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**Lecture - 34**  
**Optical Measurements and Nanometrology (Part 3 of 3)**

So, using the interference pattern techniques there are several instruments which were developed.

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### Interferometers

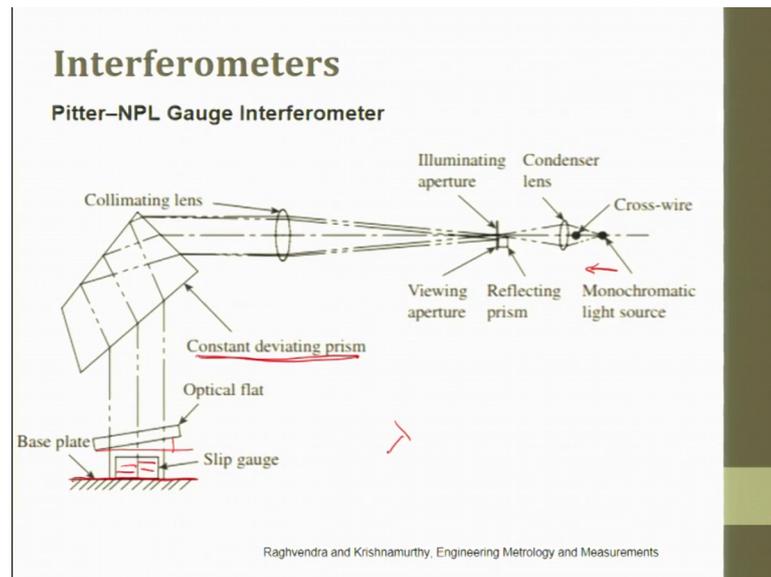
#### Pitter-NPL Gauge Interferometer

- It can be seen that the two sets of fringes are displaced by an amount 'a' with respect to each other.
- The value of 'a' varies depending on the colour of the incident light. The displacement 'a' is expressed as a fraction of the fringe spacing 'b', which is as follows:  $f = a/b$
- The height of the slip gauge will be equal to a whole number of half wavelengths, 'n', plus the fraction 'a/b' of the half wavelengths of the radiation in which the fringes are observed.
- Therefore, the height of the slip gauge,  $H = n \times (\lambda/2) + (a/b) \times (\lambda/2)$ , where 'n' is the number of fringes on the slip gauge surface, ' $\lambda$ ' is the wavelength of light, and ' $a/b$ ' is the observed fraction



So, interferometers are these instruments which work in the principle of interference of light, and they are used to measure very small variations; that means, to say very small variations in terms of lambda wavelengths. So, wavelengths are generally in nanometer. So, you can measure lambda by 2 lambda by 4 and all those things. This techniques are used light is one powerful technique which can be used for such fine measurements. So, Pitter-NPL gauge interferometer, here what they do is you can see here I will just show you the equipment.

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So, this is the principal setup. So, you have slip gauges which are arranged to the height ok, you can then you take an optical flat. This optical flat is always inclined at an angle so that you create an air wedge. So, based on this air wedge you can create the fringe patterns. So, then this is attached to a collimating this is attached to a constant deviating prism. So, and then this in turn goes to lens, and from the lens it goes to a prism here and the ahead of the prism there is a viewing aperture, then you have condensing lens, then you have a cross wire we have a monochromatic source. We are just gone the other way around. If you are more particular we can start from here.

The light goes from here, the light gets condensed through this condensing lens, then it passes through a reflecting prism, then you have a small aperture viewing aperture is there. So, this through this viewing aperture the light goes further, then you have a here it is a condensing lens, here it is a collimating lens you have, then this hits and that the light bends at an angle. For that we use a constant deviating prism. So, after this again there is a bending which is happening to the light, the light further hits down. So, if you see the light hits on a flat base plate which is flat and then on top of it you have a prism. So, the light gets reflected from here, this creates fringe patterns and these fringe patterns are measured and you try to find out the variations. You can call it as a comparator or you can also call it as a measuring device at the resolutions of lambdas.

So now, let us see so, it can be seen that 2 sets of fringes are displaced by an amount  $a$  with respect to each other. The value of  $a$  varies depending on the color of the incident light, monochromatic light source whatever we are talking about. The displacement  $a$  is expressed as a fraction of a fringe spacing  $b$  and finally, what we get is  $f$  equal to  $a$  by  $b$ . So, the height of the slip gauge will be equal to a whole number of half wavelength  $n$  plus a fraction of  $\lambda$   $a$  by  $2$  that is this fraction can be in  $\lambda$  by  $2$  of the half wavelengths of the radiation in which the fringes are absorbed. Therefore, the height of the slip gauge  $H$  can be found out as  $n$  into  $\lambda$  by  $2$  plus  $a$  by  $b$  into  $\lambda$  by  $2$ , where  $n$  is the number of fringes.

Fringes are nothing but if you are these are the fringes bright dark bright dark bright dark. So, these are the fringes on the slip gauge and  $\lambda$  is the monochromatic source light whatever we use, and  $a$  by  $b$  is the observed fraction where it is displaced with this you can try to figure out.

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**Interferometers**  
**Pitter-NPL Gauge Interferometer**

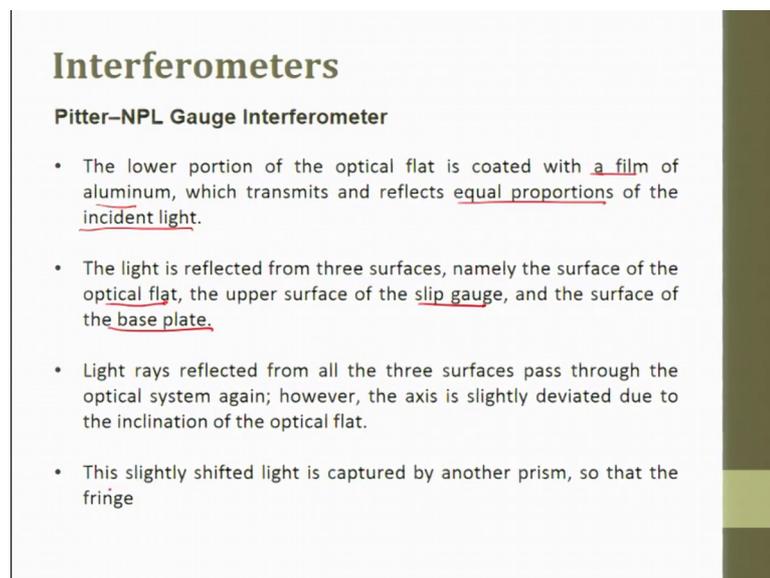
- Light from a monochromatic source (the preferred light source is a cadmium lamp) is condensed by a condensing lens and focused onto an illuminating aperture.
- This prism splits the incident light into light rays of different wavelengths and hence different colors. *400nm to 700nm*
- The user can select a desired color by varying the angle of the reflecting faces of the prism relative to the plane of the base plate.
- The prism turns the light by 90° and directs it onto the optical flat.
- The optical flat can be positioned at a desired angle by means of a simple arrangement.
- The slip gauge that is to be checked is kept right below the optical flat on top of the highly flat surface of the base plate.

Discussing about the instrument, light from a monochromatic source is condensed by a condensing lens and focused on to a illuminating aperture. This prism split, the incident light into light rays of different wavelength and hence, therefore we get different colors. So, if you look back here this is what we are trying to talk about prism reflecting prism, and you have this prism here 2 prisms.

The user can select a desired color by varying the angle of the reflecting face, because white light if you can pass through a prism you can divide it into various wavelength. So, it varies from 400 nanometer to 700 nanometer. In this you have several colors of your choice ok. The user can select a desired color by varying the angle of the reflecting face of the prism relative to the plane of the base plate. So, here the height and there is a base plate the difference between this also can be is taken this is taken care. The prism turns the light by 90 degrees, prism turns by 90 degrees so, here 90 degrees.

The optical flat can be positioned at a desired angle by means of simple arrangement, the slip gauge that is to be checked is kept right below the optical flat on top of highly flat surface of the base plate. So, when you do all these measurements, you should make sure the base plate is also perfectly flat. If there is a small variation in the base plate, that will be in turn amplified when you keep a slip gauge on top of it, then a slip gauge as a variation it goes to it.

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## Interferometers

### Pitter-NPL Gauge Interferometer

- The lower portion of the optical flat is coated with a film of aluminum, which transmits and reflects equal proportions of the incident light.
- The light is reflected from three surfaces, namely the surface of the optical flat, the upper surface of the slip gauge, and the surface of the base plate.
- Light rays reflected from all the three surfaces pass through the optical system again; however, the axis is slightly deviated due to the inclination of the optical flat.
- This slightly shifted light is captured by another prism, so that the fringe

The lower portion of the optical flat is coated with a film of aluminum which transmits and reflects equal portion of the incident light. See optical flat you can have one side optical flat, you can have 2 side optical flat; that means, to say both sides one side reflecting and both sides transparent. So, different types of optical flats are there.

The light is reflected from 3 surfaces. Namely the surface of the optical flat, the upper surface of the slip gauge, the surface of the base plate. 3 reflections correct right.

Because the optional flat is at an angle so, you might have one from here, one from here also. The light rays reflect from all the 3 surfaces, passes through the optical system again. But however, the axis is slightly deviated due to the inclination of the optical flat. This slight shifting light is captured by another prism so that the fringes can be done; so, that the fringes can be taken in this setup.

So, instead of this monochromatic light we can also use laser. Laser interferometer is exhaustively used today because if you wanted to find out in a 3 dimensional object; where the features whatever you do are of nanometer range. Or, if the tolerance is in nanometer; that means, to say variation is in nanometer, then laser interferometric techniques are used to measure the deviations and report.

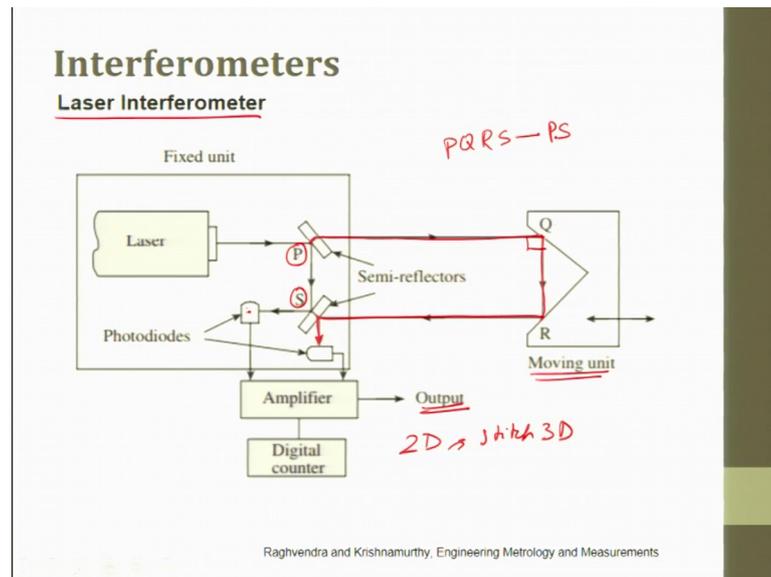
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**Interferometers**  
**Laser Interferometer** → 3-D object → features of nm → tolerance in nm

- Laser light first falls on the semi-reflector P, is partially reflected by 90° and falls on the other reflector S.
- A portion of light passes through P and strikes the corner cube. Light is turned through 180° by the corner cube and recombines at the semireflector S.
- If the difference between these two paths of light (PQRS - PS) is an odd number of half wavelengths, then interference will occur at S and the diode output will be at a minimum.
- On the other hand, if the path difference is an even number of half wavelengths, then the photodiodes will register maximum output.
- Each time, the moving slide is displaced by a quarter wavelength, the path difference (i.e., PQRS - PS) becomes half a wavelength and the output from the photodiode also changes from maximum to minimum or vice versa.

So, the same technique interferometry is used, instead of a monochromatic size we use a laser. The laser light first falls on a semi reflector P is partially reflected by 90 degrees, and falls on the other reflector S. So, let us first look at the diagram laser light.

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So, this is a fixed unit, the laser light falls on a semi reflected one. So, or we can call it as a beam splitter. So, there is a split happening. So, then it gets reflected here, then you have a semi reflecting this in turn goes to a photodiode, and this whatever falls on this photodiode the values are very less. So, it gets amplified and then you count the number of fringes.

So, the amplified output can be taken from here ok. So now, what you do is, the light half get split here, the half-light gets transferred through the reflector through the beam splitter, it moves to the moving unit. So, here is a prism where it can internally reflect and create exactly 90 degree. So, it falls on here it hits here, and it again comes back ok. So, here is a beam splitting so, P S it goes and then it gets photodiode can be measured, and the rest you can see which get split from here goes through this path, then comes here, and then goes to this path and this you can get it counted here.

So now, if you try to take the variation or the difference between these 2, in the counting then you try to get a proper output. So, basically what do you get is a 2D line plot, then you stitch join several of this 2D you get a 3D on a surface. With this you can try to measure on a surface using laser interferometer techniques. And by the way very far up distance can be measured for example, you have very large table today we talk about table size table bed size of 10 meters. So, we use laser interferometric techniques to find out the variation all along the flat.

A portion of the light passes through P and strikes the corner cube, this is called as a corner cube. Light is turned on by 180 degrees, right. So, it is turned on by 180 degrees. So, corner cube so, the moving unit is called as a corner cube, by the corner cube and recombines at the semi reflector S. If the difference between the 2 paths is PQRS minus PS; let us go back, PQRS minus PQRS minus PS, minus PS is an odd number of half wavelength, then interference will occur at S and the diode output will be minimum. On the other hand, if the path difference is an even number on half wavelength, then the photodiode will register a maximum output. So, bright dark bright dark right fringe patterns so, we get minimum and we get maximum.

Each time the moving slide is displaced by a quarter wavelength, the path difference PQRS minus PS becomes half a wavelength and the output of the photodiode also changes from maximum to minimum and vice versa. So, as and when you start moving, the fringe patterns also move based on this you can try to find out the distance.

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**Optical Measurements**

- The distance between the gauge and the optical flat in the first position has increased by a distance  $\delta_1$ , over the length of the gauge, and in the second position by a distance  $\delta_2$ . It is clear that the distance between the gauge and the optical flat changes by  $\lambda/2$ , between adjacent fringes.
- Therefore,  $\delta_1 = n_1 \times \lambda/2$  and  $\delta_2 = n_2 \times \lambda/2$ . The change in angular relationship is  $(\delta_2 - \delta_1)$ , that is,  $(\delta_2 - \delta_1) = (n_1 - n_2) \times \lambda/2$ .

$$\delta_1 = n_1 \times \frac{\lambda}{2} \quad \delta_2 = n_2 \times \frac{\lambda}{2}$$

$$\delta_1 - \delta_2 = (n_1 - n_2) \times \frac{\lambda}{2}$$

Let us the distance between the gauge and the optical flat in the first portion has increased by a distance del 1, over the length of a gauge. And the second position by a distance by del 2. It is clear that the distance between the gauge and the optical flat changes by lambda by 2 between the adjacent fringes. Therefore, del 1 is represented as n times del 1 is nothing but n times lambda by 2, and del 2 will be n times lambda by 2. So, what is the difference? The change in angular relationship will be del 1 minus del 2

which is nothing but  $n_1 - n_2$  into  $\lambda$  by 2.  $\lambda$  by 2 is the wavelength of the light whatever you use,  $n_1$  and  $n_2$  is the number of fringe patterns which has got created.

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**Numerical Problem**

**Question:** A slip gauge is being inspected using the NPL flatness interferometer. It is recorded that the gauge exhibits 10 fringes along its width in one position and 18 fringes in the other position. If the wavelength of the monochromatic light source is 0.5 $\mu$ m, determine the error of flatness over its width.

*The distance between the gauge and optical flat changes by  $\frac{\delta}{2}$  between adjacent fringes*

$$\delta_1 = 10 \times \frac{\lambda}{2}$$

$$\delta_2 = 18 \times \frac{\lambda}{2}$$

Therefore

$$\delta_1 = 10 \times \frac{\lambda}{2}$$

$$\delta_2 = 18 \times \frac{\lambda}{2}$$

$$\delta_1 - \delta_2 = 8 \times \frac{\lambda}{2}$$

Now, let us take a question and try to solve it. A slip gauge is being inspected by using NPL flatness interferometer. The first interferometer what we saw? It is recorded that the gauge height exhibits 10 fringes along its width in one position and 18 fringes in the other position. If the wavelength of the monochromatic light source is 0.5 microns determine the error in flatness; how do you solve it?

So,  $\delta_1$  equal to 10 times  $\lambda$  by 2, ok. So, next one on the change is going to be  $\delta_2$  is equal to 18  $\lambda$  by 2 ok. If you want to write down what is given in the problem, I will write it down the distance between the gauge and the optical flat changes by between adjacent fringes. Therefore,  $\delta_1$  so, we can make it as  $\delta$  by 2,  $\delta_1$  equal to 10 into  $\lambda$  by 2,  $\delta_2$  is equal to 18 into  $\lambda$  by 2, ok. So now  $\delta_1 - \delta_2$  will be equal to 8 into  $\lambda$  by 2, ok.

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### Numerical Problem

The change in angular relationship  
 $(\delta_1 - \delta_2) = 8 \times \frac{\lambda}{2}$   
and the error in parallelism is half of its value.

$$\frac{8 \times \frac{\lambda}{2}}{2} = 4 \times \frac{\lambda}{2}$$
$$= 4 \times \frac{0.005}{2}$$
$$= \underline{\underline{0.001 \text{ mm}}}$$

So, the change in angular relationship is  $\delta_1 - \delta_2 = 8 \times \frac{\lambda}{2}$  and the error. So now, we have to multiply with the  $\lambda$ , the error in parallelism is half of its value. So, so this will be equal to so,  $8 \times \frac{\lambda}{2}$ . So, it is by 2 ok. So, then this becomes equal to  $4 \times \frac{\lambda}{2}$ . So, then what is  $\lambda$ ?  $\lambda$  is  $4 \times 0.005$  divided by 2. So, that is nothing but 0.001 millimeter this will be the error ok, fine.

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### Scales, Gratings and Reticles

#### Scales

CNC slide  $\rightarrow x, y, z$

- Scales are often used in optical instruments.  $\rightarrow$  
- It typically involves a read-out system in which an index point is moved mechanically until it frames the scale line and then reads the amount of movement that has taken place.  $\rightarrow$  
- The preferred choice of material for a scale is stainless steel.
- It takes good polish, is stable, and lasts longer. However, its higher thermal coefficient of expansion compared to other materials limits its use.
- Glass is another popular material used for making scales.
- Scale graduations can be produced by etching photo-resistive material. Scales are meant to be read by the human eye.

So now let us get into Scales, Gratings and Reticles. Scales, where are the scales used? So, the scales are used for measurement in machines. For example, if you have a CNC

machine and you have something called as a slide. So, in CNC machines we have slides, and these slides move in x direction, y direction and z direction. The displacement each time has to be measured. So, if the displacement has to be measured, then what we do is, we try to create these scales ok. So, these scales what happens is, we will try to have a source of light and then we have assumed that we have a scale here, and then we will have a photodiode here. So, this is light, this is scale, I am talking about a linear scale. And then there is a photodiode.

So, perpendicular to the to the screen right, perpendicular to the screen if the slide keeps moving; so, the line falls on the scale where there is graduation and based upon the graduations there will be a counting done by the photodiode and we try to measure what is the displacement. If you wanted to change the linear with a rotary; that is also possible you have a light, you have a rotary disc and then you have a photodiode. This light falls on a disc so, this disc is on photodiode and it starts doing ok. These are called the scales; the scales are often used in optical instruments. So, here what is the beauty that is non-contact measurement. So, there is no wear and tear, and the scales you can try to have with the finest accuracy.

It typically involves a read out system in which an index point is moved mechanically until it frames the scale line, and then reads the amount of the moment that it is taken place. The preferred choice of material for the scale is stainless steel. It takes good polish is stable and last longer; however, it is higher thermal coefficient of expansion compared to the other materials limits is used. Glass is another popular material which is used for making scales. The scales graduation can be produced either by etching photo resist material, the scales are meant to read out by human eyes; the graduations if you make it thinner and thinner and thinner you can use the light and directed by the photodiode.

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## Scales, Gratings and Reticles

### Scales

- However, the human eye is invariably aided by an eyepiece or a projection system, which not only reduces the fatigue of the human operator but also improves reading accuracy to a large extent.
- In more advanced optical instruments, photoelectric scale viewing systems are preferred.

However, the human eye is invariably aided by an eyepiece or a projection system; which not only reduces the fatigue of the human operator, but also improves the reading accuracy to a large extent. Now these things are getting automated. In more advanced optical instruments of photoelectric scale viewing systems are preferred. That is nothing but a photodiode is used.

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## Scales, Gratings and Reticles

### Gratings

$\frac{100}{mm}$  

- Scales with a continuously repeating pattern of lines or groves that are closely spaced are called reticles.
- The line spacing may be of the order of 50–1000 per millimetre.
- They are invariably sensed by photo-electric read-outs.
- There are two types of gratings: Ronchi rulings and phase gratings.
- Ronchi rulings consist of strips that are alternatively opaque and transmitting, with a spacing of 300–1000 per millimetre.
- Phase gratings consist of triangularly shaped, contiguous grooves similar to spectroscopic diffraction gratings.

Gratings, the marking what you do on the scales are called as gratings. The gratings can be as thin as possible. For example, you can try to have 100 lines drawn per millimeter.

So, when you draw 100 lines marks on a scale. So, this is called as a grating. Scales with a continuous repeating pattern of lines or groves that are closely spaced are called as reticles. The line spacing maybe in the order of 1,000 per millimeter, they are invariably sensed by photoelectric readouts whatever I have already told. There are 2 types of grating. One is called as Ronchi rules and phase gratings. Ronchi rule consists of strips that are alternatively opaque and transmitting with spacing of 300 to 1,000 lines per millimeter, gratings per millimeter. The phase grating consists of triangularly shaped contiguous grooves similar to spectroscopic diffraction patterns. These are phase grating phase grating used in reticles.

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**Scales, Gratings and Reticles**

Reticles

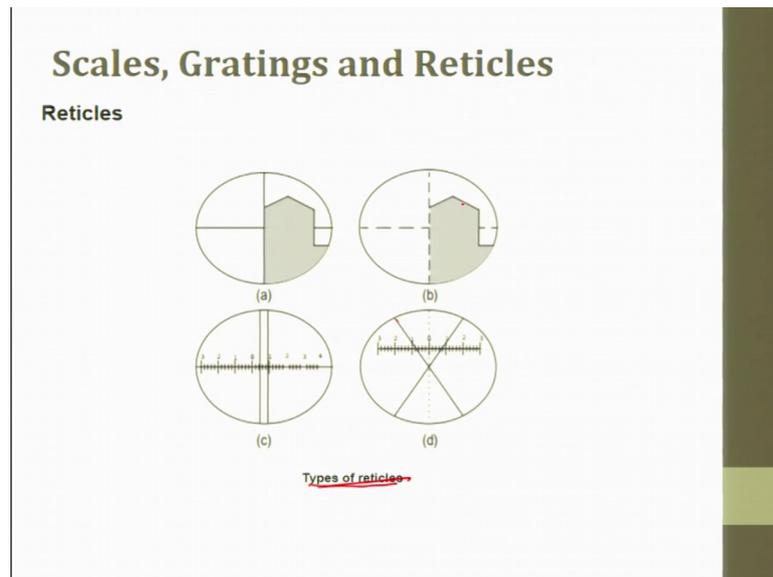
- Parallel lines spaced slightly wider than the scale lines enable precise settings to be made.
- In this case, the eye averages any slight irregularities of the edges of the scale lines when seen in the clear spaces along each side.
- This is known as bifilar reticle.

• Linear Scale for measures in CNC m/c.

• Scales { linear } => Linear encoders  
Circular

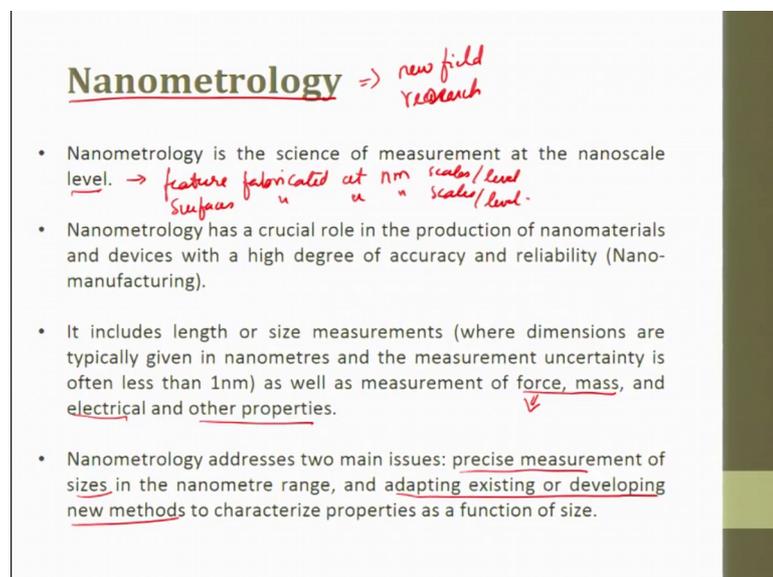
Reticles are nothing but parallel lines spaced slightly wider than scale lines enabling precise setting to be made. In this case, the eye average the averages any slight irregularities of the edges of a scale line when seen clearly space them each. So, they are also known as bifilar reticles ok. So, basically these reticles are used in used as linear scales for measurements in CNC machines ok. And the scales can be of 2, it can be linear, it can be circular. So, basically people call it as linear encoders and circular encoders ok. So, these are nothing but scales gratings and reticles which are used for measurement.

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So, this is a simple different types of reticles. So, you can reticle for measuring a b; so, you can see c and d ok. So, these are cross patterns which are used, these are linear patterns which are used to measure the gratings.

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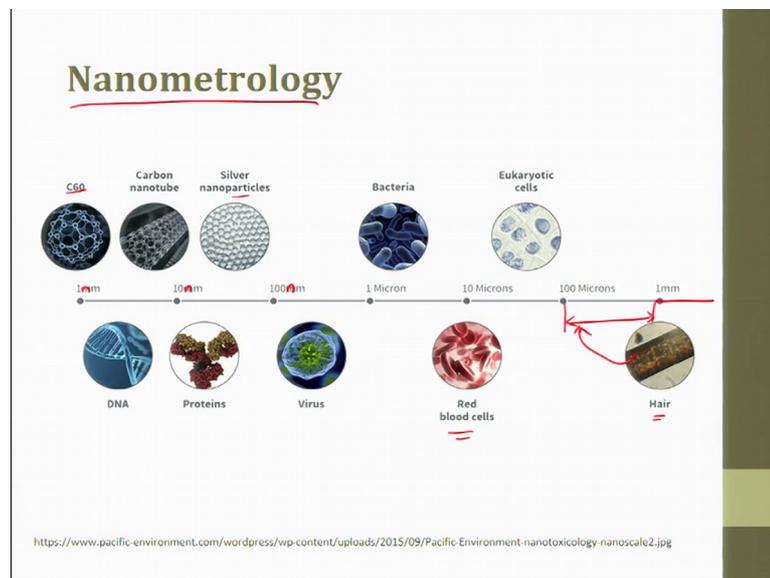


The last part of the optical measurements is nanometrology. As I told, nanometrology is the talk of the term, nanometrology is the science of measurement at nanoscale levels. So, here what we are measuring is we are trying to measure features which are fabricated, features fabricated at nanoscale, nanometer scale features and surfaces,

fabricated at nanometer scales or levels ok. These are the measurements we are talking as nano measurements. So, nanometrology has a crucial role in the production of nanomaterials and devices with a high degree of accuracy and repeatability. So, the interesting part let me tell you. So, here when you want to measure nano features, you cannot use the existing conventional screw gauge or gear all these things cannot be used. So, here the movement will be given by a piezo crystal ok.

So, completely different dynamics, it includes length or size measured as well as measurement of force, mass electrical and other properties we measure. Some other property from there we try to convert it into linear scales. For example, we must have the Van der Waals force and try to talk about the distance. The nanometer addresses to main issues, precise measurement of sizes in nanometer range, and adapting existing or developing new methods to characterize properties as a function of size. This is a very new field. And there is lot of research going on in research in the area of nanometrology, still there are not many tools which are available at nanoscales for measurements, ok.

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Some of the just for your understanding some of the objects which are present today and what are their levels so, C60 what we talk about carbon nanotubes. Then we have silver nanoparticles, then we have these are all in nano not millimeter nano ok. And these are all in micron bacteria is one micron, then you have red blood cells in 10 micron, you have human hair which is close to which is between 100 micron to 1 millimeter. So,

basically it is 100 micron will be for hair ok, and this keeps continuing further. This is just for your understanding, what are the different things which we know which we use regularly and what is their dimensions.

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## Nanometrology

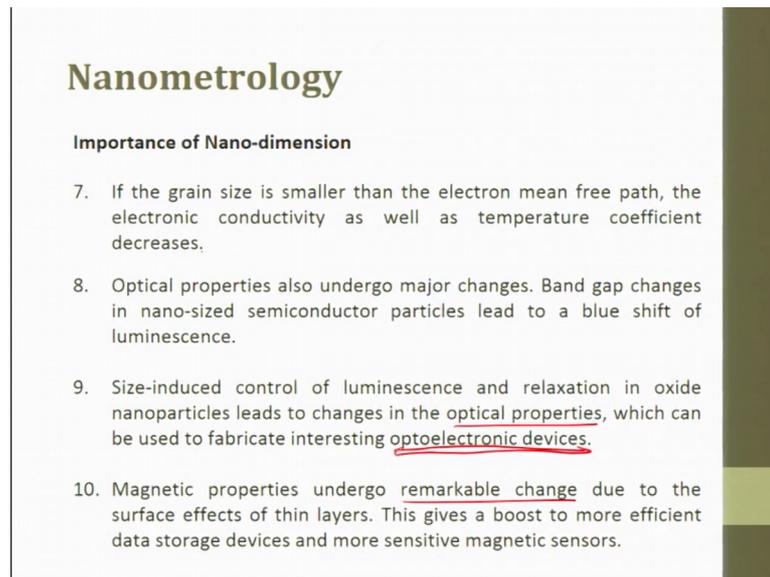
### Importance of Nano-dimension

1. Due to the contribution of grain boundaries at nanoscale, materials exhibit superior mechanical strength and ductility.
2. Thermodynamic properties also undergo a sea change.
3. Thermodynamic phase equilibrium is shifted, due to the contribution of interfaces or interface-related strains, to the free energy of the system.
4. This allows production of new non-equilibrium materials, which exhibit properties that were not known previously.
5. Tribological properties are also affected since the interacting materials are in the nanoscale.
6. These changes facilitate reduced friction and wear in applications of micro-electro-mechanical systems. (MEMS)

So, importance of nanodimensions due to the contribution of grain boundary at nanoscale, material exhibits superior mechanical property and ductility. So, you should understand the melting temperature will be different, the strength will be different. So, when we try to use these nanomaterials, you have a completely different ball game as compared to the normal materials available. So, when we try to measure it we should have such amount of precision things.

Thermodynamic properties also undergo a sea change, melting points go down. Thermodynamic phase equilibrium is shifted, this allows production of new non equilibrium materials nanomaterials allows it. Tribological properties affects since the interaction of materials are in nanoscale. These changes facilitate reduced friction and wear in application of micro electro mechanical systems which is otherwise called as MEMS. So, this is the importance of nanomaterials nanodimensions.

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## Nanometrology

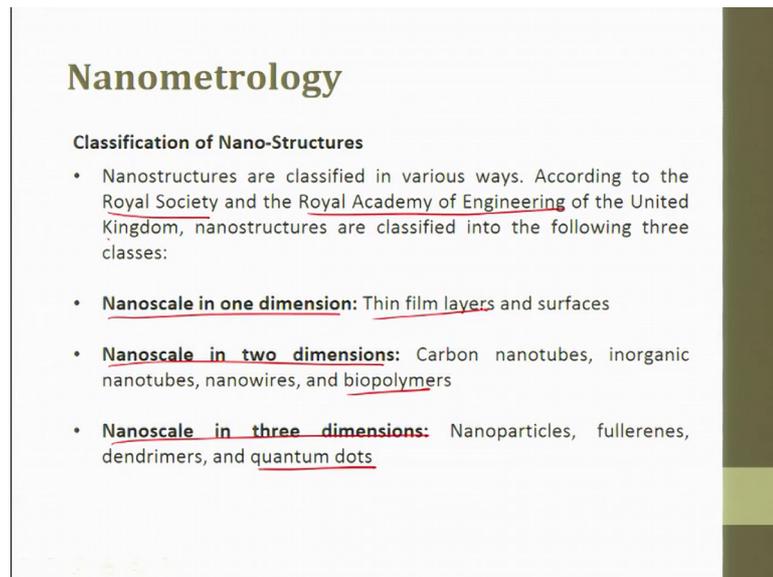
### Importance of Nano-dimension

7. If the grain size is smaller than the electron mean free path, the electronic conductivity as well as temperature coefficient decreases.
8. Optical properties also undergo major changes. Band gap changes in nano-sized semiconductor particles lead to a blue shift of luminescence.
9. Size-induced control of luminescence and relaxation in oxide nanoparticles leads to changes in the optical properties, which can be used to fabricate interesting optoelectronic devices.
10. Magnetic properties undergo remarkable change due to the surface effects of thin layers. This gives a boost to more efficient data storage devices and more sensitive magnetic sensors.

If the grain size smaller than an electron, mean free path the electronic conductivity as well as the temperature coefficient decreases. The optical property also undergoes major change, the band gap changes in nanoscale semiconductor particles lead to a blue shift of luminescence.

Then size induced control of luminescence and relaxation in oxide nanoparticles lead to a change in the optical properties; which can be used in the fabricating interesting of optoelectronic devices. So, when I do a nanometer coating on top of a of a existing material, then we see a different optoelectronic properties. The magnetic properties undergo a remarkable change due to surface effects of thin layer. This gives a boost to more efficient data storage devices and more sensitive magnetic tapes.

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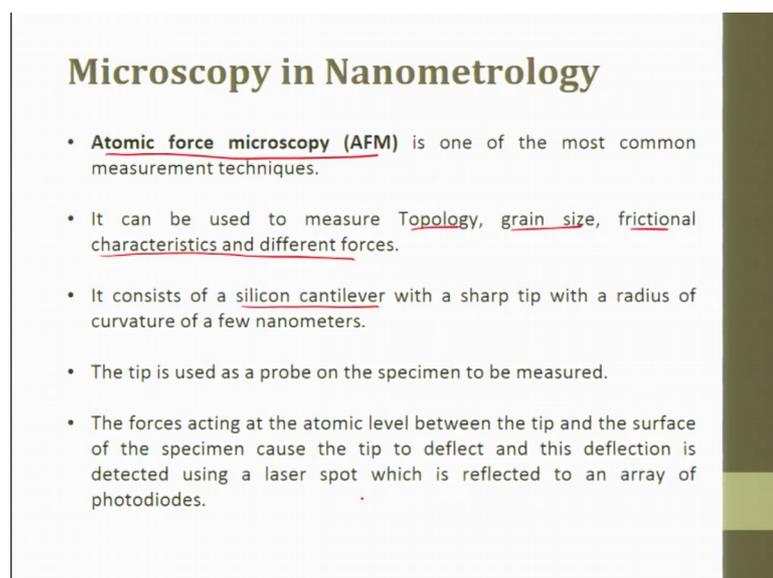
## Nanometrology

### Classification of Nano-Structures

- Nanostructures are classified in various ways. According to the Royal Society and the Royal Academy of Engineering of the United Kingdom, nanostructures are classified into the following three classes:
- Nanoscale in one dimension: Thin film layers and surfaces
- Nanoscale in two dimensions: Carbon nanotubes, inorganic nanotubes, nanowires, and biopolymers
- Nanoscale in three dimensions: Nanoparticles, fullerenes, dendrimers, and quantum dots

Classification of nanostructures nanostructures are classified in different ways. According to royal society, and royal academy of engineers in United Kingdom, nanoscale is one in one dimension, nanoscale in two dimension, nanoscale in three dimension. Nanoscale three dimension part example is quantum dots; biopolymers are two dimension thin film layer is one dimension.

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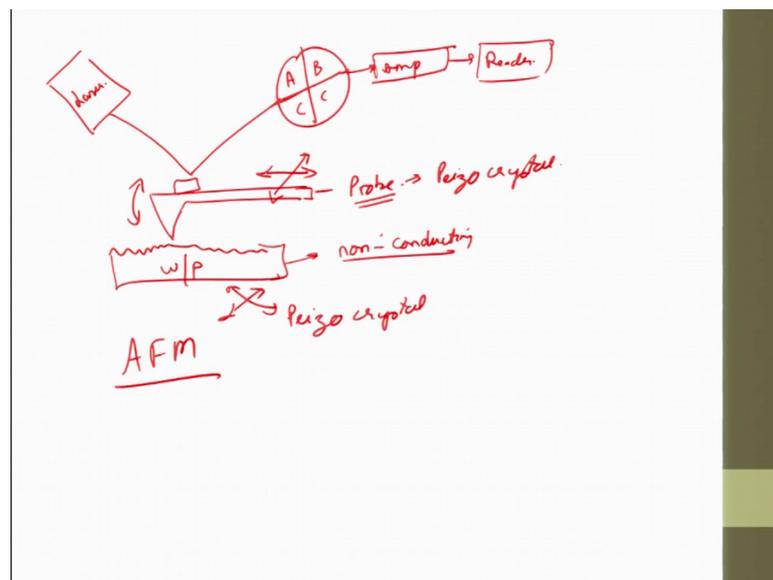
## Microscopy in Nanometrology

- Atomic force microscopy (AFM) is one of the most common measurement techniques.
- It can be used to measure Topology, grain size, frictional characteristics and different forces.
- It consists of a silicon cantilever with a sharp tip with a radius of curvature of a few nanometers.
- The tip is used as a probe on the specimen to be measured.
- The forces acting at the atomic level between the tip and the surface of the specimen cause the tip to deflect and this deflection is detected using a laser spot which is reflected to an array of photodiodes.

See some of the microscopes which are used in nanometrology one very commonly used one is atomic force microscopy; is one of the most common measurement techniques

which are used to measure nanometer features. So, it can be used to measure topological grain size frictional characteristics and different forces. It consists of a silicon cantilever with a sharp tip with a radius of a curvature of a few nanometers. This tip is used as a probe on the specimen to be measured, the force acting at atomic level between the tip and the surface of the specimen causes the tip to deflect and this deflection is detected using a laser spot which is reflected to an array of photodiodes.

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So, atomic force microscope what we are trying to say is, here is a probe. So, at there is a reflecting surface. So, here you have a laser which hits this. And then here you have a photodiode which is divided into 4 parts. And this is for example, A B C D the spot hits at here and you have a surface to measure, this is a work piece. So, this is what we say a laser tries to hit, and this it moves in any direction. Either you move the probe, this is the probe, either you move the probe or you move the work piece.

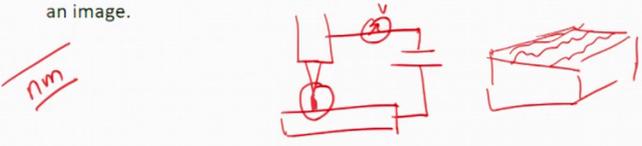
So, here what that happens is; this tip will can come in contact with the work piece can be slightly far away which follows the principle of Van der Waals bond. And sometimes you can also have tapping; that means, to say constantly vibrating. So, the laser hits from this we try to resolve from the photodiode we connected to an amplifier. And from the amplifier we connected to a reader whatever it is. So, and then we read the variations in the height along. With it is just like your surface measuring device, but here we measure it at nanometre scales.

So, this is atomic force microscope. Though see this topic is of its own a very interesting one. But you see whatever we used roughness measuring is also used here but you see the change. And here the stage will be moving in piezo crystal with every moving a piezo crystal stage or the probe will be attached to a piezo crystal. So, anyone will be there. And here we use damper so that no vibration is felt.

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### Microscopy in Nanometrology

- **Scanning tunneling microscopy (STM)** is another instrument commonly used. It is used to measure 3-D topology of the specimen.
- The STM is based on the concept of quantum tunneling.
- When a conducting tip is brought very near to the surface to be examined, a bias (voltage difference) applied between the two can allow electrons to tunnel through the vacuum between them.
- Measurements are made by monitoring the current as the tip's position scans across the surface, which can then be used to display an image.



The slide contains three hand-drawn red diagrams. On the left, the letters 'nm' are written. In the center, a circuit diagram shows a tip connected to a voltmeter, which is connected to a surface. On the right, a 3D rectangular block represents the surface being scanned.

The other one is scanning tunneling microscope. So, this is this is used generally for a non-conducting, this is generally used for a non-conducting work piece. If you have a conducting work piece so, then what we do is, we use the same, we have a tip and then we have a work piece which goes. So, between these 2 we try to attach, we try to attach to a power supply. And here, this distance is so close you will have a tunneling current which jumps from here to here, and that is measured that is measured in the voltmeter, and then we try to measure what is the distance. And knowing the distance between try to superimpose and try to get a images a 3 dimensional image of the surface, and here we talk about a nanometer scales.

The scanning tunneling microscope is another instrument commonly used; which is also used for measuring topology, it works on the concept of quantum tunneling; when a conducting tip is brought very near to the surface to be examined a bias is applied between the 2, and can allow the electrons to tunnel through the vacuum between them. The measurements are made by monitoring the current as the tip positions scans across

the surface; which can then be used to display the image. So, here what we get is, a scanned image 3 dimensionally. So, here if you see, these 2 are completely different paradigm; atomic force microscope and scanning tunneling microscope. So, here what we talk about we talk about measurements in nanometers which is not generally possible with the existing surface measuring devices ok.

So, with this we come to an end. I have given you a very brief glimpse of nanomaterials, and 2 microscopes which work which is used exhaustively to measure the topological informations informations in in brief ok.

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**To recapitulate:**

- An introduction to angle measuring instruments
- Guidelines to Optical Measurement Techniques
- What is a Tool Maker's Microscope? → w/p
- What is a Profile Projector? → Tool
- What are Optical Squares?
- Guidelines to Interferometry?
- Types of Optical Flats?
- Types of Interferometers? { NPL, Laser.
- Use of Scales, Gratings and Reticles
- Nano metrology

To recap what all we saw in this particular chapter; we saw an introduction angle measurement instruments, then guidelines to optical measuring techniques, tool makers microscope which is used in workshops and tool rooms. Then profile projector again in tool rooms, then we saw optical squares wherein which if there is any deviation one the datum which can take care of it, then we saw interferometry guidelines for interferometers, then what is the instrument used to do where you generate this interferometers is by optical flat.

Types of interferometer one is NPL and then we saw laser, and we saw different scales gratings and reticles. And finally, we saw a very brief about nanometrology also. With this we come to an end to this chapter.

Thank you.