Course material

Course:

## Micro and Nanofabrication (MEMS)

Video:

## 7.5 Inspection and metrology 5

Concepts (extracted from automatically generated subtitles):

**Charged electrons. Electron microscope works. Various electron signals. Very high resolution. Right side. Chapter of electron beam lithography. Image quality. So called characteristic x-ray. Resolution of a scanning electron tool. High voltage. Issue of electrons. Negative charges. Good conditions. Focused electron beam. Se detector.**

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

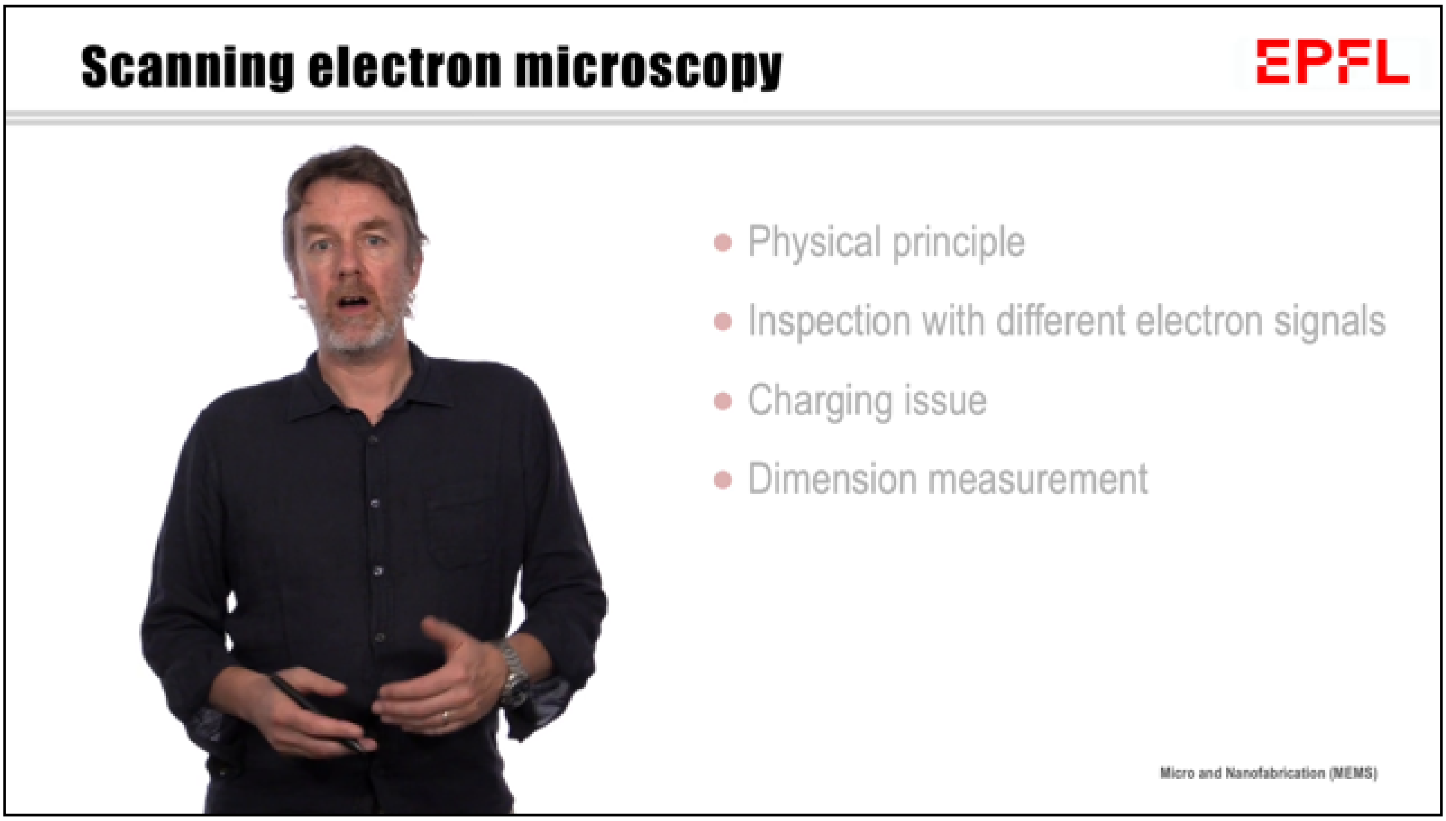
to video


...

notes

summary

0m 0s

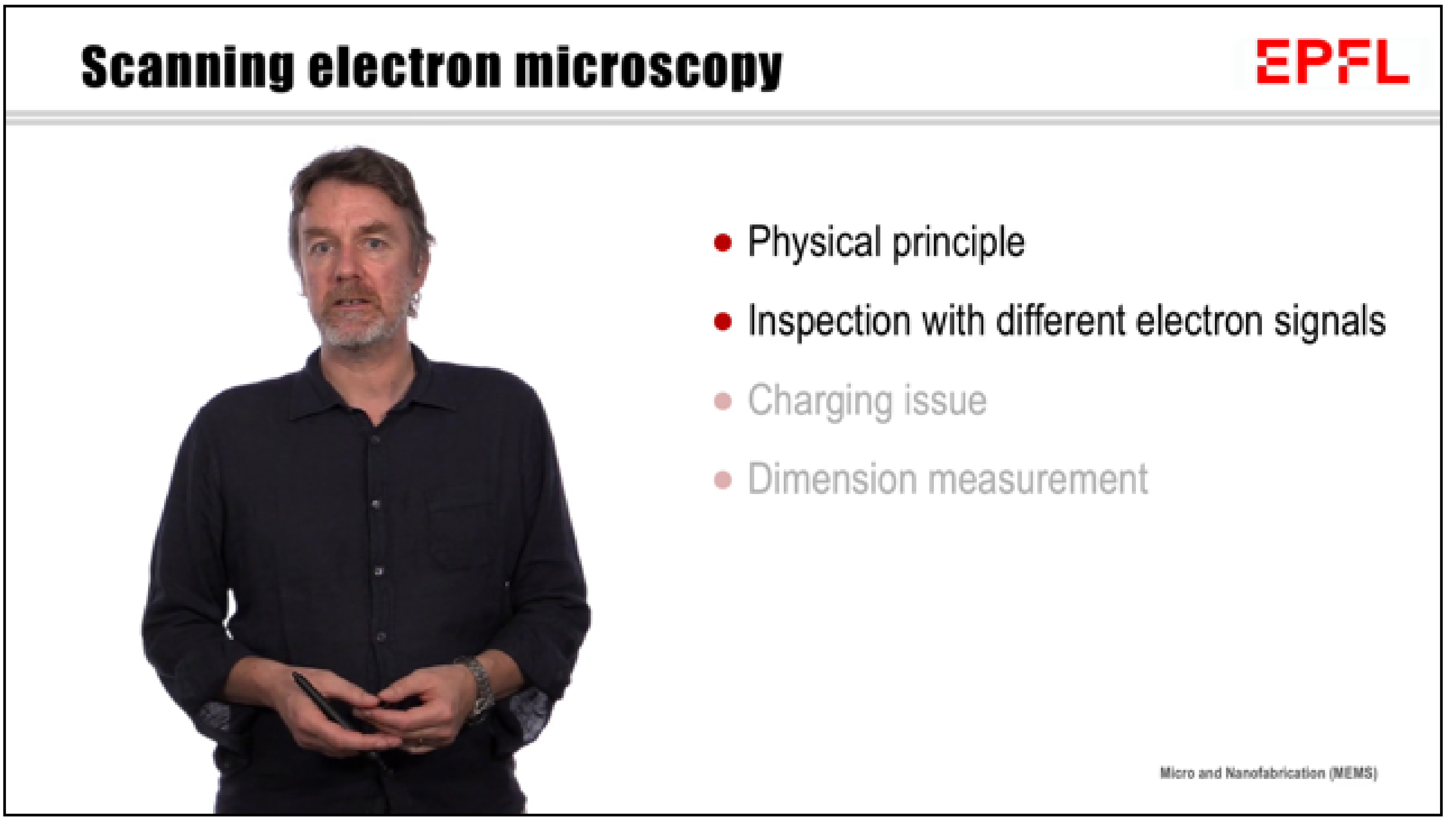



Now, I will show you how charged electrons in a scanning microscope can be used to perform

notes

summary

0m 1s




inspection, quality control, and metrology. First, I will remind you briefly how an electron microscope works and how electrons interact with matter.

notes

summary

0m 5s

## Scanning electron microscopy

EPFL

Why use electrons instead of photons?

- Overcome the optical diffraction limit:

$$\sim\lambda/2$$

- Electron wavelength, De Broglie equation

| kV | 1 | 10 | 100 |
|---|---|---|---|
| nm | 0.038 | 0.012 | 0.0038 |

$$\lambda_e = \frac{h}{p}$$

λ: wavelength
h: Planck's constant
p: momentum


Using electron results in higher resolution compared to visible light

Micro and Nanofabrication (MEMS)

Then, I will list the various electron signals that I used to examine the sample. I will briefly mention the issue of electrons charging, and show how the SEM can be used to perform dimensional metrology at a nanometer scale. As a quick reminder to what we have already seen earlier in this mooc, in the chapter of electron beam lithography. We use a focused electron beam primarily to overcome the diffraction limit of optical systems that are typically in the order of lambda over 2, or around 300 nm for visible light. Remember that electrons can be associated to a wavelength, depending on the electron energy, the associated wavelength can be as small as a few pm.

notes

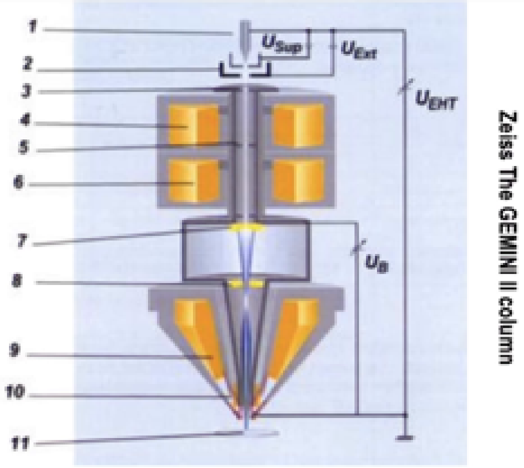
summary

0m 25s

# Schematics of SEM system

EPFL

- System similar to EBL:
  - E-gun: 0.02 – 30 kV
  - Electromagnetic lenses
  - Vacuum system
- Electrons ➔ detectors ➔ image
- Morphology & compositional analysis
- Resolution: ~1nm
- Accuracy: +/-3%
- Conductive samples required for high quality imaging




1. Gun
2. Extractor
3. Anode aperture
4. Upper condenser
5. Single hole aperture
6. Lower condenser
7. BSE detector
8. In-lens SE detector
9. Objective lens
10. Scanning coils
11. Specimen

Micro and Nanofabrication (MEMS)

Please notice however that the resolution of a scanning electron tool is not limited by the electron wavelength, but by the focusing ability of the system and the electrons scattering, as we have already seen in the lithography lesson. As a thumb rule, remember that a SEM can resolve images of conducting samples down to a few nm, as we can clearly see on this electron microscope here, showing the bi-morph cantilever in very high resolution. In a scanning electron microscope, electrons are emitted from an electron gun here, and accelerated under high voltage to obtain momentum and travel through the chamber. Several electromagnetic lenses shape and steer the electron beam. In order to avoid unwanted scattering between electrons and atmospheric molecules, the entire system is working in a vacuum chamber. The electron beam is focused on the specimen surface down here and interacts with its atoms. Detectors and filters, here, number 7 and 8 collect the back scattered electrons. The brightness of each pixel is determined according to the number of collected electrons. The electron beam is deflected to scan the sample surface pixel by pixel and line by line to record an image.

notes

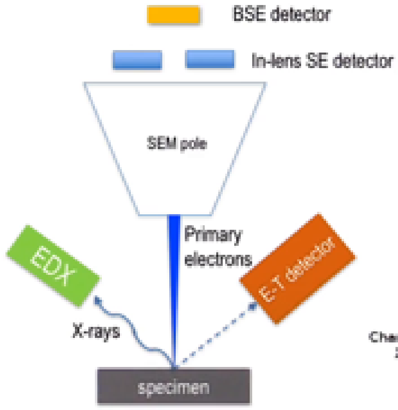
summary

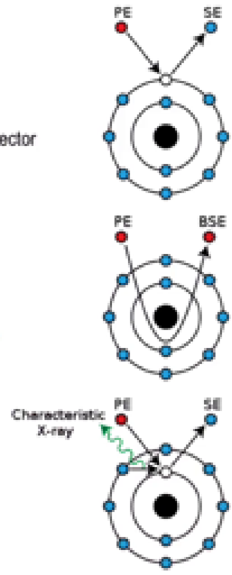
1m 13s

# Inspection with different electron signal

EPFL

- Secondary electron (SE) imaging
  - Surface structure
- Backscattered electron (BSE) imaging
  - Atomic number ↑ , BSE ↑ → material contrast
- High efficiency SE (HE-SE2) imaging
  - Topography and edge enhancement
- Energy-dispersive X-ray (EDX)
  - X-ray detection
  - Spectroscopic compositional analysis




https://commons.wikimedia.org/wiki/File:Electron_emission_mechanisms.svg

Micro and Nanofabrication (MEMS)

notes

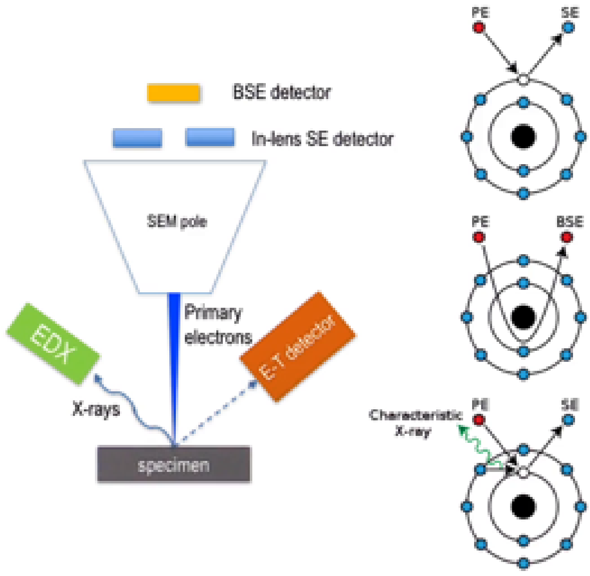
summary

2m 37s

# Inspection with different electron signal

EPFL

- Secondary electron (SE) imaging
  - Surface structure
- Backscattered electron (BSE) imaging
  - Atomic number ↑ , BSE ↑ → material contrast
- High efficiency SE (HE-SE2) imaging
  - Topography and edge enhancement
- Energy-dispersive X-ray (EDX)
  - X-ray detection
  - Spectroscopic compositional analysis




https://commons.wikimedia.org/wiki/File:Electron_emission_mechanisms.svg

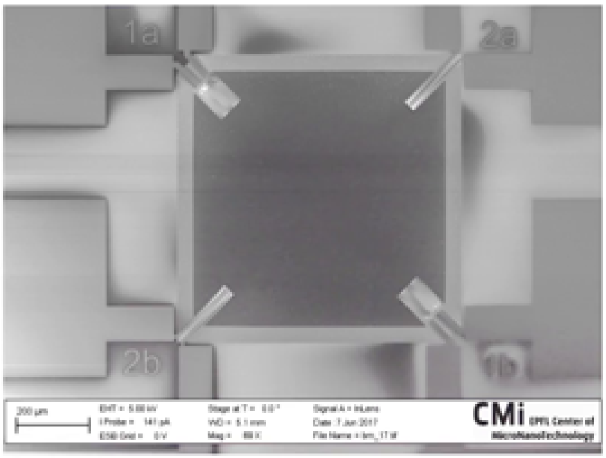
Micro and Nanofabrication (MEMS)

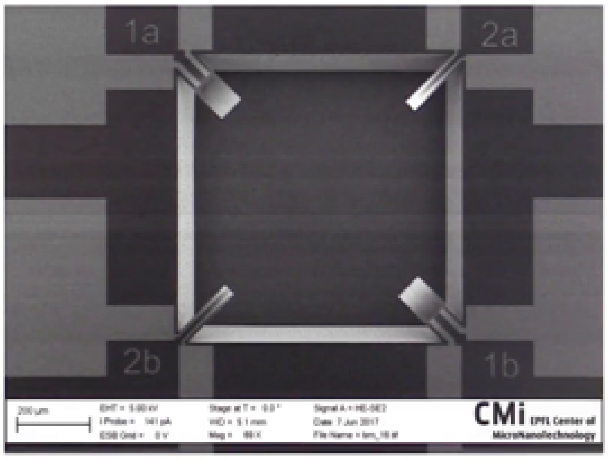
state to fill the empty state whereby a photon is released. This is the so called characteristic X-ray. By detecting the energy dispersive x ray, we can therefore, perform spectroscopic compositional

notes

summary

# Inspection with different electron signal




InLens-SE
SEM image of Bi-morph

HE-SE2
SEM image of Bi-morph

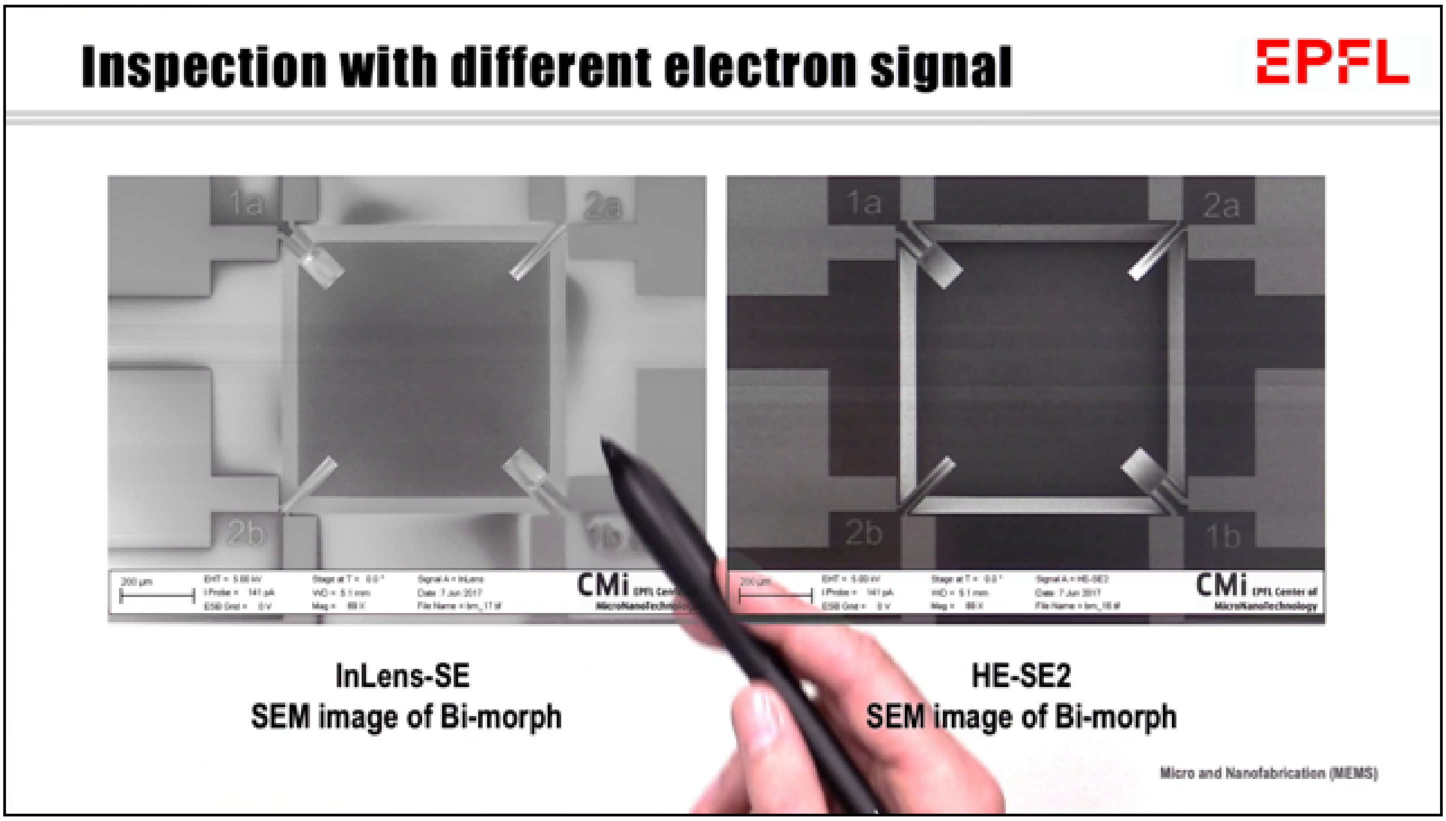
Micro and Nanofabrication (MEMS)

analysis of the sample in other words, we can determine what material we are looking at, and this at a very high spatial resolution.

notes

summary

5m 25s




Here, we can see 2 SEM image taken with different detectors. Both images are taken under same conditions such as electron energy and working distance. On the left side, we see the image taken by in-lens secondary electron detector. It is very bright because it collects most of SE.

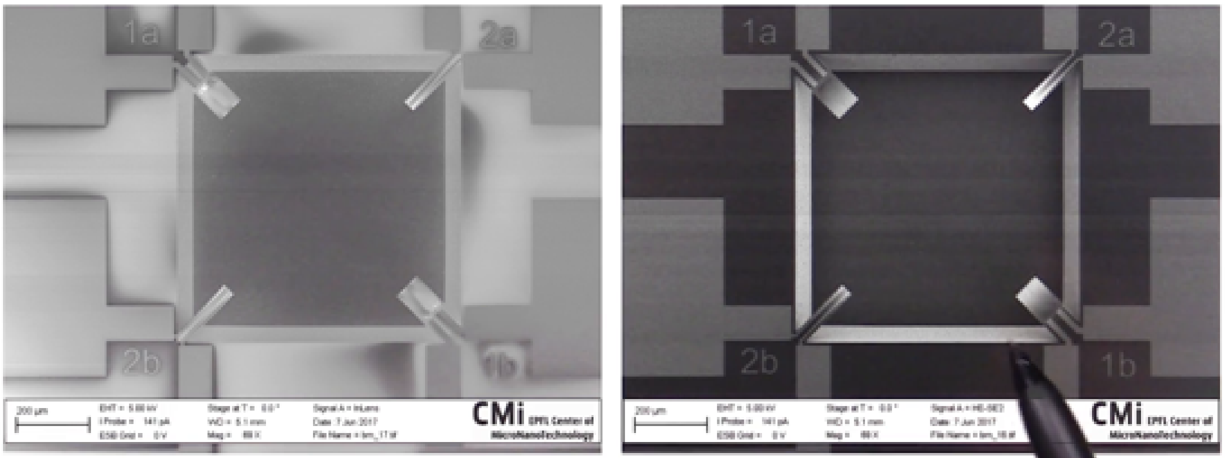
notes

summary

5m 34s

# Inspection with different electron signal

EPFL




InLens-SE
SEM image of Bi-morph

HE-SE2
SEM image of Bi-morph

On the down side, the charging effect of the sio2 layer on the bi-morph is also obvious.

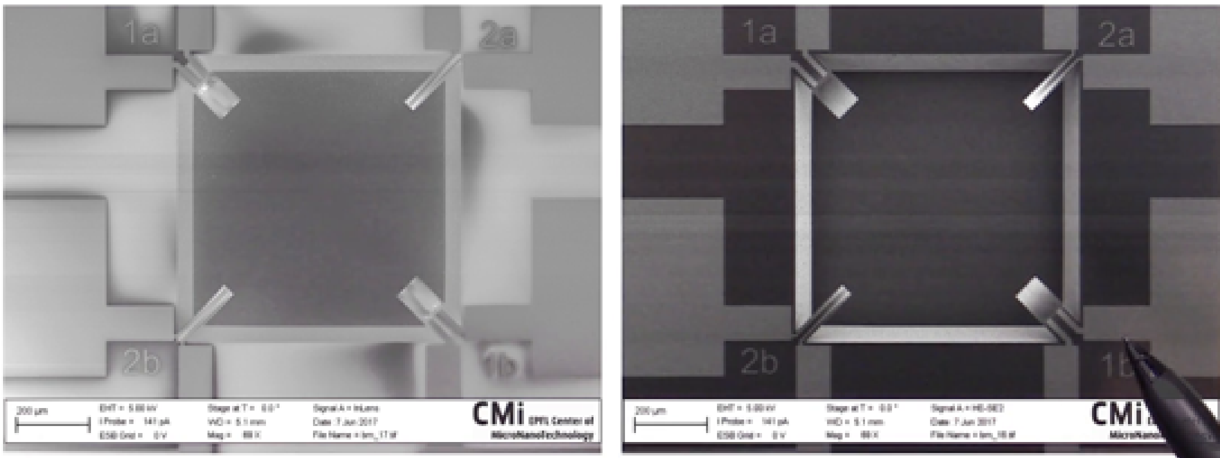
notes

summary

6m 0s

# Inspection with different electron signal

EPFL




InLens-SE
SEM image of Bi-morph

HE-SE2
SEM image of Bi-morph

Micro and Nanofabrication (MEMS)

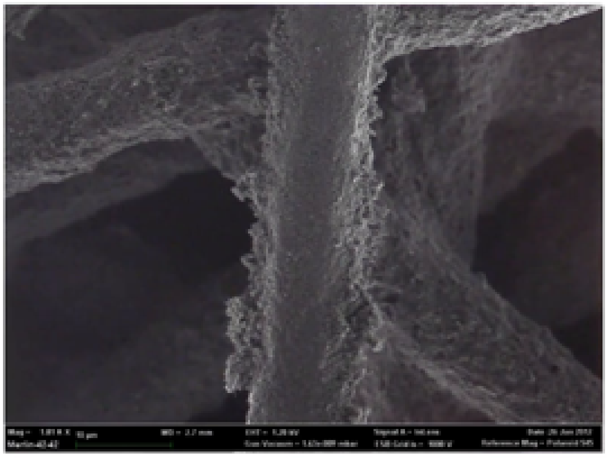
On the other hand HE-SE2 detector shown here on the right hand side provides better contrast and clearer edge definition in the case of the bi-morph device. For our purpose, the choice of this detector is thus preferred.

notes

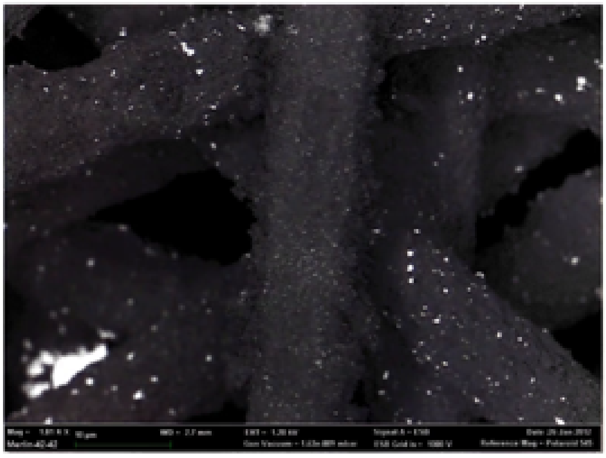
summary

6m 5s

# Inspection with different electron signal



InLens-SE
SEM image of carbon nano tube bundle



BSE
SEM image of carbon nano tube bundle

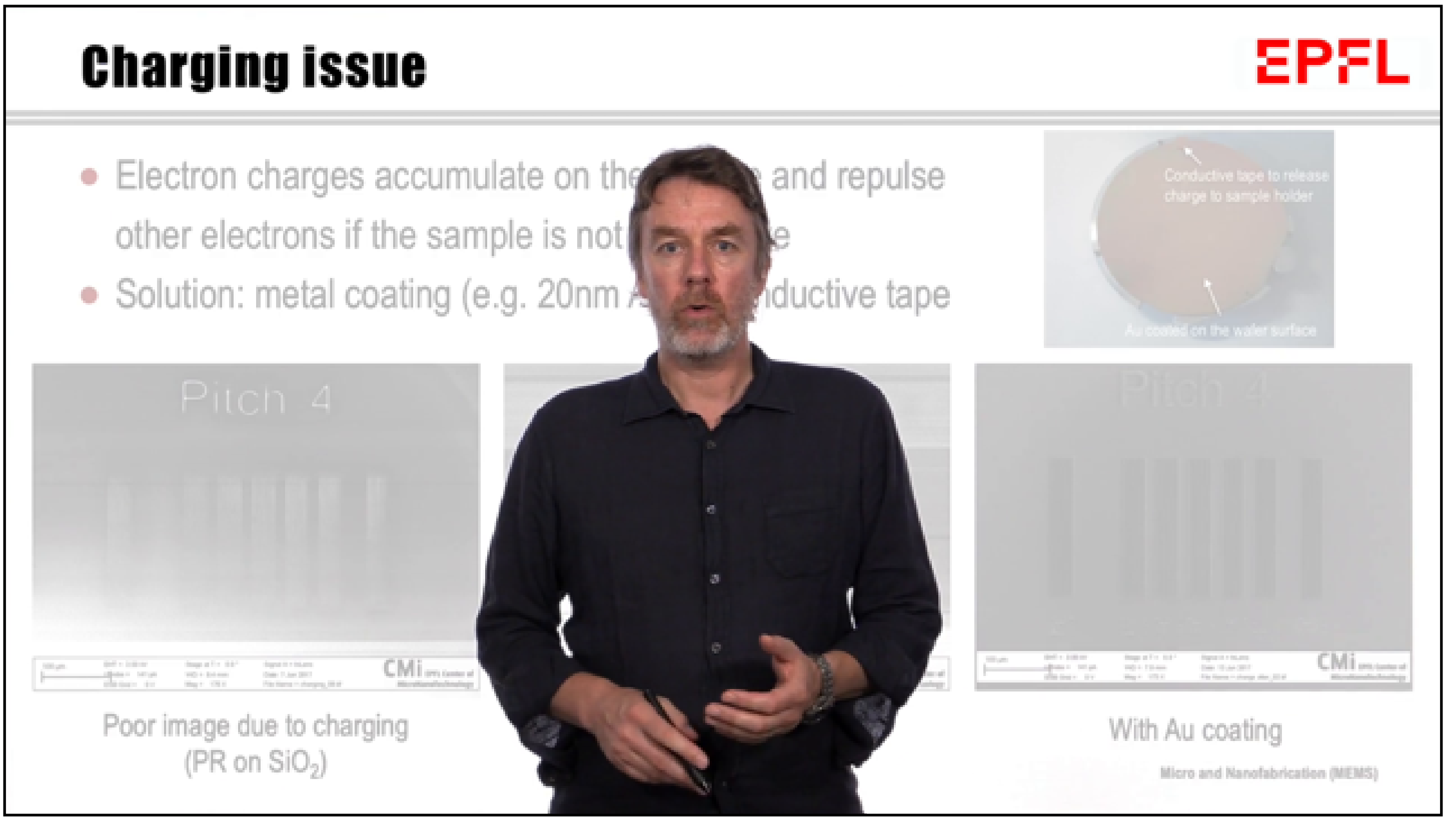
Micro and Nanofabrication (MEMS)

In order to better demonstrate the material contrast of BSE image, here, we use a carbon Nano tube sample as an example. Such a sample is used to adjust and calibrate the SEM tool. Here are bundles of carbon Nano tubes. The scale bar is 10um.

notes

summary

6m 18s




The InLens SE image on the left side, here we cannot distinguish the metal and cobalt catalytic nanoparticles that are used during the synthesis of carbon nano tubes. While in the BSE image on the right side, each catalytic particle are highlighted and can be easily detected.

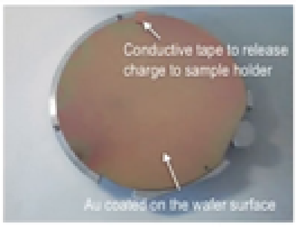
notes

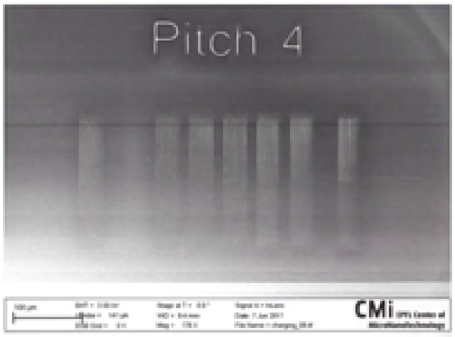
summary

6m 41s

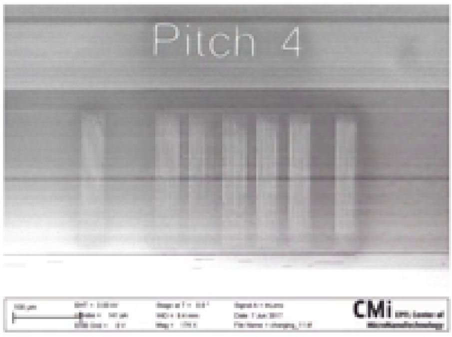
## Charging issue

- Electron charges accumulate on the sample and repulse other electrons if the sample is not conductive
- Solution: metal coating (e.g. 20nm Au) + conductive tape

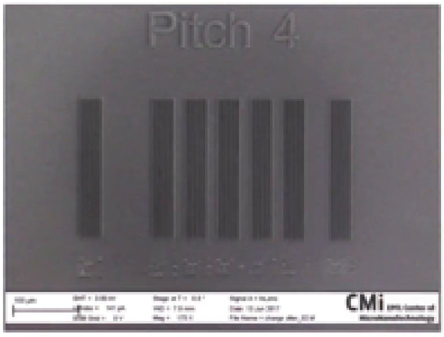



Poor image due to charging (PR on $SiO_2$)




Even worse over time (PR on $SiO_2$)




With Au coating

Micro and Nanofabrication (MEMS)

If there is one downside of charged particle imaging to mention, it is the problem of charging. If the electrons used to image the sample cannot be removed to ground, then, they will accumulate in the sample, which will deviate the trajectory of the next electrons.

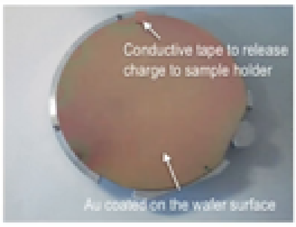
notes

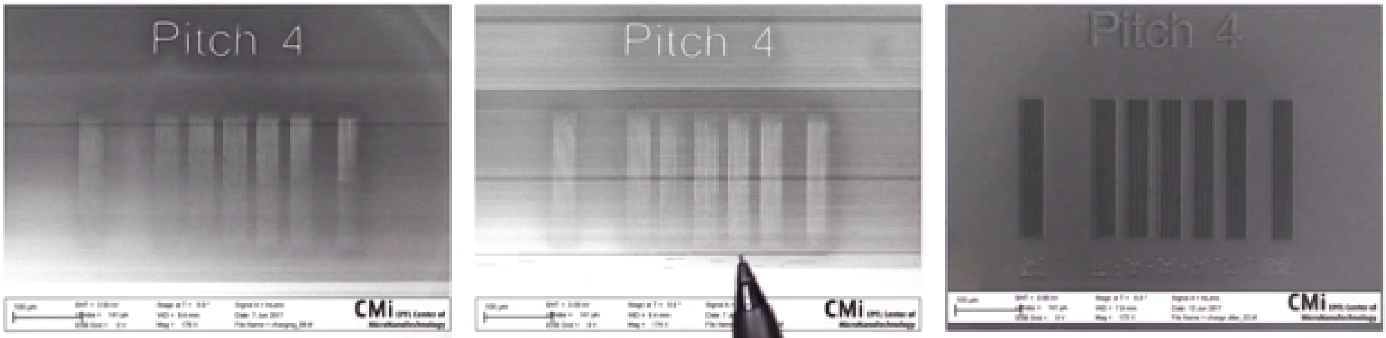
summary

7m 0s

# Charging issue

- Electron charges accumulate on the sample and repulse other electrons if the sample is not conductive
- Solution: metal coating (e.g. 20nm Au) + conductive tape




Poor image due to charging (PR on $SiO_2$)

Even worse over time (PR on $SiO_2$)

With Au coating

Micro and Nanofabrication (MEMS)

A direct consequence is a blurred image. The 3 SEM images here show photoresist which is insulating on sio2 which is also insulating.

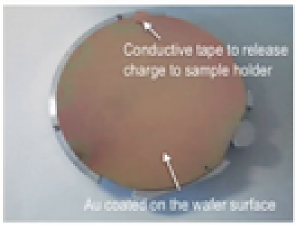
notes

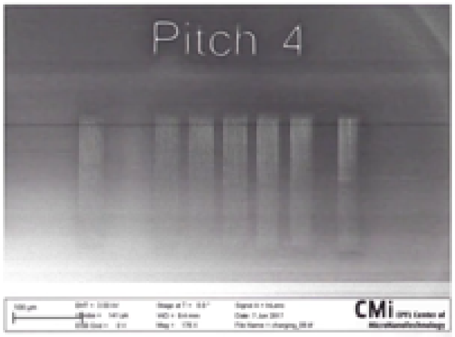
summary

7m 17s

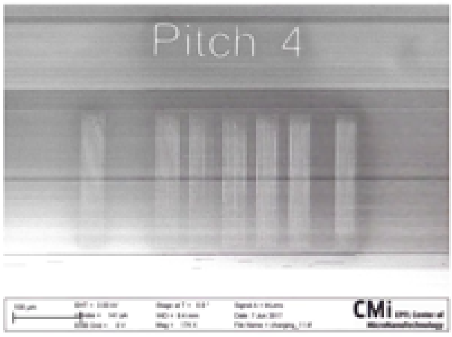
# Charging issue

- Electron charges accumulate on the sample and repulse other electrons if the sample is not conductive
- Solution: metal coating (e.g. 20nm Au) + conductive tape

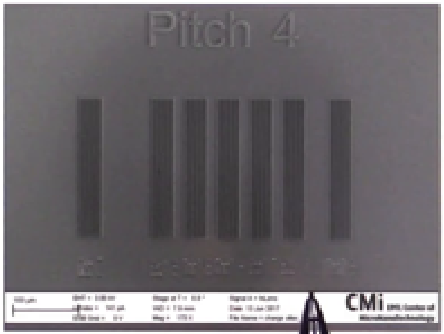



Poor image due to charging ($PR$ on $SiO_2$)




Even worse over time ($PR$ on $SiO_2$)



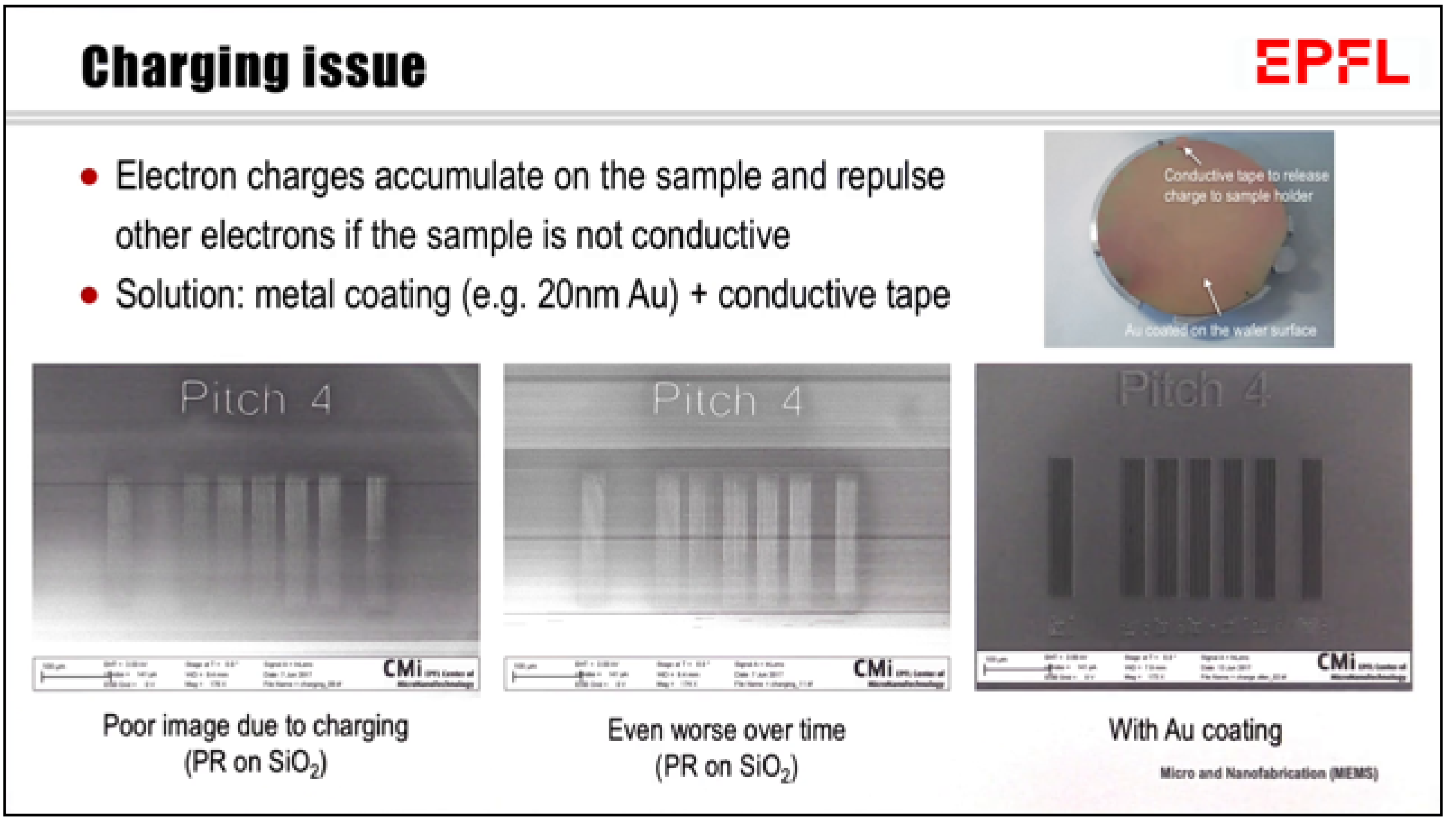

With Au coatin

One can see the charging effect in the left image that increases over time, in the middle. One remedy is to coat the sample with a very thin conducting layer, either gold or chrome layer. The result can be seen here on the right.

notes

summary

7m 31s

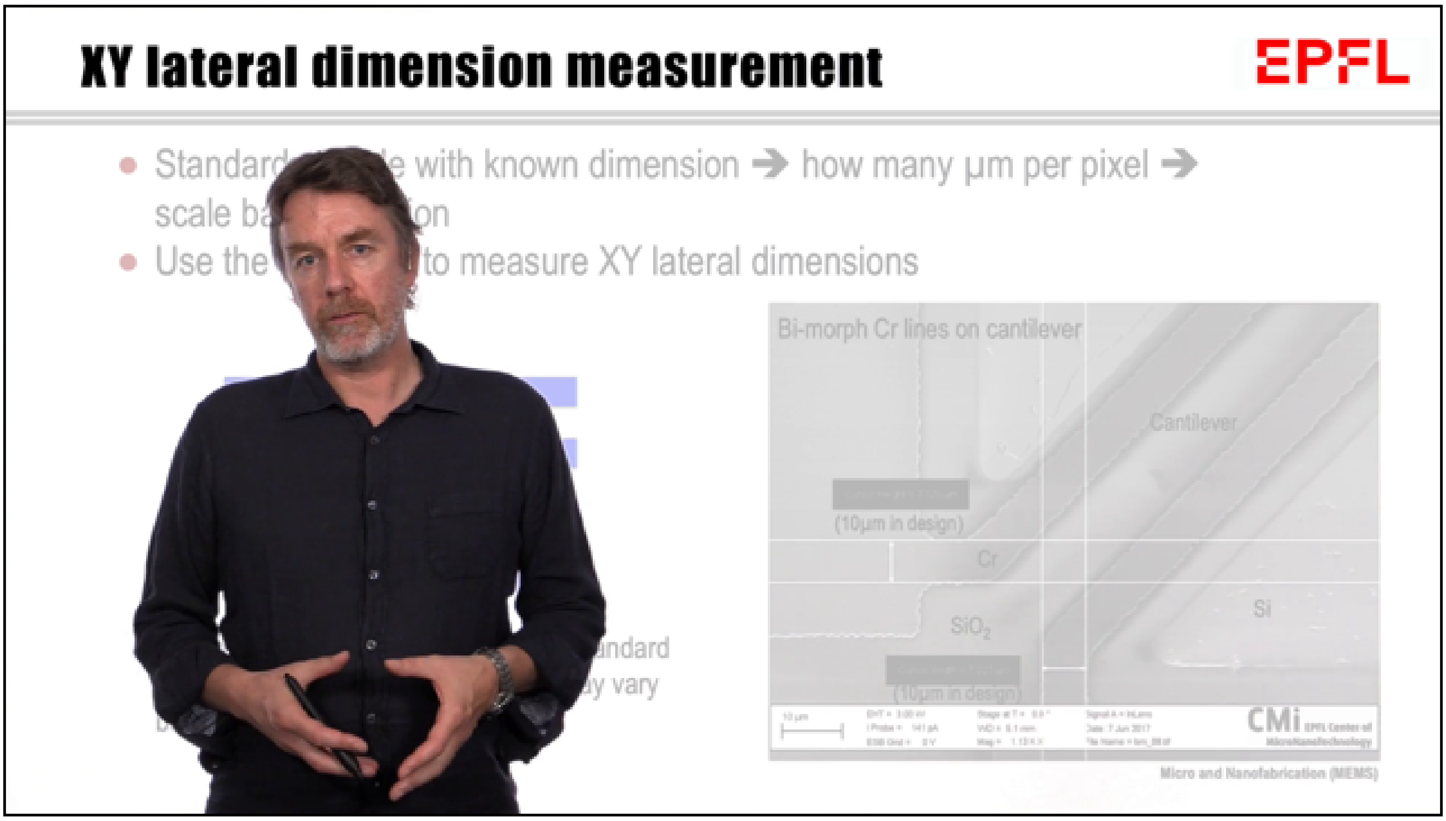



Notice that, of course, we are now imaging the gold layer on top of the sample. But for many investigations in MEMS, this is not an issue, and allow seeing the surface quality of the device. To conduct the electron charges to ground, it is important to ensure a proper conduction path.

notes

summary

7m 44s

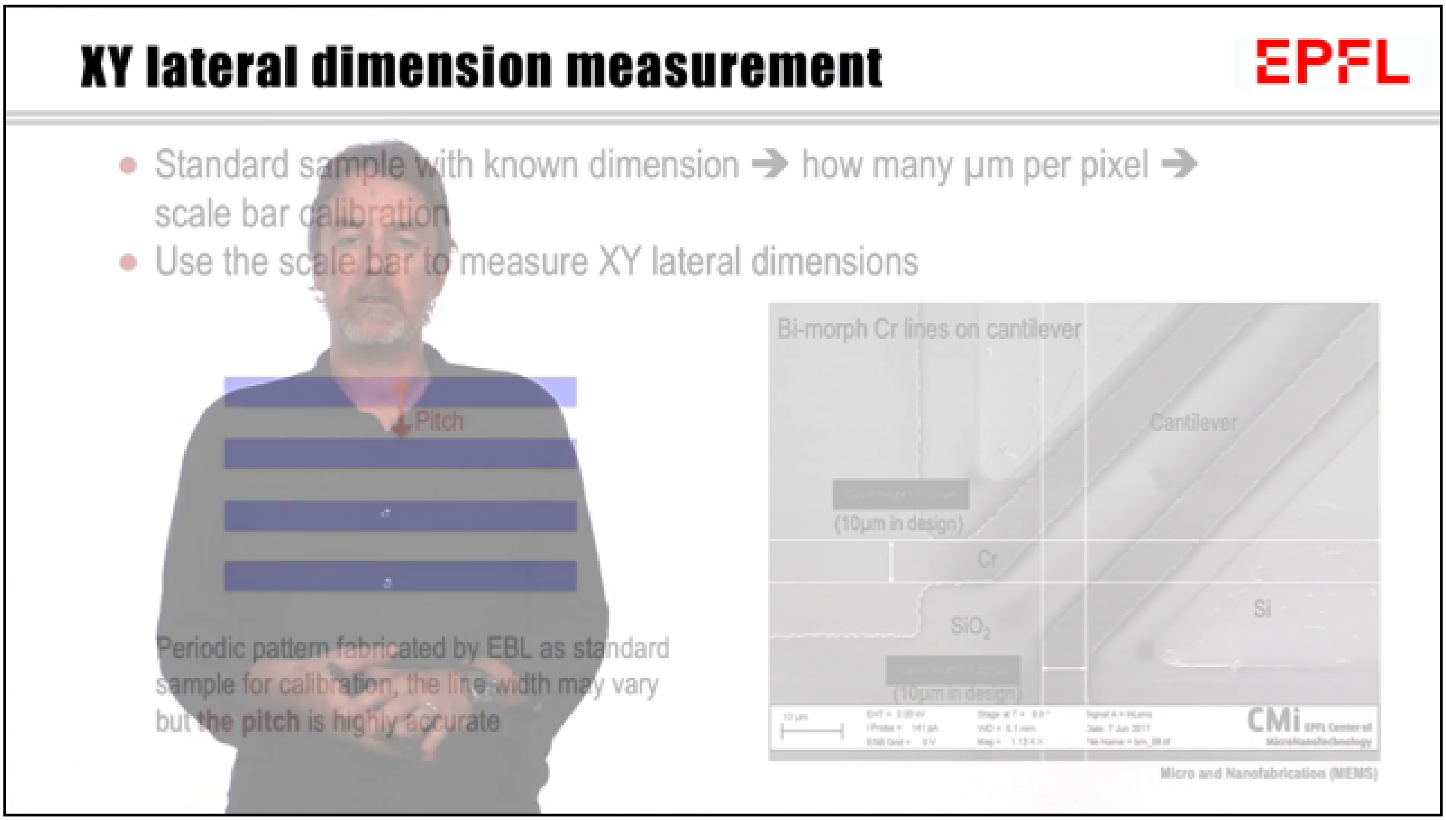



For instance by means of a conducting tape as shown here.

notes

summary

8m 1s




In order to perform a calibrated dimension measurement in an SEM, one needs to first ensure that the instrument is calibrated. This is done typically using a calibration with known dimensions. This will translate then, the conversion ratio between each pixel in the digital data acquisition and the sample dimensions in nm or um.

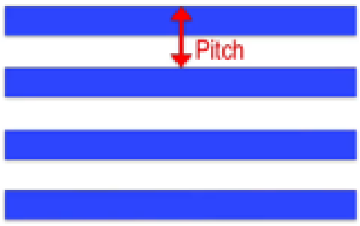
notes

summary

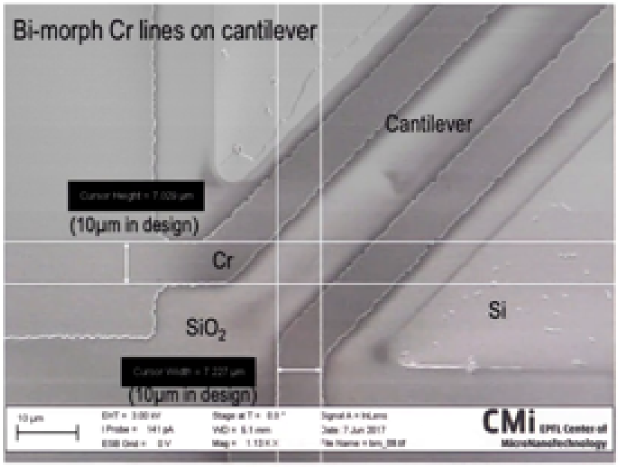
8m 9s

# XY lateral dimension measurement

- Standard sample with known dimension ➔ how many µm per pixel ➔ scale bar calibration
- Use the scale bar to measure XY lateral dimensions




Periodic pattern fabricated by EBL as standard sample for calibration, the line width may vary but **the pitch** is highly accurate




Micro and Nanofabrication (MEMS)

This allows defining a scale bar which then can be used to measure the size of unknown samples with high accuracy. The calibration sample are typically made by electrons beam lithography. It is however also well known that, due to over exposure or under exposure, or over or under development, the exact pattern whidth is not perfectly predictable. That is why instead of using the pattern line width as calibration reference, one favors a periodic pattern where the pitch is highly accurate even if the individual pattern widths are not very precisely defined. The SEM image on the right shows the surface of the bi-morph device where the SEM is now used to measure the width of the chrome pattern.

notes

summary

8m 31s

The white lines are positioned on the SEM tool to accurately measure the chrome pattern. Here we confirm now that the value obtained before, that the chrome pattern is about 7.2 um wide, which is much less than the designed 10 um, and which is due to some lithography effects. Here you see how to inspect a MEM sample in a scanning electron microscope, we mount the sample holder with the silicon MEM sample on the transfer stage. A load lock maintains the high vacuum inside the SEM chamber during the sample transfer. After the sample transfer, we setup the right configuration of the system. The first step is to position the sample to a proper working distance with respect to the electron column and detector. Then, we use the controller to tune the electron beam and the image. Here on the screen, you see the electron beam image made on a silicon sample with deep reactive ion etched grooves. You see how one can navigate around and zoom in and out. Here, we have seen how electrons, as charged particles in a SEM, can be used to inspect a MEM device surface. It allows for very high resolution in imaging, and allows for dimensional metrology. Remember that some materials might be damaged by the electron charges or heat generated.

notes

summary

9m 25s