Soft Nano Technology

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Lecture - 25
Atomic Force Microscope – 2

Welcome back. We have started our discussion now on eventually to Atomic Force Microscope, but we were sought of having some very elementary discussion on STM. Trying to understand the basic working philosophy of an AFM, because many of the concepts similar of course, right from the name itself you can find out that Atomic Force Microscope utilise on some forces, it primarily the interaction forces again between a tip and a surface and in contrast in STM realize on the tunnelling current.

However, there are in fact lot of similarities in the way they work and in fact, the limitations of STM that it requires strangling current led to the development of AFM, because if one would have used an STM, one could have been able to utilize these beautiful technique only for conducting samples, but AFM does not have any such limitation and that is exactly what has made AFM so very versatile.

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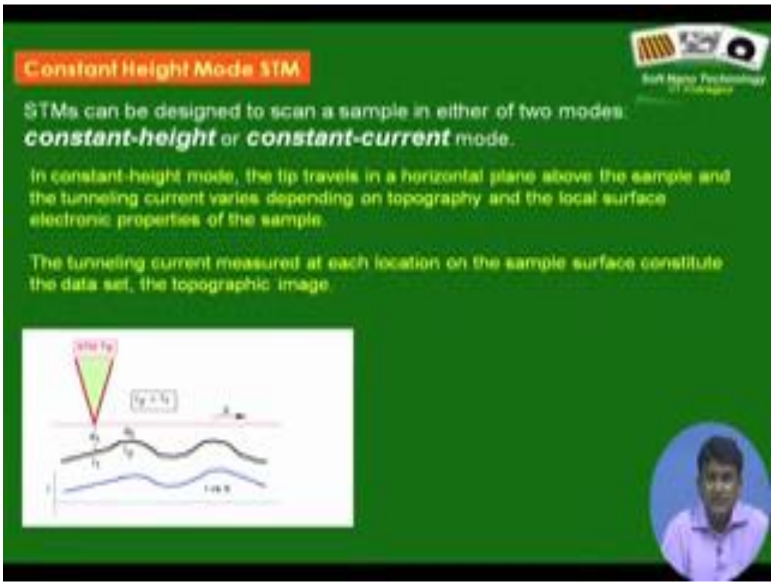

Constant Height Mode STM

STMs can be designed to scan a sample in either of two modes: ***constant-height*** or ***constant-current*** mode.

In constant-height mode, the tip travels in a horizontal plane above the sample and the tunneling current varies depending on topography and the local surface electronic properties of the sample.

The tunneling current measured at each location on the sample surface constitute the data set, the topographic image.

So, we just discussed the so called constant height mode of STM and what you have realised, if we do a quick recap am deliberately going very slowly again because this is completely new topic, what you realise the is that you can restored or move a tip in very close proximity surface and issuing the surface as some roughness, but it is not too rough. So, that the tip goes and crashes on to it, it is also not too deep that the separation distance between tip and the surface becomes too large and the tunnelling current drops to zero. You in fact, can lead the tip move over all the points over the surface back and forth.

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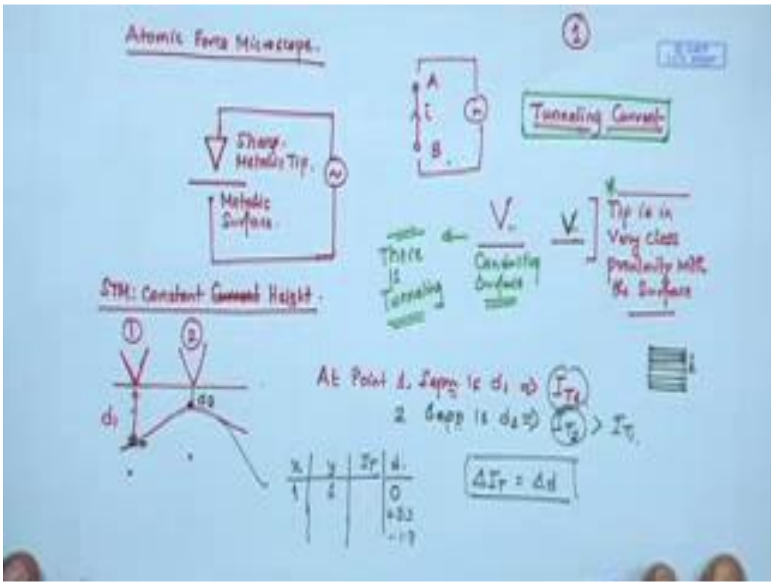

And can get an idea at every point how your tunnelling current varied with the tip. Tunnelling current varied with the location and you can thus get a map of what was the magnitude of the tunnelling current at each of these points. Understanding the fact that the magnitude of the tunnelling current is lower as the separation distance between the tip and the surface increases and it is hire when the tip is closer to the surface, you can translate this into a variation in feature height as a function of each point. And what is that? That is nothing but 3D actual image in height or actual height information of the surface at every location.

Limitation of this constant height mode it is sounds very simple. Limitation as we already realise that it cannot handle rough surface because are surface as to be very very smooth in order to led the tip move along a constant vertical height without touching it, touching will simply lead to tip crush tip will became blank there will be short circuiting and high value of current will in fact lead to the blunting of the tip and what will be the consequence of blunt tip fails to produce tunnelling.

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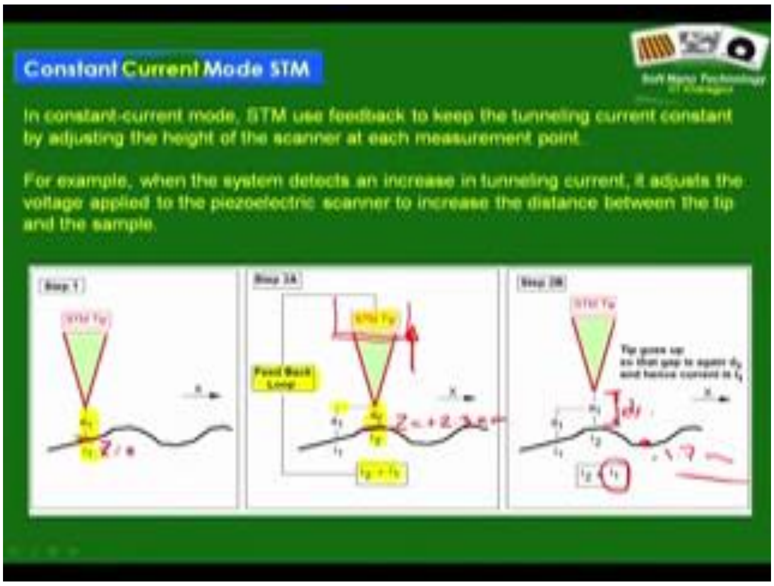

Constant Current Mode STM

In constant-current mode, STM use feedback to keep the tunneling current constant by adjusting the height of the scanner at each measurement point.

For example, when the system detects an increase in tunneling current, it adjusts the voltage applied to the piezoelectric scanner to increase the distance between the tip and the sample.

So, how does one handle this technique for a rough or sample and that leads to the introduction led to the introduction of what is known as the constant current mode. Here there is an additional piece of hardware and that is a feedback loop. The idea is that you start your scan again at particular point, were let say the separation distance is D1 that is comfortable separation distance you have to, what is a comfortable separation distance? It is a distance at which the tip is not touching the surface, as well as there is tunnelling current right. So, you do not want to be too close because the tip might crash do not want to be to further away because in that case the tunnelling current might drop to 0. So, you are at a comfortable separation distance, you know based on your experience that. D1 is such a separation distance, which will give a tunnelling current of I1 or IT1 which is fine.

And from now this point 1, you move your tip just like before 2.2. Where the separation distance is different D2 and since the separation distance according to the drawing D2 is less than D1 therefore, tunnelling current at that point I2 is higher than I1, but what is the mode is you are using, constant current mode. So, that you want to meant in the current to be constant. So, all you do you generate this error I2 minus I1.

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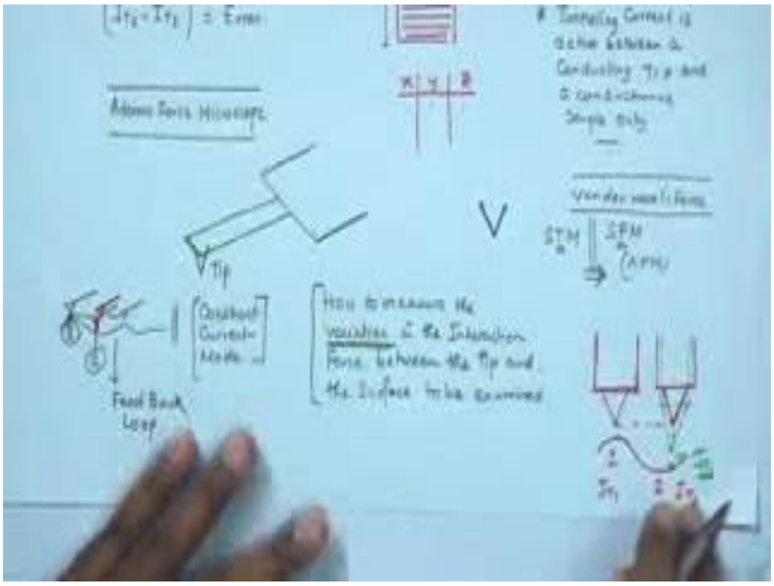

Who go for a module as because whether it is a positive error or negative error is actually going to give you whether the second point is closer or at a further distance? So, this error is simply fed to the feedback loop here. So, what does the feedback loop do? The feedback loop now has some arrangement, what arrangement I will talk later in the context of AFM I will explain it later. So, it reaches the tip upward. Up to what extent? Up to the extent the separation distance at this point, again increases and goes back to D1 because in that case the magnitude of the tunnelling current again goes back to I1. So, you short of have a set point, let say it is on the tunnelling current I1, which corresponds to a separation distance D1, you really do not it is not possible for you to measure the separation distance, but you can measure the tunnelling current.

So, typically the set point is set on I1 and now you again do the same rastering right. At every point, now what do you measure? Because now unlike in the previous case where the tunnelling current was different at every point, now that is not the case because due to the presents of your feedback loop the tunnelling current is in fact same at every location right.

So however, what you measure is at every location, how much your tip has gone up or down. If you just measure this than what you can do or you simply measure the location is a sort of a thought and some time giving, you simply low measure the location of, I mean let us could be simply how much the tip has gone up and down if you can track that let say with respect to this point if we turn this to be Z equal to 0. You can always identify at well here Z equal to plus point 2.3 nanometres, next point when it goes here it is minus 1.7 nanometer and something like that and then essentially at the end you get a data set which is simply X Y and Z.

It is like you sort of this rastering over a zone of interest. So, it is a 2D area let say from here to here is it 6Y. So, the tip simply moves along the routine of a nested do loop and it gathers the data. So, once you have this data all you need to do is you simply normalise this data with respect to the minimum and maximum elevations and you just put it on a gray scale you get an image that reflects the idea about the topography of the surface. Again this is something that I will pick up in a bit detail later.

So, this is how it works. One thing should be clear to you now in order to generate a 3D reconstructed image of the true surface, you need some sort of a variation and in the constant height mode the variation was directly in the magnitude of the tunnelling current. Here you do not relay on the magnitude of the tunnelling current because you need to feed that error and the error from one point to the other because you have a feedback loop the error from one point to the other is again the variation of the tunnelling current as the keep moves from the point 12.2, 0.2 initially that tunnelling current the magnitude of the tunnelling current is I2, but once the feedback loop gets activated it is again back to I1.

So, again when keep moves 2.31 is going to compare the difference in the magnitude of I3 with I1 and accordingly the tip will move. And all you need to do is you need to do track with respect to the first starting point, well let us say you or Z is 0, no one knows the starting point this is the very real setting, no one knows whether the starting point is the lowest point or the highest point, it does not matter it is any random point you simply mark it as Z equal to 0 and all you are going to do is you are going to track the upward and downward movement of the tip at the subsequent point with respect to that starting point it is which is marked as Z equal to 0.And you can reconstruct the surface this way.

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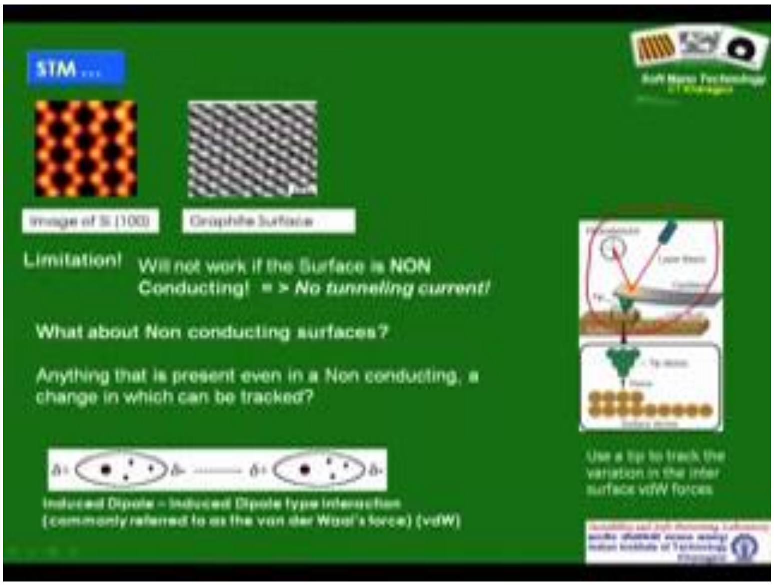

STM …

Image of Si (100)

Graphite Surface

Limitation! Will not work if the Surface is NON Conducting! = > *No tunneling current!*

What about Non conducting surfaces?

Anything that is present even in a Non conducting, a change in which can be tracked?

Induced Dipole – Induced Dipole type interaction (commonly referred to as the van der Waal's force) (vdW)

Use a tip to track the variation in the inter surface vdW forces

So, STM you go down to excellent, you can achieve excellent resolution like you can see this the let explain of silicon, you can see the graphite surface. Limitation is STM will not work for non conducting surface because the fact is you need tunnelling current.

So, it is a fact that it only an STM, you cannot really utilise the this beautiful technique for reconstruction of non conducting surfaces and that say huge limitation and therefore people started to think of how this techniques can be short of utilise or non conducting surfaces. And that in fact led to the discovery of the atomic force microscope which was one needed to understand, that you need a more general feel which is Omni presents. Because Tunnelling Current is something very specific if it is active a conducting tip and a conducting a sample only, but if you wanted to use this type of a technique a scanning probe technique. So, we already understand why we use the term SPM. You have a probe which in case of the STM is in fact the tip and it is scans it goes from point to point to gather information about that particular point. In the simplest form it gathers the information in the constant height mode, what is the variation in the tunnelling current? In the constant current mode you have a feedback loop and therefore, a it goes up and down.

So you need a probe in order to utilise this technique, but you need some analogue of tunnelling current, which is there and which will wary for a non conducting surface. This is the basic philosophy of the development AFM. So, what can be a analogue of tunnelling current which is present on all surfaces and remember your initial discussions something that is present between 2 molecules, 2 surfaces, which is always present irrespective of the nature of the material, polarity etcetera is under gone sources.

So here we go, your probe is there of course, so it now measures the force instead of the tunnelling current. So STM as led to the development of SFM the most significant member according to the image I showed at the this family tree, family history I showed is of course the AFM, but what is interesting to note is that for a non conducting sample, we rely on the variation of the interaction force between the between again a tip and the surface to gather the information about the feature height. It is interesting that an AFM also use a tip, but this tip is firstly this tip is much wider than an STM tip.

Second interesting thing is, an AFM does not need a tip in order to generate tunnelling current, but still would like to use a tip, because you are going from one point to the other, to gather the information and if you have some probe that is very bland you are going to lose on your lateral resolution. Therefore, an AFM also use a tip, but what is interesting, and what becomes very exciting, is how to track the variation in the force from point to point, and the that is something so we now understand this is genesis of Van der Waals force I will stay away from this and because we already have discussed it in great detail.

So, AFM unlike a sharp metallic probe also uses a tip, but that tip is mounted on the backside of a cantilever and this cantilever is attached to a chip which actually is fix to the instrument, this chip can be physically touched, but AFM in variability am sure that if you have tried to search some literature you will you must have seen this picture. So, this AFM as a tip, but that tip is mounted to a cantilever. So, what is the utility of steep and cantilever is something that we will try to understand.

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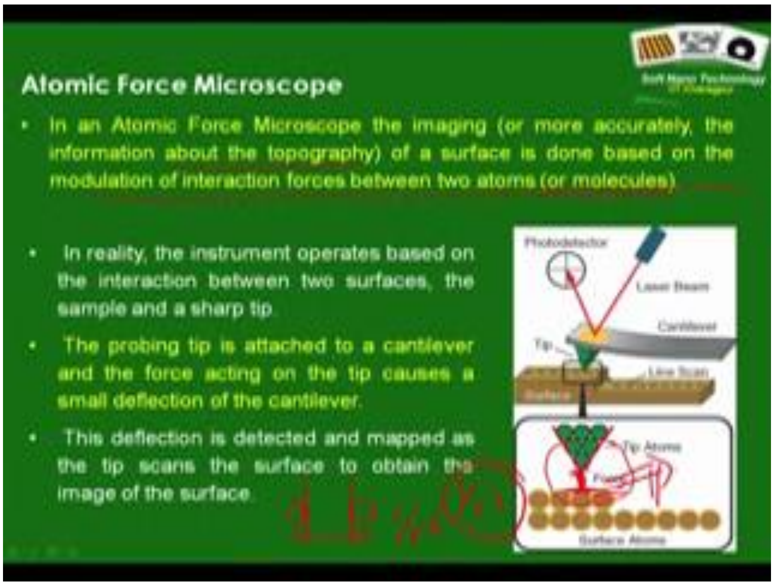

Atomic Force Microscope

- In an Atomic Force Microscope the imaging (or more accurately, the information about the topography) of a surface is done based on the modulation of interaction forces between two atoms (or molecules)
- In reality, the instrument operates based on the interaction between two surfaces, the sample and a sharp tip
- The probing tip is attached to a cantilever and the force acting on the tip causes a small deflection of the cantilever.
- This deflection is detected and mapped as the tip scans the surface to obtain the image of the surface.

So in a quick discussion, I am sure I mean we I have already been able to give you an idea about what is an AFM. So, it is an Atomic Force Microscope information about the topography of a surface based on the modulation of interaction forces between 2 atoms of 2 molecules, 2 surfaces let say. So, here again it is a picture that is a very similar who what we have already seen in the context of an STM, but see here there is no tunnelling current and that is what makes AFM more versatile because you what now talking about forces.

So, you can use yes you can also use an AFM for a conducting surface, but you can also use it for anon conducting surface and any type of a surface because movement you bring in a surface and this steep I am assuring to the another surface. So, this is something I told that between two molecules the Van der Waals interaction is sought of 1 by r to the power 6, but between 2 surfaces it is like 1 by r square there something you will learn in great detail and when you bring in a tip close to a surface there is some active Van der Waals force and you Rayleigh on that to utilise an AFM. The problem the practical is difficulty is how you measure, the problem essentially translates to how to measure the variation in the interaction force between that tip and the surface or the samples to be examined.

And why do you expect it to wary? You expect it to wary because you have taken a sample and now according to this principle your tip is going to go some one point to the other, because of the roughness present in the sample what it is going to lead to is definitely the strange of the interaction forces between the tip and the sample is going to wary from point to point. Now question comes how do you track it? Right and of course, when the AFM was discovered the constant people have already you understood the real strength of the constant current more and therefore, AFM comes with the feedback loop.

So, idea is that whatever is the interaction force at the first point at which you start the rastering you maintain that force across the sample, I utilise in the feedback loop. Of course, as the tip feature this is a cartoon, this is not the correct picture, we will learn the correct picture soon. Of course, as the tip features from point 1 to let say point 2, the interaction force here reduces because the gap has increased and what it is going to do? It is going to trigger the feedback loop and the tip is going to came down so that you are again back to the same force.

And this way as you complete you are restoring you again get to complete idea about the variation of the height along at every point of the sample with respect to the starting point. So, again you said this to be 00 and you get idea about all the other points, but still the question remains how to track this variation in the interaction force and that that in fact is a challenges and that is done in very elegant way utilising a laser source and a photo detector.

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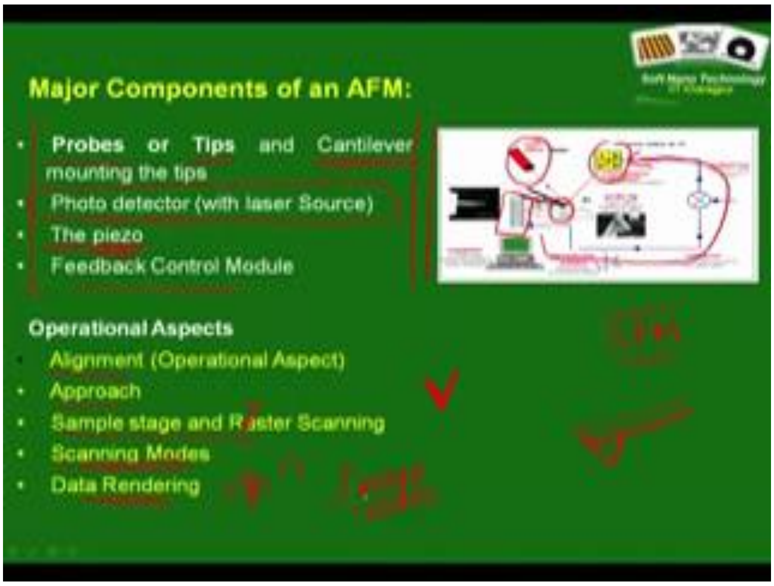

Major Components of an AFM:

- Probes or Tips and Cantilever mounting the tips
- Photo detector (with laser Source)
- The piezo
- Feedback Control Module

Operational Aspects

- Alignment (Operational Aspect)
- Approach
- Sample stage and Raster Scanning
- Scanning Modes
- Data Rendering

So, what we will do next is, we will try to understand the major components of an AFM. Of course, these are the major components of course; the first thing you need to do an AFM scan is a sharp tip, probe or tip that is mandatory because they all these instruments fall into the category of SPM. So a probe has to be there and for an STM it is a conducting tip that is capable of producing tunnelling current. For an AFM again you need a sharp tip, but this sharp tip is made mostly of silicon or silicon nitride is mounted on the bottom of a cantilever in a very unique geometries. So, this is the tip and it is mounted at the bottom of a cantilever. Why a cantilever? Cantilever is in fact, so if you have a cantilever like this and if there is some force applied at the age, the cantilever is expected to deform.

So, what type of cantilever would you take? Would you take a very rigid cantilever, well know because the forces you are going to sought of encounter here are Van der Waals forces therefore, they are of the level of the piconewton. And therefore, you would you like to take a very thin cantilever. So, that it deforms or responds to the magnitude of Van der Waals forces. That is in fact very important right.

So, if you take a very rigid, very big or a thick block of metal cantilever the whole purpose is lost. You need to take a cantilever that is sought of responsive enough to exhibit some deformation to Van der Waals forces. You need that tip mounted on the cantilever. So, these to you cannot have tip only than AFM the way it works because you need that cantilever. You need a photo detector with the laser source and this is something is very strange you need a laser, but that laser does not help you in imaging. This laser is used along in conjugation with the photo detector to track the deformation of the cantilever and that in an indirect way gives you about the variation of the interaction forces, as the interaction force between the tip and the sample surface as the tip rasters from one point to the other.

You need a piezoelectric scanner this is something that is there also in an STM, till now I did not mention it. We have been talking right from the concept of constant current imaging that the tip goes up goes down and even in fact this movement is very small, it can be a few nanometer also you need to understand that in order to raster from one point to the other the tip as to physically move by very small distances because if you if you are gap between two adjacent points is too large then. In fact, you are not going to get a good idea about the surface. So, you might want to sought of look in to an 1 micron by 1 micron area laterally and you might 1, 2 gather information about at 256 plus 256 points of 512 into 512 points so; that means, that you are splitting up this one micron into 500 at 12 points, z where each of these points your probe will be go and pick up the information.

So, even the difference or the movement from let say 0.1 to 0.2 is going to be very small. So, how do you control this and you typically control this by a piezoelectric scanner which as a piezoelectric material. Please feel free to check it mean this is not fell, please do check, what is piezoelectric material? Put it very simply piezoelectric material is something to which if you give a deformation it will produce some current or if you apply a bias to a piezoelectric material it will change it is size. So, it will deform, that is a piezoelectric material. So, what is done in this so called constant current mode let say. So, you generate the difference in the so in very simply put in an STM this tip is mounted to a piezo.

So, now I am giving to a slightly more detailed picture, it is mounted to a piezo. So, as the tip reaches from let say a 0.1 to 0.2 and you can understand that because of the proximity IT2 is going to be less then I t one. So, as it teaches here you have a feedback loop this is the constant current mode. So, it reaches here. In fact, we will see that this motion also we will seen the context of AFM.I am keeping all this discussion for later discussion for an AFM. This motion is also controlled by the scanner it itself and most of the modern instrument uses single scanner.

So, has it reaches here it realises that I t two is less than I t one this error is fail. So, the feedback loop and what does this piezo do? This piezo in fact becomes long and thin becomes like this. So, that you tip goes down all the way here, the gap between this point on this point become same because therefore, tunnelling current also become same. Same logic is applied for an AFM also and you need a piezo electric scanner to achieve the rastering.

So, here I will repeat the key components or the probes or the tips, there is the tip with the cantilever. So, this is the cantilever you have a photo detector with the laser source. So, this is the photo detector with the laser source you need that piezo, this is the piezo to which the cantilever is is mounted and of course, you need have a feedback control. These are the key aspects we which we will discuss in somewhat detail and we will discuss some operational aspects which are very fascinating in fact. We will discuss what is alignment? What is approach? Sample stage and rastering this spelling is wrong it is rastering.

We will then talk about the scanning modes and data rendering and this is where you actually generate the so called image of the surface, because till now whatever we have discussed we are only seeing you are not getting a picture, we are only getting an X Y verses Z data. So, how you generate the image we will discuss running out of time. So, will stop here and start from the different components. In fact, we will start with the key components and talk about next lecture.

Thank you very much.