

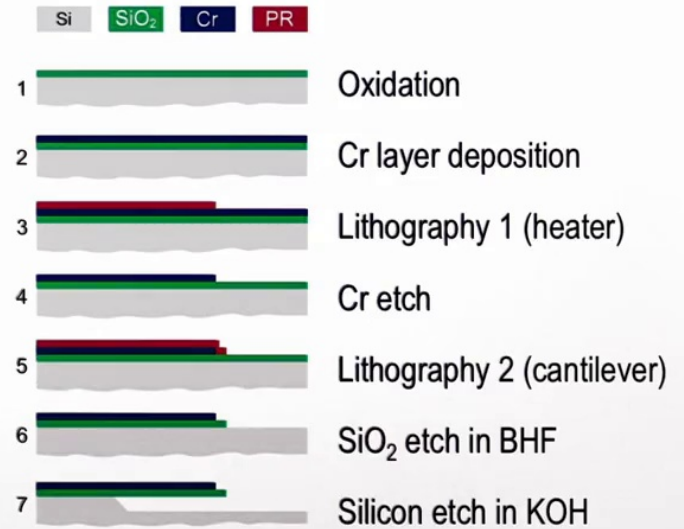
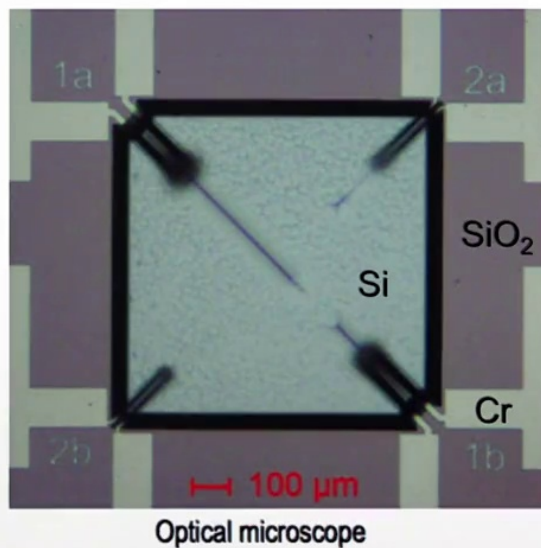


- Optical microscopy variations
 - Bright field (BF) and Dark field (DF)
 - Differential Interference Contrast (DIC)
 - Others
- Inspection under different modes
- Dimension measurement (XY & Z)
- Calibrated metrology

Micro and Nanofabrication (MEMS)

In the past lessons, we have seen the basics of micro Nano fabrication in a clean room. In the following lessons, I will show you how you can inspect and measure the fabricated structures with various methods. 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.

Bi-morph thermal actuator



How to check the process result?

Micro and Nanofabrication (MEMS)

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

Bi-morph thermal actuator

Si SiO₂ Cr PR

1 Oxidation

2 Cr layer deposition

3 Lithography 1 (heater)

4 Cr etch

5 Lithography 2 (cantilever)

6 SiO₂ etch in BHF

7 Silicon etch in KOH

Optical microscop

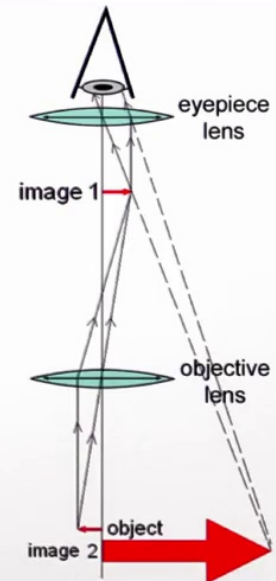
check the process result?

Micro and Nanofabrication (MEMS)

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.

Basics of an optical microscope

- 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



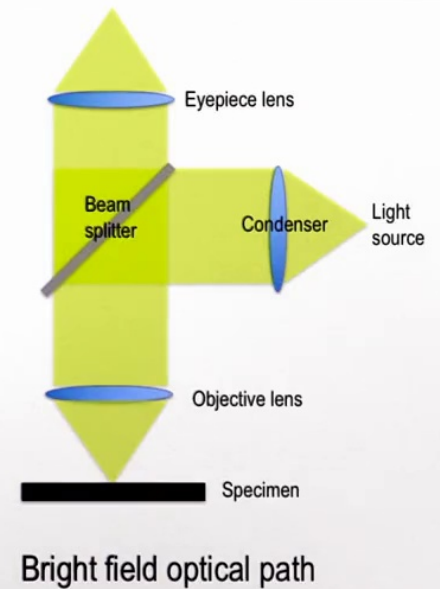
https://commons.wikimedia.org/wiki/File:Microscope_compound_diagram.png

Micro and Nanofabrication (MEMS)

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.

Optical microscope configuration

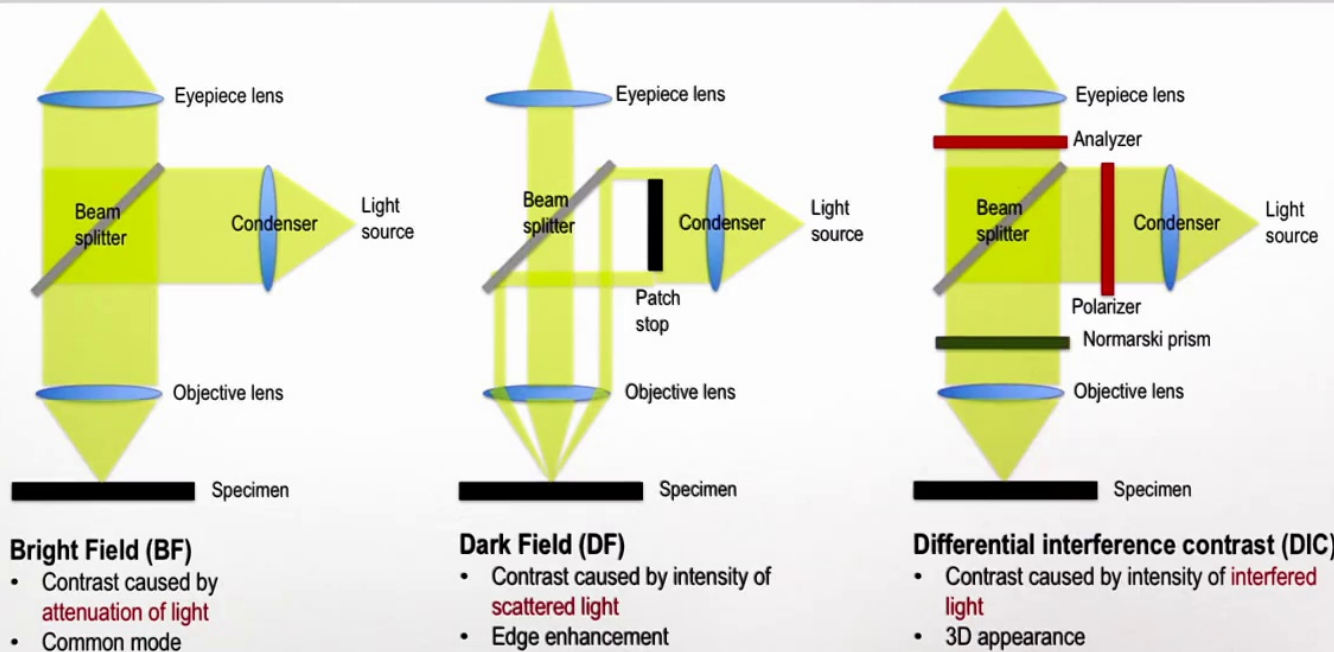
- 1) Light source
- 2) Condenser
- 3) DIC polarizer slider
- 4) Bright/dark field knob
- 5) XYZ specimen stage
- 6) Objective lenses
- 7) Analyzer slider
- 8) Eyepieces
- 9) CCD camera
- 10) Focus knob
- 11) Controller



Micro and Nanofabrication (MEMS)

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

Optical microscopy variations

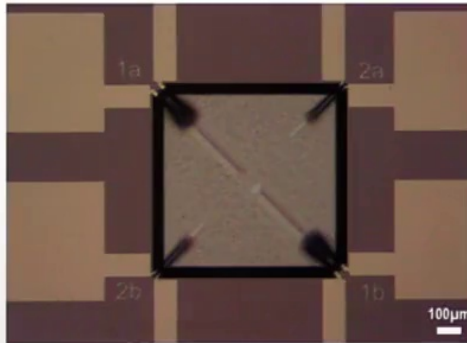


Micro and Nanofabrication (MEMS)

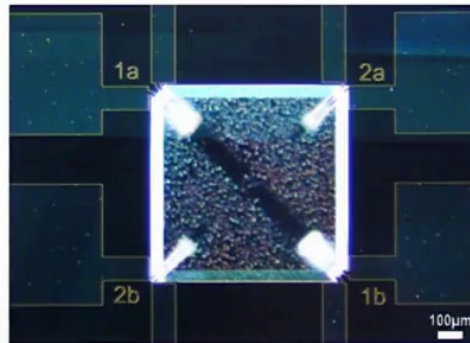
Here, you will see 3 possible and often used variations of optical inspections. Left, the already mentioned bright field imaging, in the center, the so called dark field imaging, and in the right hand side, it is the differential interference contrast mode. Let's first look at the difference between 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 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 that are shifted by about 200 nanometers. 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.

Optical microscopy variations

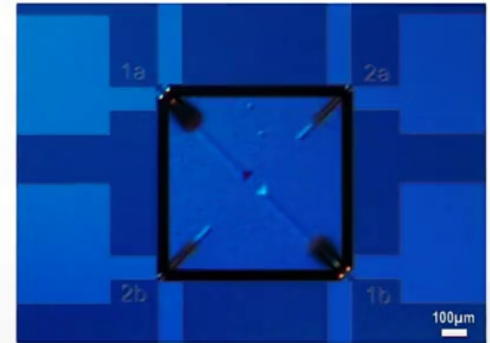
- Bi-morph actuator optical microscope inspection



Bright field



Dark field



DIC

Micro and Nanofabrication (MEMS)

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 spots on the metal contact pads 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.

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

Micro and Nanofabrication (MEMS)

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. 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. And finally, an often used mode is to work with fluorescent material that allows labelling selectively part of the sample to create additional contrast.

Dimension measurement: XY

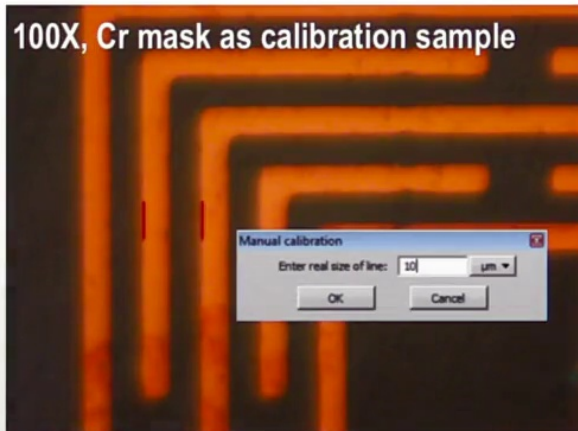
- CCD camera → standard sample with known dimension → how many μm per pixel → calibrate the scale bar in the CCD image



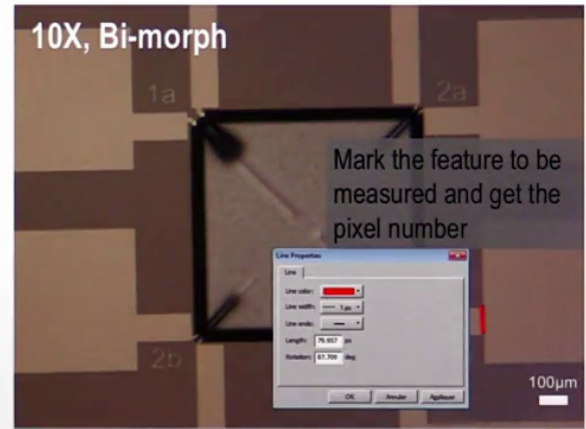
Besides quality control by optical inspection, it is often necessary to measure dimensions. This is called metrology and is meant to quantify the device length, width and thickness. Modern optical microscopes have a scale bar on the screen as a reference for the lateral dimensions. To ensure accurate 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.

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: $\sim 0.5\mu\text{m}$



Mark the feature with known dimension and calibrate
1 pixel = $0.1243\mu\text{m}$ in 100x image



Cr line width = 79.957 pixels, 1 pixel = $1.243\mu\text{m}$ in 10X image
→ $79.957 \times 1.243 = 99.4\mu\text{m}$ ($100\mu\text{m}$ in design)

Micro and Nanofabrication (MEMS)

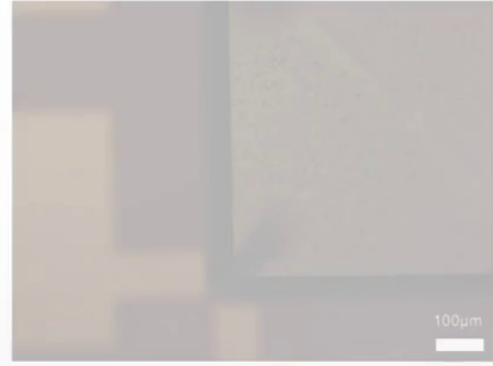
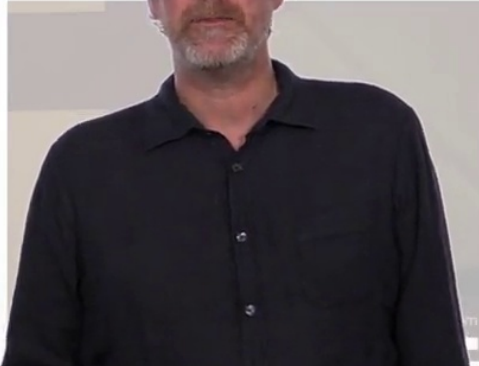
We now inspect the bi-morph device with a 10x objective to determine the lateral dimensions of the silicon dioxide beams and chrome wires by using the calibrated value of the pixel size. In this case, you measure the width of the chrome wires to be 99.4 micrometers, which is slightly less than the 100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

Dimension measurement: Z

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



Focus knob with scale



Focused on bottom of Si cavity

Es

Micro and Nanofabrication (MEMS)

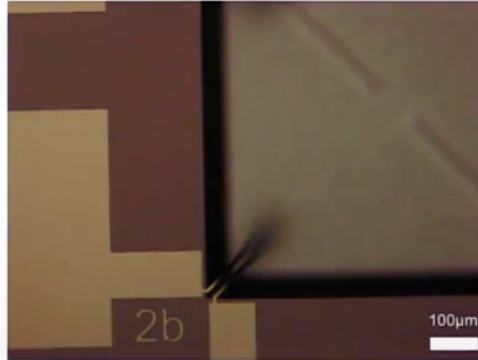
To some extent, the optical microscope also allows measuring vertical dimensions. This practice is simple to implement and allows for a first order of magnitude estimations. As we know, the depth of the focus in an optical microscope is shallow, particularly when using high numerical aperture objectives. 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,

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



Focus knob with scale



Focused on top surface



Focused on bottom of Si cavity

Estimated cavity depth is ~70 μm

Micro and Nanofabrication (MEMS)

and thereby going in or out of the optical focus. 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. 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.

Summary



- Easy, fast and cost effective method for inspection and dimension measurement
- Multiple modes for specific purpose
- Non-contact, non-invasive
- Works for both opaque and transparent specimens
- Workhorse for sample inspection

Micro and Nanofabrication (MEMS)

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 RD as well as in industrial production.
