Optical Spectroscopy and Microscopy : Fundamentals of Optical Measurements and Instrumentation

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Lecture - 40

Hello and welcome to the lecture series on the Spectroscopy and Microscopy. We were actually looking at the practical aspects of the beam size of the laser that is I mean or the output from the laser and then how do we alter that using a telescope and so forth. I had told you that we will talk about some practical issues that might arise when we actually try to do this in a lab.

And we will then go after that we will go into the lab setting and then show that actually you can set up this system nicely in the lab. So the first aspect that the what are the practical issues and then how do we go about doing this, that is what we will be covering in the next half an hour or so. And the first of the issues that you would face is that, let us say I have a laser, alright.

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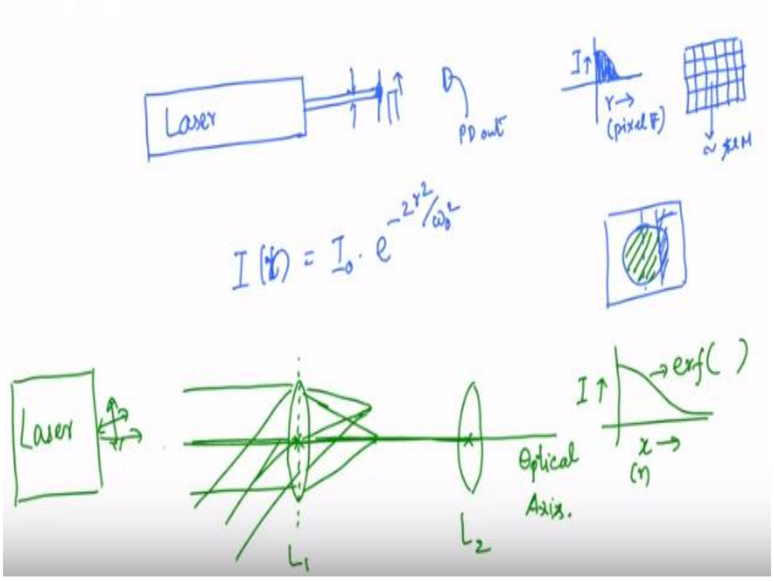

So we would be able to show that there is a laser. And now the light beam would be coming out from here. And the first thing you want to know is that actually how wide is this light beam, okay? So only when you know how wide is this light beam, then you would be able to say how big you want or how small you want to get what to get the focus aperture or a focused spot size of a defined or your of your wish.

So how do we measure it? One of the simplest and the straight way is to actually place a paper and trace it or in the modern day what you can actually you can put in a imaging sensor and then measure it. But when you do that, what you would see is a distribution that is of the signal coming from the imaging sensor as a function of spatial distance. Basically, r here in an imaging sensor would be the pixel number, okay?

So and then the intensity of the signal that you are actually measuring. But one of the problems with this is that the, if you look into the imaging sensor, which we would do in a great detail later in the course, but then for time being, if you look into the imaging sensor, the imaging sensor is divided into multiple small detection elements, each of them having a finite size.

So typically these range these are of the order of few 4 to 5 microns, I mean one I mean this typically of the order of a micron. So now, often when we are actually trying to measure this beam you are actually and then using this pixels if you are actually measuring this the limit I mean with which you can I mean the beam size that you can actually you would see probably very coarse sampling, okay.

So the beam sizes that we are actually dealing with is are themselves are millimeters or less than are hundreds of microns. So the sampling tends to be coarse. It is useful, quick, but then the sampling can be coarse and if you want to increase its density, one way of doing that and also at the same time, have a better estimate of or on a average. One way of doing that is to take in a sharp edge and then run it across while you are actually measuring the integrated intensity of the light okay.

So this is the photodiode out. So you can actually measure this and when you do that what you are actually doing is that we have the, I of t written as I of r written as I 0 e to the power minus r square by omega naught square 2 r square by omega naught square. So what we end up doing in such kind of measurement is to say that you have a beam that is distributed in a Gaussian manner.

So we are blocking out a chunk of this and then moving it across and integrating this entire remaining portion, right. So I should, we are blocking out that region and then integrating this entire region the remaining portion, right. So when you do that what you see is that you get a profile that is a mark of an error function. From this error function you can estimate what the width of the beam is.

Now that is one way of doing that. In fact, what we will do is that we will try to do this both doing the error function and also using the, these pixels. The advantage of doing one over the other is this error function estimate by running the razor blade across the beam has the advantage of the movement and then the that you are creating here right is the x dimension or the r actually measuring and then this is the integrated intensity that you are measuring here.

So this is very uniformly sampled because you are you will be using a small micrometer razor blade mounted on a micrometer and moving it across. So when you do that and then measure the intensity you are sampling it uniform. However, when you are actually putting it through an image sensor, you want to have these pixels being very uniform in size and its sensitivity.

And any variation, surface variations are across the field variation. So as they are called, can look can be seen as a variation in the beam profile itself. So now, that can be an advantage as well as a disadvantage. The advantage is that if you actually calibrate the image sensor really well in sense of the variations are accounted for in terms of the size as well as the, I mean uniformity of detection.

Then you have a much better much more information when you are actually taking the surface when you are imaging using an imaging sensor. But given that, that can be harder and then the sizes are limit, then in this case what you have is that you are moving uniformly because the micrometer can be nicely, much more easily calibrated and can be nicely moved in a uniform manner.

And then you get to get this data and as an integral of the rest of the intensity. So it while the amount of light that you get is more it also covers up I mean it also does not let you measure the variations in the profile itself, the intensity variations and inside the profile itself. So both of them have their advantages.

We will use both and then see how we can actually cross calibrate each I mean, we can measure the size of the beam. So that is for measuring the size of the beam. Second is to be able to send the light through the lens itself. So now we know if we take a lens, for you to be able to see a focused beam of light emerging out from the light, you would see that the light need to be sent in a or the lens need to be placed in a plane perpendicular to the incoming wavefront, right.

If you place it at an angle, then the light beam will not at the I mean if you are to keep it like this, and then the light beam would be focusing at some point somewhere here versus the light beam that need to be somewhere here. So the second, so the idea here is to change the width of the beam right using a telescope. That is what we are going to demonstrate.

So now, if you there is nothing wrong if you send it at an angle, provided these lenses are thin lenses, they do not introduce any aberrations any big aberrations for this angle rays. So leaving aside those problems now having a focus here or here shifted between these two points is not of a big issue if nothing happens after this, alright. You can always move your sample to the focus and then get the measurement.

However, if you have to put another lens and that leads to quite a few issues. So the best and the point is to be able to send this beam such that they are not only normal to the lens surface, but also passing through the center of the lens, which means we are talking about matching the propagation axis of this laser beam to a defined geometric line in the laboratory frame. So what defines the geometric line?

And so here we are talking about a tool and system forming a telescope. So lens 1 and lens 1. So if you have tool and system, you have a center of this lens and center of this lens, a line passing through that I mean two points. And then if you have two points, you can connect them and then make a line that defines a line. And then this line, the line that is passing through these two centers defines a geometric line in laboratory frame.

We call that as optical axis. Often in a laser or an optics lab, the thing that you most work on is what is called us aligning the beam. What it means is making sure that the beam's propagation axis that is the axis about which the beam is moving matches to that of the optical axis, okay. When that happens, you say that the beam is aligned. Now how do you do that? The way you do that is let us again take a laser beam.

Now if you were to be able to have a laser and at will be able to move it in x, y and z what you can actually do is you can actually place them at the center of this lens and then keep adjusting it to make sure that the light that is coming out from the laser matches to the optical axis. Often the lasers that we are talking about right the mode locked lasers, femtosecond lasers or acoustic lasers, they are quite big and hefty and it is not easy to actually move around like that.

And often it is also that the amount of light that is generated is often quite large and you typically would like to use it over or split the beam and use it over many different experiments. In such a case, then you need to have an independent way of sending the beam through a defined optical axis in a geometric line laboratory frame. So you do that by using a set of optomechanical hardware called as Mirrors and Kinematic mounts.

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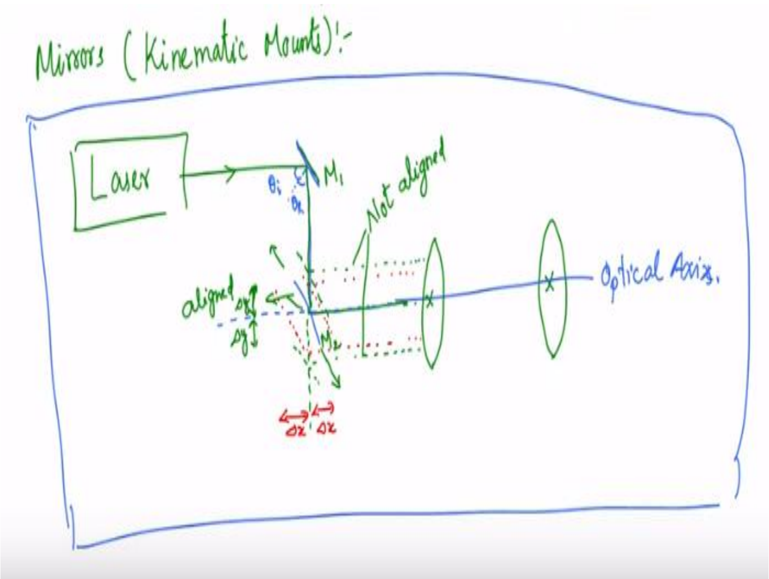

We will see each of this part during the practical aspect of the course. But the theory here is that when you have a laser sending out the light beam, so the beam coming out here defines the axis and this is our propagation axis. So and then of course, we want to match our optical axis here, right. So the way you do that is using a set of two mirrors. Now if you closely look at it and the beam, we will see, the beam falling on this mirror, okay the beam falling on this mirror is going to get reflected.

And the way it is going to get reflected is given by the angle between the beams incoming axis and mirrors normal, right. It is the angle of incidence, we will call it as theta i. And if you place it at 45 degree for example, it is going to reflect the beam such that the angle between the incoming and outgoing beam is 90 degree because it is theta i equals theta r.

And similarly, if you have if you place a beam, if you place a mirror, another mirror now depending on where you place this mirror this light, okay this light ray can so let us take three different positions for this mirror and three different colors to actually represent possible direction. So the first one let be the correct position.

What we ideally would like to do it is to place it in a point where the propagation axis of the light defined by this mirror M 1 and the optical axis when it is extrapolated meet, okay. You want to keep, you want the mirror to be placed right at this point in space okay. So imagine this is the huge this whole whiteboard is our laboratory frame and we are looking from having a bird's eye view like looking from the top.

And what you want to do is that you want to be able to place this mirror at the point where the incoming beam and optical axis, right. Optical axis here is defined by our two lenses choice of two lenses, right. So the center points of this two lenses, now these two meet. If you place anywhere else, what is going to happen? Then we have two degrees of freedom, right? One is actually placing it along this axis at different points.

As you can see, when you place it at different points, it is going to actually hit this lens at different place, not at the center, okay. So these two are not aligned position and this is the blue I mean, this is the aligned position, right. Okay. I mean, this is aligned beam and then these two are this is the aligned beam, alright. These two are not aligned beam. So now you can do this or you can also move this.

You can place this mirror off from its axis. So again here if it is an infinite mirror then you as long as you move it, so if you have to keep it along, as long as you move it in this direction, there is no problem. However, if we were to move it such that if you had to place it such that now, instead of it is off placed along this axis that is more towards the M 1 or more towards the M 2 or the other end of the mirror.

So I am going to I am sorry. So I am going to label this mirror as M 2, okay. So now and I can, I could have placed this second mirror, just the way I displaced it on top and bottom, I could place it either completely off here or here. Now again, you can see as long as my angle is the same, I am moving it parallel.

So what it is going to do is that any of this, off place off placed mirrors would make the beam go not in my intended axis, not along the axis though it may go on along the intended direction, but it may not go to the point or the go along the axis that I am actually wanting to do. But what you can actually do is as soon as you see it, okay you can also there is also another degree of motion right?

So I have fixed this theta i and theta r and similarly here the angle at which the mirror is rotated. We have not analyzed what is going to happen to them, right? We actually fix them fixated on that and we just moved this mirror in delta x in this direction or plus minus delta x or plus minus delta y and then said what it means to say that it is off aligned or not aligned. So similarly, we can do the analysis for the angle, okay.

So when we do the angle, so we can do the similar analysis for the angle. So I am going to copy this so that I do not have to.

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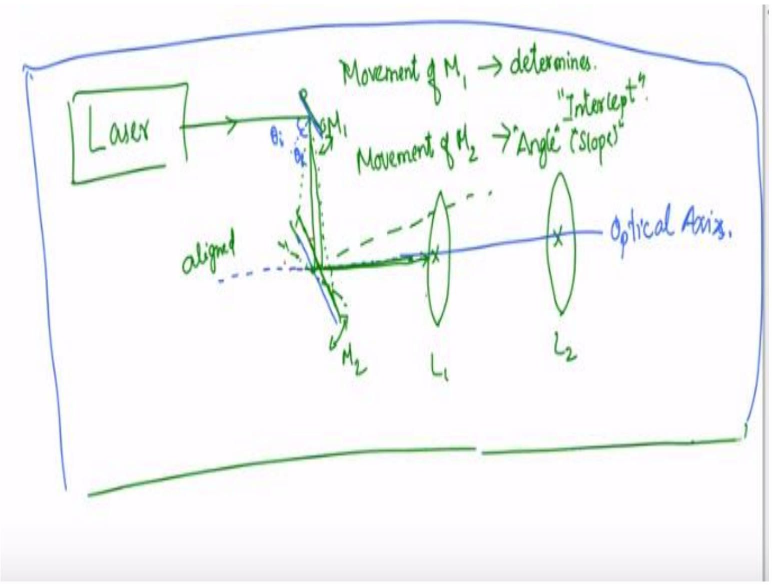

So we looked at the displacement, I mean if it is off placed in delta x or in the y direction, but we can also think of the incoming angle, alright? For the time being, let us restrict the motion on the M 1. But then we can think of the rotation of this M 2 itself. Now M 2 were not to be placed at 45 degree, right? We expect it to be at 90 degree and so that the beam that is going out, is hitting this point as well as that point.

If it is not at 45 degrees the beam is not going to be at 90 degree with respect to the incoming beam. As a result, let us say let us introduce a small angle here, right. When you do that, the beam that is coming out from here is going to go and miss this lens. Of course, a combination of this angle and a displacement with that you may be able to get the beam to go through this point.

But you will never be able to get the beam to go through this point as well as this for anything other than this placement of the mirror at this point at that angle of 45 degree for an incoming beam that is fixated here, okay. So this is one and the only position and the idea of alignment is to be able to achieve this. And it is very simple and very easy. What we do is that we place this mirror and then we as I was explaining to you, there are two degrees of freedom, right?

One is the rotation and the second is the placement. Now this place this the so both of them could be done in a iterative fashion by moving, I mean by fixating both these mirrors, okay. And then we can move this mirror, I mean we can rotate this mirror, okay? The idea here is that if you when anything that you want to do in iterative fashion you need to be able to go back and forward back and forth with the same good degree of accuracy.

And that is what is being provided to you by kinematic motions of this mirror mounts. So you can actually move back and forth. And so which means these movement of the mirror that we displacement movement, which we talked about, we would like to actually change it into a back and forth movement of a mirror mount. So that is why what you can actually do is that you can actually place this mirror in a kinematic mount.

And when you rotate this mirror, what you are actually doing is you are spawning this beam and space okay. Now what it does is that it allows you a way of, so this when it does when you have this it allows you a degree of freedom in, it takes away the criticality of having to locate that point in the beam provided you have a large size mirror right.

So because what it allows you to do is that if you had to say ultimately you have to reach this point, no doubt about it. You need to have a mirror to reach there. But then what you can actually do is that if the beam were to be coming in like this, then you would be able to keep a mirror let us say at a slightly displaced position.

So now, when you have that instead of hitting at the middle of this mirror and what you will, what this movement will allow you to do is that be able to let you hit at a slightly a position that is slightly below or in this case actually, yeah slightly lower than the center of the mirror. So you are going to take route like this. Now since this is incoming beam is a triangle, this cannot be at a 45.

So you have to the, it would have gone like this. So now you need to rotate this mirror to bring it back. So that kind of degree so basically what you have done is you have changed, you have made this movement here right, movement of M 1 determines where the optical axis and the incoming beam meets, right. We can call that as intercept of your outgoing beam and you can alter that using the movement of M 1.

While the slope or the angle at which the outgoing beam goes is altered by movement of M 2, okay or the slope. Since you have both the, I mean independent way of because you are not using the same mirror to adjust both the things. You have a independent way of altering M 1 and M 2, thereby you have an independent way of altering intercept and the slope, thereby you can actually define a straight line in space using two mirrors, alright.

But this is in one of the planes. Now you have a horizontal plane as well as a vertical plane. So you will have in the mounts that we see two adjustments one to adjust this movement or this angle in a horizontal plane, the other one is to adjust this angle in a vertical plane so that you can actually send the beam. So this is what we have talked about all is in a horizontal plane which is a plane that is parallel running parallel to the whiteboard right.

So that we are remember we are looking from the top with the bird's eye view. But you can actually think of similar argument when you are looking from the side, side-on view and then there is a plane and there also you need to make sure that the beam is centered onto the lens and so that you can think of as a vertical plane. So in a laboratory demonstration, what we will see is that how do we actually achieve this using these two mirrors, how do we place them?

How do we what feedback are we going to look at to tell that is the mirror I mean this mirror, I mean M 1 need to be adjusted or M 2 need to be adjusted and is the adjustment over, alright. So we will do that and then change the size of the beam and we will visually see that the size of the beam is changed and then of course, practically I mean quantitatively measure how the size has changed before and after the two lengths arrangement L 1 and L 2.

And from that we will be able to show a small optical setup, this whole arrangement we call it as an optical setup and the hardware associated with it and the tricks or the small experimental hands-on details of how do we actually get this whole telescope going. I hope to do that in the next lecture.