Instability & Patterning of Thin Polymer Films

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Lecture No. # 24

Atomic Force Microscope - III

Welcome back, we will continue discussing about atomic force microscope. We just got introduce to the concept of an AMF in the last couple of lectures. So, today we will do a quick recap of the major hard work components, which we have already talk about, and then we will move on to the basic working principle of an AMF of course, atomic force microscope one needs to understand, as I have already pointed out it is a relatively new instrument. So, there is lot of development that still coming up in this area, people are using it for various other things, various things other than just routing is scanning or according the information about the surface typography. We will try to cover or give you glances of some of these methods or advance techniques also, but fundamentally we will discuss the basic operating principle in the two most widely use to modes, that is the contact mode on the intermit contact mode which I have already talk.

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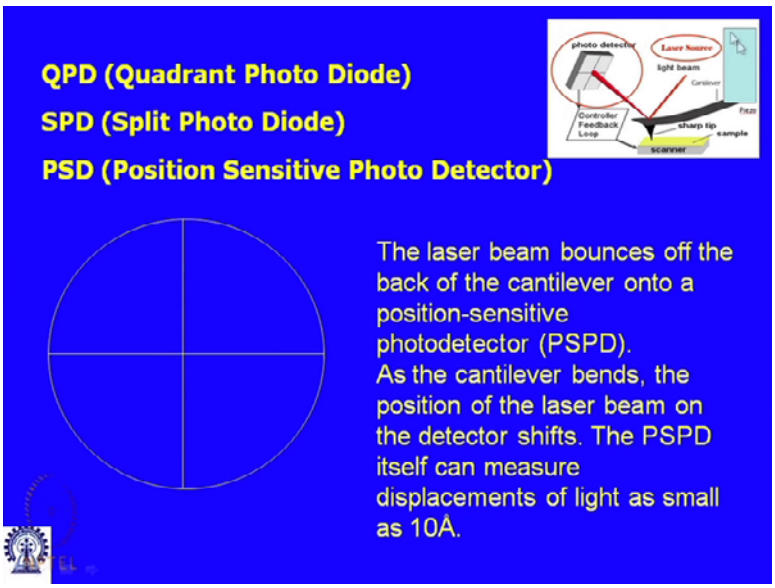

So, let us get started. So, this is if you look at this particular figure towards the right side of the screen probably it makes much more sensitive right now, you understand that there is a piezoelectric element to which is the scanner essentially, we will discuss a little bit more on the scanner today. You understand this sharp cantilever tip, what is it is other sharp cantilever, what exactly is it is role? You also understand that there is a sharp tip, which is used for actually prodding the surface and then. So, this is the tip then you also understand that there is a photo detector, which is use to track the deflection of the cantilever. You also understand that there is a leaser source which reflects back from the back side of the cantilever though the shining area it has, you know that there is a feed back control loop which maintains the constant deflection and things like that. So, here is a little enlarge few of the photo detector or the QPD or the position sensitive photo detector.

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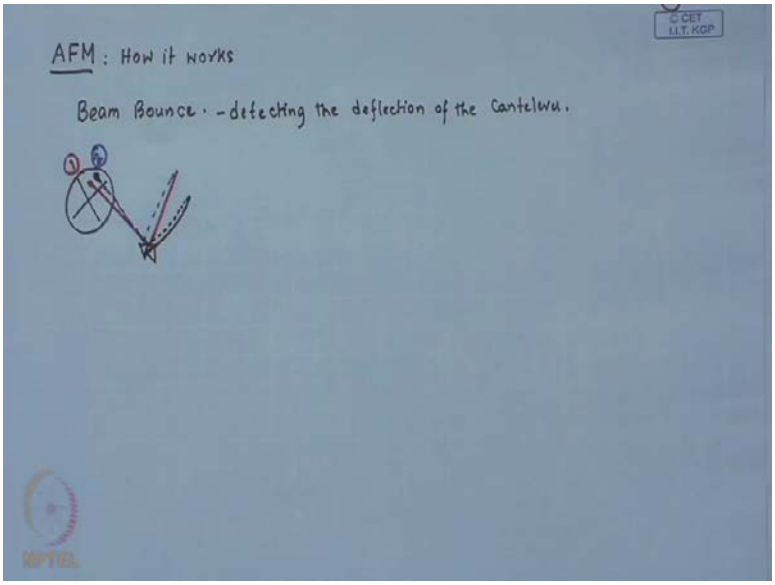

So, essentially you would now know that the laser beam bounces of the back of the cantilever, on to the position sensitive photo detector bounces of the back side. So, that is the reason this technique is known has the beam bounce method, for the detection of the deflection of the cantilever detection for detecting the cantilever, this is sort of the industries standard every commercial instruments sort of uses this approaches. So, we are not going to discuss any other methodology. As the cantilever bench the position of the laser beam on the detector shifts. So, suppose you have a specific location of the

cantilever corresponding to which let us say. So, you have this leaser source out here, we will discuss about all these things in detail.

So, let us say this particular configuration, this is the spot for the laser beam is falling. Now, the moment that deflection changes let us say now, it sort of changes to this location. So, the moment it changes what happens is the laser spot now, shift to some other location let us say this. So, this correspondence to 2 or correspondence to 1 so, there is another add that is generated in terms of voltage between these two points and they has we have told in the previous couple of class, that this area is now fare to the feedback control loop, which again sort of adjusts the position of the scanner in such a way or the cantilever in such a way by sort of elongation or contraction, let us put it in gen victims has dimensional change of the piezoelectric scanner. So, that the deflection of the cantilever comes back to the same level and the reflected beam again goes on falls at location 1.

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So, this particular aspect we will understand in greater detail. So, as the cantilever bends, the position of the laser beam on the detector shifts the PSDP itself can measure displacement of light as small as around 10 Angstroms. So, therefore, this gives noun providently literal regulation down to about nano meter and where down to about 10 nano meter. Literal regulation is pretty routing without ultra high back, you make more anything and a vertical regulation of a few nano meters is also achievable with an atomic force microscope.

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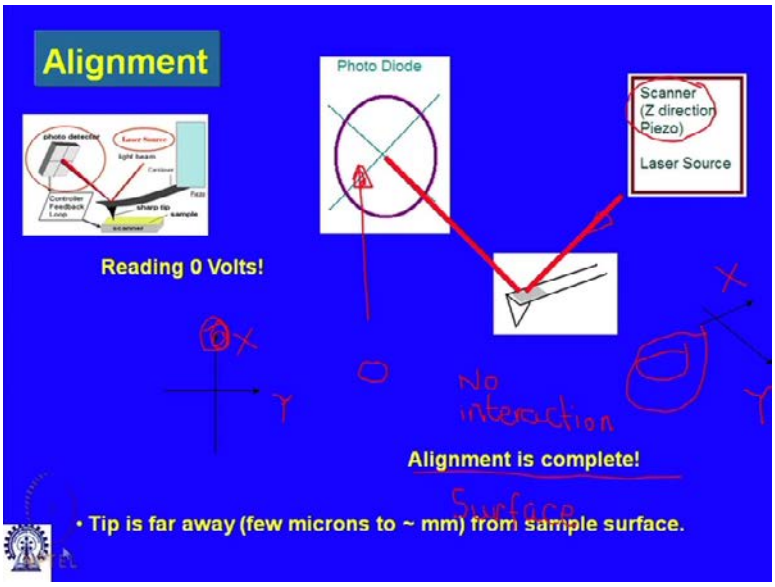

So, these things we talk about, we had also talk about the sequence of alignment. So, these are the hard elements you have, you have the cantilever and the probe city grapier here which has this reflecting surface, which can be seen from this particular shining silver area. You have two sets of swerves for moment in the x and y directions respectively, you have a laser source from which the laser is coming you have the scanner, it can be z direction piezo or it is a piezoelectric scanner we will see that it is no longer limited to z direction piezo. So, some where this cantilever is attached to the scanner and first thing what you need to do, as a part of your approach sequence is as fallows. So, first thing is you have to adjust these two swerves.

So, that your cantilever now shifts and the reflecting coating sort of goes below the laser path. So, this is the first thing you do this is the stage one of your alignment process. Once this happens immediately, what starts happening is that the laser beam now starts reflecting from this reflecting area. So, now the laser path is travelling in this direction, you now have the position sensitive photo diode and what you need to do you again have two sets of swerves over here, for let us say the x and y motion and what you need to do you need to do turn them in such a fashion. So, that the photo diode now moves and shifts to a location. So, that it is centre is now in a position to accept the reflected laser beam.

So, essentially you shift it in this direction. So, that this is the location. So, we have already talked that this is a perfectly aligned atomic force microscope. Now, you need to understand that the surface you want to scan is still far away. So, this is the surface you would like to sort of scan or investigate under the microscope, you perform the process of the alignment far away from the surface. So, what it means? It means that there is no interaction between the cantilever tip and the surface at the stage of alignment. So, this is important to understand.

So, the first thing one of the first thing you get going is after mounting the cantilever or the probe on to your atomic force microscope, which as an cantilever holder and this cantilever holder is typically attach to the piezo scanner which we will soon understand.

The first process you operationally what you would be doing is to align the instrument and that is achieve by two steps. So, you have two sets of swerves, one for the cantilever holder and one for the photo diode. So, first thing you do is you rotate these two swerves for horizontal motion in x and y direction respectively. So, that you reflecting surface of the back side of the probes comes in the laser path. The laser light starts reflecting and then you bring in photo diode (( )) photo diode in such a fashion.

So, that the laser reflected laser light falls of the centered of the photo diode so, reading is essentially 0 mile volt. So, these are perfectly aligned atomic force microscope and what you need to understand, this the align process of alignment is performed far away from the surface. So, still there is no interaction. Now, once that instrument has been aligned you now know you ready that you will be using this strip to scan this surface. So, the next process of course, you understand is going to be bringing this cantilever of the probe close to the surface on these are very small things. So, we have all ready talk this length of this cantilever chip is few hundred micron and this has a high of few tens of Nano meter. So, you cannot do it manually, there are immediate thing it is going to happen is that, you are going to break the cantilever or the probe.

So, this also automated and typically some slow speed stepper motors are used to achieve, this are to bring the cantilever or the probe in close proximately to the surface, this is what is known as the. So, tip is far away few microns to few millimeters from the sample surface and the next set you need to do is to bring the aligned cantilever probe.

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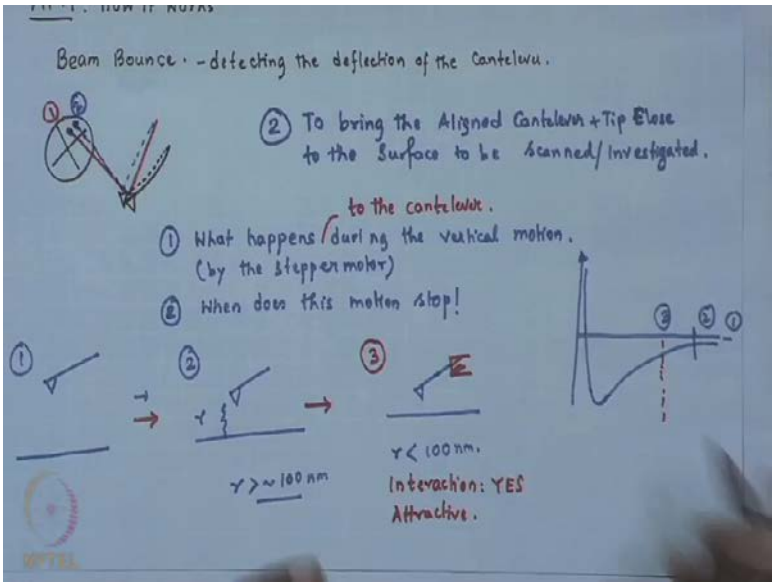

So, stage two would be aligned close to the surface to be scanned or investigated.

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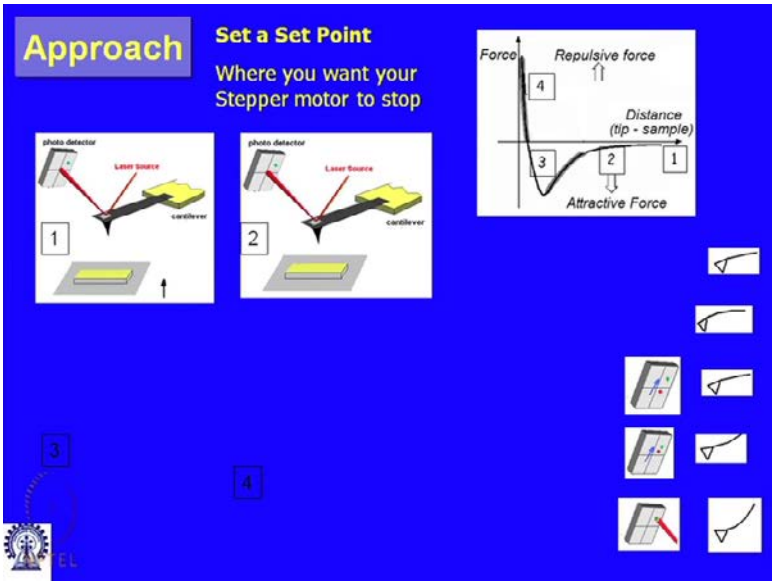

So, this is how it looks like right at this moment, this is an aligned AMF. So, the surface sample surface is far away, what do you do is this stepper motor takes care and gives a vertical movement to hither the sample you either bring in the sample close to the tip are you bring in that whole assembly close to the sample works either way is the same. So, it is starts to move and then two things are important here, what happens during the sequence of moment and the second thing to understand the realize or immediately the

question that should come to a mind, I am giving a vertical motion, but the question is when do you stop? So, we will talk about this or two questions number one is what happens during the vertical motion by the stepper motor?

Let us put it like, what happens to the cantilever when during the vertical motion by the stepper motor and question number two is, when does this motion stop? So, what did you expect to happen? Firstly, what is happening is that here, is the line cantilever and surface is far away. So, this is stage one, stage two is you bring it close, but still it is quite far away and what is this quite far away? This r since, we are now talking about two surfaces the surface of the probe and the sample surface.

So, if this r is sort of beyond hundred Nano meter nothing happens, but next when it is even closer. So, let us say this separation distance now is less then hundred Nano meter. So, what happens? If you remember your potential curve which is also given here now? So, one and two you have bet you have no interaction, but beyond this. So, you are now. So, this is the generic nature of the potential curve we already understand this. So, let us say one was somewhere over here, two was somewhere over here, but let us say three is here. So, what happens now you no longer can say that there is no interaction between the tip and the sample surface there is interaction? So, interaction yes and the nature of interaction are attractive.

So, therefore, and do not forget this is a cantilever. So, this same it sort of fixed with the mounting of the chip, but this end it is free and then in the previous class, we have talking greater detail about the spring constant. The material of the stiffness of the spring or the cantilever, you chose and we had are good that we will always going for a soft spring or a cantilever with a lower spring constant. So, what does it mean and how low is low essentially, it is in such ranges that it deforms these type of forces these type of inter surface forces. So, you now have a cantilever which sort of response to these attraction forces and what is the likely consequence since, this inch ten one side this end.

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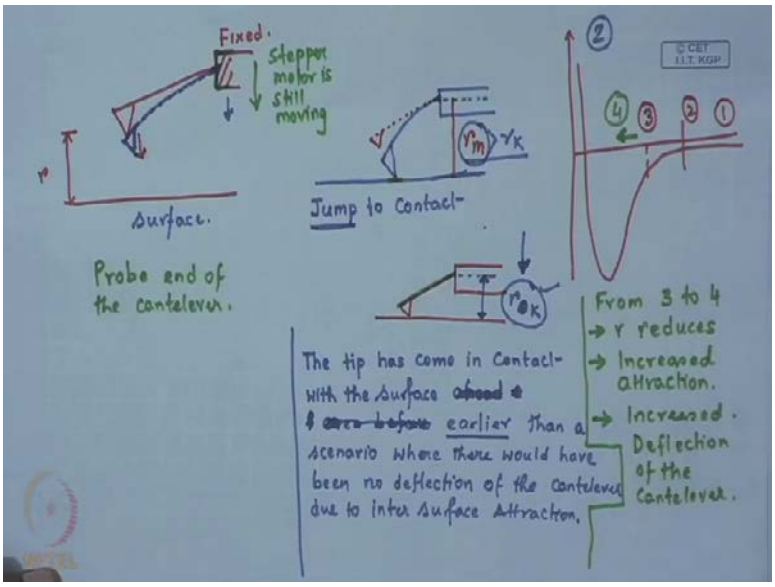

So, I will sort of draw a blown of picture. So, now, this fills an attraction. So, this r first thing to realize is somewhere over here, let us say there is an active interaction and this is fixed at this end and this feels an attraction and additionally the cantilever is soft enough to deform to these type of forces. So, what happens is the tip starts to bend like this, because of the attraction it feels from the approaching surface simultaneously, your vertical motion give to the stepper motor is still progressing. So, on one side this bends, because of the attraction alone the other side you are still bringing in the cantilever in close proximity, in closer proximity to the surface.

So, consequently what happens, after a while the cantilever sort of touches the sample surface and it touches? So, this was the original deflection fee configuration of the cantilever. So, any way had there been no interaction force or the spring was Stephan of not to deform to these inter surface forces. Even then since, you are bringing in the, because of the vertical movement of the stepper motor, since you are bringing in the cantilever close to the surface any way it would have touched, but let us say it would have touched at separation distance of r 0.

Now, what happens? So, let us say we hypocritically consider a case where you have taken a very stiff spring, which does not deform to the inter surface forces you use the stepper motor to bring it contact with that and let us say the distance of some the time let us say here, would have been r 0 or r k let us say, but what happens here if you now, look

at this separation distance let us say this separation distance is r m, this remains is found to be higher than r k. So, what does it mean? So, it means that the tip of the cantilever as come in contact with the surface, be sort of before it could it should have come in to contact had there are been no attraction.

So, we will write it down quickly. The tip has come in contact with the surface a head or before even before or let us put it like this, substrate earlier than a case scenario where there would have been no deflection of the cantilever, due to inter surface attraction I would this is clear to you.

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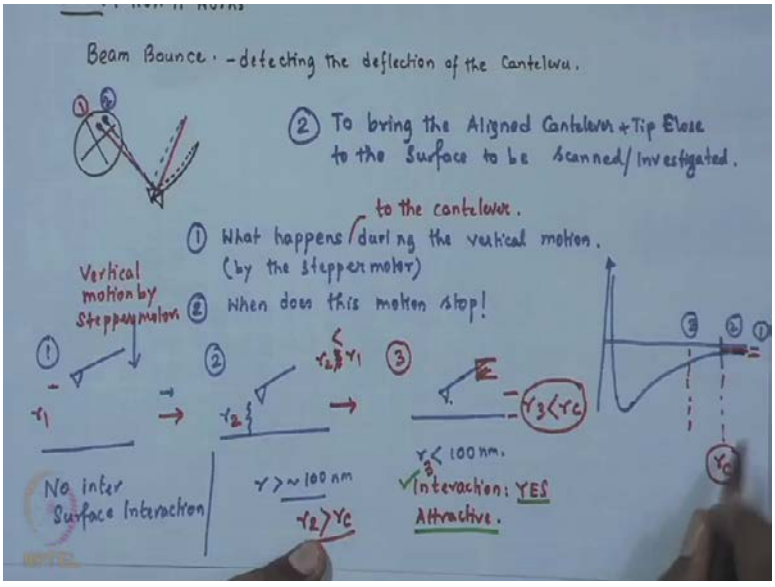

So, here we take an aligned cantilever, it is far away from the surface. So, no inter surface interaction, you start a vertical motion using a stepper motor. So, on the first curve position one, where you have an aligned is few millimeter away or hundred of microns away. So, there is absolute no interaction you start the vertical motion, you are still at resume where there is no interaction. So, the separation distance let us say goes on reducing.

So, this one is let us say r 1 here this is r 2, r 2 is less sorry r 2 is less then r 1, but still if you mark this as r c the critical separation distance below which the interaction starts here, r 2 is still greater then r c. So, there is no interaction, but then as you bringing the cantilever closer and closer, what happens is the separation distance. Let us say r 3 over

here is now, lower than r c therefore, what the additional thing that proxy up is now there is an active interaction between the two surfaces, that is the tip and the surface of the or the yeah that the sample surface.

So, and we also understand the nature of this interaction is attractive. So, what happens since, you have taken a cantilever or a spring which is flexible enough, the stiffness is low enough to deform to this type of forces and the cantilever is mounted or fixed on this particular end. So, happens the probe end of the cantilever deforms or starts fills the attraction and starts deforming in this fashion and simultaneously, you must realize that the stepper motor is still active, it still moving in the vertical direction.

So, this whole thing progressively comes closer to the surface and eventually, there is a point for the deflected probe tip this deflection is originating, because of this inter surface attraction. So, you can understand you are bringing it closer. So, also the level of attraction increases. So, the level deflects that increase level of attraction gets reflected in terms of increase level of deflection this is important.

So, from 3 to let us say you come to 4, which is even closer. So, from 3 to 4 what happens is r reduces. So, increased attraction and this gets reflected in increased deflection of the cantilever and finally, what happens is at some point the tip touches the sample surface and this you now, compare it with a scenario where suppose there was no attractive interaction which is a difficult case to imagine because Vander Waal's force has we all now is one of the most fundamental forms of course, but you can hypocritically think about a not exactly, hypocritical this is a valid point you can think about a cantilever which is very stiff which does not deform to these forces.

So, what will happen this is one of the things we had been repeatedly talking in the previous class about the choice of the cantilever material. So, suppose you take a cantilever which does not deform, and then if you trigger this motion of the stepper motor any way that we will come in contact with the surface, it is not that it do not come in contact, but what will happen let us say the separation distance at which it comes in contact is something like this, but what you will find here that since you have an active interaction and the cantilever bends or deflects this cantilever tip of the probe tip comes in contact with the surface a head of this r k. So, this is what is known as jump to contact

and this shook jump is a manifestation of inter surface attraction between the probe tip and the sample surface.

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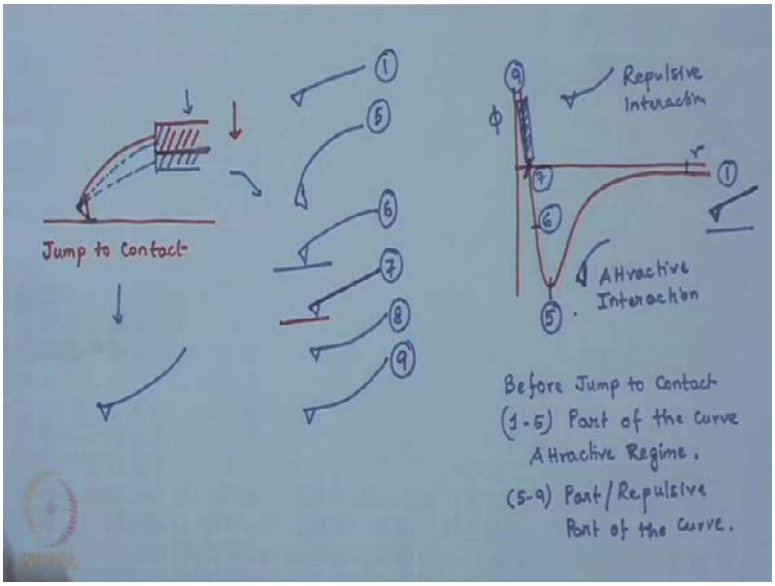

So, this is what happens even now what you need to understand that the stepper motor has not let start. So, now, you are in situation where jump to contact has been achieve and the stepper motor is still sort of pushing it down. So, this is the force curve it has already jumped to contact. So, we understand in the force curve.

What is the point of contact?

This is the point of contact. So, the tip is already here, but your stepper motor is still pushing it down. So, what will happen progressively, the deflection will now reduce like this and finally, if it still pushes the deflection will change to something like this. So, I would put it like this is the configuration let us say jump to contact you push it further it is going to be like this. So, what is the difference, let us say we mark this as 5, 6, 7, 8 and 9. So, let us try to identify and the force curve this is the point 5 this you see is the scenario over there is no deflection it is again straight.

So, can you identify that point beyond 5 what you need to understand that the any push that is important by the stepper motor you are now in the repulsive regime, before jump to contact you are traverse in that the motion of the tip was following or the interaction was following the one five part of the curve, that is the attractive part of the curve. Now,

once the jump to contact has been achieved and the stepper motor still pushes your tip down wards what now you are actually traverse in the five nine part of the curve and interesting thing is. So, has you sort of the point six will be somewhere over here. So, what is interesting to note that locally there is now in repulsion, because the tip is already in contact with the surface, but over all magnitude wise your still in the attractive regime and therefore, the deflection is something like this.

So, from the stand point of a deflection of the cantilever probably, we can now identify that any attractive interaction will lead to a deformation of the cantilever like this and any repulsive interaction, because of the fact that now this side is sort of is no longer fee to move so, this is now confining by its contact with the surface. So, whatever change in to deflection occurs that will now occur at this again in the shape of the deflection of the cantilever. So, an attractive interaction will have a shape of the cantilever deforming like this. While a repulsive interaction will have shape of the cantilever like this of course, when there is no interaction it will be like this it will be straight, but in between you want you see that I have drawn deliberately is case seven where again the deflection resemble, the deflection at one where there was no interaction.

So, no interaction means there was there was no interaction. So, let us try to located the point seven, this is the point seven where again the cantilever apparently appears the deflection of the cantilever apparently appears same as that of the one, but there is a first deference between the two in position one, there was no interaction between the surface and the cantilever tip. So, there was no attraction there was no repulsion, but our position seven what happens is the net deflection on the cantilever is again zero, but this is because of the fact that the attractive component of the repulsion now, balances are matches exactly the repulsive component of the deflection. So, once it crosses the position seven now what happens now there it is in the mate repulsive regime. So, now, the shape of the cantilever sort of changes likes this.

So, this is the sequence of approach or the first question we posed as to what happens to the cantilever during the vertical motion by the stepper motor. So, this is how the deflection of the cantilever sort of gradually changes. So, if I add here. So, there is no deflection then it is starts to sort of fill the attraction deforms in this way, then it goes to jump to contact, then further approach sort of gradually reduces the overall attractive interaction finally, it again cross to this critical point at seven and then there is a net

repulsive interaction. So, this is the overall sequence that happens that the cantilever sort of under goes during the sequence of approach that is fine.

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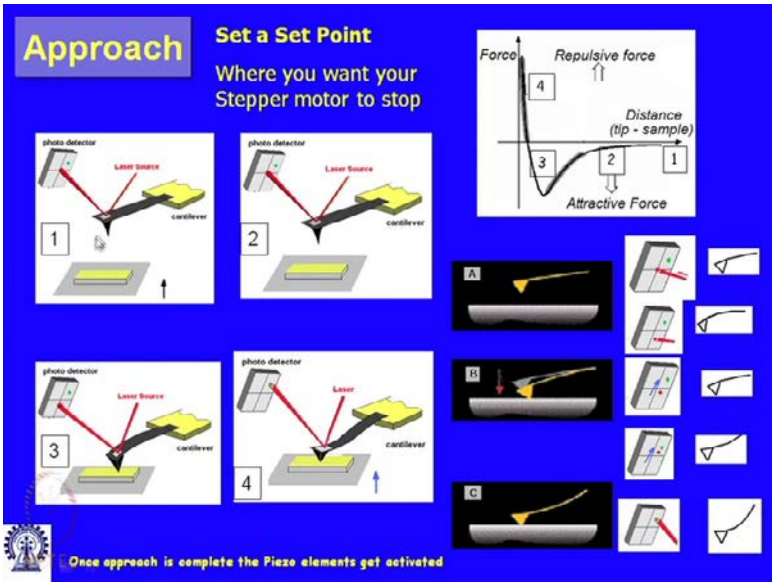

So, if you now look to these cartoons over here provably, it will make sense.

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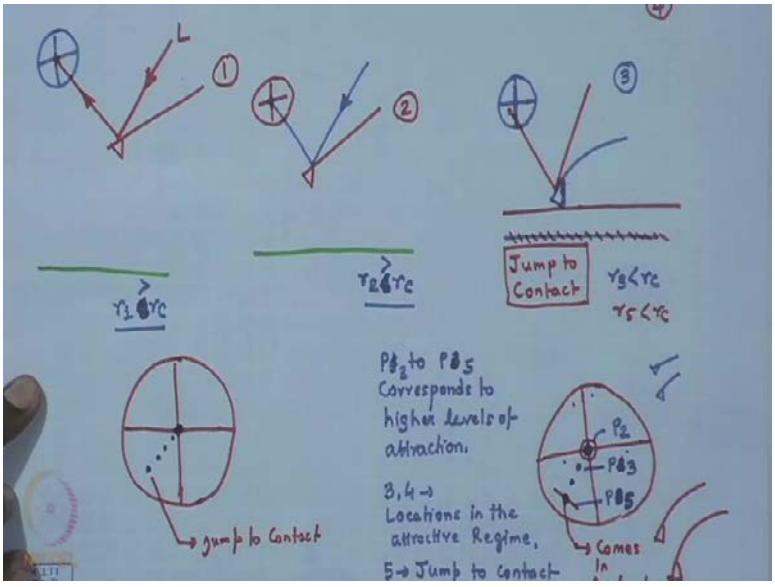

So, this position correspondence to our location one over here, what we have manually drawn where there is no deflection, then the subsequent figure number two is similar to the figure to over here where the motion has started, but there is still no deflection,

because of the fact that your r 2 is greater than the r c. So, you are still somewhere over here in the force curve. So, still no interaction then the figure three you now see the cantilever as sort of deflected due to the positive attraction. So, we have talk about it is correspondence to this configuration, but what you now see additionally on this cartoon is something, we deliberately did not talk I did not one ten you two sort of get confused and avoided talking it.

So, what we need to now understand how this deflection sort of gets manifested on the photo diode. So, if you remember these configurations one is a sort of deflection fee configuration and if you remember, the sequence of alignment. So, let us say this is the configuration one corresponding to the cantilever and this on the QPD of the PSD implies that your laser light is getting reflected and. So, this is the laser source it gets reflected and falls at the center of the QPD. So, let us now go on adding these configuration or. So, conformation or the position of the laser like on the QPD. So, on one the light falls over here, we understand laser come it is still align. So, it falls over here may be I draw it in a meter fashion.

So, one it falls over here is the sample surface at two it is (( )) it is closer, but still there is no interaction we have talk. So, on the QPD there is no change in the position of the laser light, it still falls of the centre. So, I would say r 1 is greater than smaller than r c, r 2 is also smaller than r c, then we come to location 3, where I am sorry r 1 is greater than r c, r 2 is greater than r c, but r 3 is now less than r c and what is r c? We are talking about r c is this critical location on the on the force curve we are talking about beyond below which there is active interaction beyond which there is no interaction. So, r three now is less than r c and we already understand that, because of the attractive interaction the cantilever now bends like this and simultaneously, what happens is now since there is a deflection on the cantilever.

So, the laser light blow longer falls on the center, but it sort of shifts and this is high this is exactly high a deflection is spotted. So, if you sort of compare with the fact that at perfectly align condition, the deflection was zero you already see that, because of this deflection corresponding to the attractive force experienced by the tip due to the approaching surface there is already a shift in the laser live now once. So, subsequent step would be let us say the step four, the step five, would be jump to contact next step is jump to contact, sorry I just avoided the trouble of drawing it once again and now it is in

jump to contact. So, as we understand, we already talk that has the separation distance sort of reduces the attraction progressively increases.

So, separation distance reduces you are traversing in this direction, because of the motion of the stepper motor. So, the attraction increases and what does that mean attraction increases, means that progressively this deforms more and more and consequently from here this was the location of the align one, has that attraction increases the laser like sort of dotes more and more from the center. So, from let us say position P 1 to P 3 higher level of attraction. I hope it make sense to you well we just route it here. So, let us say from 3 to 4, we drew on this particular curve. So, just have your attention on this part of the drawn graph, we talk about three to four and let us say this is the point five we say.

So, we also change it to P 3 to P 5, three four are both points let us try to understand, what is three and four three and four are both points in the attractive regime. In the attractive regime; however, it is not in contact. In contrast five is the point where the jump to contact has been achieved so, from three to four. So, before it started to experience the attraction let us say up to the point P 2, the laser spot was falling still at the centre of the QPD there was no deflection beyond this P 2, it is started to experience the attraction and therefore, it is configuration started to change from a deflection freak configuration to a configuration which cover response to a attraction and consequently the laser spot also started to shift in this direction.

So, here will route that from three to four or any point r reduces the separation distance reduces you can see that the separation distance, the inner surface separation distance. The separation distance between the tip and the sample surface progressively reduces and consequently the attraction increases, the attractive interaction increases and this results in increase deflection of the cantilever up to this we wrote what we did not right, then what we understand now that this also leads to higher level of deviation of the laser spot on the PSPD from its central point. So, higher is the level of interaction or level of deflection on the cantilever higher will be the extant by which the major spot shift from the centre of the QPD or PSPD.

So, I will just to a quick recap from. So, at very far away the AFM is fully aligned. So, the laser spot reflected the beam, the bound laser spot falls of the center it, the stepper motor starts to move still you are beyond are see there is no interaction. So, the laser spot

still remains of the centre now you come to you come to a separation distance which is closer than r c. So, consequently your cantilever now experiences is an attraction, the moment it start experience even attraction what happens is the laser spot also shifts it is position from the centre or the or it is aligned location and then you by virtue of the motion of the stepper motor, you bring the tip even closer to the sample surface two things happens, first thing is the separation distance reduces the magnitude of the attractive interaction increases.

This increase in the magnitude of the attractive interaction gets reflected as an increased deflection of the cantilever. As we have documentary it here it results in an increase deflection of the cantilever and this increase deflection of the cantilever results in for progressive or gradually shift of the laser spot from its aligned central location. One can also understand the maximum distance of the maximum deviation will result will occur at the point it sort of comes in contact. We have drawn please do not get confuse that it has to move in this direction, but we have drawn it just to explain the things to you it is a QPDS it is a similar to a graph paper, this is first code second, third and fourth. We argue that this is the attractive regime or the negative force. So, we are in the sort of negative side it is a nothing really hidden first it has to move in this direction, one can always it has moved in this direction due to the attraction or any direction only thing is you need to keep the force curve in your mind.

So, now we understand that this is the configure this is the position of the laser spot on the QPD at jump to contact. Now, what happens beyond jump to contact, what happens beyond jump to contact is, if you still go on push in the cantilever if the stepper motor still goes on pushing the cantilever. What now happens is now, the deflection sort of starts reducing, because you are now following this part of the force curve. So, as the deflection starts reducing what happens is now. So, let me draw it again on enlarged view. So, this is what the laser spot was at alignment, this is how it progressively shifted has the cantilever tip started experiencing attraction and let us say this is the maximum deviation we see at jump to contact. Now, beyond jump to contact if the approach process is still on now, the attraction or the deflection progressively starts reducing.

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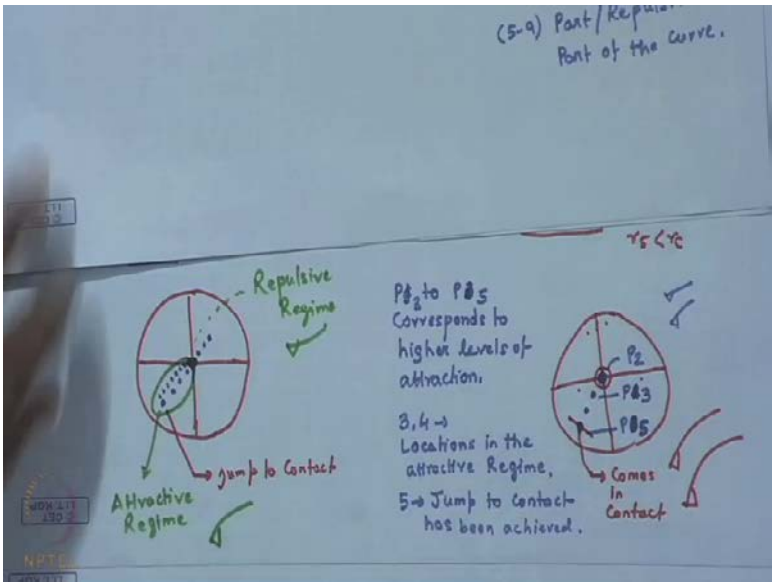

So, consequently as it is starts reducing. So, as the deflection was increasing in the attractive direction, it sort of shifted in this direction. Now, as the deflection reduces the laser spot now goes back along this particular way and all the way, you was understand that at point 7, we again encounter a situation where they that make deflection of the cantilever is 0, which is identical to the conformation of the cantilever after alignment or in other words now, the laser that gets reflected again falls back on the centre and beyond point 7, if you push the cantilever further due to this approach it is now in the repulsive regime. So, now for the first time the laser spot starts shift in this direction. So, you need to understand that if this is the attractive regime, this is the now repulsive regime and the other thing that should remain in your mind, that the configuration of the cantilever of the nature of deflection of the cantilever in the attractive regime remains like this, the nature of the deflection of the cantilever in the repulsive regime remains like this. So, this is again we get back to the two questions, we post of the beginning of the class.

What happens to the cantilever during the vertical motion?

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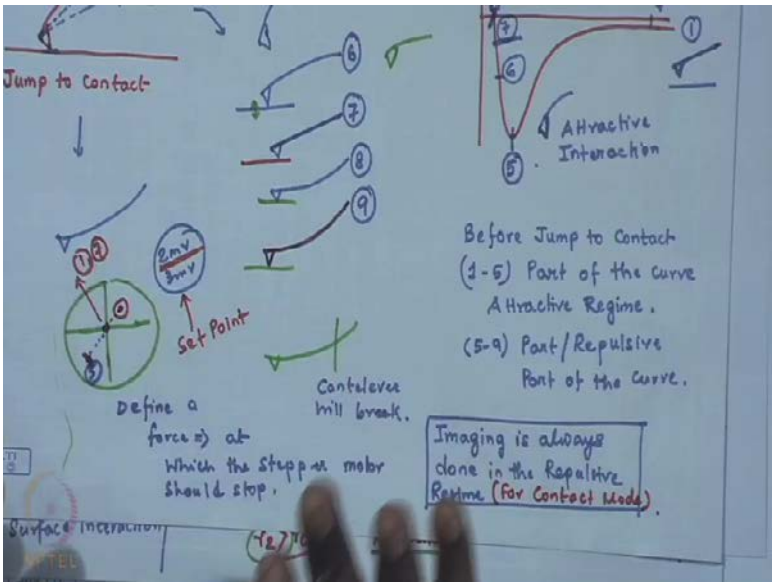

So, now we understand the full cycle what happens to the cantilever from here down to nothing happens beyond this, it experiences in attraction interaction beyond that there is now repulsion, but also can be dispute in to two parts. So, first you have a repulsion local repulsion or the tip, but the overall you are still in the attractive regime. So, you have a situation like this where locally there is a repulsion, but you are still in the attractive regime they are 4 your sort of deflection is still like this then you cross this critical point at seven where the attractive interaction balances the repulsive interaction and then you are in the completely repulsive regime.

So, in adhesion to that, we now also understand how the laser spot progressively changes location on the QPD from here, let us say point one down to point 5 over here at approach, then again all the way back during this particular part and beyond 7 it is like this. So, this is how the whole sequence of approach sort of leads to a deflection as well as the moment of the laser spot on the QPD, but if you look at this second question we have post we still do not have any clue about it, when does it stop, when does the motion stop? Because what is going to happen it is now in the repulsive regime and you still go on pushing it or your stepper motor still goes on pushing it.

So, finally, what is the lightly consequence lightly consequences is that if you do not stop it will just nap off, the cantilever we will simply break. So, what needs to be done that you need to define a force, at which the stepper motor should stop and that force can be

let us say two mille volt, three mille volt whatever it is, but typically remember that that we are going to discuss is contact mode AFM, but other mode also imaging is always done in the repulsive regime, this is a gross statement I would say. So, I will add for contact mode which is the simplest one and we are going to discuss it soon or shortly.

So, again we repeat from one due to the attraction it goes all the way up to 5, which correspondence to the jump in contact, then beyond jump in contact again it traverse is back this path crosses 0 again at 7. So, this point now correspondence to one as well as seven and then now there is a net repulsive deflection and the moment sort of the deflection matches this set point. So, let us say 2 mille volts is here and your deflection is shifting like this, the moment it matches this 2 mille volts set point the approach stops. So, in other words what happens is. So, let us say this is your set point you have specified 2 mille volts you understand the moment this deflection now matches 2 mille volts the approach stops or the stepper motor stops.

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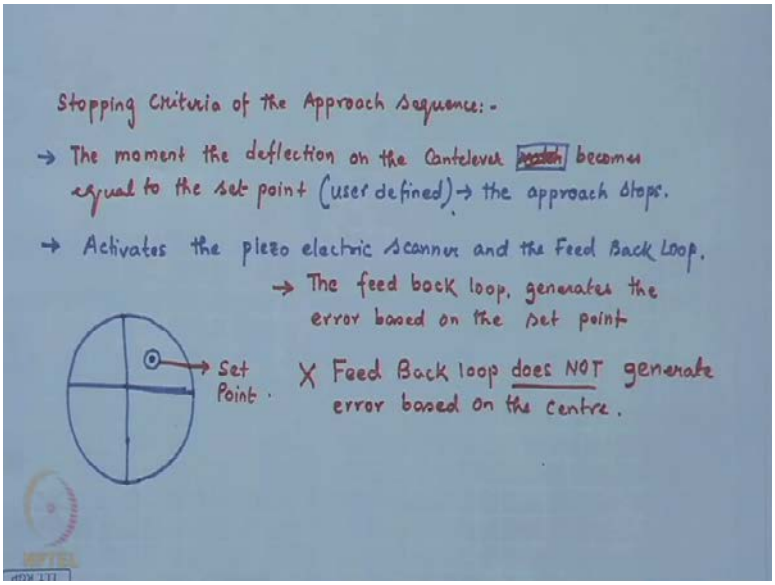

So, stopping criteria of the approach sequence, the moment, the deflection on the cantilever becomes equal to the set point which is user defined and this force at which you would like to scan is a function full lot of things sticking of the surface, stiffness of the surface and to a large extent is a function of operator choice operator experience. The what happens when the deflection becomes equal to the set point approach stops. Now, stopping of approach concurrently activates the piezo scanner and the feedback loop.

So, the feedback loop essentially is a PID controller depending on the situation, but important thing to remember is that, the feedback loop will generate error based on the set point. We will see it in the immediately preceding discursion, the feedback loop please do not confuse that the feedback loop generates the error from the centre of the QPD. The feedback loop I will write it down and keep this in your mind feedback loop does not generate error based on the centre.

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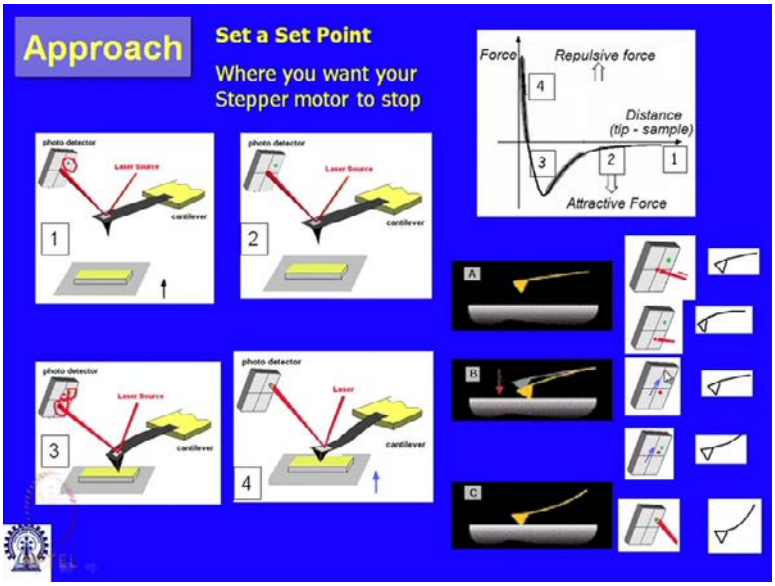

So, this is how the whole thing looks like let us revisit this whole cartoon again. So, set a set point and. So, this is the align cantilever you doubt trigger the stepper motor. So, it is moving now first it comes closer, but nothing happens. So, you are still beyond that point of let us say r c and. So, you are still beyond r c and then you come closer. So, there is a make positive attraction. So, the cantilever deflects like this and now you see if you examine carefully over here, which we did not do before is that this is the centre, it has deflected like this and you see that is a small green spot. So, this green spot here write from this particular figure.

So, this green spot is nothing, but the set point and then what happens is you approach further and finely the nature of deflection changes from attractive to repulsive and when the reflected beam sort of goes and coincides on this green spot that is a set point now, you are approach sequence stops and the piezo vats activated the feedback loop activated and the AFM ready to scan. So, these also capture sort of the configuration of the nature

of the deflection on the cantilever, as well as how the laser spot sort of moves on the QPD.

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So, this is at the align position this is when it subject to attraction it shifts in this direction this is beyond jump to contact, it is now traversing back following the same path some of the figures we have drawn. So, after alignment it was over here then, due to attraction it sort of shifted in this direction. This correspondence to the jump in contacts, the maximum deviation in the negative direction and then since, you last our traversing this part of the potential curve. So, it follows back the same path and then finally, when it matches the set point it stop, it is now ready to you scan which we will how the AFM scans in contact mode, we will discuss in the subsequent class important thing to note is an AFM imagine is always done in the repulsive regime in the contact mode, and why that it is the case we will discuss in the next class thank you.