Course material

Course:

Micro and Nanofabrication (MEMS)

Video:

7.3 Inspection and metrology 3

Concepts (extracted from automatically generated subtitles):

White light interferometer. Bi-morph example. Laser beam surface profiler. Principle of the white light interferometer. Thickness of the chrome line. Additional examples of optical inspection. Bending of cantilever devices. Light path difference. Film stresses. Measured line width of the chrome pattern. White light interferometer system. Right side. Detail of interference part. Flat sample surface. Light path of the reference.

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

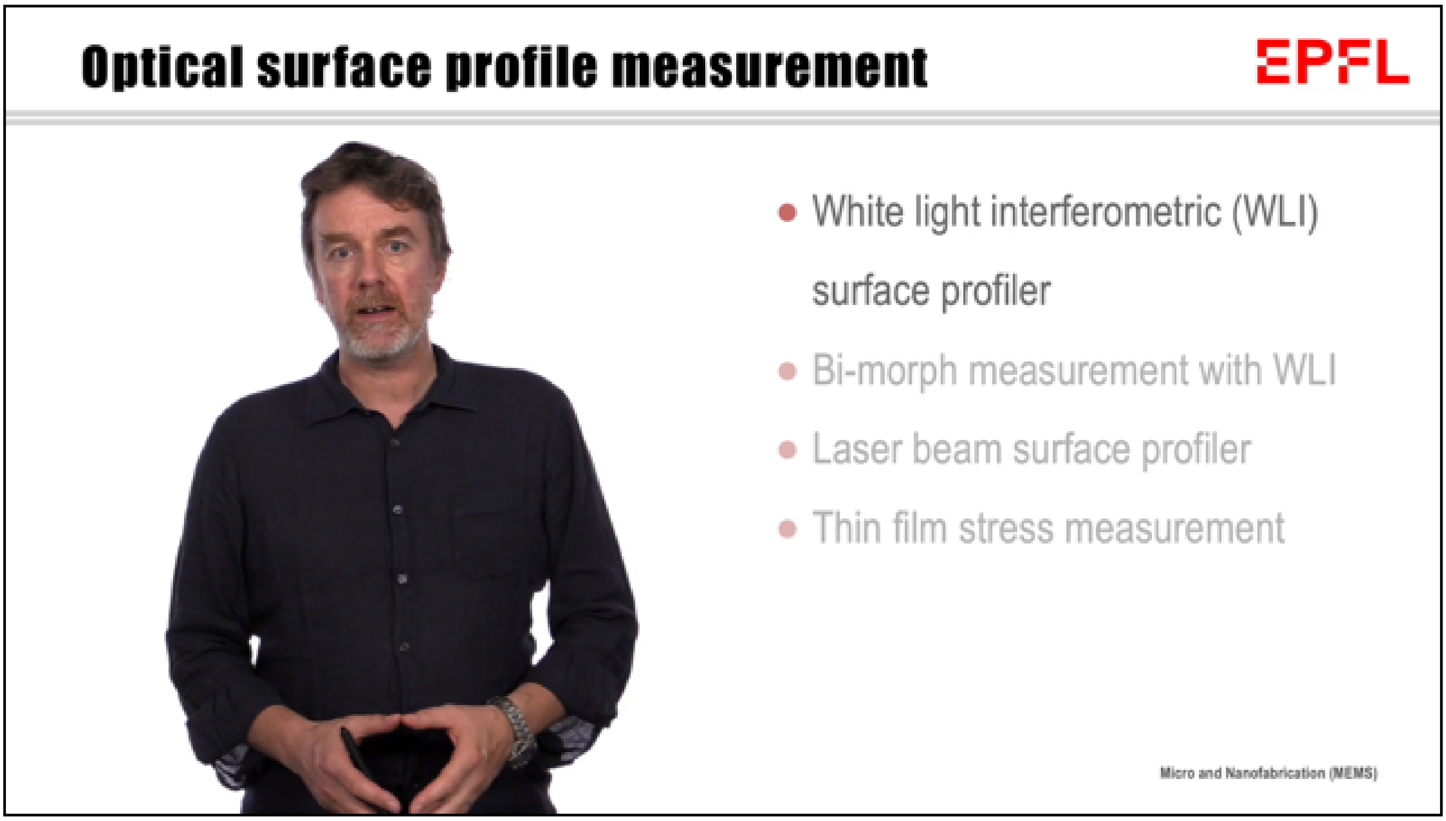
to video

...

notes

summary

0m 0s



Two additional examples of optical inspection and metrology

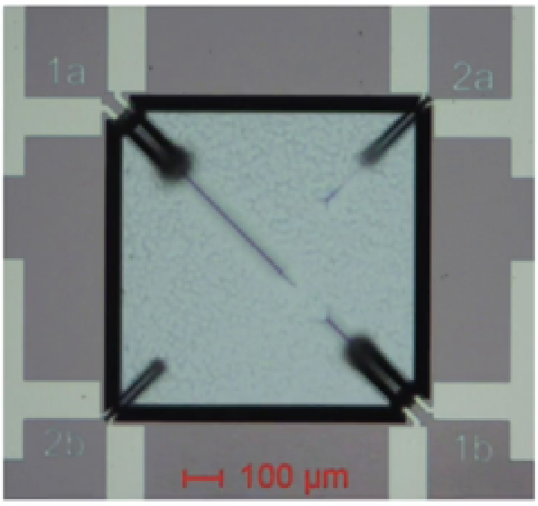
notes

summary

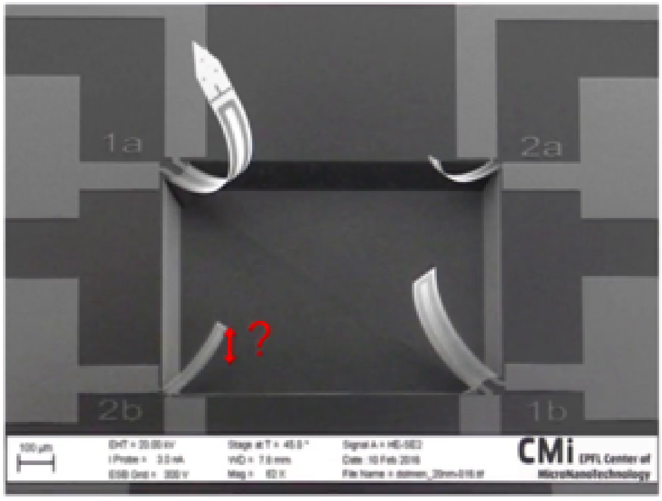
0m 1s

Bi-morph surface profile measurement

EPFL



Optical microscope



How high is the cantilever bending upwards?

Micro and Nanofabrication (MEMS)

are a white light interferometer and the laser beam surface profiler. They are particularly useful to determine the 3D aspect of MEMS surfaces as well as film stresses. We will use again our bi-morph example and will use both methods to determine the bending of substrate and the bending of cantilever devices.

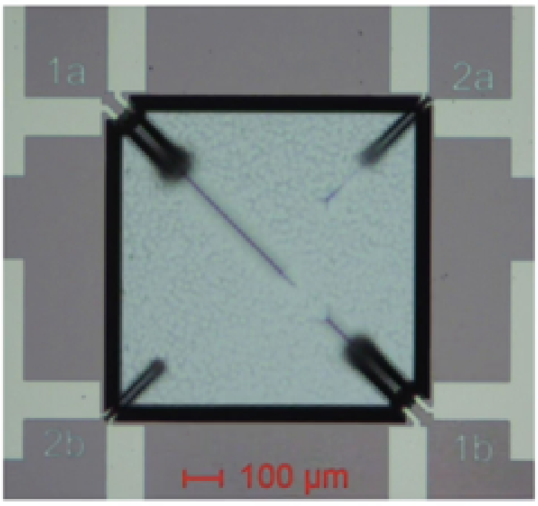
notes

summary

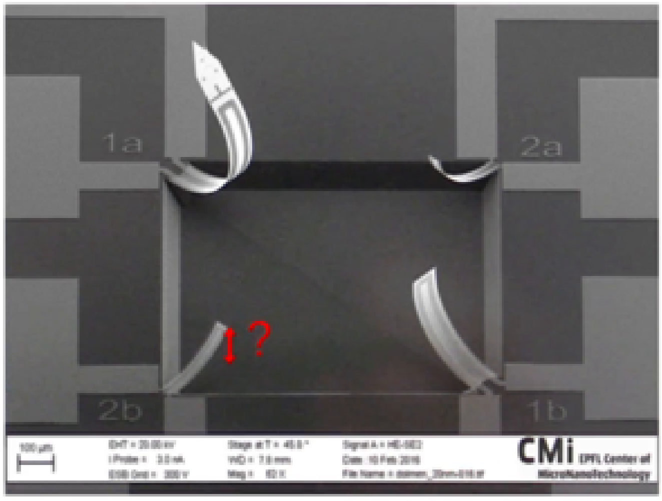
0m 9s

Bi-morph surface profile measurement

EPFL



Optical microscope



How high is the cantilever bending upwards?

Nanofabrication (MEMS)

Here you see again our well known bi-morph actuated devices, let us now quantify precisely how much actually a cantilever is bent upwards.

notes

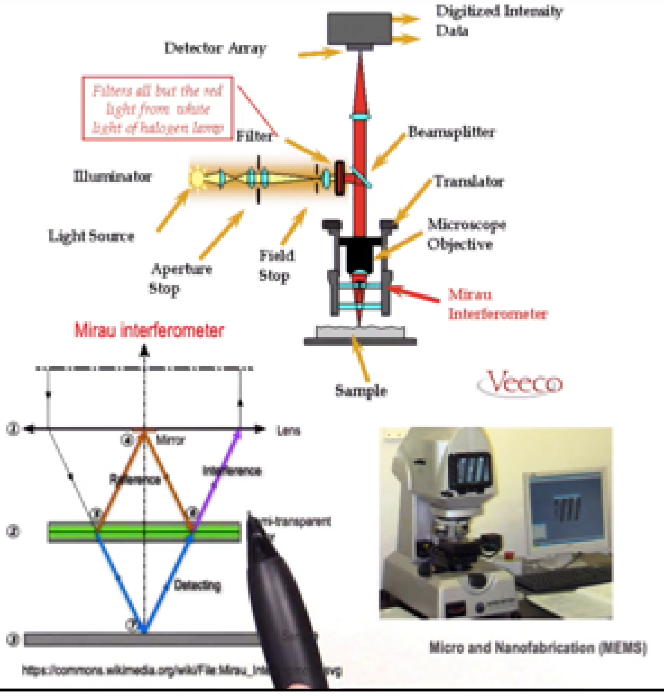
summary

0m 30s

White light interferometric surface profiler

EPFL

- Mirau interferometer embedded objective lenses
- Surface topography ➔ optical path change ➔ interference change
- Scan in vertical direction to obtain 3D surface profile
- Field of view: up to 2.5mm x 1.9mm
- Vertical resolution: < 1nm
- Vertical scan range: 1mm
- Non-contact, non-destructive



Micro and Nanofabrication (MEMS)

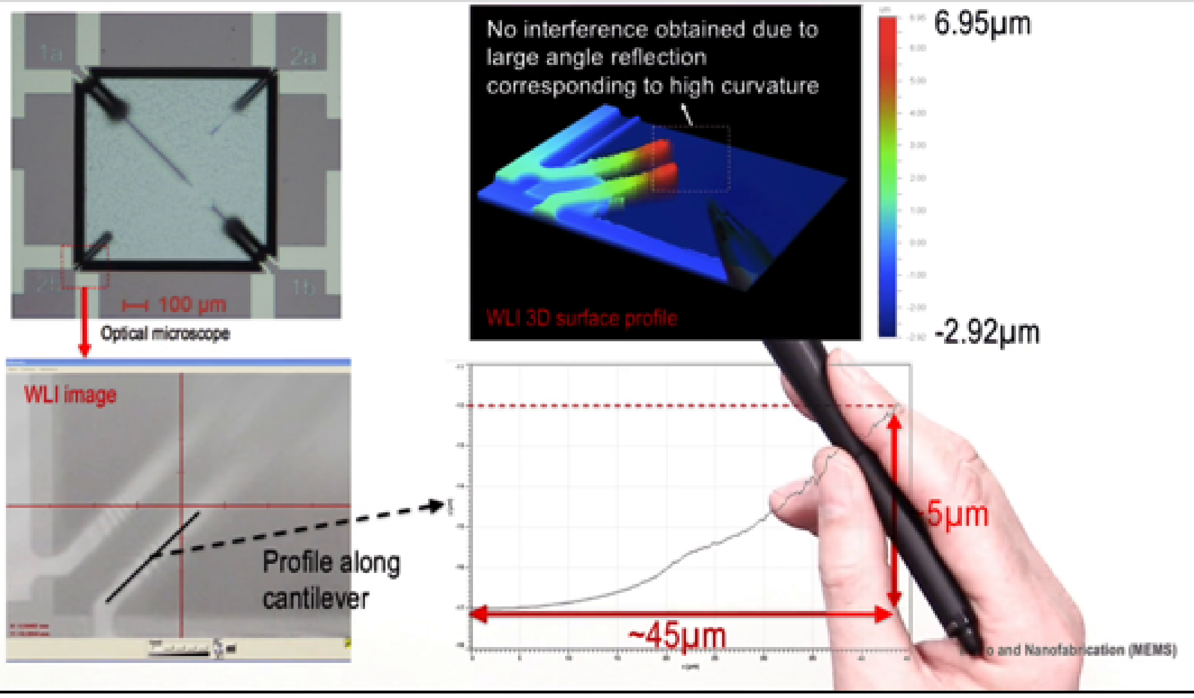
Remember we could estimate this value by the focus control of an optical microscope like shown here. But, let's have a much more precise approach now. The principle of the white light interferometer is shown here on the right side with a general overview of the setup, a zoom into the detail of interference part, and the photography of the system in our clean room. The white light interferometer system works as follows.

notes

summary

0m 41s

Bi-morph measurement with WLI

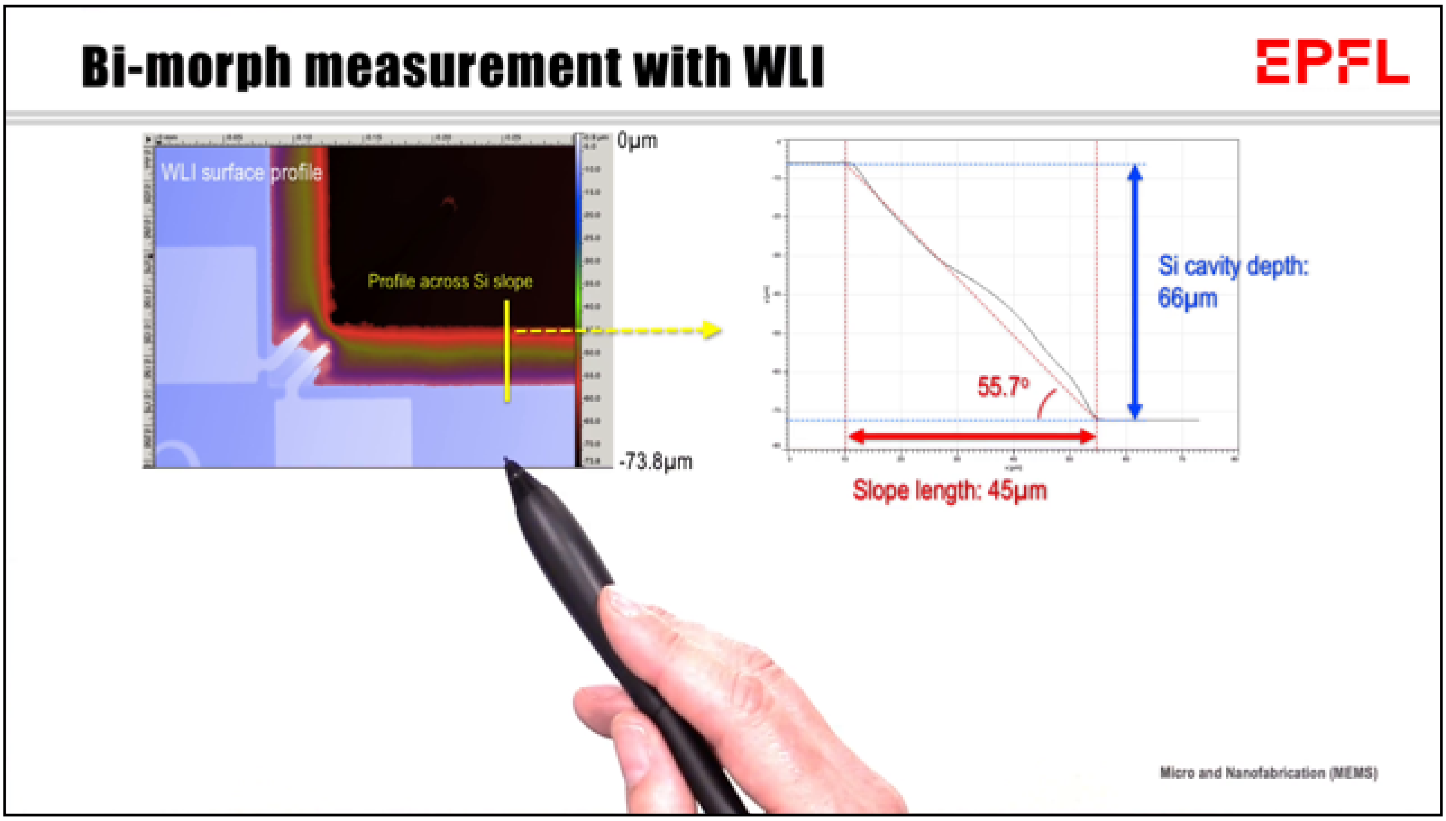


The light coming into the mirau interferometer, is focused by the lens, and further split into 2 beams using a semi-transparent mirror. The reference beam is shown in orange, whilst the object beam is shown in blue. On a flat sample surface, the light path of the reference and the object beams are totally identical, which means the light path difference is 0 and hence constructive interference occurs. On the other hand, if the sample surface is not flat, the light path difference between the reference and the object beam is no longer 0. Instead, interference intensity as shown in purple here, will change accordingly and is detected by a light intensity detector. This way, the topographic information of the sample surfaces is obtained, typical values for field of view resolution and "z" scan range are listed here. On the left side, you see the bi-morph cantilever device imaged with the normal optical microscope. Inspecting the bi-morph under the white light interference gives us additional information. White light interference image delivers interference fringes that allow quantifying very precisely the out of plane bending of the cantilever. We can see these fringes here on the bent part of the cantilever. By creating a profile along the cantilever, you obtain the bending curve with quantitative values as shown here. Please notice that for high bending angles above 45 degrees, the system cannot detect any more interference fringes. This can be seen in the curve, by the noisy curve and bumps. The white light interference allows creating a 3D colored map on the high profile.

notes

summary

1m 13s

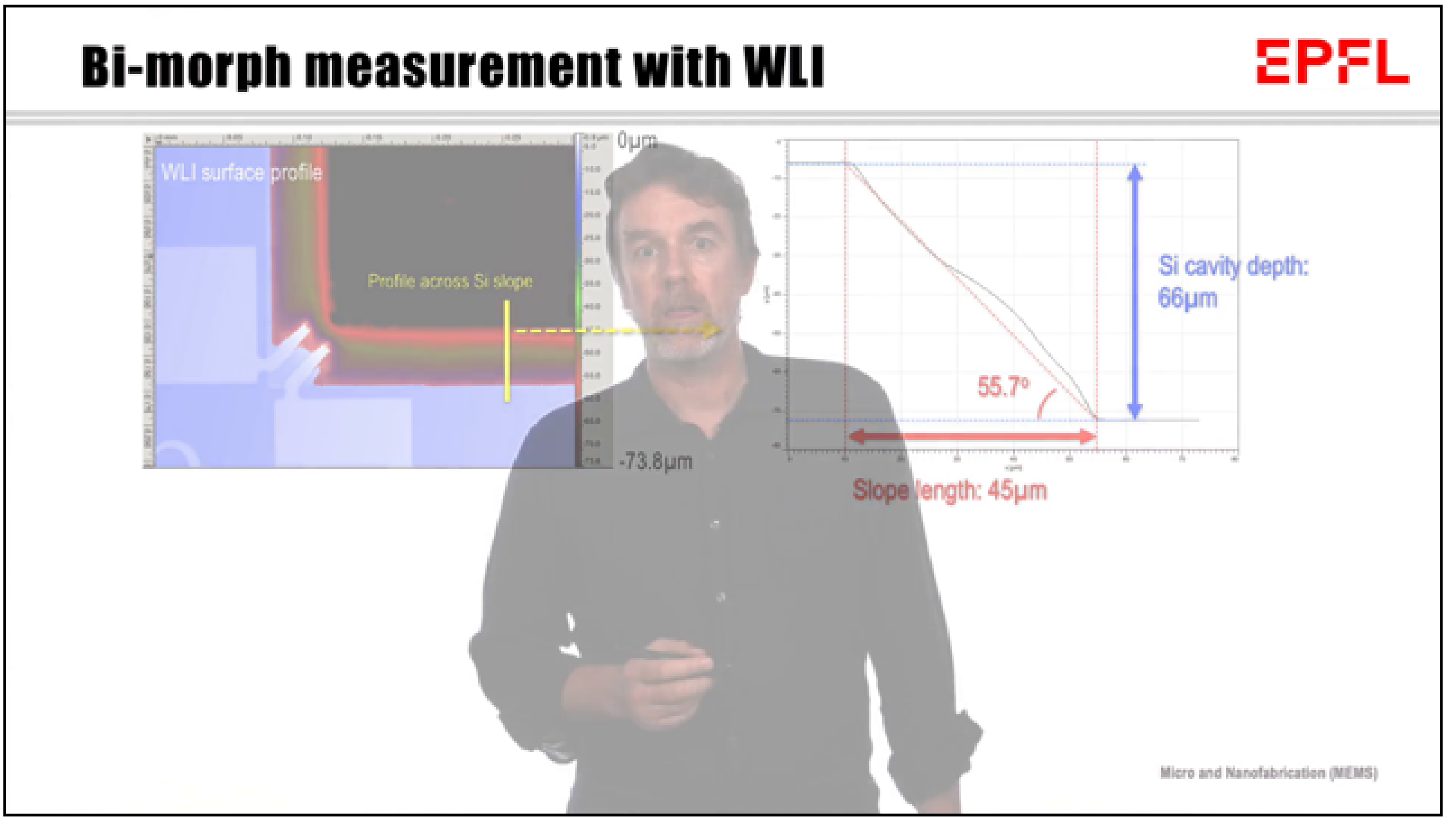


Here, red means high, and blue means low. From a certain point the value and height cannot be extracted, because the bending curvature of the cantilever is too high. In this case, tilting the sample could be a solution. The white light interferometer also allows measuring the width of surface patterns and depth of edge grooves as shown here. In this example, let us assess the silicon slope

notes

summary

3m 12s

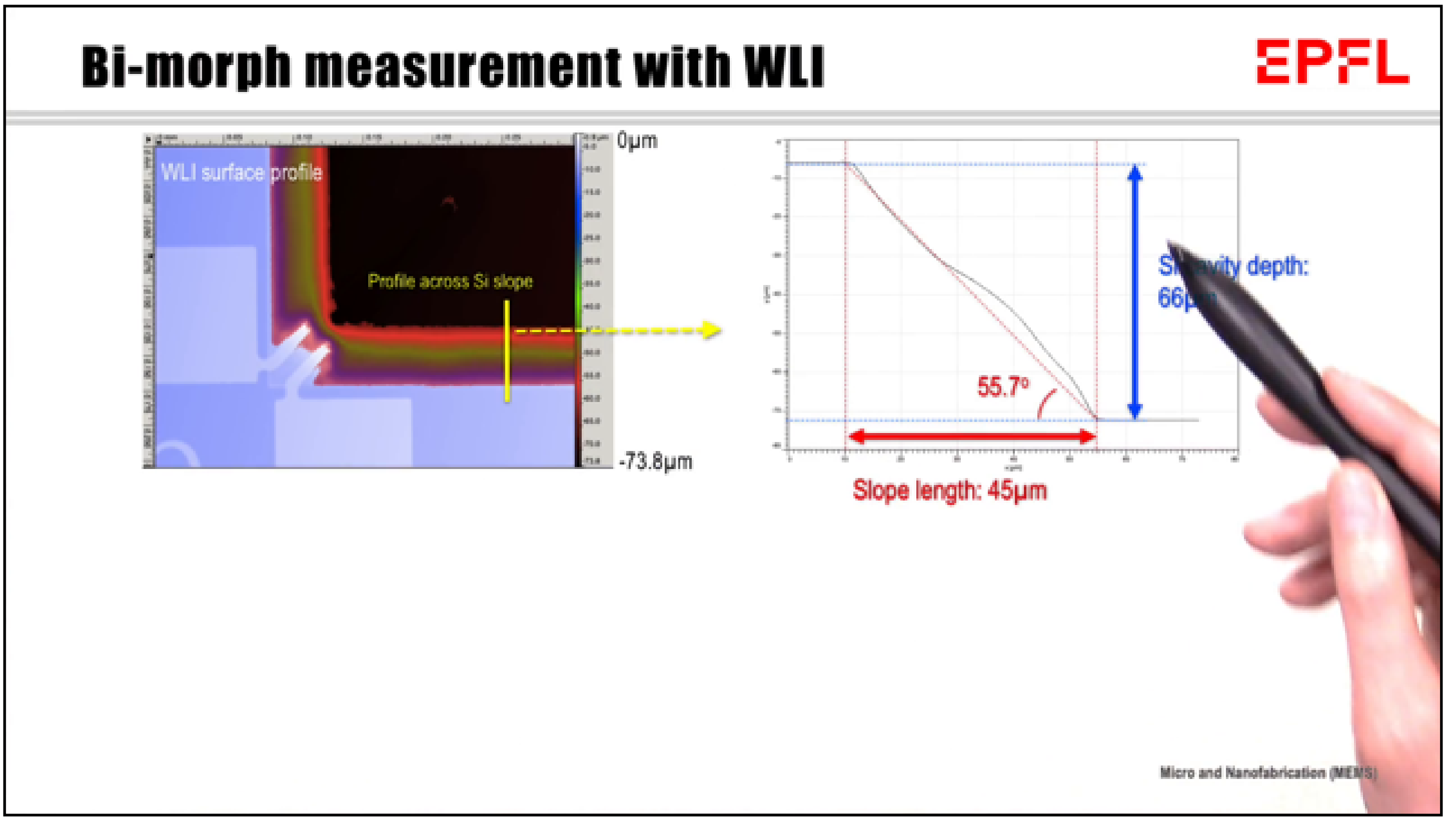


that results from the anisotropic silicon etching in KOH.

notes

summary

3m 37s



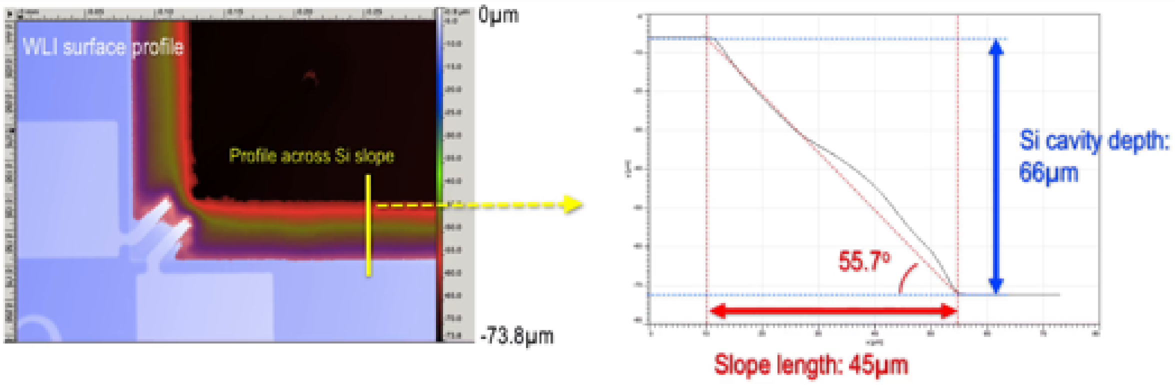
We know it should be about 54.7 degree, which is the angle between the 100 and 111 crystal planes of the silicon. But let us measure it now.

notes

summary

3m 42s

Bi-morph measurement with WLI



Micro and Nanofabrication (MEMS)

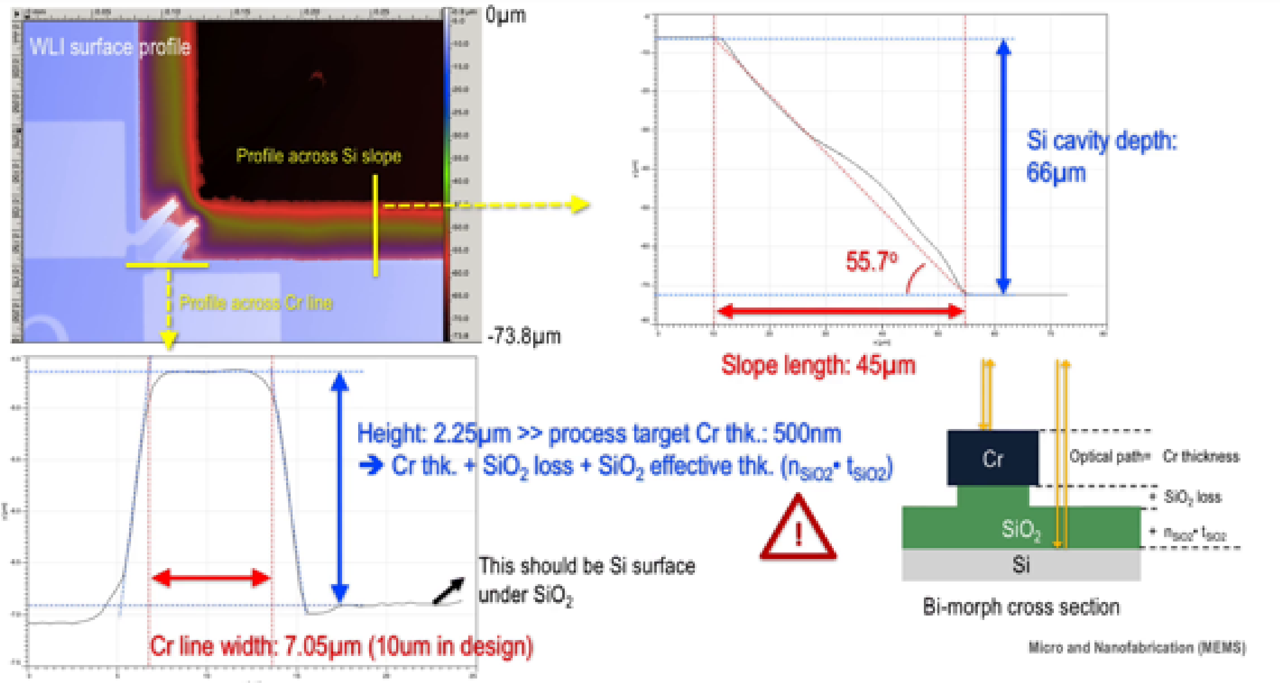
The data from the white light interferometer tells us that the silicon cavity is 66 um deep. And the silicon slope is 45 um long.

notes

summary

3m 58s

Bi-morph measurement with WLI

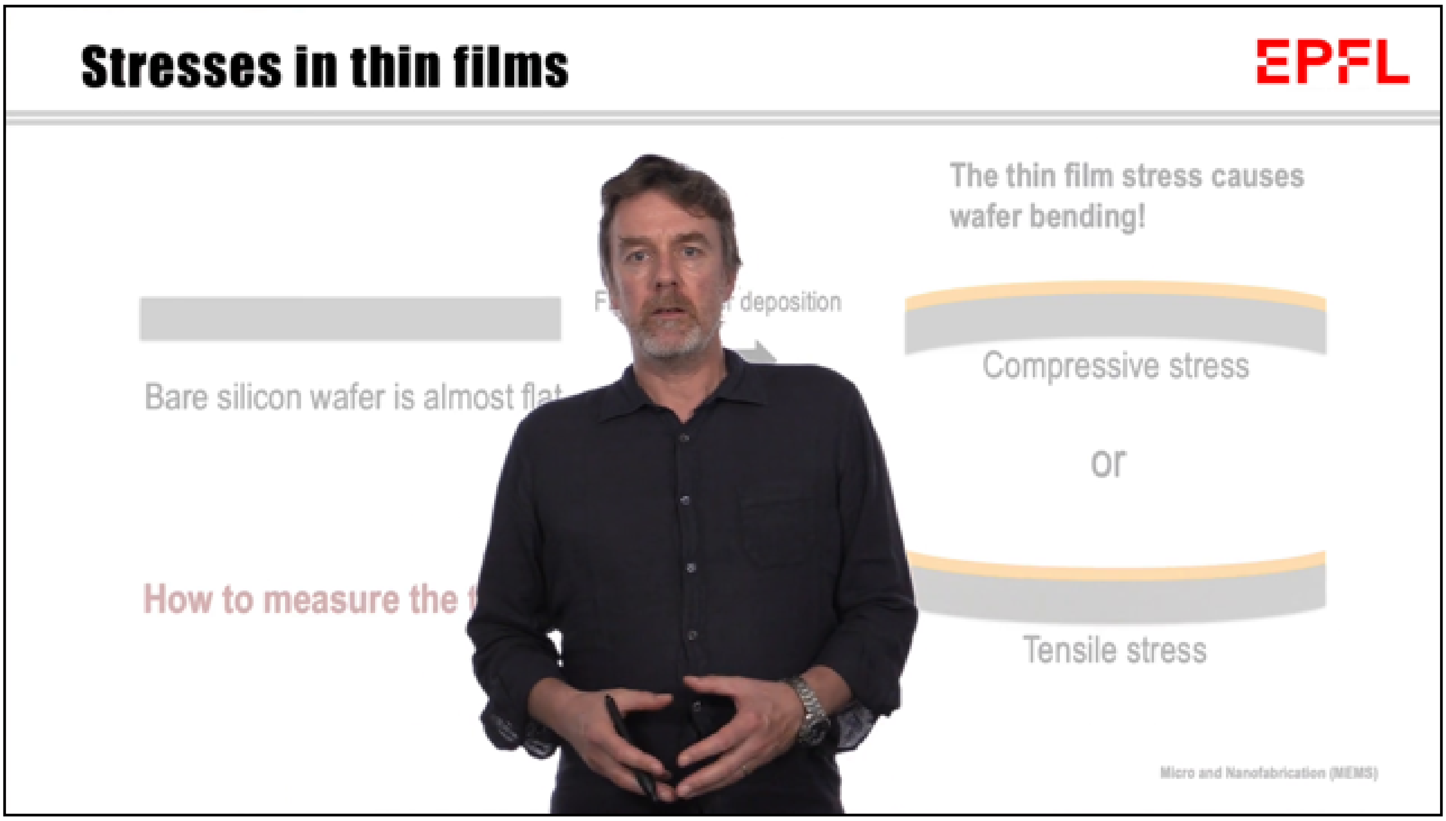


With these two values, we calculate the angle to be 55.7 degree, which agrees very well with the theoretical value. We can also measure the width and the thickness of the chrome line here. But doing so, I also would like to draw your attention that each measurement should be accompanied with a thorough consideration of the sample condition, to be able to correctly interprets the measurement results. Here, the measured line width of the chrome pattern is 7.05 um. This is quiet in contrast to the design width of 10 um. This difference in values is most likely a result from a non-optimized lithography and chrome wet etch process, and should be improved for more critical devices. The thickness measurement indicates 2.25um as thickness. Remember that chrome thickness was designed to be 500 nm. So, how come that we measure 2.25 um now ? Let us have a look here at this drawing which shows the cross section at the point of interest. The white light interferometer actually detects the surface of silicon underneath the transparent silicon dioxide film. Here. Therefore, the optical path difference is the sum of both: the thickness of the chrome and the thickness of the silicon dioxide. In addition, we need to take into account that the SIO2 has a reflective index of about 1.5. Which also changes the light propagation inside this medium. Therefore, since the height difference is detected by the light path difference between the reference and object beams, we have to consider the silicon dioxide thickness as effective thickness, which equals the refraction index of silicon dioxide multiplied by the thickness of silicon dioxide.

notes

summary

4m 3s

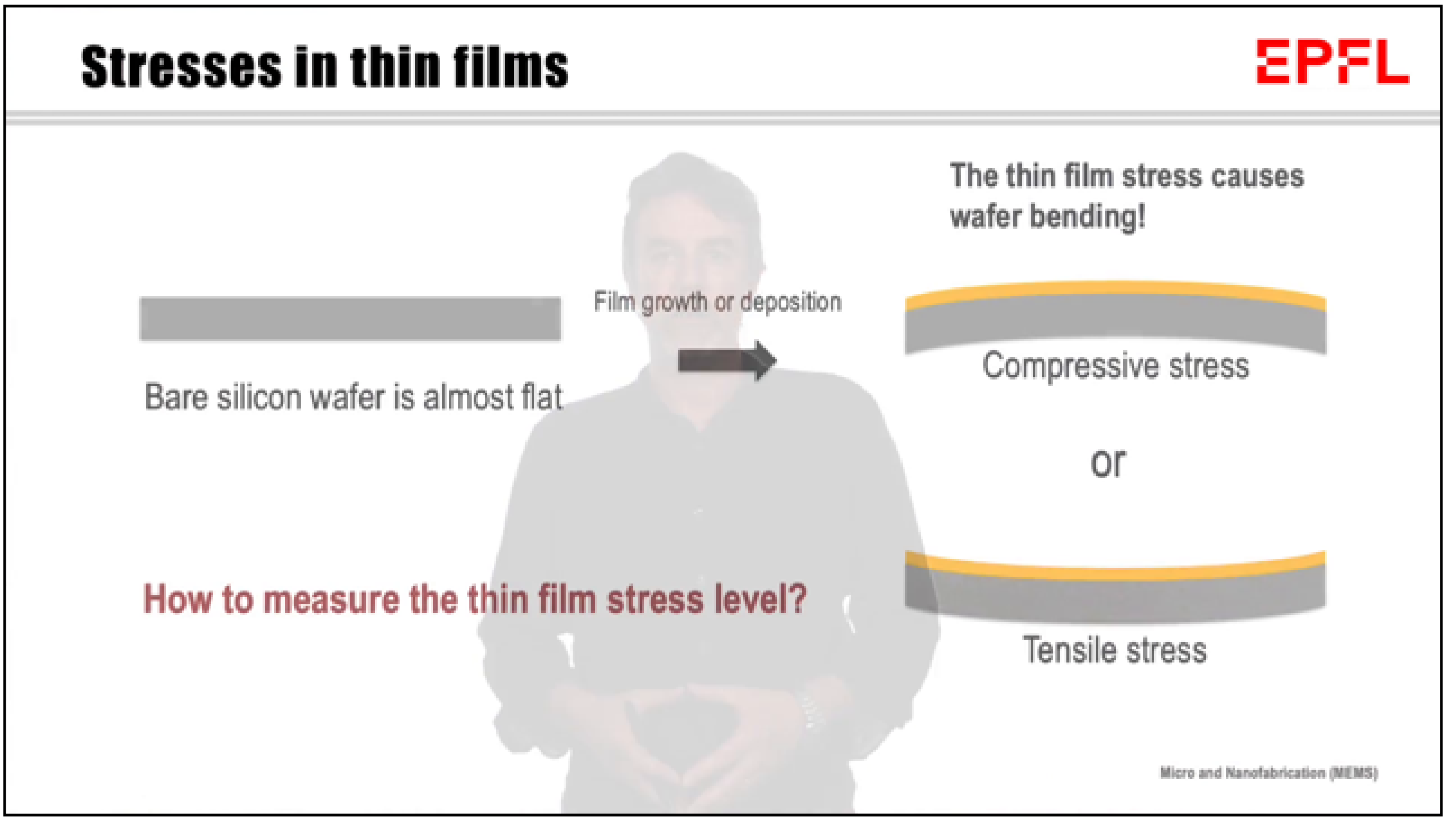


Therefore, the measured total height difference is obviously larger than the true summation of 500 nm for the chrome thickness, and the true silicon dioxide thickness of about 1.3 um. If we take into account the thickness loss due to the KOH etching and which was already confirmed by the measurement result in the previous lesson. The situation here reminds us always not to trust a measurement result without reasonable evaluation.

notes

summary

6m 1s



Remember in the mooc lesson on physical vapor deposition, we mentioned that the stress from the deposited thin film could lead to wafer and device bending.

notes

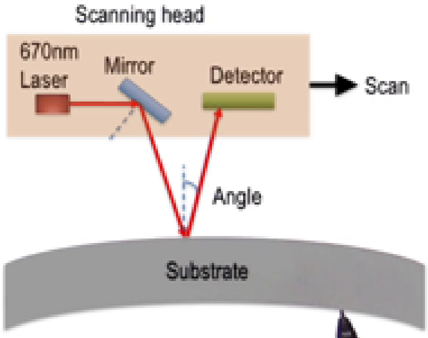
summary

6m 32s

Laser beam surface profiler

EPFL

- Laser beam to detect the entire wafer surface profile ➔ curvature
- Too large wafer curvature will affect fabrication process
- Wafer curvature ➔ thin film stress level
  - Stoney equation:



$$\sigma_f = \frac{E_s}{6(1-\nu_s)} \cdot \frac{t_s^2}{t_f}\left(\frac{1}{r_{sf}} - \frac{1}{r_s}\right)$$

σ_f = stress in film in [Pa], by convention negative stresses are compressive
E_s = substrate Young's modulus in [Pa]
ν_s = Poisson ratio of the substrate
t_f and t_s = film and substrate thickness in [m]
r_{sf} = radius of curvature of the substrate with the thin film in [m]
r_s = radius of curvature of the substrate before deposition in [m]

Micro and Nanofabrication (MEMS)

The origin for this upward or downward pending can be either compressive or tensile stress. Here, I would like to introduce a methodology to determine a thin film stress level by measuring the wafer bending before and after thin film coating. To this end, we use a laser beam surface profiler. It creates a line scan over the entire wafer surface and thereby determines the surface profile and radius of curvature. The drawing here on the right side shows the principle.

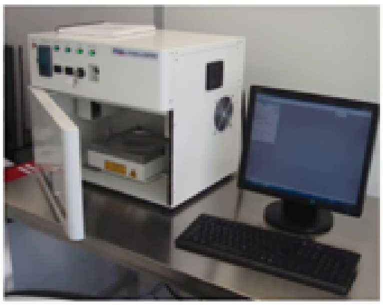
notes

summary

6m 40s

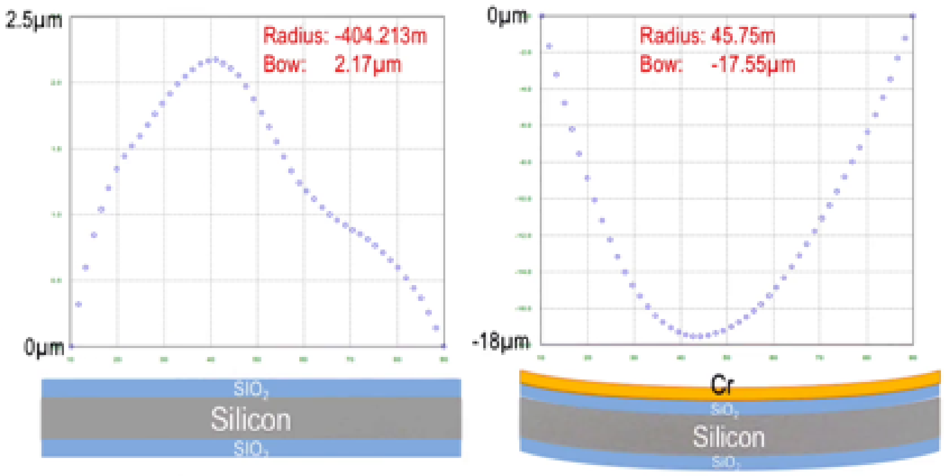
Thin film stress measurement

EPFL



Laser beam surface profiler

Bi-morph wafer:



Before Cr deposition

After Cr deposition

$$Cr\ \ film\ \ stress=\frac{185GPa}{6(1-0.06)}\cdot\frac{(525\cdot10^{-6}m)^2}{0.5\cdot10^{-6}m}\left(\frac{1}{45.75m}-\frac{1}{-404.213m}\right)=0.44GPa=440MPa\ \ (tensile)$$

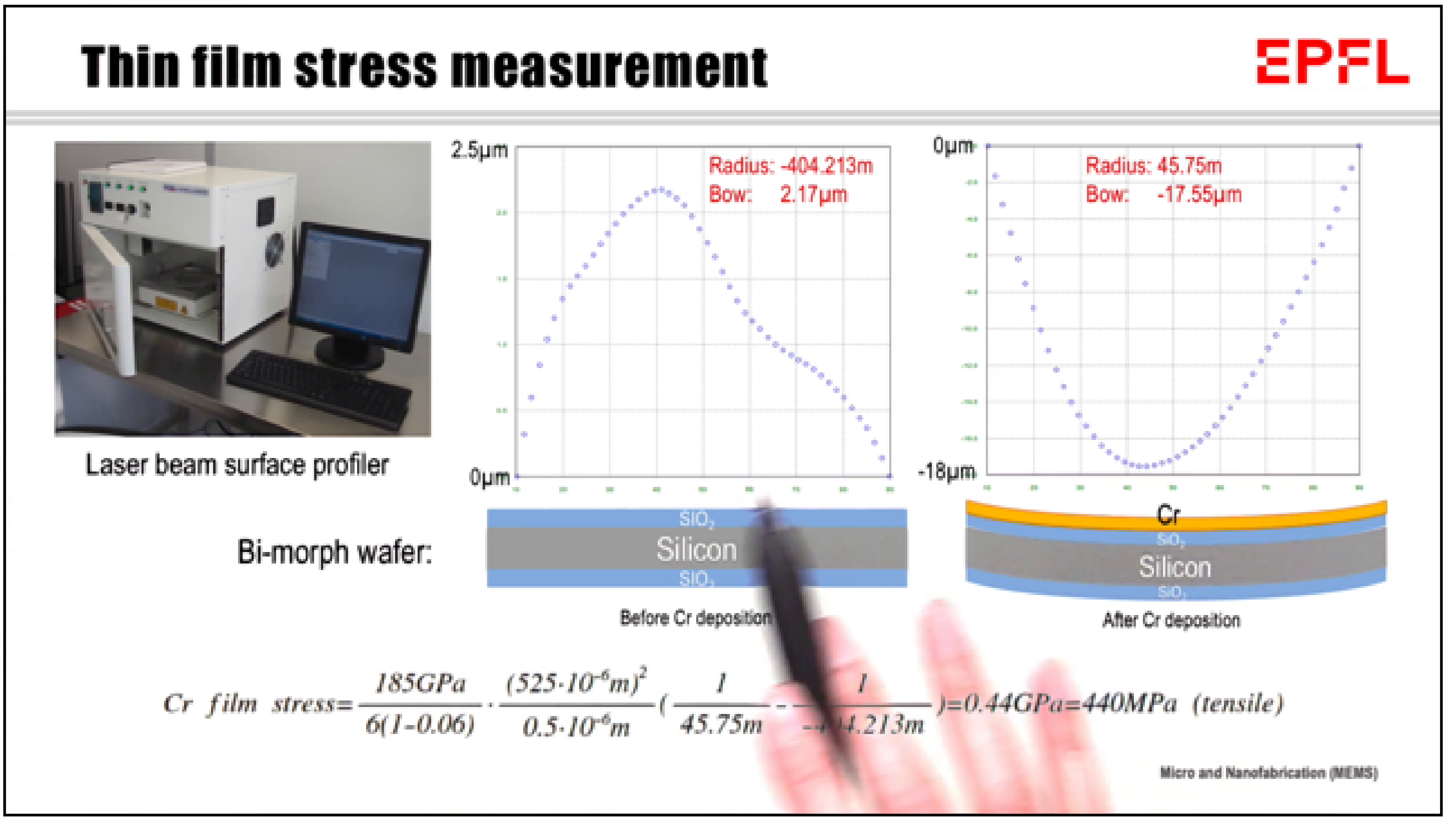
Micro and Nanofabrication (MEMS)

A laser beam is aligned to the wafer surface and then the reflected beam is detected. The scanning head incorporated both the laser source and the detector. The head is scanning across the entire wafer at a fixed height, and any bending of the wafer will induce changes in the angle of reflection. Therefore, the curvature profile of the entire wafer surface can be obtained. To determine any stress built up during fabrication, we measure the wafer curvature before and after the film deposition. Then we calculate the thin film stress values according to the Stoney equation shown here. You already know it from a previous lesson.

notes

summary

7m 13s



Taking the wafer with bi-morph cantilever device as an example, let us now see how by adding the chrome film, the shape of the wafer changes. The left curve shows the profile of the silicon wafer coated on both side with SIO2. shown here... before chrome,

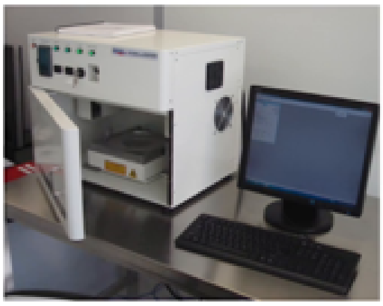
notes

summary

8m 2s

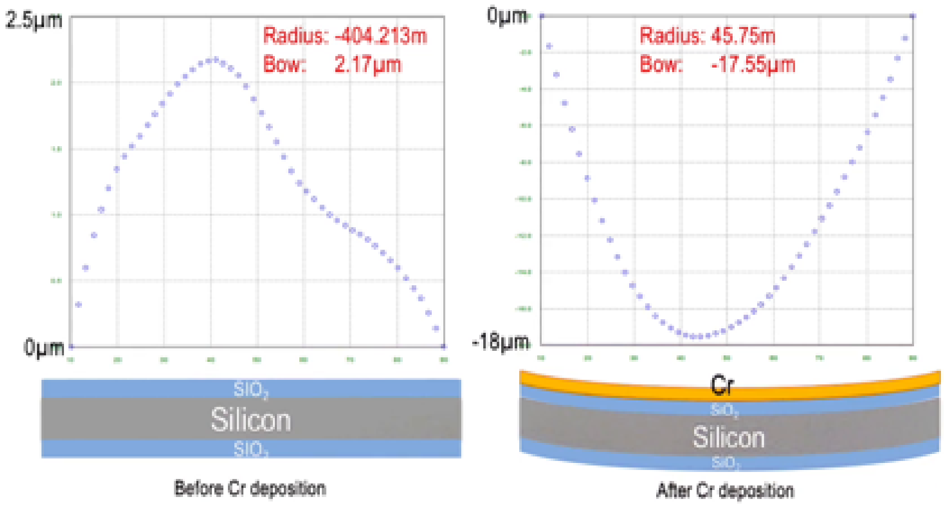
Thin film stress measurement

EPFL



Laser beam surface profiler

Bi-morph wafer:



$$Cr\ film\ stress = \frac{185GPa}{6(1-0.06)} \cdot \frac{(525 \cdot 10^{-6}m)^2}{0.5 \cdot 10^{-6}m} \left(\frac{1}{45.75m} - \frac{1}{-404.213m} \right) = 0.44GPa = 440MPa\ \ (tensile)$$

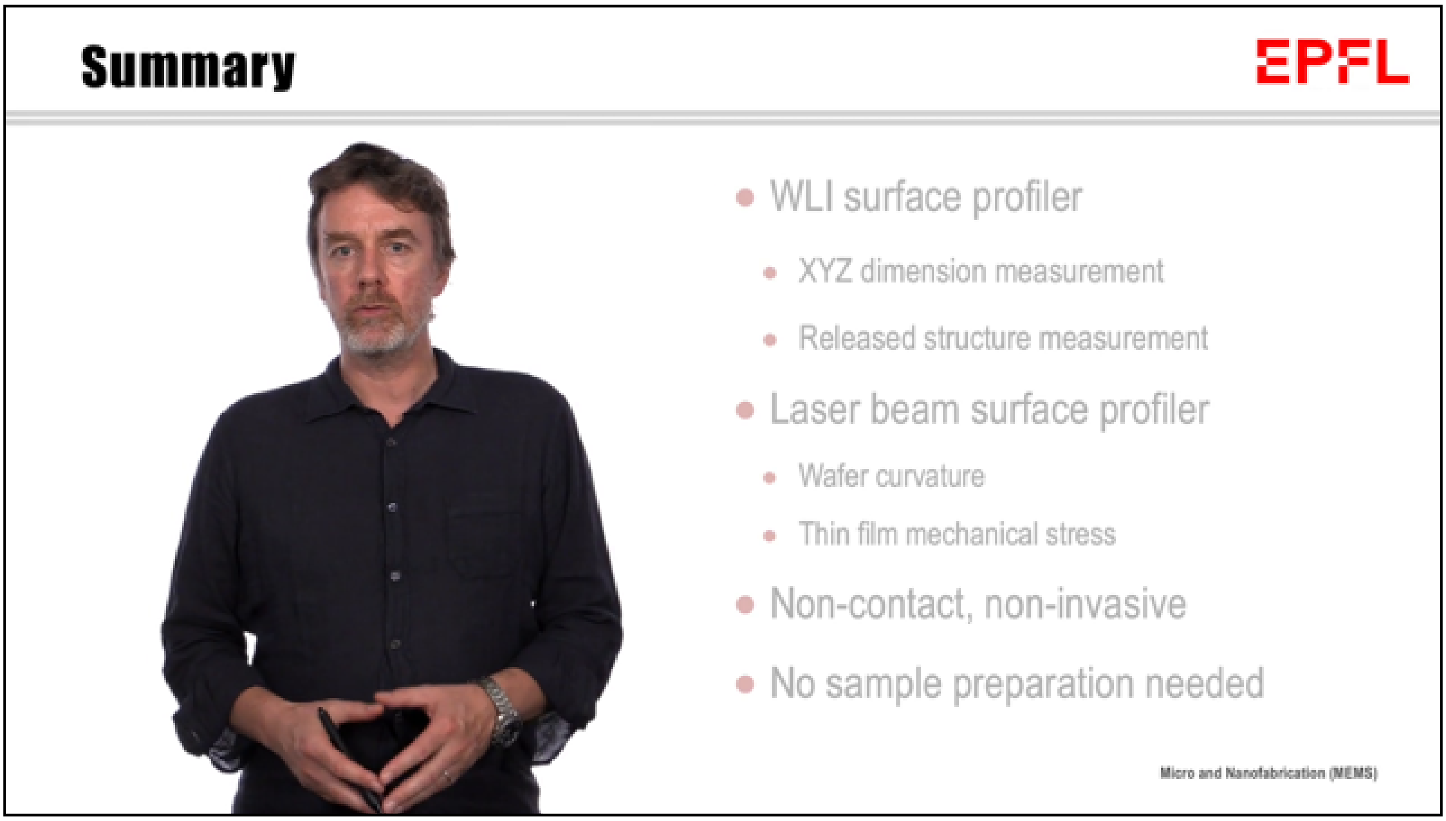
Micro and Nanofabrication (MEMS)

the bow is 2.17 um which comes slightly from the wafer cutting and polishing. The right curve shows the same wafer after 500 nm thick chrome layer on one side.

notes

summary

8m 25s



Now the bow is about -17.55 um. From these values, we calculate the chrome film stress to be 440 Mpa(Mega Pascal) in the tensile direction, based on this formula. Such values are typical and induce the resulting bending as a common artifact during thin film processing. The bow here in the measurement result, indicates the height difference between the peak and the valley of the surface profile. This concludes this lesson on optical surface analysis method for MEMS inspection and metrology. I have shown the white light interferometer and the laser beam surface profilometer. Both are non-contact and thus do not contaminate or damage the sample. They are simple to use, and allow for important in-process characterization of thin film and stress parameters.

notes

summary

8m 33s