Course material

Course:

Micro and Nanofabrication (MEMS)

Video:

7.1 Inspection and metrology 1

Concepts (extracted from automatically generated subtitles):

Main areas of use. Optical microscope. Different imaging modes. So called bright field. Magnified image of the object. So called dark field. Often used mode. Already mentioned bright field imaging. Magnification of samples. Device surface. Light path. Light source. Various imaging modes. Bi-morph actuator. Dark field.

to video sequence search
(within Micro and Nanofabrication (MEMS).)

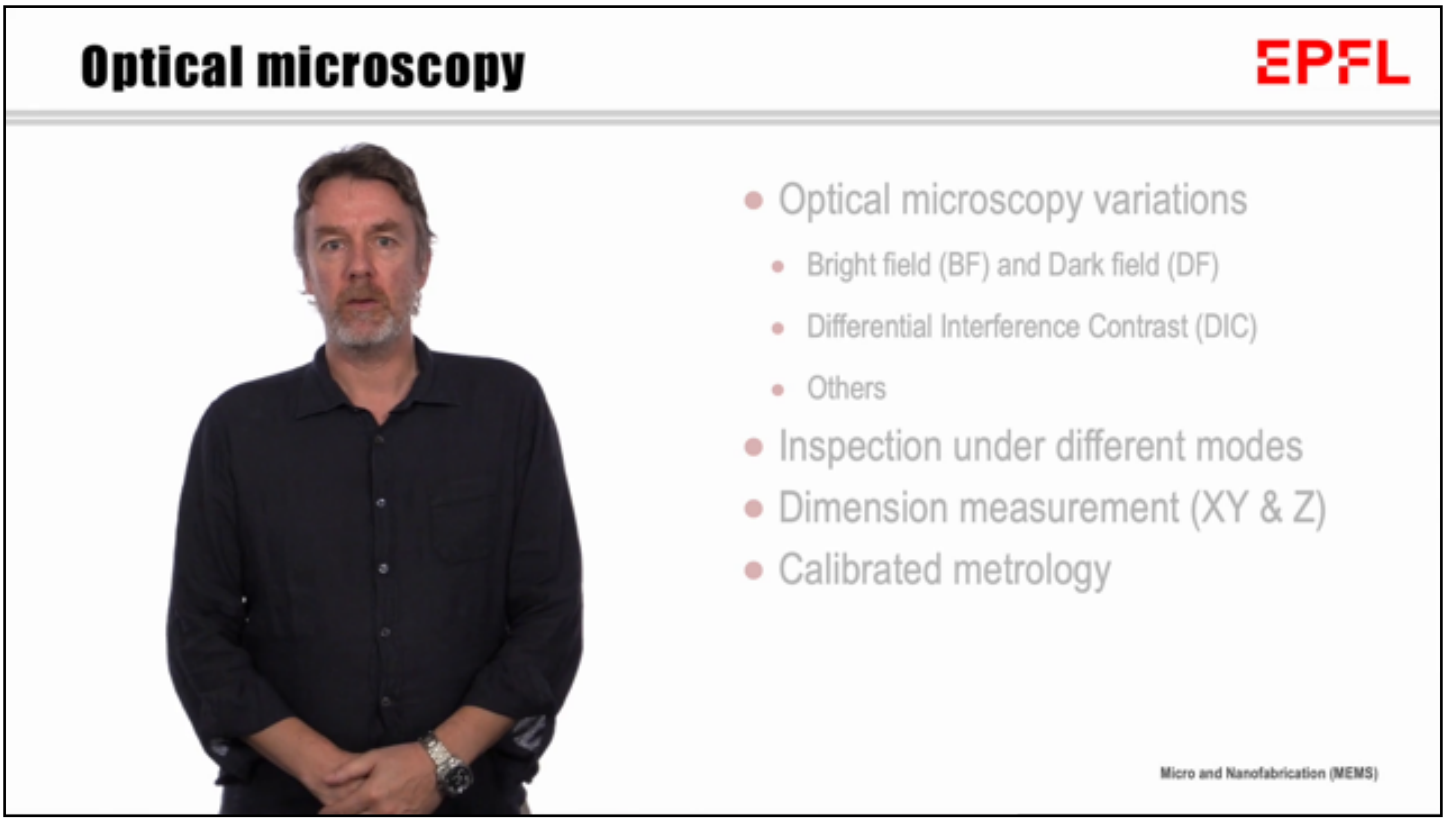
to video

...

notes

summary

0m 0s



In the past lessons, we have seen the basics of micro Nano fabrication in a clean room.

notes

summary

0m 1s

Optical microscopy

- Optical microscopy variations
  - Bright field (BF) and Dark field (DF)
  - Differential Interference Contrast (DIC)
  - Others
- Inspection under different modes
- Dimension measurement (XY & Z)
- Calibrated metrology

Micro and Nanofabrication (MEMS)

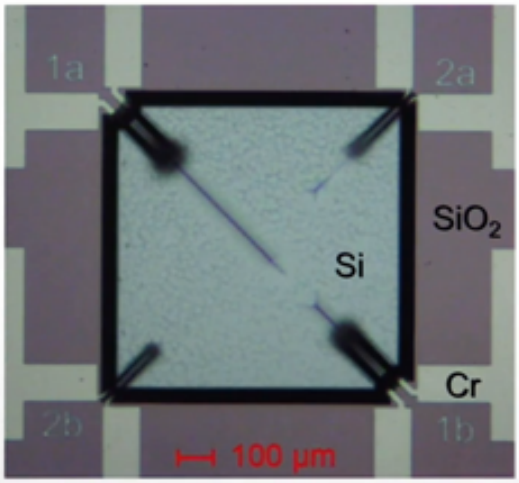
In the following lessons, I will show you how you can inspect and measure the fabricated structures with various methods.

notes

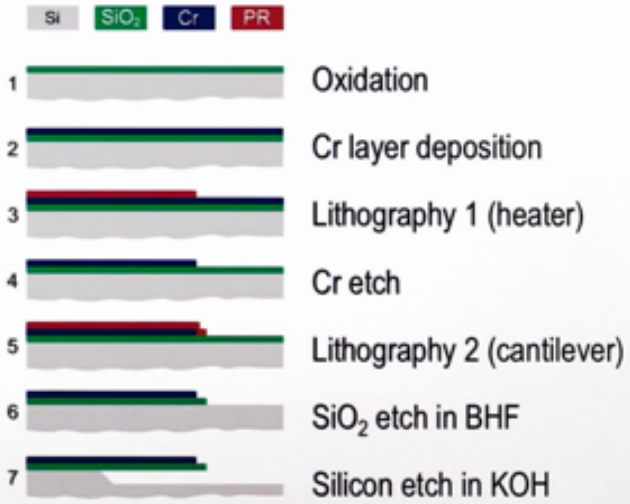
summary

0m 5s

Bi-morph thermal actuator



Optical microscope



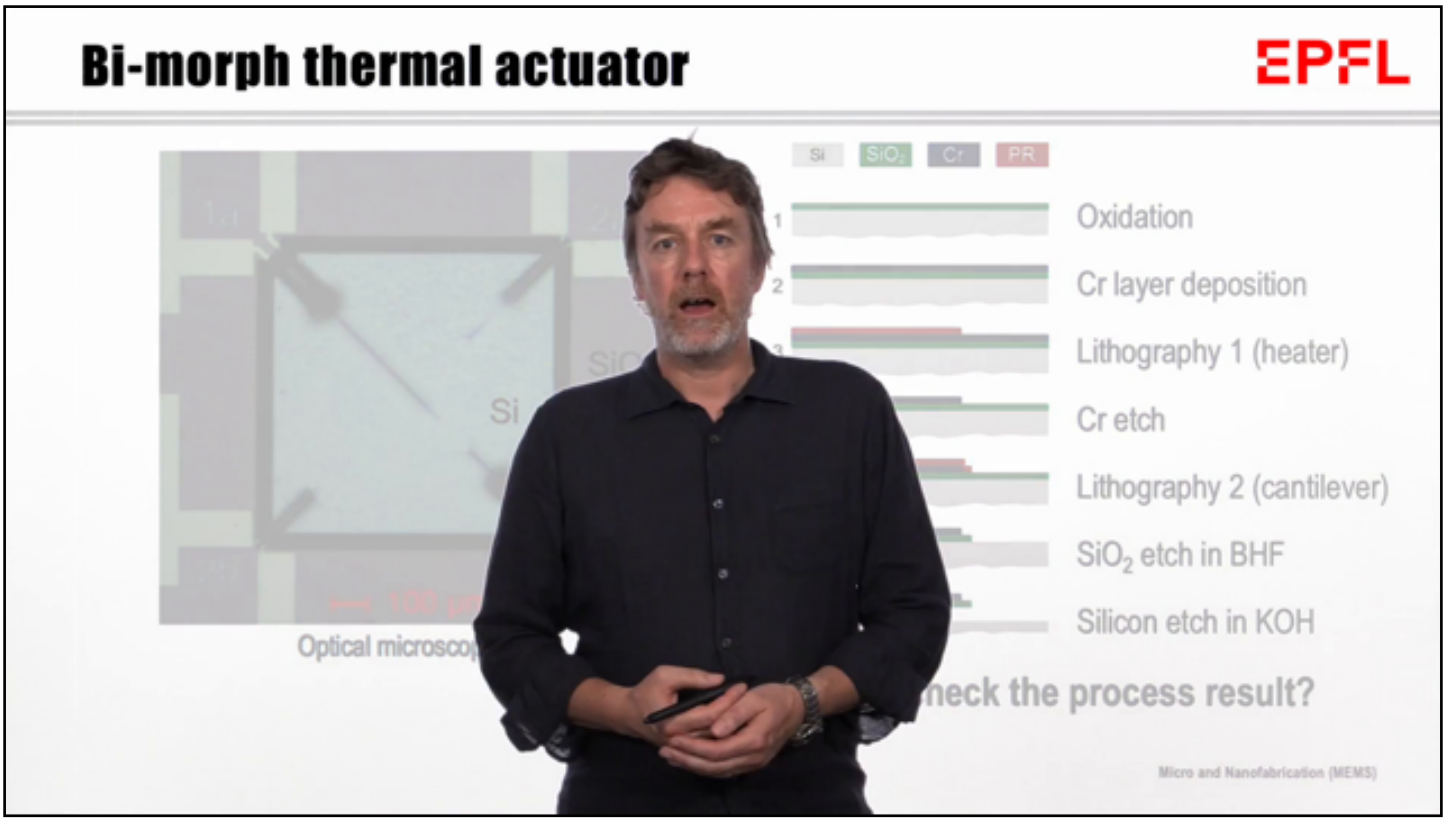
How to check the process result?

I will start by introducing how you can use the optical microscope in different imaging modes to visually inspect the device surface. I will also show you how you can use the optical microscope to quantitatively measure "xy" lateral dimensions and to some extents also film thickness and vertical features in the "z" direction. I will briefly mention the important concerns of calibration. So let's inspect the bi-morph actuator that we use as a case study in this book. Let us see how we can inspect it in order to validate that the fabrication process was successful. On the left, you see a photograph taken with a camera mounted on optical microscope. The scale bar, in red, is very important and serves as a reference to perform dimensional metrology.

notes

summary

0m 21s



You certainly remember from the earlier lessons that the cantilevers are bent out of plane and consequently are not in focus.

notes

summary

1m 13s

Basics of an optical microscope

EPFL

- Compound lenses to magnify the object
- Total magnification = (magn. of eyepiece lens) x (magn. of objective lens)
  - Magn. of eyepiece: 5x, 10x (the most common), 15x, 20x
  - Magn. of objective lens: 5x-100x
- Transmitted light for transparent specimen
- Reflected light for opaque specimen

https://commons.wikimedia.org/wiki/File:Microscope_compound_diagram.png

I will show later how focusing on the optical microscope can be used to determine the vertical extension of the micro fabricated MEMS device along the "z" axis.

notes

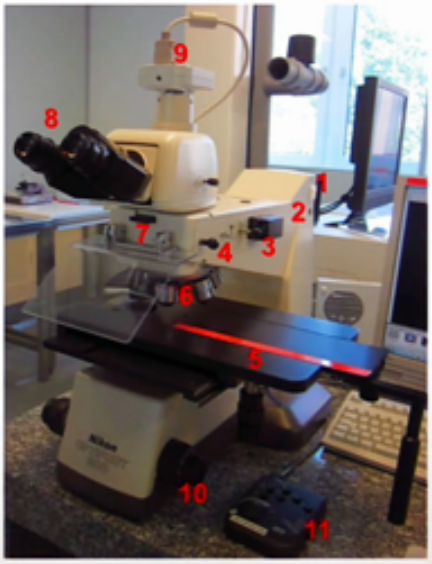
summary

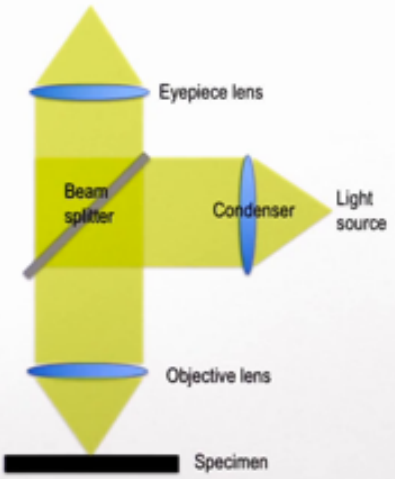
1m 18s

Optical microscope configuration

EPFL

1) Light source
2) Condenser
3) DIC polarizer slider
4) Bright/dark field knob
5) XYZ specimen stage
6) Objective lenses
7) Analyzer slider
8) Eyepieces
9) CCD camera
10) Focus knob
11) Controller





Bright field optical path

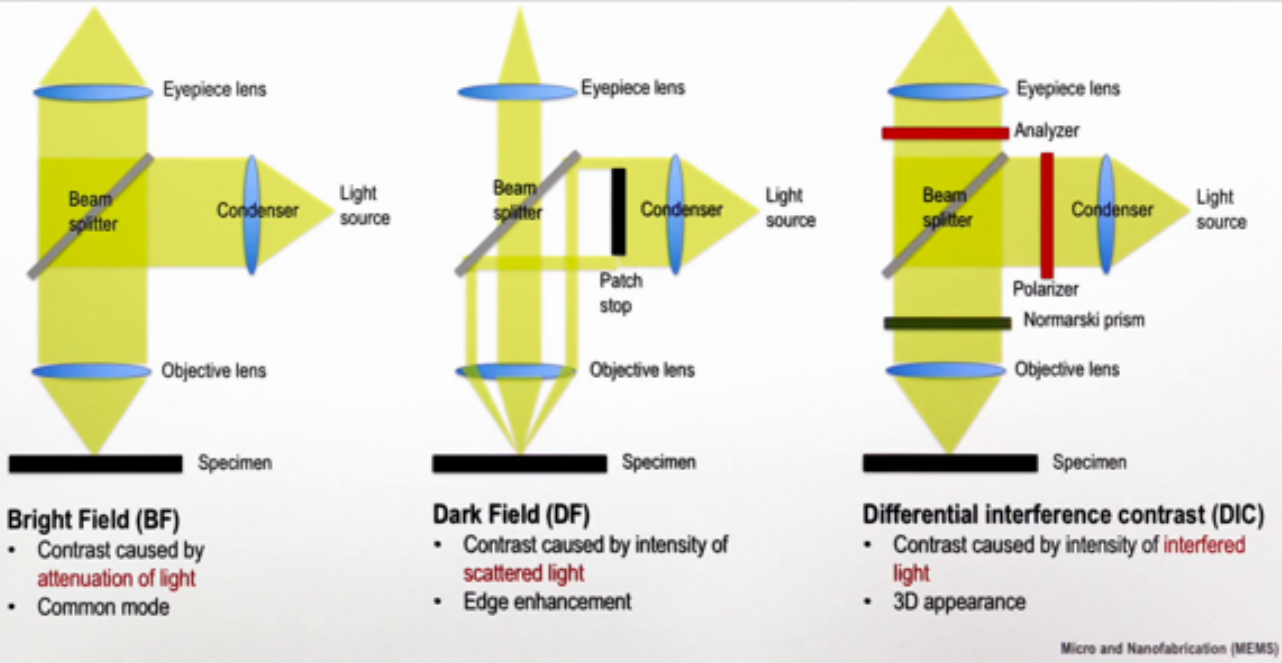
The optical microscope is projecting the magnified image of the object via several lenses onto the imaging plane which is either an eye piece or a camera. Modern microscopes have both modes available. Using the eye allows somewhat to get a quick overview and identify contrast mechanisms in the image quite fast. The camera is then better suited to record images and videos to perform metrology and to do image processing. Magnification of samples can go up to 1000 times, which allows seeing features as small as half a micrometer for high contrast samples. Light is either transmitted through transparent samples or is reflected from opaque surfaces. This photo shows a typical optical microscope which is installed in a clean room. The numbers 1 to 11 indicate the key components of the instrument that allow adjusting the microscope settings for various imaging modes and for the x, y, z positioning of the sample. The right side shows the light path coming from the light source going through the lenses into the sample and back to the eyepiece or camera. In this situation, the specimen is viewed in the so called bright field imaging mode.

notes

summary

1m 28s

Optical microscopy variations



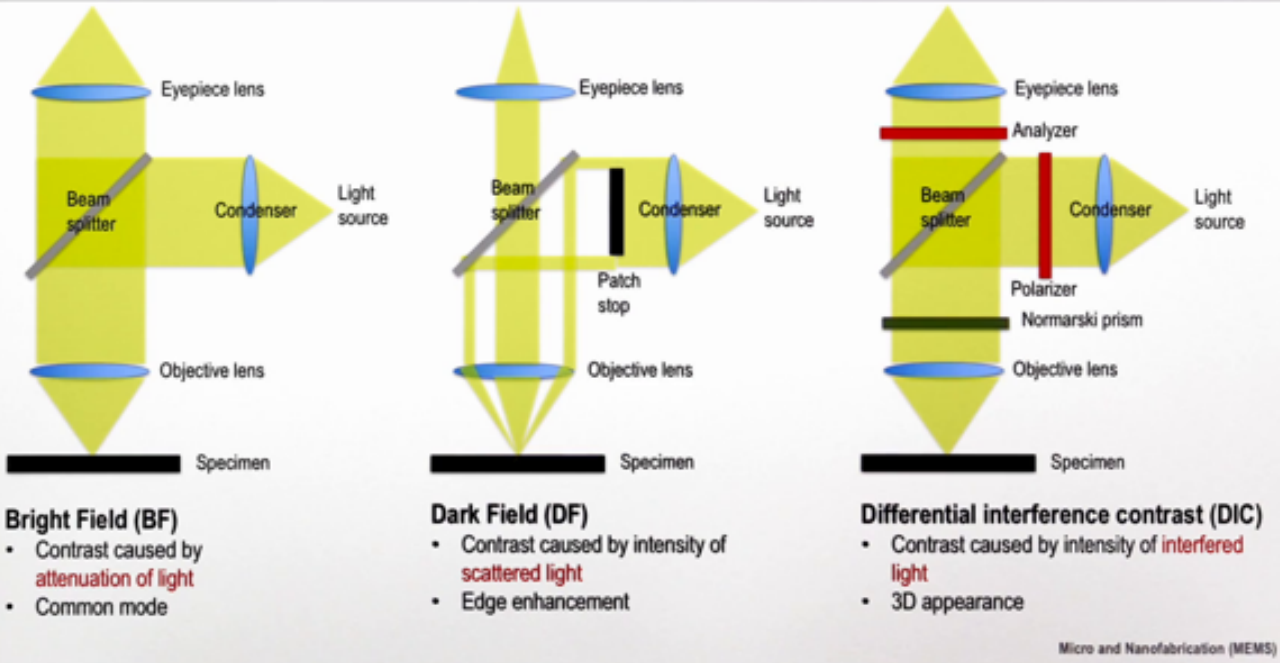
This means that, basically, all the light is used to image the surface.

notes

summary

2m 49s

Optical microscopy variations

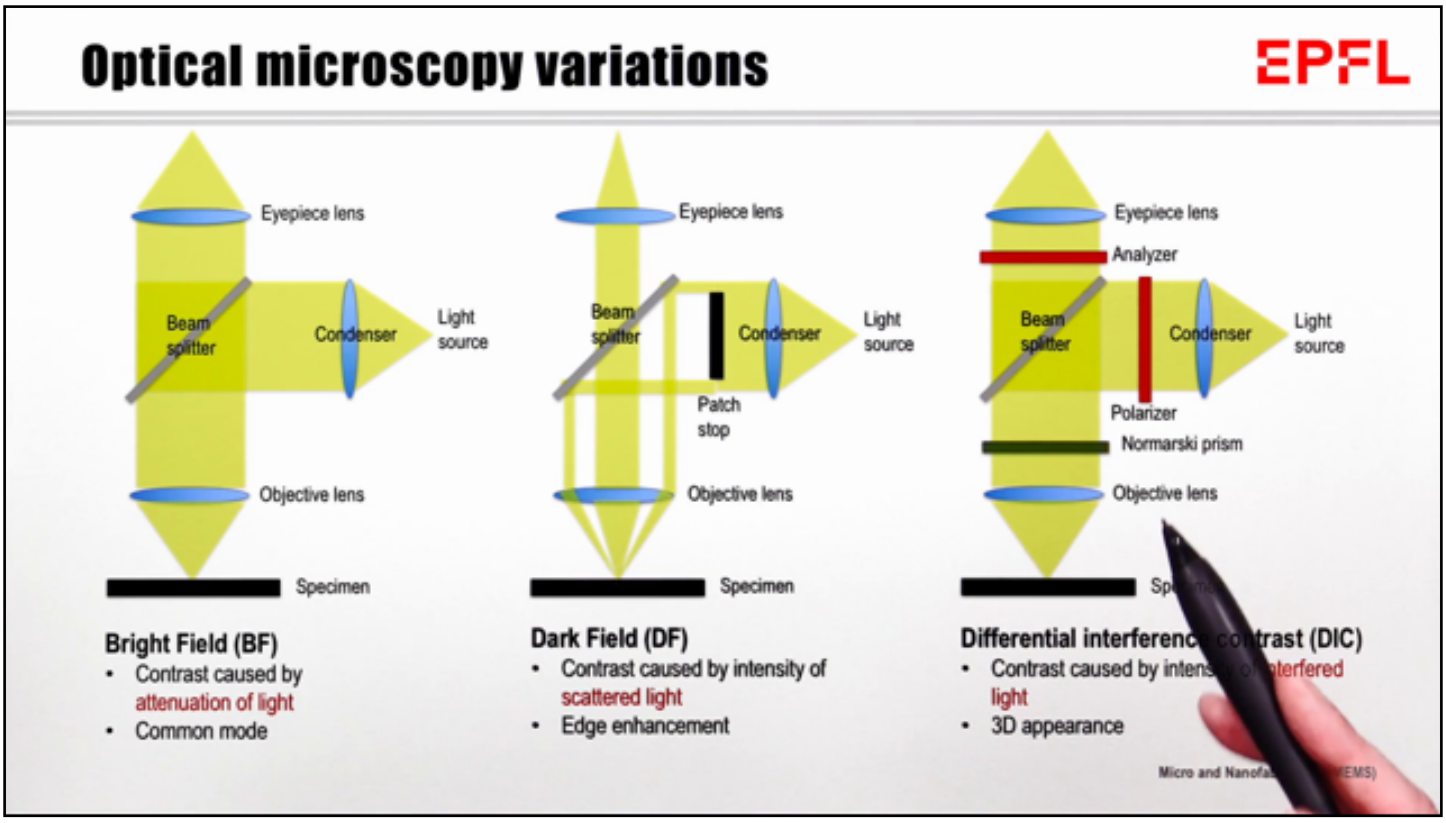


Here, you will see 3 possible and often used variations of optical inspections. Left, the already mentioned bright field imaging, in the center, the so called dark field imaging, and in the right hand side, it is the differential interference contrast mode. Let's first look at the difference between bright field and dark field. In dark field, there is a path stop introduced in the light path that blocks the central part of the illumination. Using only the peripheral part of the illumination greatly reduces the image brightness but enhances the detection of scattered light. This dark field imaging mode is therefore much darker, but it shows much better

notes

summary

2m 56s



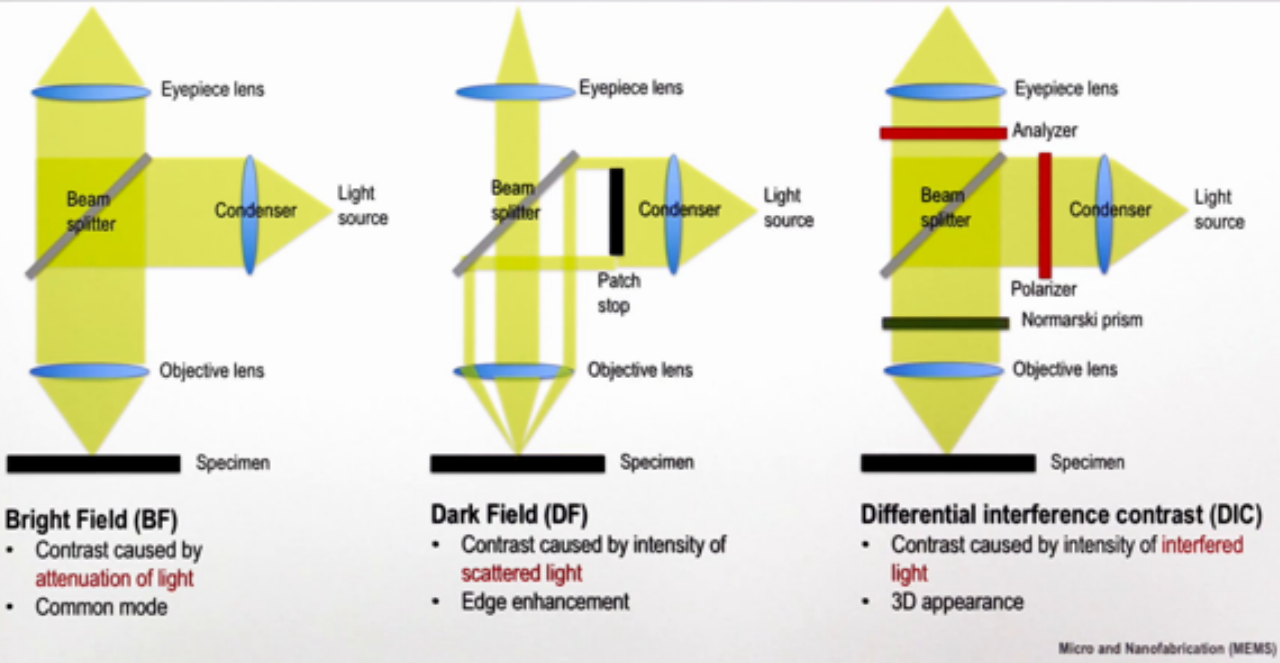
any irregularities on the surface such as edges, defects and dust. In the DIC mode, a Nomarski prism is introduced to split the incoming light into two beams

notes

summary

3m 37s

Optical microscopy variations



that are shifted by about 200 nanometers.

notes

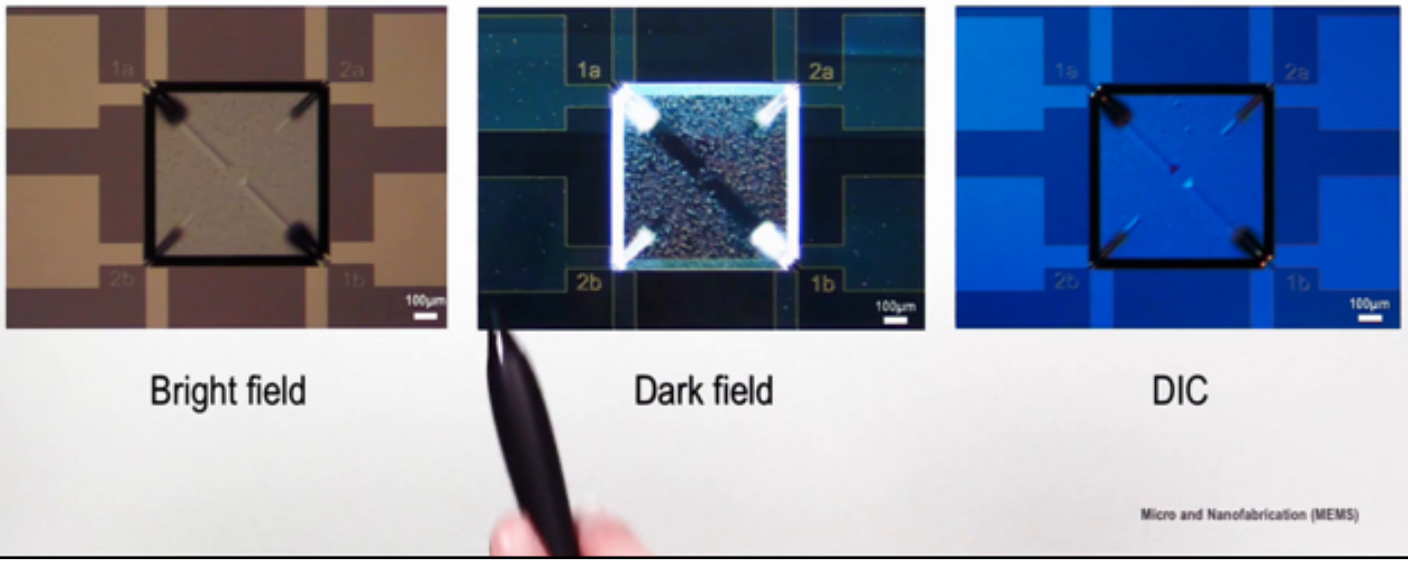
summary

3m 47s

Optical microscopy variations

EPFL

- Bi-morph actuator optical microscope inspection



Any light path difference between these two beams caused by surface topography will result in interferences. Using linearly polarized light ensures that the two polarizations of the two split incident light beams are orthogonal to each other after passing through the prism. This way, no interferences will occur until the reflected light from the sample is passing through the prism again, but the polarization of the split light beams is rotated back to the same direction. Interference between the lights from the 2 adjacent points allow quantifying the height difference on the sample surface which provides a 3d appearance of the image in the DIC mode. When we inspect the bi-morph device in these 3 modes, we can then see clearly how the images are different. The bright field image shows the true colors and gives a general overview of the sample surface and dimensions. The dark field is darker in general and highlights parts of the sample that scatters the light beside the bent cantilevers and the KOH etched slopes in silicon, you can see in particular the sharp edges of the metal pattern, you can also small bright

notes

summary

3m 51s

Optical microscopy variations

Method	Features	Main Areas of Use
Bright field	• The most common mode • Entire field illuminated	• Commonly used
Dark field	• Observing the scattered light • Edge enhancement	• Defect inspection
DIC	• Enhance the topography • 3D appearance	• Topographical inspection • 3D structure inspection
Phase contrast	• Contrast from interference due to phase shift	• Transparent sample • Live cells observation
Polarizing	• Contrast from specimen birefringence	• Mineral crystals observation
Fluorescence	• Observing fluorescence light	• Cells/tissues labeled with fluorescent dye • Auto-fluorescence

spots on the metal contact pards which shows some surface roughness due to processing. They could also be dust or contamination particles in case the sample was taken out of the clean room. The DIC image here on the right side reveals a sort of a 3D surface image as it highlights small surface topographic variations by the interference effects. All three imaging modes show complementary information if relevant, one should use them all to complete the inspection of a micro or a Nano structure surface. This table provides an overview of optical inspection variations along with the particular features and main areas of use. Besides the 3 modes already mentioned, the bright field, the dark field and the DIC modes, the table also lists other imaging modes that are not shown in detail in this course, but that are used depending on the sample nature.

notes

summary

5m 3s

Optical microscopy variations

Method	Features	Main Areas of Use
Bright field	• The most common mode • Entire field illuminated	• Commonly used
Dark field	• Observing the scattered light • Edge enhancement	• Defect inspection
DIC	• Enhance the topography • 3D appearance	• Topographical inspection • 3D structure inspection
Phase contrast	• Contrast from interference due to phase shift	• Transparent sample • Live cells observation
Polarizing	• Contrast from specimen birefringence	• Mineral crystals observation
Fluorescence	• Observing fluorescence light	• Cells/tissues labeled with fluorescent dye • Auto-fluorescence

For instance, when imaging living biological cells that are transparent, one often uses a phase contrast mode to create contrast by interference of the light caused by phase shift inside the sample. Polarizing the light is another way to create contrast due to birefringence effects often used when imaging minerals crystal.

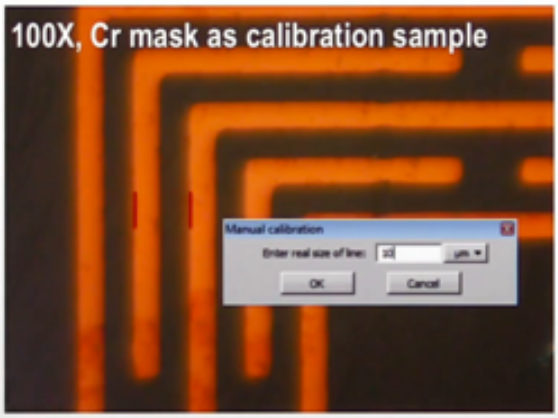
notes

summary

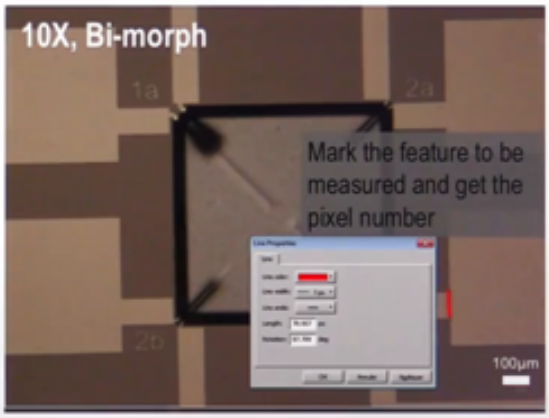
6m 1s

Dimension measurement: XY

- CCD camera ➔ standard sample with known dimension ➔ how many µm per pixel ➔ calibrate the scale bar in the CCD image ➔ use the scale bar as a ruler
- Resolution limitation: ~0.5µm



Mark the feature with known dimension and calibrate
1 pixel = 0.1243µm in 100x image



Cr line width=79.957 pixels, 1 pixel = 1.243µm in 10X image
➔ 79.957 x 1.243 = 99.4µm (100µm in design)

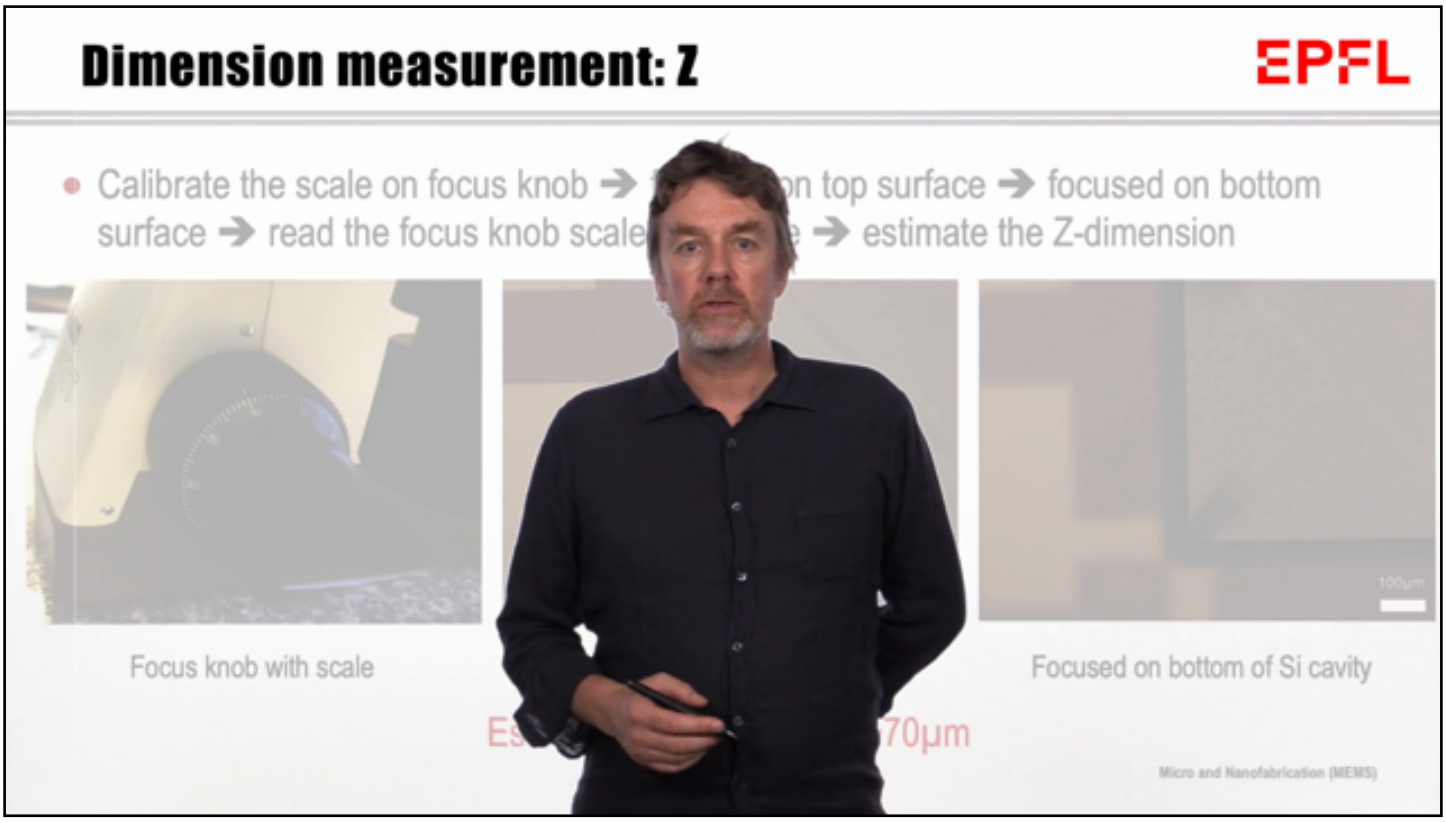
Micro and Nanofabrication (MEMS)

And finally, an often used mode is to work with fluorescent material that allows labelling selectively part of the sample to create additional contrast. Besides quality control by optical inspection, it is often necessary to measure dimensions. This is called metrology and is meant to quantify the device length, width and thickness. Modern optical microscopes have a scale bar on the screen as a reference for the lateral dimensions. To ensure accurate dimensions, one performs measurements on a well-known calibration sample. This allows converting the number of micrometers per image pixel into physical dimensions. Using the one handed x objective on a chrome mask calibration sample, one can see that 1 pixel corresponds to about 0.1243 micrometers.

notes

summary

6m 25s



We now inspect the bi-morph device with a 10x objective to determine the lateral dimensions of the silicon dioxide beams and chrome wires by using the calibrated value of the pixel size. In this case, you measure the width of the chrome wires to be 99.4 micrometers, which is slightly less than the 100 micrometers in the design. This deviation is most likely a result of telefography processes and chrome etching. Please also remember that the resolution here, is limited by difraction to about 500 nanometers.

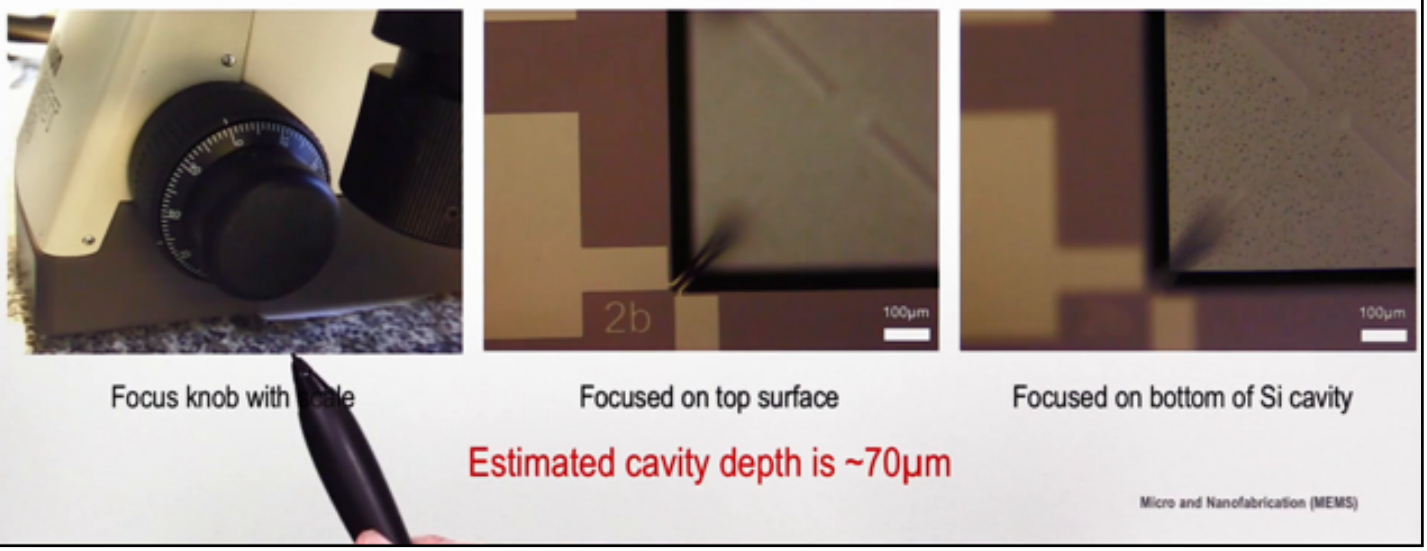
notes

summary

7m 13s

Dimension measurement: Z

- Calibrate the scale on focus knob ➔ focused on top surface ➔ focused on bottom surface ➔ read the focus knob scale difference ➔ estimate the Z-dimension

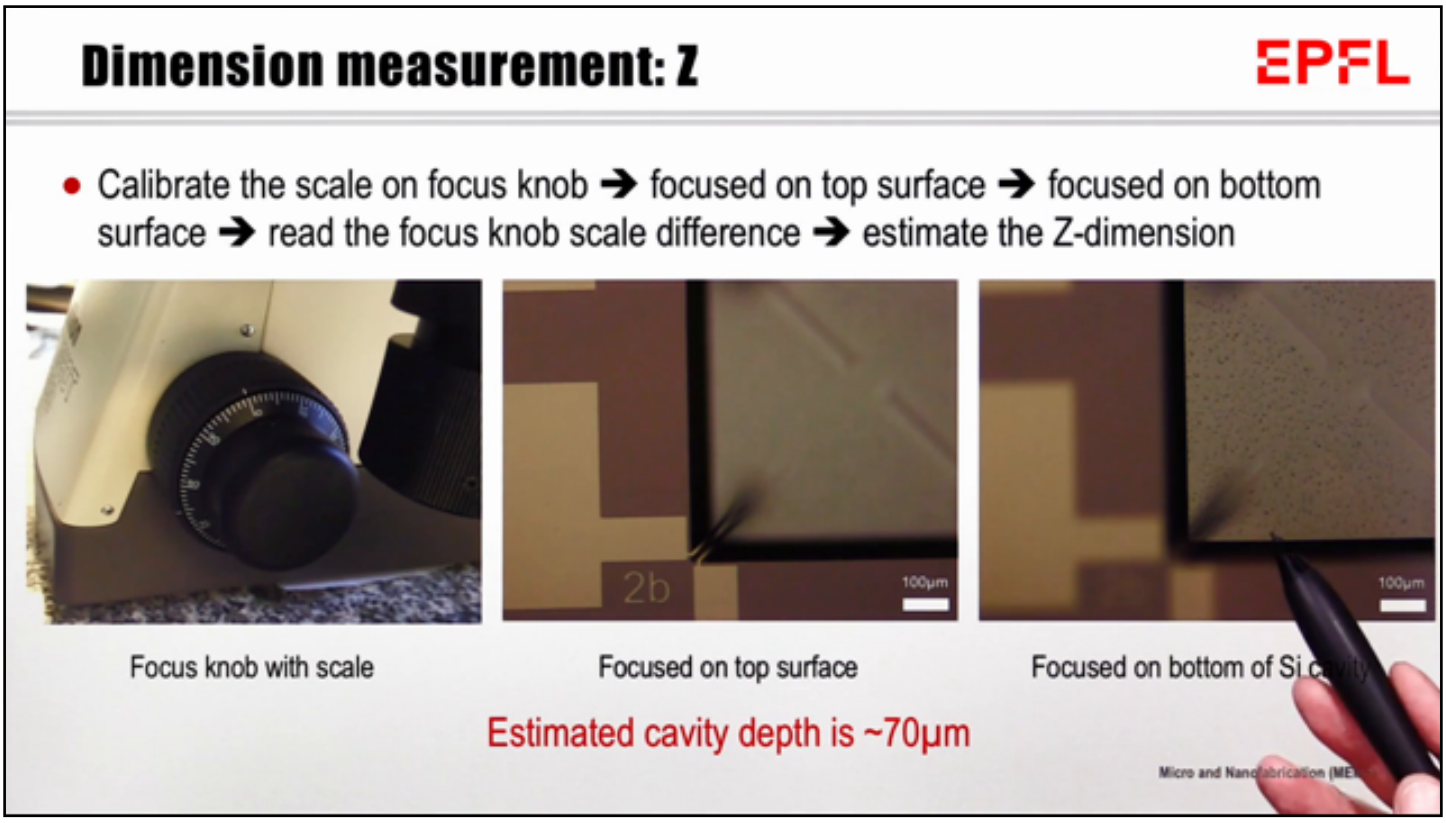


To some extent, the optical microscope also allows measuring vertical dimensions. This practice is simple to implement and allows for a first order of magnitude estimations. As we know, the depth of the focus in an optical microscope is shallow, particularly when using high numerical aperture objectives. If there are 3D at surface features on the surface that touches bent cantilevers or etched holes, we can manually displace a sample up or down by along the z axis by the knob, and thereby going in or out of the optical focus.

notes

summary

7m 48s

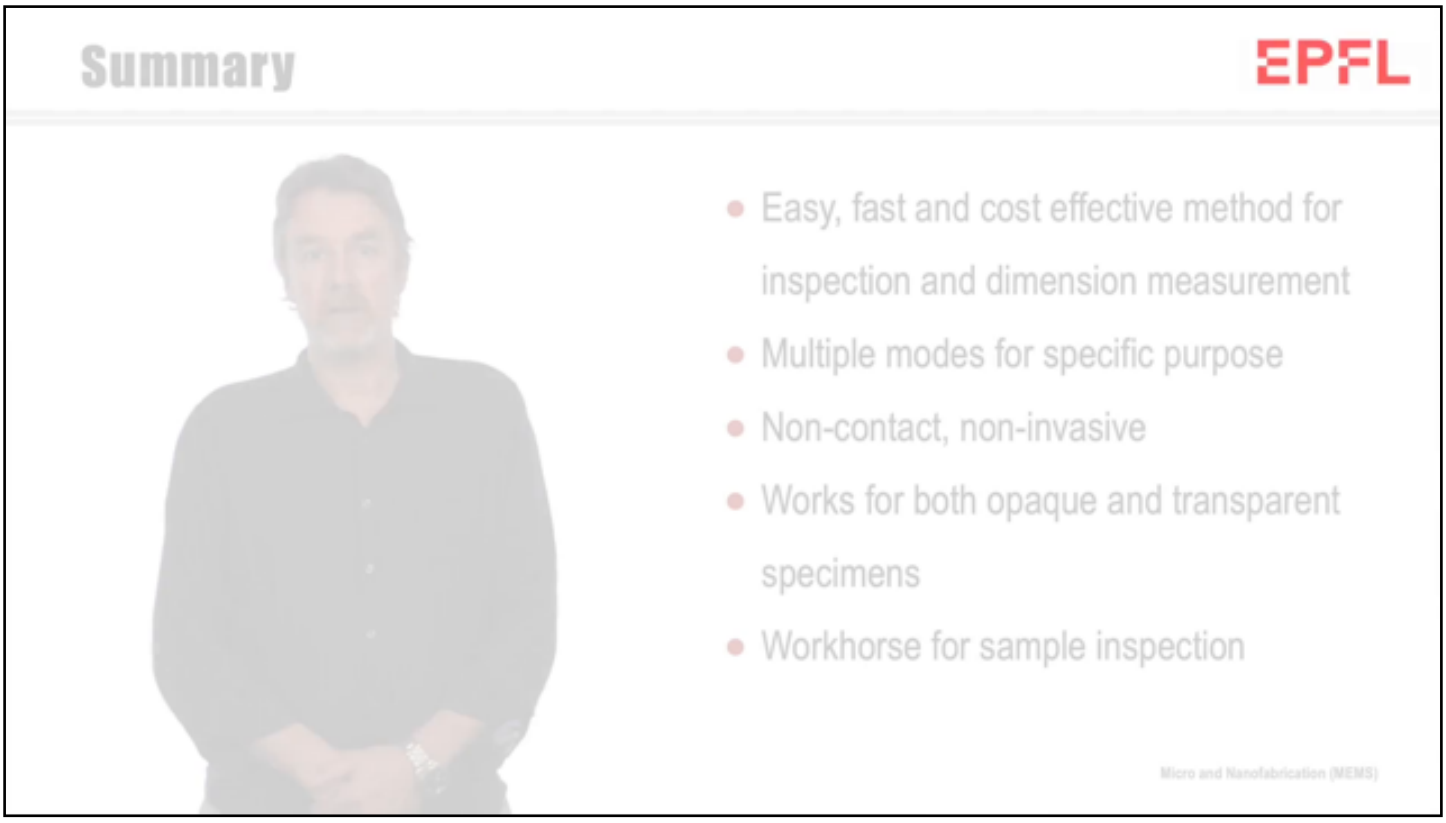


This knob here, has scales with 1 micrometer of resolution. If we focus on the top surface of the bi-morph, record the scale number and then shift focus to the bottom of the silicon cavity, we can read on this scale the travel of the sample and hence its radical extension. Here, we measure the focus displaced in z axis by about 70 micrometer, which is roughly the depth of the edge grooves.

notes

summary

8m 25s



For more precise measurement, one should use another metrology tool such as an optical or mechanical profilometer, for instance, as shown later in this mooc class. In this lesson, I have shown you how the optical microscopy can be used, as convenient method for inspection, quality control and dimension measurements of micro fabricated systems. After every step in a micro and nano fabrication process, it is recommended to perform a visual analysis of the sample to detect any potential defect or mistake, before continuing the processing. The optical microscope is a workhorse instrument that provides much information on the device quality and dimensions. There is no need to contact the sample and it works for both opaque and transparent specimen. It is regarded as a fundamental and very important method which is used very frequently in R&D; as well as in industrial production.

notes

summary

8m 49s