you can use this LIDAR technique and actually that is used regularly to monitor the you know health condition of the upper stratosphere levels, where ozone is there, and you can figure out that how much ozone is you know there, is there any region where there is a high depletion of ozone in the stratosphere and if you know that by using this LIDAR technique, then you also know that in through that reason how much u v light is entering ok.

And how harmful that is for us, so you can see that this one particular technique which has been you know really, you know coming to the existence due to the you know invention of laser has been helping the mankind in so many different ways. If I give you another example, you know there are several volcanoes active or passive around the world, now you do not know when a volcano is going to erupt right, it is unpredictable, but using this technique people are trying to develop a quite a bit of you know predictive understanding of you know the volcanic eruption.

How because this volcanoes they when they erupt they release, lot of gases say for examples sulphur dioxide, lot of sulphur contents are there, now at the beginning of this volcanic eruption there is a particular concentration and then after volcanic eruption there is a different concentrations. So, if a volcanic eruption is monitored using LIDAR by monitoring the particular constituency for example, sulphur containing gases say sulphur dioxide, then you can have a kind of you know calibration will, which will help you in developing some kind of you know a predictive understanding of this volcanic eruption.

So, if you know station one LIDAR base system, for a particular volcanic region and you continuously monitor the you know sulphur dioxide concentration, you will get an ideal when suppose the you know concentration of sulphur dioxide you know certainly changes that there might be a possibility of a volcanic eruption soon third example, I will give you like you know it is very much related to the you know ozone layer depletion say for example, we have several factories which has there you know chimney outlets and this chimney they you know releases a lot of different molecules in the atmosphere.

So, by using LIDAR you can monitor this gases and you know particularly the static gases from a far, far distance without being you know noticed by you know people involved in that particular industrial zone. Let how many, how much of these gases are you know being release there, which are harmful for the atmosphere.

So, by now we have you know more or less you know said you know how, what is LIDAR? How it is applied? Now few more detail about this things, so I said like normally what kind of laser is used it is a pulsed lasers are used, and what kind of pulse lasers you used mostly Q switched pulse lasers are used for so Q switched lasers are used. So, normally for this scattering based LIDARs you use ruby has been applied quite a lot Nd YAG you know is used quit regularly.

Now, there also other lasers also which are used in the LIDAR applications and as I was mentioning at the beginning that though I say it is based on scattering predominately, but there are other ways to do that, one of such ways is florescence based technique essentially laser induced florescent. So, other than this light scattering one can use laser induced fluorescence.

So, so you can understand from the name itself that this is the laser light which is triggering the florescence from any particularly analyte, now florescence is presented by absorption and this absorption, we will take it to particular state and from there it will emit, now from this scheme you can understand that the light which comes out from this particular analyte it should come you know quite fast.

So, that is why scattering is so you know popular because scattering happens instantaneously. So, there is no time lag and I know that this is limited by the detector response and also from the you know by the laser pulse with. So, Q switched Nd YAG lasers they are in the order of say a few nanosecond, 10 nanosecond say roughly. So, I must you know take care of few things, if I want to use the laser induced florescence as my probe in the LIDAR technique.

What are those that I should not have a you know excitation two states which are really long lived? So, the excitation must take the molecules that is my analyte to a very short lives you know states from there it will emit within few nanoseconds. So, they should have nanosecond life time so this is the limitation of this laser induced florescence, but they can be you know they are used in several particular cases, and for specific molecules which are very good in showing laser induced florescence they are monitor by LIDAR based on LIF or laser induced florescence.

Third what we can do, we can use absorption as our probe. So, third is absorption and specifically we use differential absorption, what is that? So, so far whatever I talked about in LIDAR technique based on scattering you can pretty much use any wavelength of light at least I mean the light wavelength should be such that you know the scattering cross section is not too low, when I go for absorption base technique then I must be having a way to tune my laser wavelength.

So, that it over laps with a absorption spectrum of the analyte. So, essentially what it is done instead of one laser wavelength two laser wavelengths are you used, one wavelength just provides you the information based on scattering and the other wavelength gives you the absorption. So, what happens in that case, the you know the scattering wavelength will give you a signal like this and absorption wavelength it will suffer absorption by the analyte, so there by the scattering intensity will drop.

So, from these two different wavelengths I can easily figure out, what is the you know concentration of a particular analyte at a particular region in a much better way fine. So, apart from these three there are also other techniques like Raman spectroscopy. So, many of you probably know what Raman scattering is, but in case you do not know I will very briefly I will talk about that one. So, if you molecule is in the ground state and if you bring in a very high power light that is with high electric field, it will force the molecule to take that field and go somewhere there may not be any real state.

So, we write it as a virtual state and from there, it will scatter back and it the molecule molecular ground state which is an electronic state to start with they will have different vibrational levels. So, this is a very simply drawn the vibrational levels that I am drawing looks like they are equi space, but actually they are not.

So, this is just the simple drawing for your understanding and within the vibrational state you will have several rotational states correct. So, this molecule which is excited to this virtual state can come down to different vibrational and rotational level. So, I will get stokes shift, so I will get stokes shift in my scattering signal and this is a Raman scattering, I can also have entire stokes, which will give you more energy than your initial photon energy we are not going to talk about that one.

So, now these photons which are coming back to different, different vibrational and rotational line states, if I plot them as a function of the you know frequency or wavelength I will get a spectra which is known as Raman spectrum. So, this is Raman spectrum is a kind of fingerprinting technique. So, if I can detect the Raman spectrum coming from one particular analyte there I can unequivocally tell that that is my analyte right.

So, for that what I need to do, I need to have a you know device which will allow me to separate the you know signal intensities at different, different frequencies or wavelength. So, what I will need, I will need a monochromator here between the detector and the boxcar integrator. So, in this case I will need monochromator, so which is essentially based on sorry, I put it in a wrong place, so this monochromator should be write here ok.

So, here should be the monochromator which has a grating and that will disperse different wavelengths and I will exactly know, what is my you know spectra of the molecule. So, this is essentially expressed in wave number and this is the intensity, so this is my Raman spectrum. So, from this Raman spectrum I can say which molecule is present. So, this is a fingerprint technique and I can use this in my LIDAR system.

So, there are certain advantages of using Raman spectroscopy in LIDAR, what is that not only I can unequally say, which particular analysis is present, but also several other things I will give you one example, if I want to know about the temperature of say certain gases at a particular region say in the atmosphere upper atmosphere anywhere, say in above volcano, I can do that if I can do an analysis of the rotational Raman line intensities ok.

So, by doing rotation line you know analysis of rotational Raman, so I said like you know there vibrational, rotational, states there within electronic state. So, I can have vibrational Raman, I can have rotational Raman, altogether I can have row vibrational Raman spectra and from the rotational line intensities, I can also get an idea of the temperature of the analyte that is the analyte is at a particular you know environment which has particular temperature and the you know molecule will be in that particular temperature, but.

So, if I know the temperature of that particular molecule, I can get an idea about the temperature in that region. So, this is you know wonderful you know application of laser based technique LIDAR by which I can you know not only find out the presence of an analyte at a very far distance, I can detect it, I can detect it with a very high sensitivity I can go to like p p m p p b even p p t level, without requiring to be present at the place of that analyte, but we one can be at very far distance or as far as you know 100 kilometers, and we can find out what is the amount of that particular analyte there not only the presents and we can also find out about the environment of that analyte such as the temperatures surrounding region.

So, we will come back in the next class with lot more applications of laser spectroscopies.

Thank you very much.