Inspection and metrology

MICRO-331
Microfabrication technologies

J. Brugger
& teams

2024 edition

Program

Wednesday 18 Dec

- 1st hour:
  - Metrology part one
- 2nd hour:
  - Q&A with pointsolution

Thursday 19 Dec

- 1st hour:
  - Metrology part two
- 2nd hour:
  - Q&A with pointsolution

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microfab

Class polling

WEBPAGE **TTPOLL.EU**

ID: **CMI24**

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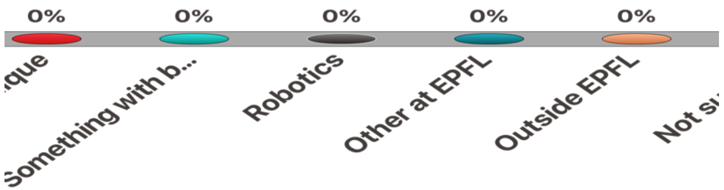
My preference for the Master is…

A. Microtechnique
B. Something with bio
C. Robotics
D. Other at EPFL
E. Outside EPFL
F. Not sure yet



What means metrology to you?

Inspection and metrology

- What means inspection?
- What means metrology?

Interesting website from Hitachi:

https://www.hitachi-hightech.com/global/products/device/semiconductor/metrology-inspection.html

Metrology

- Scientific study of measurement
- Calibration, standards, units
- Dimensions, mass, time
- The goal is to validate that the device or system is within certain specs that are allowed by the design
- Insurance that it will work as expected

Swiss Federal Institute of Metrology

- METAS
- https://www.metas.ch/metas/en/home.html

Inspection and metrology for microfabricated devices

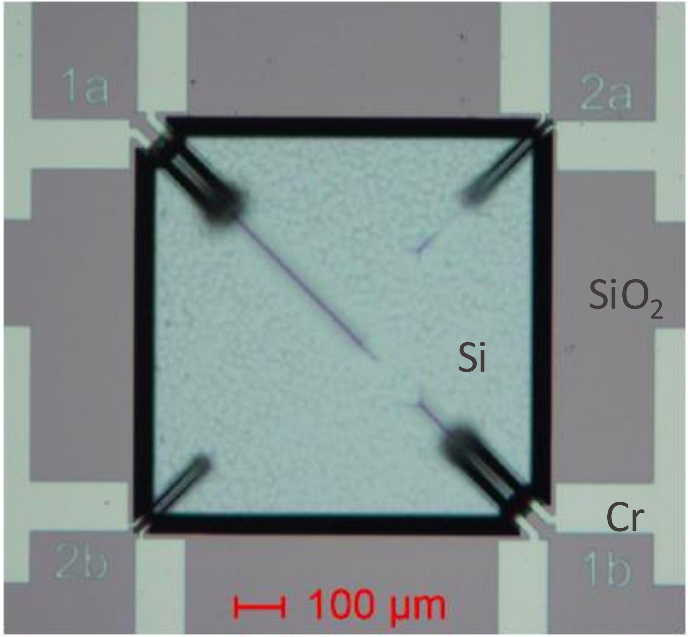
- Optical inspection
- Thin film characterization
- Electrical characterization
- Advanced techniques (SEM, FIB, AFM)

Optical inspection

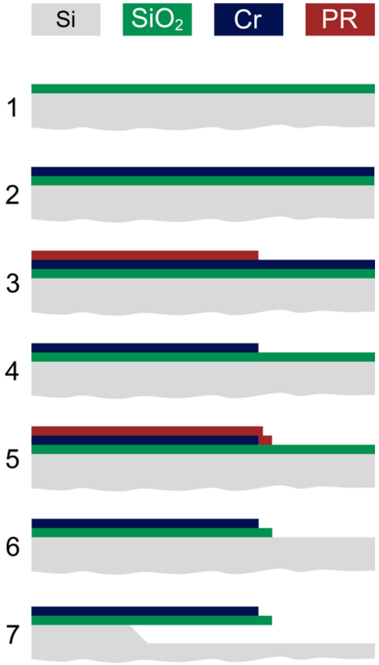
- What you see is what you believe
- Optical microscopy
  - mm - down to micrometer (10^{-3} to 10^{-6} m)
  - Colours
  - Planar x,y metrology
  - What about z? out of focus
  - Interferometer, nm precise thickness measurements
  - (example: Graphene)

Bi-morph thermal actuator

How to check the process result after each step?



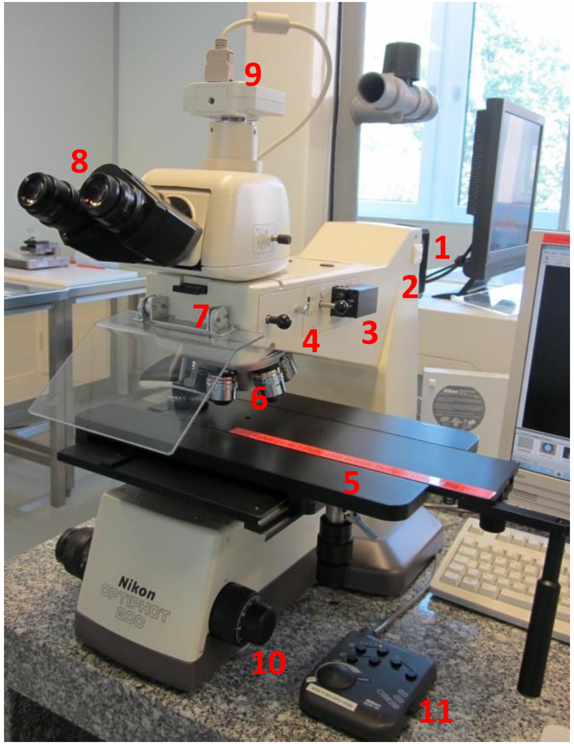
Optical microscope

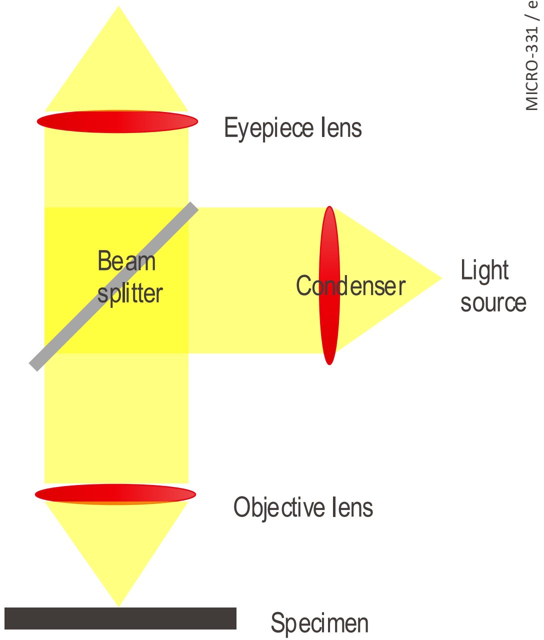


1. Oxidation
2. Cr layer deposition
3. Lithography 1 (heater)
4. Cr etch
5. Lithography 2 (cantilever)
6. SiO$_2$ etch in BHF
7. Silicon etch in KOH

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

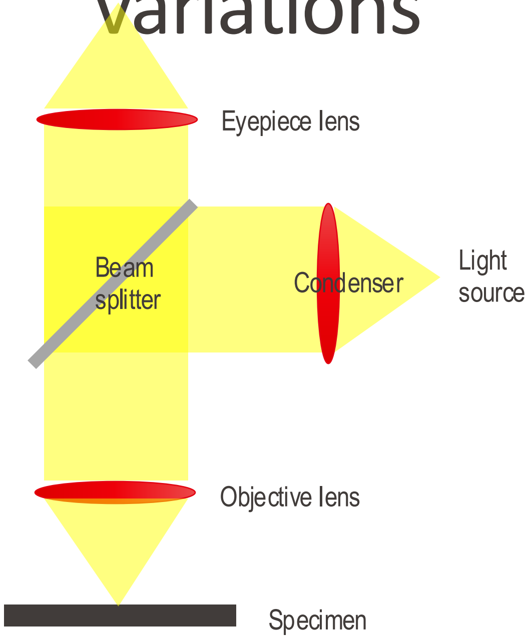




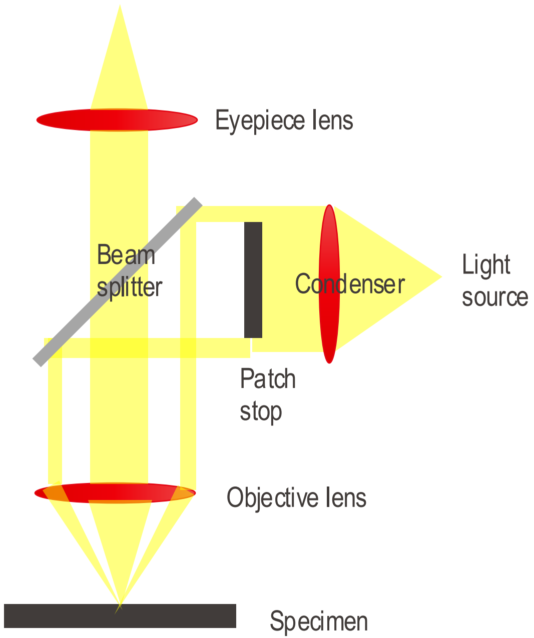
Bright field optical path

EPFL

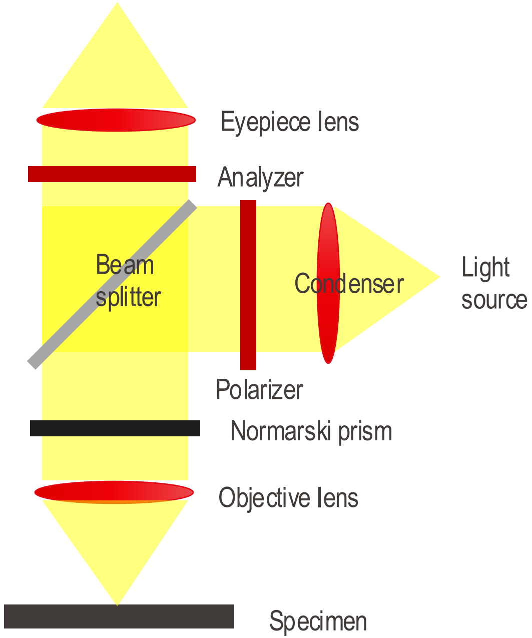
Optical microscopy variations



Bright Field (BF)
- Contrast caused by attenuation of light
- Common mode

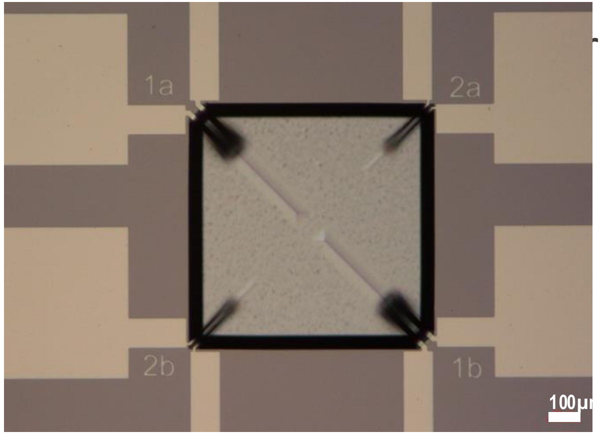


Dark Field (DF)
- Contrast caused by intensity of scattered light
- Edge enhancement

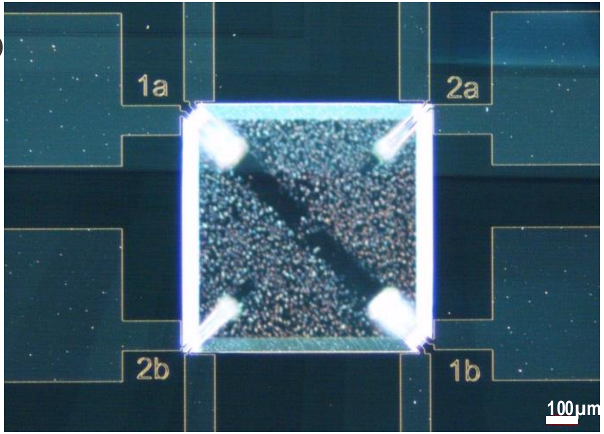


Differential interference contrast (DIC)
- Contrast caused by intensity of interfered light
- 3D appearance

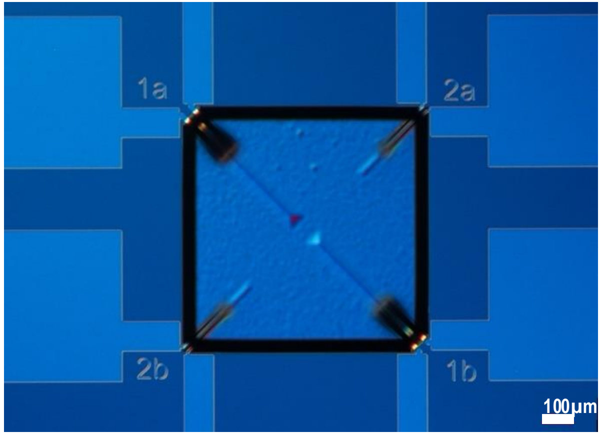
Optical microscopy variations



Bright field



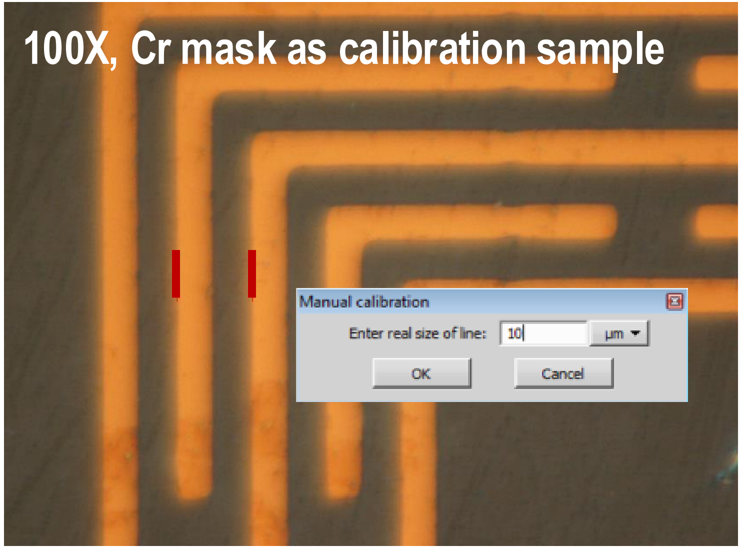
Dark field



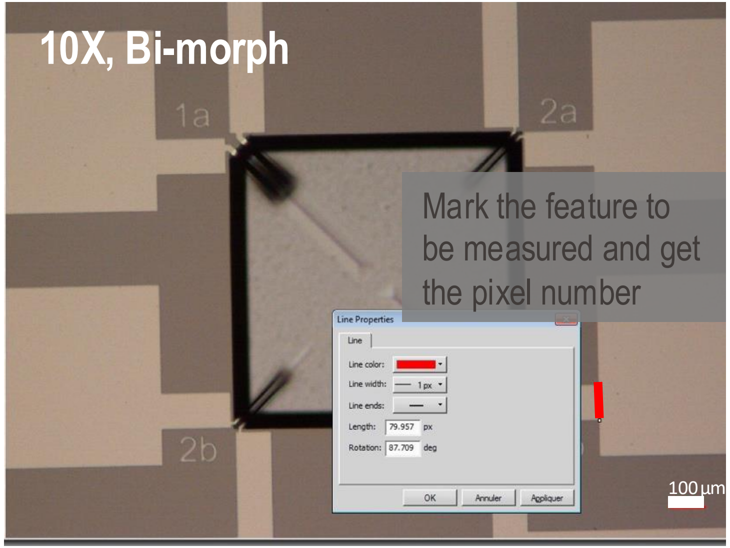
DIC

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

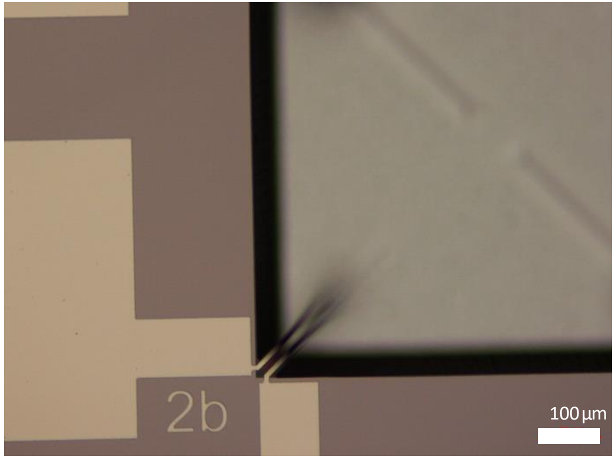


Cr line width=79.957 pixels, 1 pixel = 1.243µm in 10X image
➔ 79.957 x 1.243 = 99.4µm (100µm in design)

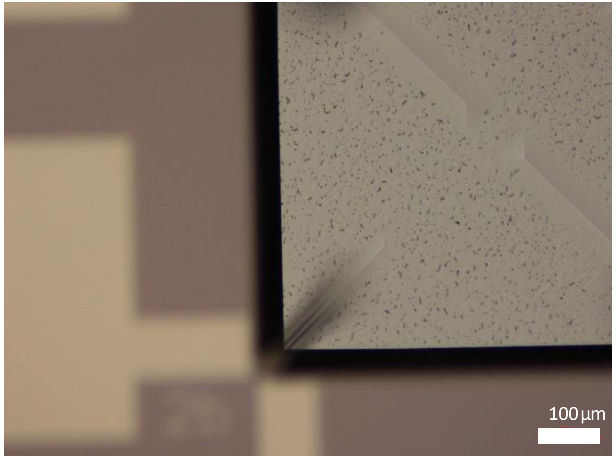
Dimension measurement: Z

- 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 ~70µm

Optical inspection
Summary

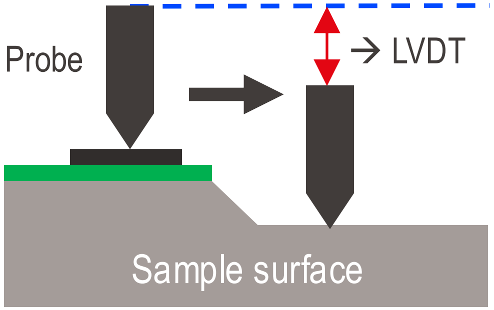
- Easy, fast and cost-effective method for inspection and dimension measurement
- Multiple modes for specific purpose, colour
- Non-contact, non-invasive
- Works for both opaque and transparent specimens
- Workhorse for sample inspection

Thin film metrology

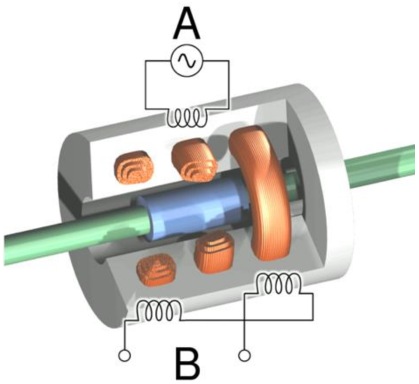
- Thickness measurement by profilometer
  - Mechanical
    - z very sensitive
    - x,y not so precise
    - For all types of materials (not too soft)
  - Optical, ellipsometer
    - For optically transparent films

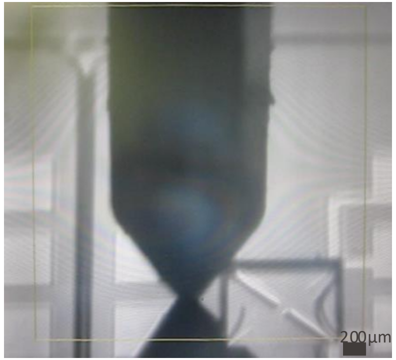
Mechanical surface profiler

- Diamond probe scans the surface
- Surface height ➔ probe position ➔ electrical signal
- Resolution in Z: ~1nm
- Measurement range in Z: up to 1mm
- Scan length up to 55mm
- Risk to damage the probe or sample



LVDT

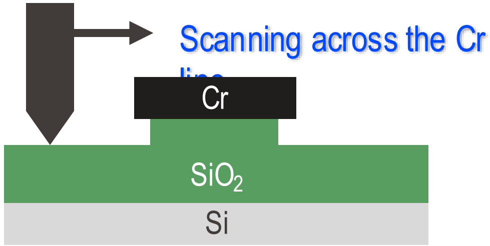


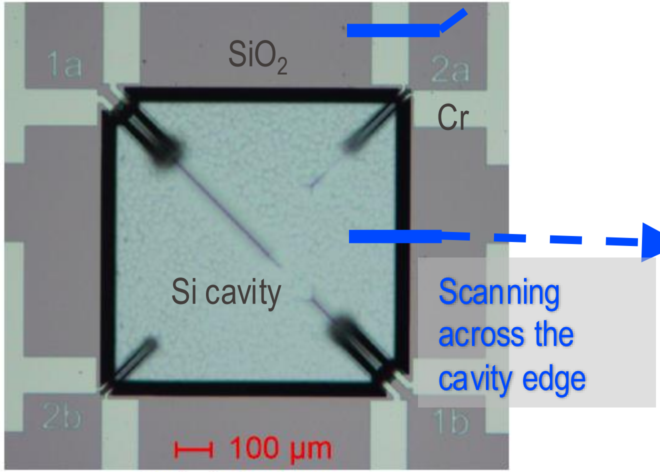


LVDT = linear variable differential transformer

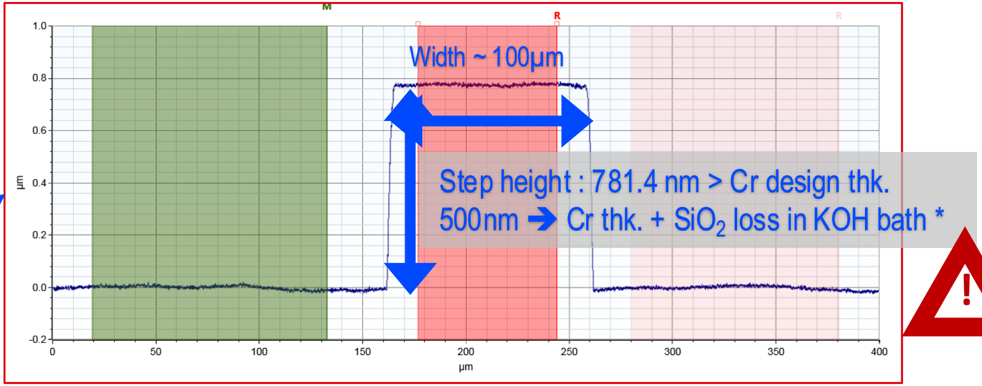
https://commons.wikimedia.org/wiki/File:LVDT.png

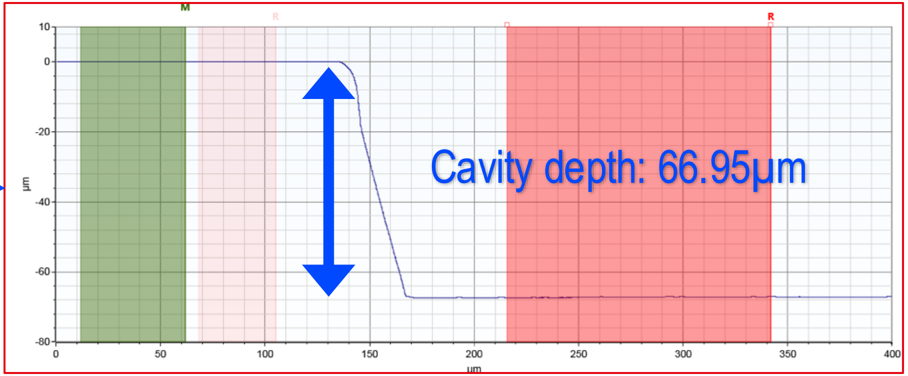
Surface profile measurement





Optical microscope

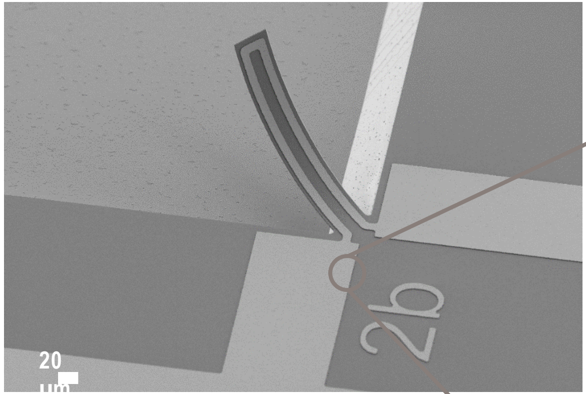




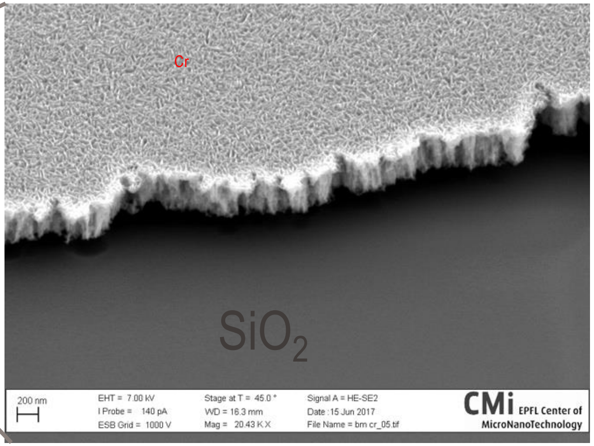
* Please refer to the previous module: **Case study: thermo-mechanical micro-actuator**

Bi-morph surface roughness measurement

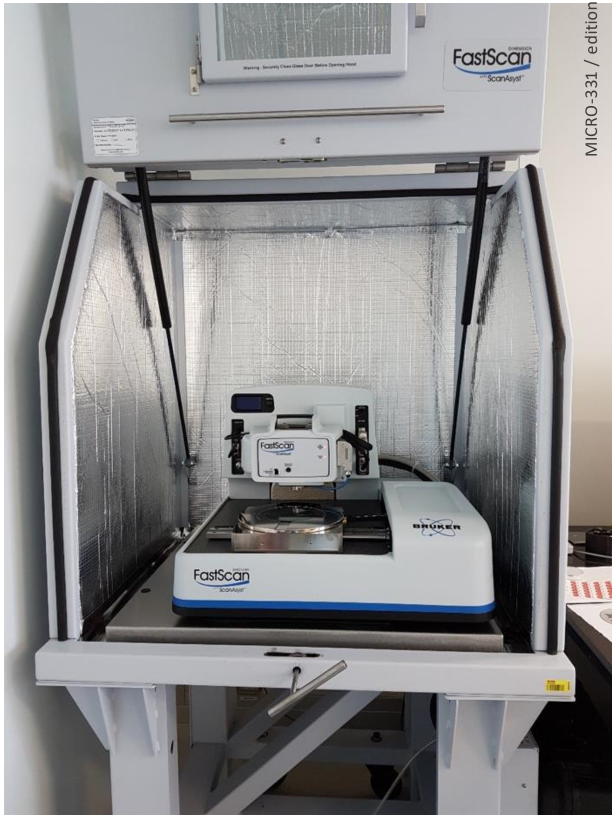
- To measure the surface roughness of Cr and SiO_2



SEM image of the bi-morph @ 3 keV and 45 degrees tilt

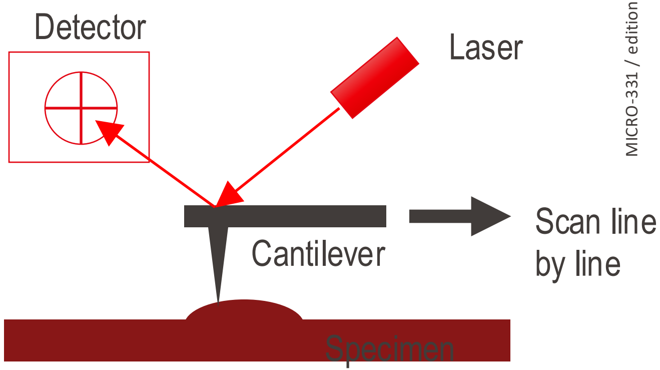


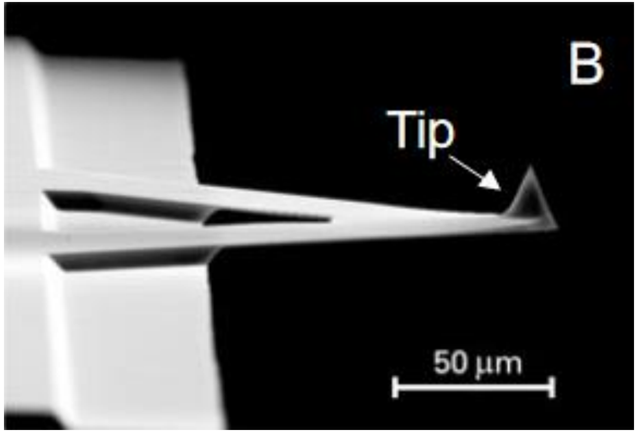
SEM image to indicate where the surface roughness is measured

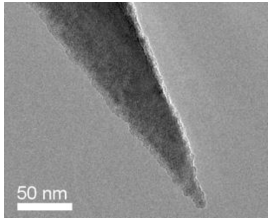


Atomic force microscopy

- A cantilever probe to touch and scan the surface
- Surface height ➔ probe position ➔ laser signal
- Z resolution: ~ 0.1nm
- XY lateral resolution: < 10nm
- Nano scale 3D surface profile map
- Surface roughness measurement





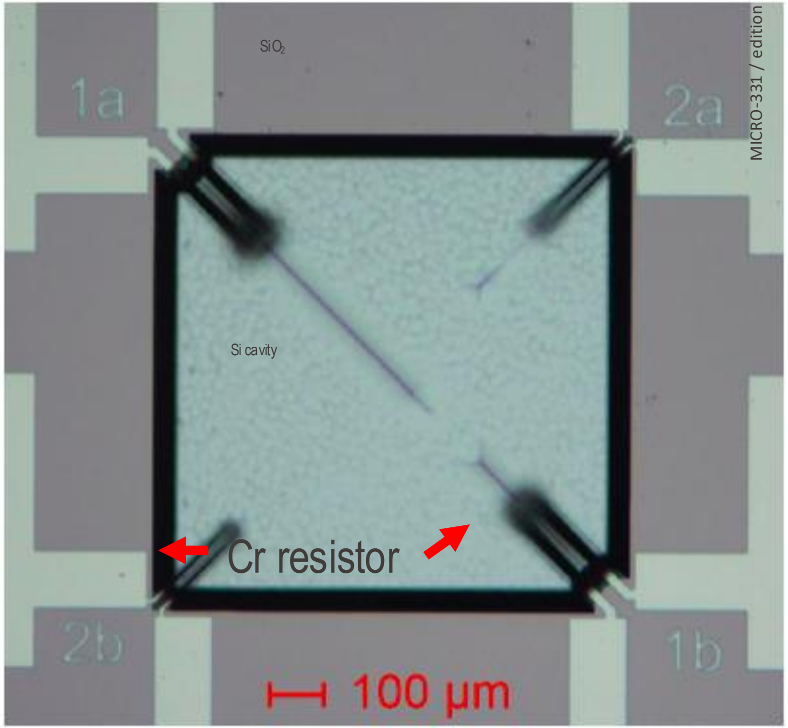


Electrical characterization

- Resistivity, doping, material properties
- 4PP
- Piezoresistive, strain gauge
- Micro-prober system

Bi-morph electrical characterization

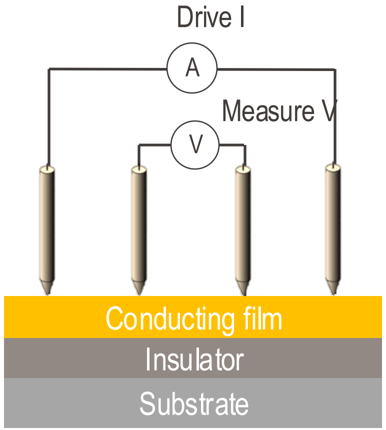
How to evaluate the Cr film quality and determine the resistance of the Cr heaters?

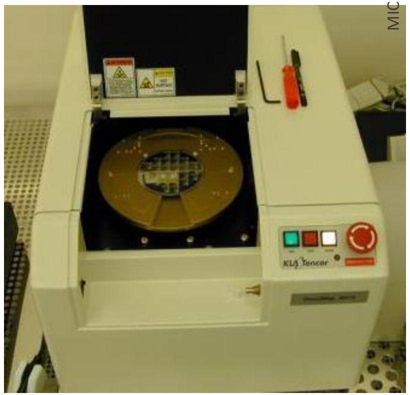


Optical microscope

Resistivity meter

- To evaluate the metal film quality
- Van der Pauw 4-point measurement
- Probe spacing: ~ 1mm
- Unpatterned film with known thickness on an insulator
- Accuracy: +/- 0.5%



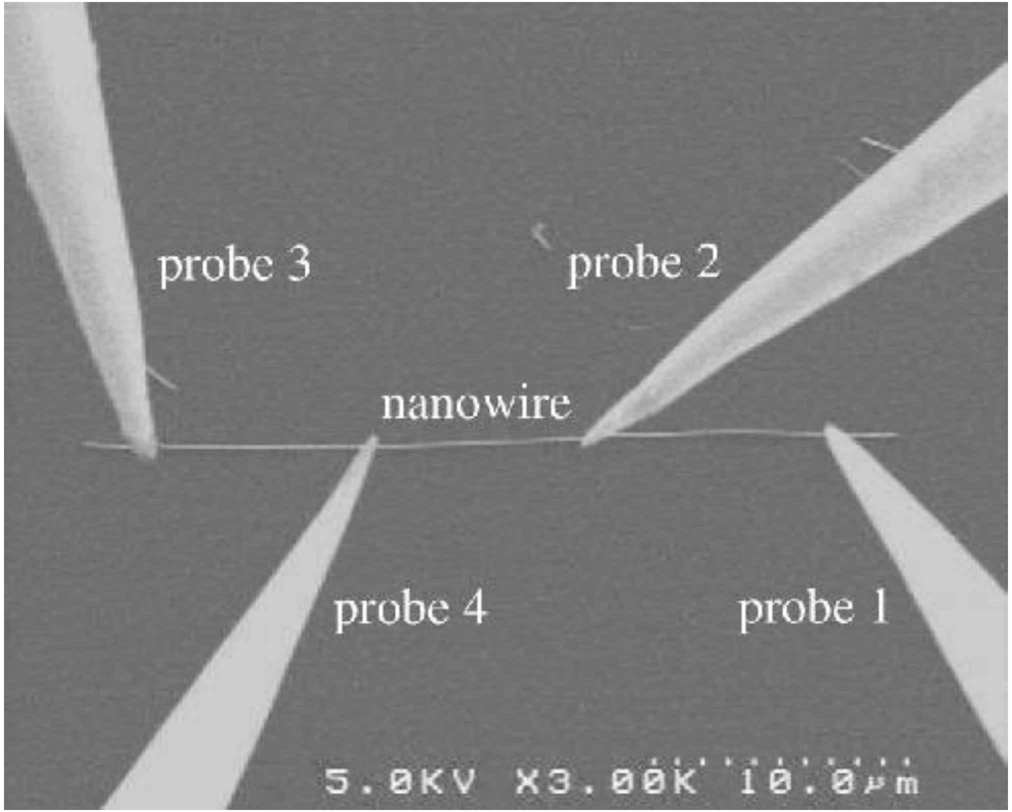


Van der Pauw formula for 4-point measurement: $$R_s = \frac{\pi}{ln2} \cdot \frac{V}{I}$$

Calculate resistivity: $$\rho = R_s \cdot t$$

R_s	:	Sheet resistance (ohm/sq)
V	:	Voltage (V)
I	:	Applied current (A)
ρ	:	Resistivity (ohm•m)
t	:	Film thickness (m)

4PP measurement is needed to avoid contact issues



Bi-morph Cr resistance calculation

$$R = \rho \frac{L}{tW} = R_s \cdot sq. \quad where \quad R_s \equiv \frac{\rho}{t} \quad sq. \equiv \frac{L}{W}$$

R : Resistance (ohm)
ρ : Resistivity (ohm•m)
L : Resistor length (m)
t : Resistor thickness (m)
W : Resistor width (m)
R_s : Sheet resistance (ohm/sq.)
sq.: Square number

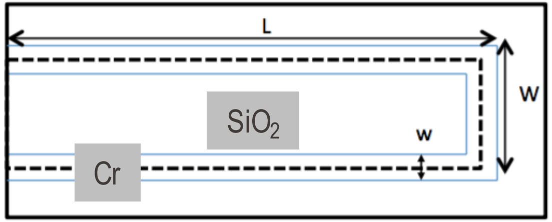
For Cr resistor:

R_s = 2.152 ohm/sq.

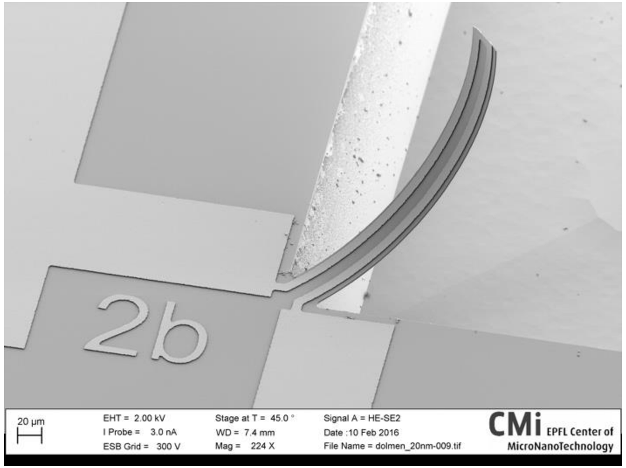
L = L_{eff} = 640 µm

W = 7.13 µm

The resistance of Cr = 2.152 x (640 / 7.13) = 193.2 ohm

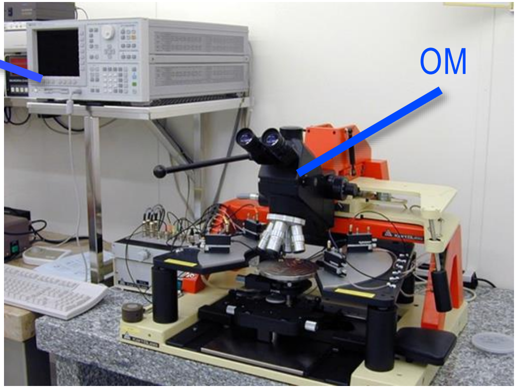


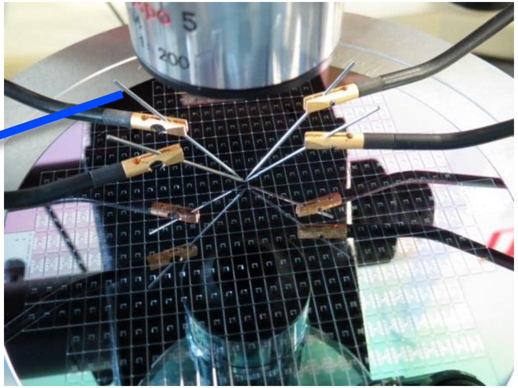
$$L_{eff} = 2\left(L - \frac{w}{2}\right) + W - w$$



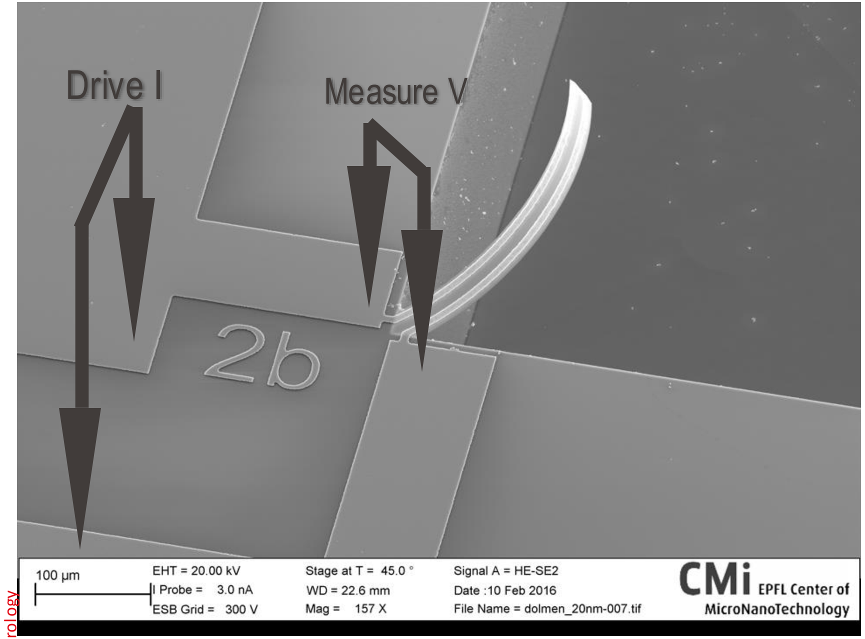
Prober station

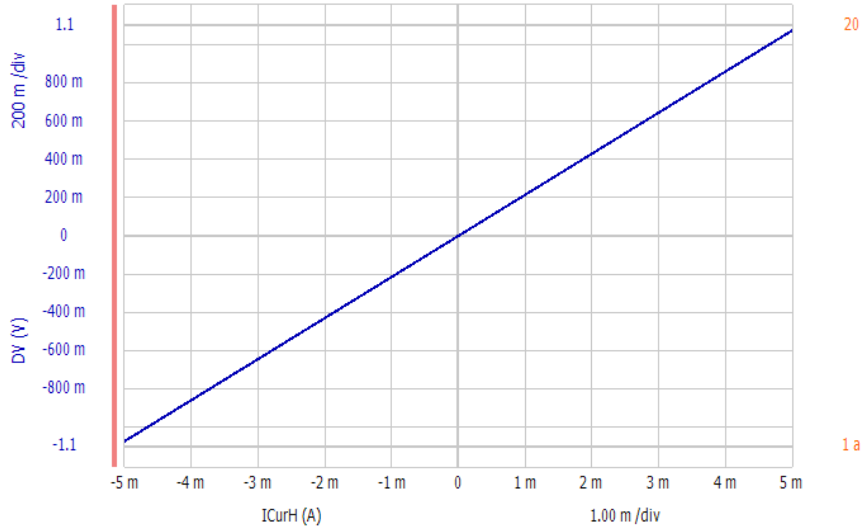
- OM + tungsten micro probes + multimeter & power supply
- Metal pads needed: > 50 x 50 µm^2
- Electronics characterization
  - Current (0.1 fA – 1 A), voltage (0.5 µV – 200 V)
- I-V, C-V, C-f, C-t curves
- MEMS resonant frequency





Bi-morph Cr resistance measurement





Cr resistance = 215 ohm
(Calculation: 193.2 ohm)

Advanced techniques

- SEM, TEM
- Focused Ion Beam
- Advanced AFM