MICRO-331 Microfabrication technologies

Inspection and metrology

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& teams

2022 edition

Inspection and metrology

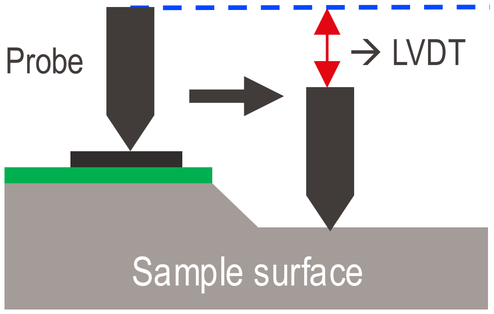
- Optical inspection
- Thin film characterization
- Electrical characterization
- Advanced techniques (SEM, FIB, AFM)

Optical inspection
Summary

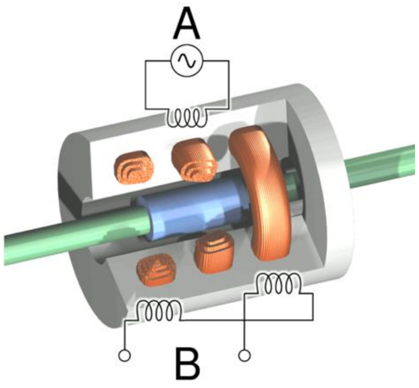
- Easy, fast and cost-effective method for inspection and dimension measurement
- Multiple modes for specific purpose, colour
- Non-contact, non-invasive
- Works for both opaque and transparent specimens
- Workhorse for sample inspection

Mechanical surface profiler

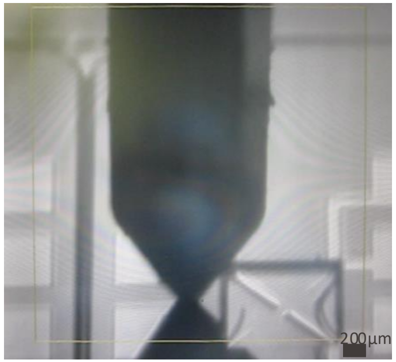
- Diamond probe scans the surface
- Surface height ➔ probe position ➔ electrical signal
- Resolution in Z: ~1nm
- Measurement range in Z: up to 1mm
- Scan length up to 55mm
- Risk to damage the probe or sample



LVDT

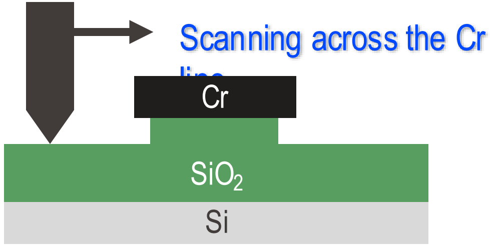


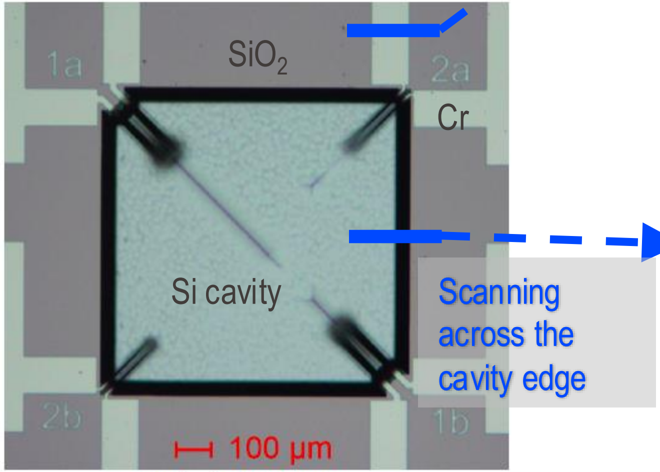
https://commons.wikimedia.org/wiki/File:LVDT.png



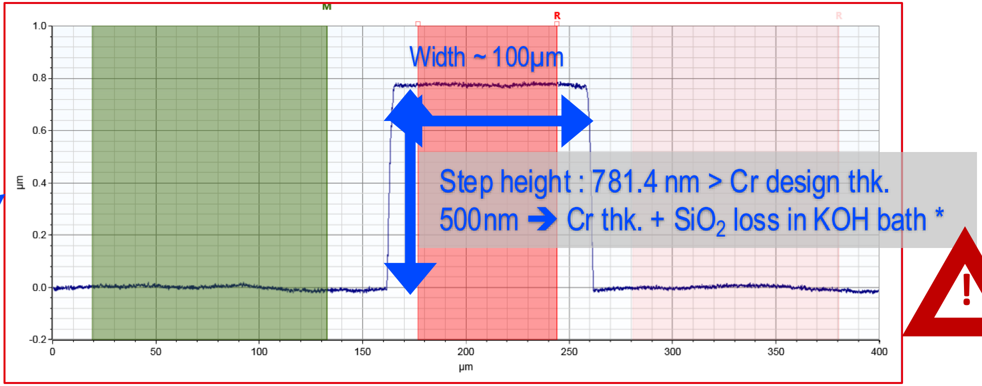
LVDT = linear variable differential transformer

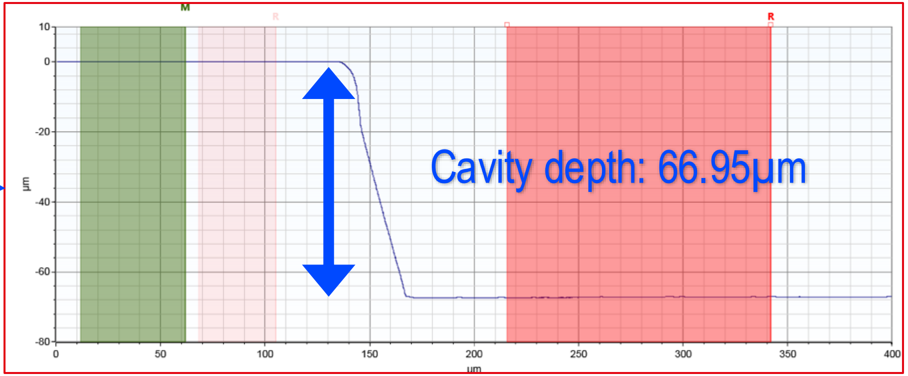
Surface profile measurement





Optical microscope

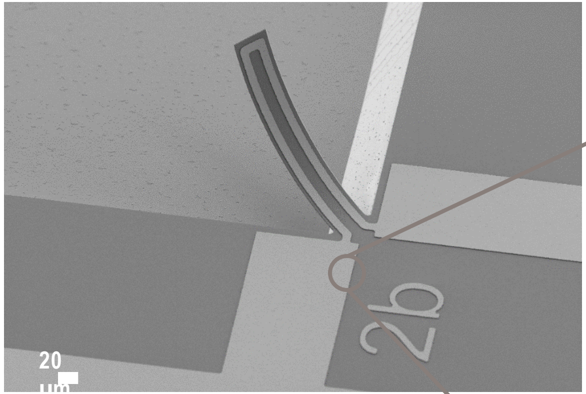




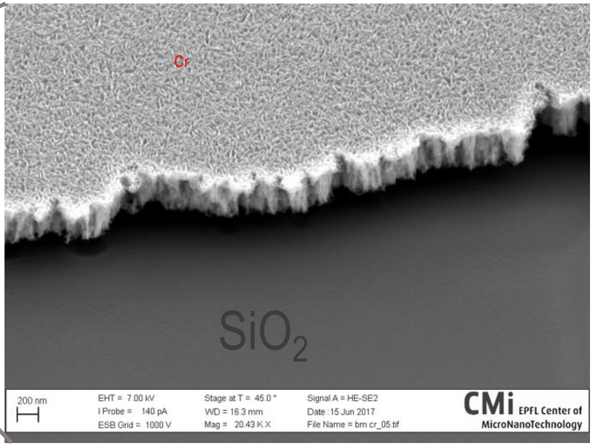
* Please refer to the previous module: **Case study: thermo-mechanical micro-actuator**

Bi-morph surface roughness measurement

- measure the surface roughness of Cr and SiO_2

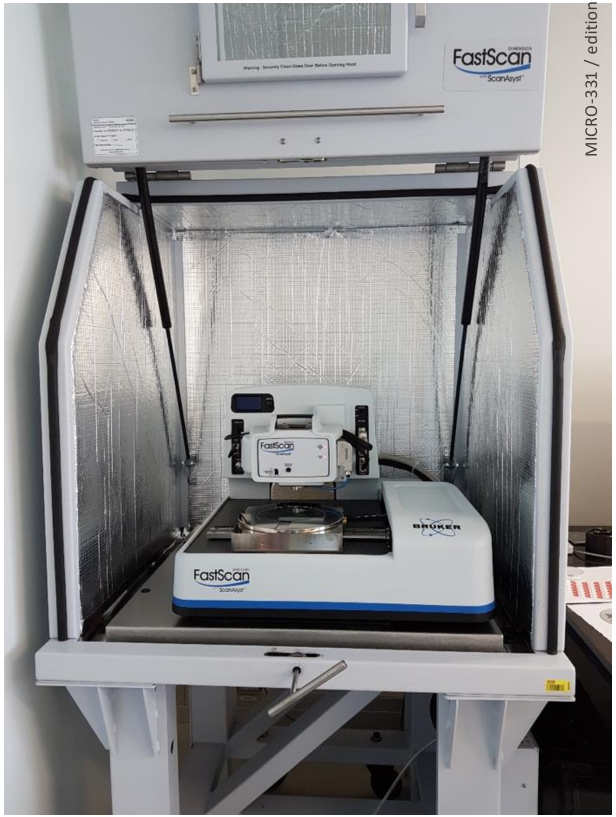


SEM image of the bi-morph @ 3 keV and 45 degrees tilt

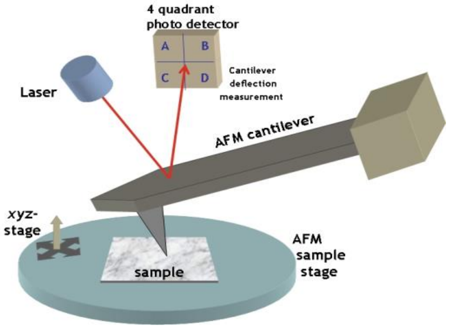


SEM image to indicate where the surface roughness is measured

Atomic Force Microscope: AFM



3 types of Microscopes
Probing a surface / detecting the reaction



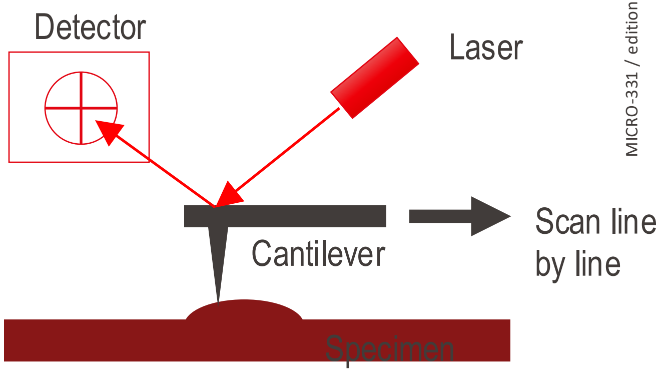
Optical ("light") microscope
'Probe': Light that is reflected from or transmitted through sample.

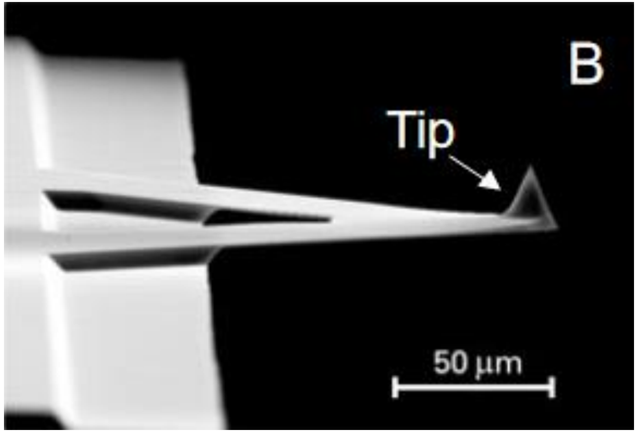
Electron microscope
'Probe': Electrons (shorter wavelength) that are re-emitted from or transmitted through sample.

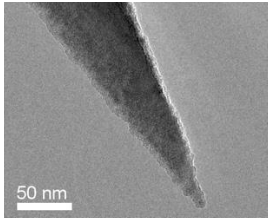
Scanning Probe microscope
'Probe': tip that interacts locally with surface (force, electrons, photons)

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

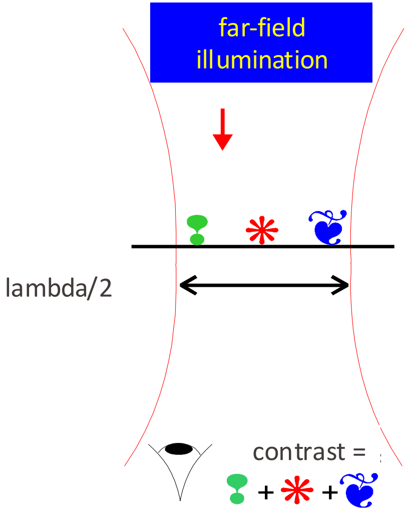


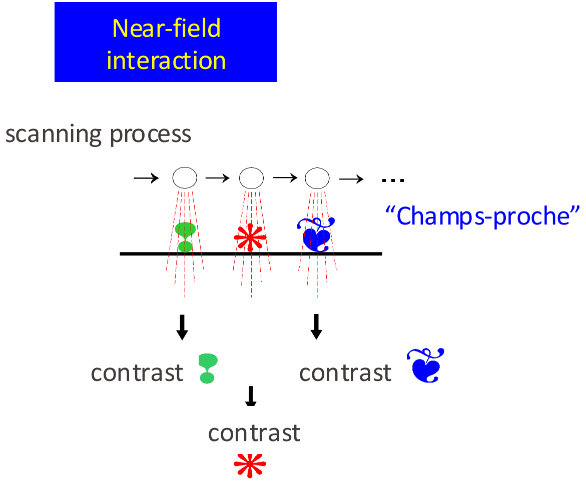




Scanning Probe Microscopy

- conventional microscopy
  - wavelength
  - resolution prop. lambda
- probe microscopy
  - spatial dimension
  - resolution = f (a,d,…)





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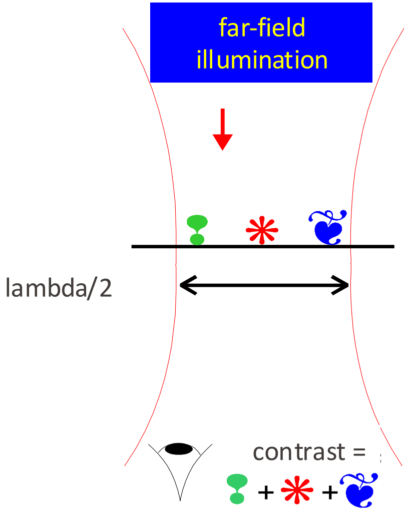
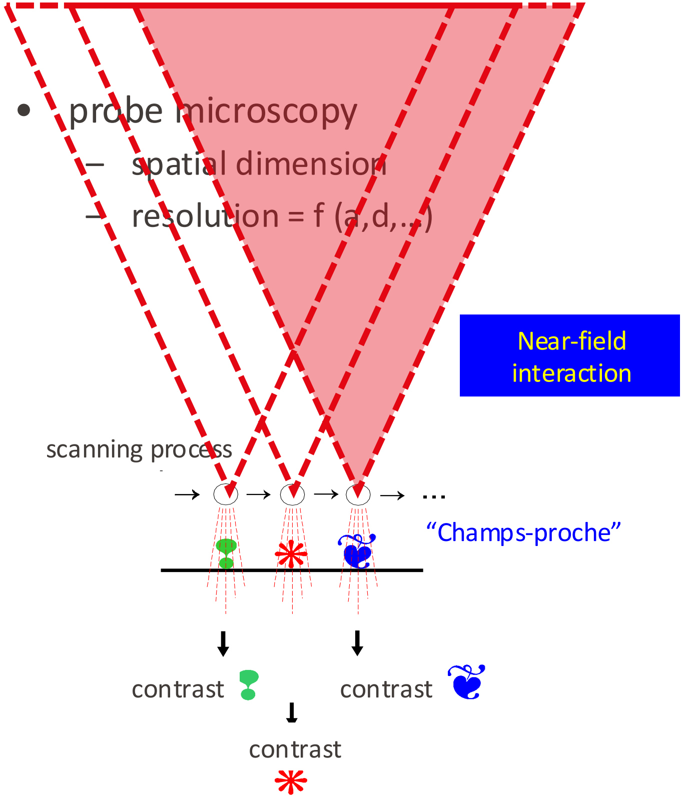




Microfabrication of cantilevers

- Cantilever = force transducer
- Important parameters
- Spring constant k
- Resonance frequency f
- Practical values
- E: Young's modulus (material constant) E_{si} = 1.7 E11 N/m^2
- I: cross sectional moment of inertia (square cross section I = w t^3/12)

Forces: Micro/nano/pico Newton

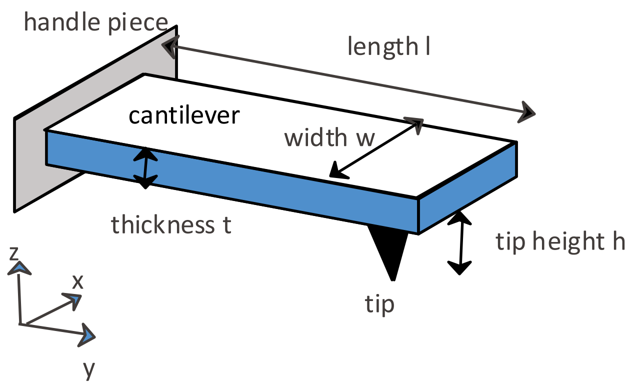
general

$k = 3 E I / L^3$

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m_{eff}}}$$

Rectangular shape

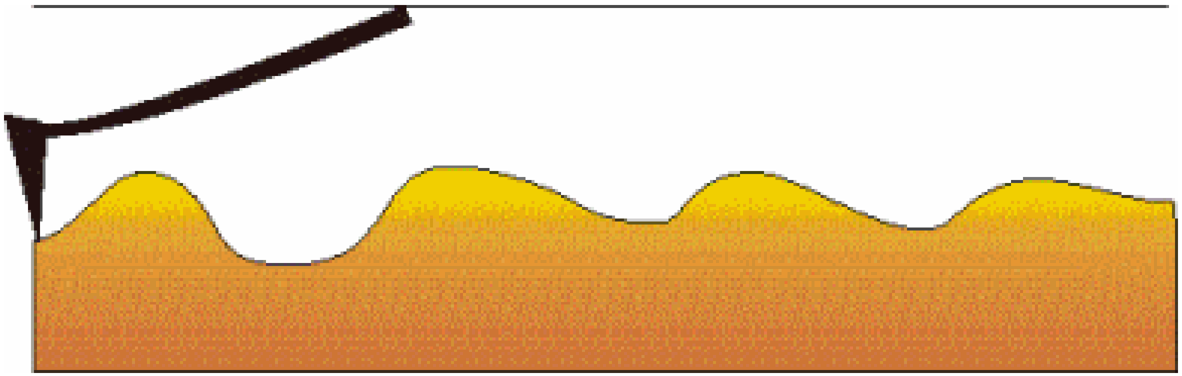
$$k = \frac{Ewt^3}{4l^3}$$



k: 0.01-10 N/m
f: > 10kHz

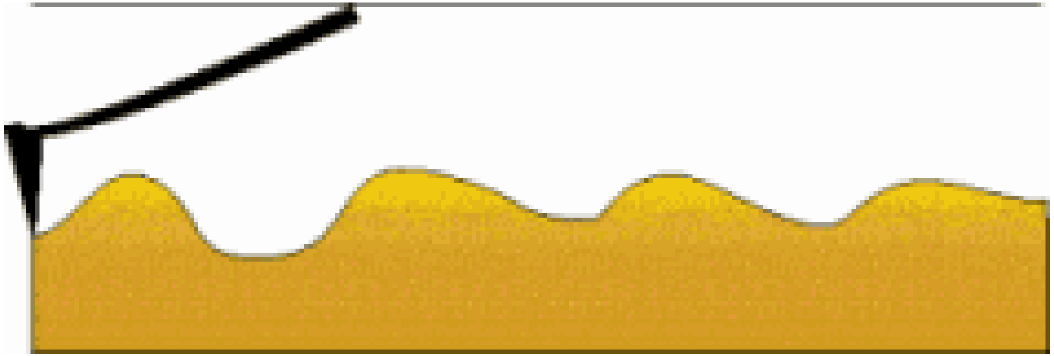
Contact mode SFM/AFM (constant height)

- Constant height (no z-axis actuation)
- Cantilever is bending
- Contact force is modulated
- Risk of tip and/or sample damage

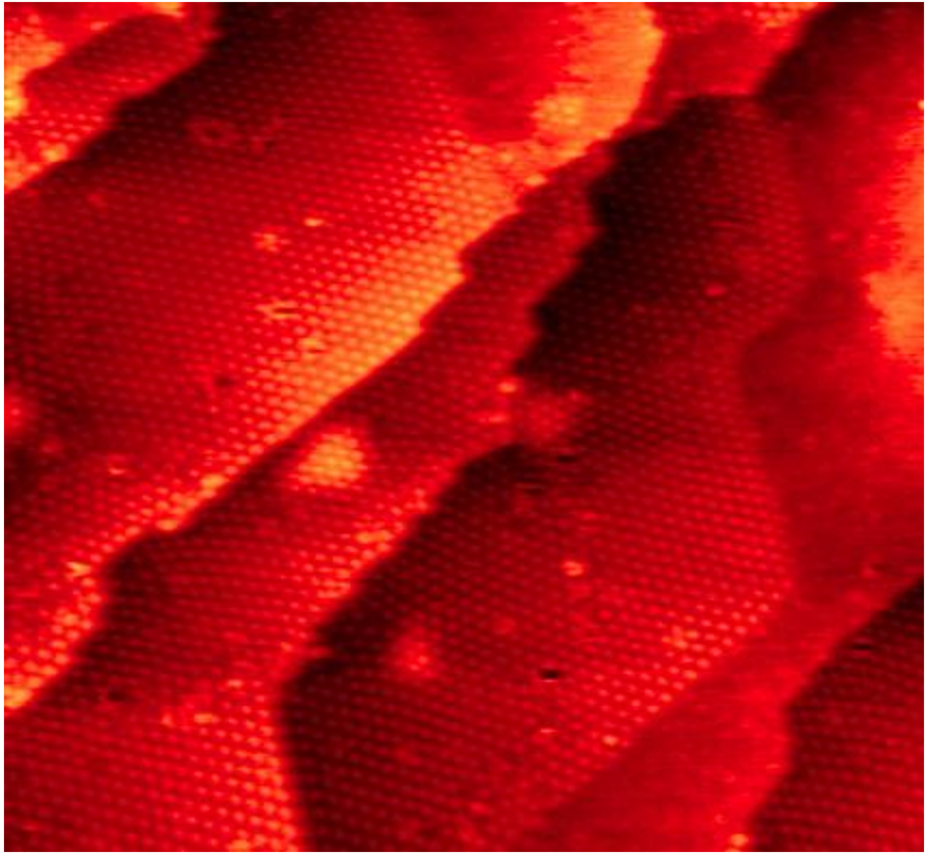


Contact mode SFM/AFM (constant force)

- Constant force during scanning (z-axes actuation)
- Cantilever bending is constant
- Z-feedback moves sample vs. probe
- Avoid tip damage
- Avoid sample damage
- Important for friction force measurements

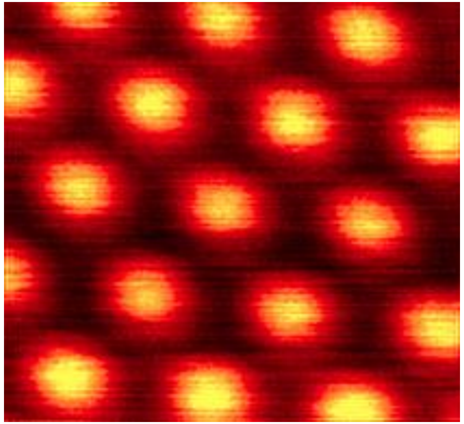


AFM of graphene

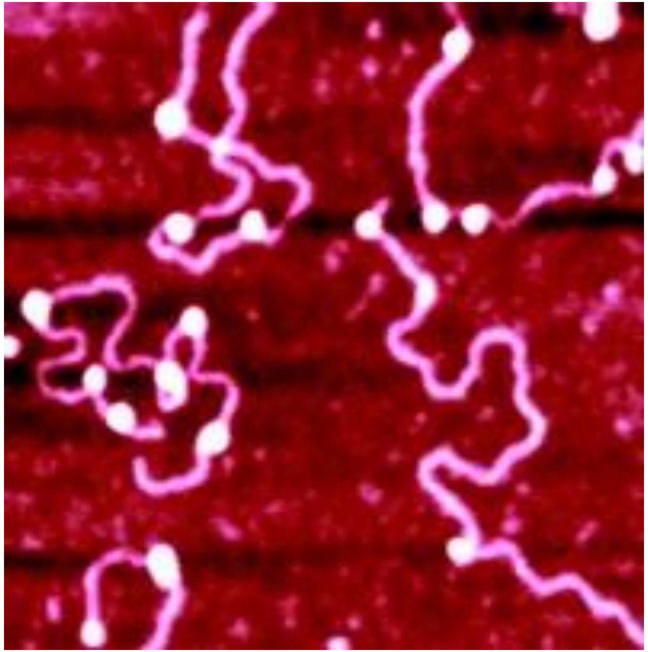


150 nm x 150 nm

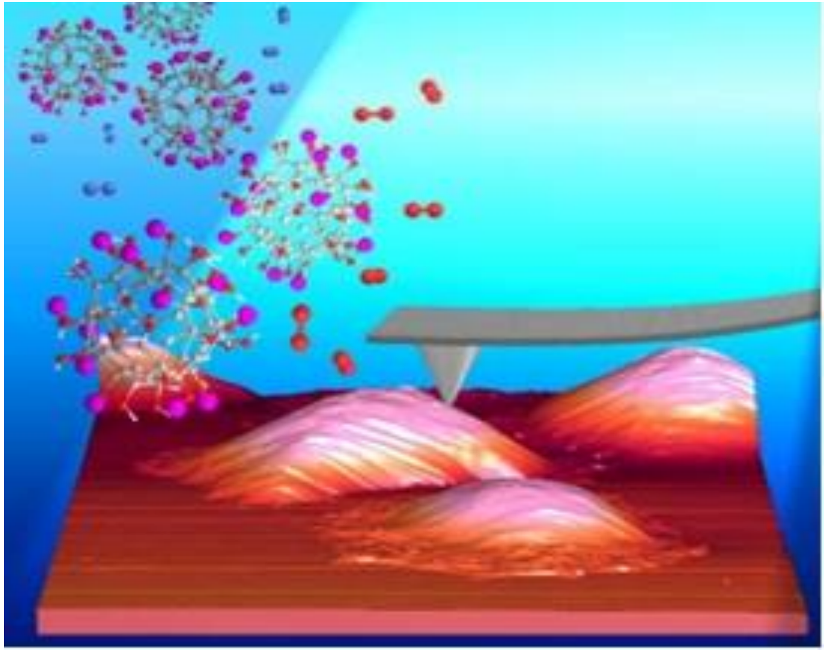
9nm x 9 nm



Microscopy in biology



DNA molecules

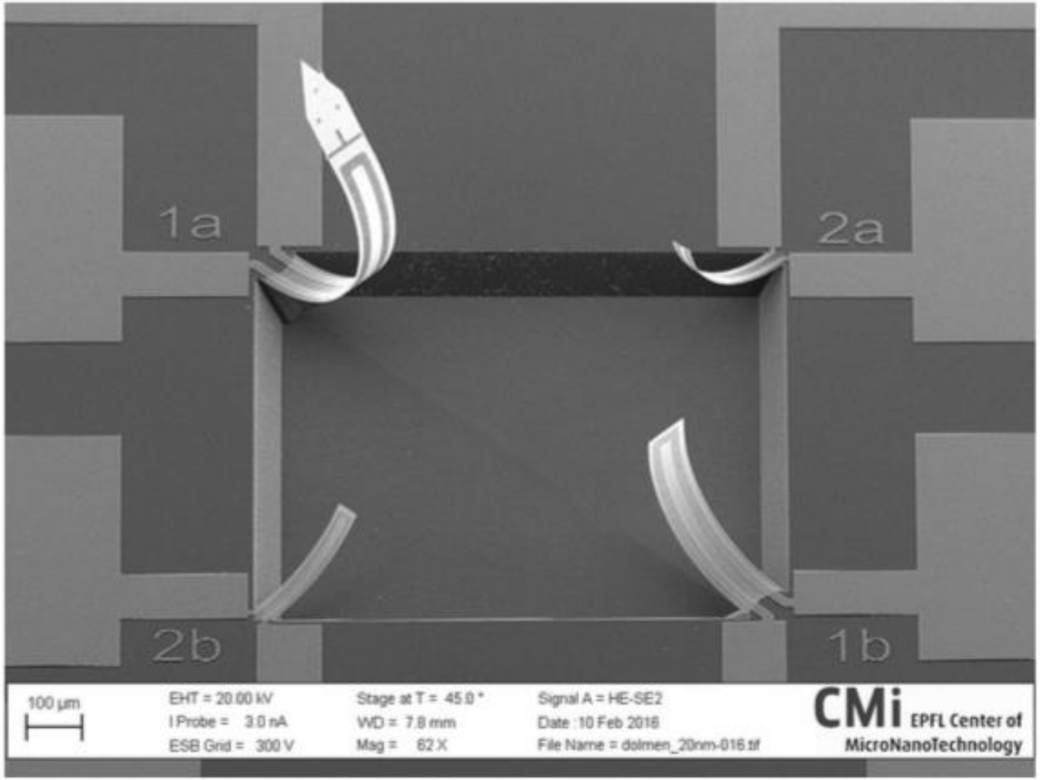


AFM on living cells

Scanning electron microscopy SEM

École
polytechnique
fédérale
de Lausanne

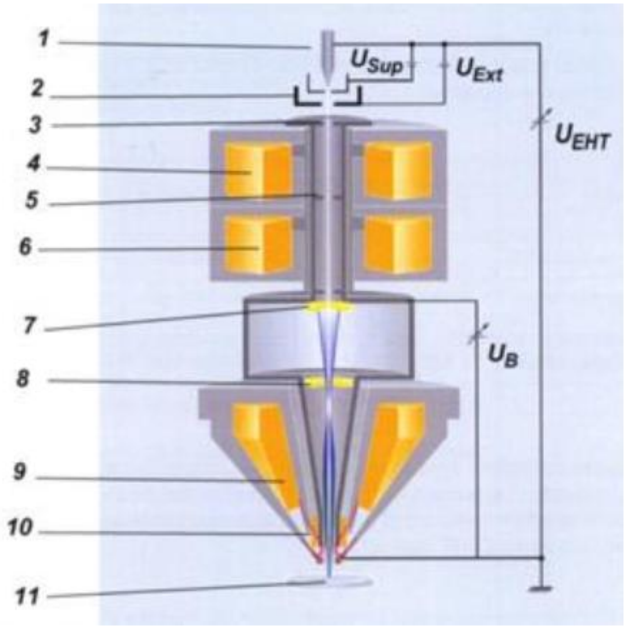
Scanning electron microscopy



Using electron results in higher resolution compared to visible light

Schematics of SEM system

- 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

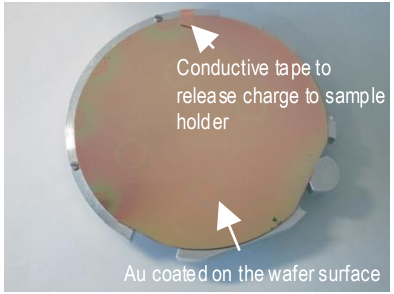


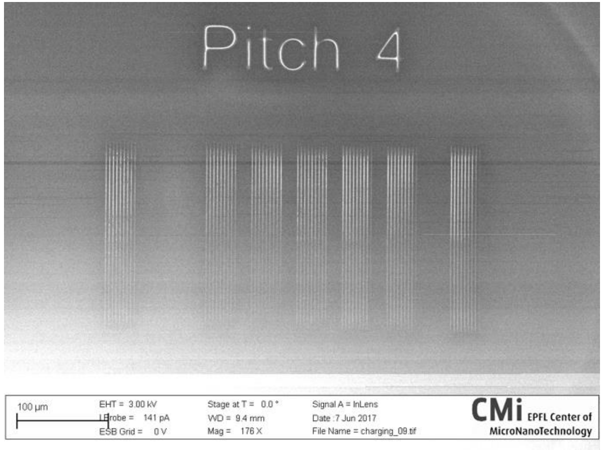
Zeiss The GEMINI II column

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

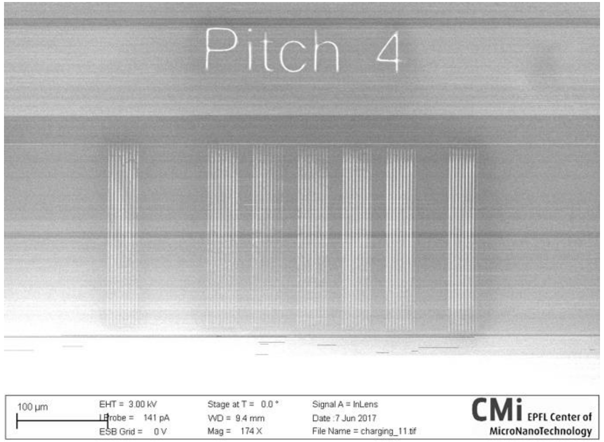
Charging issue

- 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

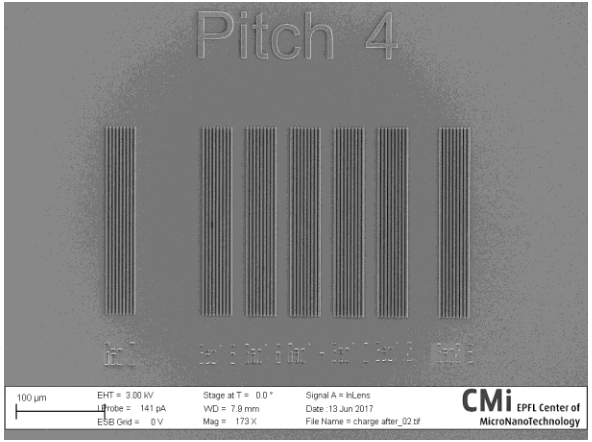




Poor image due to charging
(PR on SiO_2)



Even worse over time
(PR on SiO_2)



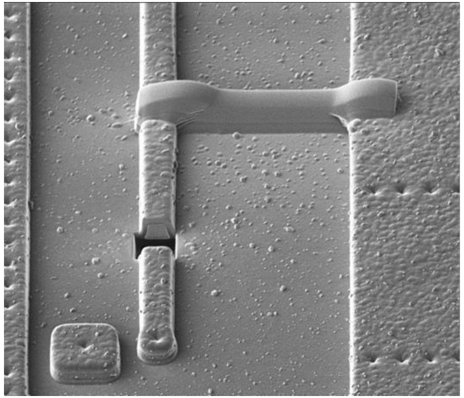
With Au coating

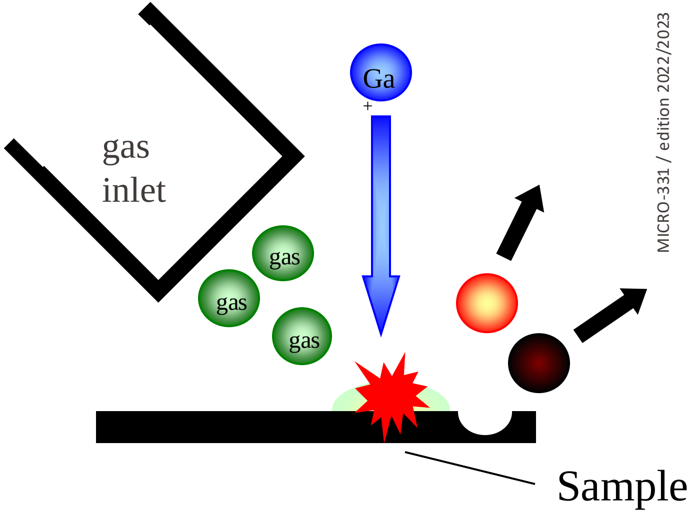
EPFL

Focused ion beam FIB

Access to inner parts of IC

Gas-Assisted Etching and deposition





Enhanced milling rate

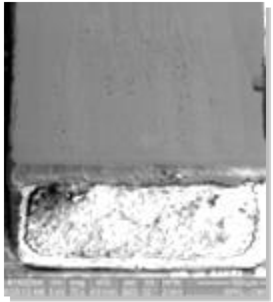
Redeposition is reduced due to volatile reaction products

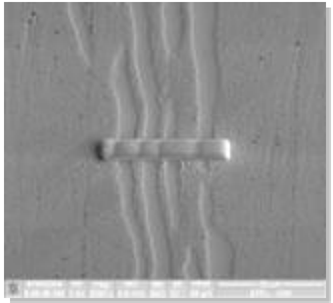
Typical gases: Cl_2, I_2, H_2O, XeF_2

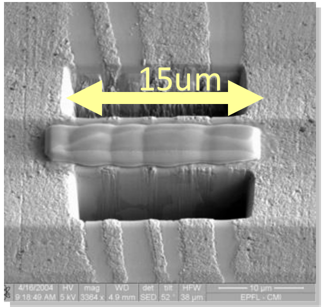
Etch enhancement:

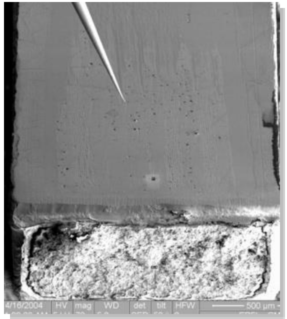
	Si	Al	W	SiO_2
Cl_2	7-10	7-10	None	none
XeF_2	7-12	none	7-10	7-10

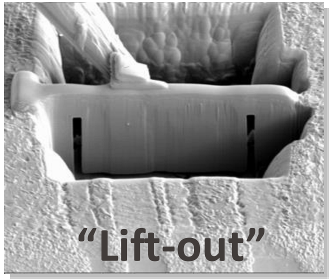
Applications TEM-lamellas and Lift-out











TEM grid, 3mm diameter

https://www.youtube.com/watch?v=omcxfWGJzsw