Soft Nano Technology
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Lecture - 24
Atomic Force Microscope – I

Welcome back. We now start the 24th lecture of the course and we start of a different module. I am not very formally following the module number or whatever. We can say that this is sort of the 4th or may be a 5th module.

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If we consider introduction to be the first module, basic concepts related to surf to the surface tension to be the second module, even consider patterning techniques to be one module as a whole or you can consider may be we will better. Let us consider photolithography to be the 3rd module, soft lithography will be the 4th module.

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So, that way we are now starting our 5th module. So, when I upload this in the list I will make this as 5. So, 5th module looks very short, but it is a very interesting and exciting one I can I show you because, again you are going to learn something. Typically you might be worried because most of the time you talk about learning and instrument you end up mugging up a of lot of things and that is something I am not going to do make you do up till now probably you have understood that.

We are focusing more on the physics reason I want you to learn atomic force microscope, is that it involves physics that is very elegant number one and based on whatever we have discussed so far primarily one of the thing that is the Van Der Waals forces that plays a very significant role even in the operation of an atomic force microscope.

Thirdly AFM or one can say that the invention of the AFM is one of the prime movers in tremendous amount of activity that one has seen in nano technology. May not be in quantum dot type experimental nano signs where the transmission electron microscope plays the most significant role. There are areas where one is to use other techniques like scattering and things like that, but particularly when it comes to nano technology or nano scale research related to surfaces when you see features, when you have very tiny features you probably cannot make any progress without an atomic force microscope.

That is why whenever you talk about a microscope, the first thing that comes to your mind is an optical microscope. I am not teaching you optical microscope. When one talks about higher magnification imaging the most popular device across the world is a scanning electron microscope, which also I am not teaching you because there are n number of courses on material characterization and things like that where you really line learn lot of things about scanning electron microscope. How the lenses focus and how you generate image and things like that, but I am focusing you only on atomic force microscope because I think it is very important to know it and also you have already seen that many of the things we have discussed you actually need AFM.

A classic example for that is the last example we took in the last lecture of soft lithography. You create structures with different features height, but who tells that you have actually succeeded in creating structures with different features height and only AFM can tell because all other microscope just like a photographic image presents to you a projection of a 3D assembly or 3D objects or surface with some limited vertical feature height on a 2D plane. Only an AFM generates an image in a completely different way and therefore, it is important in fact, it is not a n over statement. The concept of an atomic force microscope in fact, changes the idea of how one sees.

So, that is really translation of signs I mean things got completely different beyond this. It is also very interesting that AFM is a very young, a very reasonably recent development. The whole concept was development first in 1982 by a couple of scientist by Binning and Rohrer show their photography really what showing and. So, powerful in fact, it was 1982 AFM was not been discovered AFM was discovered in 1986, but the (Refer Time: 04:51) up to that atomic force microscope scanning, tunneling microscope STM was discovered in 1982 and the discovery was so, powerful that they were rewarded with the Nobel Prize in 1986. This is one of the in the recorded history, this is one of the fastest example so, where from a discovery to a Nobel price has taken such a short period of time.

In fact, the year they got the Nobel price they came up with the discovery of atomic force microscope in 1986. This is 2016 so, that way we are actually celebrating 30 years of existence of AFM, which is a good time for all of you to learn and enjoy this wonderful instrument. So, this is what we will learn in AFM.

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Then what remains in module six will be thin film instability and association pattern formation, which I again tell you it is going to be exciting. So, a brief history about the SPM in 1980s scanning probe microscope produce the first real space image of a surface. What does that mean? In simple terms you first get an idea about the height the z component because in all other microscopes what you actually see is some features like this and you see it in the form of a picture so, that is actually a projection.

A projection on 2D just likes a photograph; so if you look at a photograph, you tend to get a 3D feeling right? You take picture of 2 people standing one closer to you one far away; you take a photograph with your camera or your cell phone or whatever. From the photography you can still tell well a person is standing closer than person b. That is because you have some knowledge about perspective and from that you can tell somebody who is closer to you will look big, but reality is if one asks you to find out from the photograph what is the gap between these two persons you cannot tell that. That you cannot tell because you have essentially mapped a 3D system on 2D plane and therefore, you lose some information everything comes at a cost and in this case the information is the gap between them.

So, how this is one done we will learn in this lecture and may be in the subsequent few lectures. SPMs are used in wide variety of disciplines including fundamental surface science routine surface roughness analysis, 3 dimensional imaging and literal resolution with an STM at least one can go down to at least atomic level, but even may be micron size other stuff are useful. The scanning probe microscope with a vast dynamic range so, certain things are there. In certain cases it is another very very important aspect of an SPM. I should have highlighted I forgot. This you see we have written a heading SPM which stands for the scanning probe microscope.

But in the course I declared sort of we are going to focus more on the atomic force microscope. So, there will be a slide soon which actually to gives you an idea about the SPM family and AFM is the most prominent member I would say of this SPM family, but there are other methods and many other names you will find again here pretty similar to soft lithography of course, which actually use the AFM, but in different modes under different conditions to generate additional information and that is exactly what is written here. The scanning probe microscope can measure physical properties such as surface conductivity, static charge distribution, localized friction, magnetic field, elastic modulus etc.

As a result applications of SPMs are very diverse. Having said that I must admit that I am not an expert in AFM and all I will do is in this course I will give you a basic gleams about the function of the basic functions of an atomic force microscope, with some idea about some of the advance features, but one can easily run a full 40 hour course on different aspects of an atomic force microscope and obviously, due to constraint of time I cannot do that and that will not be such a general course it will require specialized knowledge.

So, please do not expect that please do not feel that since you have heard 4 or 5 lectures by me on AFM may be very some basic sketch idea about the STM that you have become an expert. That is not the case, but my whole idea is essentially to give you a platform. So, that you know how an AFM works and if you really want to build your carrier or want to go deeper I think this course will provide you some bit of platform from which you can start integrating your knowledge.

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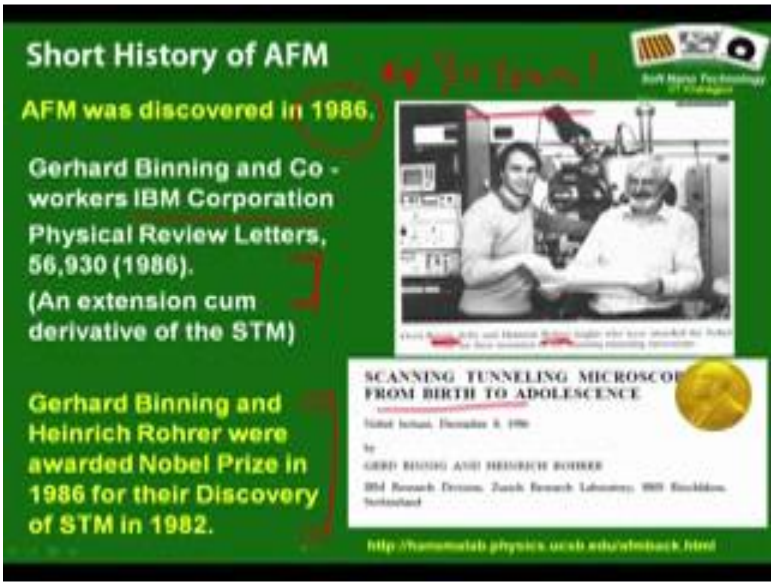

So, how does it work? I mean again coming back to what I just said. So, AFM was discovered in 1986 so, we are celebrating this which is good. So, Binning and Rohrer and Binning these two are the IBM Corporation. They discovered the this is the paper in PRL that talked about the invention of the AFM, but they already got the Nobel prize for their invention of the STM in 1982 and you can find out all the details about it is worth reading about how it works.

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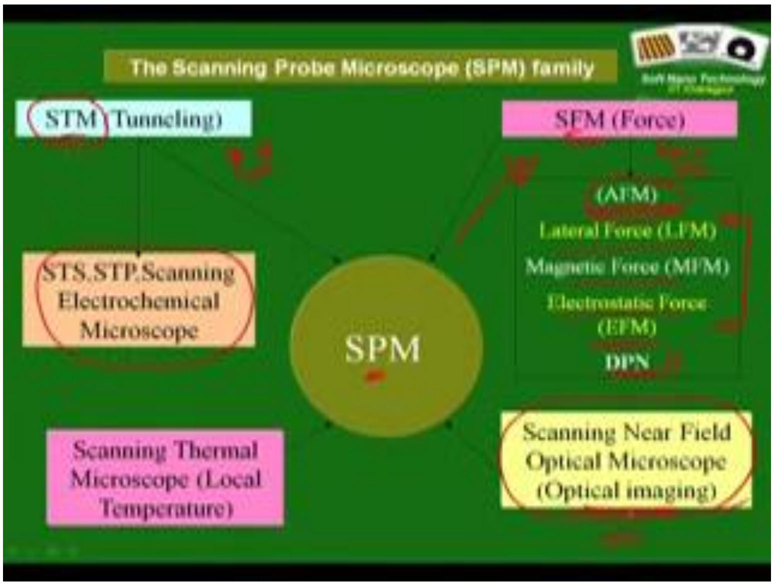

So, what is it? This is again a good slide which sort of highlights you about the different members or the different variants of SPMs that are available scanning probe microscope. This P is very important. You actually have a probe which may vary between an AFM and STM which of course, varies between AFM and STM which in fact go either touches the surface or goes very close to the surface and then gathers the information. So, first thing to understand that an atomic force microscope does not have any optical lenses through you actually see.

A probe goes and generates some data and all the images that you see with an SPM or an AFM or STM are whatever is sort of artificially rendered data. We will soon see what type of data an AFM actually generates as it scans? Why this scanning because this probe scans the surface in a rostering mode. It visits a particular area interest about which you would like to gather information it goes from one point to the other picks up certain information and finally, generates the data file which one converts to an image. Again you can understand that STM runs with a computer interfacing and it is a very late development in 1982 the computers are already there.

So, you really do not have any version of an AFM that runs without a computer interfacing; so the key members of the SPM as I told you the first one. One of the most powerful once even today for certain type of research, scanning tunneling microscope STM and then there are other version of STM. We will just very briefly touch upon this because understanding the concept of AFM is easier from the concept of an STM and then also you will realize the motivation of this group that they invented STM they got the Nobel prize and then they still came up with a AFM which in fact, is now more widely utilized by groups across the world.

So, AFM falls into the second category major broad category SFM scanning force microscope. What is this force that is an important thing to understand? We will see what force we are talking about. We will be talking mostly about the atomic force microscope. Again a very simplified view how it works, what are the key components and what are the things you can do, but as I told you there are various additional modes that are possible in an AFM and I will touch up on may be some of them. There is another very strong group of technique and this DPN is a very fascinating technique. It is DPN nano lithography.

So, it is sort of essentially combines the concept of an atomic force microscope with the rastering of let say focus stand beam or lithography, but it does not use any high energy beams, but instead it realize on self assembly. Again a forming self assembly mono layers along the contours or along the trajectory over which the AFM probe as travels. So, maybe I will spend two minutes on this technique as well.

There are a group of techniques which are known as scanning near field optical microscope. It is a very advanced technique and I am sorry, I will not be talking about them in this particular course. So, if you want to have an idea you can find out additional things from the literature.

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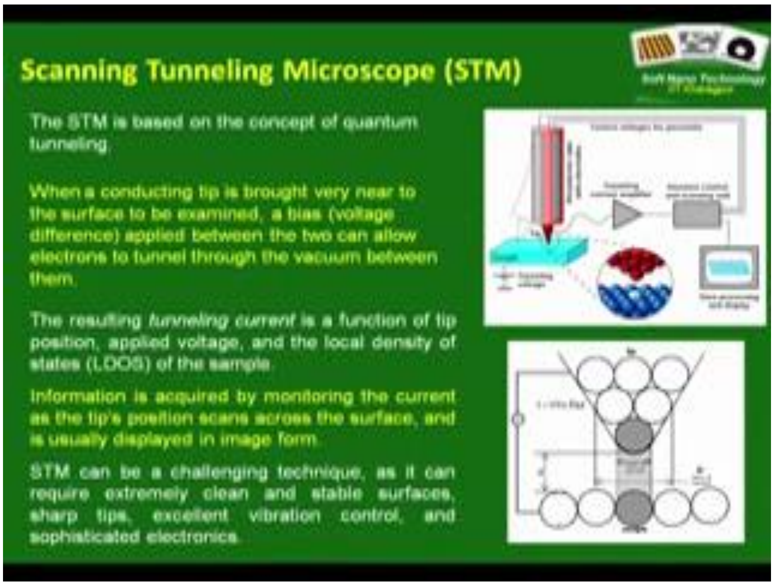

So what is a tunneling microscope? In order to understand this you need to sort of have a very elementary idea about what is tunneling, tunneling current. See we all know that

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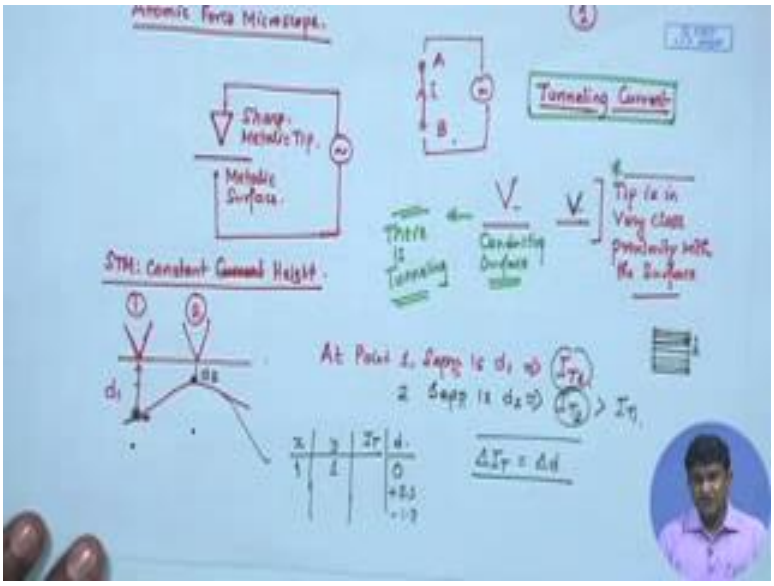

If you have a conductor a conducting wire is connected between points A and B and you apply a voltage. There is flow of electricity. This is known this is conduction, but it turns out that if you take a very sharp metallic tip, very close to a metallic surface and apply a voltage it is a very simplistic picture.

Let me tell you apply a voltage there might be some electrons flowing from the tip may this is what it tells. So, there might be some electrons flowing from the tip to the surface through the medium right? Because there is no physical contact between this tip and this surface, but both of them have to be conducting. So, again the same thing here it is exaggerated here, but there can be some flow of electrons or which means that there can be some current this current is known as tunneling current and this is known as the tunneling effect.

Again this is like a school wise idea what is tunneling current, but for our context I think that is more than enough. Quick thing to know of course, tunneling current is seen when the tip is in very close proximity with the surface however, within that range within that proximal range the strength of the tunneling current varies amongst other things like the local density is of state of the surface etc. Let us not get into the all those quantum mechanical details because even I do not have much knowledge on these things because you need high quality knowledge in physics, but what we can argue that within that range where you see tunneling current or you observe tunneling current the strength of the tunneling current depends on the precise separation distance between the tip and the surface.

So, in other words very simply put if the tip is closer to the surface the strength of the tunneling current will be higher of course, if the tip touches then there will be direct conduction there will not tunneling. That is something you do not want to have. So, these are the two quick things to remember when a very sharp metallic tip comes in contact with a metallic or a conducting surface. So, that there is tunneling and if you sort of vary very precisely the relative position or relative gap between the tip and the surface you can vary the strength of the tunneling current.

So, let us start our discussion of how an STM works based on this. The resulting tunneling current as it says when a conducting tip is brought very near to a surface to examine it as to be a conducting surface of course and a bias so, the voltage difference is applied between the two can allow electrons to tunnel through the vacuum of course, you need a vacuum because you do not want to this area or want to perform this experiment in air. Why because the electrons which are tunneling if you have a air molecules present they might collide with the air molecules and get scattered which you do not want to have. Therefore typically an STM is a high vacuum instrument. It operates under high vacuum. The resulting tunneling current is a function of the tip position.

How close of a far away it is applied voltage and the local density of states of the sample. What information is acquired? We will talk later. STM can be a challenging technique. In fact, it turns out one of the reason why AFMs becomes more popular one must understand is one of the thing is that it sort of eliminates one major limitation of an STM I do not know whether you have noticed, while I have been discussing and that limitation is the basic physics allows an STM to run only for a conducting sample and not for all other types of materials. So, that is in deeded limitations. AFM as we will see circumstance in that problem that was one of the key motivations for the development of AFM. The STM was there it was such a wonderful technique, but it was only limited to metallic surface.

But the other thing is that STM really requires is a very very sensitive instrument an AFM is a much less sensitive instrument. It does not required vacuum or any sample preparation and things like that and therefore, it has become very versatile and it is quite popular.

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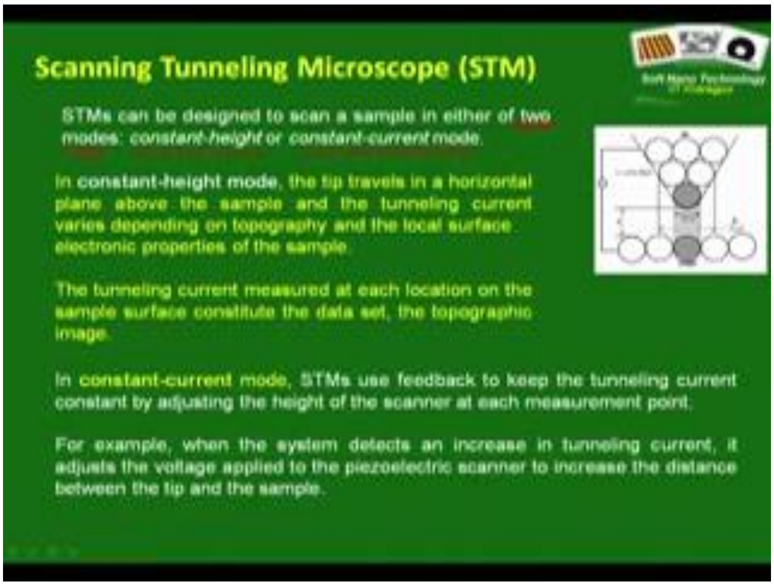

So, how does an STM work? Well STM in fact, works let us read what is written there. I am going bit slowly because it is a completely new topic. So, STM can work in two modes, let us read and then we will understand it is very simple either it is a constant height mode or constant current mode.

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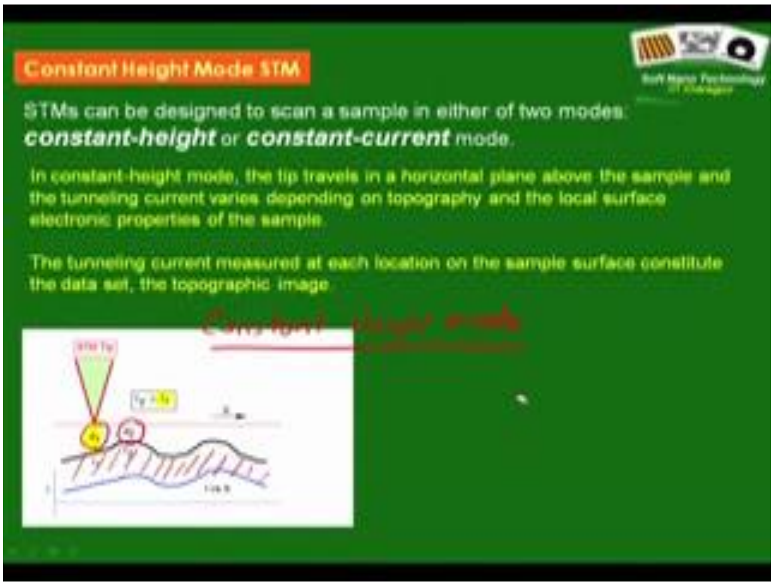

Let us not read all this, let us move on. So, what we mean by a constant height mode? This is the schematic of a constant height mode. So, suppose this is a surface that you would like to scan or you would like to examine right? You take an STM tip; of course you need to have some mechanism that makes you allow that allows the tip move from one point to the other point very slowly. So, you take a tip you have surface like this and you have to have a mechanism so, that your tip moves slowly and now how it is done we will learn it in the context of AFM with a piezo electronic scanner. For the timing let us assume it can be done.

So, here you see you have this tip and it is in a very close proximity with the surface of course, d1 is a separation distance at which tunnel definitely takes place. So, this is very close tunneling takes place and of course, corresponding to the separation distance d1 you have a magnitude of the tunneling current I1.

Now suppose the tip moves from the point d1 to point d2 which due to the roughness of the sample surface is at a higher location. It is a rough sample any practical sample or any real surfaces certain amount of roughness of course, you can immediately understand this mode will not work for a very rough sample because of the simple fact if this surface is too rough and here is the tip it moves and it is simply going to crash on the surface. So, it cannot work for a very rough sample, but this is perfect for understanding the basic concept.

So, as the tip now moves from one point d1 to point d2 what happens? What happens is in fact, very interesting that needs some space or maybe I will use it here. So, here is what is drawn, here is the path along which the tip will move. Let say this is point 1 and this is point 2. So, so at point 1 separation is d1 and let say the corresponding tunneling current is I T1.

Now, as you reach as the tip reaches point 2 the separation distance is d2. According to the picture d2 is closer than d1. So, therefore, what you expect the tunneling current I T2 is going to be greater than I T1. So, in this process you can generate a data set for every point and idea about the tunneling current. So, I am showing it the scanning of the tip along a line, but you can look into a area of a surface where the tip first examines every point according to this line, then it comes back examines the second line and it can go on like this. So, it can examine every line by line. So, what you can get at the end is a data set where you can for every x and y you can get an idea about the tunneling current. What does it give you the variation in the tunneling current gives you a variation a qualitative variation in the separation distance?

Now, if you can co relate and find out what is the d1 and d2 with corresponding to the tunneling current. So, you know the difference between these two. So, that gives you an idea about how much this delta IT corresponds to in terms of delta d. In the process what you get now? You now get the maximum and minimum locations or variation in the maximum what I mean is with respect to any datum let say it started from here and this is the surface. So, you now know with respect to this point if let say at 1 1 you have a value of IT. So, you add a fourth column whatever is the height this is 0. So, you can get some numbers plus 2.3 minus 1.7 and something like that and you can in fact, get a full 3D image of the surface.

How it converts I will discuss later, but this is sort of a nut shell the idea that if the tip events cancel along a constant height and because of the roughness seems every point on the surface is at a different separation distance from the tip, that leads to variation in the tunneling current. You can simply record this variation in the tunneling current and you will get a map about the idea of how I varies as x and y let say and that sort of qualitatively straight away reflects the topography of the surface which you can with some using relation how the tunneling current skills with the there are relations are available with the separation distance you can in fact, get a get a true topographic image.

But there are limitations of this constant height mode and one of the limitations is that it cannot handle a roughness surface because the difference in the height must be very very less. None of the point should come and collide with the tip because then it will crash.

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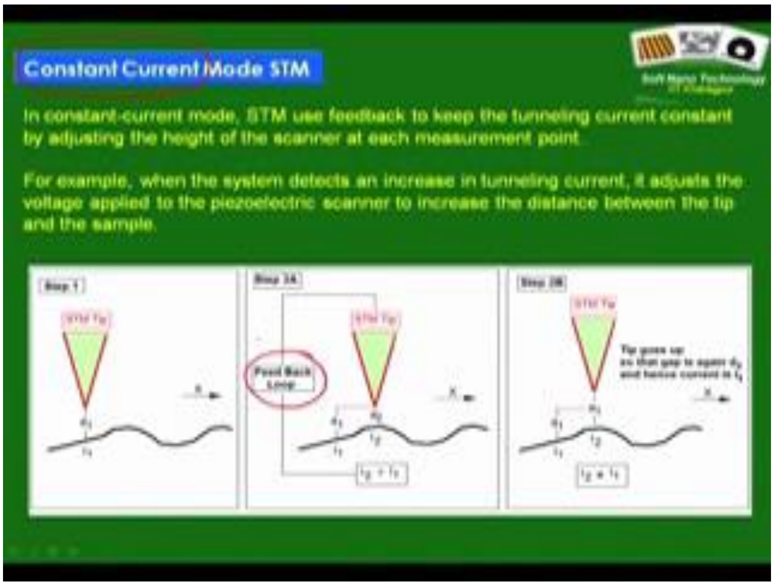

So, a better option is the constant current mode. Where there is an additional hardware element and that is a feedback controller. I think I am running out of time in this particular class. So, in the next class I will start from here and then move on to an AFM.

Thank you.