Instability & Pattering of Thin Polymer Films

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Module No#01

Lecture no #20

Atomic Force Microscope- IV

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Welcome back, we will now continue our discussion atomic force and micro scope, and we will discuss, how the images actually get generate. So, we are building our fundamental step by step. First we discuss what are the hardware elements, what are the key operational aspects, and then we got in to some bit of details, and in the previous class if you remember, we discussed the sequence of approach. So, now, we have an atomic force micro scope, which has sort of approached, and therefore the piezo is now active, and so is the feedback loop.

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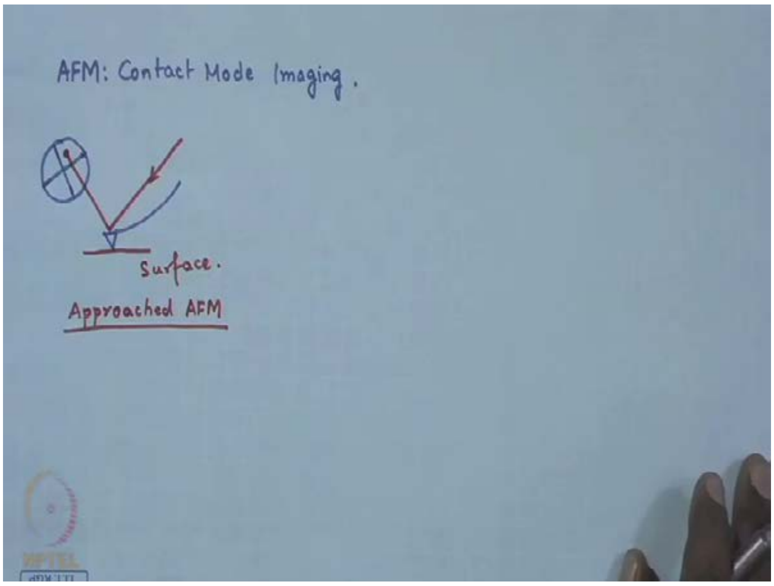

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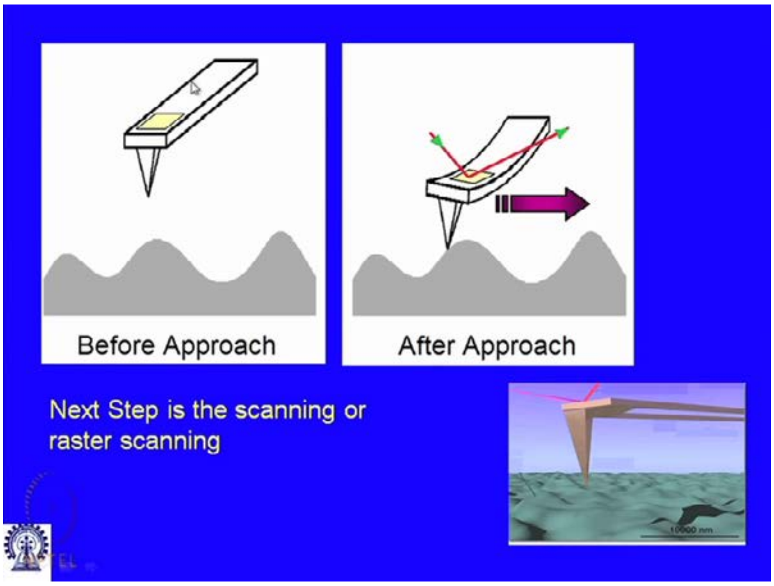

So, the configuration of the cantilever is like this. It is in the repulsive region, and the reflected been, is now following at the set point location, and it is in contact with the surface. So, this is now an approached A F M, and based on this now the scan sort of starts. So, this is quick recap. So, this is before approach no defluxion. So, you were essentially somewhere here, in the force curve. The laser off course was falling and was going to the center, and this is after approach. So, here is the laser that is coming, this gets reflected, this gets reflected, and this falls at the position that corresponds to the, set point. So, if I may allow to add. So, this is the q p d, let’ say this is the set point we have.

So, the laser goes and falls on the set point. So, this is, now ready for the approach, this is more of a imaginative nice cartoon, you can see, so the tip is now with contact with the surface. Here is the laser beam, that false from the laser source and goes to the q p d.

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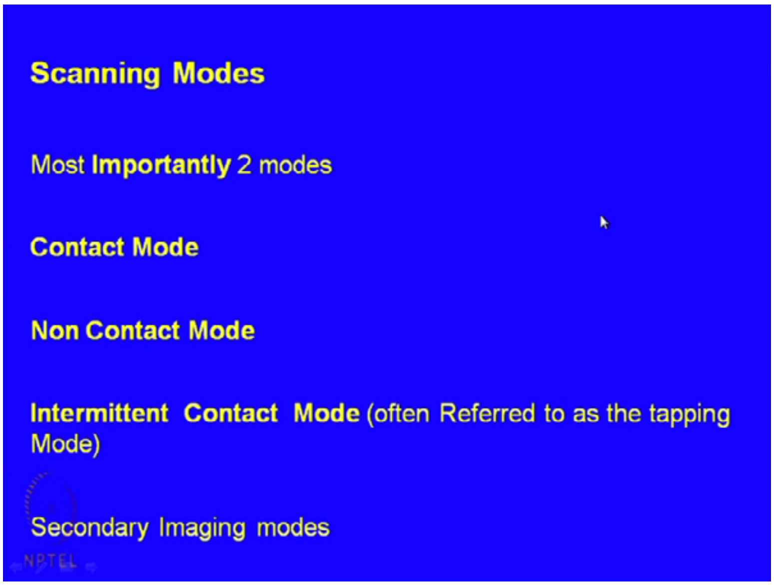

So, before we move on to how it works, first we will. So, there are the essentially two important modes, in which an A F M can operate. It is the contact mode, and the noncontact mode. Now noncontact mode unfortunately has some limitations, particularly in terms of immerge resolution. So, it is rarely used in isolation to image, though it has certain advantages, but the more popular one is an intermittent contact mode, which is very popular and is often referred to as the tapping mode, but scientifically we should use the word intermittent contact mode, because tapping mode is word which is sort of more of a trade mark of one particular A F M manufacture, but in many cases you will find that people are usually using are word tapping mode, which is also perfectly fine, it refers to the mode of intermittent contact. And then we had whole lot of secondary imaging modes, which we will also discuss some of them, but your understanding of atomic force micro scope, how it works depends largely, or you will able to acquire reasonably good amount of idea, about how an A F M works, if you understand contact mode, and that is what we are going to do at least in this class.

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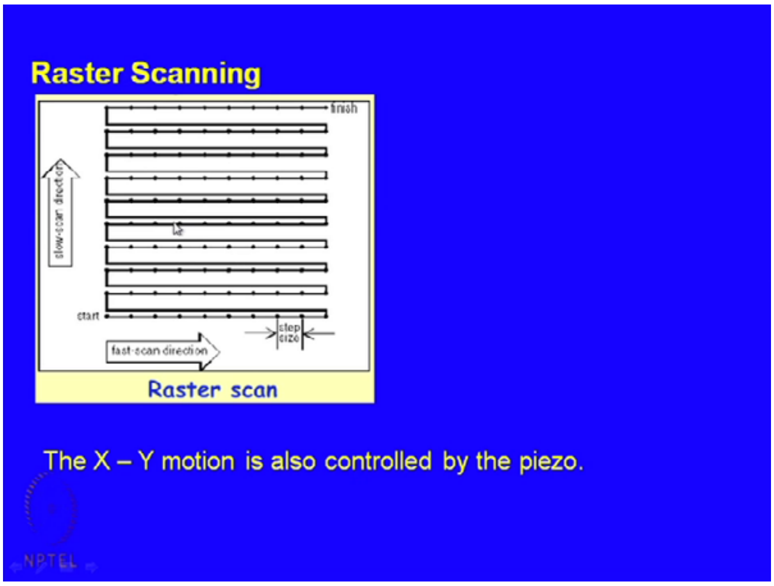

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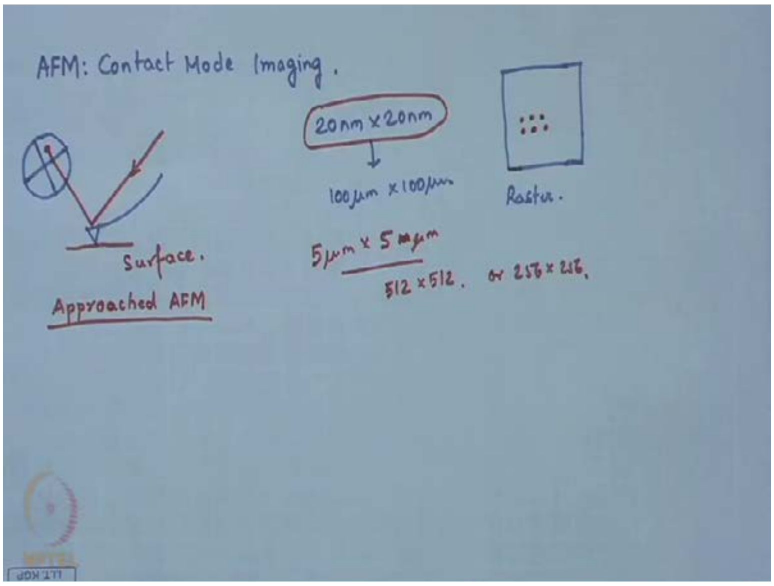

So, then we had already talked about the raster scanning operation, so essentially you identify a zone, which can be may be 500 nanometers square up to, let us say 100 microns square. So, A F M scanner has this type of ranges. So, it can be as low as 20 nanometer, cross 20 nanometer to 100 micron, cross 100 micron. Typically it is an in commercial A F M x square zone, but there are instruments which allows you to scan rectangle zones we have also, and then we does raster scan, so what is this raster scan. This raster scanning is the essentially, the tip travels from one point to the other.

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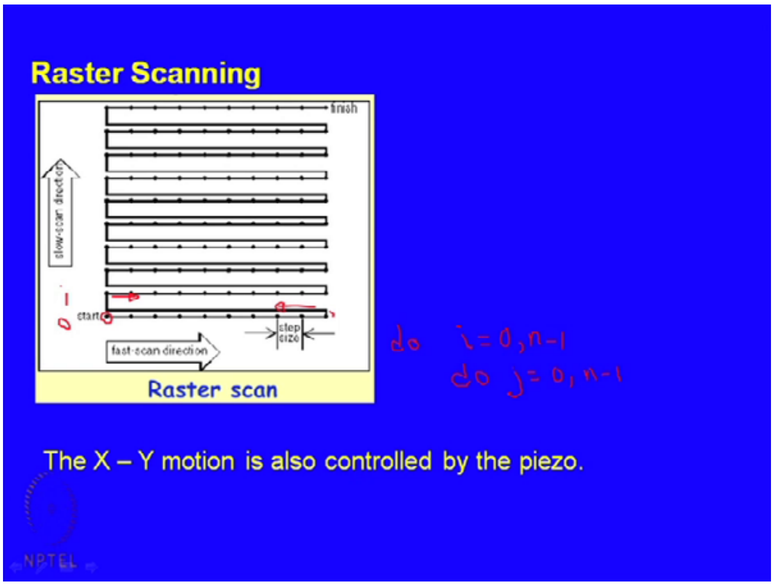

From one point, every point to point it point travels. So, this starts from here, let us say moves on to the next point, next point next next next, and then again it comes back in this direction, comes back all the way back to here, then again moves to the next location and goes like this. So, it is more like performing a do, a nested do loop. So, do i equal to, and then again within that. So, for every i let us say this is equals to i equal to zero. It goes to every point from j equal to zero, one two all the way to n minus one. Then comes backs moves on i equal to one, then again moves from j equal to two n minus one and something like that. This is a raster scanning, but just think. So, typically one would divide this zone in to 512 by 512 and 256 by 256 data points.

So now, thing of a situation you are not doing some ultra small zone scan, but let us say five micron by five micron, scan area is very common, and you have divided it in to 512 by 512 points are, even let us say 256 by 256 points. So, what we have understood, that the gap between the two subsequent points or two subsequent lines is very small. In this particular case, for example the gap is of the order of 40 nanometer or 20 nanometer, let us say. You can just divided micron divide by 256 and you will get the number, terms out to as per my mantle calculation, it is close to 20 nanometer. So, how do you really, which motor, which equipment do you use to sort of position this motion, from one point to the other.

It is ready easy to say that you do a raster scan, and but the reality is. This is not a computer program we are running to generate some data. The tip as to be physically travel to this data point, then move on to precisely at the next point which is 20 nanometer away, then to the next point which is again to the 20 nanometer away, then to the next point again like this. So, how do you control this, and it is an important this x y motion, because it can be very precise and demanding is also controlled by the piezo, by the piezo electric scan. So, most of the earlier atomic force microscopes, they used to come with three separate piezos; one for the x direction, one for the y direction and one for the z direction to control the vertical height, how the vertical height is control we will come to it.

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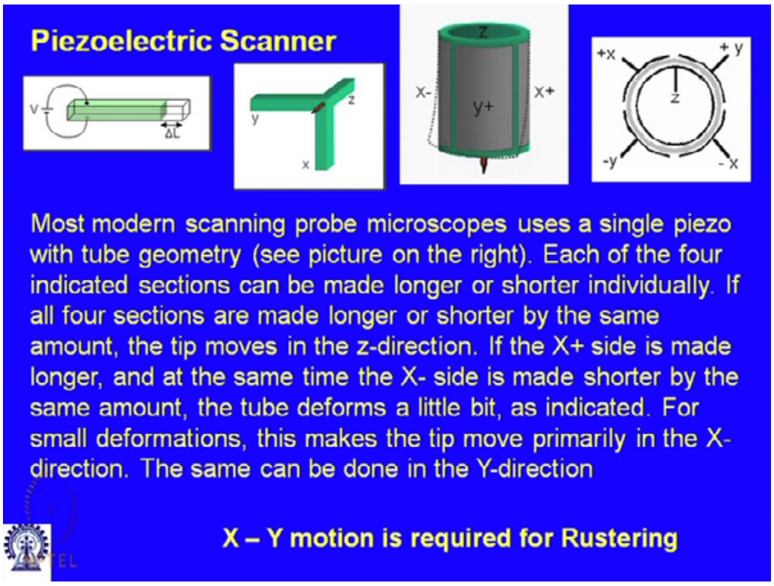

But, majority of the modern piezos, now come with one cylindrical, hollow cylindrical piezoelectric element. So, piezoelectric scanner, you understand what is a piezoelectric material, we have very grossly discussed about it. This is not the right course to discuss about the physics of a piezoelectricity or piezoelectric ceramics materials. I would strongly recommend you look in to some complementary lecture to understand more about it piezo, but very briefly if you apply a voltage to a piezoelectric material, there is a dimensional change. So, in other words let us say we apply positive voltage to piezoelectric material. It might become longer and consequently thinner, and to the same material if you apply a negative voltage, let us say it might become sorter and therefore, consequently the cross section becomes wider. So, this is what is the, in a not shall is a piezoelectric element.

So, as I pointed out that initial model, they sort of relied on three distinct piezos; one for the x, one for the y, and one for the z direction. This we can see the tip mounted to this piezoelectric scanner, this is the A F M tip, but modern instruments have sort of done away with this three independent piezos, and they use one single piezo and. So, this is we have been telling that the tip is mounted at the bottom of the piezo, this is like more of cartoon. So, this is like piezoelectric element and we have the cantilever holder some over here, and the tip is here, the configuration is something like this. So, most modern probe s p m's uses single piezo with tube geometry, and each of the. So, it is now spit in to four destining zones over here, this is zone number one, this two, this is three and this is four.

If all the four sections are made longer or shorter by the same amount, of course then you understand that, the tip moves in the z direction, that is a vertical move. In contrast, if let us say the x plus side, this is the x plus side, this is the x minus side, this is the y plus side, and this is the y minus side. So, in contrast if the x plus side is made longer, at the same time x minus side is made shouter, how do you make this longer and short. It is based on the error voltage that that gets generated. So, you apply a voltage, which can be an error voltage, or if you are restring the voltage, necessary voltage will come from the software of their computer interfacing. The computer which is interfacing your instrument will take care of this. So, just as a click look, if the x plus side is made longer and at the same time x minus side is made shorter by the same amount, the tube deforms a little bit as indicated, it is like this.

And for small deformation this makes the tip move primarily in the x direction. The same can be achieved also for y. So, we can see, by independently sort of controlling the voltage, you can ether use this piezo to move in x are y detection, or you can also make it move in the z direction. Now soon we will realize when we talk about the operational principal, that this restring thing is move like an independent variable. So, you want your A F M to raster at every point, therefore it raster, it travels from one point to be other. So, this voltage that is necessary to make this, make the piezo move along the x y direction, is sort of given from the software, it is a software control. So, when you press the scan button, it will give voltages for the movements form one point to the other.

It will give the necessary voltage across the piezo, so that it moves from one point to the other, but as you see that, you can also give another type of voltage in put to the piezo, where it sort of all the four components are x plus y plus x minus and y minus, sort of made longer and shorter by the same height, so that you have a control over the z. This comes from the topography of the surface, and the free error that gets generated in the feedback. So, this is what we are going to discuss in the next section. So, this is the rastering, so you need to understand the rastering motion, is the software control thing, its parts of it, it’s necessary to generate the data of, part of the scan and this is achive by doing something like this. So, x plus side is made longer and x minus side longer made shorter.

You may also understand that, if this is let us say, the x detection, and this is the y detection, you can also change your loops. So, from instead of i and j, it can be j and i. So, this axis is known as the fast axis, and this is known as the slow axis. So, corresponding to the fact that, these are the x and y directions. Most at commercial A F M, so they will give you the freedom to pick up, weather you want to have you x as the fast axis or y as the fast axis, and depending in certain samples particularly if you have very regularly feature samples like, ratings for examples. You need to choose the scan direction of the fast axis, or the slow axis, depending on the geometry is the feature size, which is also important and I think we will give you some examples of that.

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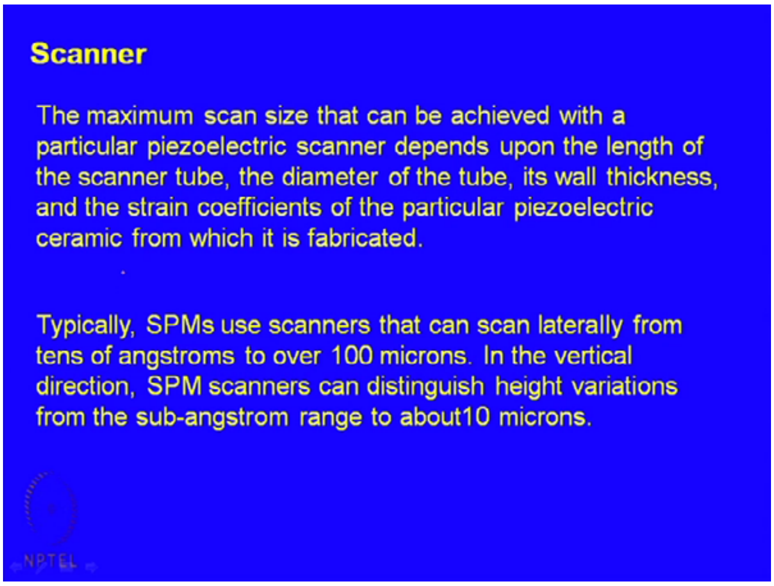

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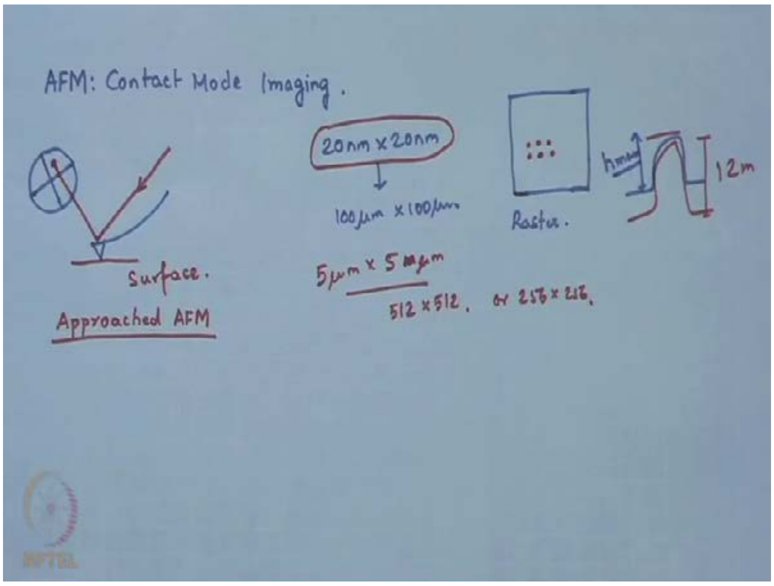

So, the next thing is, so the scanner, just a quick recap on the scanner. So you understand it is a hollow piezoelectric tube with four different zones, each of which can sort of deform separately, or in tandem depending on which type of deformation you want to achieve. So, the maximum scan size that can be achieved with a particular piezoelectric scanner also depends up on the length of the scanner tube, the diameter of the tube, its wall thickness, and the strain coefficients of the particular piezoelectric ceramic, which has been use to fabricate. Typically S P M scanner can scan laterally from tens of angstroms few nanometers to over hundred microns. In the vertical direction S P M scammers are sort of limited up to seven, up to ten microns, ten microns is the, I would say higher size. So, majority of the A F M s, the vertical height is limited to seven and half microns to eight micron. So, if you have sort of features which are higher than that, let us say that you have a feature like this, which is twelve micron. The scanner will not be able to cover it, and it will generate profile like this, which will corresponds to the maximum range of the scanner, and this is often refer to as a truncation error.

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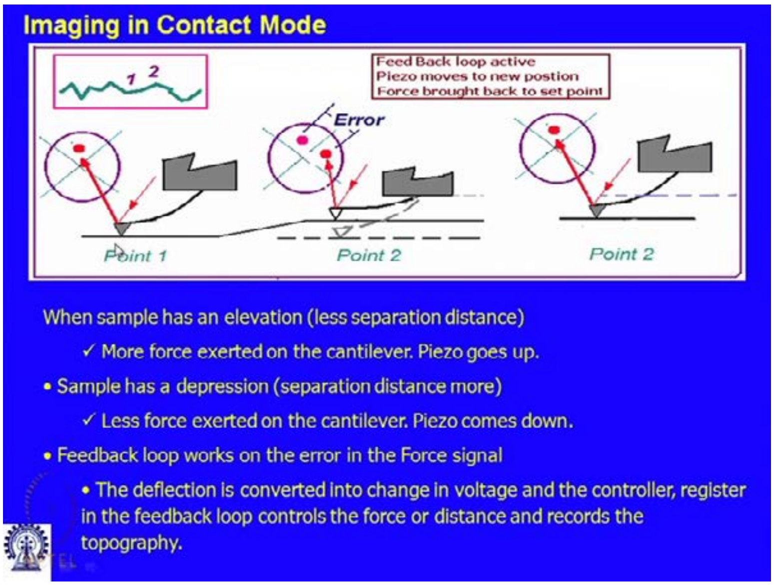

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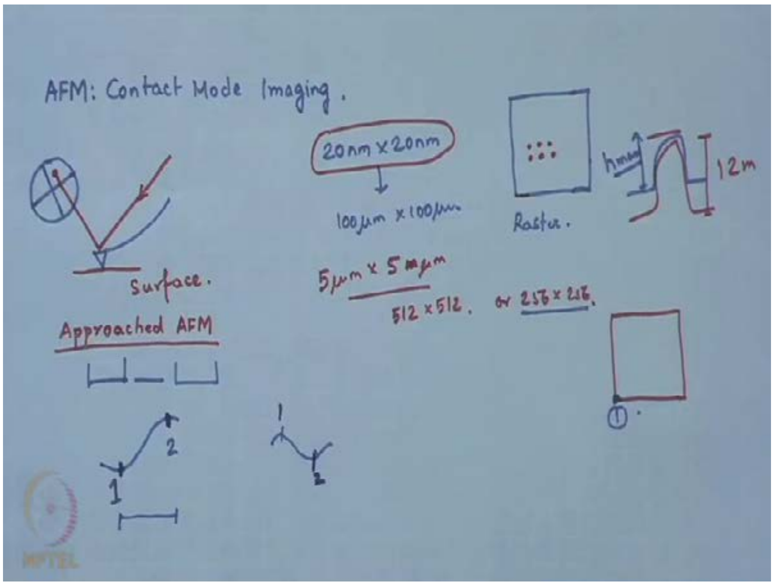

Let see now, how imaging is done in the contact mode. So, let us say that, you have approached, the A F M has approached at location one. So, what is this point one, it is part of this rastring zone and let us say it has approached here one of the ages. So, this is let us a point one, where it has approached. And this is the piezoelectric scanner to which the cantilever is mounted. You can understand now a lot of things. You can understand that why the shape of the cantilever is like this, because it deflected, deflected because of the positive deflected, because of its repulsive region. The laser light falls gets reflected, gets reflected from the, small tine reflection zone which is there on the cantilever. The laser light gets reflected on falls at the set point on the P S P D. Now let us say, you would like your scanner to move from point one to point two, what is point two, point two is depending on the scan area, if you divide by the number of points, if the next location where the scanner should go, and collect the data.

So, let us say from point one to point two, the scanner moves and there is only deflection of the piezo in the x direction, so that it can move by this exquisite amount. So, since there is no vertical deflection, what happens is, the vertical height of the piezo elements remains the same at the beginning. So, what happens is, let us say the point two is at a higher elevation, as compare to point one. Therefore, since the point two is at a higher elevation, the deflection changes or the force increases. So, let us say, the moment you have a change in elevation the deflection will change, but you can also argue whether point two depending, on whether point two is at a higher or lower elevation as compare to point one, the magnitude of the force will also increase or decrease. So, what happens is, if the point two is at a higher elevation, what happens is the repulsive force on the cantilever increases, because of the fact that it is now getting, rippled by even larger extend, because it is closed, you can see it here, because the tip is in contact with the surface, surface is now closer to the scanner, so the force increases.

In contrast if the point two, is at a lower elevation or lower level, as compare to point one, what is going to happen is that, the force is sort of going to reduce, but either way, the moment of the force changes or the extent of deflection changes on the cantilever, immediate consequences, that the lasers spot which earlier was falling at the location corresponding to the set point, now falls at some other location, and immediately and error gets generated, this is clear. So, from one point to the other, because of the change in topography, there is a change in the extent of the deflection in the cantilever, and we have already argue that the moment there is change in the deflection, in the cantilever, that refers to the fact that the forces have changed, and simultaneously a change in deflection results in a change in the location at which your laser spot had been falling.

So, at point one the laser sport was initially falling at the location, which corresponded to the set point, but from point one to point two, since there is change in elevation. So, this results in a change in the force or the extent deflection of the cantilever, and consequently the lasers spot now falls at a new location. It does not falls on the set point, which is now mark with pink, so this deference on the p s p d, actually the error. Now what is done, this error is fed back to the feedback control loop, and depending on whether this error is s positive error or a negative error. This feedback loop now gives an appropriate signal through the piezo scanner and this signal is in such a fashion. So, that all the four components sort of get elongated or shorthand by the same amount. So, that the movement of the scanner bottom easily the vertical direction only.

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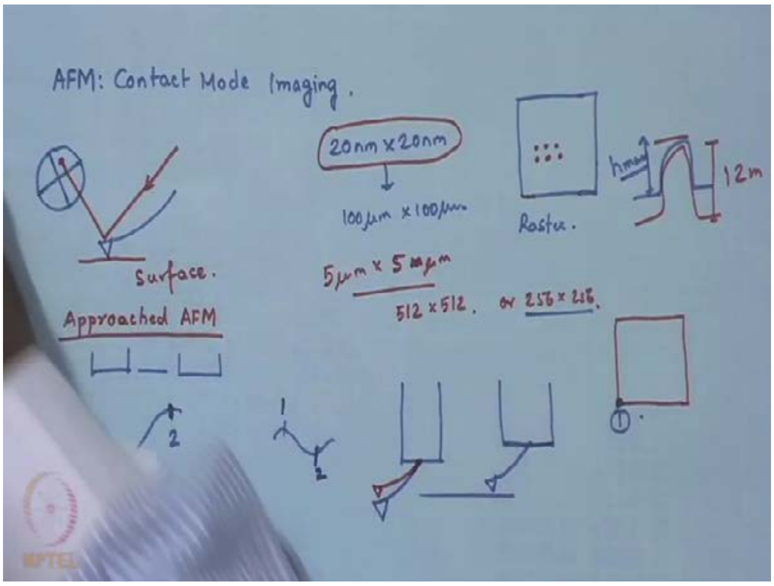

So, now what happens, it sort of, for this particular configuration you would. So, let us say this was geometry of piezo. So, this was initial configuration at point one, came to point two, it become like this. So, the deflection has increased. So, in order to sort of take it back it is original configuration what is needs to be done. The bottom of the piezo has to go up, and this can be achieved if now the piezo of the piezo tube becomes, wider and shorter. So, what happens is, for this particular configuration the feedback given in such a way, so that, the piezo becomes shorter and wider. So, that the deflection now after the piezo has reorganized itself in the z direction, matches the deflection that corresponded, that was here in point one, which in other word is the deflection that corresponds to the cantilever after approach. So, every scanning step, so from this point to this point, you see that, it is two steps.

So firstly, the piezo the scanner moves at a constant height, and then there is an intrinsic error, that is gets generated due to the change in the reflection, and that error is now effect to the piezo, and then the piezo readjusts itself, so that the cantilever again alters its height now, and the force back to the same level. So, this is grossly how a contact mode imaging is aching. So, every point to point first the piezo goes to the new point, then checks out what is the error that is, getting generated, and based on that error, the feedback operates and that appropriate error voltage is given, across to the piezo, so that the piezo vertically re adjusts its height. So, when a sample is an elevation, less separation distance more force exerted on the cantilever, piezo goes up, we have already discussed it. Sample has depression; depression means from point one to point two. The deflection is converted in to change in voltage, and the controller register in the feedback loop, controls force and distance record of the topography.

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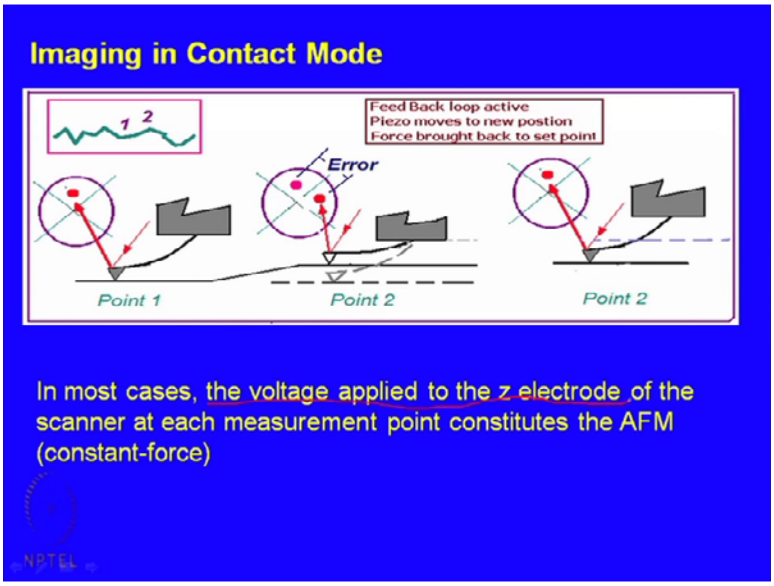

So, in most cases, the voltage applied to the z electrode, z direction of the scanner, at each measurement point constitutes the A F M data, we will discuss this in later detail.

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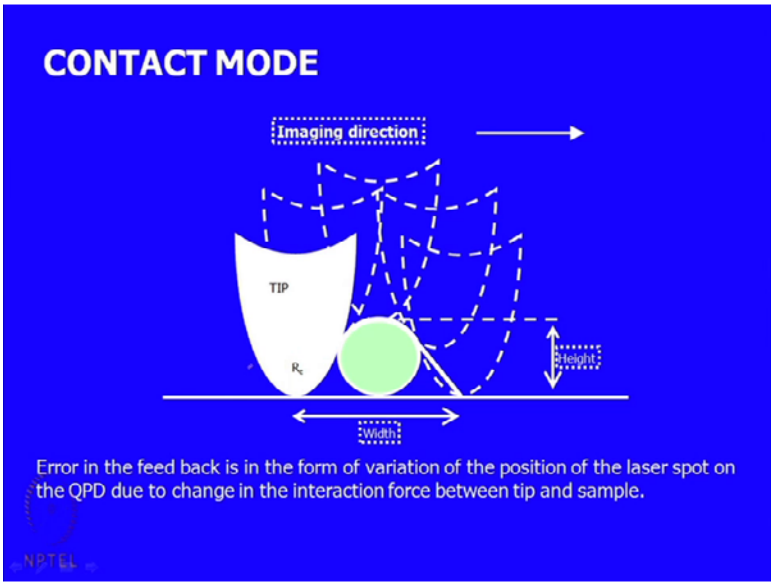

So, this is how contact mode actually works, here comes the tip, we have a feature height. So, it sort goes up and then eventfully comes down, and consequently we also understand that, every scan location, every time it moves from one point two other. One point to the other means one restring point to the next restring point. It actually under goes two intermediate locations; first there is a motion in the constant, maintaining the constant height, same height of the scanner. Then there is change in the deflection, change in the force, which results in change in the location of the laser spot, from the set point location, and then based on that, the error there is fed to the to the feedback loop to the scanner. So, that the scanner readjusts its dimension, and the level of force is back to the same value, as it was after approach. So, at every location, as the data is acquired, the level of deflection goes back again and again and again and again and again to the deflection you had set after approach, that is, in other words it is necessary for the A F M to ensure, before at lives that specific point, that the reflected laser beam is following at the point which the corresponds to the set point, that is how it operates.

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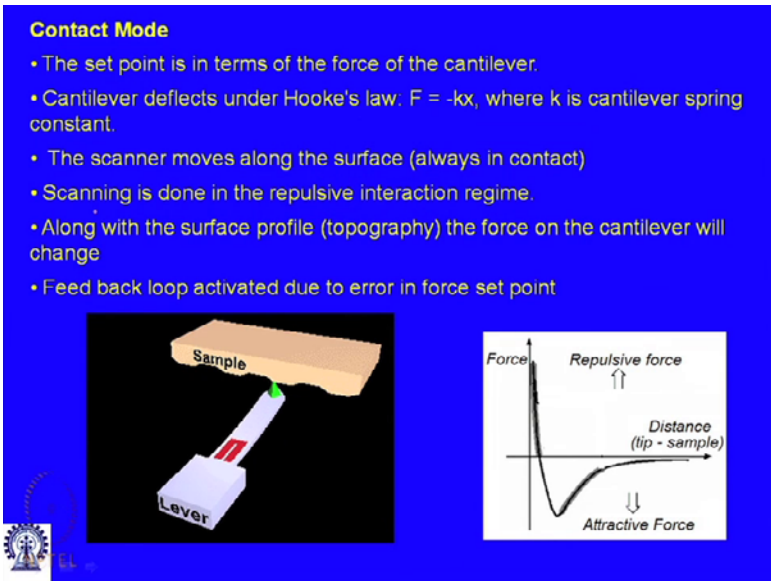

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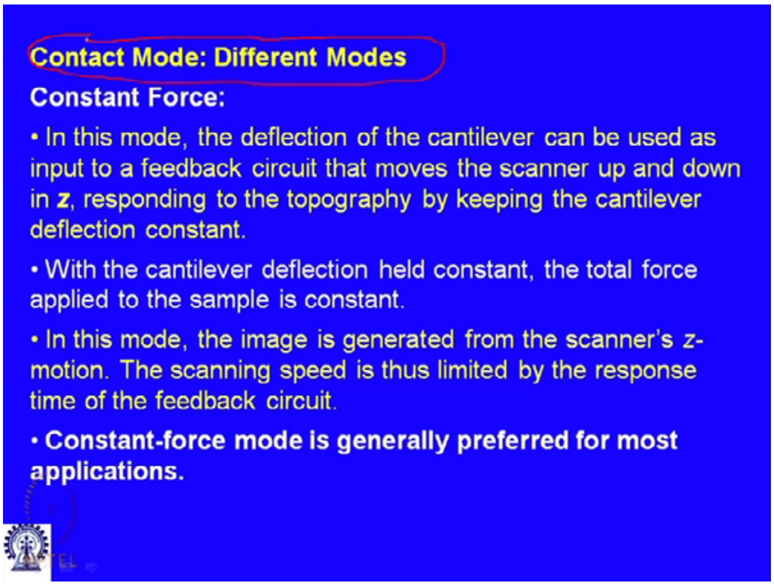

So, this carton, you can sort of see, the tip sort of adheres to the surface, and it scans. Typically there are two modes of contact mode of A F M scanning; one is the constant force mode, which have already discussed. In this mode the deflection of the cantilever can be used, as input to a feedback circuit; that moves the scanner up and down in z, responding to the topography by keeping the cantilever deflection constant. I guess you now know understand what it means. With the cantilever deflection held constant, the total force applied to the sample also is constant. In this mode the image generated from the scanners z motion. So what happens is, you can see here, the motion, the z motion of the scanner is actually now a reflection of the surface topography.

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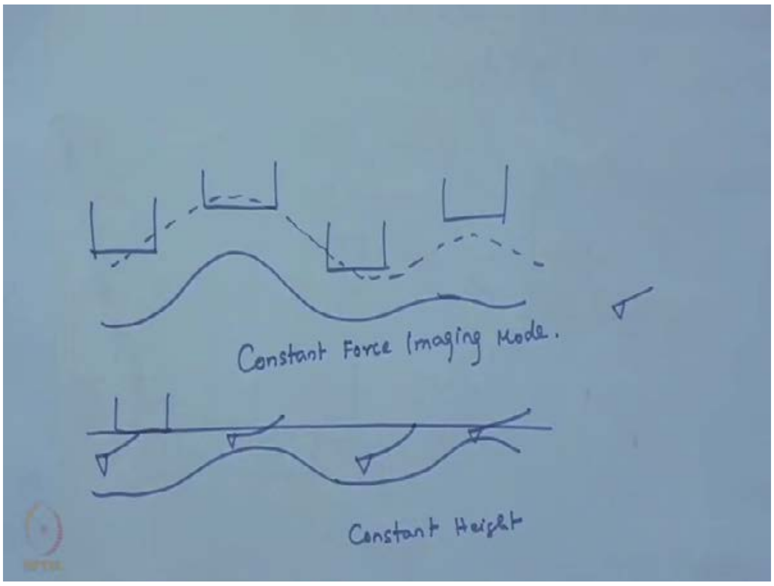

So, if you have a surface topography like this, your scanner will also move along in that direction. So, if you can simply track, the locos of the z motion of the scanner, then itself you are through with the generating of the topography of surface. So, this is what happens in constant force imaging mode. Constant force mode is very widely used and is very popular, and is used for most applications. There is a principle a constant height mode, in this mode the special variation of the cantilever deflection is used directly. So, in this case, the cantilever maintains a constant height, it does not change, and therefore what happens is, depending on the topography, from point to point, the deflection will change, and one tracks the deflation to generate the topographic constant. The biggest problem is that, your cantilever is short, and if the feature height is very large, it might not be able to capture it.

But since, we now understand in great detail, how the internal adjustment is done in a scanner. We realized that, even in constant force mode, the motion actually is spilt in to two parts, the motion of one point is other is split in two parts; first the motion is at a constant height, and then additionally. So, constant height mode is anyway is operational, and then additionally what happens is, after the first moment has been done based on the constant height mode. Then the change in the deflection of the cantilever in a constant force mode track, and according that the feedback loop sort of operates and you re adjust the vertical position of your scanner, and forces the back to the same level. So, you can just imagine that, if this part of your readjustment based on the vertical direction as well as the feedback loop, is somehow made absent, the what remains is actually the constant height mode of imagine.

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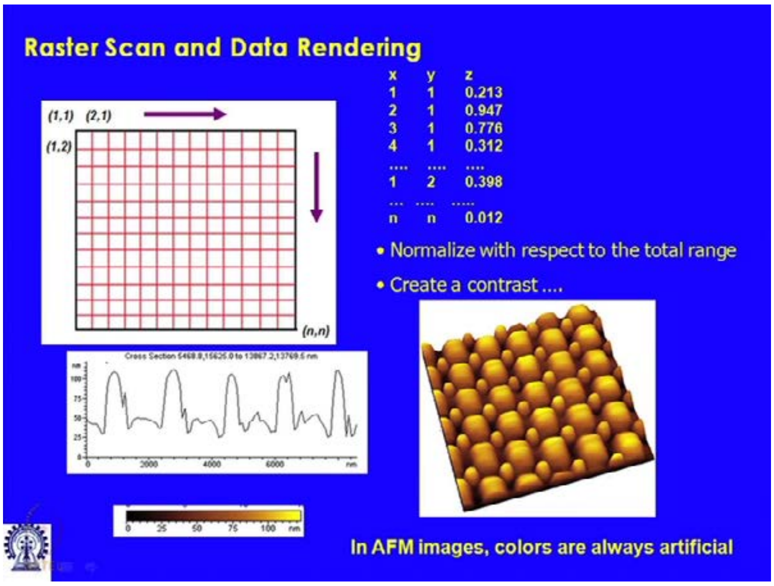

So, then what happens is that, once the raster's scan is over, so this is typically atomic force microscope image, what you could see. You see some color, but do not be surprise, that this has been brown color, what gets generated is actually a data file, which is like x y and z position. So either, the vertical position of the scanner, or the error voltage corresponding to the set point, either of the two, and this can be if it is in terms of voltage, it can be sort of transferred or converted in terms of the topography type. So, what we have is that, this is grid over rastering has been achieved, and at every point, so x and y. So, this is as we have already pointed out depending on the direction of the fast axis and slow axis, the tip physically visits every point, point by point and it captures the z information at that point.

So, unlike any other microscope, which is the final product is actually and optically image of the features. Here what you get, is not any image, but you get actually data file, x y verses z. So, you get the true z information at every point, and what is done to generate image like this is, to normalize the vertical height, and just create a constant contrast in a gray scale or something like that. Based on this normalization, you typically most commercial A F M will give you a color code like this, and which varies, again depending on the feature height. We will get images similar to this, but if you have very rough surface, the maximum scale will may be read has five micron, however you have a smooth surface, shallow features it can be a few hundred nanometers.

So, thing to understand, looking at this is color scale itself it becomes clear, so the darker zones are deep or varies and brighter zones are closer at higher locations. Remember that is an A F M images, the colors always artificial. This is more of a pictorial representation of a data file. The actual output is the data file, but what is most interesting, this is the only microscope that gives you the actual vertical resolution or vertical information. So, now you can sort of at any location, let us say along this line you can get a cross sectional line analysis. All you need to do, you need to do identify the line at which you want the information. The software typically does it; let us say this is for j equal to twenty five. And at every location corresponding to j equal to twenty five you have the z information. So, we can vey easily get a cross sectional image like this, which no other micro scope will allow you to get.

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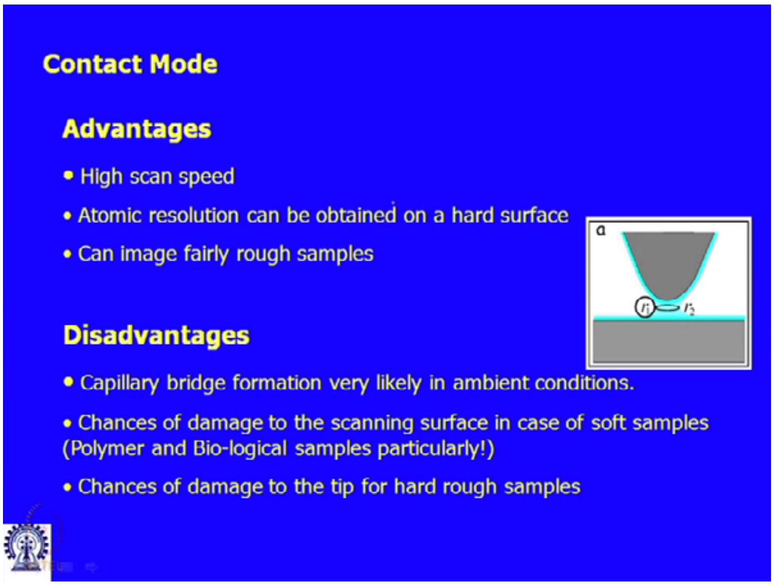

So, contact mode which is the simplest mode, and it is perfectly well suited for hard surfaces or hard samples like metals for examples, ceramics metals etcetera. The advantages are hi scan speed. Atomic resolution can be achieve to the hard surface, this is the easiest mode to implement, can image fairly rough samples, this off course, what is not written in the view graph, we must remember that this provides the best lateral resolution or as it is already written, off course that this is possible to achieve atomic resolution, but even other than that, even with a routine atomic force microscope without vacuum and anything. Seeing a lateral feature of three four nanometer, a contemn dart or nano particle is pretty root in using the contact mode imagine, but there are some disadvantages also. If you are not using a vacuum and your scanning in ambient, and let me also point out that an atomic force microscope can sort of work extremely well in ambient. You do not need any vacuum or sample preparation, or any specific chamber for running a atomic force microscope. And there can be capillary bridge formation, due to condensation of water from the atmosphere, between the tip and the surface samples.

So, that sort of what happens, is then this capillary meniscus sort of becomes the affective tip, you can still get the image, but this become this affective tip, and towards letters part of this class or may be next class we will talk about something tip consolation. So, this capillary bridge affectively increases the size of your tip, and that sort of destroys the resolution to large extent. Since you are actually, physically dragging your tip over the sample, so there is a possibility of a damage to both the cantilever, so which sort of can become blunt. The other possibility is that, if you are trine to new get a soft sample, instated of scanning this draggi**n**g action, this restring action can result in scratches on the film or on the sample. There is a potential possibility of both sample damage, as well as tip damage in contact mode imaging. And so these are some of the disadvantages.

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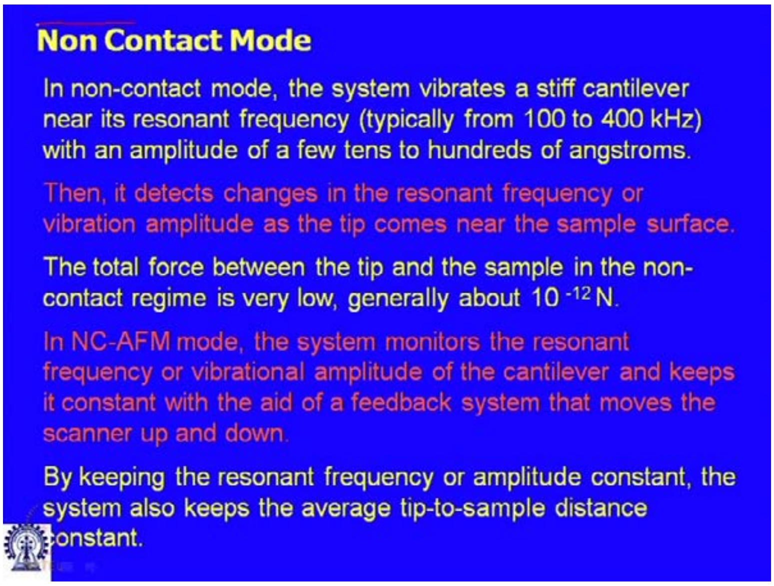

So, the next mode that came in to existence, was the non contact mode. I have pointed out that non contact mode is rarely used, and you will soon realize why. It is really used for imaging purpose, but there are some special purpose imaging, like electrical force microscope or magnetic force microscope to identify electrical or magnetic domains on the surface, where non contact mode imaging is used, I mean, but it often used in conjugation something like a contact mode imaging, and then by a subtract mechanism or something like that, you would like to dig out different domains. We will discuss some of these techniques probably in the next class, so then you will have an idea.

So, what is done in noncontact mode is the, system vibrates a stiff cantilever near its resonant frequency. So, yesterday in the previous class while we were discussing about that choice of cantilevers, we also had a crate area about resonant frequency, and I mention that this resonant frequency thing will be critically important, when we talk about the contact, when we talk about the noncontact mode, and the taping mode, so here it is. So, the system vibrates as stiff cantilever near its resonant frequency, typically from range is one 100 to 400 kilo hertz, with an amplitude of a few tens to hundreds of angstroms. The amplitude is few tens of nanometer.

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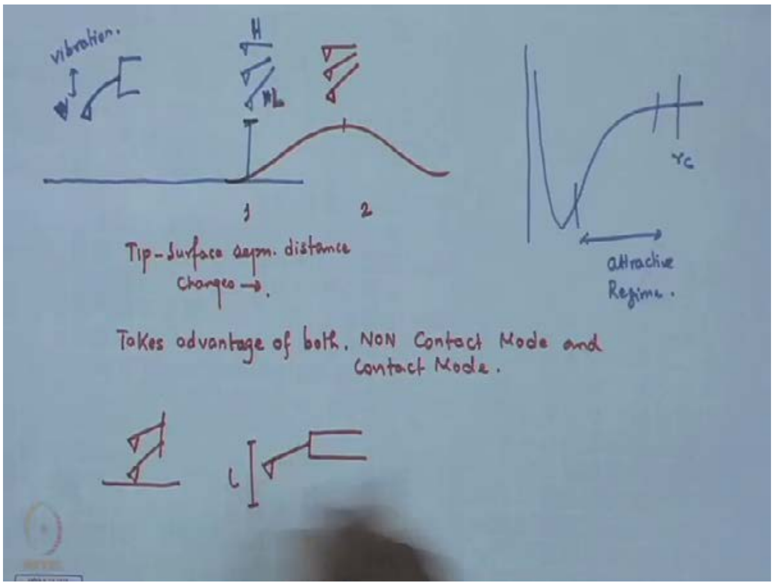

So, what is does something like this. So, it is not in contact, it is somewhere over here. It is within certainly closer to r c, but it is within the attractive region, and then an additional drive, it is given a vibration or oscillation. So, there is now an oscillation with an amplitude let us say, x sort of oscillates between this stage. What is done is that it now rusters in this configuration. So, the cantilever is oscillating like this, it is oscillating like this, and simultaneously rastering in along this x and y, along the fast axis and slow axis. In contact mode while rusters it is in direct contact with the surface. Here it is not in contact, first thing to realized that it raster’s, but it is not in contact. And secondly in contact mode cantilever was tapping, but here you apply and additional vibration. It vibrates, so there is an oscillation like this, but as a part of the no part of the cantilever, during the oscillation, torches the samples surface completely in non contact.

So, the limits of the oscillation, ensures the there is finite gap between the sample surface and cantilever tip. So, its oscillating like this, between its lower and higher position and h and l, and in this configuration it sort of moves. Now what happens is, so let us say this is point one this is point two, as there is a topography. So, first thing we have to ensure that, you are far away from the surface. So, depending on how rough your surface is you choose the location, where you want to do this imagine. So, what happens is from this point to this point. Since the surface is now closer, this amplitude sort of gets effected, because of that fact that while it is that the lower end of it is oscillation, it experiences the interaction of the attraction of the surface. So, this change in the oscillation, the detection changes in the resonant frequency or the vibration amplitude.

So, either the resonant frequency mike change, or the vibration amplitude mike change, as the tip surface separation distance changes, which is actually tract, and based on that you generate a contrast. So the contrast, which was there in terms of. So, based on that, you first generate an error. So, again this can be mounted to a piezo, that can piezo can sort of move up and down, to maintain the level of oscillation or resonate frequency, to its original level, and based on that, you can again generate a similar data file, as corresponding to what we have done in contact mode, but the only deference is, here the variation in the height was based on an error, which was generated on the Q P D, based on the actual change in the deflection of the cantilever, due to change of force.

In a noncontact mode error is generated not based on the depletion of the cantilever, but is based on the amplitude, resonant frequency or the vibration amplitude of the cantilever. Important to note since the cantilever, the probe is not in direct contact with the sample. So, the forces are very low, it is of the order of the ten to the power of minus twelve neutron, which is grossly four orders, three to four orders, lower than the forces, you typically you do with non with a contact mode. By keeping the resonate frequency the amplitude constant, the system also keeps the average tip sample distance constant, so this is what we already said that the feedback, now operates on the amplitude or the frequency. So, the controller sort of tracks, the change in the amplitude that is typically what is done, and when we discuss taping mode it will be clearer, how this change in the amplitude can be detected.

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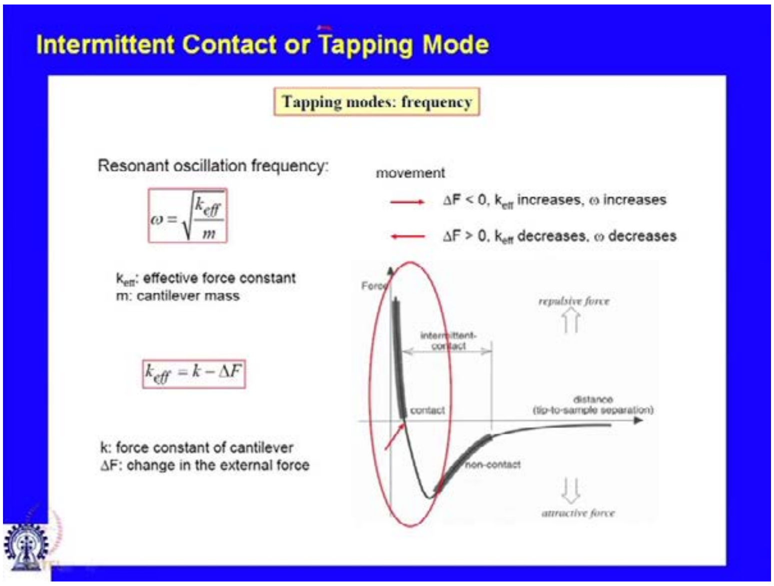

So, this is more important, so the biggest problem is. So, taping mode is something, or the intermittent contact mode, which sort of take advantage of both, noncontact mode and contact mode. So, the biggest advantage of contact mode is good quality image, in the better quality resolution, but the biggest advantage of noncontact mode also has its own advantage, and that advantage is that the chances of sample damage is negligible, because the tip does not never comes in contact with the sample. So, chances of sample damage during rastering or the tip becoming blunt with progressive usage, both are almost minimal in noncontact mode, but it since it does not coming contact, it is sort of this advantages, is more than offset in terms of poor resolution. So, taping mode is halfway in between. You apply this additional amplitude or vibration to the sample tip, but instead of maintaining the sample, oscillating entirely in air, what you allow is that, as a part of this. So, you bring it closer enough, so that has a part of this oscillation, it in one of the ends it sort of touches or taps the surface. So, it is grossly the same concept, that you given an amplitude. So what happens is, you now give a free amplitude, so after you align you give a free amplitude, let us say the limit is l.

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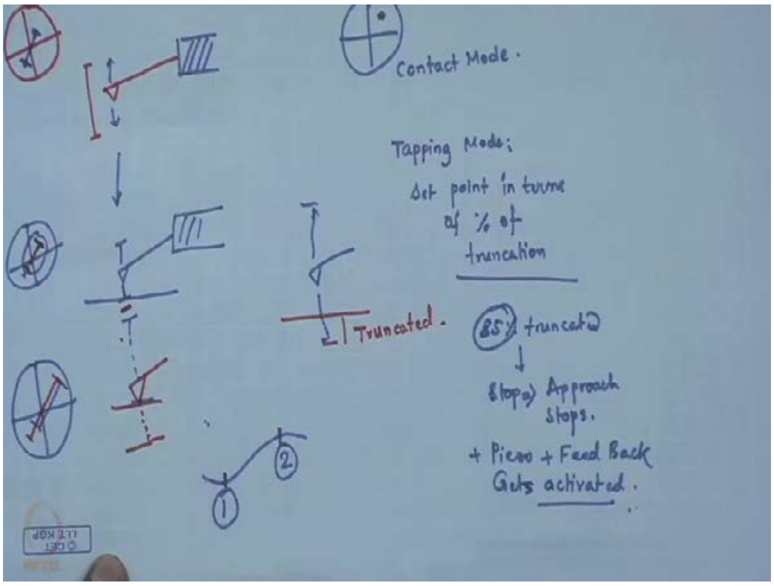

So, correspondingly on the Q P D, now the laser spot sort of travels, continuously from this two limits. So, this is the free amplitude of the cantilever that you have given. The frequency that is chosen for oscillation is the resonate frequency. We all know what is resonant frequency, we know what resonant frequency. So you are somewhere over here, closer than a noncontact mode operation, but little further away from contact mode operation, which is purely in the repulsive region. And what happens is, your approach now is with a cantilever, which is not only align. So, unlike a contact mode approach, where your approach started with a cantilever, which was aligned purely aligned. Here your approach starts off with a cantilever, that is first aligned and then a amplitude is given to it.

So, what happens is, as the cantilever comes closer and closer to the surface, as it is oscillating, so what happens is, at some point it start's hitting or tapping the surface towards this end of it is oscillation. And consequently on the Q P D. let us say this was the range corresponding to the free oscillation, the range now gets truncated, because it cannot go beyond this. Suppose this was the maximum, up to which it should have gone, because of it is oscillation, but what has happen, because the surface has now come. So, this part blown up picture, during the oscillation it touches here, and it fails to travels this part of the oscillation, because of the surface. So, instead what it does, it is goes on taping or knocking the surface like this, and this results eventually.

So, this is an intermittent contact, unlike a contact mode cantilever things were always in control that is not case, but it is coming in contact. A noncontact mode a cantilever could be something like this, it is just oscillating in air, it is never coming in contact. So, here is a noncontact mode cantilever, here is let us say a taping mode cantilever. And a contact mode cantilever could becoming straight, touching the surface like this. A taping mode is something like this, noncontact mode is something like this. You give an oscillation, so a noncontact mode, this is let us say the surface we would like to scan, it will scan like this. In taping mode it will be scanning like this, so this is the difference. It is it sort of the essential physic of the operational principal of the noncontact mode scan, but it does in intermittent touching.

So, it again feels the sample like a contact mode cantilever, which was completely absent in case of noncontact mode imaging. The noncontact mode in noncontact mode imaging, the tip was never actually gaining access to the sample. So, what happens is, because of this truncation in the oscillation, it cannot cover this part of the cycle, and therefore there is truncation, so I will write again in a bigger fashion. So, let us say this is the Q P D, this corresponds to the free amplitude, and because it is now truncated part of it. So, this was the, let us say the free amplitude in air. Now, the surface comes in, so this part of the thing is truncated. And this truncation limits it is oscillation of the laser spot by this amount. So, you typically, unlike in contact mode, where you set a set point in terms of force, here you would in tapping mode, you set a set point, in terms of percentage of truncation.

And so you say that when my signal is 85 percent truncated, I would stop. Stop means approach ends, and pieso and feedback gets activated. So, now it has reached one location, let us say on the surface where it has approached, where it is taping with eighty five percent or eighty percent, or whatever is the number. You have chosen a free amplitude, it goes to the next location, because of the variation in topography, it can be further truncated. So, suppose it was eighty five percent of the free amplitude, this location is closer, so it is further truncated by some additional percentage, let us say it drops now to seventy eight percent. So, that seven percent additional truncation, now access the error. This error now fed to the scanner, which now retract or changes its dimension in such way. So, in this particular case, the scanner could sort of become fat and short, so that the tip edge can go up, and it sets back to eighty five percent limits again.

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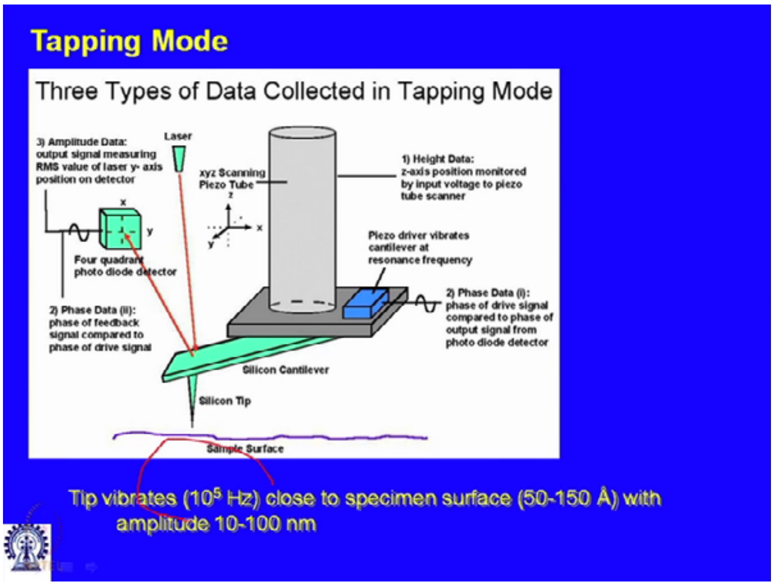

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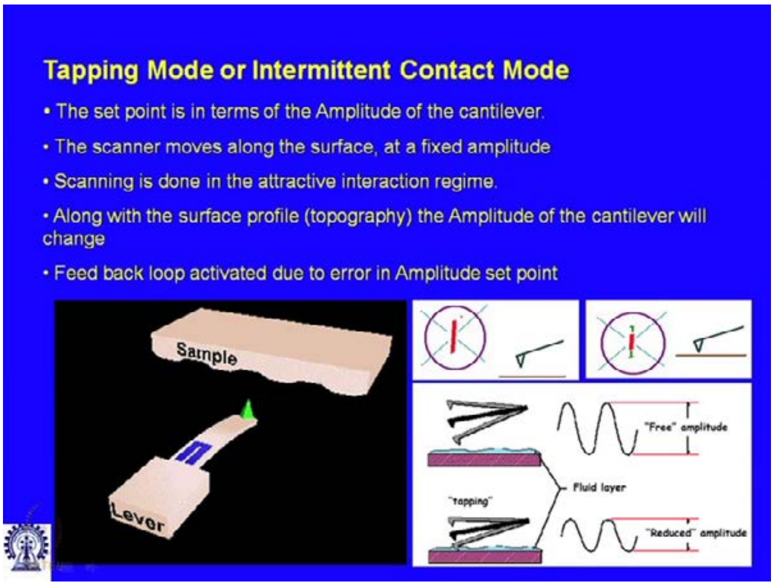

So, this is how, sort of tapping mode works. So tip vibrates close to the sample surface, five to fifteen nanometers away with an amplitude hundred to ten nanometer, and this cartoon will give a nice idea about the taping mode. So, here you see the, this is the moment of the laser path, as a corresponding to the free amplitude oscillation, and this is far away from the surface, and since the surface is now close it is sort of gets truncated. I would rectify this figure, so one side it gets truncated, and this is the error that is get generated. So, first thing is, did you utilize this truncation, to pick up the location or the position at which would like to accomplish or complete your approach. So, you can specify a instrument will come with an option, to say (( )) stop, and in case of contact mode you will be specify in the force, let us say three mini force that corresponds that amount of deflection.

In taping mode or intermitted contact mode, you will be specifying the percentage of free amplitude at which, you would like it to stop. So, this again, gives you an idea, so this is the free amplitude. And here since tapping on the surface or due to the confinement imposed by the surface. The amplitude sort of gets reduced, and based on this set, you set your set point, and then one point to the other as the probe moves or the instruments, or the cantilever moves from one point to the other. There is further truncation, and that generates the error. And this error is given to the feedback loop, to generate the errors signal and piezo sort of, then retracts or contracts in the in the usual fashion, and the data gets generated. So, the final imaging option is very much the same.

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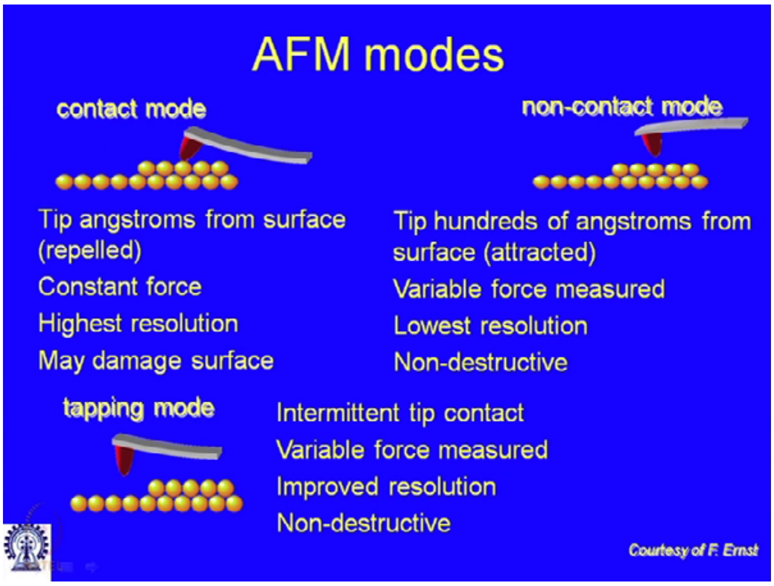

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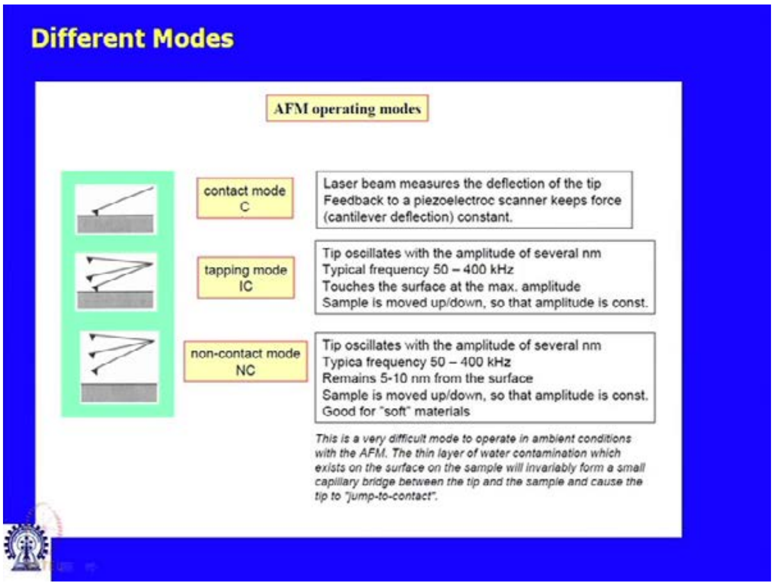

So, advantages are pretty high littoral resolution much better than noncontact mode. No damage to the sample and the cantilever tip, can image fairly of surfaces, and ideal for scanning liquid surfaces, liquid cells like that. Disadvantages, off course resolution is poorer then contact mode. Scan speed is much lower as compare to contact mode, and under liquid, because of continuous tapping or continue motion, there can be repulse or local turbulence, that can be get generated, which adds to the noise. So, in a nutshell this is sort of an idea what you get, about the deferent modes of A F M. This is contact mode, this is noncontact mode, what is missing in this carton is that non contact mode, also should also should oscillate, like the one see here, is this is what tapping mode does. So, it sort of oscillates and then moves. This some sort of compression between the operating modes. So, these are the critical three modes I would now say. Though fundamentally I would still stick to may two mode or the two mode classification we did, that is the contact mode and the noncontact mode. In contact mode, off course first difference between noncontact mode and contact mode is the contact mode is the cantilever stationary, in noncontact as well as in intermittent contact mode.

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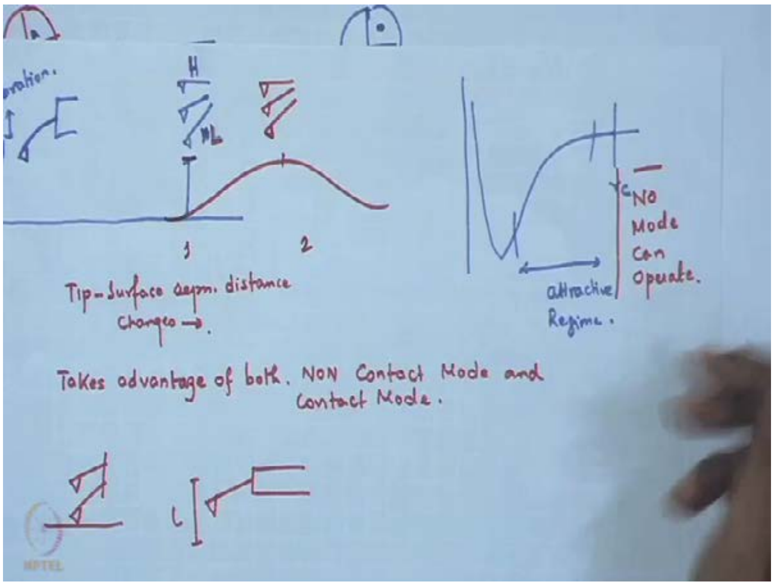

What you do is that given additional oscillation, again based on a piezo eclectic driver to the cantilever, and it sort of oscillates at it is resonant frequency. You choose the amplitude by choosing the motor power of the drive power. And you track this change in the amplitude as a function of proximity of your surface to the tip. In the difference between, but in contact mode, there is no hardware to give any fluctuation to the cantilever driver, cantilever. So, it is stationary it is directly station on the surface, it operates in the purely repulsive regime, as you can see here. In contrast the noncontact mode operates for that away surface, but important thing to note is all the modes, operates only when, you are at a zone or at a location, where you have active interaction, so none of the A F M modes can operates here.

So, that not possible, because you need to have the atomic interaction of the forces in place for in A F M to operate. Then, the some of the limitations of contact mode are set of taken care of by the noncontact intermittent contact mode. So, particularly for polymeric material, or soft materials so one would preferable not use the contact mode, because what happens is the tip is sort of during the rastering, tip sort of drags along the surface, and then there is problem of scratching, so one would go for contact intermittent contact or noncontact mode. So, now the standard practices to use either contact mode, or a intermittent contact mode. So, here are the details which are sort of already I have discussed. Noncontact mode also exists, but is really used for imaging, and off course we will see that, in some special cases it is used.

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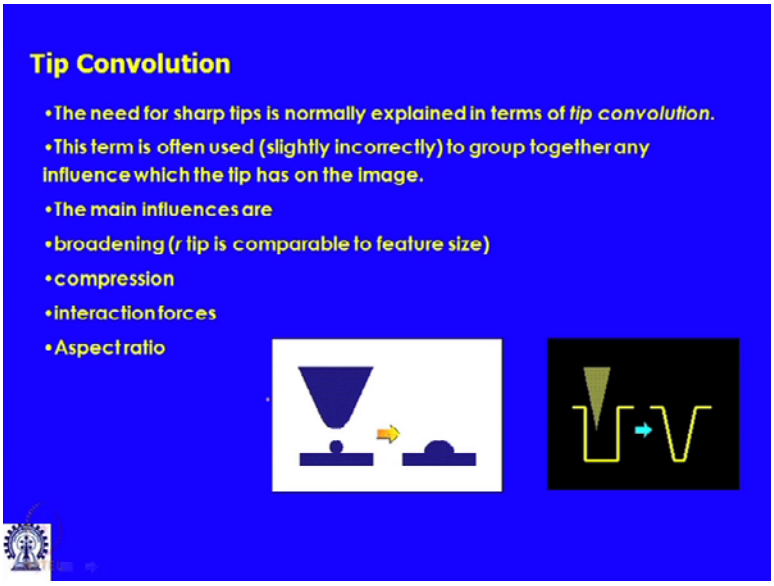

So, one of the, so this is applauding principle of A F M, but one has to very careful, because the image you are seeing is sort of raided image. It is not a true image, that is you get an x y verses z data, and which is the transfer to sort of an image. So, that it can be understandable to the user. One major thing is that the resolution of the image to a large extend, as we have been repeated telling. The resulting resolution of the image large extent is an function of the tip size, because you can understand that if you have a feature like this and your tip is wide like this. What we will see is, a large feature like this, or if you have a deep (( )) like this, and we have a tip, which cannot go in, because of confinement or fouling over here. The effective geometry you will see, will be something like this.

So, this effect I mean, I would say that, it is some sort of an artifact, that sort of gets generated, because of the geometry of the tip to a large extend, which can be, because of the some geometrical dimensions of tip are comparable to the feature size, that can be one of the problems. The other problem is that, during operation tip has sort of become blunt, or something like that, or your tip is to large has compare to feature size. It is not that if you are trying to scan five nanometer feature, with a tip feature tip radius of curvature of 20 nanometer, your instrument will fail to scan, but what you need to understand that 20 nanometer tip, you cannot really scan a five nanometer feature, what you will get will be. There are complicated relations as I am not going into it, but what will get, will get much larger than that. And the artificial dimensions what will come out, will be sort of, to a large extent dependent on the geometry, or the radius of curvature of the tip.

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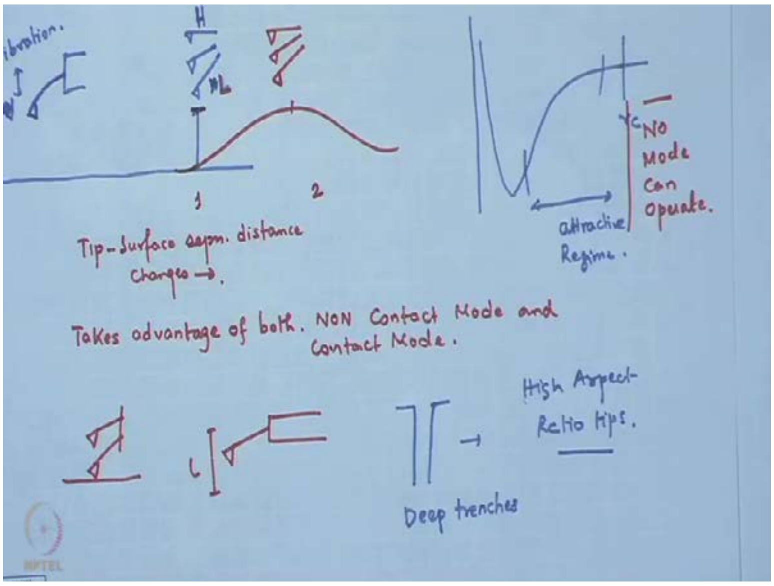

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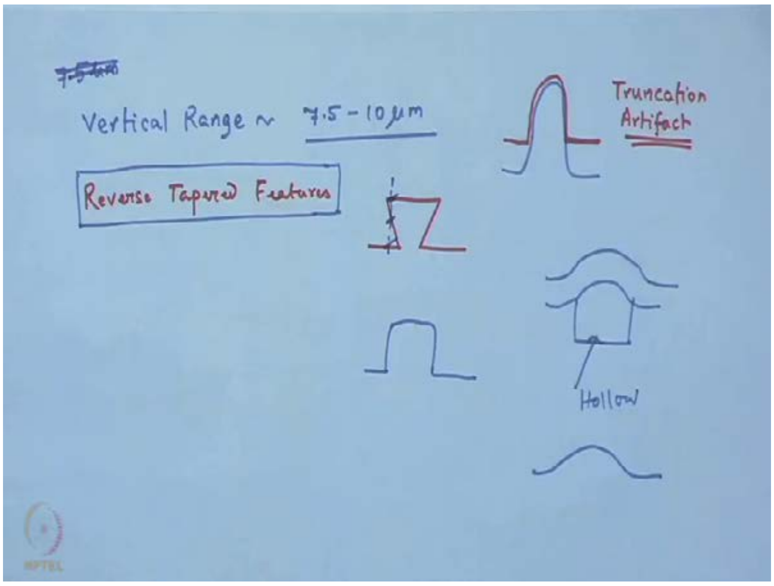

So, this is in order to tip convolution, it is extremely important that you have some bit of idea, about the surface you want to use or you want to scan, and you get appropriate tips. So, if you are, let us say trying to scan surfaces with deep trenches. It is better to go for high aspect ratio tips. Interesting thing to remember or important thing to remember, is that, here unlike any other microscope like scanning electronic microscope or an optical microscope, the feature size is not limited by the optical diffraction, of the depletion of the elimination source, but large extend the feature size is limited by the tip size of the radius of curvature of the tip. And in certain cases it can also be a function of the height of the tip.

Height is an important parameter that comes in over here in an atomic force and microscope, because no other microscope can give you any idea about the height of the features. A F M can sort of scan almost any type of surfaces, off courses we mentioned in one of the pervious slides, the vertical range ten micron. So, it cannot scan feature which are rougher than that. Off course it is can scan, but if you have a rough feature the image you will get will be something like this. Again some sort of an artifact, this is a truncation artifact that will come in. So, you have to worry about this thing, but only one type of feature, it cannot scan or generate the true images, and they are the reveres tapered features. We need to understand that if you have some features, which are like this.

Your A F M will not be able to scan, and you may want to think what would be the likely, geometry, you will get something like this, because a tip, since its coming from one position to the other, it will pick up, it cannot pick up three different heights of the sample corresponding to the one single line z. So please remember that, those A F M was a extremely versatile, reverse tapered features or hollow features or something like that, it is not possible. So, if you have some hollow features like this, let us say your A F M will pick up the surface feature. So, with that we come to an end of this particular class. In the next class I will take of the some of the additional imaging information or additional information, that can be extracted from an A F M as part of its scan, which are sometimes refers to as the secondary imaging modes. Thank you.