AFM Calibration Procedure and Studies of Mechanical Behaviour of MEMS/NEMS Micromembranes

M. Michałowski[1], G. Ekwiński[2], Z. Rymuza[1]

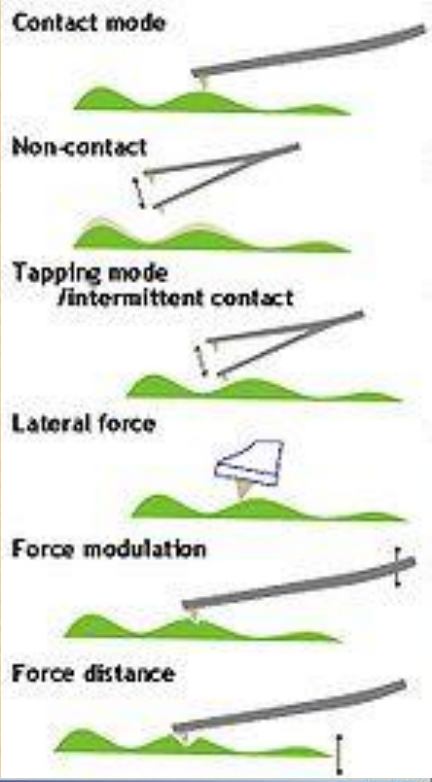
[1] Warsaw University of Technology Institute of Micromechanics and Photonics, Poland
[2] Nanoidea, Poland

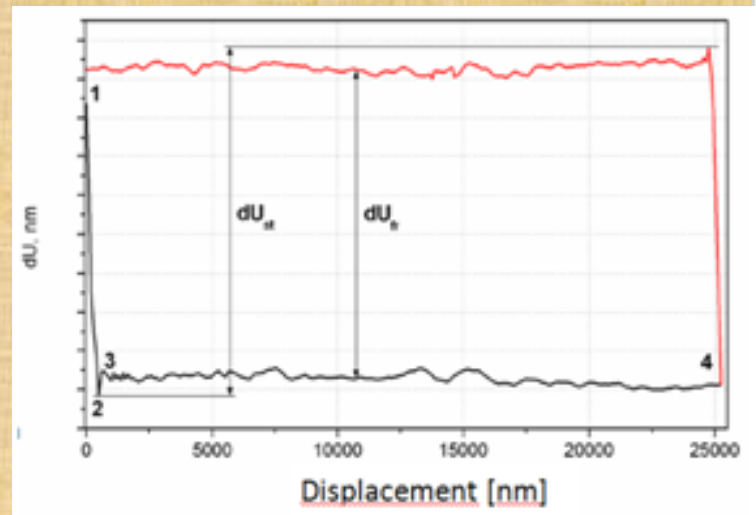
Presentation overview

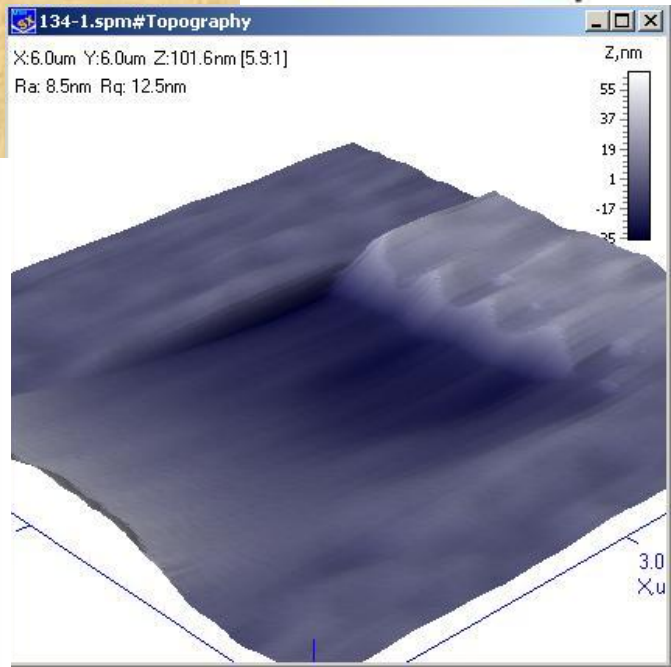
1. AFM Measurements
2. Purpose of Calibration
3. Calibration method
4. Tested membranes
5. Results
6. Summary

AFM measurements

- Topography
- Friction
- Pull-off force
- Stiffness
- Wear

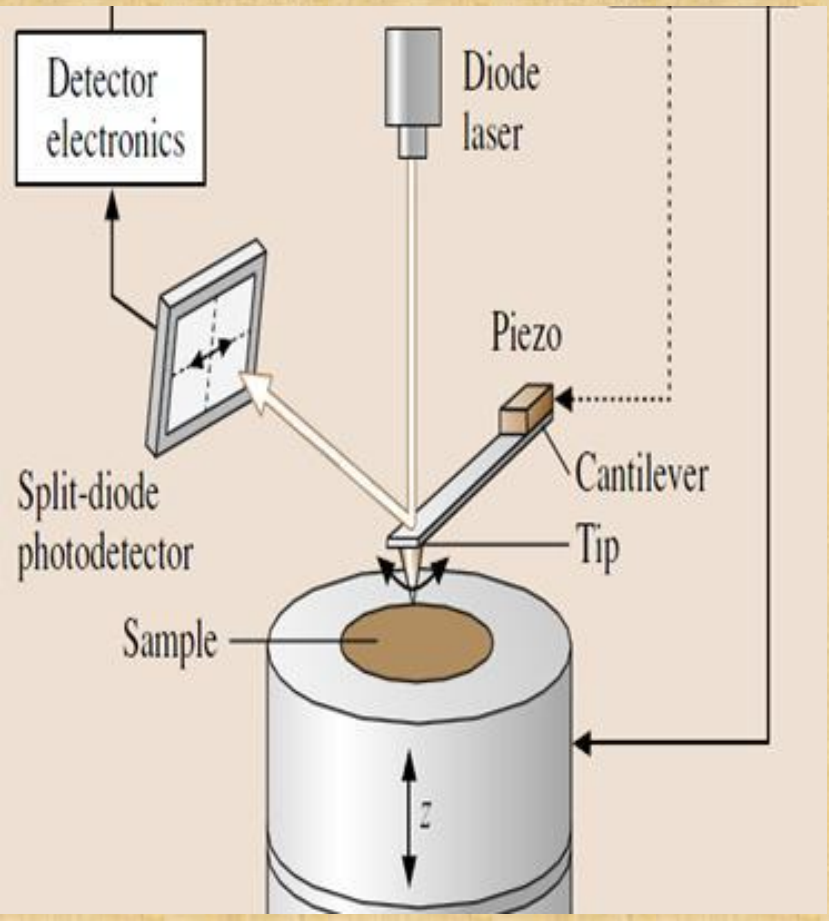




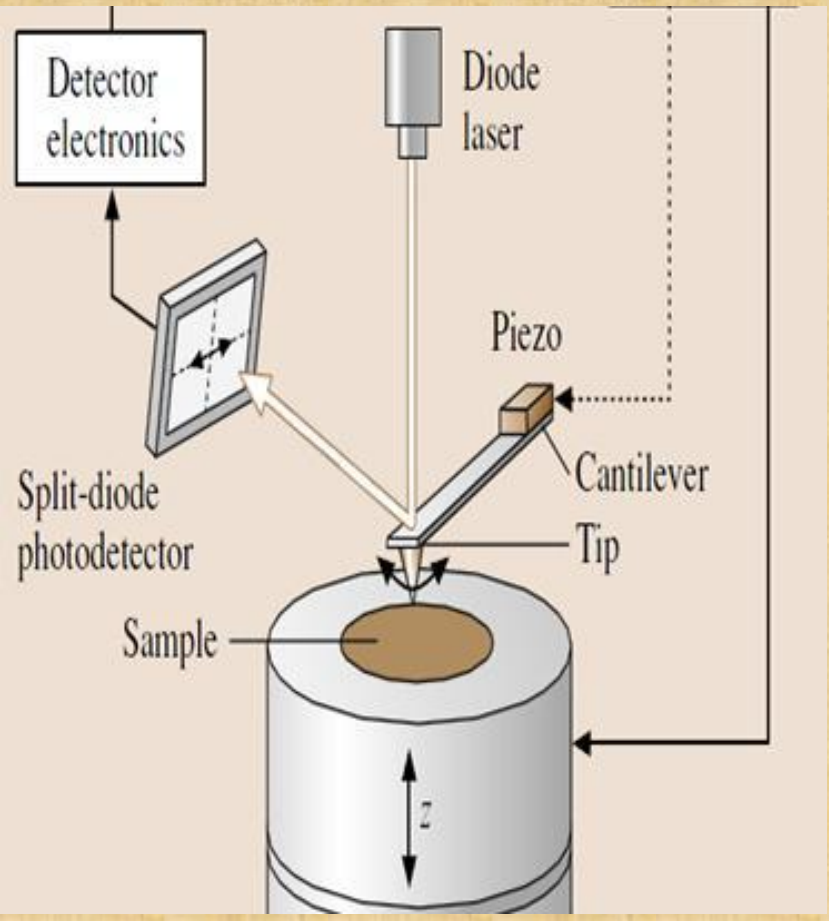


Purpose of calibration

Rationale

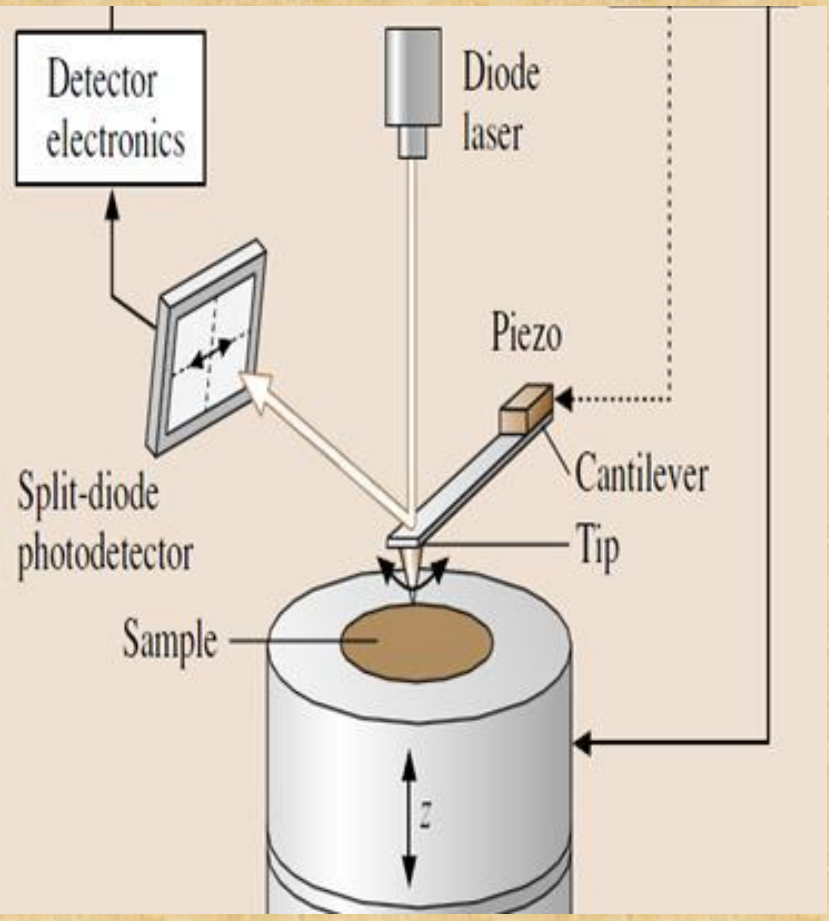

Detector electronics
Diode laser
Piezo
Cantilever
Split-diode photodetector
Tip
Sample
z

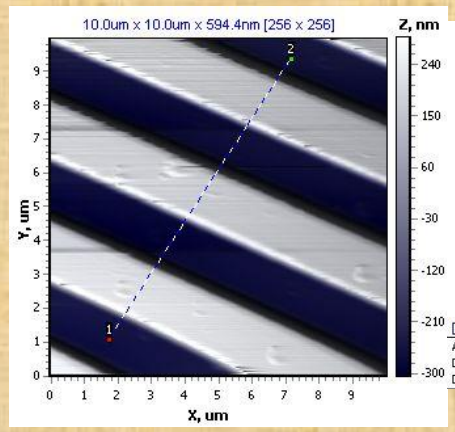
Rationale

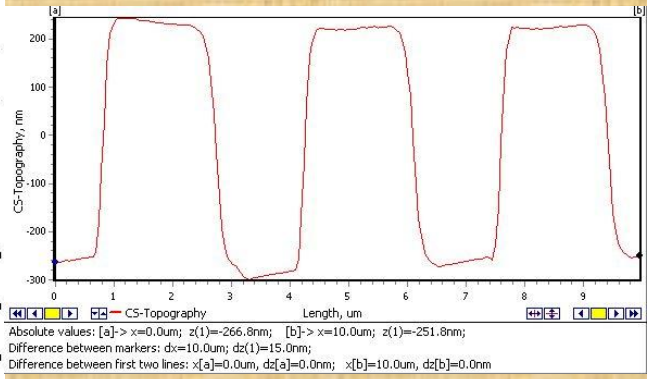


→ No actual values! Only arbitrary units!

Rationale







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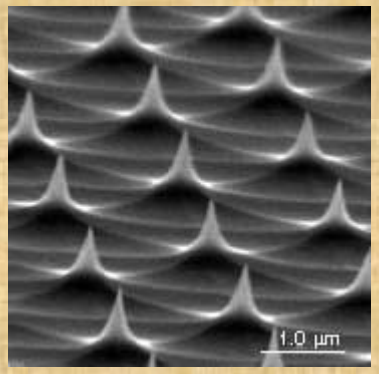

Calibration

Tested friction coefficient on a sample		
Min	Typical	Max
0.15	0.2	0.25

Calibration

Tested friction coefficient on a sample		
Min	Typical	Max
0.15	0.2	0.25

Force Constant, N/m		
min	**typ**	max
20	**40**	80

Calibration

Tested friction coefficient on a sample		
Min	Typical	Max
0.15	0.2	0.25

Force Constant, N/m		
min	typ	max
20	40	80

Actual friction coefficient		
Min	Typical	Max
0.075	0.2	0.50

AFM measurements

- Topography
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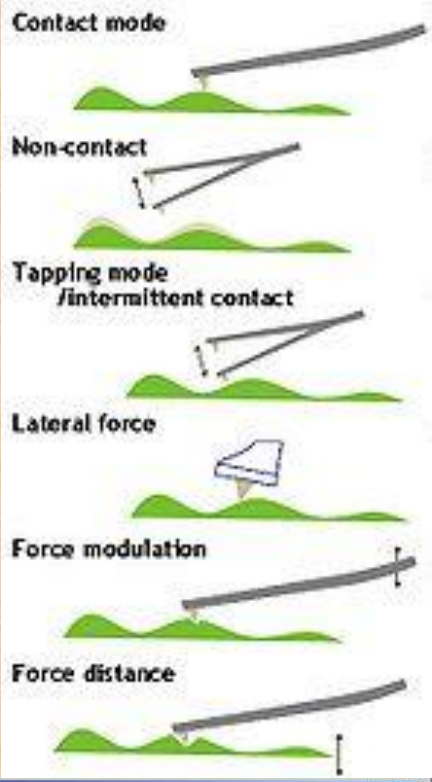
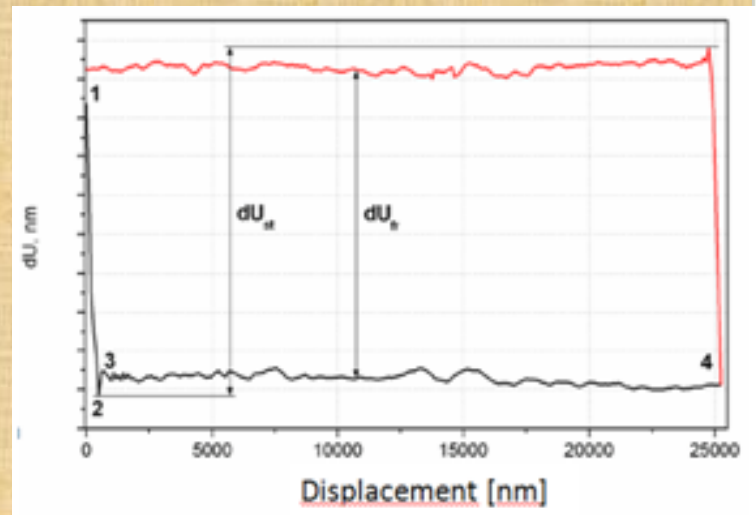
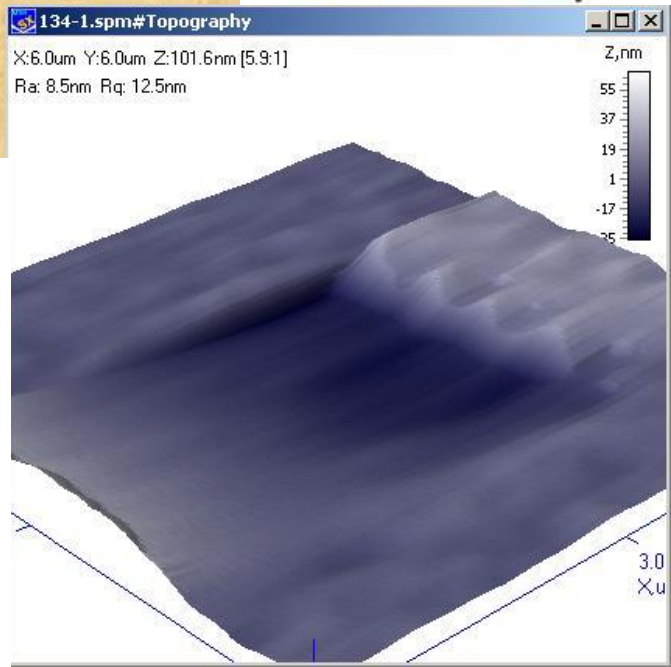
- Pull-off force
- Stiffness
- Wear







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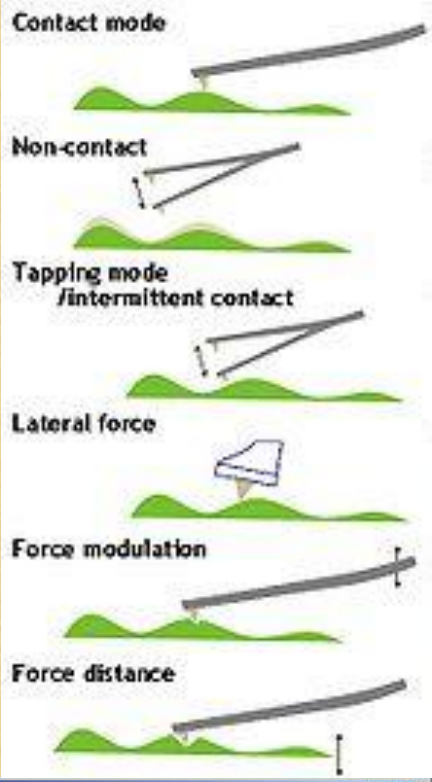

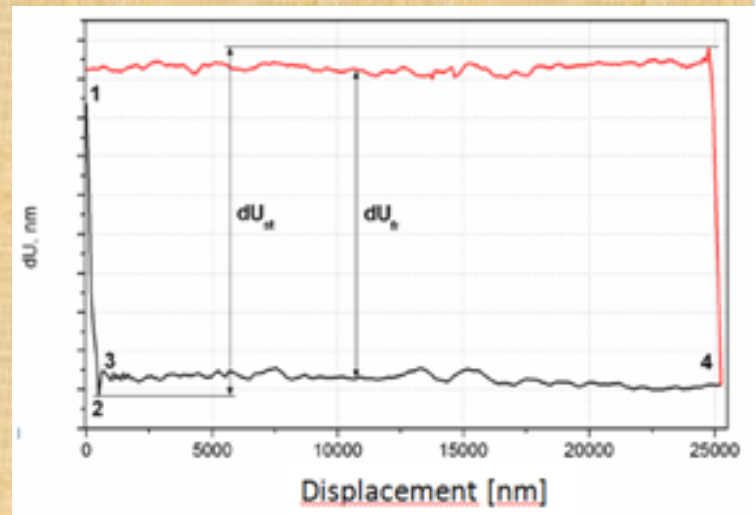

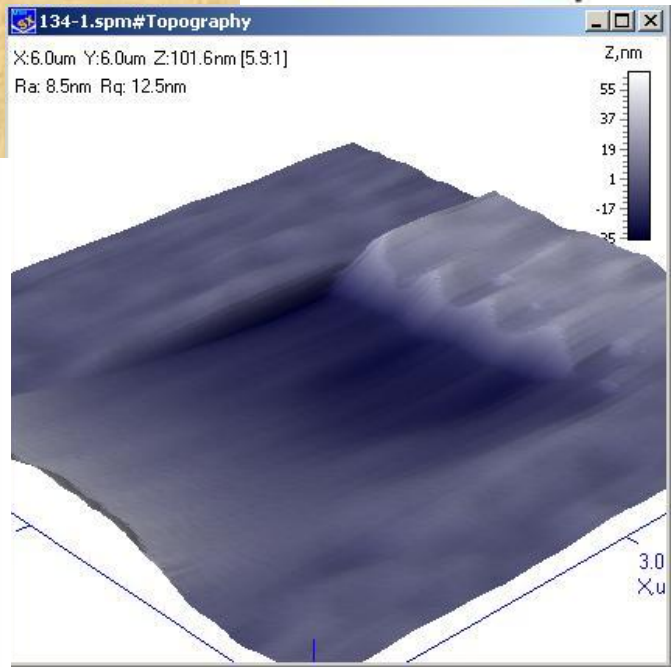

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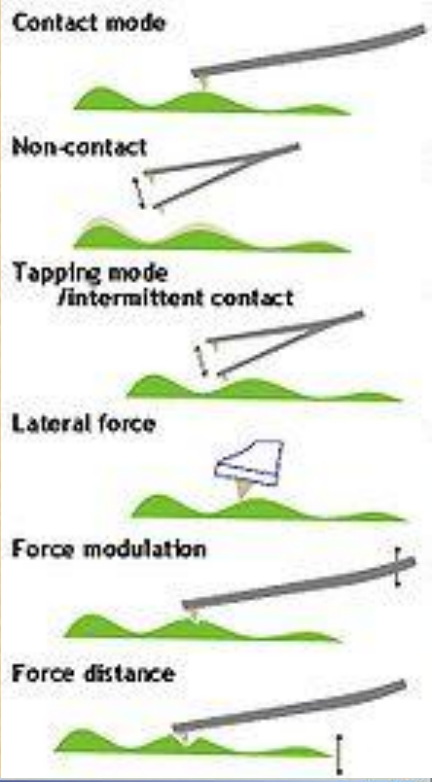
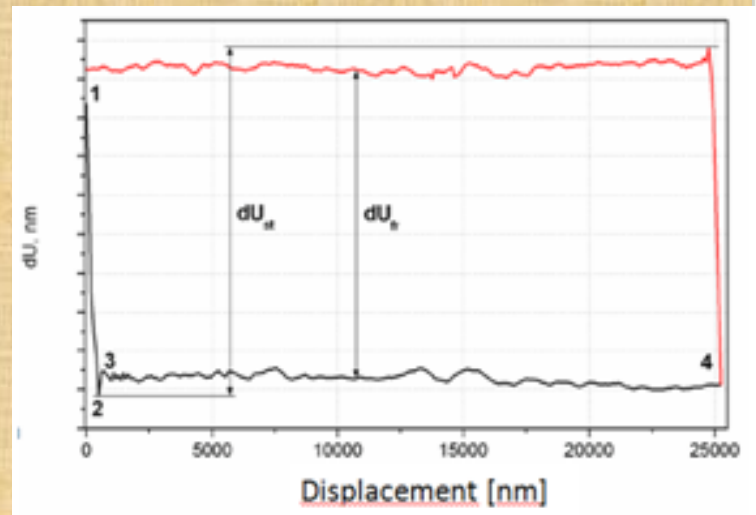
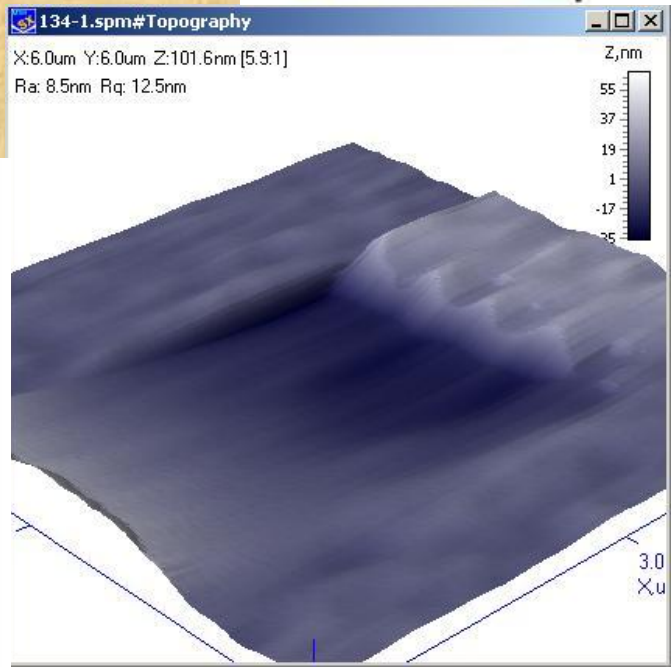


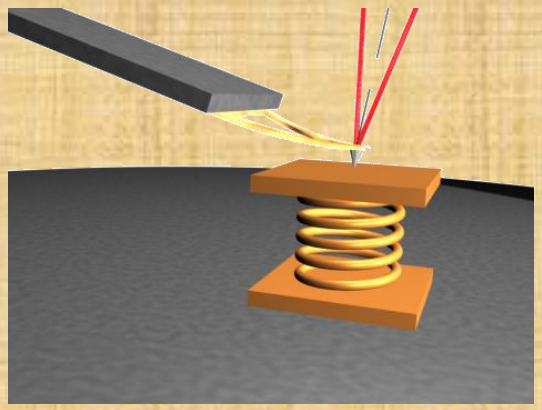




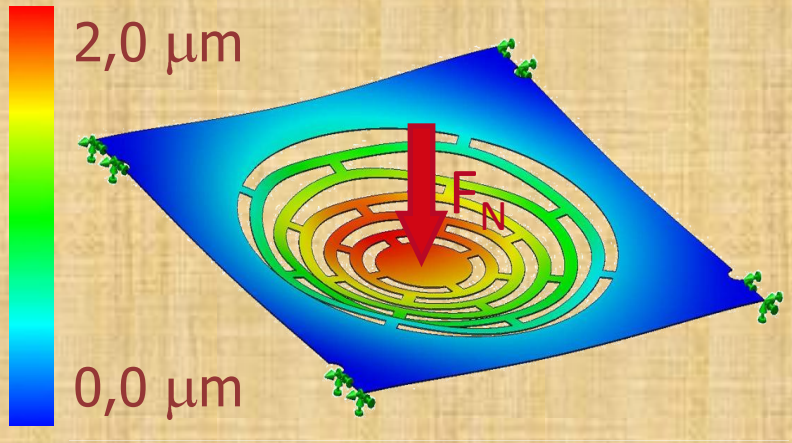
Stiffness calibration method

Calibration

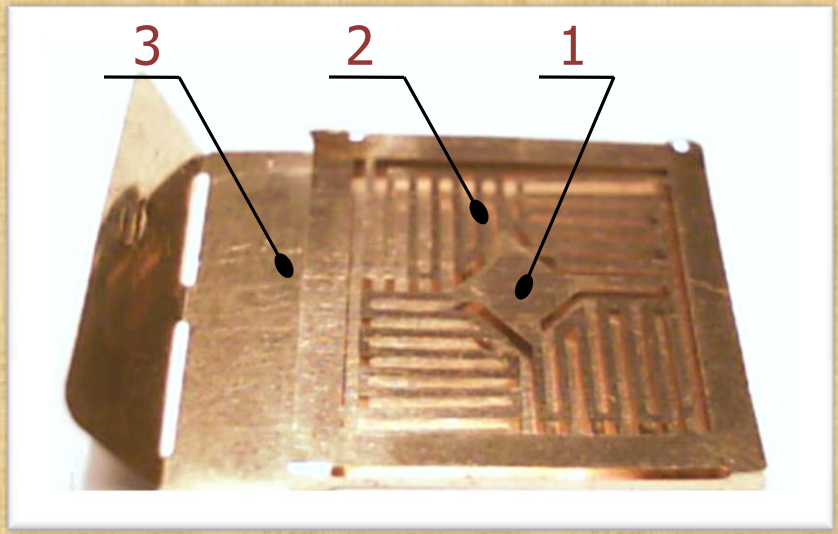
The idea of calibration



Simulation result – displacement for the applied normal force F_N

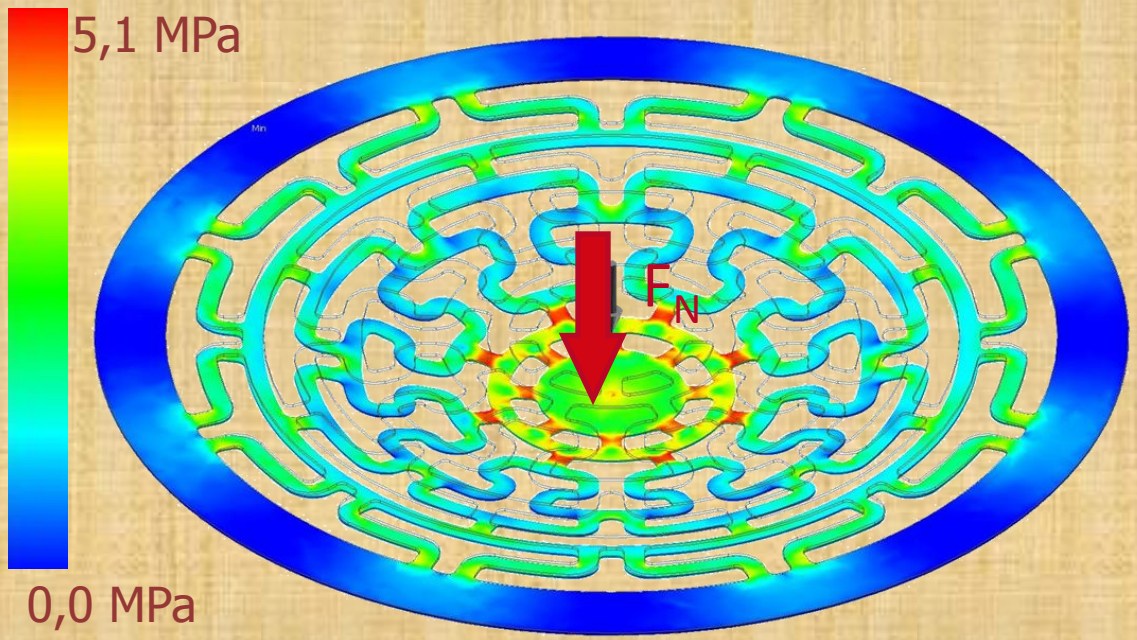


Model of the calibration structure



1 – tip – calibration structure contact area
2 – membrane
3 – handle and mounting surface

Calibration



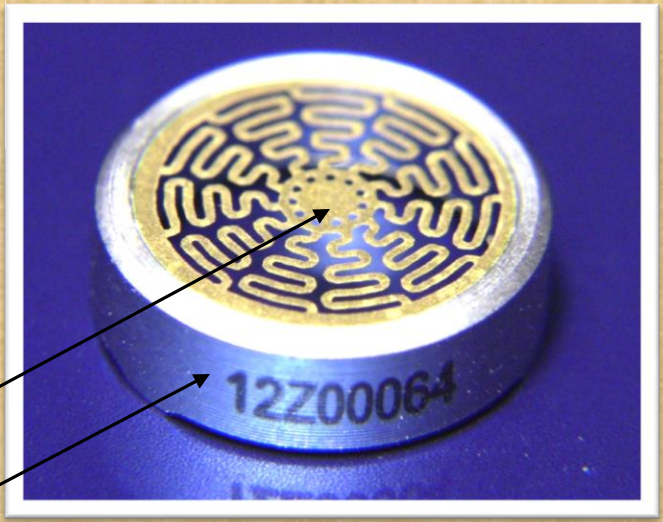
Simulation result – stress
for the applied normal force F_N

Product - the calibration structure

External diameter D=12.4 mm,
Height h=4.0 mm

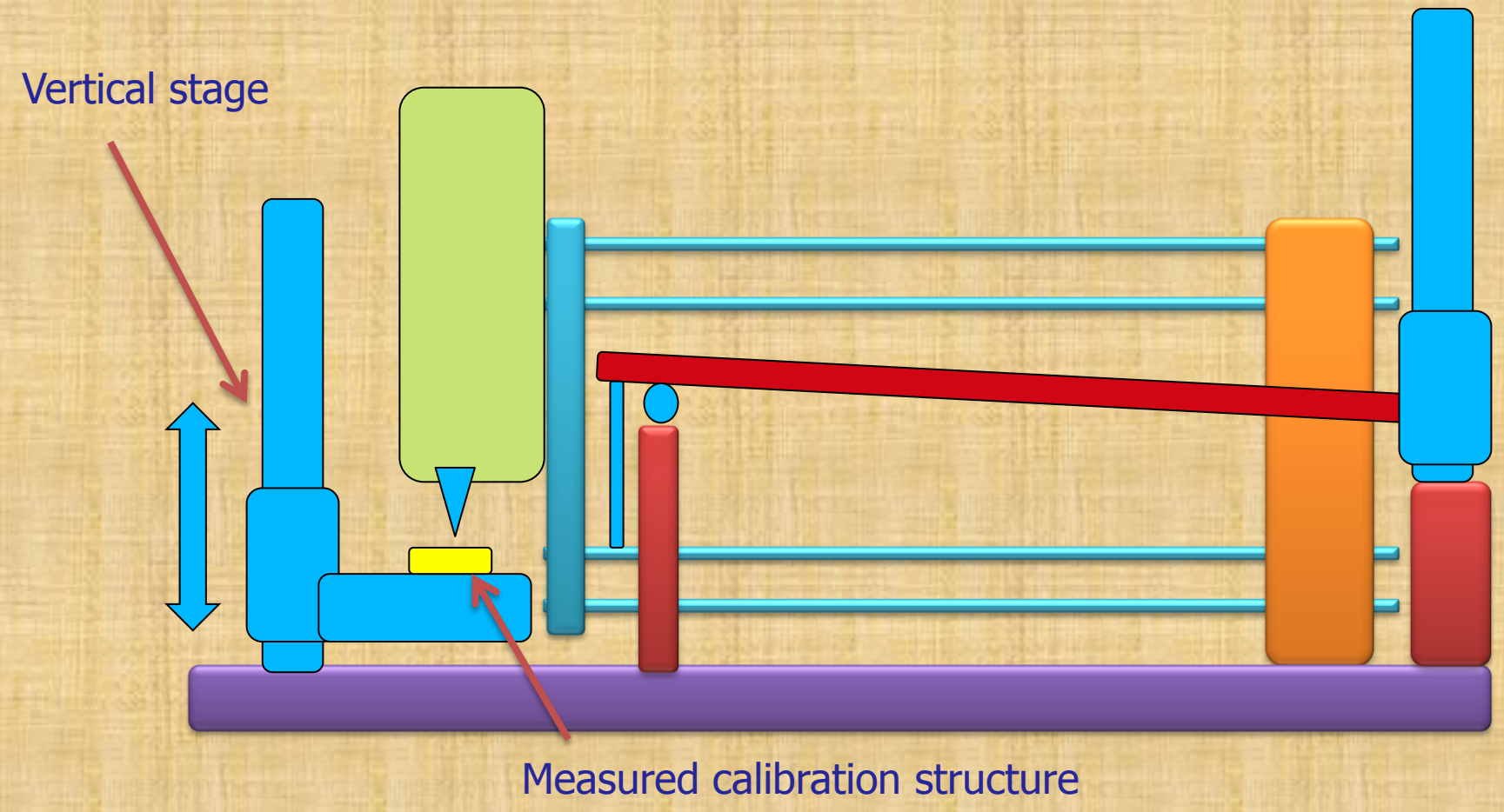
membrane
(brass 10-60 μm)

rings

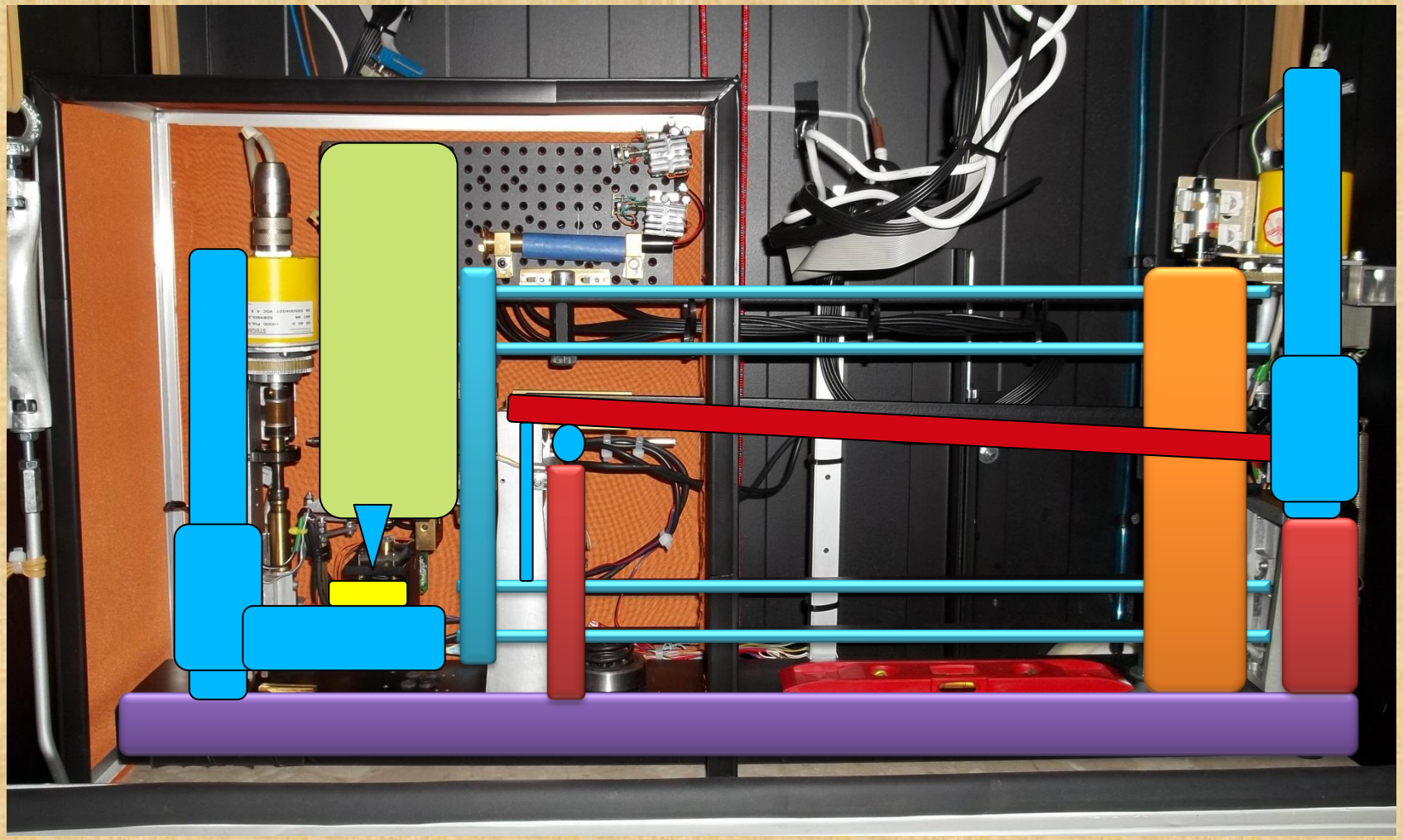


Nanoidea calibration structure

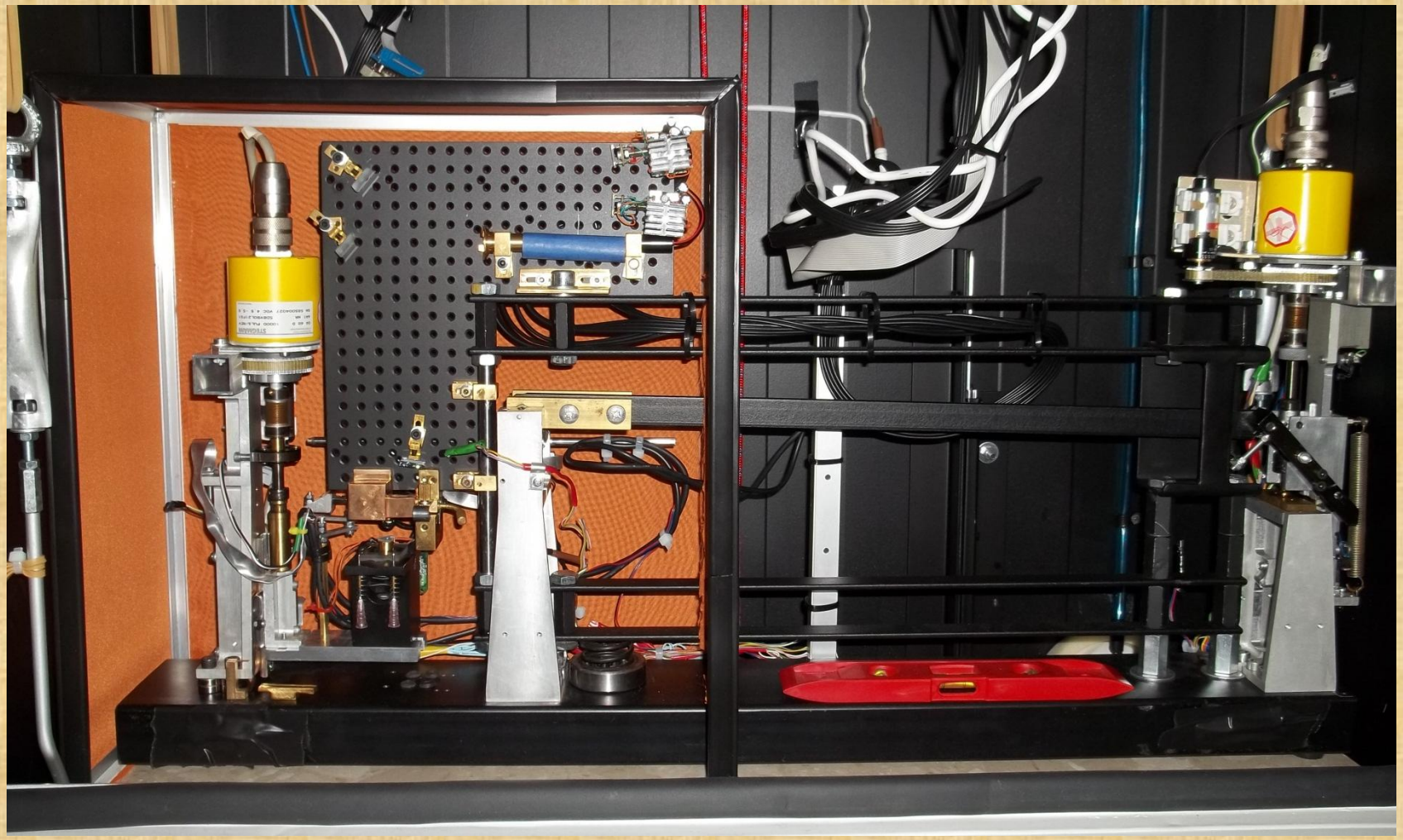
Calibration of structures



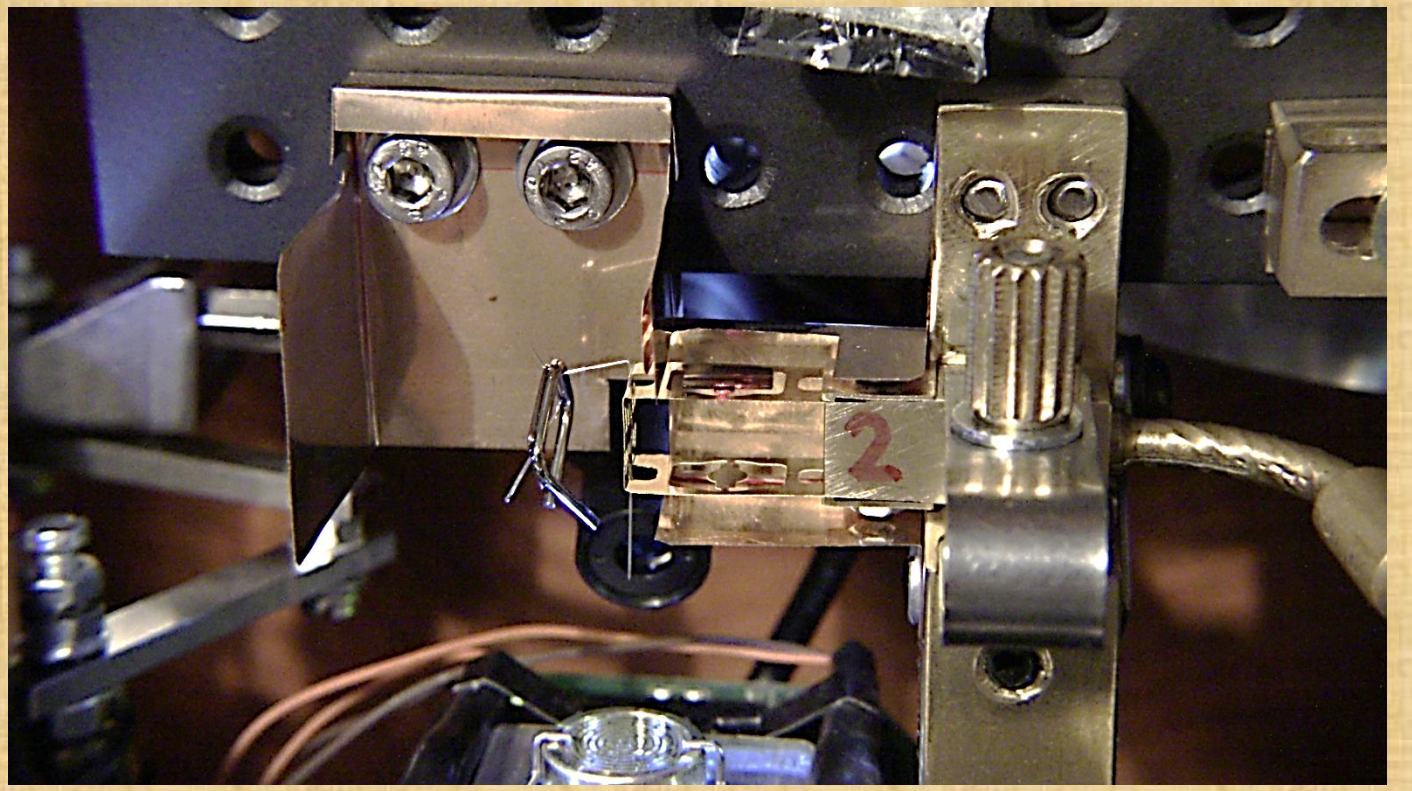
Calibration of structures



Calibration of structures



Calibration of structures

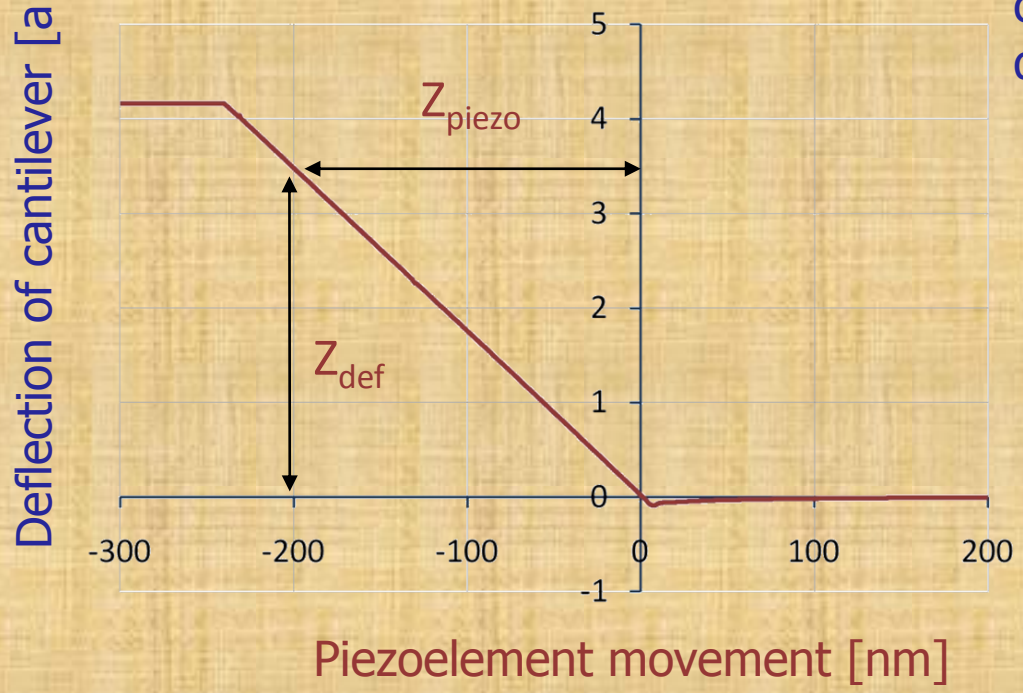


- Optical amplification of sensor deflection – 200 to 300 times
- Measurement range 200 nm to 40 um
- Sensor stiffness – 0.3 N/m to 2000 N/m
- Force range – 60 nN to 80 mN
- Noise smaller then 2 nm

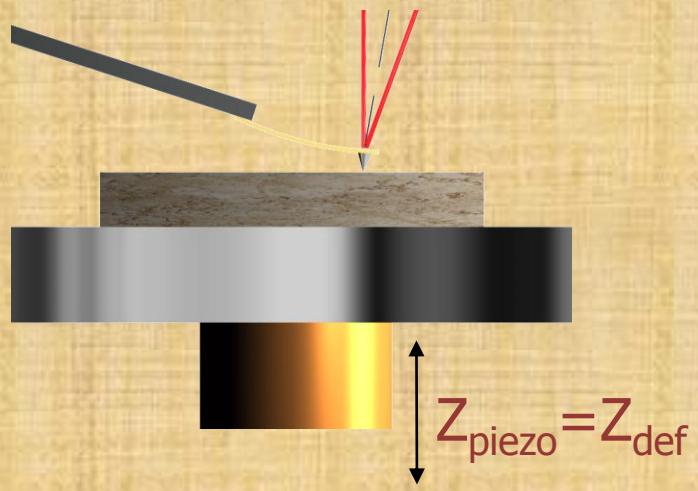
Calibration

1. Cantilever deflection calibration

Force – distance curve



Calibration on the rigid sample – calculation of the cantilever's deflection



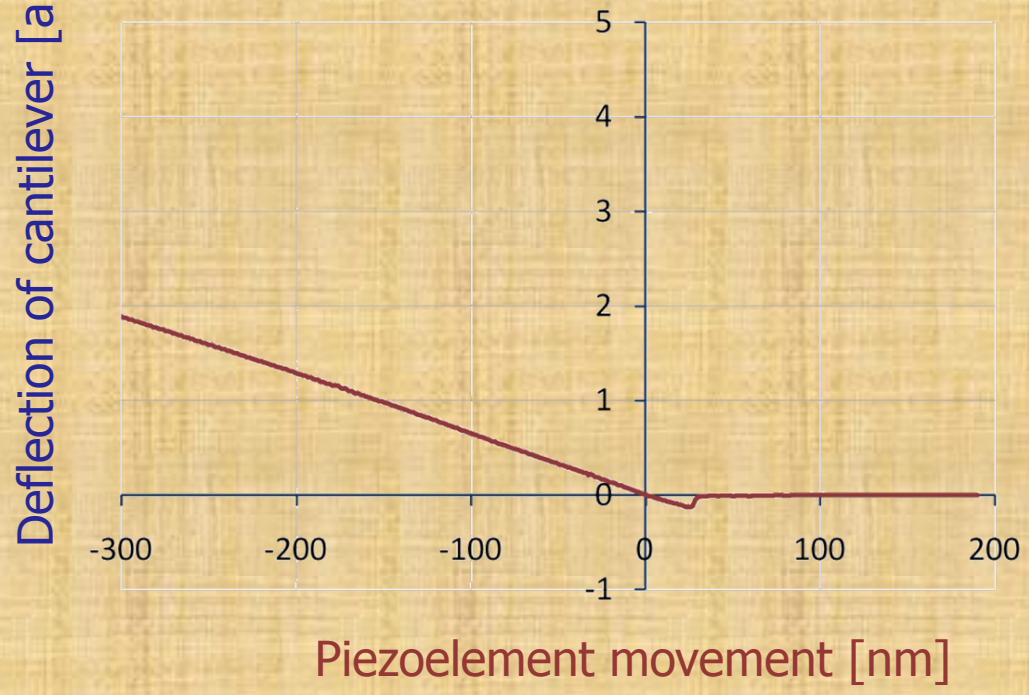
Z_{piezo} – AFM table movement
Z_{def} – deflection of the cantilever in arbitrary units

200 nm (Z_{piezo}) = 3.47 a.u. (Z_{def})

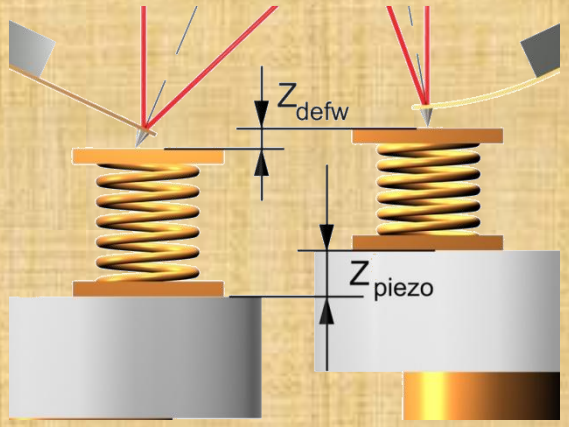
Calibration

2. Cantilever stiffness calibration

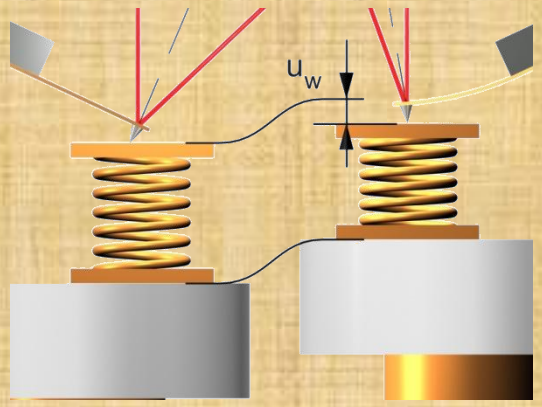
Force – distance curve



Movement of the cantilever and piezoelement



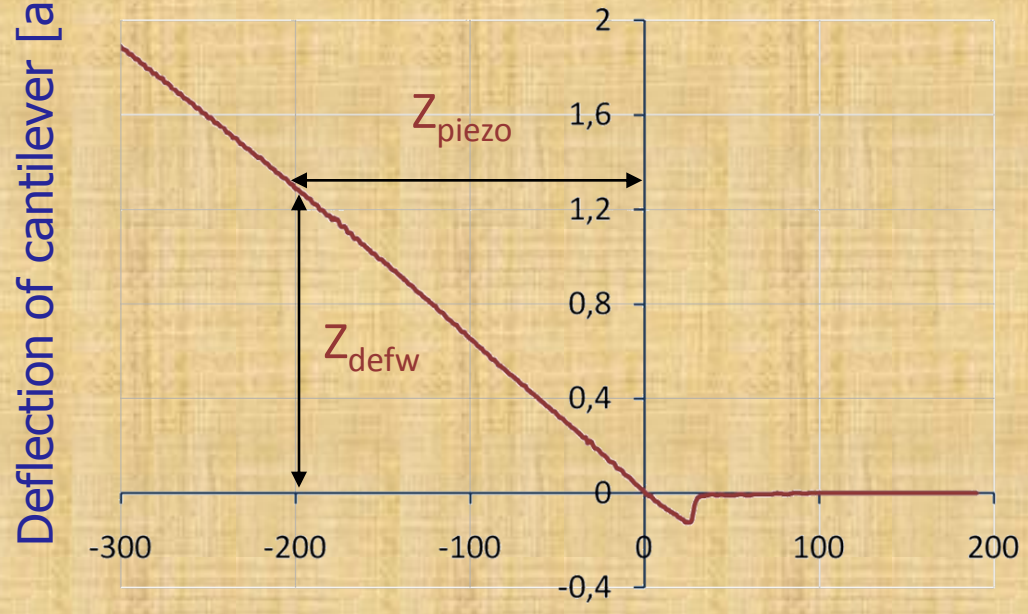
Deflection of the calibration structure



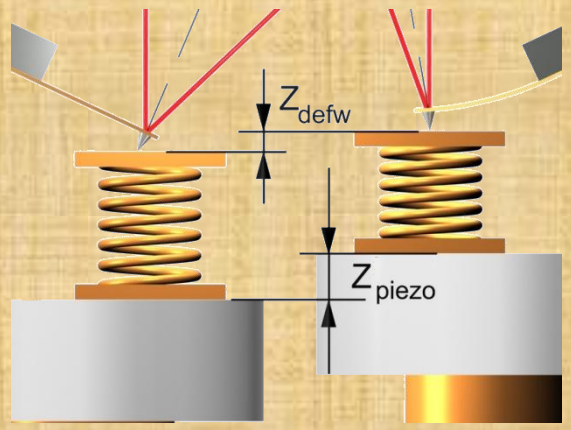
Calibration

2. Cantilever stiffness calibration

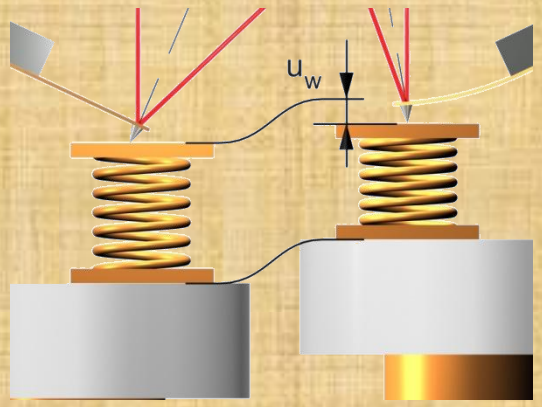
Force – distance curve



Movement of the cantilever and piezoelement



Deflection of the calibration structure



200 nm (Z_{piezo}) = 1.29 a.u. (Z_{defw})

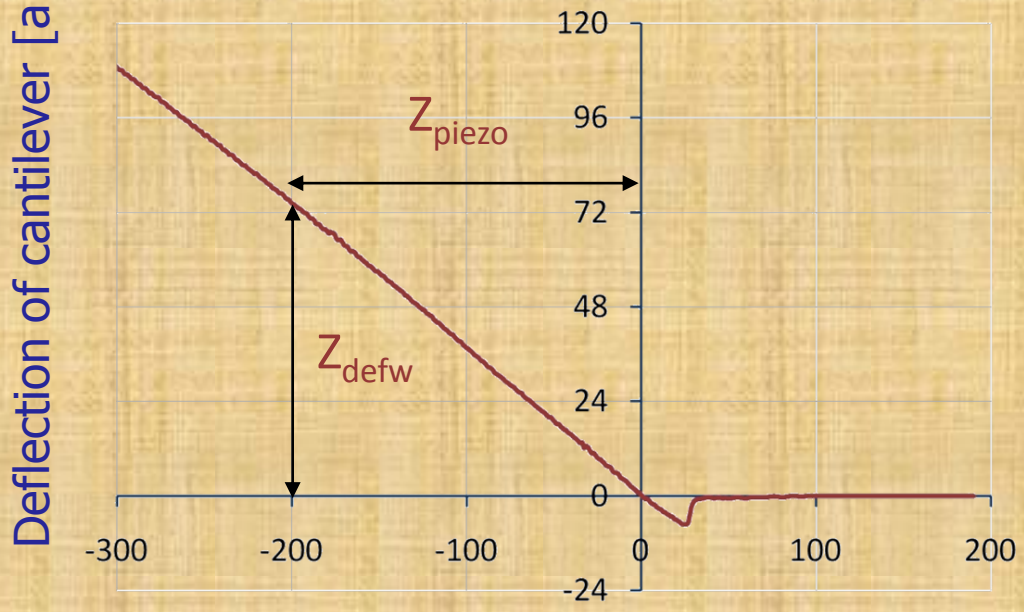
Knowing that 3.47 a.u. = 200 nm

We calculate: 200 nm (Z_{piezo}) = 74 nm (Z_{defw})

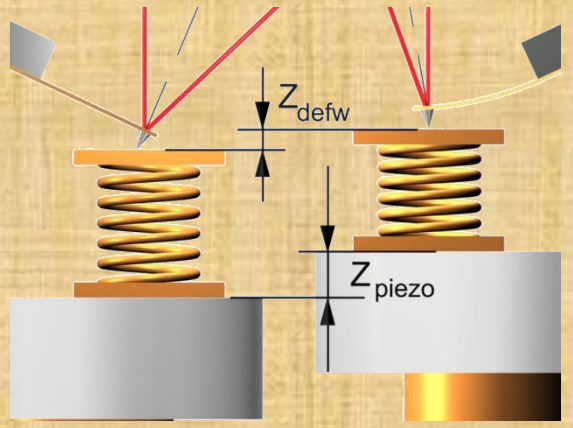
Calibration

2. Cantilever stiffness calibration

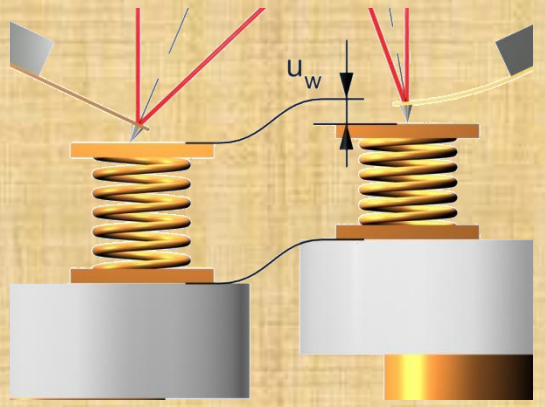
Force – distance curve



Movement of piezoelement and cantilever



Deflection of calibration structure



$\mathbf{u_w} = Z_{piezo} - Z_{defw} = 200\ nm - 74\ nm = \mathbf{126\ nm}$

Z_{defw} – cantilever's deflection
Z_{piezo} – displacement of the AFM table
u_w – deflection of the calibration structure

Calibration

2. Cantilever stiffness calibration

$\mathbf{Z_{defw}}$ = 1.29 a.u. = **74 nm**

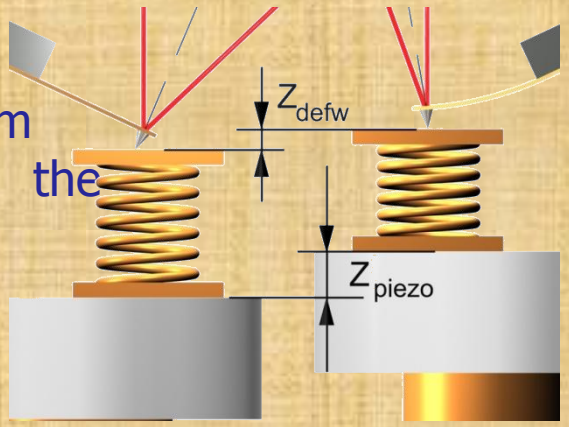
$\mathbf{u_w}$ = **126 nm**

Stiffness of the calibration structure eg. $\mathbf{k_w}$ = 7.24 N/m

Force that is applied by calibration structure on the cantilever:

$\mathbf{F} = \mathbf{u_w}$ $\mathbf{k_w}$ = 126 nm 7.24 N/m = 912 nN

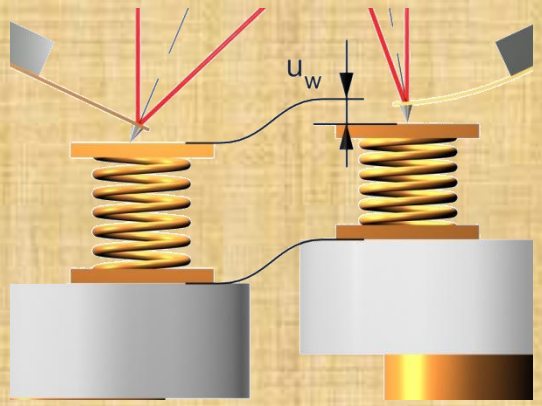
Movement of the cantilever and piezoelement



Deflection of the calibration structure

Stiffness of the cantilever $\mathbf{k_c}$:

$\mathbf{k_c} = \mathbf{F} / \mathbf{Z_{defw}}$ = 912 nN / 74 nm = **12.32 N/m**

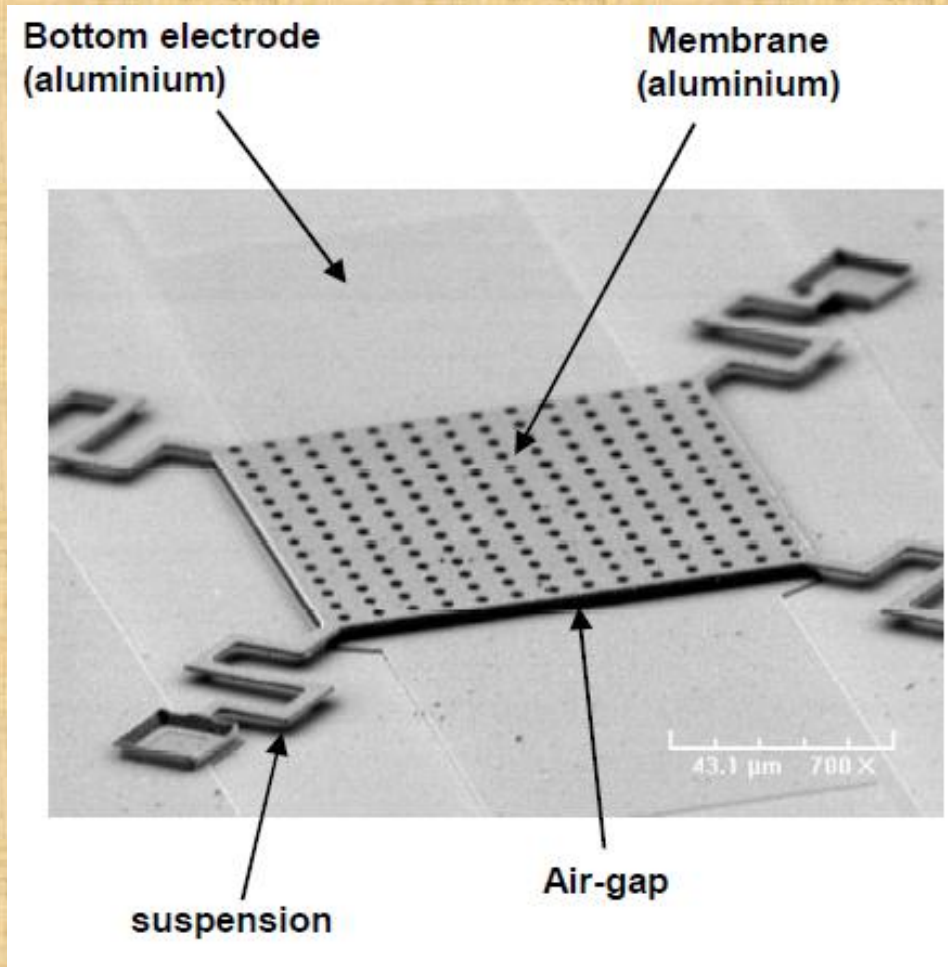


Tested MEMS

Membranes

- What is the stiffness of membranes?

Fabricated by:
Cork-Irland Tyndall Institute
Base parameters:
Size:
100 µm x 100 µm
Thickness:
1 µm
Air gap:
2 µm
Membrane material:
- Aluminium
- Titanium



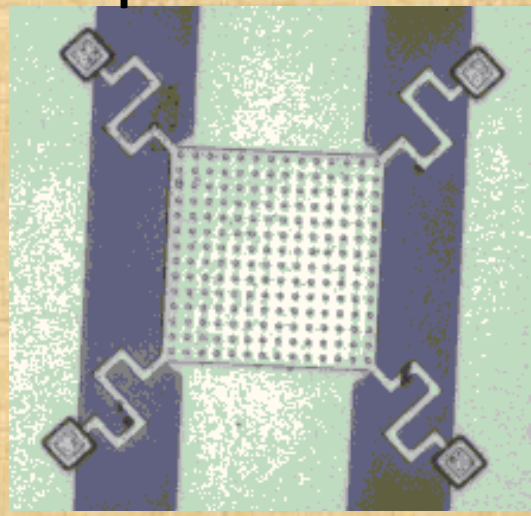
Membranes

- How does it vary based on diffrents suspension?

Suspension types:

1. Meander
2. Straight
3. Spiral

1



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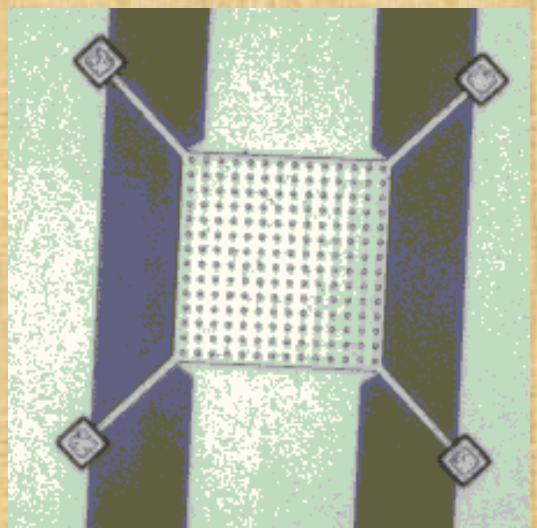

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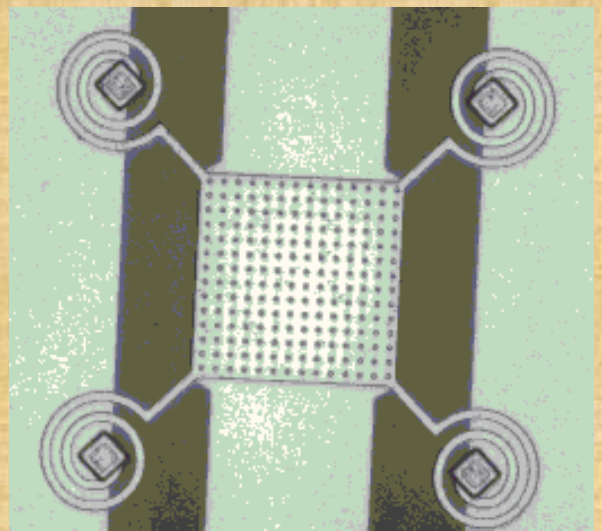
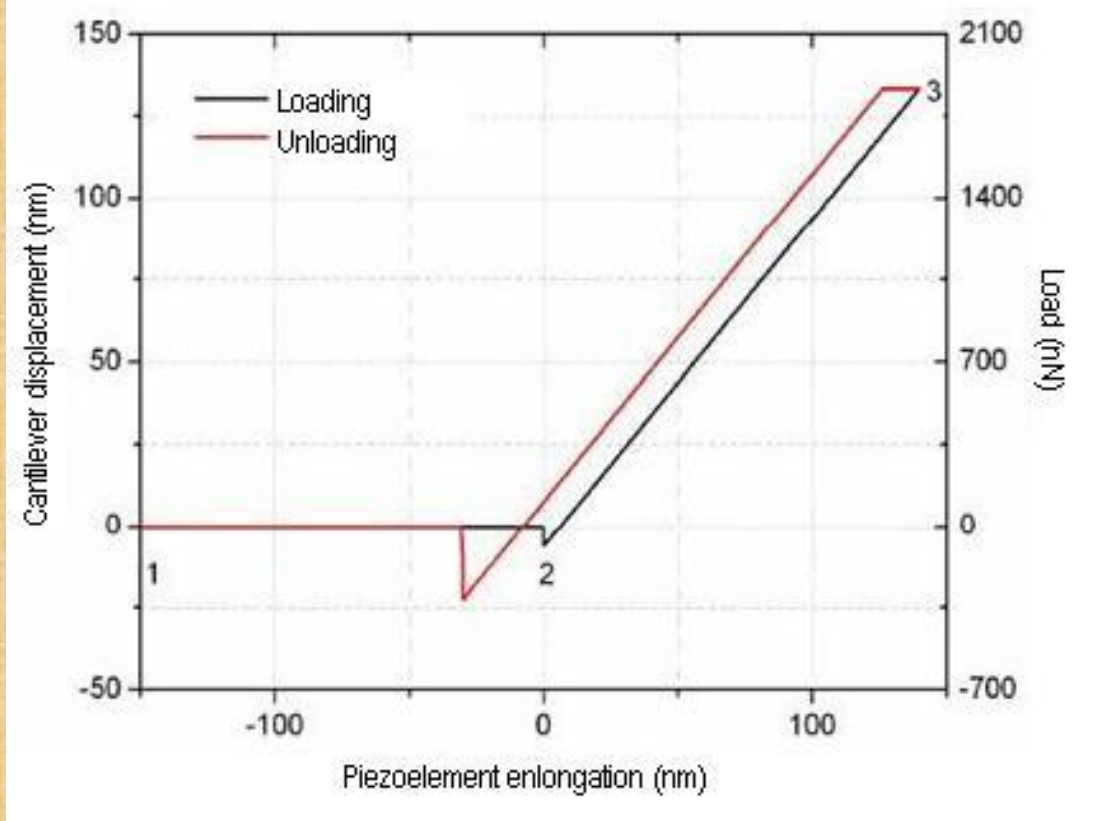


Measurements

AFM measurements



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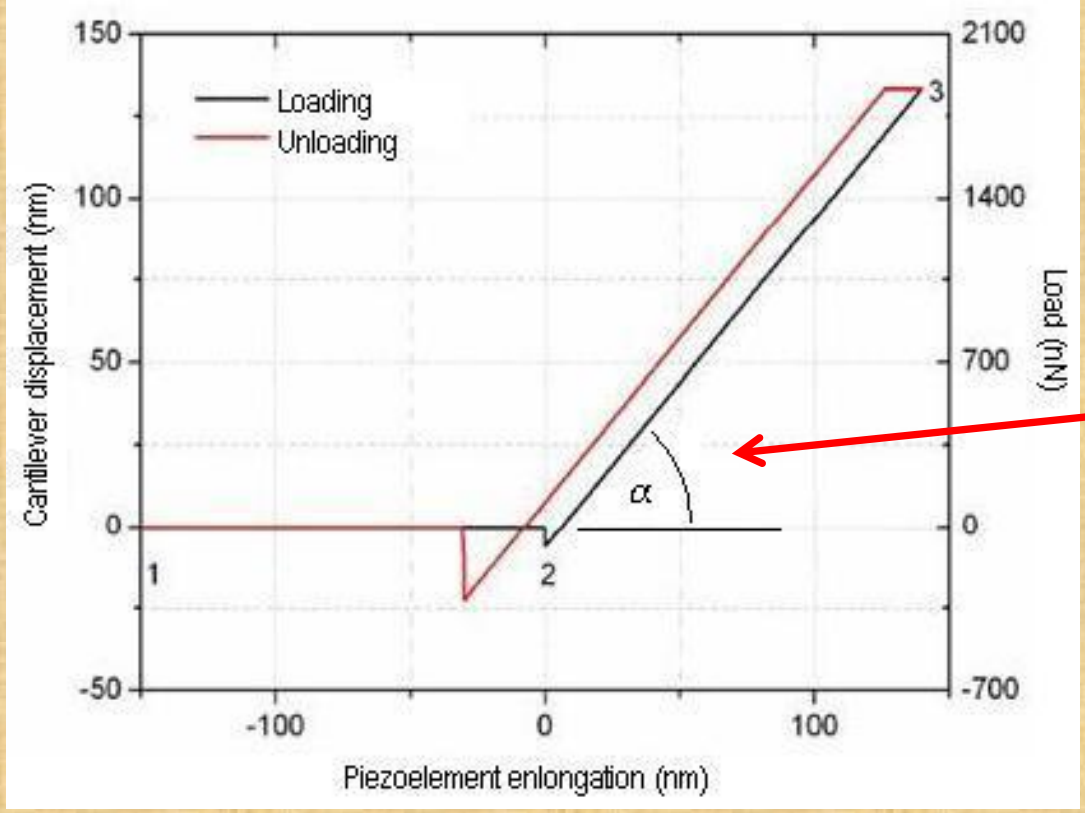
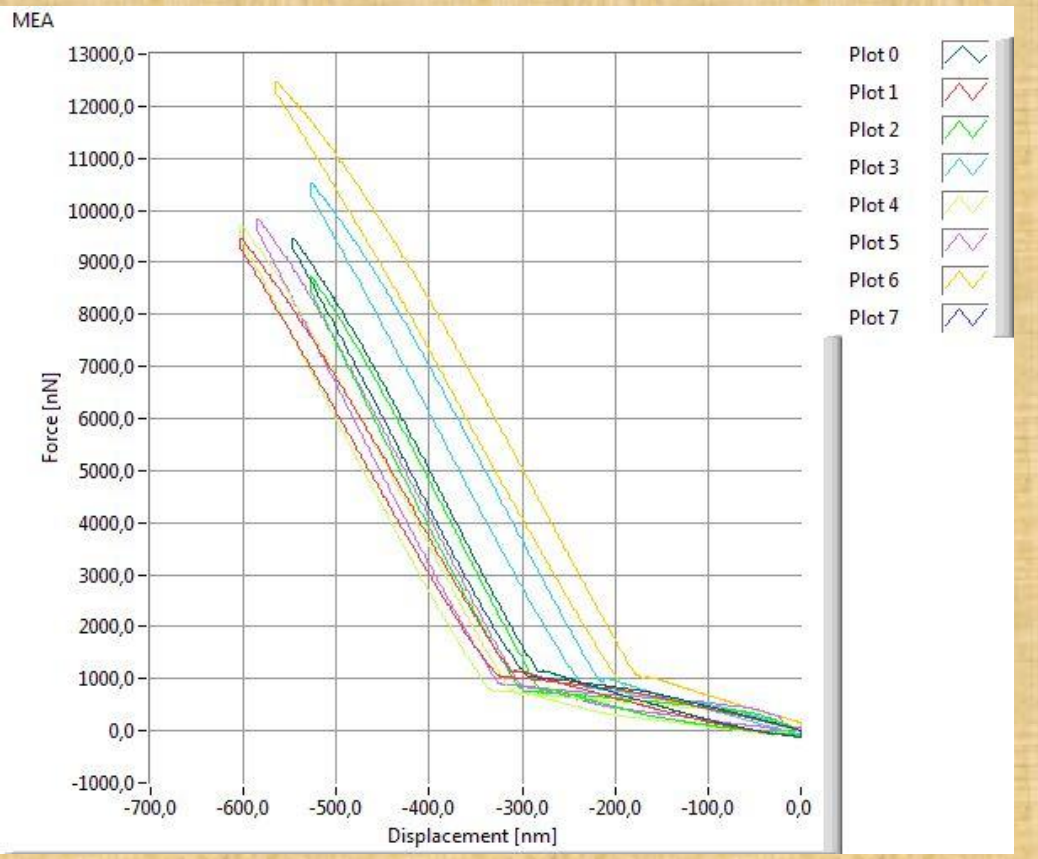


Sample results



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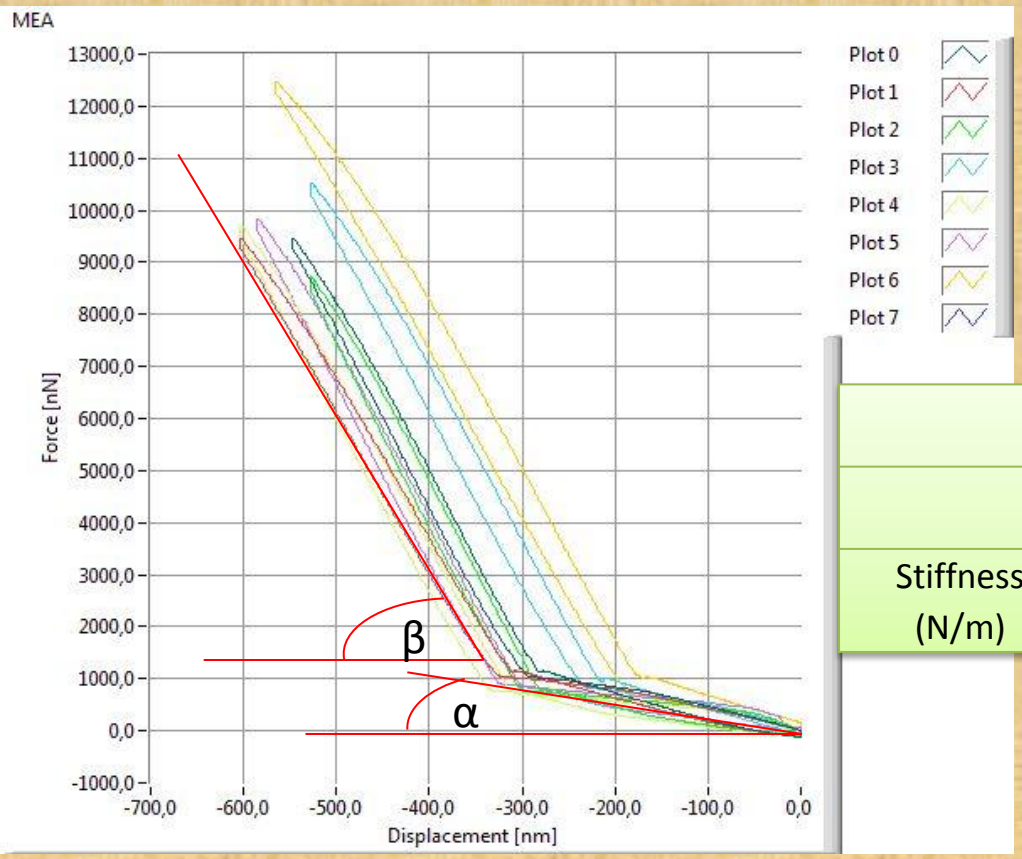
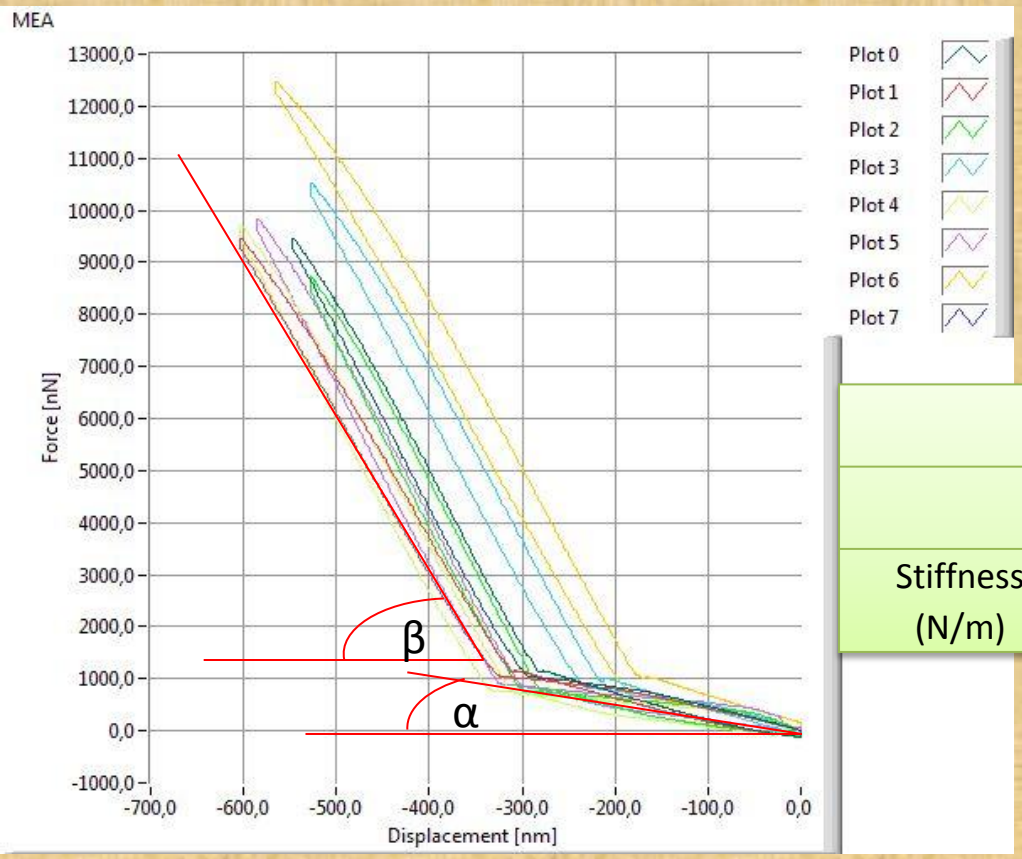


Cantilever Stiffness = 68.91 N/m

	II - Stage		I - Stage	
	Loading	Unloading	Loading	Unloading
Stiffness (N/m)	64.17	62.18	3.00	4.22

Sample results



Cantilever Stiffness = 68,91 N/m

What would we get if we had cantilever stiffness range just from producer? Range 35 N/m to 140 N/m?

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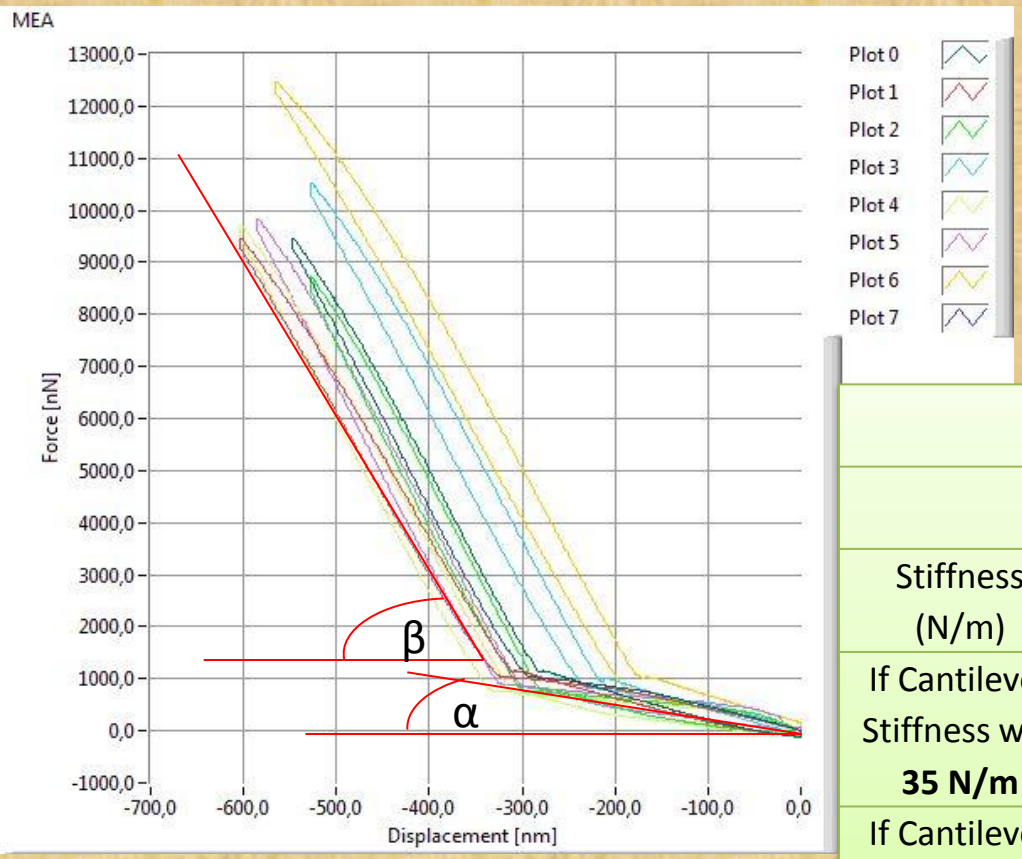

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	Loading	Unloading	Loading	Unloading
Stiffness (N/m)	64,17	62,18	3,00	4,22
If Cantilever Stiffness was **35 N/m**	650	460	3,3	4,6
If Cantilever Stiffness was **140 N/m**	44	42	2,8	3,8

Summary

- Calibration by Nanoidea membranes significantly lowers error of measurements
- Calibration process is non invasive and relatively fast
- Testing method allows to measure MEMS component stiffness
- MEMS membranes show two levels of stiffness, firstly lower values after some load stiffness increases