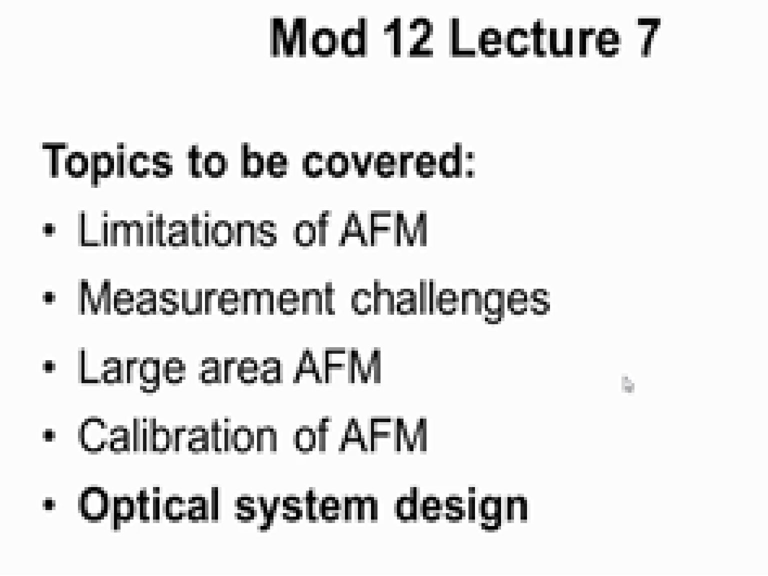
Metrology
Prof. Dr Kanakuppi Sadashivappa
Bapuji Institute of Engineering and Technology Davangere

Lecture – 43
Optical System Design

(Refer Slide Time: 00:40)

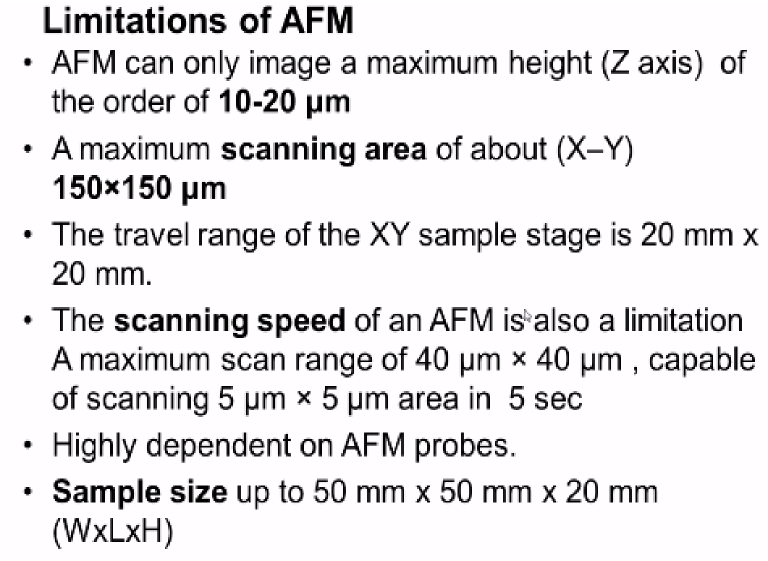


Mod 12 Lecture 7

Topics to be covered:
- Limitations of AFM
- Measurement challenges
- Large area AFM
- Calibration of AFM
- **Optical system design**

I welcome back on the lecture series on metrology now we will start module number 12, lecture 7 in this lecture we will cover the following topics limitations of atomic force microscopy measurement challenges associated with AFM and large area AFM and calibration of AFM and finally we will start the discussion on optical system design.

(Refer Slide Time: 00:52)



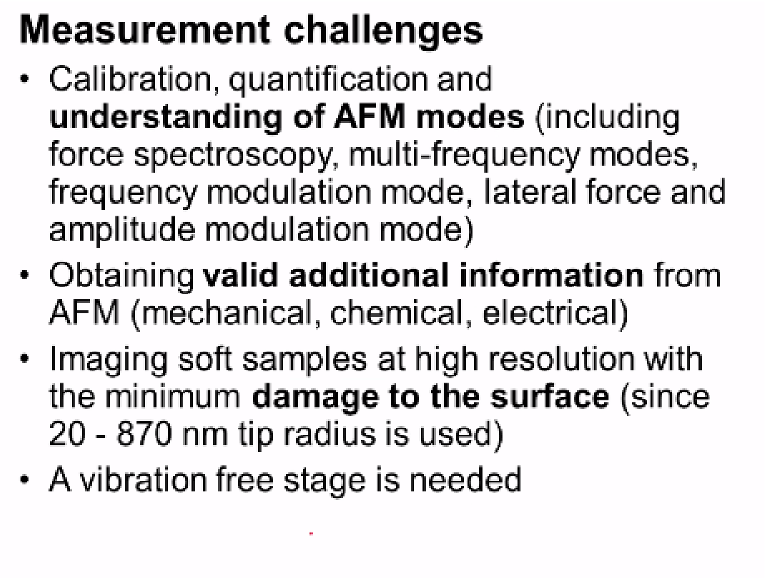
Limitations of AFM
- AFM can only image a maximum height (Z axis) of the order of **10-20 µm**
- A maximum **scanning area** of about (X–Y) **150×150 µm**
- The travel range of the XY sample stage is 20 mm x 20 mm.
- The **scanning speed** of an AFM is also a limitation A maximum scan range of 40 µm × 40 µm , capable of scanning 5 µm × 5 µm area in 5 sec
- Highly dependent on AFM probes.
- **Sample size** up to 50 mm x 50 mm x 20 mm (WxLxH)

In the previous lecture, we discussed about the constructions and the working of atomic force microscopy also we discussed about the application of AFM. Now let us study what are the limitations of AFM major limitation is scanning area. It can image a maximum height of 10-20 micrometer and maximum scanning area is X axis and Y axis scanning size is 150 x 150 micrometer.

The travel stage is 20 millimeter x 20 millimeter and z axis movement is limited up to 20 millimeter the scanning speed of AFM is a important limitation of this device of a maximum scanning range of 40 micron x 40 micrometer capable of scanning 5 micron x 5 micron by area about 5 seconds to scan this much area so the scanning speed very slow also the functioning of AFM is very much depended on the cantilever and probe design.

The size of probe tip the material of cantilever so very precise cantilever probe are needed to get meaningful measurement results sample size can go up to 50 millimeter x 50 millimeter if work piece size is> this then it may not be possible with the regular AFM devices and currently large area AFM decide which we will discuss after a short by.

(Refer Slide Time: 03:15)



Measurement challenges

- Calibration, quantification and **understanding of AFM modes** (including force spectroscopy, multi-frequency modes, frequency modulation mode, lateral force and amplitude modulation mode)
- Obtaining **valid additional information** from AFM (mechanical, chemical, electrical)
- Imaging soft samples at high resolution with the minimum **damage to the surface** (since 20 - 870 nm tip radius is used)
- A vibration free stage is needed

Now what are the measurement challenges associated with AFM the calibration qualification and understanding of different modes of working AFM is a big challenge, so we should properly understand the different modes of operation like force spectroscopy mode, multi-frequency mode, frequency modulation mode lateral force and amplitude modulation mode.

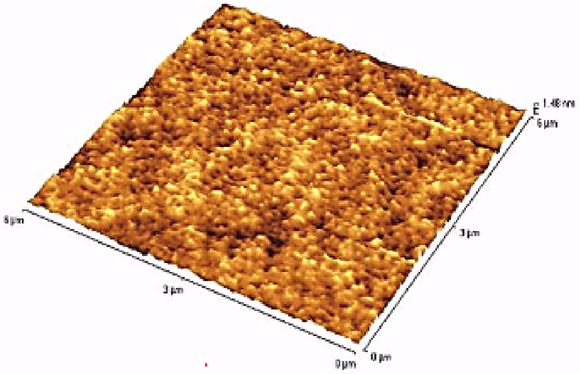
Properly we should select the mode depending upon the application and obtaining valid additional information from AFM in another challenge and imaging soft samples at high resolution with the minimum damage to the surface is another challenge reason as they are using a sharp probe tip with 20 to 870 nm tip radius.

So there are chances to the tip may scratch the surface so imaging the soft samples is another challenge associated with fm and other big challenge is the necessity of vibration free stage requirement if there is a vibration of a stage all the measurement results will not be meaningful.

(Refer Slide Time: 04:52)

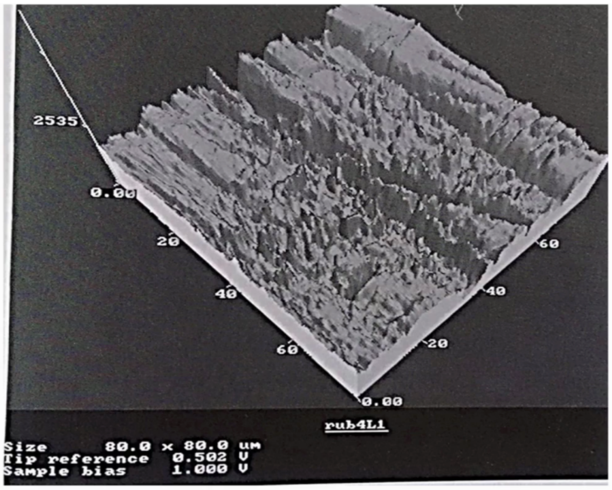
Roughness of clean glass surface : 0.8 nm

Area scanned: 6 x 6 micrometer



Now you can see image obtained by AFM this is the glass surface clean glass surface this glass area is 6 micrometre x 6 micrometre and roughness of this glass surface is 8 nm.

(Refer Slide Time: 05:20)

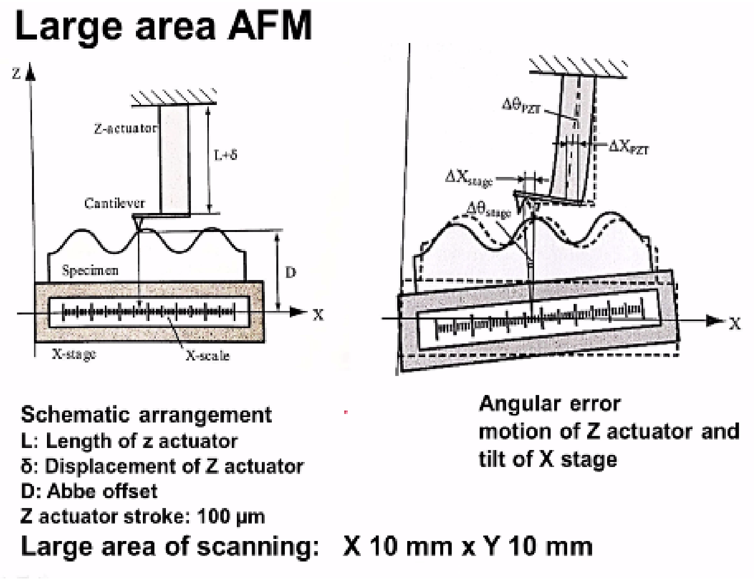


```
Size          80.0 x 80.0 um
Tip reference  0.502 V
Sample bias    1.000 V
```

AFM 3D image of an ultra high speed face milled austenitic stainless steel surface

Another image with 3 dimension image of an ultra high speed face milled stainless steel surface you can see the scanned area is about 80 millimeter by 80 micrometer by 80 micrometer.

(Refer Slide Time: 05:42)



Large area AFM

Schematic arrangement
L: Length of z actuator
δ: Displacement of Z actuator
D: Abbe offset
Z actuator stroke: 100 µm

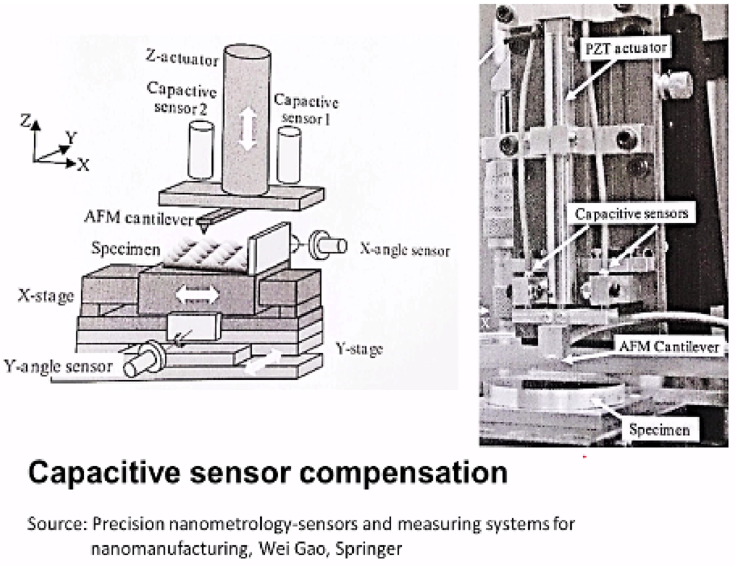
Angular error motion of Z actuator and tilt of X stage

Large area of scanning: X 10 mm x Y 10 mm

Now the conventional AFM they have a limited scanning range so recently large area AFM devised wherein area of scanning as large as 10 micrometer by 10 micrometer you can see the schematic arrangement of large area AFM the cantilever probe is attached to the Z axis and this is the table X axis of sample table and the specimen is placed on the table D is the distance that is a way of set the height of the work piece off set reference axis and delta is displacement of Z axis.

L is length of Z actuator delta is the displacement of Z actuator and Z actuator stroke of 100 micrometer is possible in large area scanning AFM and again you can see the errors in AFM so the Z activator is as shown in the cantilever also tilt and then the table can also tilt you can see the building of X axis because of this the measurement results or affected so we should compensate for these circular errors by using appropriate sensors.

(Refer Slide Time: 07:33)

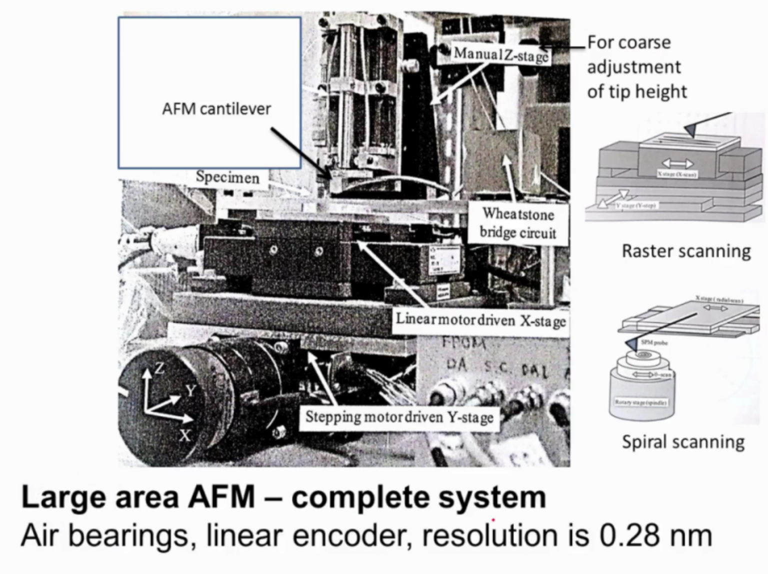


Capacitive sensor compensation

Source: Precision nanometrology-sensors and measuring systems for nanomanufacturing, Wei Gao, Springer

Now you can see here the capacitive sensor are used for compensation so this is the Z actuator at 2 capacitive sensors are used compensating the tilt of the z actuator to compensate the tilt of the table surface X angle sensor and why angle sensors are used and we can see the photographic view of the large area AFM this is the fugitive activator and 2 capacitive sensors are used and then we have AFM cantilever and this is stage sample stage sample placed on the sample stage.

(Refer Slide Time: 08:21)



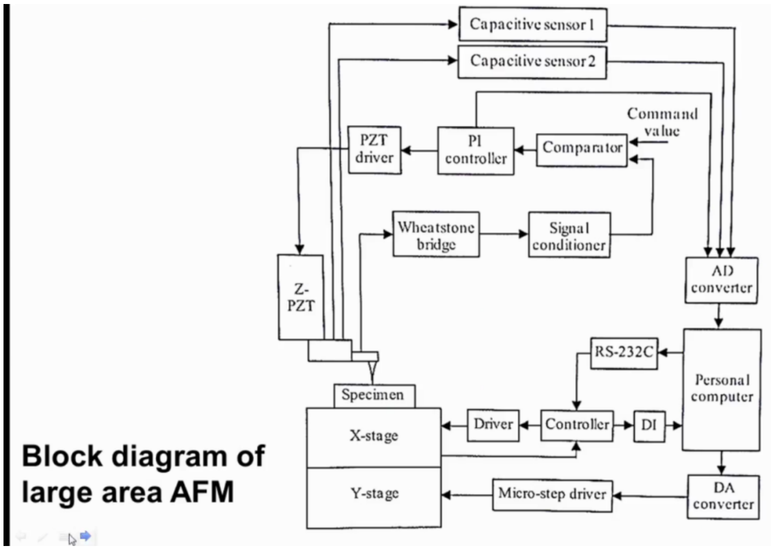
Large area AFM – complete system

Air bearings, linear encoder, resolution is 0.28 nm

Now this picture show a complete system of large area fm this is manual jet stage depending upon the height of liver piece the initial adjustment of Z axis is made manually and this is for coarse adjustment of tip height and we have specimen and this is the linear motor driven X stage and we have stepping motor driven by stage.

Then raster scanning is possible by moving X and Y stage and spiral scanning is also possible by using rotary stage as shown here and normally air bearings are used linear encoders for feedback purpose the resolution of such as 0.28 nm

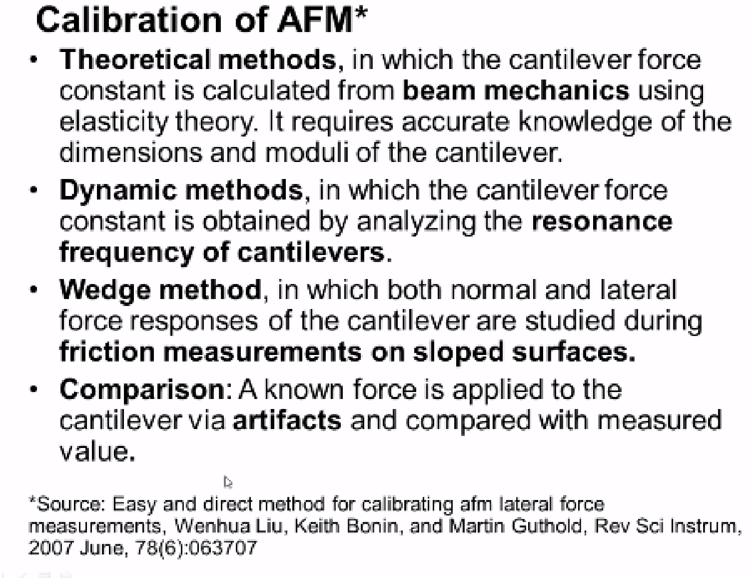
(Refer Slide Time: 09:22)



Block diagram of large area AFM

You can see the block diagram of large area a fm you can see X, Y stage with appropriate drivers and this is the stage table surface on which specific specimen is mounted and this is the cantilever with the probe and the measurement results sent feedback system this is the PZT, PZT driver and capacitive sensors are used for compensation purpose.

(Refer Slide Time: 10:06)



Calibration of AFM*

- **Theoretical methods**, in which the cantilever force constant is calculated from **beam mechanics** using elasticity theory. It requires accurate knowledge of the dimensions and moduli of the cantilever.
- **Dynamic methods**, in which the cantilever force constant is obtained by analyzing the **resonance frequency of cantilevers**.
- **Wedge method**, in which both normal and lateral force responses of the cantilever are studied during **friction measurements on sloped surfaces.**
- **Comparison**: A known force is applied to the cantilever via **artifacts** and compared with measured value.

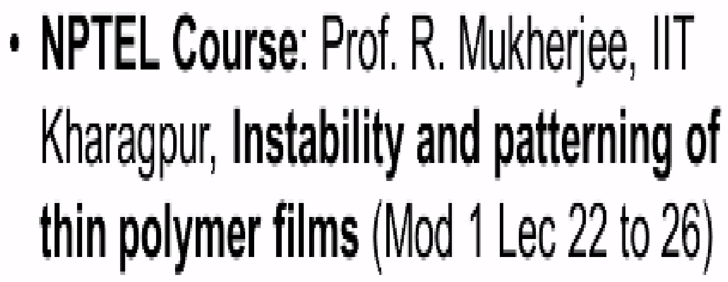
*Source: Easy and direct method for calibrating afm lateral force measurements, Wenhua Liu, Keith Bonin, and Martin Guthold, Rev Sci Instrum, 2007 June, 78(6):063707

Now how do we calibrate the AFM so there are different methods available in the theoretical method the cantilever force constant is calculated from beam mechanic using elasticity theory so this requires a very accurate knowledge of dimensions of cantilever that is length, width and thickness of the cantilever and hence model of cantilever.

Another method is dynamic method in which the cantilever force constant is obtained by analysing the resonance frequency of cantilever. The third method is the which method in which both normal and lateral force responses of the cantilever or study during friction measurement on slope surfaces in this way also we can calibrate AFM.

Very important method of calibration is comparison and non force is applied to the cantilever via artifacts and the measured force the value is given sensor compared with applied force there by the calibration AFM possible.

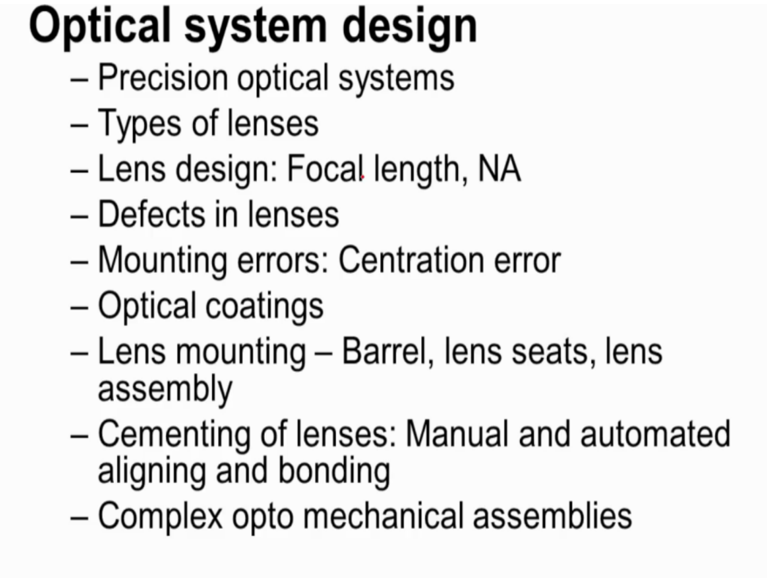
(Refer Slide Time: 11:29)



- **NPTEL Course**: Prof. R. Mukherjee, IIT Kharagpur, **Instability and patterning of thin polymer films** (Mod 1 Lec 22 to 26)

Now for detailed discussion on atomic force microscopy one can go through the NPTEL course by professor R Mukherjee from IIT Kharagpur the topic of the courses in stability and patterning of thin polymer films.

(Refer Slide Time: 11:53)



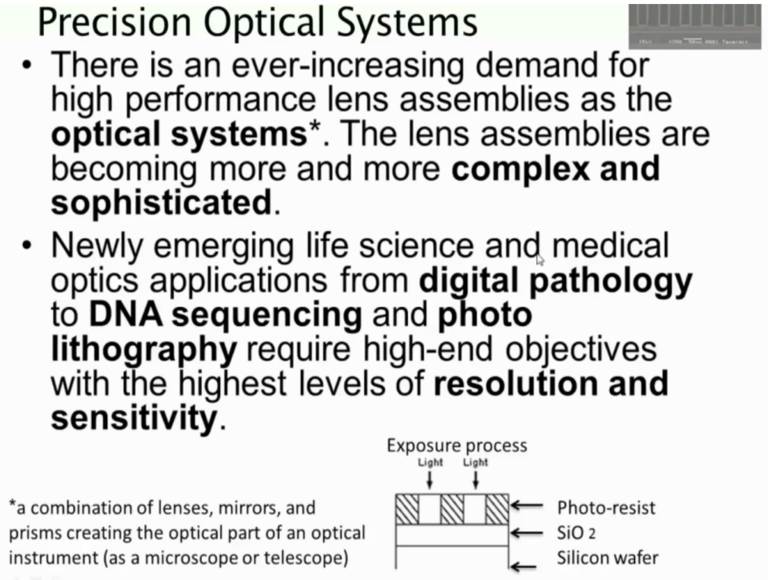
Optical system design

- Precision optical systems
- Types of lenses
- Lens design: Focal length, NA
- Defects in lenses
- Mounting errors: Centration error
- Optical coatings
- Lens mounting – Barrel, lens seats, lens assembly
- Cementing of lenses: Manual and automated aligning and bonding
- Complex opto mechanical assemblies

With this we will close the discussion of a fm and start the discussion on optical system design under this we will discuss about the requirement of precision optical systems what are the different types of lenses used in optical system and lens design defects in lenses and what are the mounting errors possible.

when we mount lenses in the barrels and what are the optical coatings used and how do we mount the lenses what are the arrangements possible and we will discuss about the lens assembly and cementing of lenses the manual and automated align aligning and bonding and we will discuss about complex opto mechanical assemblies.

(Refer Slide Time: 12:55)



Precision Optical Systems

- There is an ever-increasing demand for high performance lens assemblies as the **optical systems***. The lens assemblies are becoming more and more **complex and sophisticated**.
- Newly emerging life science and medical optics applications from **digital pathology** to **DNA sequencing** and **photo lithography** require high-end objectives with the highest levels of **resolution and sensitivity**.

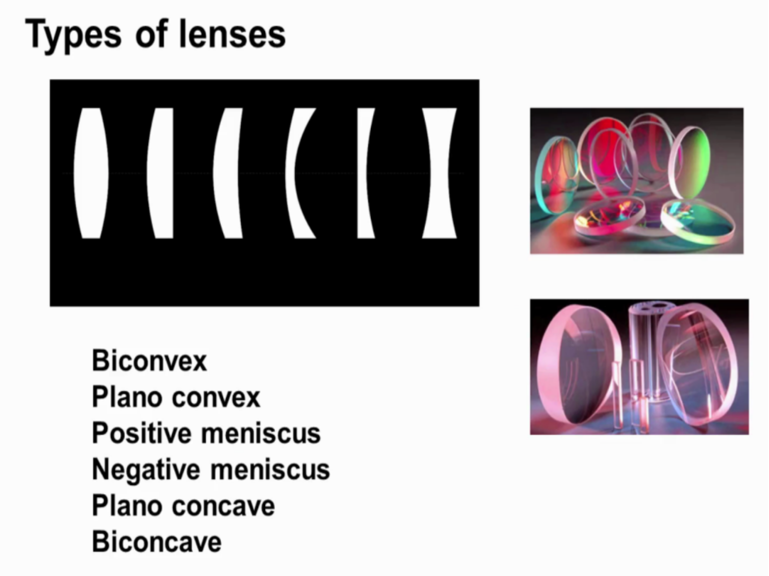
*a combination of lenses, mirrors, and prisms creating the optical part of an optical instrument (as a microscope or telescope)

Optical system is basically a combination of lenses mirrors and prisms creating the optical part of an optical instrument as a microscope, camera or telescope. There is an ever increasing demand for eye performance lens assemblies. The lens assemblies are becoming more and more sophisticated newly emerging life science and medical optics applications from digital pathology to DNA.

Sequencing on photo lithography requires high end objectives with highest level of resolution and sensitivity. The lens system must provide an extremely high level of performance such as high numerical capture large file angles, broad spectral bandwidth and perfect wave front correction. This makes lenses high sensitive to all sources of manufacturing errors.

Especially to lens alignment and air spaces during assembly. The main challenge is not only to create compatible lens designs but also to manufacture and assemble them so that the desired level of performance is obtained.

(Refer Slide Time: 15:39)

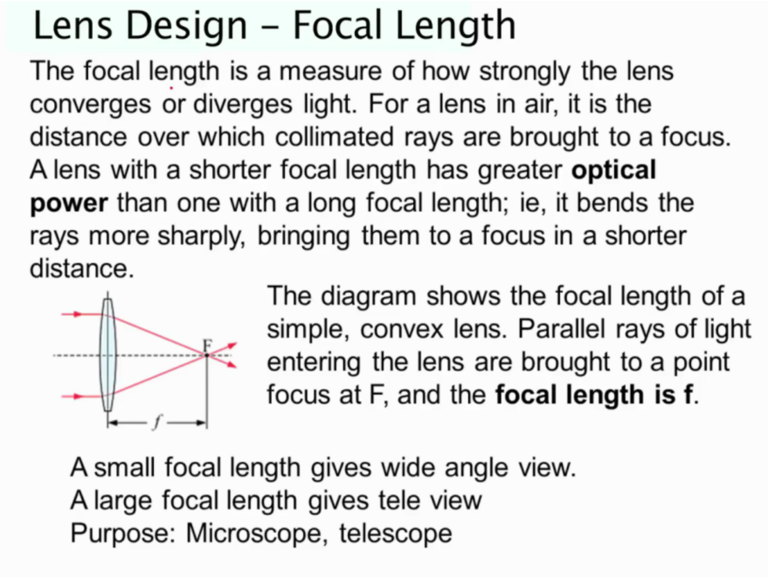


Types of lenses

Biconvex
Plano convex
Positive meniscus
Negative meniscus
Plano concave
Biconcave

Conex lens has 2 convex surfaces and center it is bulged plano convex lens has one surface is flat another surface is concave Positive meniscus Negative meniscus are the other types of lenses.

(Refer Slide Time: 14:24)



Lens Design – Focal Length

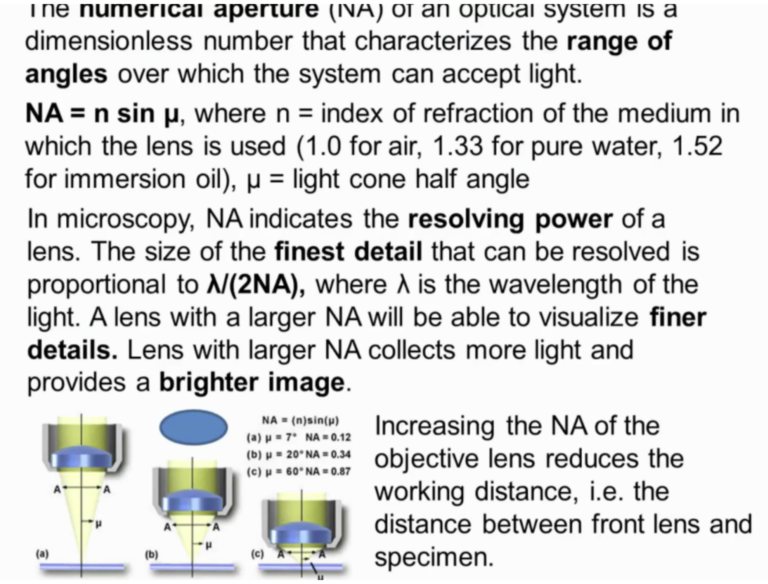
The focal length is a measure of how strongly the lens converges or diverges light. For a lens in air, it is the distance over which collimated rays are brought to a focus. A lens with a shorter focal length has greater **optical power** than one with a long focal length; ie, it bends the rays more sharply, bringing them to a focus in a shorter distance.

The diagram shows the focal length of a simple, convex lens. Parallel rays of light entering the lens are brought to a point focus at F, and the **focal length is f**.

A small focal length gives wide angle view.
A large focal length gives tele view
Purpose: Microscope, telescope

The focal length is a measure of how strongly the lens converges or diverges light For a lens in air, it is distance over which collimated rays or brought to a focus A lens with a shorter focal length as greater optical power than one with long focal length that is its bends the rays more sharply bringing them to focus in a shorter distance. A small focal length gives wide angle view. A large focal length gives tele view purpose microscope and telescope.

(Refer Slide Time: 18:27)



The **numerical aperture** (NA) of an optical system is a dimensionless number that characterizes the **range of angles** over which the system can accept light.

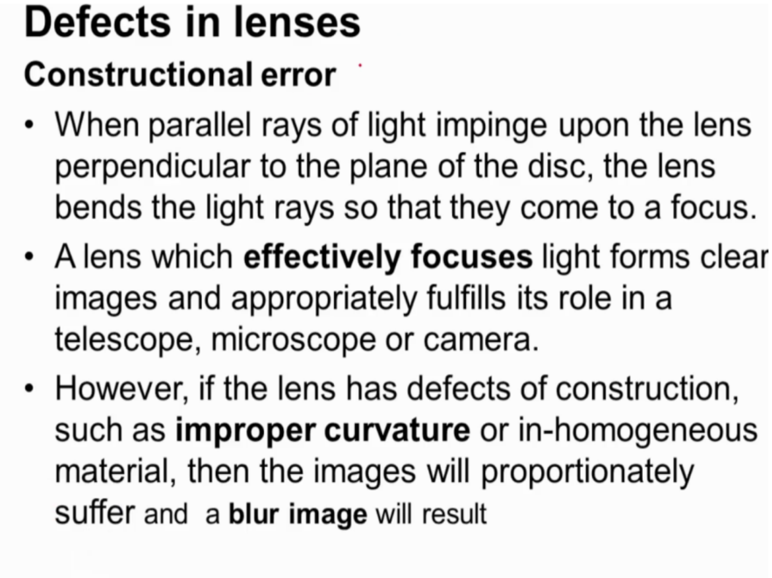
NA = n sin μ, where n = index of refraction of the medium in which the lens is used (1.0 for air, 1.33 for pure water, 1.52 for immersion oil), μ = light cone half angle

In microscopy, NA indicates the **resolving power** of a lens. The size of the **finest detail** that can be resolved is proportional to **λ/(2NA),** where λ is the wavelength of the light. A lens with a larger NA will be able to visualize **finer details.** Lens with larger NA collects more light and provides a **brighter image**.

Increasing the NA of the objective lens reduces the working distance, i.e. the distance between front lens and specimen.

The numerical aperture of an optical system is a dimensionless channel number that characterizes the range of angles over which system can accept light in microscopy indicates the resolving power of a lens the size of the finest detail that can be resolved is proportional to equation Lambda /(2NA), where lambda is the wavelength of the light .A lens is a larger and NA will be available to visualize final details lens with larger any more light and provides a brighter image.

(Refer Slide Time: 20:38)



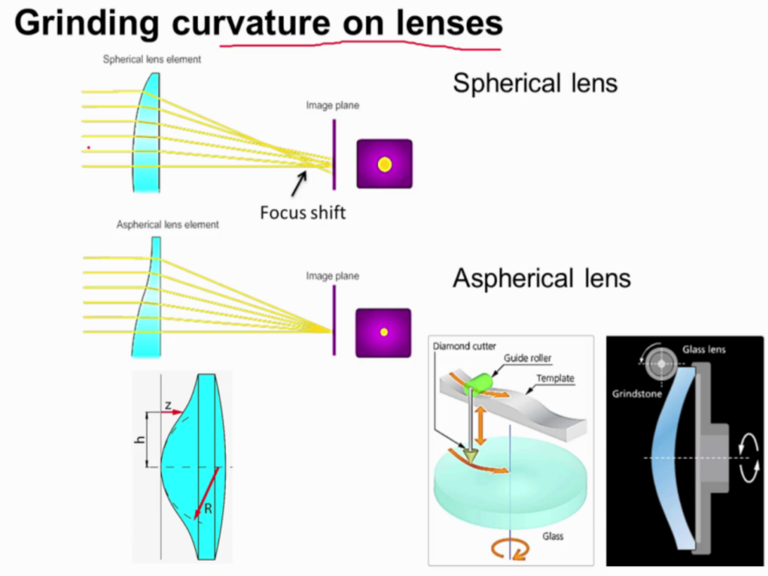
Defects in lenses

Constructional error

- When parallel rays of light impinge upon the lens perpendicular to the plane of the disc, the lens bends the light rays so that they come to a focus.
- A lens which **effectively focuses** light forms clear images and appropriately fulfills its role in a telescope, microscope or camera.
- However, if the lens has defects of construction, such as **improper curvature** or in-homogeneous material, then the images will proportionately suffer and a **blur image** will result

Defects in lenses constructional error when parallel rays of light impinge upon the lens perpendicular to the plane of the disc the lens bends the light rays so that they come to your focus. A lens which effectively focuses light comes clear images and appropriately fulfilled its role in and telescope microscope or camera however if the lens has side effects of construction such as improper curvature or inhomogeneous material then the images will proportionately Safe and a Blur image will result.

(Refer Slide Time: 21:50)



Grinding curvature on lenses

Spherical lens

Aspherical lens

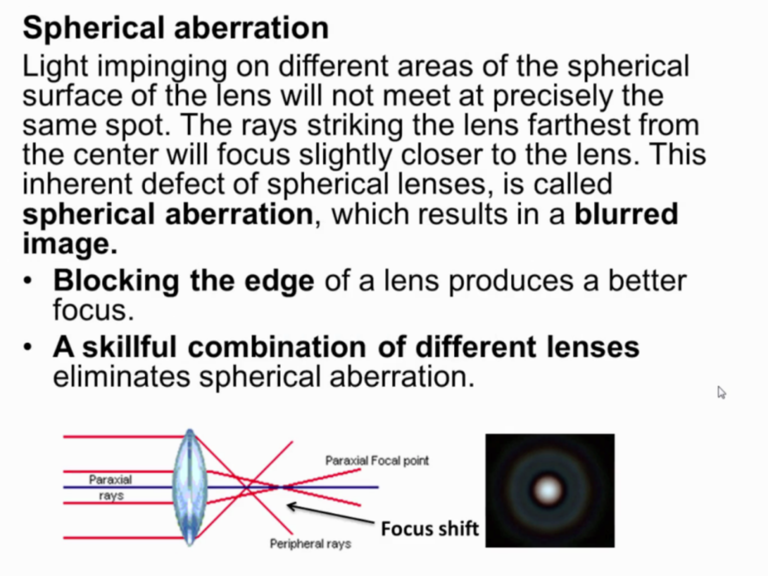
Now you can see here how the grinding curvature on lenses is made we have a spherical lens this is curvature is there the length and the light rays are falling on curved surface of the lens and the light rays are made to focus from this picture we can understand that this is the centre of the lens light rays entering the lens at a great distance nearer to the edge of the lens are made to focus on the shorter distance from the lens surface.

Whereas the light rays entering the lens very close to the centre are made to focus at a larger distance from the lens so because of this focus shift happens and image will not be clear so in order to get a clear image we need to provide as miracle curvature on the lens on the details of aspherical curvature is shown here it has a special curvature shown in this diagram.

So because of this aspherical nature all the light rays are made to focus at one point and we can get a sharp image so now how these are spherical curvature provided on the lengths you can see here this is the length blank holder and this is the glass lens and this is the grinding stone which is drains the surface of the lens this is the work piece which is rotating and to provide the required curvature a template is used as a guide role.

The diamond cutter move on the glass surface and it going the required curvature of the glass work piece and hence we get the curvature on lens.

(Refer Slide Time: 24:12)



Spherical aberration

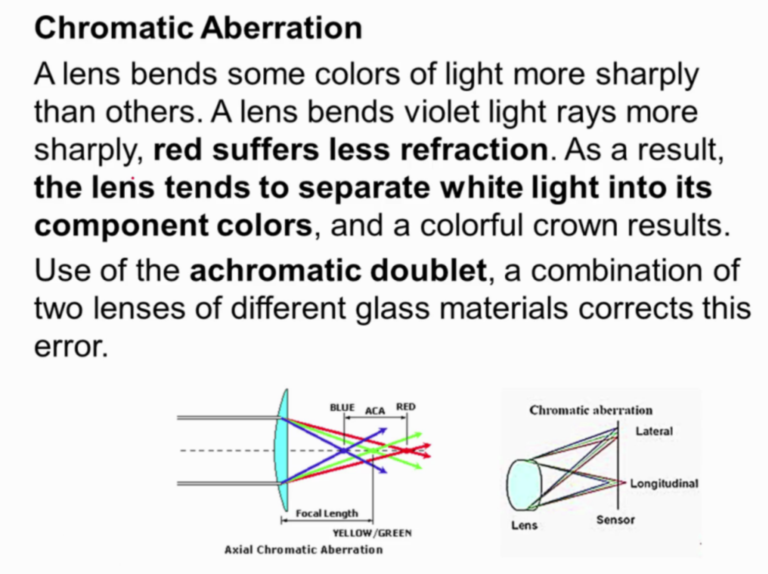
Light impinging on different areas of the spherical surface of the lens will not meet at precisely the same spot. The rays striking the lens farthest from the center will focus slightly closer to the lens. This inherent defect of spherical lenses, is called **spherical aberration**, which results in a **blurred image.**

- **Blocking the edge** of a lens produces a better focus.
- **A skillful combination of different lenses** eliminates spherical aberration.

When we use the spherical lenses a focus shift occurs and this is known as spherical operation and due to this spherical aberration a blurred image results there are 2 ways in which we can eliminate this spherical aberration so the first one is blocking the edges of the lenses that means we can block the edge of the lens.

So that the focus shift is minimized and other method is a skillful combination of different lenses so by combining the lenses skillfully we can eliminate spherical aberration and we can get clear image sharp image.

(Refer Slide Time: 25:29)



Chromatic Aberration

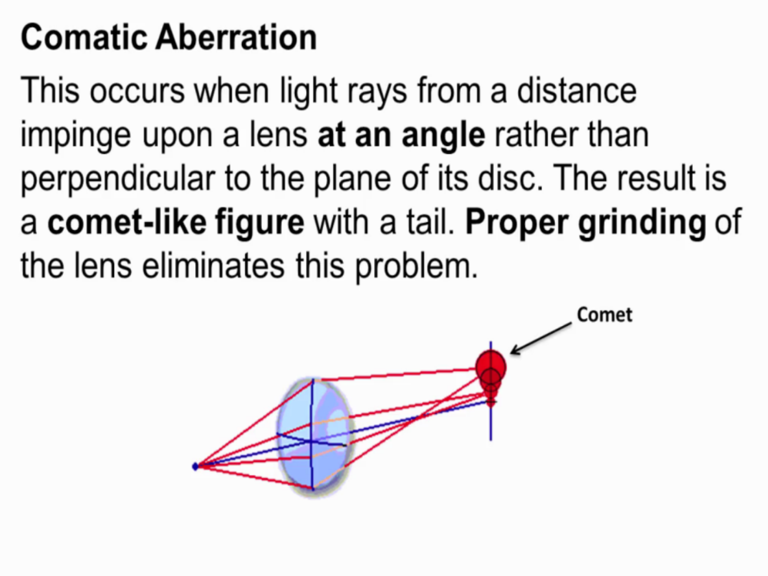
A lens bends some colors of light more sharply than others. A lens bends violet light rays more sharply, **red suffers less refraction**. As a result, **the lens tends to separate white light into its component colors**, and a colorful crown results.

Use of the **achromatic doublet**, a combination of two lenses of different glass materials corrects this error.

Now the chromatic aberration the length bend some colors of light more sharply than others so in this diagram we can see the blue rays or more sharply when we can see the focus point very close to the lens surface for the blue rays and for the red color ray the focusing for further distance so this is known as chromatic aberration.

So this chromatic aberration occurs longitudinally as well as latitudinal by using chromatic doublet that is a combination of 2 lenses of different glass material is chromatic aberration can be correct.

(Refer Slide Time: 26:40)

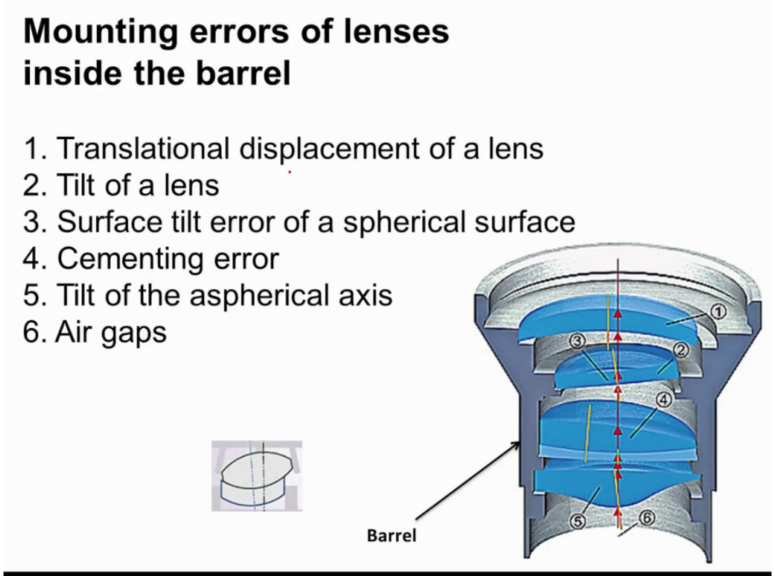


Comatic Aberration

This occurs when light rays from a distance impinge upon a lens **at an angle** rather than perpendicular to the plane of its disc. The result is a **comet-like figure** with a tail. **Proper grinding** of the lens eliminates this problem.

Comatic aberration this occurs when light rays from a distance impinge upon lens at an angle that means we have a. source here and light rays from point source of falling on the lens surface the result is a comet like figure with a tail appears as shown here so this is known as comatic operation, so proper grinding of lens eliminate this problem.

(Refer Slide Time: 27:19)



Mounting errors of lenses inside the barrel

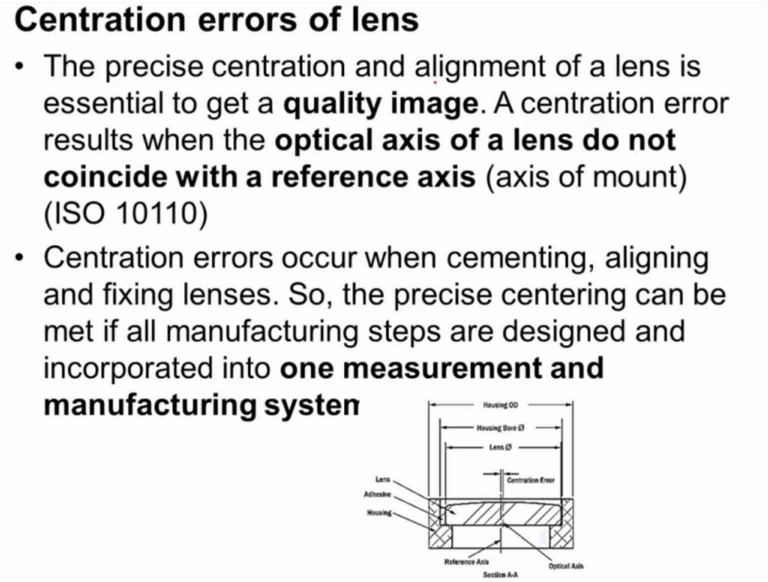
1. Translational displacement of a lens
2. Tilt of a lens
3. Surface tilt error of a spherical surface
4. Cementing error
5. Tilt of the aspherical axis
6. Air gaps

Now during the mounting of lenses in the barrel errors can occur these are known as mounting errors so different types of errors are listed here so first one is translational displacement of a lens that means that is of the lens is not coinciding with the axis of the barrel so this is known as translational error.

Another type of error is tilt of a lens so you can see here the lens is still tired so because of the image quality is affected so surface adult error so if you see sometimes what happens the lens is fitted properly but surface is filtered it is not manufactured properly that is surface tilt error and then cementing error if we see here to lenses are cemented bonded together.

So when the 2 lenses are bonded the axis of these 2 lenses may not coincide that is known as cementing error. Tilt of a spherical axis so we have a spherical lens here the axis of the lens is tilted and then they can be add gaps between these 2 lenses because these errors the image quality will be affected.

(Refer Slide Time: 28:59)

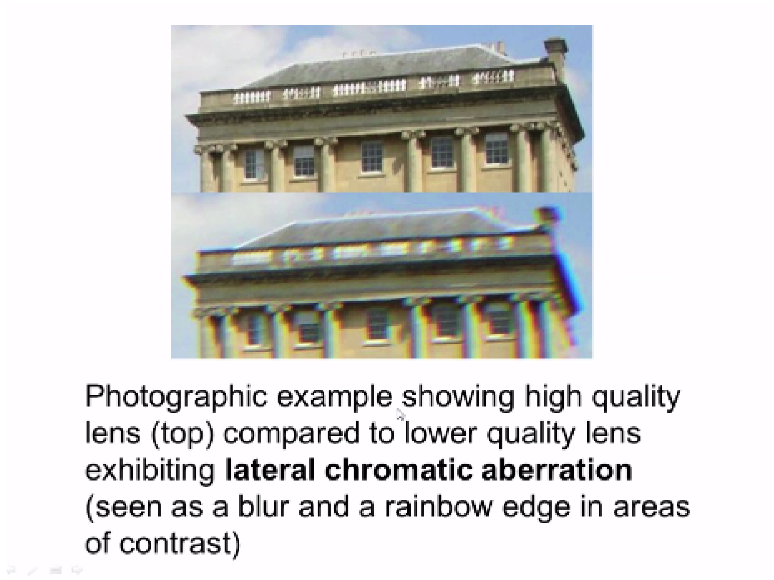


Centration errors of lens

- The precise centration and alignment of a lens is essential to get a **quality image**. A centration error results when the **optical axis of a lens do not coincide with a reference axis** (axis of mount) (ISO 10110)
- Centration errors occur when cementing, aligning and fixing lenses. So, the precise centering can be met if all manufacturing steps are designed and incorporated into **one measurement and manufacturing systen**

The precise centration and alignment of the lens is essential to get your quality image authentication error occurs when the optical axis of a lens do not coincide with a reference axis. Centration error occurs when cement in aligning and fixing lenses so the process centering can we meet you all manufacturing steps are designed an incorporated into 1 measurement and manufacturing system.

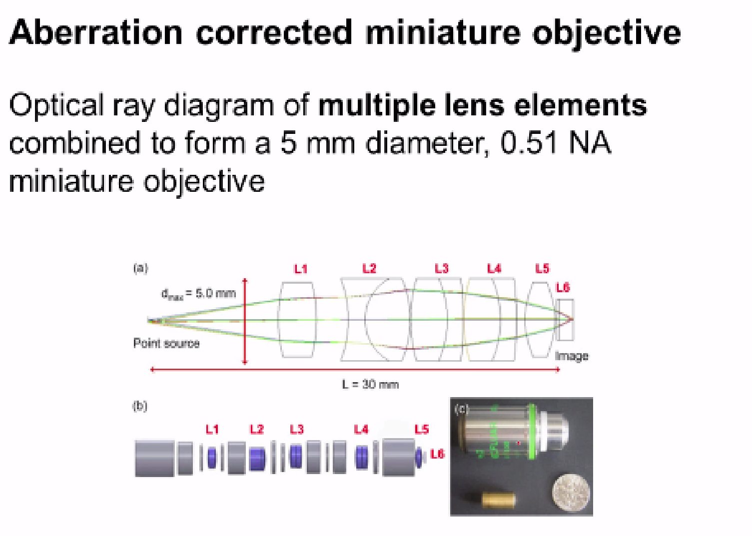
(Refer Slide Time: 30:19)



Photographic example showing high quality lens (top) compared to lower quality lens exhibiting **lateral chromatic aberration** (seen as a blur and a rainbow edge in areas of contrast)

Now here we have a set of pictures the photographic example showing high quality lenses when we use high-quality lens the image quality like this and if you use lower quality lens the result will be like this. We can see a blur image and rainbow edge, rainbow edge appearing so blur image will be result if the quality of the lens is not proper.

(Refer Slide Time: 30:52)

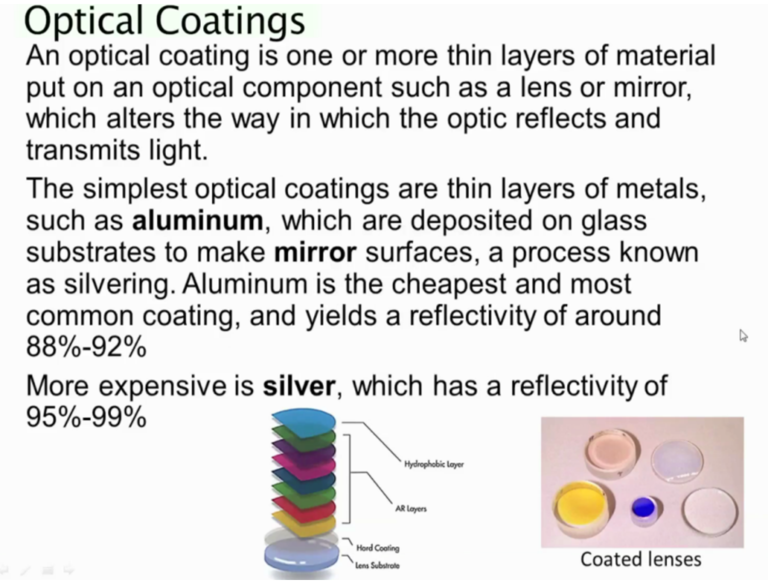


Aberration corrected miniature objective

Optical ray diagram of **multiple lens elements** combined to form a 5 mm diameter, 0.51 NA miniature objective

Now this assembly of length we can observe here by using a series of lenses are assembled properly we can correct the aberration error so this is a compact assembly of objective miniature with minimum operation and numerical aperture of this objective is.0 51 and the diameter of the lens is 5 mm diameter.

(Refer Slide Time: 31:30)



Optical Coatings

An optical coating is one or more thin layers of material put on an optical component such as a lens or mirror, which alters the way in which the optic reflects and transmits light.

The simplest optical coatings are thin layers of metals, such as **aluminum**, which are deposited on glass substrates to make **mirror** surfaces, a process known as silvering. Aluminum is the cheapest and most common coating, and yields a reflectivity of around 88%-92%

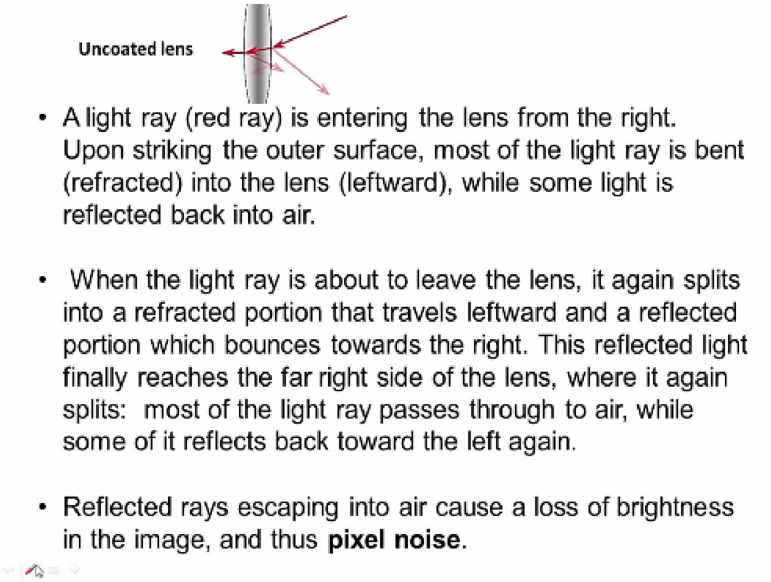
More expensive is **silver**, which has a reflectivity of 95%-99%

Now let us discuss about optical coatings some layers of materials or applied on the lens surface to change the reflective ati of the surface and to change the transimity lenses of surface now the simplest optical coatings are thin layers of metals such as alumium which are deposited on glass substrates to make mirror surfaces so this process of applying material on land surface to make it mirror is known as silvering.

Aluminum is the cheapest and most common coating and heels reflectivity of around 88 to 92% so other important material is applied on glass surfaces to make to improve the reflective it is the silver which has a reflective of 95 to 99% now in this picture we can see some of the lenses coated with some coating materials here we can see a lens substance with glass lens and hard coating is provided to make it a scratch proof.

You can see multiple layers are applied on the hard coating surface and these are anti reflective layers to increase the transmit of the lens and to reduce the loss of light rays in the form of reflection and finally you can see there is other coating nitro phobic layer is applied to make the surface water resistant.

(Refer Slide Time: 33:51)

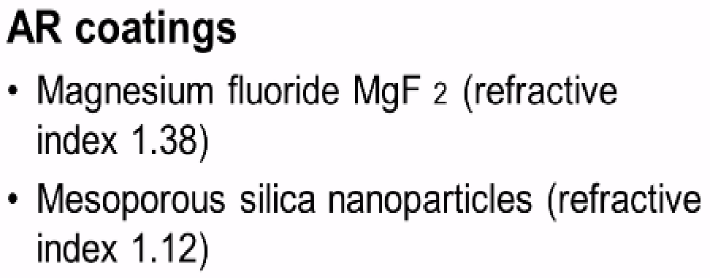


- A light ray (red ray) is entering the lens from the right. Upon striking the outer surface, most of the light ray is bent (refracted) into the lens (leftward), while some light is reflected back into air.
- When the light ray is about to leave the lens, it again splits into a refracted portion that travels leftward and a reflected portion which bounces towards the right. This reflected light finally reaches the far right side of the lens, where it again splits: most of the light ray passes through to air, while some of it reflects back toward the left again.
- Reflected rays escaping into air cause a loss of brightness in the image, and thus **pixel noise**.

Now here we can see where length no coating is applied and a light ray entering on the surface of the lens some portion of the light is reflected back and most of the light is refracted it is passed through the glass surface and when the refracted light reaches in pinchers the other surface again the splitting takes place in some portion the light is reflected back and some portion leaves the glass and enters.

Now this reflected light reaches the right side surface of the lens that is the spot, which means it undergoes splitting some light is reflected back and some light is refracted and enters into the air this reflected light rays are last light rays so due to the loss of these light raise the brightness of the image is formed reduces now this reduction in brightness of the image is known as pixel noise.

(Refer Slide Time: 35:24)

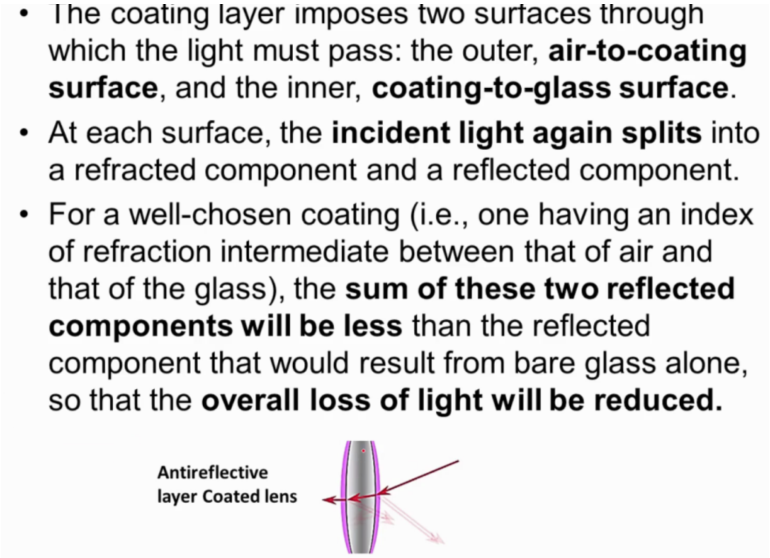


AR coatings

- Magnesium fluoride MgF_2 (refractive index 1.38)
- Mesoporous silica nanoparticles (refractive index 1.12)

Now to reduce the loss of light that is to reduce the reflecting reflection of the light rays into the line surface and reflecting coatings are applied on the land surface normally magnesium fluoride with refractive index of 1.38 is applied on the line surface and other material is meso porous silica nano particles with refractive index of 1.12 can also be applied on the lens surface to increase the transmit.

(Refer Slide Time: 36:03)



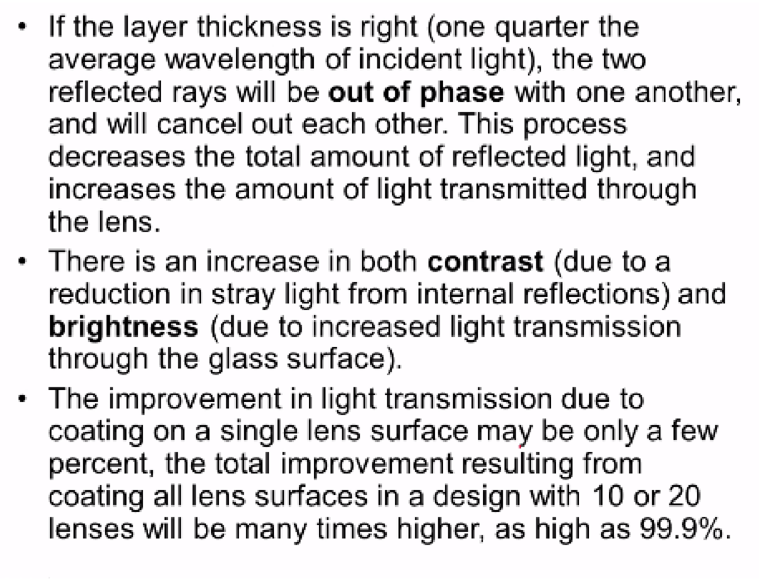
- The coating layer imposes two surfaces through which the light must pass: the outer, **air-to-coating surface**, and the inner, **coating-to-glass surface**.
- At each surface, the **incident light again splits** into a refracted component and a reflected component.
- For a well-chosen coating (i.e., one having an index of refraction intermediate between that of air and that of the glass), the **sum of these two reflected components will be less** than the reflected component that would result from bare glass alone, so that the **overall loss of light will be reduced.**

Now this picture shows a lens with anti reflective layer applied on the both surfaces again the light is pinching now when we apply this antireflective layer like this which is the bare lens glass surface coating is applied. Now when the light impinges the surface first it has to enter into the anti reflective coating and then it will enter from anti reflective coating to the glass surface into the glass.

Now when the light falls on the anti reflective coating surface some light is reflected back and remaining light will pass into the coating again it reaches the surface of the glass and again the splitting take place some light is reflected back and some light will pass into the glass now where the reflector light is again falls on the interface against the splitting takes place some light will pass into the air some light is reflected back.

Now you can see this is the amount of light that is lost that is reflected light now some of these 2 reflected components will be less than the reflected components that would result from where glass alone so that the overall loss of light will be reduced, so by applying the anti reflective coating the amount of light is lost is reduced so most of the light will pass through the lens so the image quality will improve.

(Refer Slide Time: 38:12)



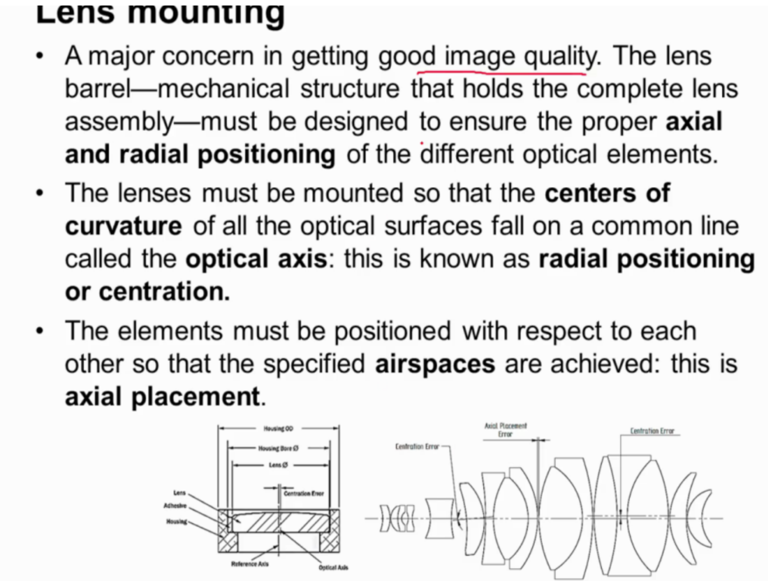
- If the layer thickness is right (one quarter the average wavelength of incident light), the two reflected rays will be **out of phase** with one another, and will cancel out each other. This process decreases the total amount of reflected light, and increases the amount of light transmitted through the lens.
- There is an increase in both **contrast** (due to a reduction in stray light from internal reflections) and **brightness** (due to increased light transmission through the glass surface).
- The improvement in light transmission due to coating on a single lens surface may be only a few percent, the total improvement resulting from coating all lens surfaces in a design with 10 or 20 lenses will be many times higher, as high as 99.9%.

Now if the layer thickness anti reflective coating layer thickness is correct that is one fourth of the wavelength of incident light then the reflected light rays will be out of phase with one another and they will cancel out each other so this process decreases the total amount of reflected light and increases.

The amount of light transmitted through the lens so because of this the contrast increases this is the reason is the reserved reduction in the stray light from internal reflection since the reflected light amount decreases the internal reflection will reduce and the contrast image will increase and brightness of the image will also increased due to the increased light transmission through the glass surface.

The improvement in the lights transmission due to coating on a single lens surface may be a very few percent and total improvement resulting from coating on lens surface in a design with 10 or 20 lenses will be many times higher as high as 99.9%.

(Refer Slide Time: 39:52)



Lens mounting

- A major concern in getting good image quality. The lens barrel—mechanical structure that holds the complete lens assembly—must be designed to ensure the proper **axial and radial positioning** of the different optical elements.
- The lenses must be mounted so that the **centers of curvature** of all the optical surfaces fall on a common line called the **optical axis**: this is known as **radial positioning or centration.**
- The elements must be positioned with respect to each other so that the specified **airspaces** are achieved: this is **axial placement**.

Now let us start the discussion of length lens mountings this lens mounting is a major concern in getting a good quality picture the lens barrel which is a mechanical part this barrel holes of the lens and lens assemblies the lens barrel should be properly machined to ensure proper axial and radial positioning of all the optical elements now in this diagram we can see a barrel mechanical structure which holds the lenses of proper sitting should be machined.

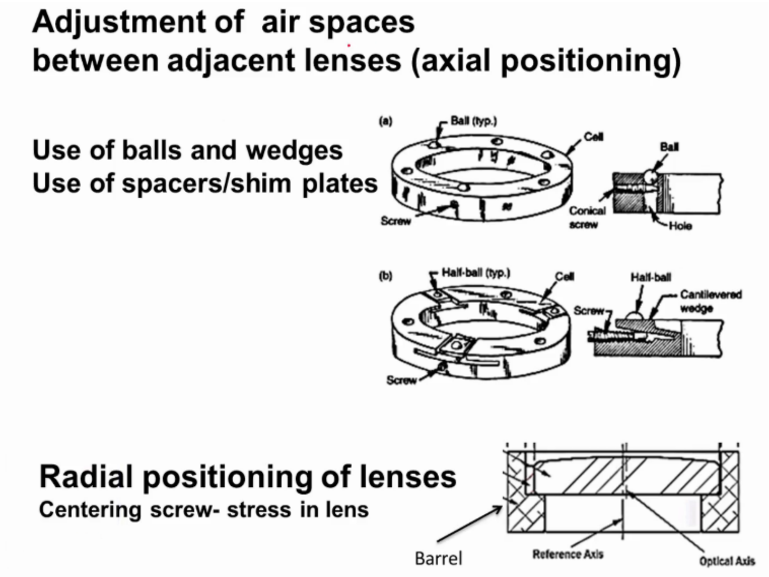
So that the lenses can be placed properly the tolerances maintained appropriate tolerances should be maintained so that the radial position is obtained the lenses must be mounted inside the barrel so that the centre of curvature of all the optical surfaces fall on a common line called the optical axis you can see here we have this common line which is known as optical axis.

There are many elements many lenses are there the centre of curvature of these all elements should fall on this optical axis if they do not fall the centre of curvature is not falling on the axis then the image quality will be suffered you can see here this particular sub assembly we have the access of subassembly this is the axis then we have the common axis the optical axis now there is a gap so this gap is known as centering error.

So because of this diminishing quality suffers also the tilting of lens we can see here when the length tells the centre of curvature curvature will not fall on the optical axis because of this image quality suffers also the radial positioning of the lenses is very very important proper gap should be provided between the 2 lenses adjacent lenses.

So that image quality is enhanced now this gap between 2 lenses is also known as airspaces

(Refer Slide Time: 43:14)



Adjustment of air spaces between adjacent lenses (axial positioning)

Use of balls and wedges
Use of spacers/shim plates

Radial positioning of lenses

Centering screw- stress in lens

The adjustment of air spaces between adjacent lenses there should be some promise provision for a space adjustment for that we can always use spaces and some place between 2 adjacent lenses so proper gap is maintained and also we can maintain balls and wedges you can see some mechanism here.

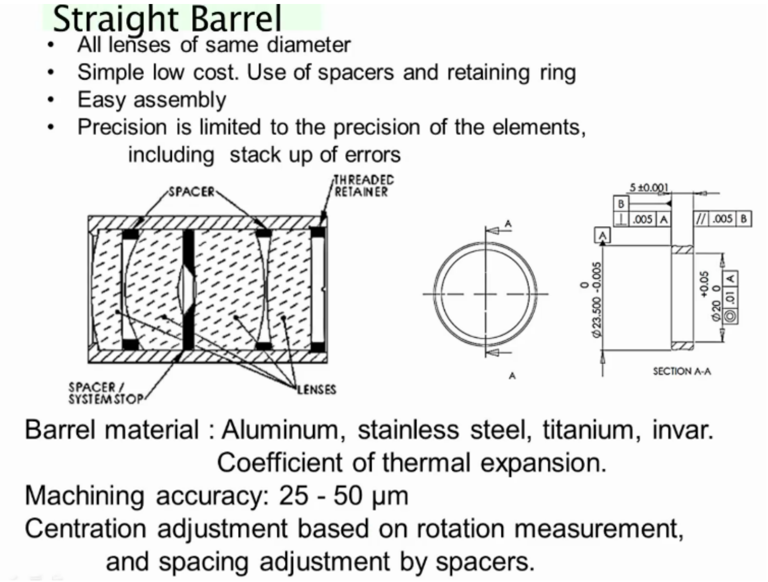
So we have ball and we have a screw here with the conical screw is driven inside it pushes the ball outside the ball races and here we can see a cantilevered wedge carrying of a ball so when the screw is driven inside the wedge shaped this which moves up along with the ball when the ball moves up the lens will also more up.

So when the ball up the lens will also move up and hence we can maintain the required a space between the 2 lenses so some mechanism like this should be provided for the adjustment of the lenses in the axial direction so radial positioning of lenses is also very important you can see the barrel here with the seat machine.

Now you can see the optical axis length and that is the barrel access that is referral axis now there is a shift one side length has displayed so this is known as radial positioning or centering error show some mechanism should be provided for example centering screw should be provided here so here we can make screw.

So by rotating these screw, screw can be provided here so by rotating the screw the lens can be centered care should be taken to see that the screws should not be over tightened if they are over tightened the lenses are get trained stresses which will affect the image quality.

(Refer Slide Time: 45:46)



Straight Barrel

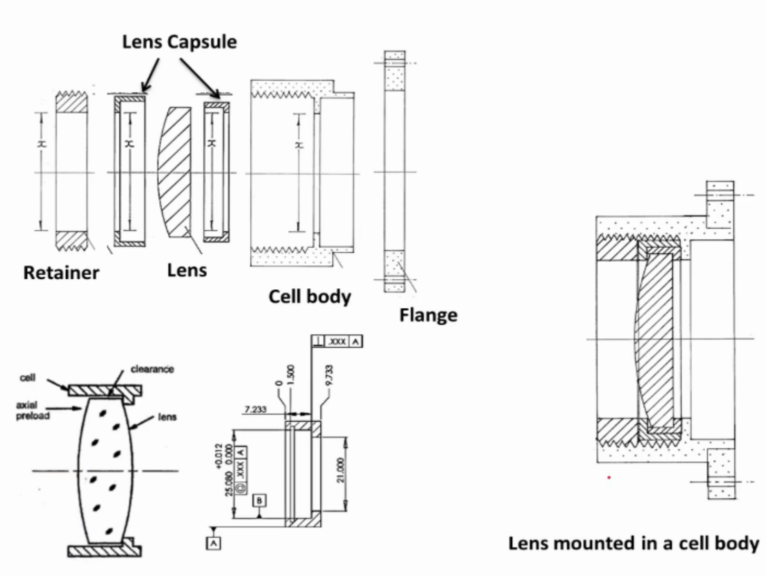
- All lenses of same diameter
- Simple low cost. Use of spacers and retaining ring
- Easy assembly
- Precision is limited to the precision of the elements, including stack up of errors

Barrel material : Aluminum, stainless steel, titanium, invar.
Coefficient of thermal expansion.
Machining accuracy: 25 - 50 µm
Centration adjustment based on rotation measurement, and spacing adjustment by spacers.

Now straight barrels can be used for assembling lenses if we use straight barrel all lenses of same diameter we can see here straight barrel and many lenses are placed inside the barrel and spaces are provided here to maintain the proper air space between the 2 lenses now this straight barrel is easy to mission and the cost is less and all the lenses can be easily mounted inside the barrel the position is limited to the position of the elements including stack up of errors.

now normally the aluminum, stainless steel, titanium invar used to make the gap barrel we should select the appropriate material with very low efficient of thermal expansion so that thermal effects are minimized and the machining accuracy is normally from 25 to 50 microns and centration adjustment based on the rotation measurement and spacing adjustment by spaces can be provided.

(Refer Slide Time: 47:13)

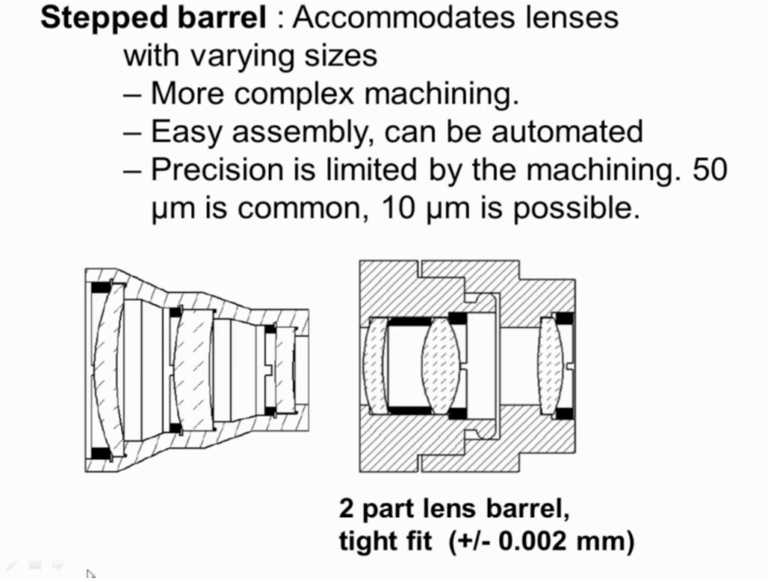


So you can see an assembly of lens in the barrel in the cell body this is the cell body and it has got internal threaded portion and then we have lens then we have lens convex lens with the 2 lens capsules for excellence is placed in the capsule and it is assembled and the complete length capsule is assembled and inserted into the cell body.

They can see here the externally threaded retainer and retainer ring is pushed inside threaded inside to assemble the lens capsule into the body so this shows the lens capsule inside the cell body and by rotating the retainer we can apply axial preload to the lens.

So that it sit properly in the seat so we should not play over preload in that case the lens will be stressed and the mission quality suffers now there is a small clearance between the length and the cell body which will be filled by the gum.

(Refer Slide Time: 48:51)



Stepped barrel : Accommodates lenses with varying sizes

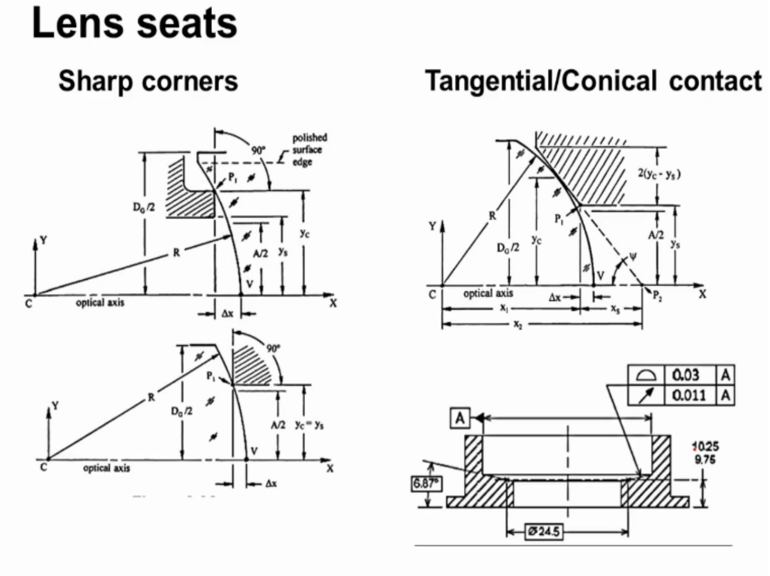
- More complex machining.
- Easy assembly, can be automated
- Precision is limited by the machining. 50 µm is common, 10 µm is possible.

2 part lens barrel, tight fit (+/- 0.002 mm)

The elements must be positioned with respect to each other so that the specified airspaces are achieved this is axial Placement. Stepped barrel accommodates lenses with varying sizes more Complex machining. Easy assembly can be automated Precision is limited by the machining 50 micrometer is common 10micrometre is possible. Add centration adjustment to Elements using rotation optical measurement Labor intensive assembly.

Achieve 10 micrometer easily 1 micrometer is Rotate lens system on air bearing adjust lens centration. Part lenses in place spacing adjustments with shims. Choose custom spacer labor intensive assembly achieve 25 micrometer easily 5 micrometer is possible.

(Refer Slide Time: 49:46)



Lens seats

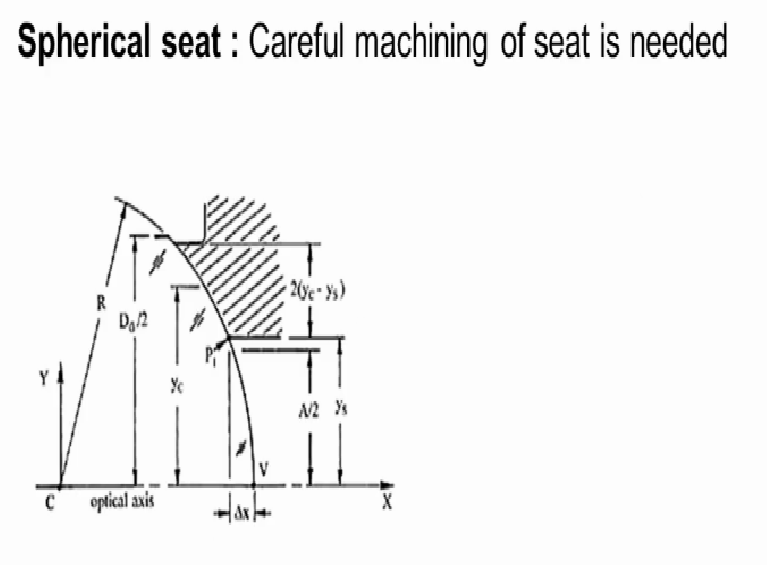
Sharp corners

Tangential/Conical contact

Proper length seat should be provided in the cell body at the barrel so that there seated properly here you can c sharp corner seat and this is the concave surface of the length it is resting on the sharp corner of the seat here we have a convex lens which is resting on the sharp corner of the seat appropriate radius should be provided to this corner.

So that the scratching of the lens is minimized and here you can see tangential or conical seat the convex surface of the lens is in contact with the tangential with the particular seat so proper geometrical tolerances should be provided on the barrel, so that the sitting of the lenses is proper.

(Refer Slide Time: 50:58)



Spherical seat : Careful machining of seat is needed

This picture shows this spherical seat the centre of curvature of the radius of the curvature this portion of seat and the radius curvature of lens should match each other so careful machining is required to get this spherical seat.

(Refer Slide Time: 51:21)

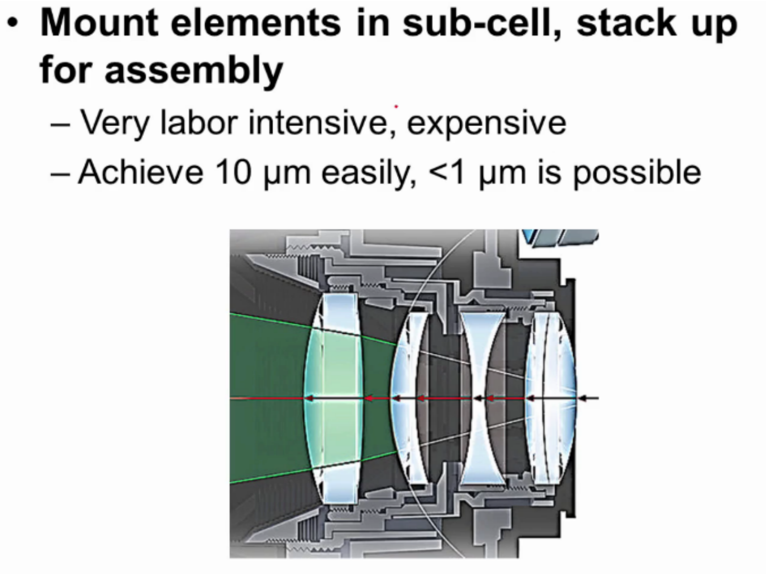
- **Add centration adjustment to elements** using rotation + optical measurement
  - Labor intensive assembly
  - Achieve 10 μm easily, 1 μm is possible
  - Rotate lens system on air bearing, adjust lens centration and pot lenses in place
- **Spacing adjustment with shims**
  - Choose custom spacer
  - Labor intensive assembly
  - Achieve 25 μm easily, 5 μm is possible

Now in the barrel we can provide centration adjustment by providing screws centering screws are by using rotation and optical measurement technique we can send the lenses but this process will be labor intensive process and we can achieve 10 micrometer easily where is 1 micrometer is possible.

So we should have an arrangement to rotate the lens system on air bearing and adjust length centration and put lenses in place and there should be provision for spacing adjustment with axial adjustment with shim, so he can always select a proper spacer this method will be labor intensive assembly and we can achieve 25 micrometer is easily and 5 micrometer possible.

You can see some shims and some assembly process of shim in barrel in the assembly here you can see shim played between the adjacent lenses

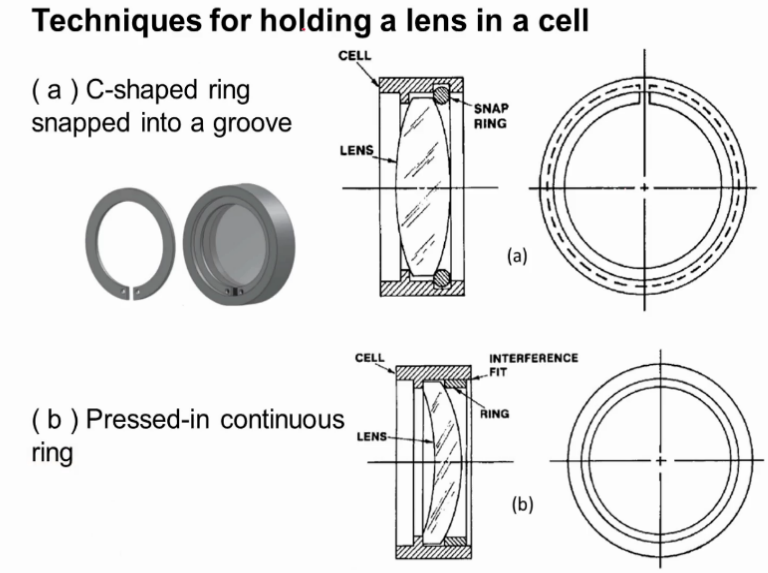
(Refer Slide Time: 53:07)



- **Mount elements in sub-cell, stack up for assembly**
  - Very labor intensive, expensive
  - Achieve 10 μm easily, <1 μm is possible

We can always count the lenses in sub cell and you can make sub assemblies and the individual of sub assembly may look into the barrel to check up the complete assembly for this will be very labor intensive and extensive and this achieve 10 micrometer easily and less than 10 less than 1 micrometer is possible.

(Refer Slide Time: 53:44)



Techniques for holding a lens in a cell

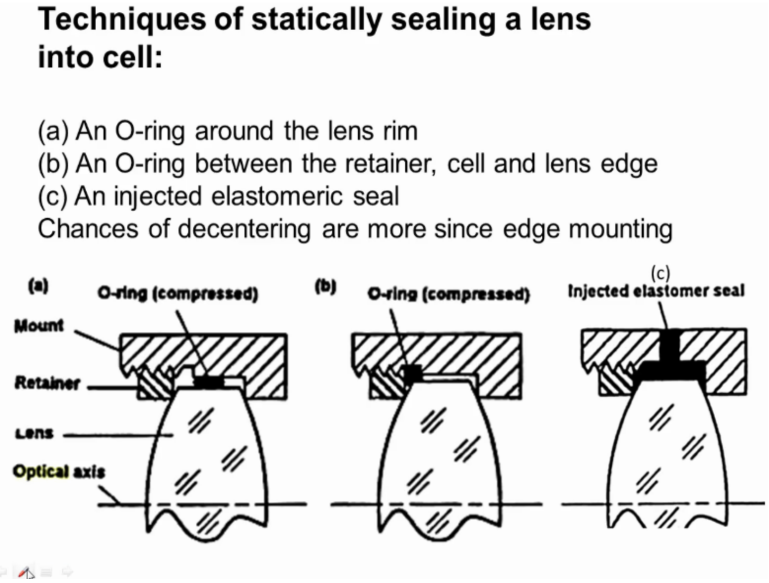
(a) C-shaped ring snapped into a groove

(b) Pressed-in continuous ring

And how do we hold the lens in a barrel how do we eliminate the falling of lens inside the barrel you can see here c shaped ring snapped into a group so this is the cell or barrel this is a lens and this c shaped ring is snapped into the groove there is a group here you can see the crew and this is the seat for lens.

Lens is placed in the cell body and the this c shaped ring is placed in the crew so that the lengths will not fall and we can also use press in continuous rings, so here we have continuous ring that is press fitted into the cell body which holds the lens position.

(Refer Slide Time: 54:50)



Techniques of statically sealing a lens into cell:

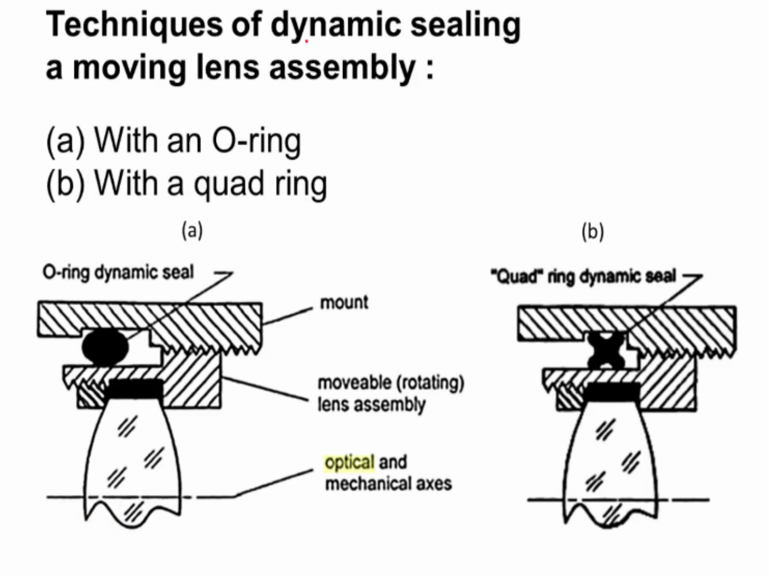
(a) An O-ring around the lens rim
(b) An O-ring between the retainer, cell and lens edge
(c) An injected elastomeric seal
Chances of decentering are more since edge mounting

Statically ceiling a lens inside cell now different methods are available so here we can see and rolling around the O ring so this is the length and this is the edge of the lens and this is the amount and this is the cell body and the o ring is placed between the length and the cell body it is pressed and pushed into the place then retain threaded is positioned.

Now here we can see the O ring between the retainer cell and lens edge so we have the cell body on the barrel body and we have the lens soaring is placed in the cell body and the lens edge and then the threaded retainer is positioned and another method is injecting elastomeric seal.

So the lens is placed inside body cell body and the retainer ring is threaded into the cell body to hold the length and then the elastomer seal hold into the body that means there should be a small hole in the cell body to pour the elastomeric seal and then elastomer is allowed to solidify which holds the lens in position.

(Refer Slide Time: 56:48)



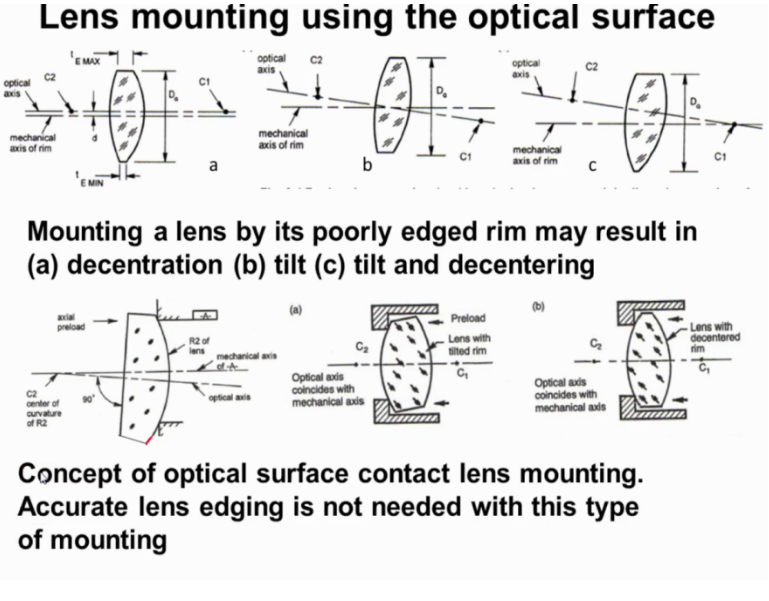
Techniques of dynamic sealing a moving lens assembly :

(a) With an O-ring
(b) With a quad ring

Now let us see how we can achieve the dynamic ceiling of moving lens assembly is if we observe this picture we can understand that is mount we have the length and there is a movable lens assembly.

So this will be moving parallel to the optical axis so in such cases how to see the lenses so you can always use o-ring dynamics feel so that the lens is positioned properly or another method is quad ring we can use a quad ring as shown here dynamically seal the moving lenses.

(Refer Slide Time: 57:39)



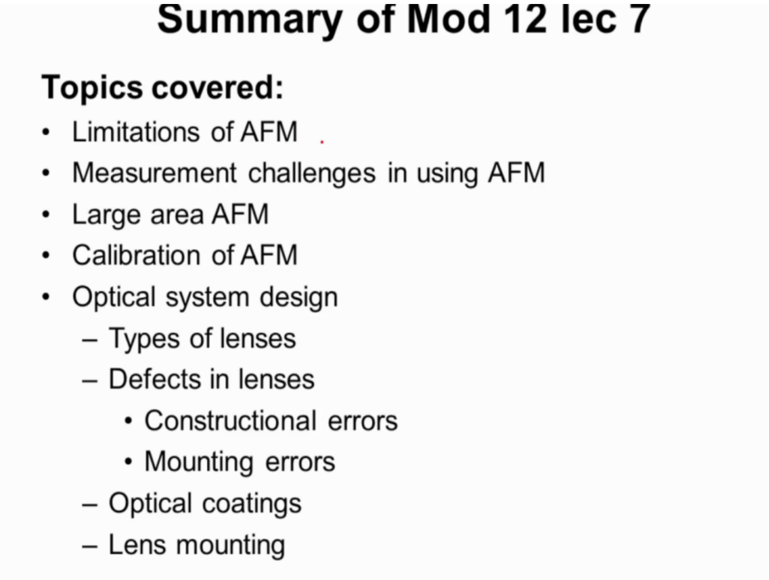
Lens mounting using the optical surface

Mounting a lens by its poorly edged rim may result in (a) decentration (b) tilt (c) tilt and decentering

Concept of optical surface contact lens mounting. Accurate lens edging is not needed with this type of mounting

Lens mounting using the optical surface mounting a lens by its poorly edged rim may result in a way wanting a lens why is poorly, it result in decentration tilt and de-centering. Concept of optical surface contact lens mounting accurate lens edging is not needed with this type of mounting optical.

(Refer Slide Time: 58:46)



Summary of Mod 12 lec 7

Topics covered:

- Limitations of AFM
- Measurement challenges in using AFM
- Large area AFM
- Calibration of AFM
- Optical system design
  - Types of lenses
  - Defects in lenses
    - Constructional errors
    - Mounting errors
  - Optical coatings
  - Lens mounting

Topics covered are limitations of a AFM measurement challenges in using AFM, large area AFM calibration of AFM optical system design, types of lenses defects in lenses constructional errors Constructional errors Mounting errors, optical coatings and lens mounting that is all from now, Thank you.