Metrology
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Lecture – 42
Micro and Nano stages, Nano technology

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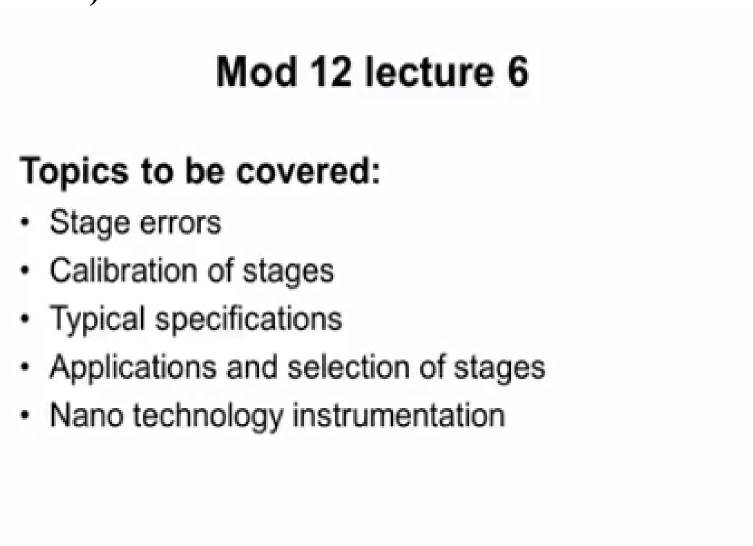

I welcome back to the lecture series on meteorology. Now let us start lecture number 6 and module number 12 in this lecture before going the topics will be covered stage error calibration of stages typical specifications of the micro stages and nano stages and application and selection of the different kinds of stages and finally we will discuss about the nano technology instrumentation.

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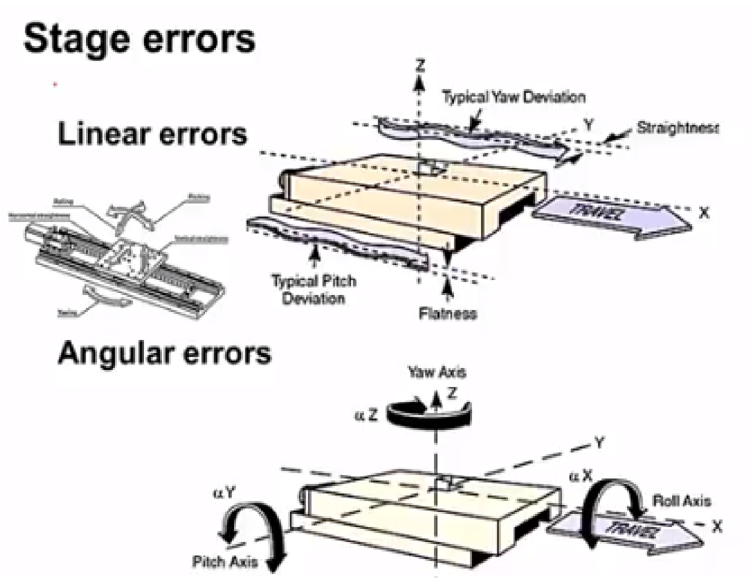

In the previous lecture we discussed about the different types of stages linear stages rotary stages and what are the different kinds of drives used in different stages. Like now we will understand what are the various errors that occur in the metrology stages. We can see here they have linear errors and angular errors.

So this picture shows the table this is the table surface and the table is moving in the x direction when it moves it mean it moves up and down the table surface move up and down that is flatness error. Similarly when it moves it may move like this in a horizontal in a vertical plane it may move like this so this is straightness error.

These errors linear errors occur in all the 3 axis in x axis movement in y axis movement as well as z axis movement and coming to the angular error each access they can be there in the yaw access that means in the that table is rotating in this fashion, so it is yaw access. Similarly along the pitch axis the table method it may tilt the table surface and along this x-axis it may roll the table surface may roll.

So that is apart from the linear error from the x-y axis direction that can be roll axis error, y axis error and pitch access error that means designing and manufacturing the micro and nano stages the care has to be taken properly design. So in the manufacturing proper care should be taken so that these errors are minimized.

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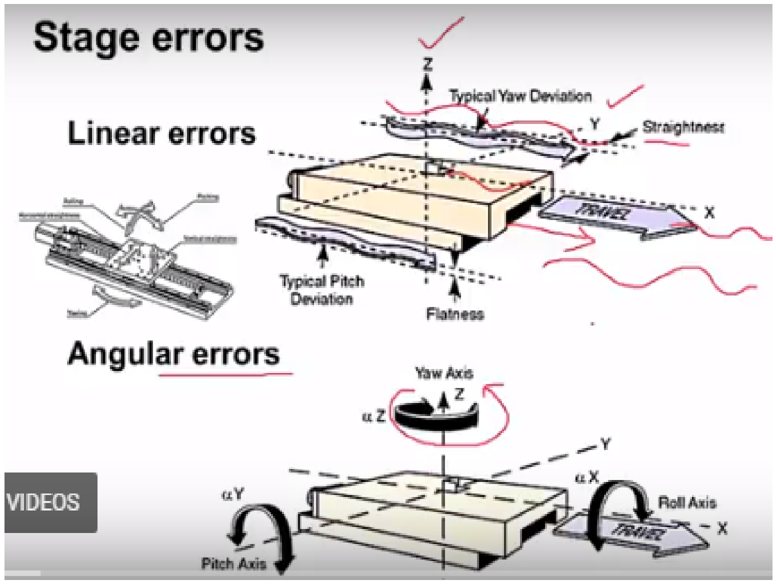

Now these graphs show the repeatability that is the position of the states and y axis shows the deviation in millimeter now after assembling the stage we have to conduct experiment and performance test many times and then repeatability should be established we can see here the error at each position in the in the table is moved along the different axis x axis y axis and z axis.

What is the amount of error at different position example at 25 mm position what is the amount of air and the multiple readings are taken and then finally we can calculate the average values that means this line shows the mean error in the forward direction similarly in the reverse direction also we can conduct the experiment to get the by directional repeatability performance like this curve shows the error in the forward direction

The yellow line indicates the error in the reverse direction and the table moves in the reverse direction and this blue curve indicates the average of both the error in the forward direction and the average value so this is zero error line and different positions of the axis what is the amount of the error so these experiments should be conducted in all the axis. X axis y axis and z axis and then we will come to know, what is the repeatability of the stage?

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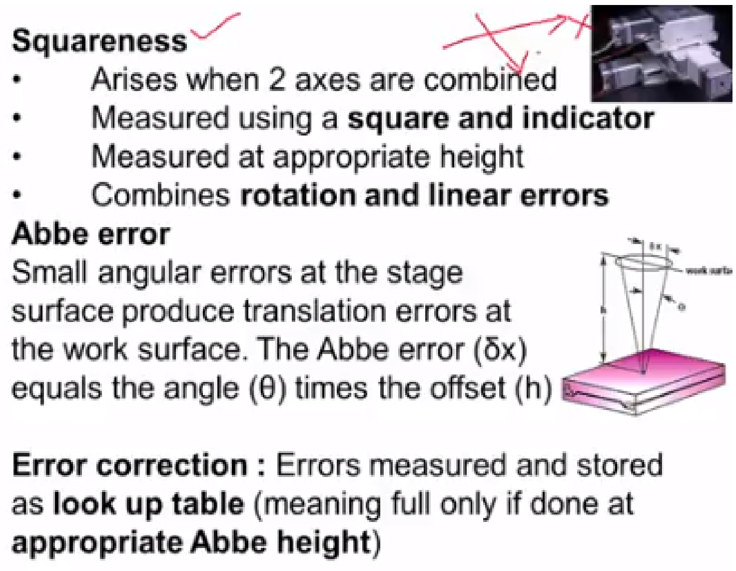

Now there can be here the square ness that means you can see here the x-y table now this is the x-axis movement and this is the y axis movement so when the table the top surface is moved whether the movement is 90 degree or not whether it is square or not they can be checked using the square and the dial indicators and at the proper height the square ness should be measured.

The square ness is basically the combination of rotation errors and linear errors similarly in stages there can be a Abbe error. You can see in this diagram the surface of the table so small angular error at this stage surface produce translation error at the work surface say we have mounted some work piece of some height h and this is the work surface if the small hair small angular error of the surface of the table if get amplified at the work surface

So that is at the Abbe error so this Abbe error the delta x is nothing but the at the angle theta time the offset head so that it gives the Abbe error. So how do we correct the error, Error correction is given for the zeros so for the different types of errors should be measured and stored as lookup table and as and when it is used this year is lookup table error and then the correction should be given so this look up table values are meaningful only when done at the appropriate height.

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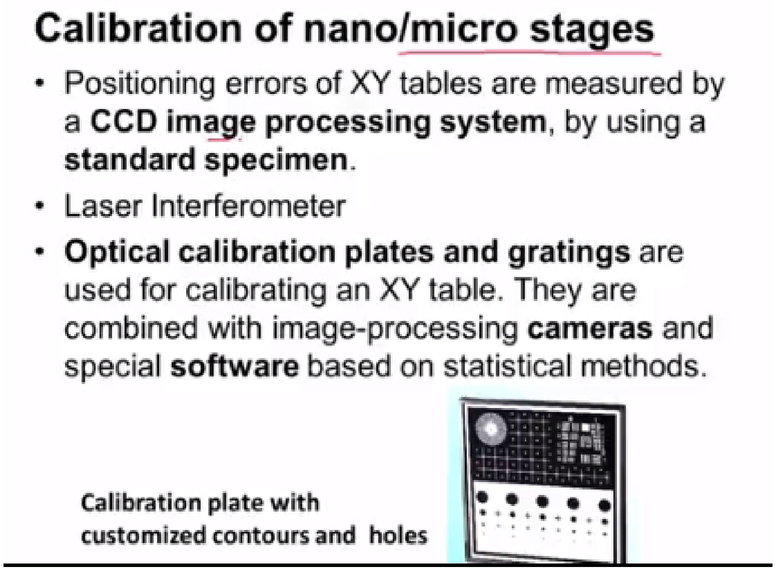

Now how do we calibrate the nano stages and micro stages so it can use the image processing system of this camera and also we can use standard specimens for calibration of nano and micro stages also we can use laser interferometer for calibration of purpose. This picture shows the calibration plate and optical gratings are also can be used.

Calibration plate has got different contour made in the plates and holes of different sizes so these calibration plates are used along with the laser system for calibrating to find what is the amount of the different positions? and then the software can be used to calculate what is the amount of error.

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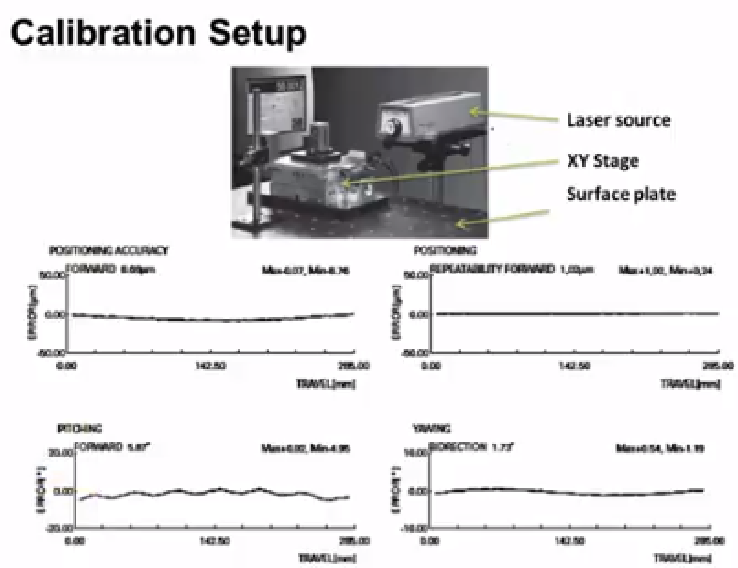

This picture show now this picture shows setup laser based calibration setup you can see the surface plate on the x y states which is to be calibration to be mounted distance between did and then there is a source the mirrors are there for the reflection of the source using such a setup we can find we can determine the different types of errors and then we can plot the errors like this.

We can see the travel of a particular axis of the x-y stage so the range is 0 to 285 millimeter travel and y axis indicates the error in terms of millimeter so when the stage moves in the forward direction what is the amount of error that is plotted here so that the maximum amount of positioning accuracy is 8.09 micrometer so similarly the repeatability can be established.

So this graph shows the repeatability in the forward direction is 1.02 nm similarly the pitch and yaw errors can be determined using such system calibration system.

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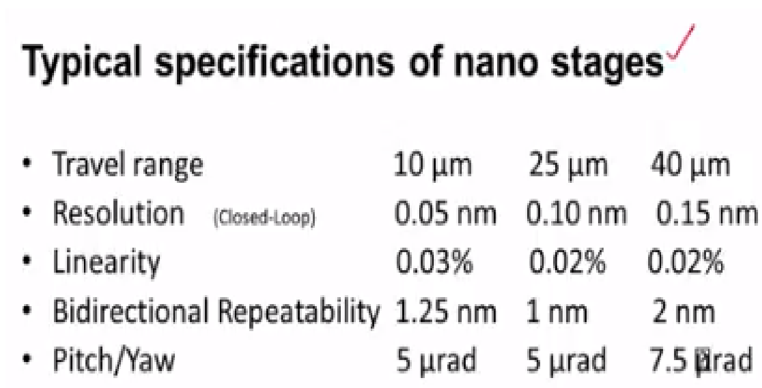

Now this table shows typical specifications of nano stages so different models are available this is model 1 model to model 3 with different travel rangers we can see and this first model the travel rangers zero to 10 micrometer and model to 25 micrometer model 340 micrometer this is a travel range of the x y and the z axis so normally x axis y axis range will be greater as compared to the z axis range.

So resolution is 05 nm in the first model second model 0.1 nm and third model varying the travel ranger is more and the resolution is 0.15 nm 15 also the linearity rangers with the 0.03%.0.02%, 0.02% are available and bi directional repeatability of 1.25 nm, 1 nm, 2 nm are available and pitch and yaw error will be something like 5 micro radians, 5 micro radians and 7.5 micro radians.

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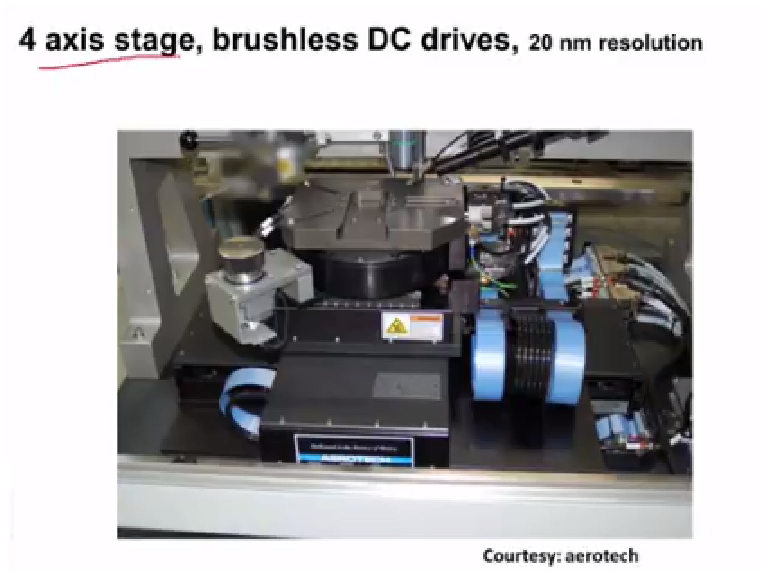

Now here we can see some of the stages nano stage with 4 axis stage x axis, y axis z axis 3 linear axes and the 4th rotary axis is available here. It runs with brushless dc drives and resolution of this table is 20 nano meters such a fine stages are available in the market.

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Now this shows a 6 axis a very compact parallel position or that means this top surface of the table moves parallel to the base and this has got 6 degrees of freedom with 3 linear axis XYZ 3 axis pitch roll and yaw. Load capacity at this particular position is 10 kg and can move in the velocity of 25 m per second that travel range is up to 45 millimeter linear movement and 25 degree rotation movement.

The resolution is 7 nm such fine accuracies are possible and 300 nm minimum incremental motion is available and repeatability is + or – 0.1 micrometer and in the range the travel ranger is more the repeatability is + or – 2.5 micro radians is possible standard positions are available and vacuum compatible versions are also available and dc motors are used in such a parallel positioners.

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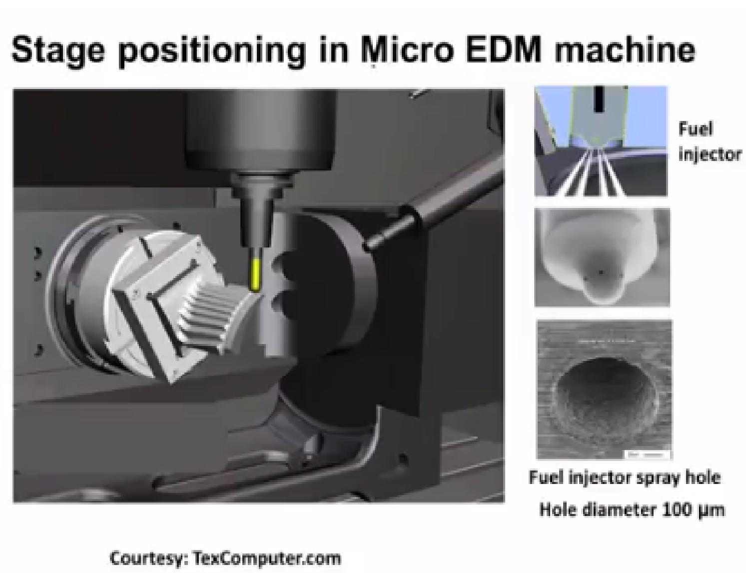

This shows show stage micro stage used in EDM machine we can see a fuel injector varying holes are machined for the supply of the fuel we can see the micro holes we can see and amplified microscopic view of a spray nozzle of diameter 100 micrometer. She said she now in order to make this fine holes.

We have to properly orient the work piece for that apart from the xyz motion of this machine should be possible to rotate the work piece and should be possible to rotate tilt the table so multiple axis machining systems are needed so in order to make these micro holes we have to position the electrode properly, so that these micro holes are made it should be possible to rotate the work piece as well as tilt it should be possible to tilt the work piece.

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Now this time now in this diagram you can see regular xyz CNC machine 5 axis machine with mounted with trunnion table to provide 2 more additional access that means the work piece can be rotated with the rotary axis as well as the table can be tilted so totally 5 axis are possible in this CNC machine the different sized CNC machines are available.

The machine with table size, different centre height then different load capacities are extra or possible. accuracy of such system such as rotary axis accuracy is 15 arc second and tilt tilting the accuracy is 20 arc seconds and repeatability of +or - 2 to 3 arc seconds is possible.

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Why air bearings?

Parameter	Units	Linear motors, Mechanical bearings	Linear motors, Air bearings
Accuracy	µm	± 5	± 0.5
Bidirectional repeatability	µm	± 0.5	± 0.2
Straightness and flatness	µm	6-12	2
Roll, pitch, yaw	arc-sec	10	2

Now why normally air bearings are used in micro and nano stages you can see here if we use linear motor mechanical bearing position accuracy is less or minus 5 micrometers it is micro stage and if we use air bearing accuracy can be enhanced to up to +or -4.5 micrometer and bidirectional repair repeatability is + or - 0.5 micrometer.

If we use mechanical bearings and if we use air bearing repeatability is + or - 0.2 micrometer and straightness and flatness error can also be reduced very much because of the mechanical bearings. Straightness and flatness error will be 6 to 12 micrometer.

Whereas in a bearing stages with air bearing the straightness and flatness error will be as low as 2 micrometer also roll error which error your error can be reduced then or seconds to 2 arc seconds that is why are bearings are used in micro stages, as well as nano stages.

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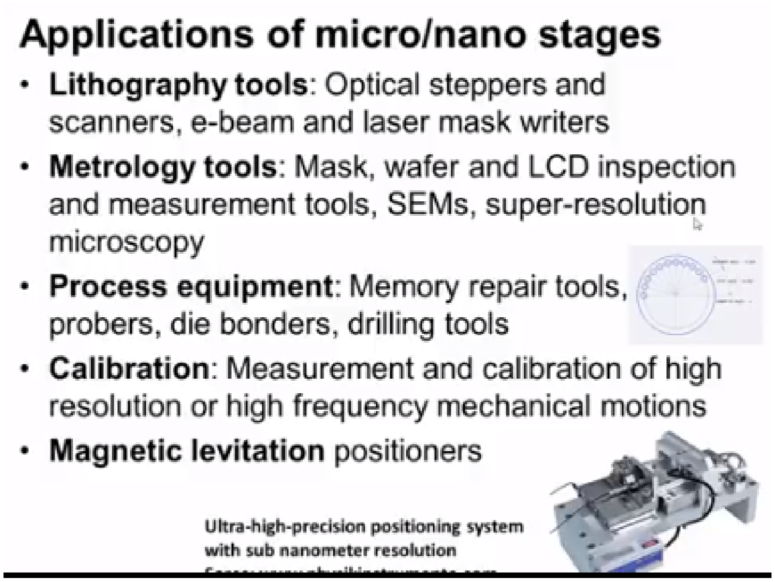

What are the different now what are the different applications of micro and nano stages these stages are used in the lithographic tools such as optical steppers and scanners a beam and laser mask writers and in the metrology tools such as mask wafer and LCD inspection systems and measurement tools standing electron microscopes super resolution microscopy systems.

They are also used in the process equipment such as probers, die bonders, drilling tools for making very fine adjust the stages are used we can see the micro drill in a work piece such a drilling is possible. If we use micro stages and nano stages they are also used in calibration equipment measurement and calibration of high resolution or high frequency mechanical motion system and the stages are also used in magnetic levitation positions.

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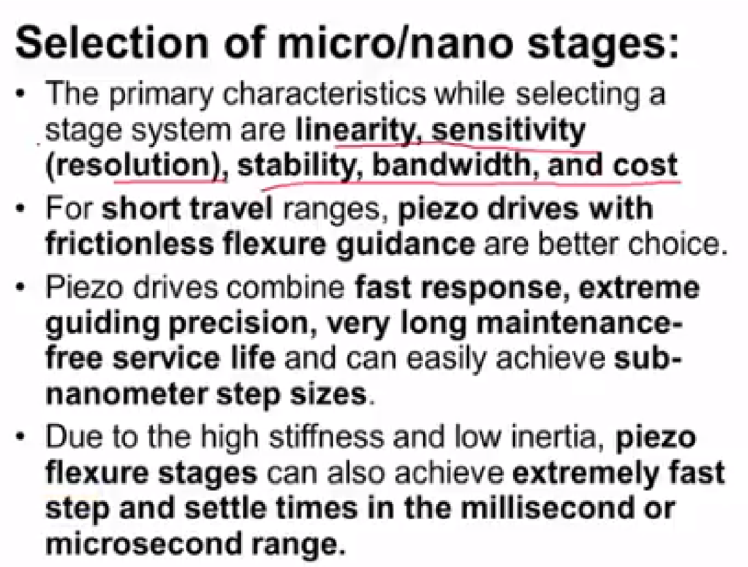

Now this picture shows ultra high precision positioning systems with sub nanometer resolution. Now how do we select this metrology stages the primary characteristics while selecting a shared system or linearity sensitivity that is resolution stability bandwidth and cost these factors are considered as by selecting the stages for short travel rangers not only piezo drive with friction less flexure guidance used for better accuracy.

Piezo drive combines with fast response extreme guiding procession very long maintenance free service life and they can be easily achieve used way sub nanometer steps sizes are needed due to high stiffness and low inertia piezo flexure stages can be achieved extremely fast step and settle time in the millisecond or microsecond range.

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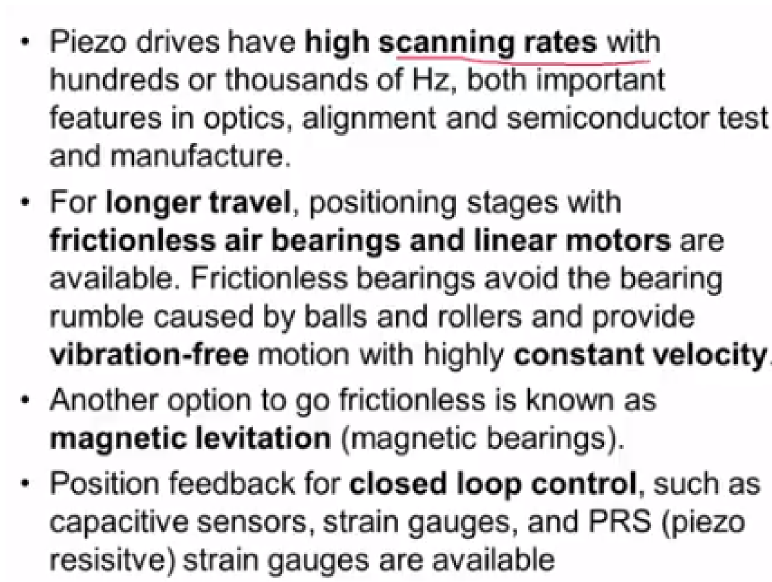

piezo drives have high scanning rates with hundreds of thousands of heard this high scanning rate is very important in optics alignment and semiconductor test and manufacture for longer travel rangers positioning the stages with the frictionless air bearing and linear motors are used.

Frictionless bearing avoid the bearing rumble are caused by balls and rollers and provide vibration free motion with highly constant velocity and other option to go frictionless is known as magnetic levitation that is magnetic bearings position feedback for closed loop control such as capacitive sensors strain gauges and PRS strain gauges are available.

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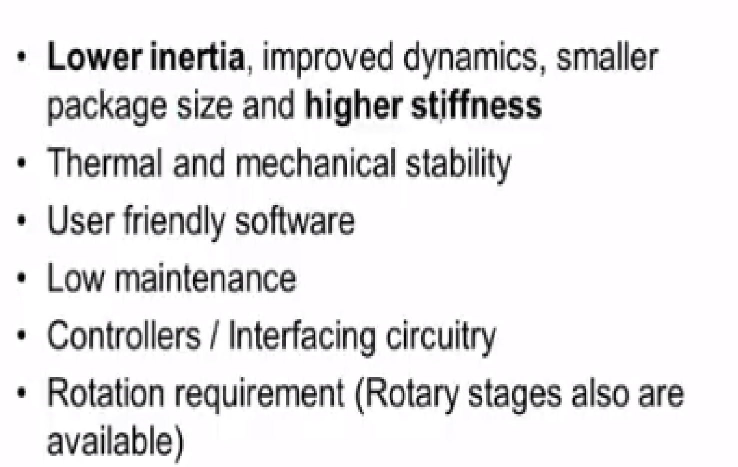

Whenever low inertia improved dynamics and smaller package size and higher stiffness we can go for micro and nano stages and also another important requirement to use these stages is thermal and mechanical stability also we should look for availability of the user friendly software to run the stages.

The stage should have low maintenance requirements and controllers and interfacing circuitry should be available and rotation requirement whether rotary stages are needed that also we should see with this we stop the discussion about the nano and micro stages.

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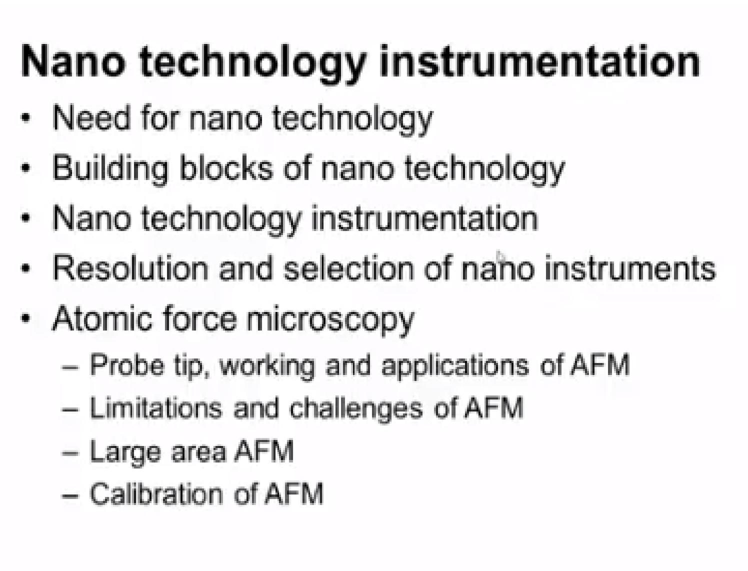

Let us begin our discussion on nanotechnology instrumentation so under this topic we will be discussing about the measurement instrumentation used in nanotechnology, so we will discuss about the need for nanotechnology and various building blocks of nanotechnology and what are the various measuring instrumentation used in nanotechnology for measuring the nano sizes and the resolution aspect of various devices.

How do we select the nano instrumentation and then we will discuss in some detail about atomic force microscopy under this we will be discussing about the property used in atomic force microscopy and working details of AFM and applications of AFM what are the various limitations and challenges of AFM and then we will move on to the discussion of large area a atomic force microscope and how to calibrate the atomic force microscope.

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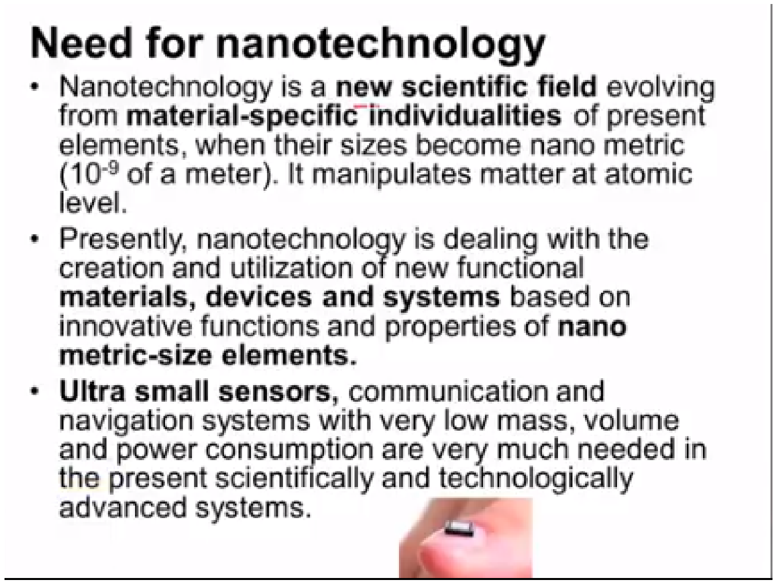

Now let us discuss what is the need for nanotechnology? now this nanotechnology is a new scientific field revolving from material specific individuality of presently available elements when their sizes become nano metric the nanotechnology man who plays the matter at atomic level.

Presently nanotechnology is dealing with the creation and utilization of new functional materials devices and systems based on innovative functions and properties of nano medicine elements and ultra small sensor communication and navigation systems with very low ma very low volume and very low power consumption are very much needed in the present scientifically and technologically advanced systems.

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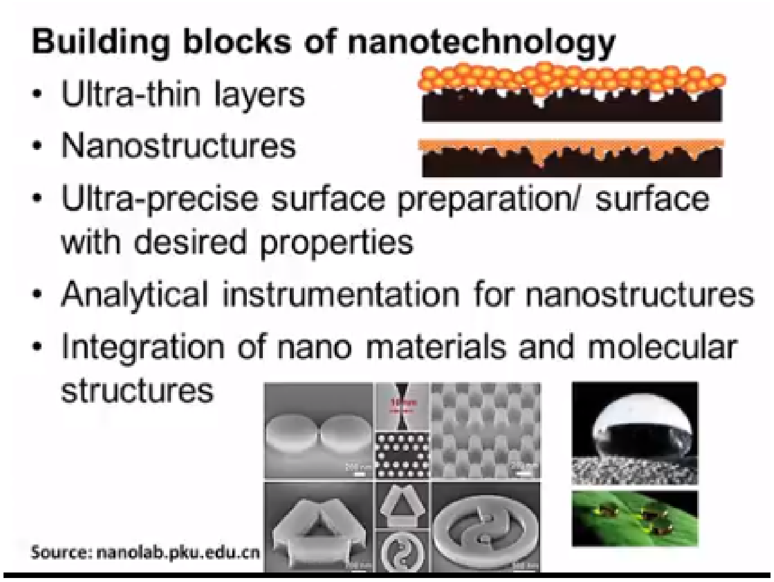

So in this aspect nanotechnology helps us to create the ultra small sensors and navigation systems. Now what are the building blocks of nanotechnology we can see here work piece this is the base material with very rough surface and now we want to change the characteristics of the surface of this base material so we can always apply ultra thin nano layer that is nano metric size can be applied on the surface.

So that the desired properties of the surface is can be achieved we can see here actually in the diagram by applying a ultra thin layer on the work piece surface the surface is converted into hydrophobic surface now nano structured can be built using nanotechnology and analytical instrumentation can be built can be used for measuring the performance of the nano structures.

Other important area in the nanotechnology is integration of nano materials and molecular structures now in this picture we can see very small nano sized disc are made and here vacancy nano sized round part and here again the nano sized cubic or rectangular shaped all these are made using the nanotechnology.

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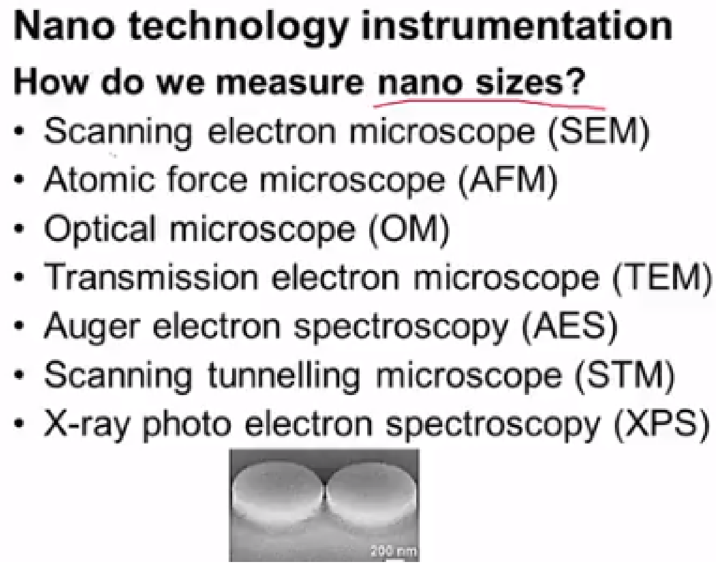

Now how do we measure the nano sizes different instrument patients are currently available some of them are listed below we can measure the nano sizes using the scanning electron microscopy or atomic force microscopy, optical microscopes with very high resolution transmission electron microscope, auger electron spectroscopy, scanning tunneling microscope, x-ray photoelectron spectroscopy.

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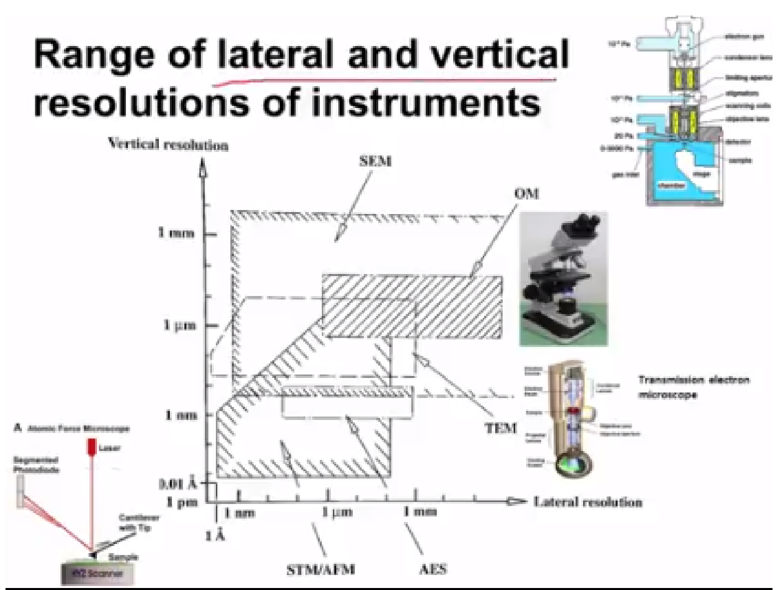

So these devices can be used for the measurement of nano sizes of the work pieces. Now let us try to understand the range of lateral and vertical resolution of various nano instrumentation we can see here x-axis is the lateral resolution and y axis is vertical resolution now we can see we have the scanning electron microscopy, it has the very wide area is covering the very wide area the lateral resolution of the scanning microscopy.

It starts the from 1 nm it goes up to few millimeter vertical resolution of scanning electron microscopy it starts from few micrometers or few nano meters up to few millimeter and then lateral, lateral resolution of the optical microscope is it starts from 1 micrometer it goes up to few millimeters and vertical resolution it starts from approximately 1 micrometer and it goes up to 400 micrometers.

Now we can see that we have this atomic force microscopy which is having the very low lateral resolution of fraction of nanometer and goes up to few hundred micrometer and vertical resolution of AFM is very low, less than the nano meter and fraction of nano meter. Vertical resolution can be obtained by using the atomic force microscopy.

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Selection of nano instrument

Analytical instrument	Resolution		Excitation method	Object of observation	Observation environment
	Vertical	Horizontal			
STM/AFM	0.001 nm	0.1 nm		Tunnelling electrons/atomic force	Atmosphere, gas, vacuum, liquid
SEM	8 nm	5 nm	Electrons	Secondary electrons	vacuum
TEM	0.08 nm		Electrons	Transmitted electrons	vacuum
AES	3 nm	10 nm	Electrons	Auger electrons	Ultrahigh vacuum
XPS	2 nm	100nm	Characteristic X-rays	Photoelectrons	Ultrahigh vacuum

Now how do we select the nano instrumentation now the very first thing is that we should understand what is the resolution requirement vertical resolution and horizontal resolution and also we should understand what is the observation environment so while considering these 2 we can select the nano instrument we can see here atomic force microscopy STM.

They can provide fractional nano metric resolution so horizontal resolution is less than 1 nm possible and vertical resolution is less than 1000 nm is possible and the observation environment is normal atmosphere it can be work pieces can be measured under the gas vacuum liquid. So a different observation environment we can use the SEM.

Now you can see standing electron microscopy the resolution vertical resolution is 8 nm and horizontal resolution is 5 nm the resolution of order 500 nm is also possible and the work pieces should be placed in the vacuum. So like this by knowing the observation environment and the resolution environment we can select the appropriate the instrument nano instrument.

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Comparison of AFM with SEM and TEM

	AFM	SEM	TEM
Sample preparation	little or none	from little to a lot	from little to a lot
Resolution	0.1 nm	5 nm	0.1 nm
Relative cost	low	medium	high
Sample environment	any	vacuum(SEM) or gas (environmental SEM)	vacuum
Depth of field	poor	good	poor
Sample type	Conductive or insulating	conductive	conductive
Time for image	2-5 minutes	0.1-1 minute	0.1-1 minute
Maximum field of view	100 μm	1 mm	100 nm
Maximum sample size	unlimited	30 mm	2 mm
Measurements	3 dimensional	2 dimensional	2 dimensional

Now here we have compared the atomic force microscopy with SEM and PEM. Sample preparation is required is very little for AFM and cost relatively low and any sample environment gaseous medium or liquid medium or normal atmosphere where is when we want to use some vacuum is required for measurement purpose vacuum environment is required only drawback of AFM is the depth of the field is very poor and work piece.

Sample can be conductive or insulating and another drawback of AFM is the time of image measurement that is it takes longer time when compared to SEM and PEM and maximum field of view is 100 micro meter where is here SEM it is more maximum sample size is unlimited where is in SEM it is limited nowadays large area AFM is valuable.

So that any area can be measured using a AFM and very important benefit or advantage of AFM is 3 dimensional characteristics can be obtained it can measure the height information varies in SEM only 2 dimensional measurements.

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Measurements	3 dimensional	2 dimensional	2 dimensional

Now let us discuss about the atomic force microscope in detail now this atomic force microscope is a very powerful survey analytical technique which can be used in different environment like a liquid or vacuum and it generates very high resolution topographic images of a work piece surface down to atomic resolution depending upon the sharpness of the tape it gives the spatial resolution of 1 to 20 nm and records topographic images.

You can see here we can have the cantilever attached to the basic body of the atomic force microscope and which is having a very sharp teeth and we can see there is a stage half the work piece is placed the stage is moved under the tip and the tip record the topographic details of the work piece the AFM can also be used for force spectroscopy.

That means it applies force on to the work piece surface vary from 5 to 50 P power newtons. To analyze mechanical or electrical and chemical properties of the surfaces it either drives into the surface to measure the nano mechanical properties such as modulus stiffness and addition or tip

tip is pulled away from the surface to investigate bond rupture and molecule of pulling, so this method of using the AFM is known as taping mode.

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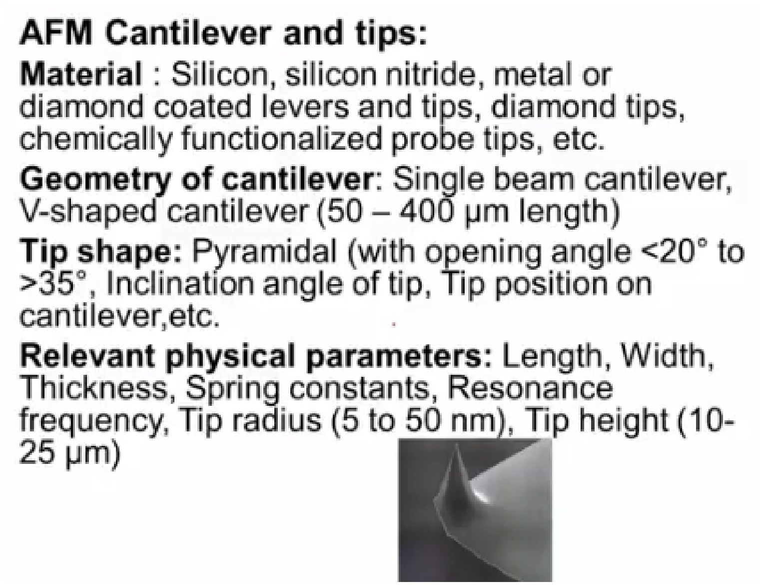

The AFM basically has a cantilever with its tip we can see the image this is the cantilever portion of the and that tip attached to the cantilever the material of cantilever of the chip is made up of silicon nitride metal or diamond coated levers and tips diamond chips or also sometimes used chemically functionalized probe tips are also used and the geometry of cantilever is it can be single beam and deliver or v shaped cantilever.

That means the cantilever can be of this shape single beam cantilever with some length width and the thickness of the cantilever or it can be v shaped cantilever like this so the end the tip is attached like this normally the length of the cantilever will be very from 50 to 400 micrometers and the tips shape it can be pyramidal with opening angle wearing from 20 degree to 35 degree.

Inclination angle of the tip that means this is the cantilever that it can be like this or sometime tip can be like this. So this is inclination angle of the tip or the tip position on the cantilever so the position also vary. It can be measure or it can be the tip and then the relevant physical parameters such as length of the cantilever width of the cantilever thickness of the cantilever spring constants of the material used to make the cantilever resonance frequency tip radius.

Normally it varies from 5 to 50 nm and tip height varies from 10 to 25 micrometer.

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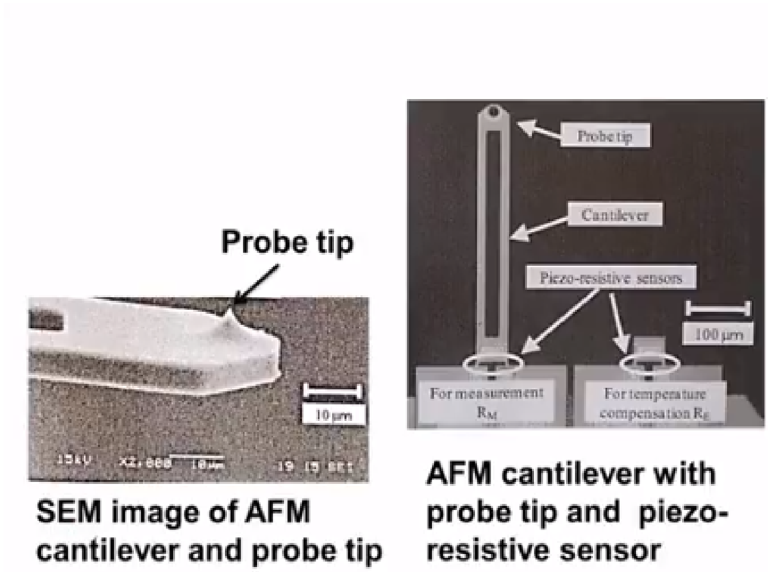

Now we can see a scanning electron microscope in the image of AFM cantilever and probe tip so this cantilever with a length of about 50 to100 micrometer and this is the probe tip attached to the cantilever and you can see another double beam type of cantilever with probe tip attached at the end of the cantilever and this has got the piezo resistive sensor attached and other end of the cantilever.

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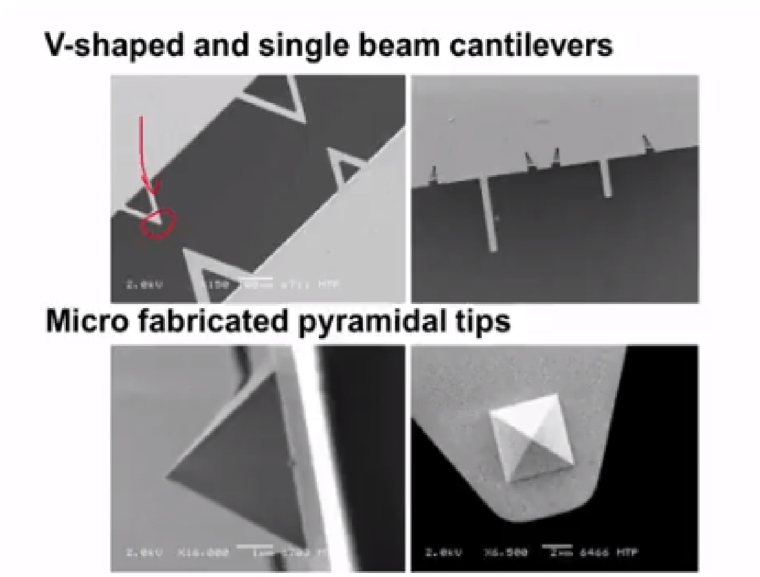

Now we can see the 2 types of the cantilever v shaped cantilevers and that if there will be probe tip and this is the single beam cantilevers with the tip attached to the end and these are micro fabricated pyramidal tips of the pyramid base with 4 micrometer and the height of the tip base about 6 to 10 micrometer.

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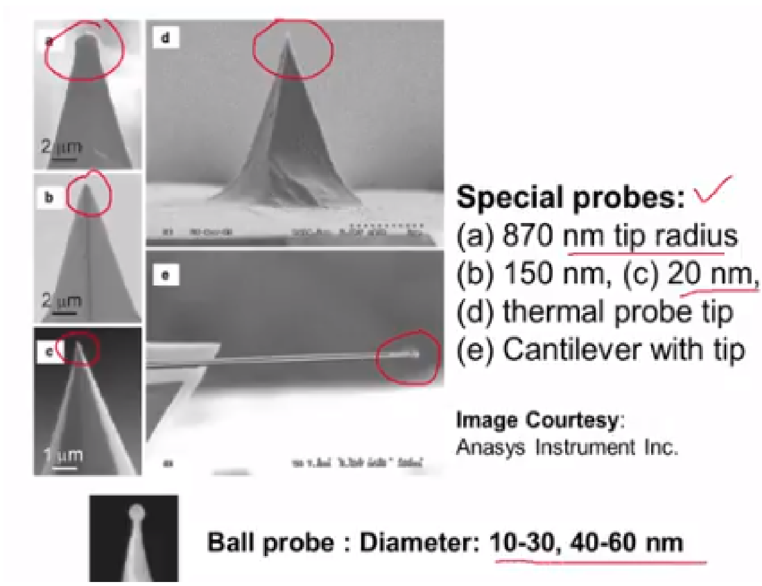

Now we can see different probe tip, special probe tips. This is probe tip with 870 nanometer tip radius and hear the tip radius is 150 nm and in this case it is very sharp probe tip with 20 nm tip radius and here is thermal probe tip which senses the temperature of the work piece surface.

This is the double beam type cantilever with the tip attached to the end and this is a special probe with the ball probe diameter varying from 10 to 30 nm 40 to 60 nm like this balls with different diameters are available.

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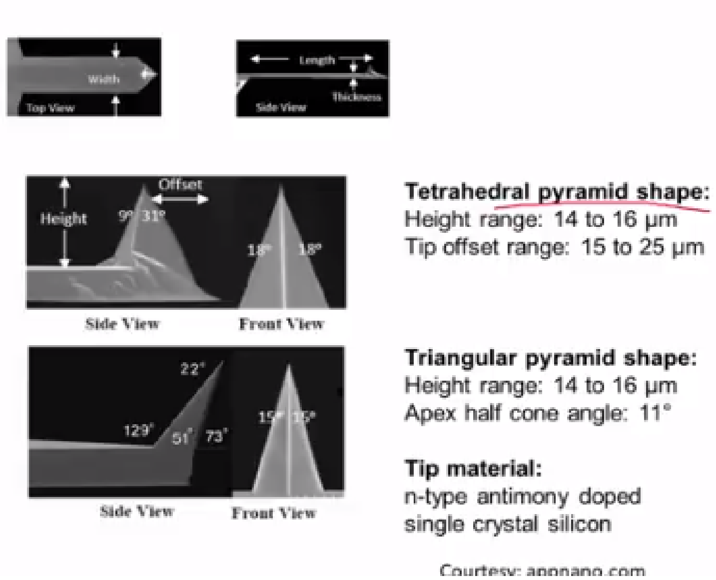

Now so these are the tetrahedral pyramid shape so this is the shape of the cantilever and this is the top view of the cantilever and the side view and the thickness of the cantilever is the length and here we can see that tip attached in and this is the close view of the tip of the having here is the tip probe tip and this is the height and this is the offset from the height what is the distance.

So this is the offset at different angles 90 degree angle this is 30 degree angle ok from different view you can see the angles here it is 18 degree the height of the probe ranges from 14 to 16 micrometer and tips offset ranges from 15 to 25 micrometer and these are the triangular pyramid type. Here the here the pyramid tip or the height range is 14 to 16 micrometer.

This is the height 14 to 16 micrometer and apex angle apex half cone angle is 11 degree tip material is n type and p antimony doped single crystal silicon material is used to fabricate the tips.

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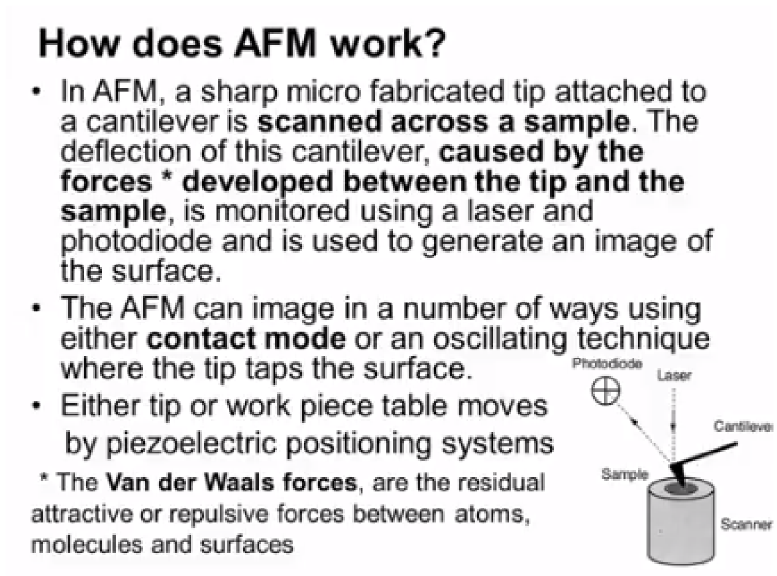

Now latest study how does the AFM work You can see this schematic diagram this is the stage the scanner stage which moves in x, y and z directions and these stages are normally piezoelectric stages with nano metric resolution and the cantilever with the tip attached to it. Now there is a laser force shortcut in which the incidental laser falling on the cantilever surface the sharp micro fabricated tip is attached to the cantilever.

This is used and the tip is used to scan the work piece surface this is the sample placed on the scanner stage now when the tip is moved near to the surface of it deflects the cantilever deflects because of the force developed is Van der Waals force developed between the tip and the sample . so the cantilever will deflect, this deflection of the cantilever deflect like this because of the attraction or if the force is repulsive it will move back.

Now this deflection is monitor using a laser and photodiode and is used to generate the reflected light will fall on the photodiode and this will generate an image of the surface. Now AFM can be image the AFM can image in a number of ways using either contact mode varying the tip will be in contact with the samples surface and the surface will be moved under the probe or the another mode is oscillating technique.

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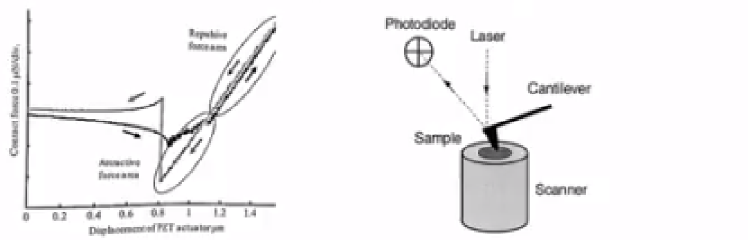
- The cantilever is designed with a very **low spring constant** (easy to bend) material (SiN), so that it is very sensitive to force.
- The laser is focused to reflect off the cantilever and onto the sensor.
- The position of the beam in the sensor measures the deflection of the cantilever, and in turn the force between the tip and the sample.



Where that if that is the surface now either tip or work piece table moved by using the pizza electric positioning system having the nano metric resolutions. The cantilever is designed with a very low spring constant material so that it is very sensitive to forces it is sensitive to human force as low as eco newton the laser is focused to reflect off the cantilever and onto the sensor material kept here the laser is falling on the back surface of the cantilever in placed here.

So that laser incident range is reflected back and it falls back on the photodiode the position of the beam in the sensor measures the deflection of the cantilever the position of the reflected beam of the laser in the photodiode measures the deflection of the cantilever and then in turn the force between the tip and the sample is measured.

We can see here depending upon the material combination material of the tip and the material of the samples there can be repulsive force or an attractive force and even the small forces as though as a few micro Newtons can be sensed and here you can see the displacement of the XYZ scanner.

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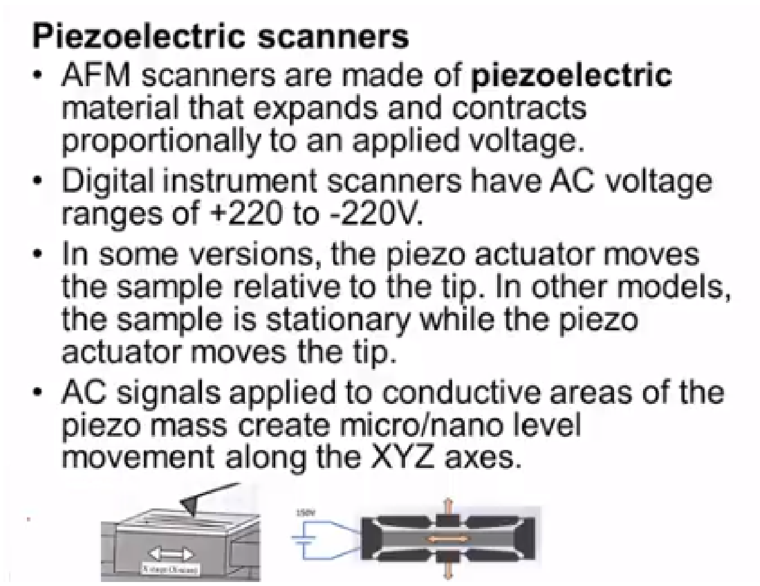

Piezoelectric scanners are used for moving the work piece under the probe A from probe. The AFM channels are made up of piezoelectric material which expands and contracts proportionally to an applied voltage this we discussed in detail inst a position metrology hear the pizza electric stage.

When voltage is applied it expand or contract depending upon the voltage that is applied and this xyz scanner on which the sample is mounted and this shows the cantilever with the probe the digital instrument scanners have ac voltage ranges of + 220 volts to - 220 volts in some versions the piezo actuator moves the sample relative to the tip that means that the tip will be constant.

It will move up and down and the sample the stage on which the sample is mounted will be moved with the piezoelectric device in some other models the sample is stationary while the piezo actuators moves that tip. AC signals are applied to conductive areas of piezo mass to create micro or nano level movement along the X Y Z axis.

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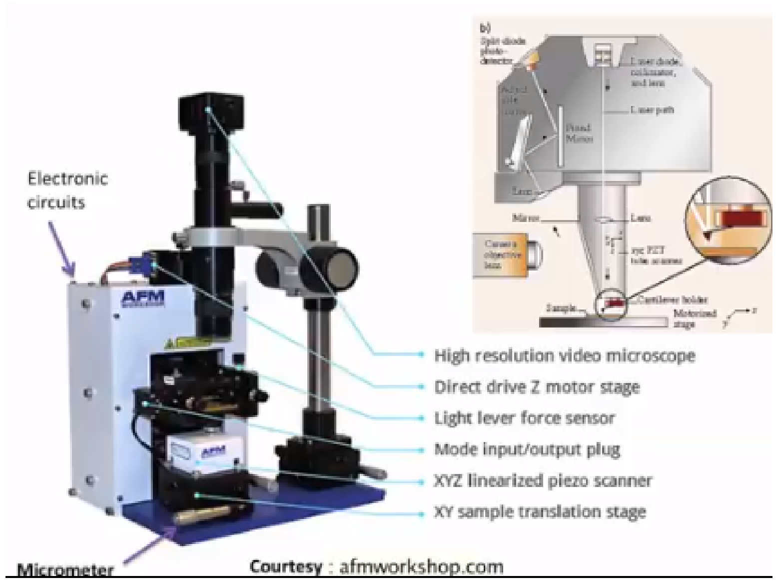

Now this picture shows the external appearance of the AFM and here we can see the schematic diagram of the AFM. So we have this white box is the xyz linearized piezo scanner on which the sample to be tested is mounted and this X, Y sample translation stage you can see 2 micrometers are provided for x moment and y movement.

The initial adjustment of the sample the initial positioning of the sample can be made using this manual micrometers and then the scanning is carried out using this xyz liberalized piezo scanner and here we can see there is a column to support this high resolution video microscope which captures the images and then all the electronics circuits will be case in this box.

Now this schematic diagram shows the internal structure of the AFM this is the area where the sample is mounted this is the motorized XY stage. so here we have manual XY stage for initial positioning whereas here for initial positioning the motorized XY stages used and this stage surface where the sample is mounted.

And we can see the prob in this zoomed view can be seen here the probe lenses and their laser is made to fall on the back surface of the cantilever and the laser is lifted back and the mirror the adjustable mirror reflects the laser and falls on this mirror and again it is reflected back on to the split diode photo this is the incident laser and this is deflected laser and this is housing carries the laser diode and the optical lenses.

And the laser is meant to fall on the back surface of the cantilever and the laser is reflected back and this mirror with is adjustable mirror reflect the laser and falls on this mirror and again it is reflected back onto the split diode photodetector the position of the laser of this detector decides. The bending of the cantilever and the here an object camera objective lenses provided for viewing the measurement or to capture the images.

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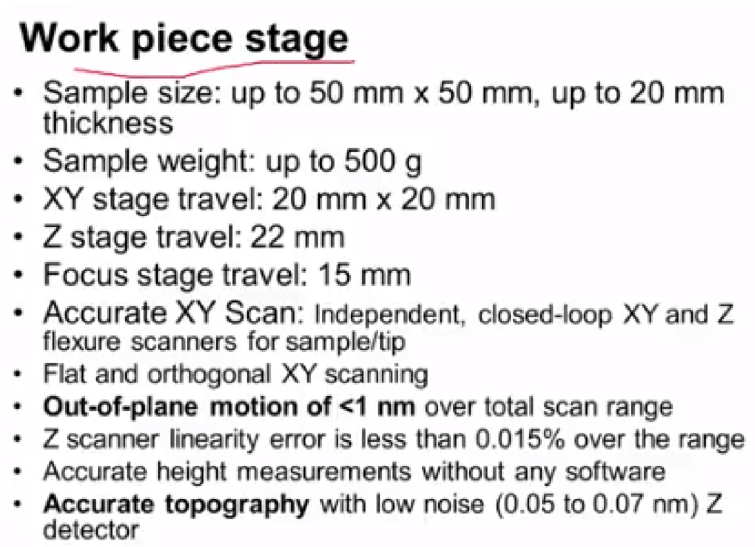

Now the work stage work piece stage of the AFM is very important where it should be free from any vibration and should have very finer, linear horizontal and vertical resolutions. So that very fine image can be captured the sample size normally is 50 mm and 50 mm and up to 20 mm thickness work pieces can be mounted sample weight can be up to 500 grams and x, y stage travel is 20 mm by 20 millimeter for initial adjustments.

It can be manual or motorized and also the cantilever is moved up and down for initial adjustments for which there is an z stage focusing stage travel is up to 15 millimeter accurate x, y scan is carried out for that closed loop x, y and z flexure scanners are provided the flat and orthogonal x, y scanning is very essential the out of plane motion of the x, y stage should be less than 1 nm over total scan range.

The z scanner linearity error is less than 0.015 % over all scanning range accurate height measurements without any software is possible with some AFMs accurate topography with low noise as low as 0.05 to 0.07 nm with z detectors are used for topographic sensing.

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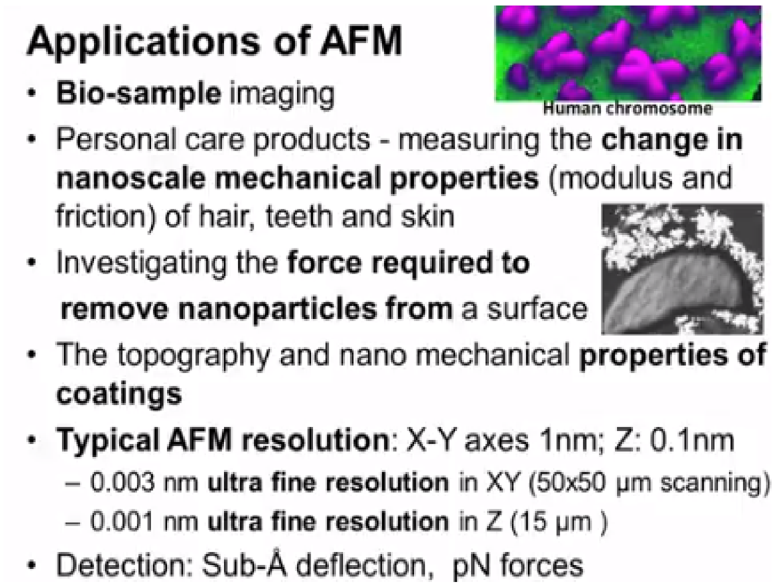

Now let us move to the application of atomic force microscope there are many biological applications of AFM. The AFM is used for getting the images of the biological samples. We can see here and an image of human chromosome obtained from AFM. So many microbiological applications AFM can be used and when we use some personal care products like gels, solids, then face changes in the hair, teeth and skin in the nano scaled level.

So what is the amount of the change in these things in these items for the measurement of that we can use AFM and we can see here sometimes the nano particle coating will be there on surfaces and we need to remove the nanoparticles from the surface and to study what is the amount of force required to remove the nanoparticles we can use a AFM and for the topographical surfaces and to get the nano mechanical properties of the coating.

We can use AFM now the normal AFM resolution. Will be like this in the movement of x y stage is sometimes like 100 micrometer or 200 micrometer then the resolution of x axis and y axis will be 1 nm where is the vertical resolution will be. 1 nm and the scanning range is limited to say 50 to 50 micrometer in such cases AFM are available with ultrafine resolution that is resolution as low as 0.003 nm and if the z axis movement is limited to 15 micrometer.

Then the resolution of 0.001 nanometer is possible and these AFM can be used for studying the sub and strong deflection of the cantilever and they can be used for the measurement of the small forces to the P power newton level.

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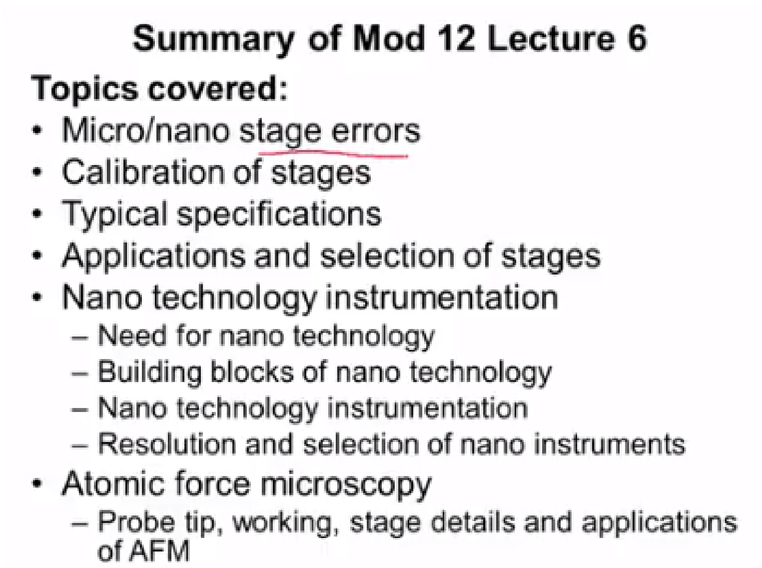

Now with this we will conclude the module 12, lecture number 6 in this lecture, we discussed the following topics. We studied the micro nano stage errors. Errors such as the linear errors in micro stages and nano stages and how do we calibrate the micro and nano stages.

What are all the facilities available from material to material based system and what are all the typical specifications for the micro and nano stages also we discussed about the applications and selection of stages then the we discussed on the nanotechnology instrumentation we discussed the need for nanotechnology and water are the various building blocks of nanotechnology and then the meteorological instrumentation.

We also discussed about the resolution and how to select the nano meteorological instrumentation then we also discussed in length some atomic force microscopy in which we discussed about the cantilever and props used in AFM how the AFM works and the stage details of the AFM and some applications of AFM with this we will conclude this lecture we will continue in the discussion in the next lecture on atomic force microscopy. Thank you.