Soft Nano Technology
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Lecture – 27
Atomic Force Microscope – 4

Welcome back, we were discussing certain operational aspects of the AFM. In fact, it is not even the exact operational aspect of the AFM it is how to get your instrument ready and it involves pretty interesting physics. So, that is exactly what we were talking.

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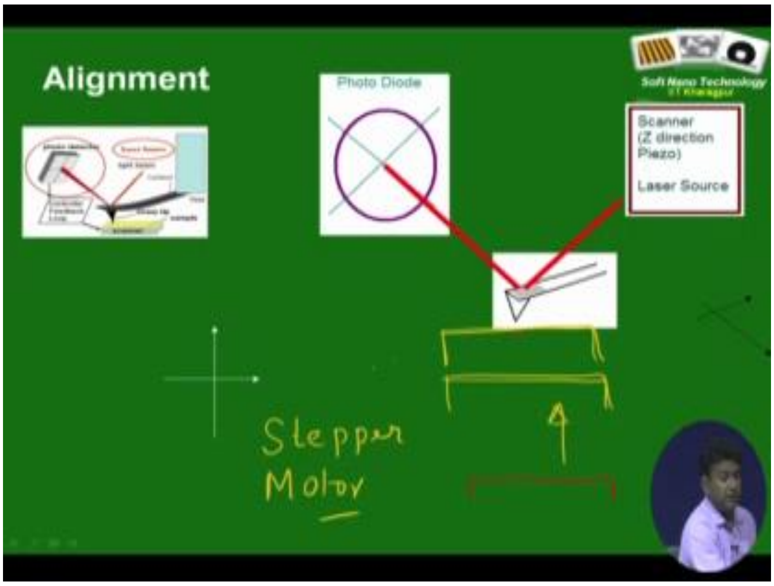

So, now this slide I will quickly recap, I hope this slide should make sense to all of you should be able to identify all the components cantilever with it is reflective coating, these are this arrows represent the screws. So, you rotate the screws. So, to bring the cantilever in the path of the laser lights, that is coming from the laser source, as a consequence of this the laser lights starts to reflects out from here, what you now do is you again turn the two screws and so you bring your photo diode move in such a way, that the reflected laser light in fact false at the center of the photo diode and the reading on the photo diode is 0 volt.

Now, I will just super impose the sample in this particular picture. So, you are sample is far away over here. So this process of optically coupling these 3 is known as the alignment and what is the next? Next is that you would like to bring in your samples in close proximity with the cantilever and that process what you do? You would use a stepper motor. Hardware wise you can either push up the sample or you can bring down the whole assembly both variants are available and you would like to bring it in close proximity to the tip so that the tip can start rastering or scanning and well there are issues like how long do you bring it, where do you stop this approach process etcetera.

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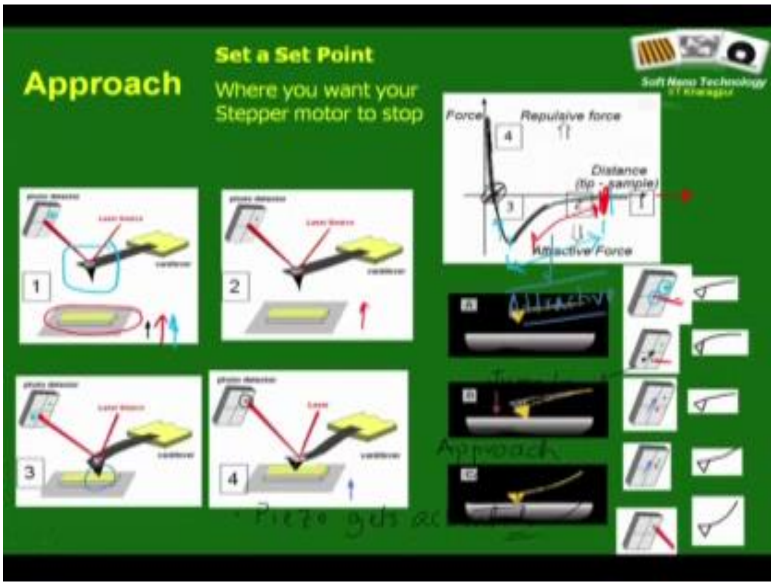

So, let us see what is done. This is what happens first let us say that sample holder is bring in there is a stepper motor is acting here and it is bringing the sample holder close to the tip. Initially the tip is far away from the sampler and there is absolutely no interactions on this curve you are somewhere over here there is no interaction. Please do not forget that you have chosen a cantilever material which is malleable enough or soft enough to deform to the magnitude of Van Der Waals sources that is extremely important.

You are bringing it up see between these 2 images the separation distances is reduce, but still you are far away and therefore, there is no interaction, but here as you go closer, you cross this separation distance and then over this area the tip and the surface starts to interact, but as it starts to interact what is the nature of the interaction? In fact, the nature of the interaction is attractive right. So, what happens is that and as a consequence of the presence of the surface. Now the cantilever feels an attraction.

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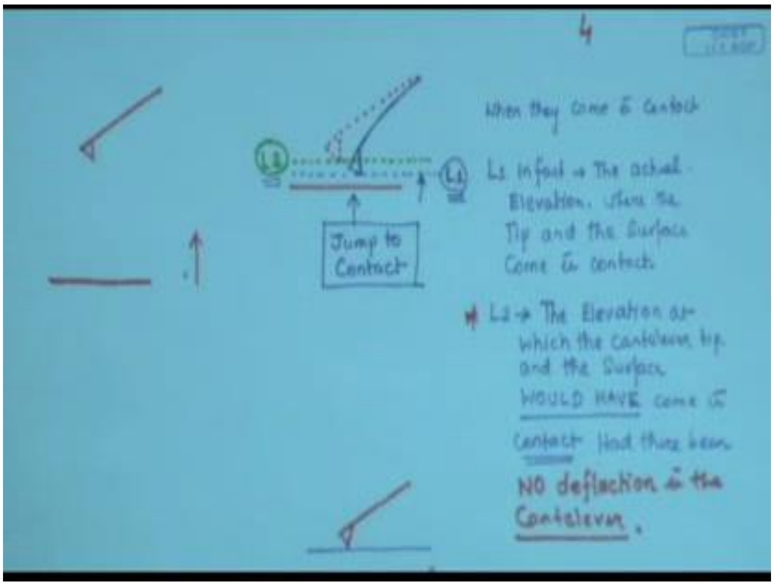

So, this was the cantilever, surface was far away, let us say the surface is moving up and now the surface is close enough to the cantilever. So, ideally this was the initial configuration of the cantilever, but what happens is because of this attraction in the surface attraction, the cantilever now feels the attraction and bends like this because your cantilever material is such that it deforms to the magnitude of Van Der Waals forces.

So, you are essentially somewhere in this region of the force curve right. Now what happens this is not the point where you would like to stop. So, the tip is still moving up the surface still moving up and these two eventually come in contact, but there is something interesting about when they come in contact. See I have drawn a dotted blue line here which I mark as line in L1 and for figuring a discussing I am drawing another green line which I am marking as L2. What is the difference between these two lines? L1 is in fact the actual elevation or where the tip and the surface come in contact.

Now, what is L2? L2 is also interesting, it is like that is the plane or line at which the cantilever and the line, the sub straight, would have come in contact had it is the elevation at which the cantilever tip and the surface would have this is extremely important to understand would have come in contact, but when had there been no deflection in the cantilever; please follow this. This is not a very important thing that you need to understand for understanding an AFM image or for doing your research, but this is very interesting science I really appreciate.

So, what is a line L2? There been a hypothetical situation, that you have taken a tip, that is 2 stiff to Van Der Waals sources or you think of a hypothetical situation again that there is no Van Der Waals force no attractive or repulsive force between the tip and the surface. Then what would have happened? You are moving your sample surface up, the tip remains unfaced, it does not care what is happening and it waits till the last moments when the sample comes in contact.

Anyway it will come into contact because you are physically moving the sample, but this is like as you are moving the sample up, as the separation distance between the tip and the sample reduces and you sort of enter this regime, what happens is since the tip is flexible enough to the forces or malleable enough to the forces of the magnitude of Van Der Waals sources, you have chosen your tip like that for making a successful AFM the tip bends like this. Bends like this because it experiences the attraction imparted or not the tip cantilever bends like this as it experiences the attraction imparted due to the presence or proximal presence of the subtract and therefore they come in contact at an elevation L1 and if that is ahead of L2. So, contact is established between the tip and the sample surface ahead, then what would have been the contact point had there been no interaction right. I hope you have got the idea clearly.

So, these 2 come in contact at the elevation L1 which is before the point L2, where the two would have been come in contact had there been no attractive interaction and this is what is called this phenomena is what is called Jump to Contact right and this is what you see here right, this is jump to contact. So, this is the deflection that is observed in the cantilever, but please do not forget in the previous step during alignment you have optically coupled the laser source, the cantilever and the reflected light was falling at the center of the QPD.

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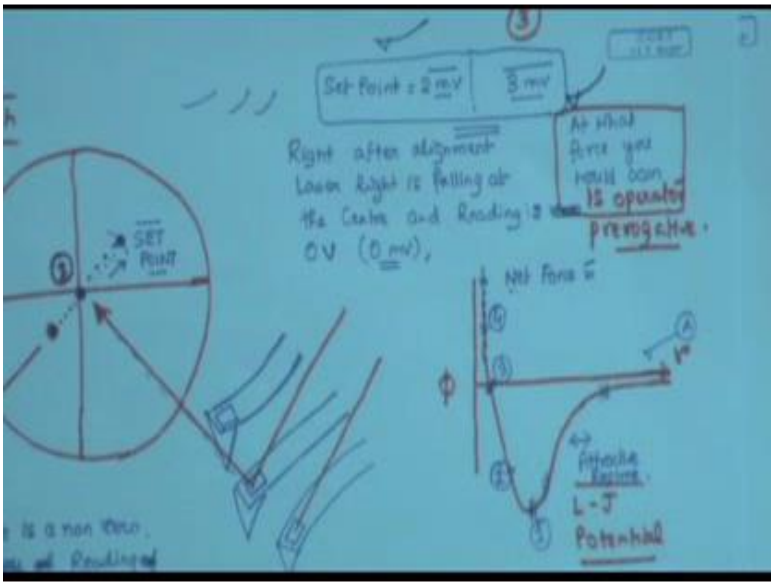

So, now what you are telling? What we are observing that because the surfaces approached the cantilever, which was initially like this has now become like this. It has sort of bend I would not say it has deformed, but it has bend. Earlier laser was falling here and getting deflected in this direction. Now also laser source is the same it falls here, but since it has deflected now laser goes in another direction. So, there is a change in direction and what is going to be the consequence. Consequence is going to be failed.

So now, we during jump to contact the cantilever has a configuration like this laser is falling from the same angle, it is actually the same thing I am just drawing side by side to make you understand what is happening and laser light does not fall here let us say laser lights falls here. So, immediately there is in fact non 0 reading on the QPD. So, this Jump to contact. This is not very important from the stand point of operating of AFM because AFM does not really run in this mode, none of the modes commercial AFMs operate in this course anyway, but you see if you look carefully.

So, this is the initial configuration, where the laser was falling at the center of the QPD and this is the jump to contact and therefore in fact this drawing is partially wrong typically laser falls over here. Do you stop there? The answer is no, why you do not stop there is something we will discuss later.

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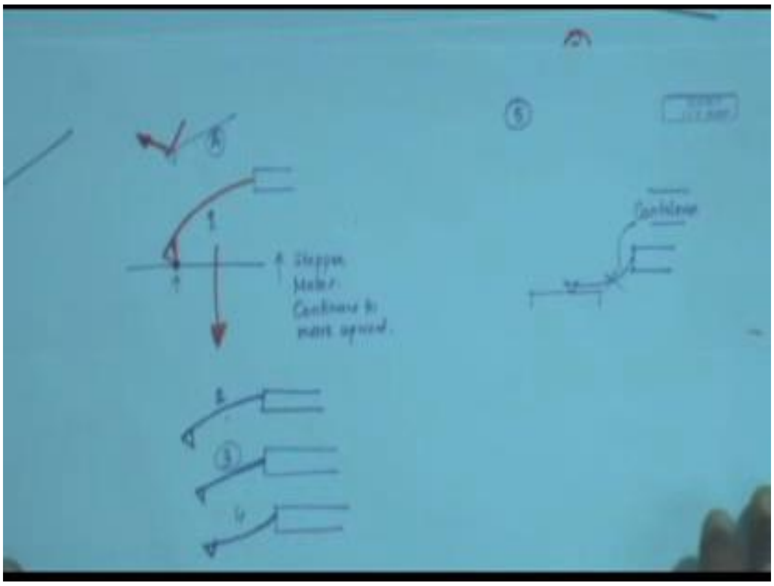

So, now the situation is something different. Let us first understand what happens at the cantilever, and then we will see what happens at the QPD. So these 2 come in contact and now, the stepper motor continues to move upward. What happens as a consequence of that? As a consequence of that, now this point the tip is sort of fixed to the surface at this particular point and the surface is moving upward right. So, the tip is fixed to the surface like this, initially when we align the tip was let us say the pen is the tip, this is the tip and here is the surface. So, the process of approach closely brings it up then the pen, then the cantilever because of Van Der Waals interaction or attractive interaction feels attraction jump to contacts.

So, now they are in contact and now you still want to move upward. So, what is going to happen? This end is fixed right therefore, since this is fixed now further upward movement. In fact, again changes the deflection of the cantilever and gradually the nature of deflection changes from this to this. What does it mean? Well what it means is, as you push it up it is obvious the it is in the attractive regime, but the movement it comes in contact you have actually reach this point and then as you go further you actually are repealing because now surface is moving up and it is physically repealing the cantilever right.

So, the net deflection on the cantilever reduces and that is what is manifested here see the curvature here at the let us say this is 1,2,3,4. I have deliberately drawn the way there are

2 the curvature is less, at 3 it is almost flat, again like when it was just aligned it is configuration is back to when it is just aligned and in 4 now you see the curvature has reversed. Can you locate it on the force curve and it is very easy. In fact, one is jump to contacts. So, this is point one.

Here is point 2 you see you are in the net attractive regime right, you are in the net attractive regime therefore, you have this type of a convex curvature, but the total net attraction has reduced as compared to that in the jump to contact because of the fact that you are surface is actually pushing the cantilever up at 3 you see that this cantilever is almost flat as if, there is no attraction, there is not net force where is it possible. In fact, it is possible here because the magnitude of the attraction sort of equals the magnitude of repulsion and 4 is a point over here where the cantilever is in the net repulsive regime. So, most interesting to note is so I should have marked this as 1, this is where I am marking it with A.

Now before the surface came in proximity with the cantilever the configuration was like this and during the process of approach you again cross the same cantilever once at this particular point on the force curve. This is fair enough, but simultaneously what is happening at the QPD that is also very important to note.

In fact, this cartoon drawn over here gives you a fair deal of idea, but I think I will sort of draw it in front of your eyes. So, that you understand even better. So, this point you understand, this point corresponds to the location of the reflected laser on the QPD corresponding to this configuration when you have not approached right. So light was falling here. Then as you bring the cantilever close to as you bring the sample close to the cantilever, there is jump to contact the cantilever takes a convex curvature and as a result the reflected laser lights now falls at this location.

So, let us identify this point as the position of reflected laser at jump to contact. Now what happens? In fact, your surface you are pushing up right and by means of what by means of the sample surface itself and eventually we have seen that at this point the deflection is going to get back 0, it is going to take the same configuration before approach sequence started.

So, what does it mean? As you traverse as the cantilever traverse or as the net deflection net convex deflection in the cantilever reduces because of increase in the repulsive force.

In fact, the laser light traverses back like this and so point 2 corresponding to here will somewhere over here. This again laser falls at point 3, laser falls at the center corresponding to the configuration shown in point 3 and now when the nature of the deflection changes to concave.

So, finally, once you cross this point the deflection in the cantilever sort of becomes like this it becomes concave right. So, what happens now? Laser starts to fall here in the first (Refer Time: 18:38). So is this clear? Initially right after approach laser was falling at the center right, then due to jump to contact it is sort of shifted to this location, then after jump to contact has been achieved the surface is pushing the cantilever upward.

So, the laser in fact traverses back the reading gradually reduces the reading of the QPD gradually reduces right and then once it cross point 3 and it enters the net repulsive regime the cantilever now starts to show a concave deflection and with increase in the concaveness of the deflected cantilever the laser gradually shifts. Question to ask at this point is how long do you allow this process of laser shifting this and that continue. In fact, you should appreciate that as this shifts away and away from the center, the deflection is increasing and that that is possible if the net force is increasing. So, a movement of laser in this direction, enhancement of the extent of curvature of the tip they all indicate increase in the net force.

So, the force is going to increase if you do not stop it an appropriate point what is going to happen? What is going to happen in very simple the surface, sample surface is simply going to break the laser, break the tip the cantilever. So, in order to prevent that breakage the approach must stop somewhere and that is something is your prerogative the operators prerogative you predefine a set point which corresponds to a particular force at which you would like to scan your sample, but interestingly that force is defined in terms of millivolt because you set that set point on the QDP.

So, where does the apropos sequence stop? I understand is bit complicated thing. So, I have tried to go very slowly. Let us see we will repeat again if necessary. So, as the deflected cantilever enters this regime and the movement of the stepper motor still continues the laser spot gradually shift, the reflected laser spot gradually shifts along this line and you let us say have put up a set point of 2 millivolt. So, what will happen is when the reflected laser spot reaches 2 millivolt, the stepper motor will stop? What does it also mean that if you have chosen set point in 2 millivolt and in another case you have chosen a set point of 3 millivolt, in the latter case you are actually going to scan at a higher force, which corresponds to on the cantilever that in the first case if this is the extent of curvature of the cantilever, in the second case the cantilever is going to a sort of bend more.

The how to, at what force you should scan? At what force you would scan is in many ways operator prerogative. Based on experience people, in fact generate an idea about what is the appropriate force for a particular type of a sample and based on that people do the scan. So, now, you understand the requirement of the so called set point into your system and if you now look back into the slides I had initially shown, I guess now you understand the meaning of this small spot that was drawn initially. So, this is in fact, the set point and that is very appropriate to draw it up priory because before your approach sequence starts, you need to assign the set point because the approach will continue till the deflection matches the force that corresponds to the set point.

So, now I think you should get a cohesive story, that initially you had this aligned AFM, there you start your approach which is been taken care by the stepper motor. Now as the surface sample surface comes in close proximity with the cantilever tip, you essentially enter this attractive regime of the force curve as a consequence of that the cantilevers till this point, there was no deflection in the cantilever and therefore, the deflected laser spot was falling at the center of the QPD. Now since the cantilevers bends it also shifts it does not no longer falls at the center any more, but it falls let us say somewhere over here or somewhere over here, this is the picture is schematic is not fully correct it falls somewhere over here. Just re draw this location is not correct, it falls somewhere over here that is where you achieve the jump to contact, but you do not stop your approach sequence had jumped to contact.

You continue to push your sub straight against the cantilever and as a consequence of that as a consequence of that the laser spot gradually shifts back and when it reaches this point. In fact, the net force on the force curve is at this point right, but you typically would like to continue with your approach sequence beyond this point. So, the cantilever now changes the nature of it is deflection, it was earlier a convex deflection, then it became straight again like as if the net, there is not net deflection and then it becomes concave and as you push it further the laser spot gradually shifts in this direction.

Till this process continues till the deflected laser light matches the force of the set point and then what happens once your laser spot coincides with the set point your approach stops and consequence where AFM the preizo gets activated and your AFM is ready to scan. So, last couple of lectures in fact we have discussed some very interesting aspects of operational aspects of the AFM. So, I hope now you can understand the meaning of these two pictures. So initially in fact one can also augment this picture by sorry I have (Refer Time: 27:29).

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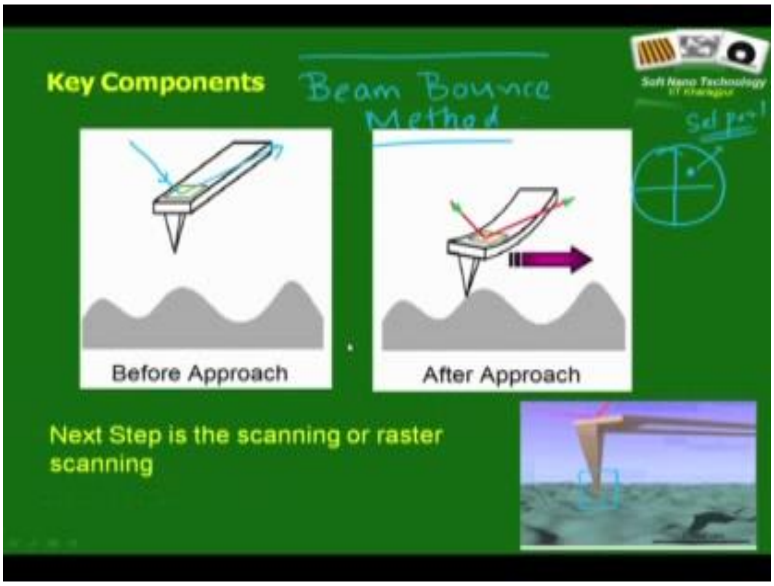

So, this is where it is before approach it is purely aligned and the laser light is reflected from an on deflected AFM from an undeflected tip and then once you approach you now understand how the approach sequence stop the configuration is somewhere like this. And after approach when your AFM is ready to scan the laser light is not falling at the center, but it is actually falling at this point which corresponds to the set point, but anyway from this point onward the preizo scanner takes over. So, this is an artist impression about the tip interacting with the surface and here you see the laser light falling and going. You have still not talked about how exactly this laser lights is capable of tracking the deflection, but this whole technique of using this laser light or tracking the deflection of the AFM cantilever is known as the beam bounce method.

So, we are running out of time in this particular lecture. So, I will stop here and we will pick up discussion on how an AFM scans and generates the data and for that we need to talk about the different scanning modes and we will discuss that in very simple terms, but before we move on I would like to really request you to revise very seriously the discussions on atomic force microscope you had so far, that is the basic operating philosophy from that of an SDM and then what are the major components we have.

And then how we align and how we approach particularly the condition of the reflected laser spot during approach as well as the configuration or the nature of deflection on the cantilever tip you re-approach. This will really help in understanding the scanning sequence.

Thank you very much.