Profilometry

NNUM thematic seminar

Analysis

Wednesday 10 May 2017

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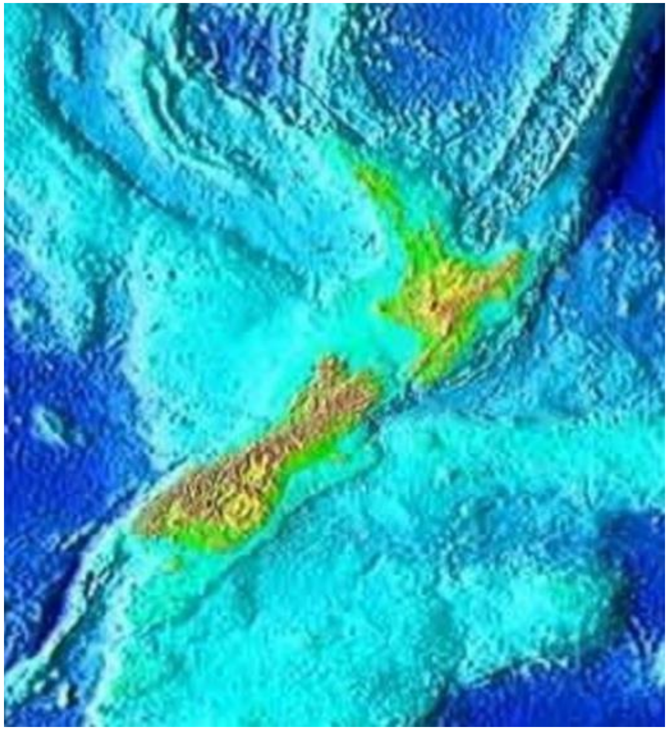
NNN Nordic Nanolab Network

Outline

- What is topography?
- Techniques for measuring topography
  - White Light Interferometry (WLI)
  - Atomic Force Microscopy (AFM)
- Summary: When to use which technique

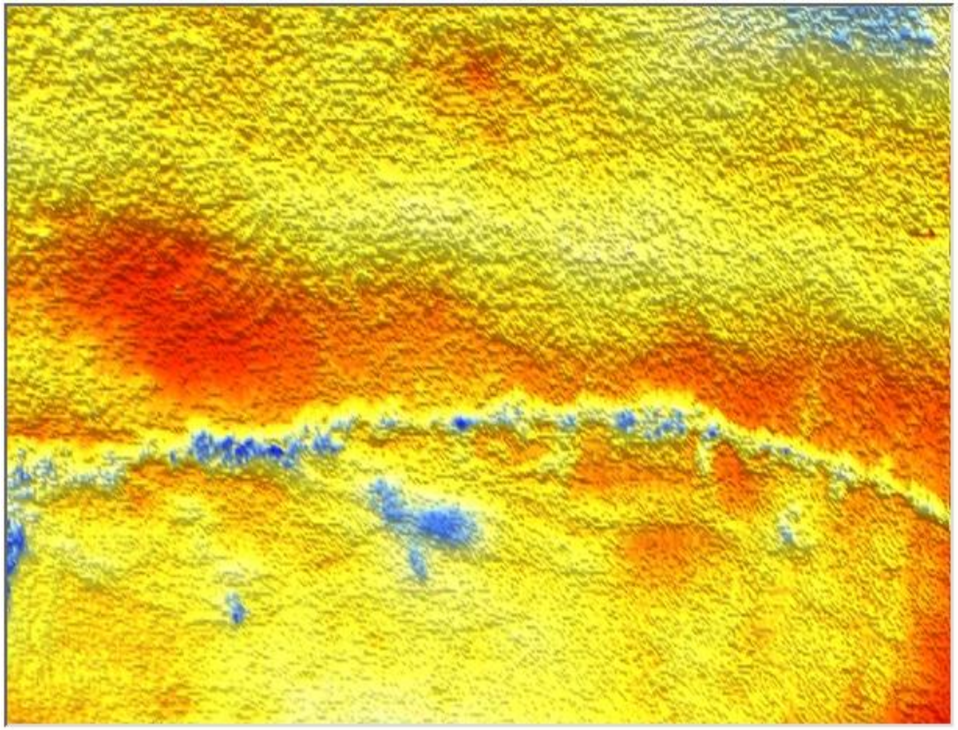
Topography

100 km



New Zealand
and surrounding sea bed

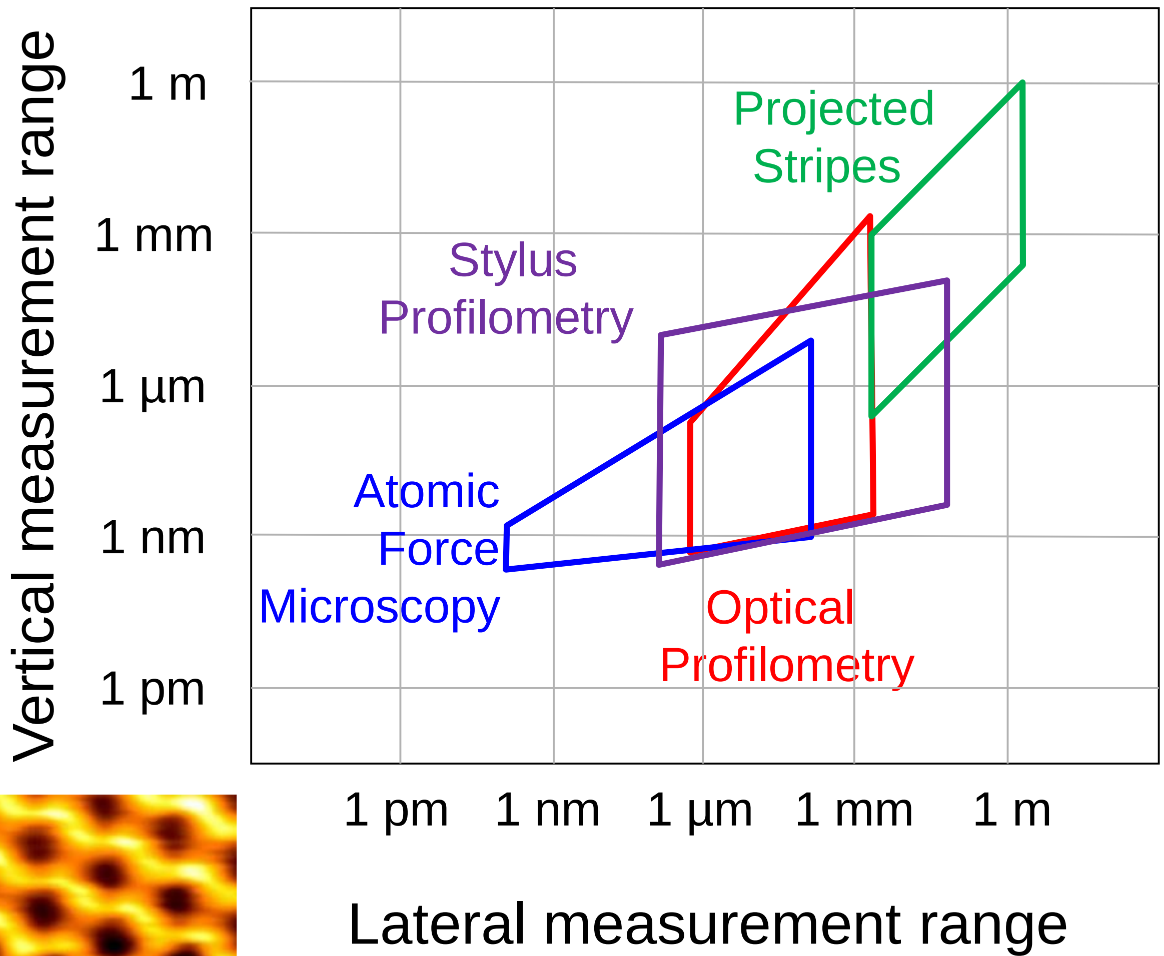
100 µm

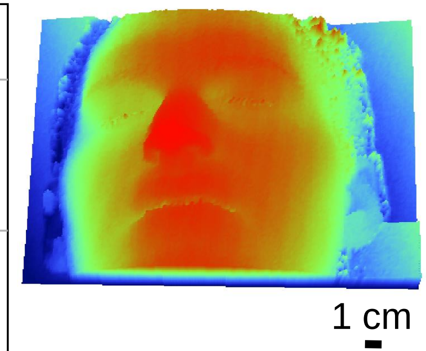


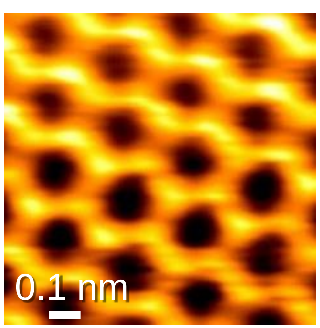
Surface of a tooth with an amalgam filling

Topography can be measured on different scales!

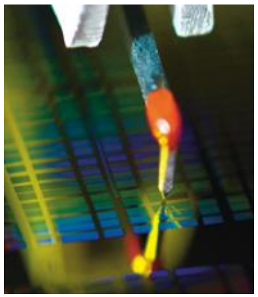
Techniques for measuring topography





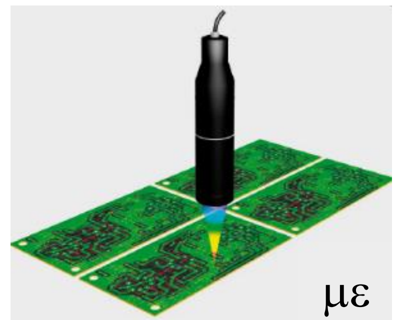


Profilometry (measuring topography)


Dektak

Mitutoyo

- Stylus Profilometry
  - 2D systems [Mitutoyo]
  - 3D systems [Dektak]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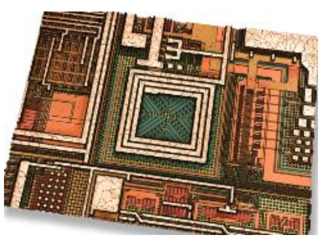
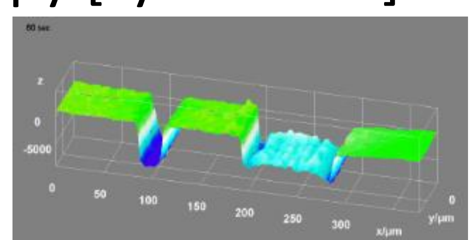
- Optical Profilometry
  - Chromatic Confocal Sensing [Stil, με]
  - Confocal microscopy [Leica, Nikon]
  - Focus variation [Sensofar]
  - White Light Interferometry [Wyko, Zygo, Sensofar]
  - Digital Holographic Microscopy [Lyncée Tec]
  - etc.


Nikon

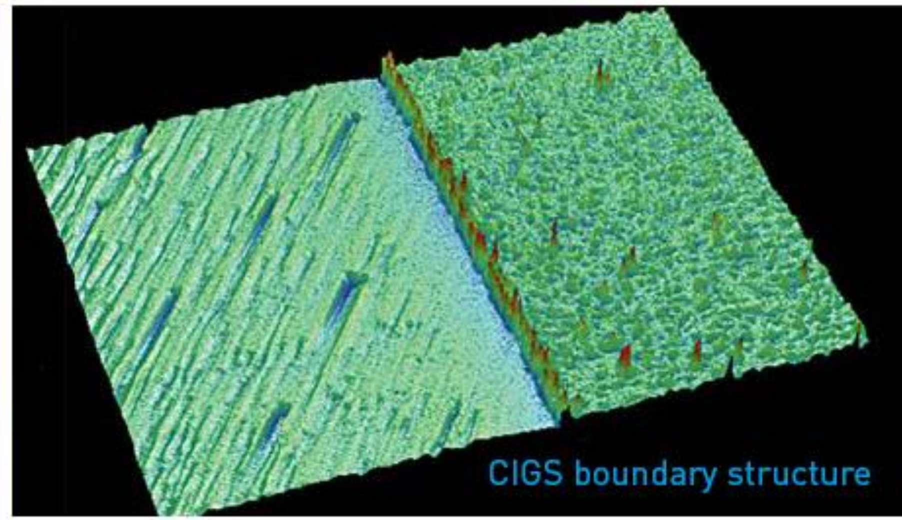

Sensofar

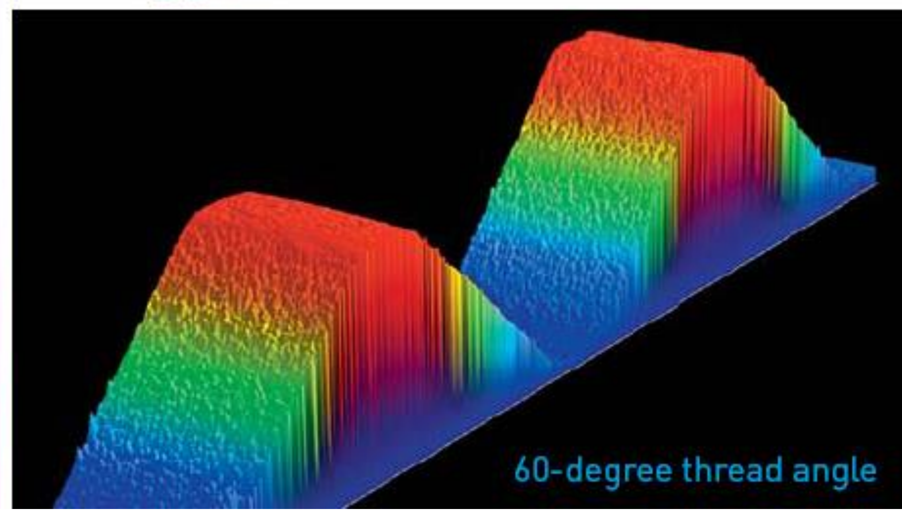


Availability of instruments near you

Location	Stylus Profilometer	Atomic Force Microsopes	Optical Profilometer
NTNU NanoLab	Dektak 150		
Lund Nano Lab	Dektak 6M		
Chalmers (NFL)	Tencor P15, Tencor AS500, Dektak	Dimension 3100 and ICON	Wyko NT1100
Uppsala (MSL)	Dektak 150, Dektak XT		Wyko NT1100
DanChip	Dektak 8, Dektak XTA	Dimension ICON PT	Sensofar
UiO	Dektak		
USN	Dektak		Wyko NT1100
Aalto	DektakXT, Alpha		
SINTEF		DI MultiMode	Wyko NT9800

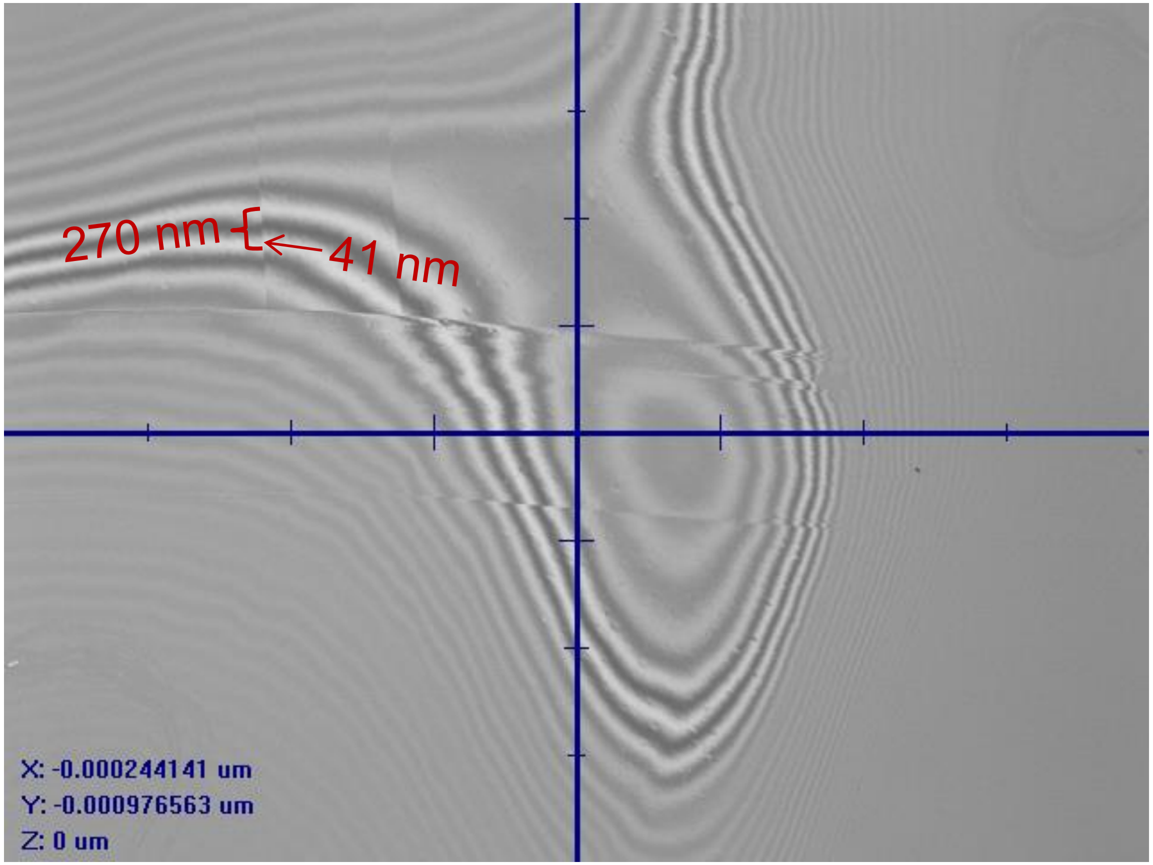
White Light Interferometry (WLI)
WYKO (Veeco/Bruker) optical profiler

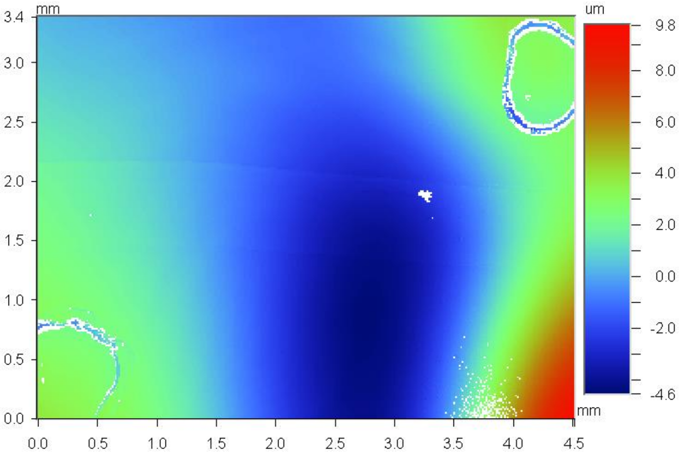




Vertical Scanning Interferometry (VSI)

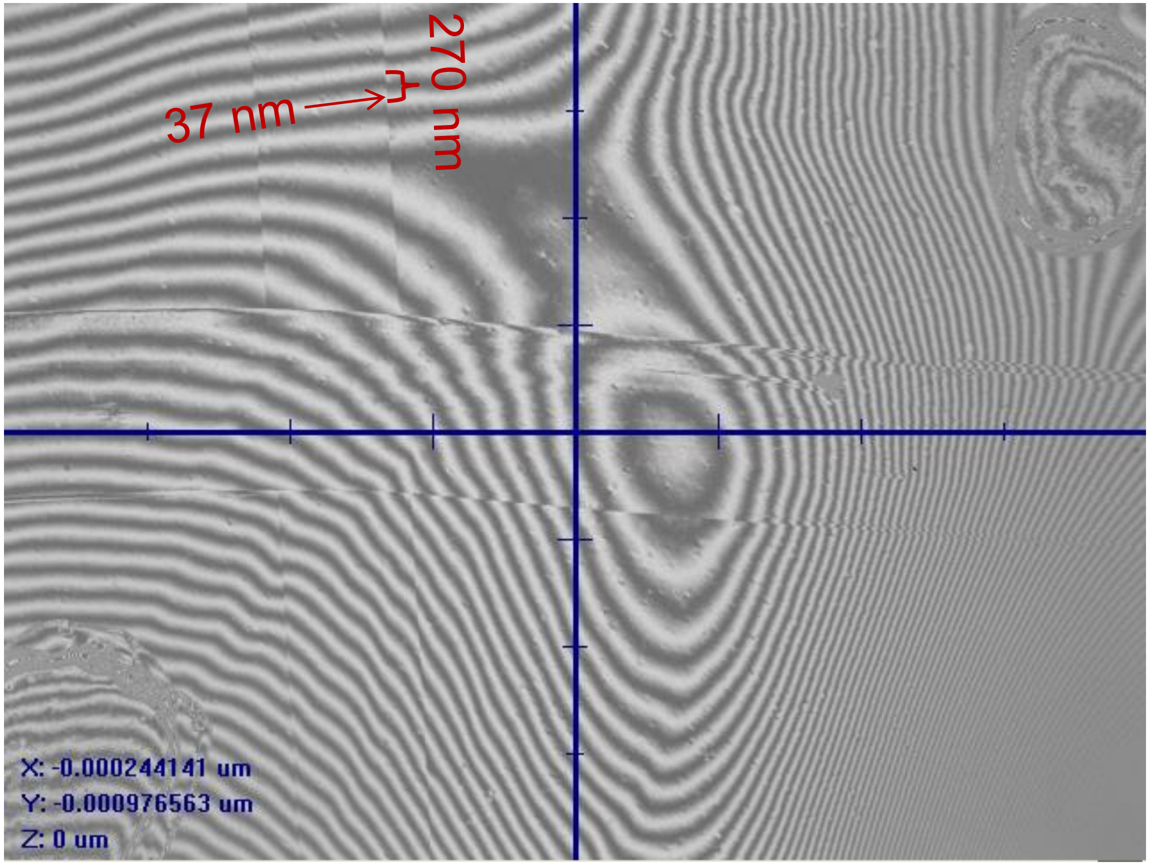
- Height range: Several millimeters
- Noise level (3 nm) too high for very flat surfaces

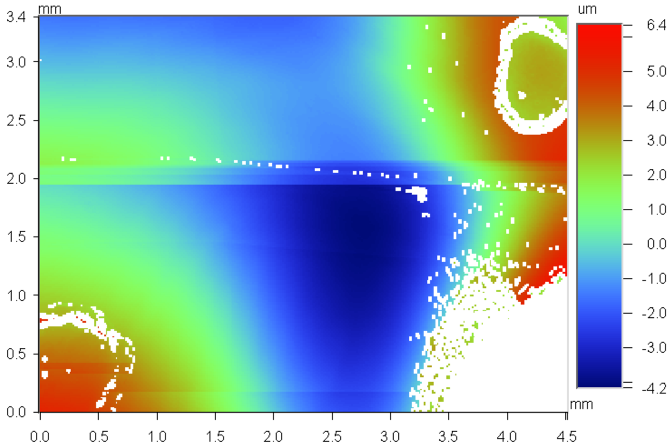




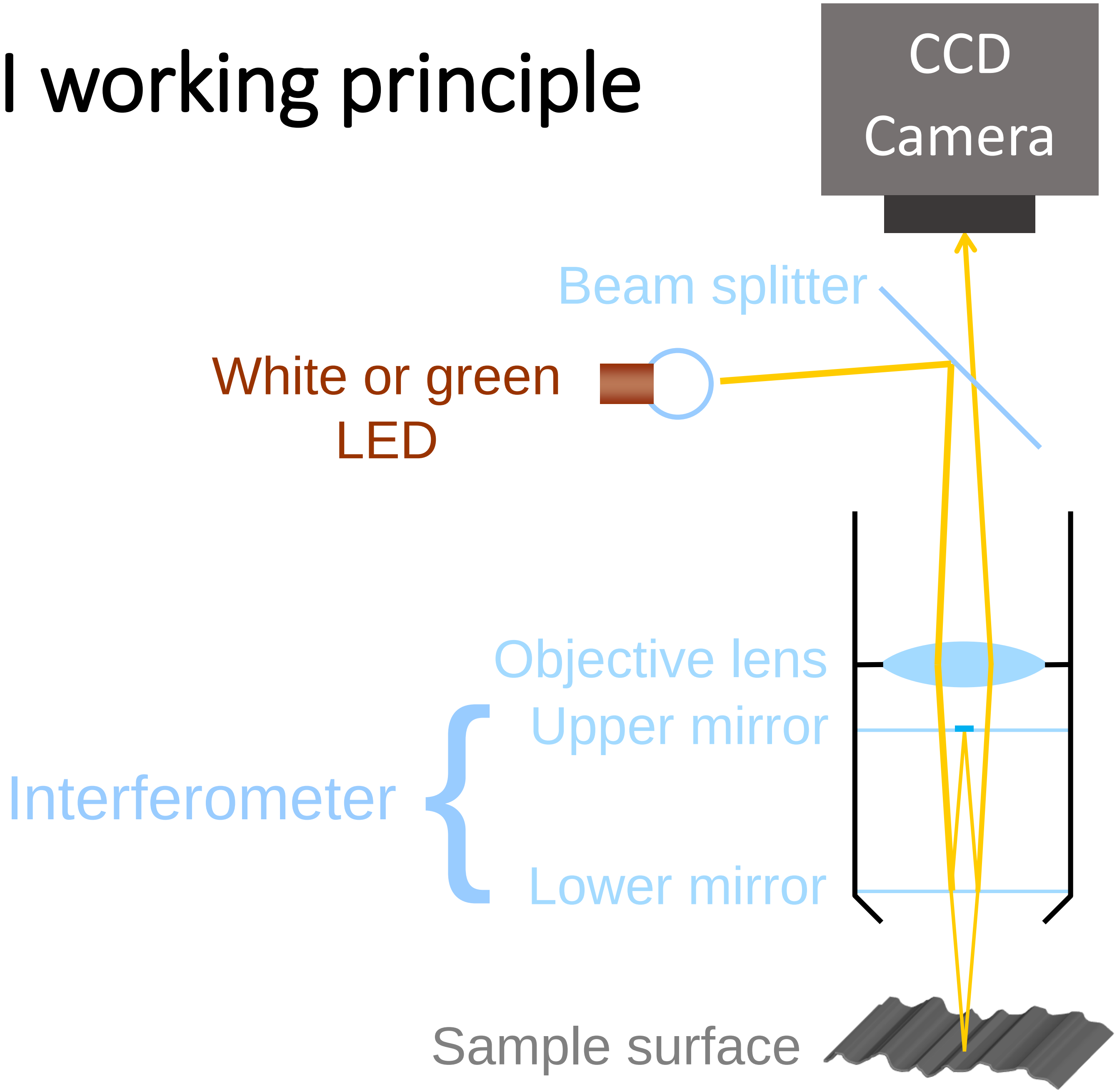
Phase Shifting Interferometry (PSI)

- Low noise level (0.3 nm), good for flat surfaces
- Can not measure sharp steps

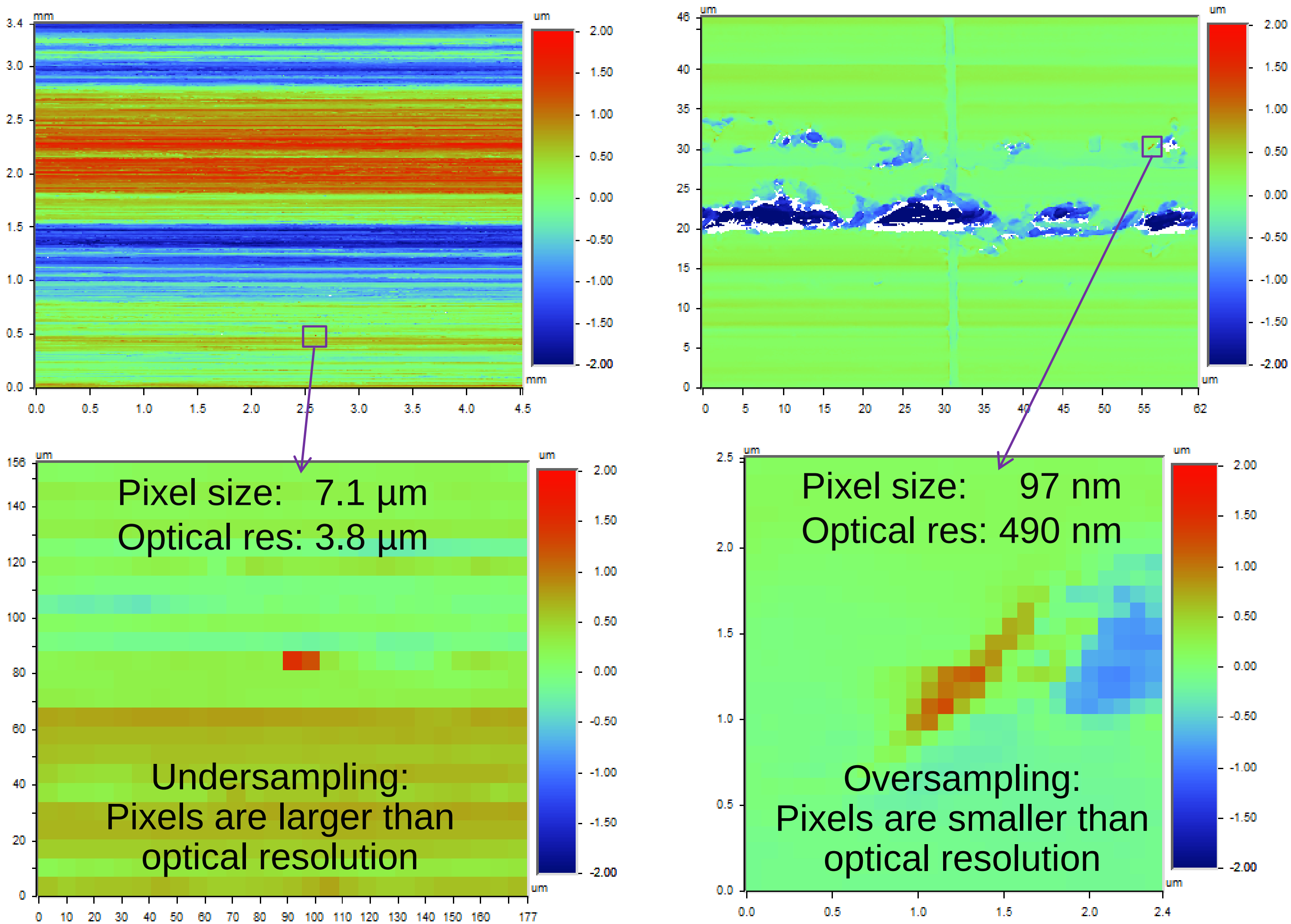




WLI working principle



Pixel size vs. Optical resolution



Magnification: 2.5*0.55x=1.4x

Magnification: 50*2x=100x

Wyko NT9000 Series Optical Profiling Systems Objectives Chart

OBJECTIVE SPECIFICATIONS WITH STANDARD-RESOLUTION CAMERA

	Parfocal Set A Objectives[1]								Parfocal Set B Objectives			Non-Parfocal
Magnification[2]	2.5XL	5X	5XL	10XBF	10X	20X	50X	100X	2XLWD	5XLWD	10XLWD	1.5XL
Interferometer Type	Michelson	Michelson	Michelson	Brightfield non-interferometric	Mirau	Mirau	Mirau	Mirau	Michelson	Michelson	Michelson	Michelson
Numerical Aperture	0.07	0.12	0.13	0.25	0.3	0.4	0.55	0.7	0.06	0.14	0.17	0.04
Working Distance (mm)	3.5	6.7	9.4	10.6	7.4	4.7	3.4	2	22	22	22	9.6
Optical Resolution (µm)[3]	3.82	2.23	2.06	1.07	0.89	0.67	0.49	0.38	4.86	1.91	1.57	6.52
Practical Maximum Slope (deg)[4]	1.9	3.8	3.8	—	7.6	14.2	26.7	34.8	1.5	6.4	7.6	1.2
Turret Mountable	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No
Field of View, with magnification selector lens (mm x mm)[5]												
0.55X	4.61 x 3.46	2.3 x 1.73	2.3 x 1.73	1.15 x 0.86	1.15 x 0.86	0.58 x 0.43	0.23 x 0.17	0.12 x 0.09	5.76 x 4.32	2.3 x 1.73	1.15 x 0.86	7.68 x 5.76
0.75X	3.38 x 2.53	1.69 x 1.27	1.69 x 1.27	0.84 x 0.63	0.84 x 0.63	0.42 x 0.32	0.17 x 0.13	0.09 x 0.07	4.22 x 3.17	1.69 x 1.27	0.84 x 0.63	5.63 x 4.22
1X	2.53 x 1.9	1.27 x 0.95	1.27 x 0.95	0.63 x 0.48	0.63 x 0.48	0.32 x 0.24	0.13 x 0.1	0.07 x 0.05	3.17 x 2.38	1.27 x 0.95	0.63 x 0.48	4.22 x 3.17
1.5X	1.69 x 1.27	0.84 x 0.63	0.84 x 0.63	0.42 x 0.32	0.42 x 0.32	0.21 x 0.16	0.08 x 0.06	0.04 x 0.03	2.11 x 1.58	0.84 x 0.63	0.42 x 0.32	2.82 x 2.11
2X	1.27 x 0.95	0.63 x 0.4[illegible]	[illegible]	[illegible]	[illegible]	[illegible]6 x 0.12	0.06 x 0.05	0.03 x 0.03	1.58 x 1.19	0.63 x 0.48	0.32 x 0.24	2.11 x 1.58
Spatial Sampling, with magnification selector lens (µm)[5]												
0.55X	7.2	3.6	3.6	1.8	1.8	0.9	0.36	0.18	9	3.6	1.8	12
0.75X	5.28	2.64	2.64	1.32	1.32	0.66	0.26	0.13	6.6	2.64	1.32	8.8
1X	3.96	1.98	1.98	0.99	0.99	0.5	0.2	0.1	4.95	1.98	0.99	6.6
1.5X	2.64	1.32	1.32	0.66	0.66	0.33	0.13	0.07	3.3	1.32	0.66	4.4
2X	1.98	0.99	0.99	0.5	0.5	0.25	0.1	0.05	2.48	0.99	0.5	3.3

Undersampling

Oversampling

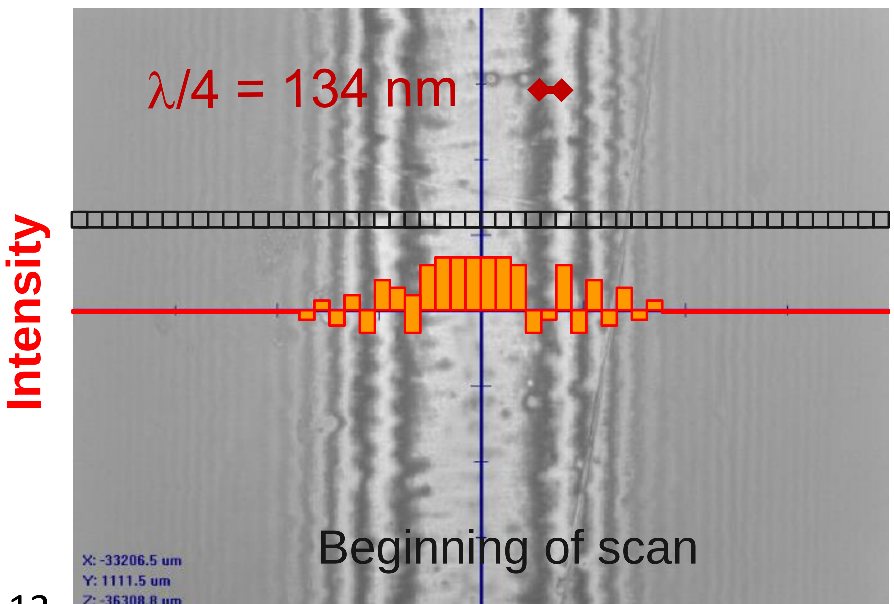
[1]Objectives are parfocal within their respective set (i.e., set A objectives are parfoc
[2]Chart specifications are based on nominal magnifications. Actual magnification is … NIST) traceable calibration standards.
[3]Optical resolution based on Sparrow Criteria at 535nm.
[4]As measured on an optically smooth surface and 1X magnification selector lens. Practical slope limit for non-specular surfaces may be higher.
[5]Field of view and spatial sampling are based on full resolution 640 x 480 pixels measurement array, 9.9µm x 9.9µm pixel size.

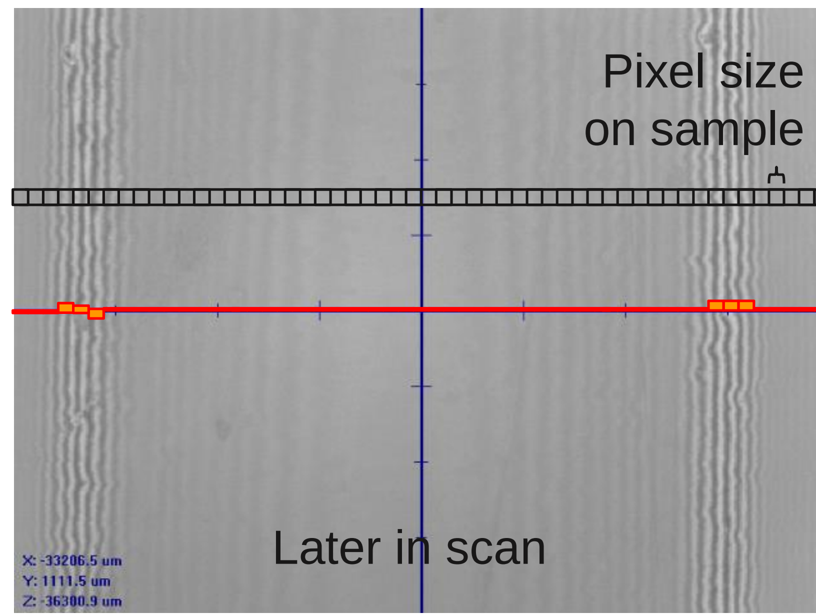
Limit for the surface steepness

- If a dark and bright fringe fills the same pixel, the average is grey so the interference is not detected.
- The **practical maximum slope** gives the steepest surface tilt that can be measured:

$$\theta \leq \arctan(\Delta z / \Delta x) = \arctan(134\,\mathrm{nm} / \mathit{pixelsize})$$

Cylindrical sample surface





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Turret Mountable	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No

Practical maximum slope between 2° and 35°

Field of View, with magnification selector lens (mm x mm)[5]												
0.55X	4.61 x 3.46	2.3 x 1.73	2.3 x 1.73	1.15 x 0.86	1.15 x 0.86	0.58 x 0.43	0.23 x 0.17	0.12 x 0.09	5.76 x 4.32	2.3 x 1.73	1.15 x 0.86	7.68 x 5.76
0.75X												x 4.22
1X												x 3.17
1.5X												x 2.11
2X	1.27 x 0.95	0.63 x 0.48	0.63 x 0.48	0.32 x 0.24	0.32 x 0.24	0.16 x 0.12	0.06 x 0.05	0.03 x 0.03	1.58 x 1.19	0.63 x 0.48	0.32 x 0.24	2.11 x 1.58

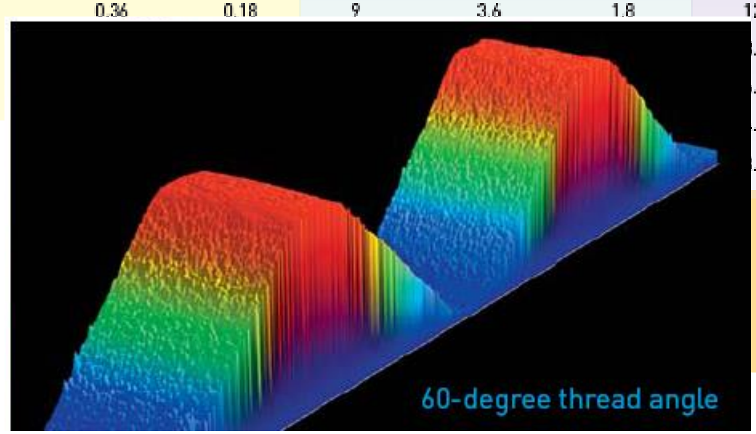
You need a high-magnification lens to see steep facets

Spatial Sampling, with magnification selector lens (µm)[5]												
0.55X	7.2	3.6	3.6	1.8	1.8	0.9	0.36	0.18	9	3.6	1.8	12
0.75X	5.28	2.64	2.64	1.32	1.32	0.66						.8
1X	3.96	1.98	1.98	0.99	0.99	0.5						.6
1.5X												.4
2X												.3

[1]Objectives a
[2]Chart speci
[3]Optical reso
[4]As measure
[5]Field of view

Wyko is a re

If the surface has a high local roughness, you may be able to measure steeper slopes

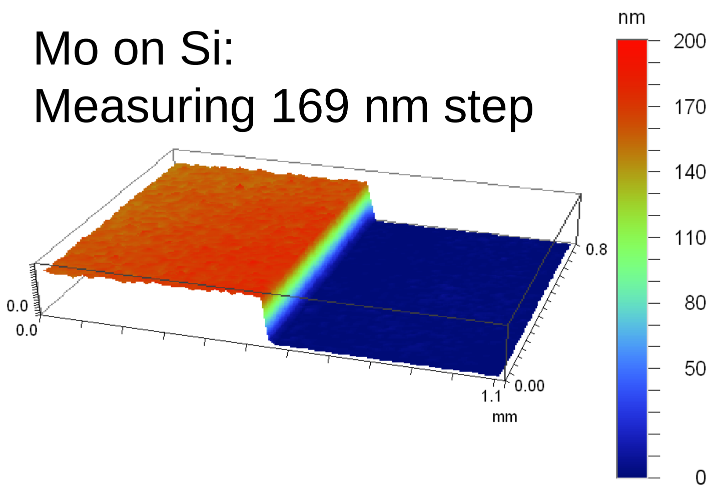


Wrong step height if different materials

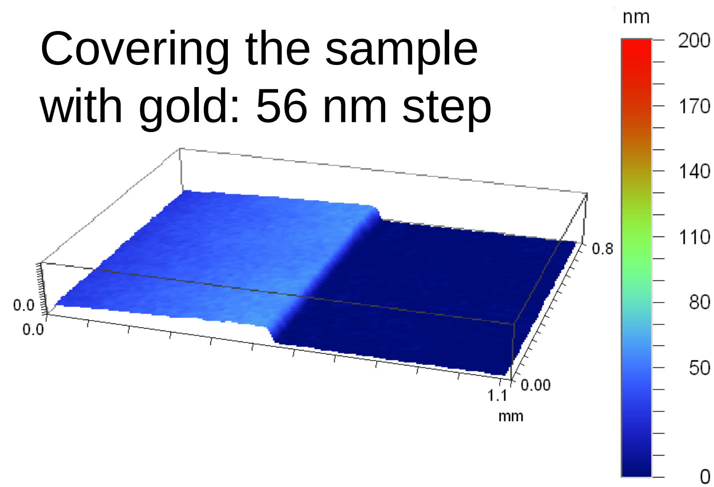
Be careful when measuring

- Transparent materials on a substrate (May give reflections from both surfaces)
- Different materials within the same image (Phase changes upon reflection)

Mo on Si:
Measuring 169 nm step



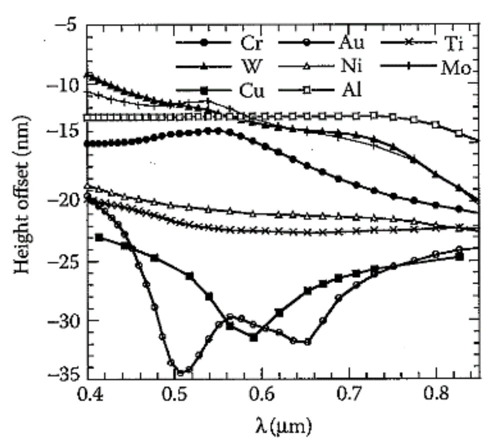
Covering the sample
with gold: 56 nm step

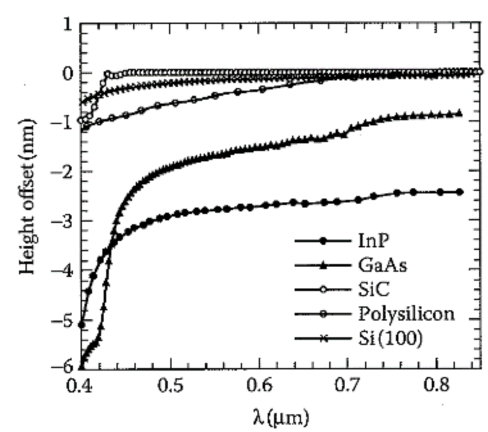


Height offset from material:

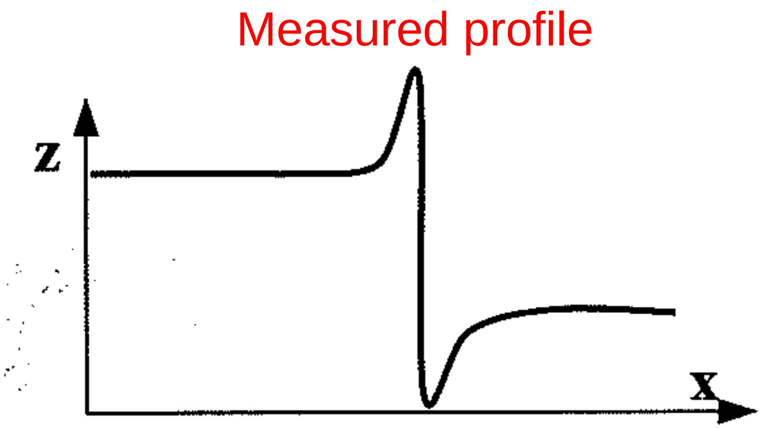
$$h_{offset} = \frac{\lambda}{4\pi}\varphi_S(\theta = 0) = \frac{\lambda}{4\pi}\arctan\left[\frac{2\kappa}{1 - n^2 - \kappa^2}\right]$$

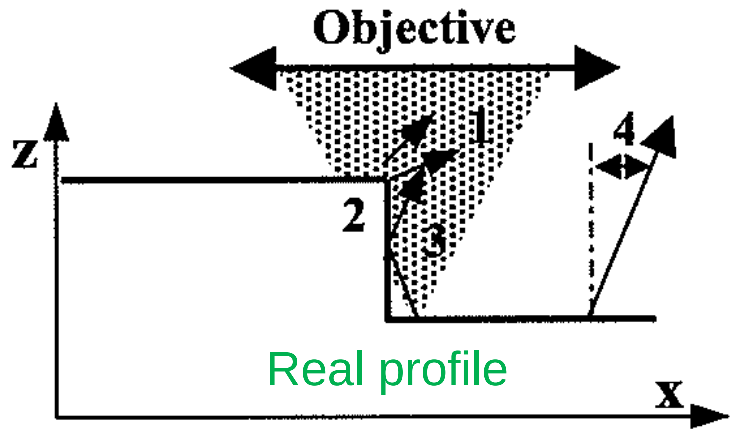
n and κ are real part and imaginary part of refractive index





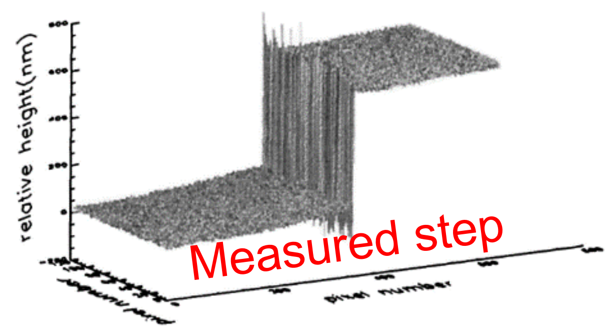
Beware of artefacts near sharp steps

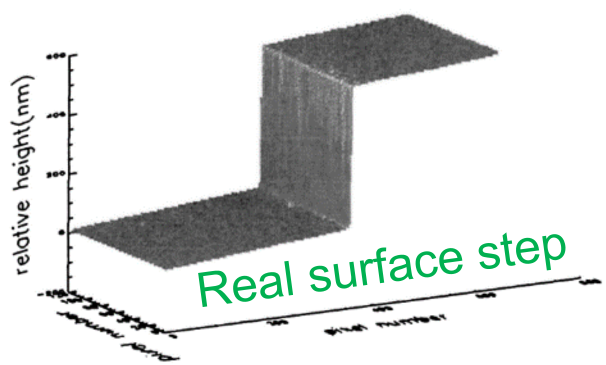




Step height profile display *batwings* due to

- Light diffraction
- Shadowing
- Light reflection
- Lateral translation/tilting during vertical scanning





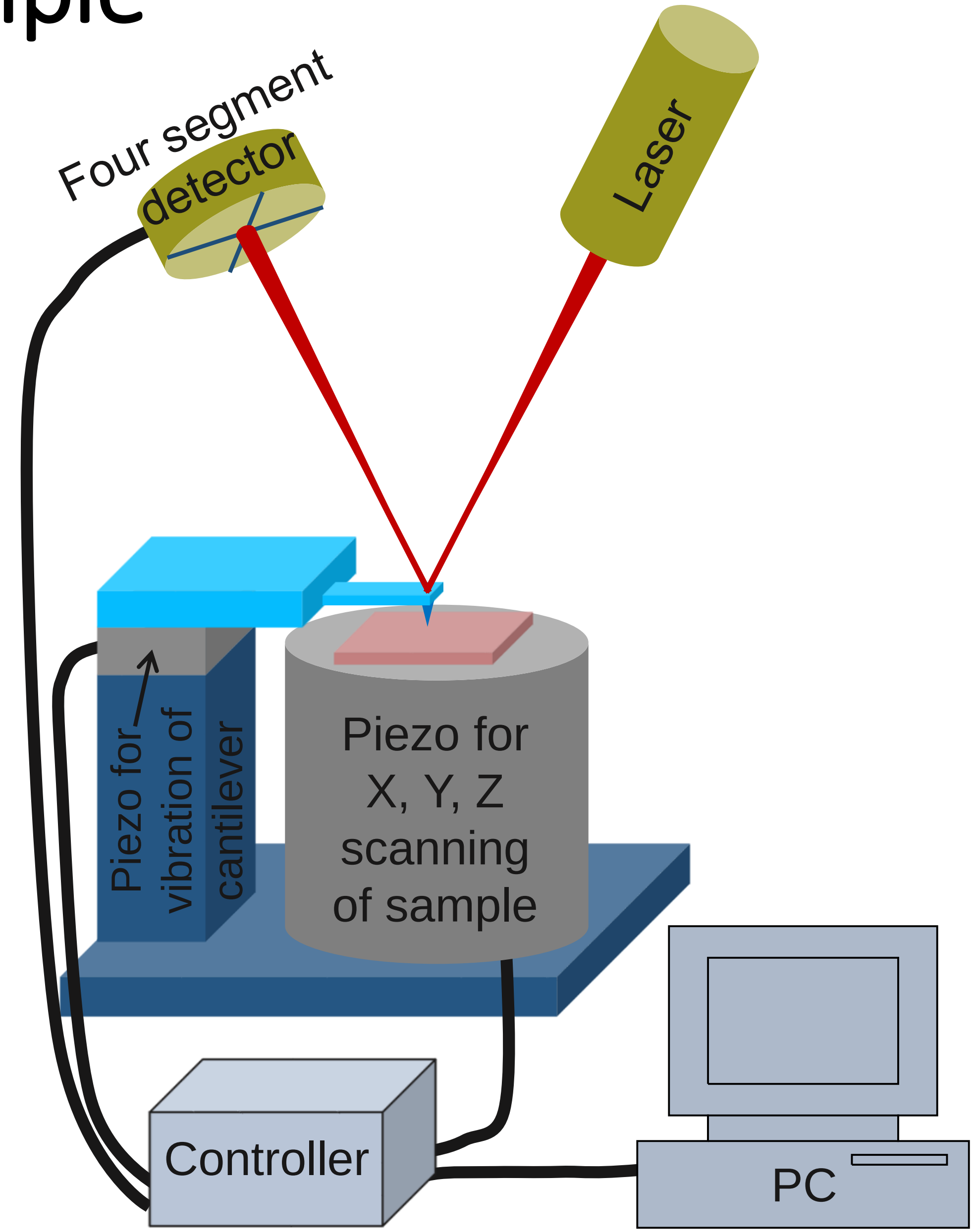
A Harasaki, J Schmit & J C.Wyant, *Applied Optics*, **39**, 2107-2115 (2000)

Atomic Force Microscopy (AFM)

Live demo of intermolecular forces

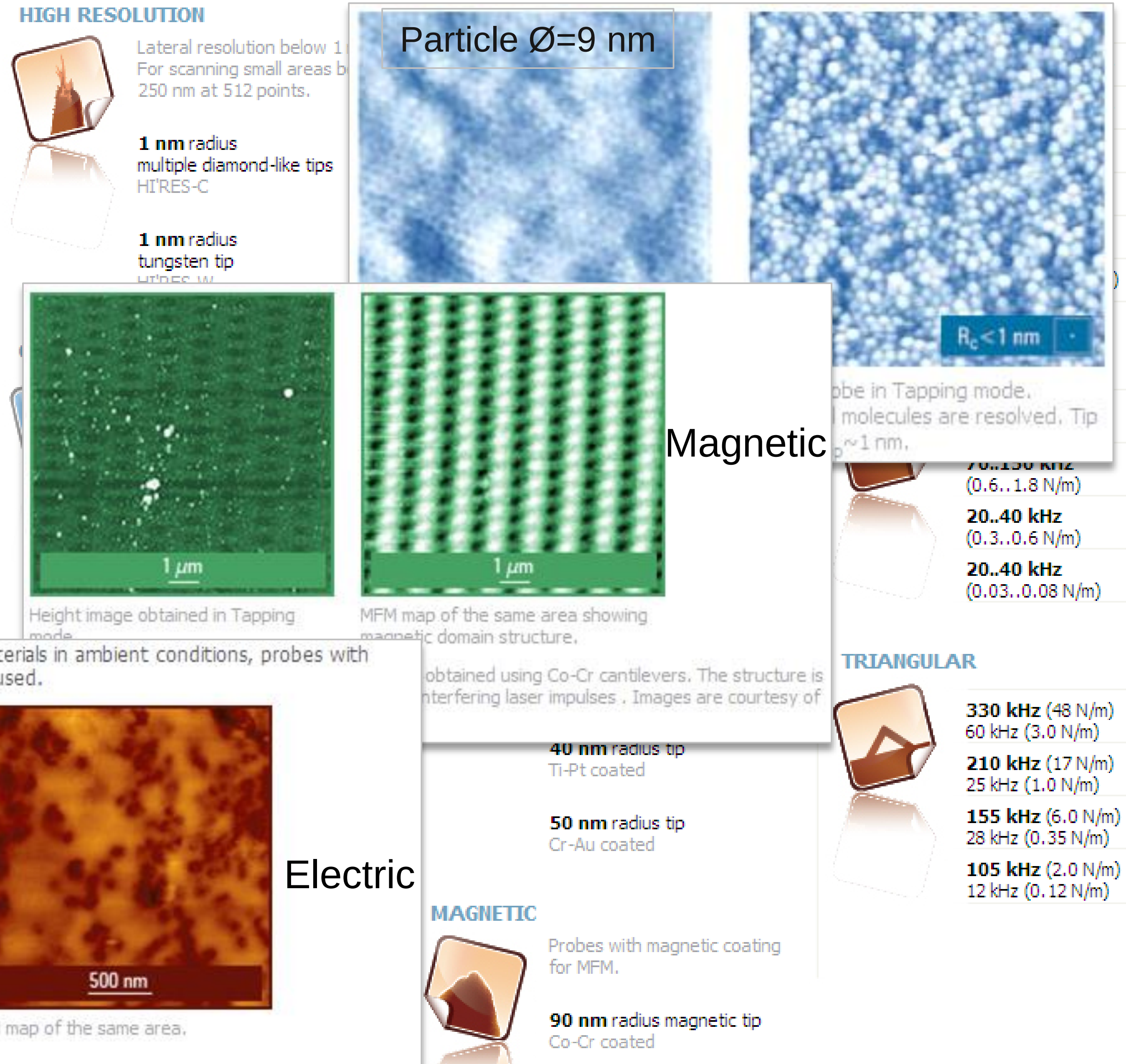
AFM working principle

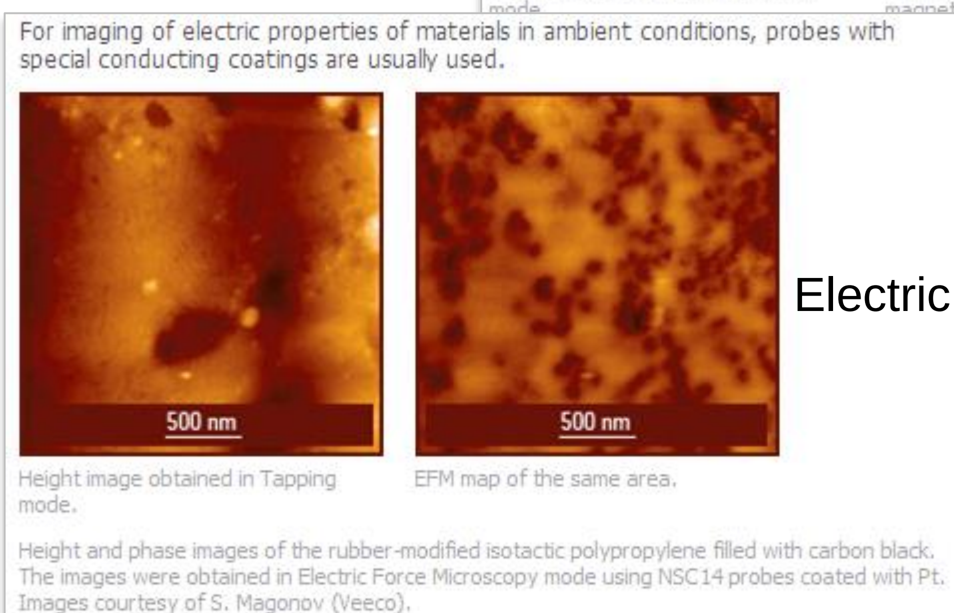
AFM with optical microscope



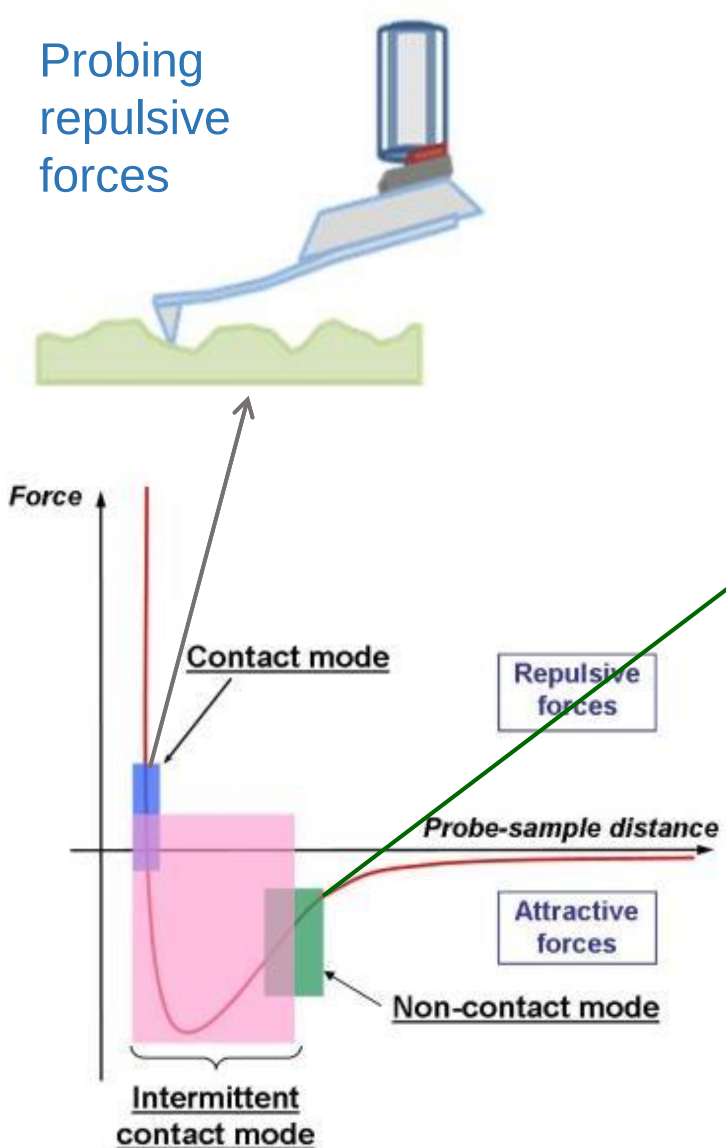
Cantilevers and tips

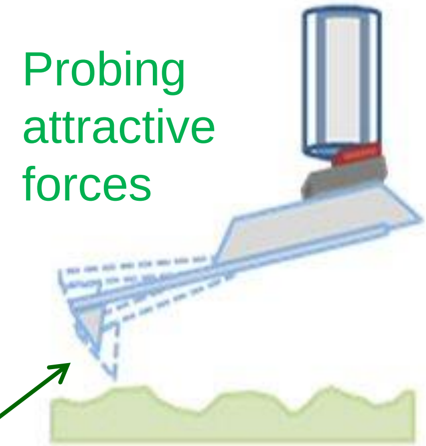
- Many types exist, for different applications





Contact mode vs. Non-contact mode

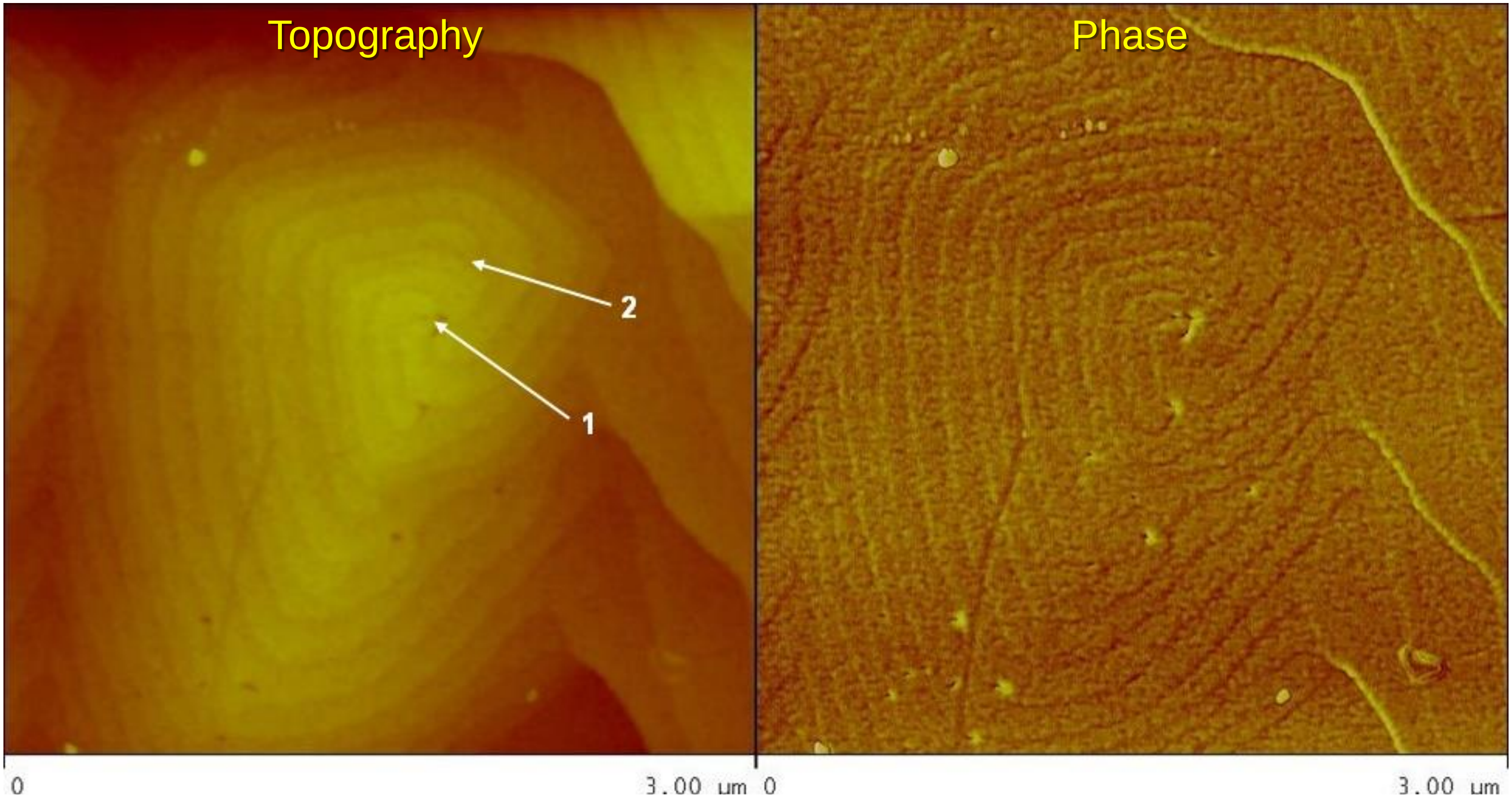




- Contact mode used for hard surfaces
- Non-contact mode for soft surfaces or to detect softness contrast

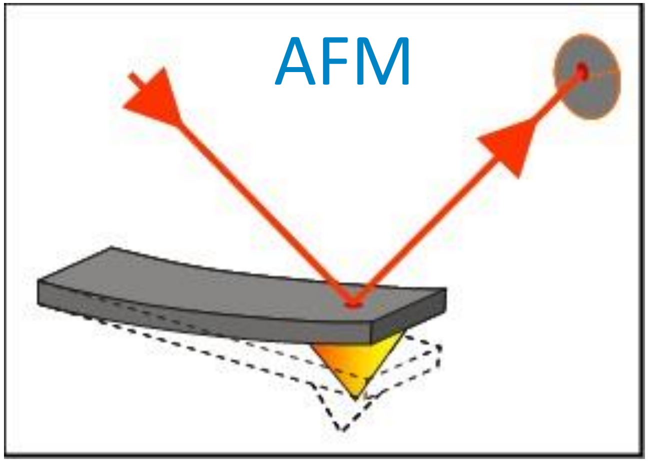
http://perso.univ-lemans.fr/~bardeau/laboLPEC/afm/afmintroduction.html

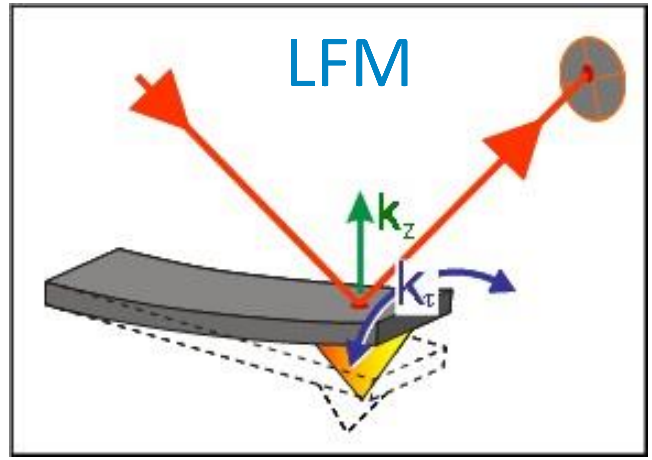
Non-contact mode gives both Topography and Phase images

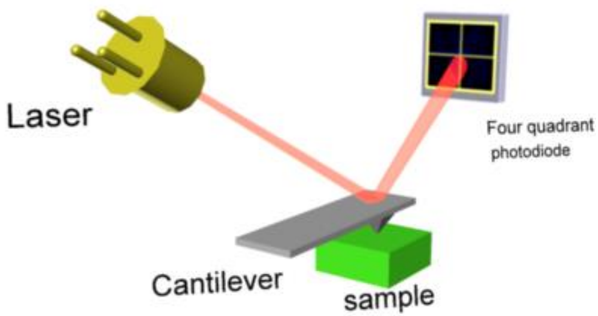


Displaying the same data in different ways:
The absolute height and its derivative

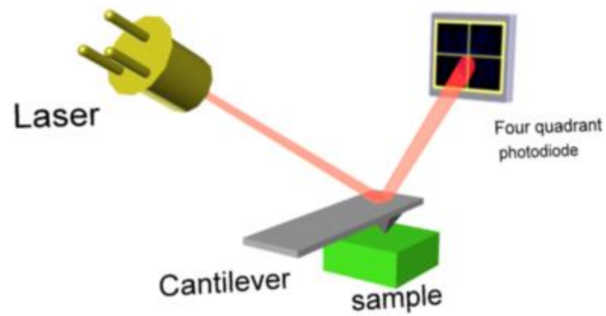
Lateral Force Microscopy (LFM)





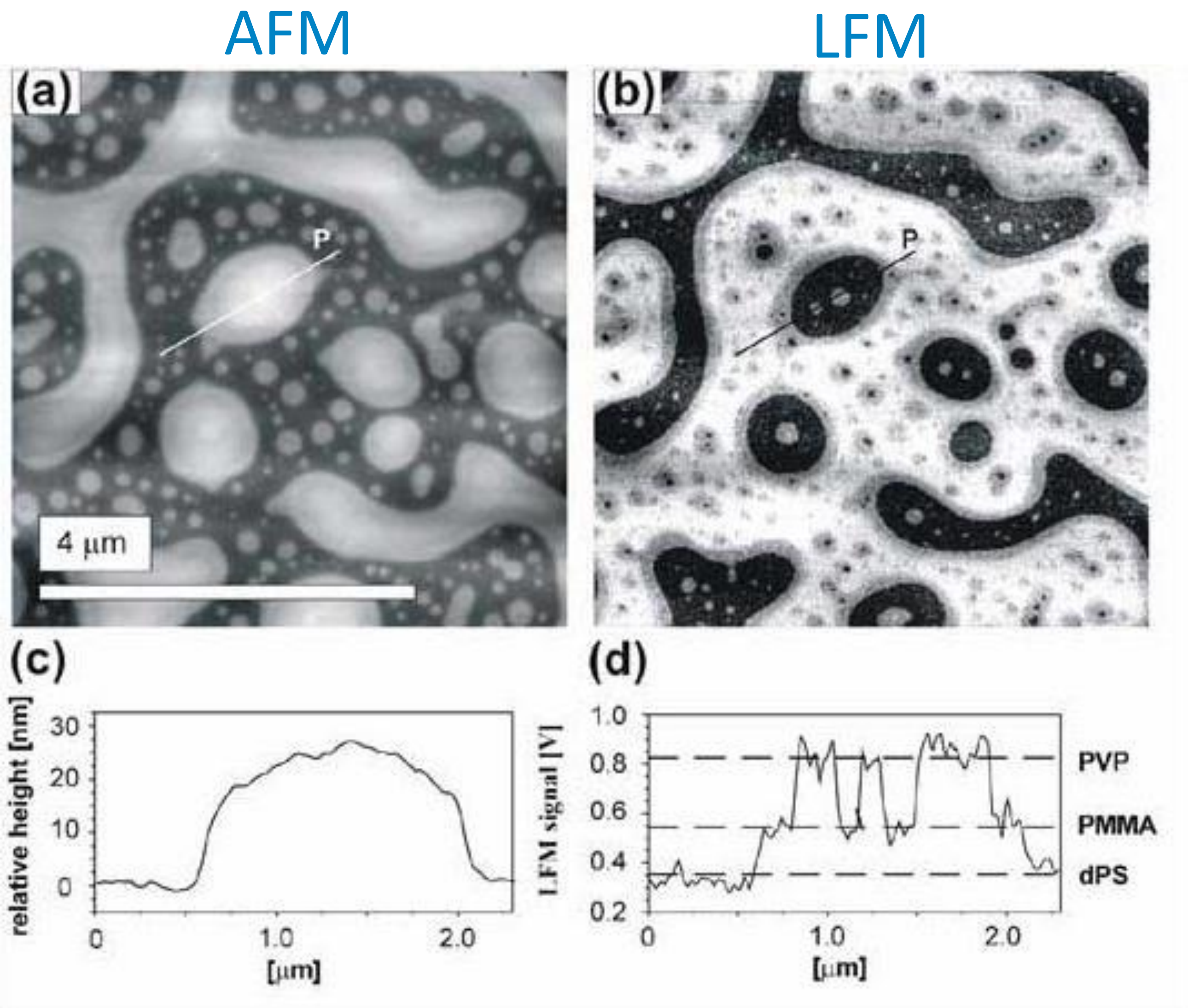


Measuring topography



Measuring frictional forces

Lateral Force Microscopy (LFM)



Useful for distinguishing between polymer materials

http://www.nanotribo.org/research/polymer_blends

Using AFM to study MEMS device

HiVe Master student Huy Quoc Nguyen came to Oslo to use the AFM at SINTEF Materials and Chemistry

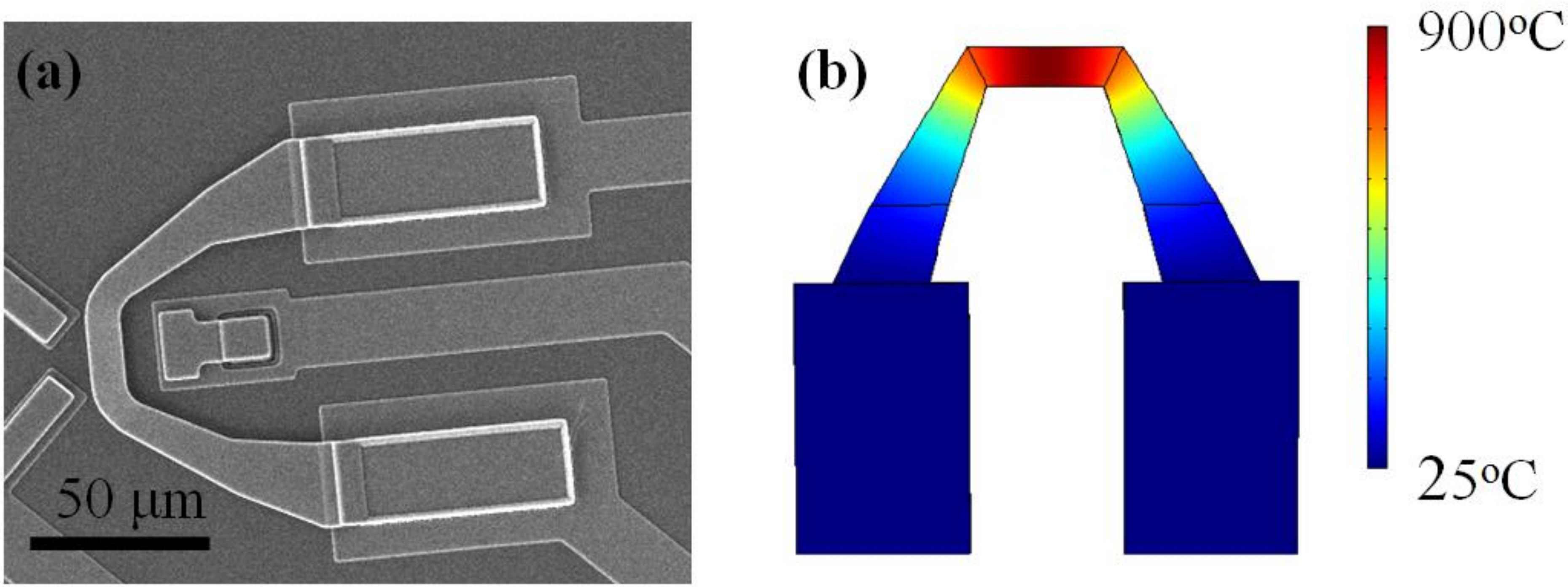


Figure 1: (a) Microheater geometry, (b) Simulation of temperature gradient on the surface of the microheater.

Using AFM to study MEMS device

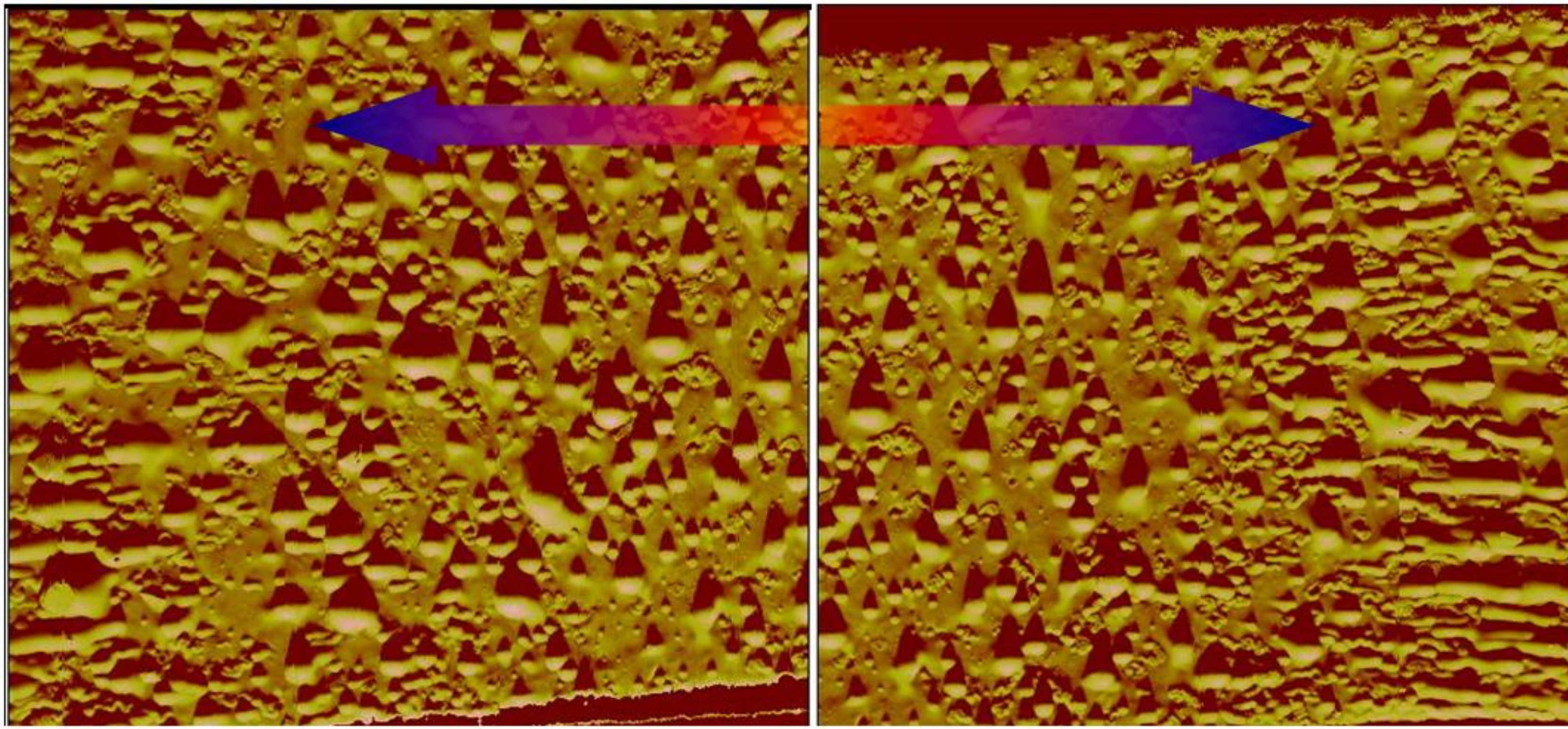
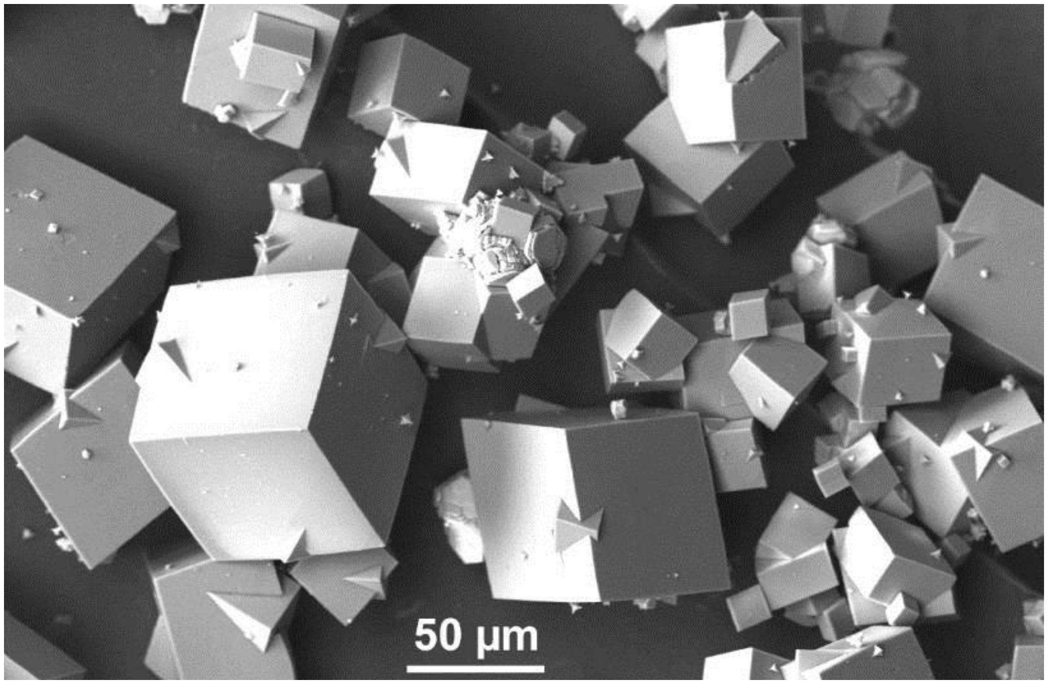
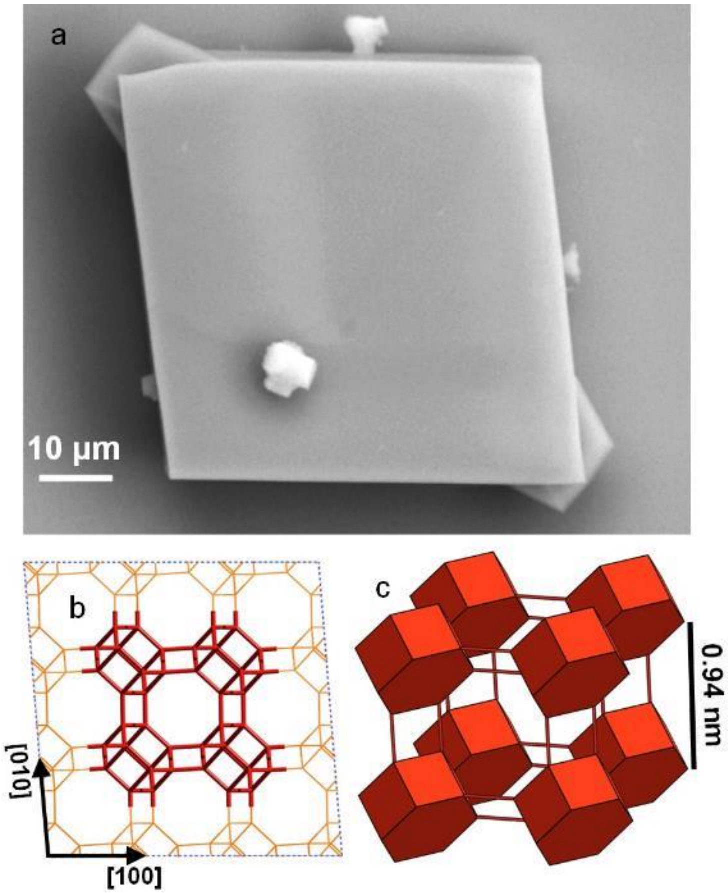


Figure 4: 10 μm x 10 μm AFM phase contrast images showing that nanoparticles move away from the hot spot in the middle of the bridge following the temperature gradient.

WLI + AFM on SAPO-34 catalyst grains

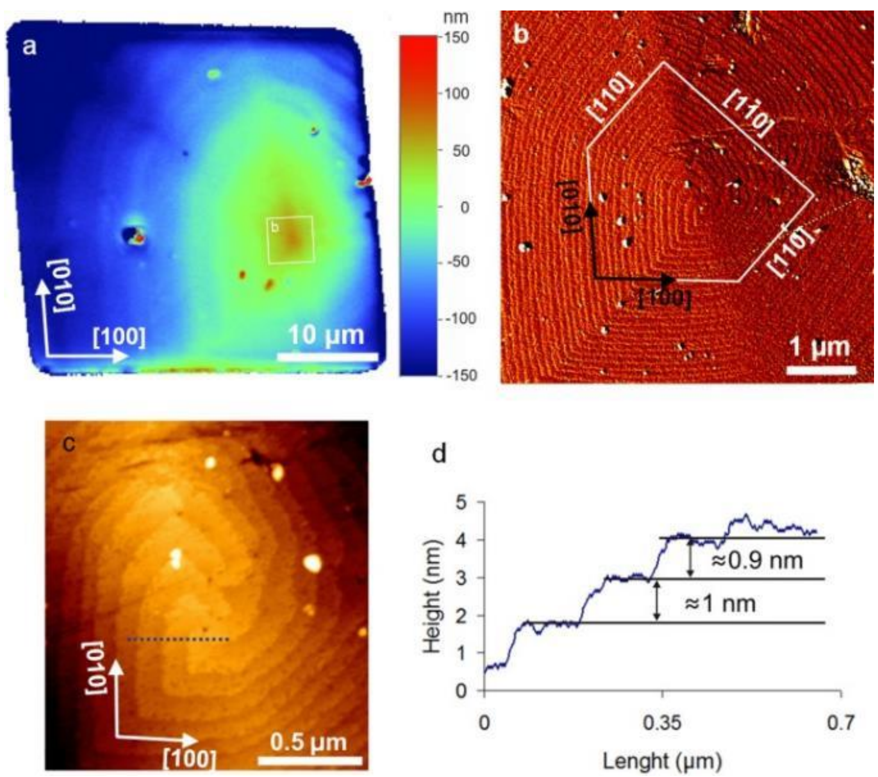


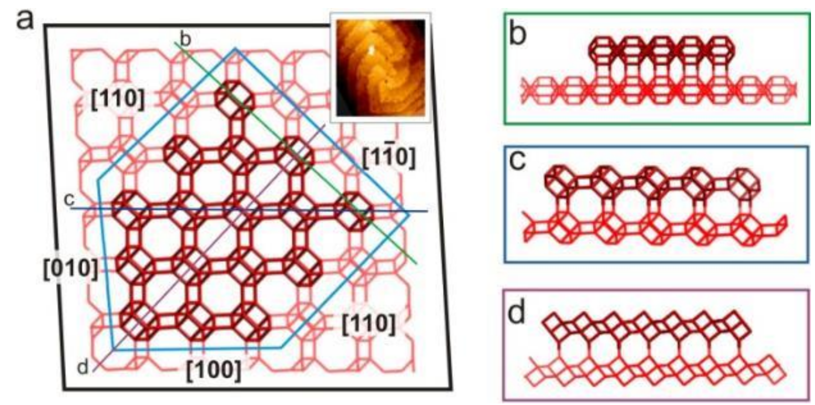


- SEM images show nearly cubic grains

- The shape can be related to the crystal structure

WLI + AFM on SAPO-34 catalyst grains





Relating the pentagonal growth spirals to structural details

Børge Holme, Pablo Cubillas, Jasmina Hafizovic Cavka, Ben Slater, Michael W. Anderson, Duncan Akporiaye

Growth mechanisms in SAPO-34 studied by White Light Interferometry and Atomic Force Microscopy

Crystal Growth & Design ***10****, 2824-2828 (2010)* *doi: 10.1021/cg9016118*

When to use which technique?

- Use AFM when you
  - need to see lateral details < 1 µm
  - need info on surface softness or friction
  - need info on magnetic or electrical properties
  - want to interact physically with the sample

- Use WLI/Stylus when you
  - want to measure rough surfaces or step heights >10 nm
  - want images larger than 100 µm
  - want fast imaging
  - want easy quantification of heights