master thesis presentation

Development of an Atomic Force Microscope

author
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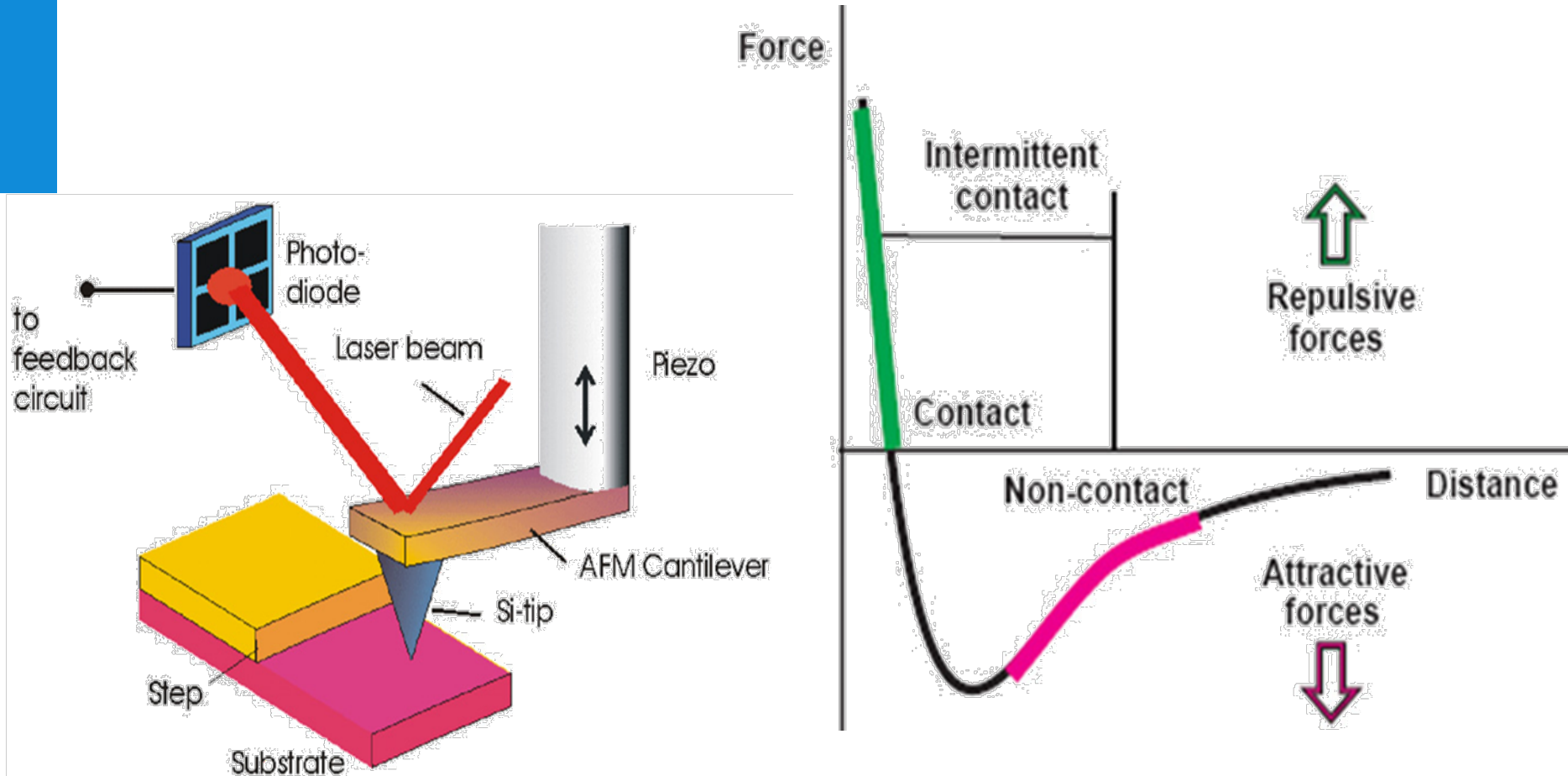## supervisors
Eric S. Buice
Jonathan D. Ellis
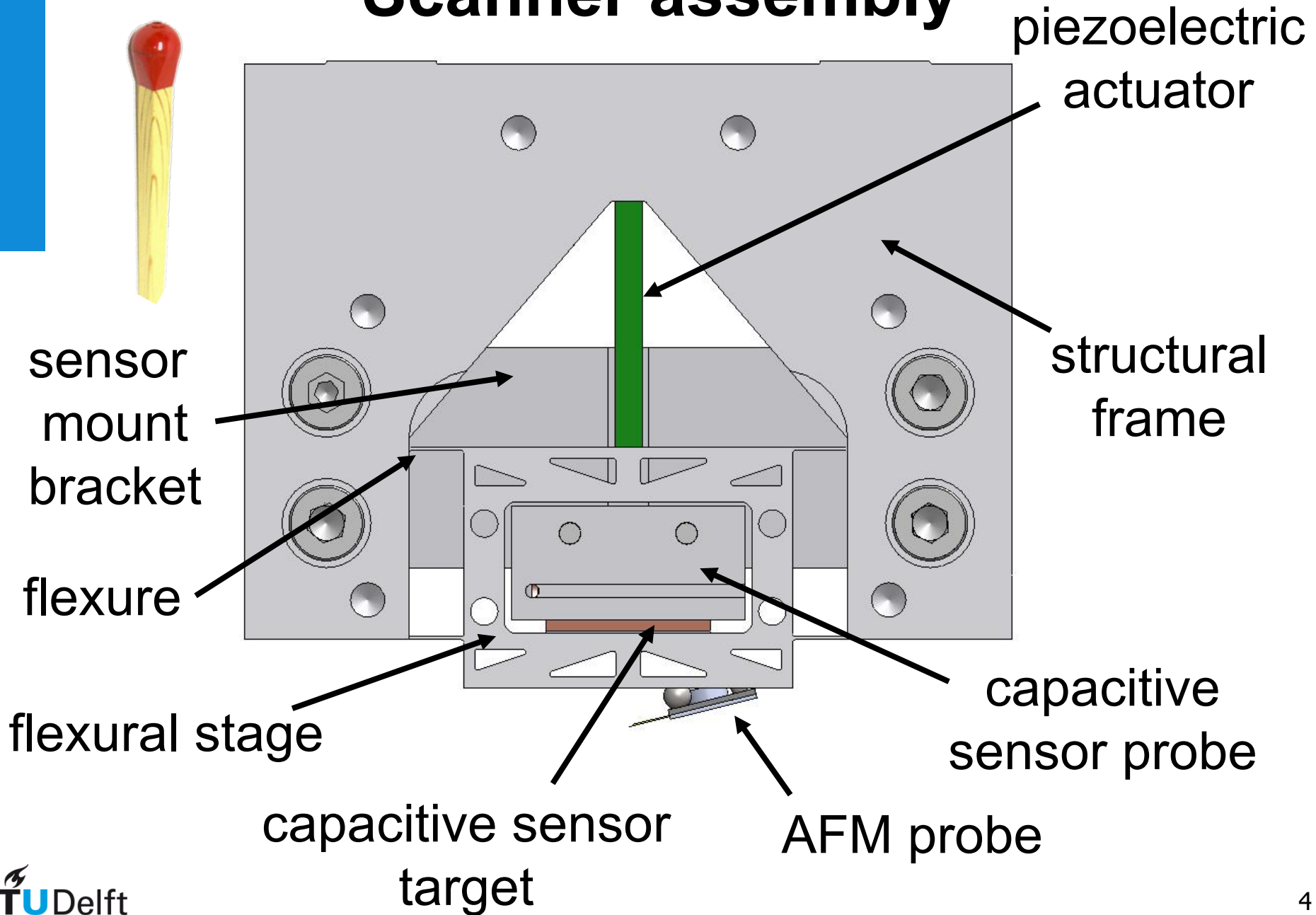Jo W. Spronck

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AFM technology introduction

Yacoot A, Koenders L. topical review: Aspects of scanning force microscope probes and their effects on dimensional measurement. Journal of Physics. 2008 May; **41**(10)
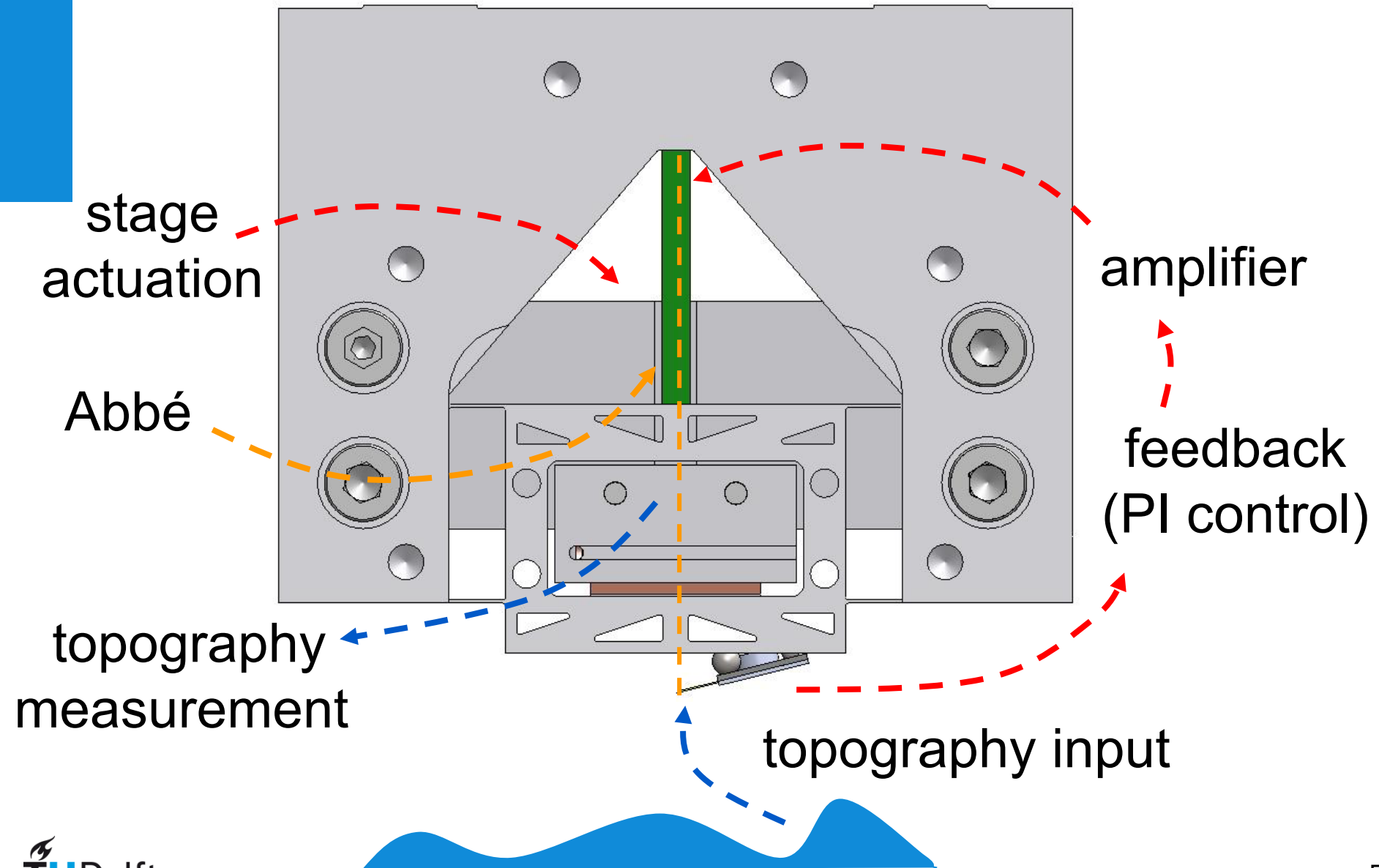
Assignment description

- Design of an AFM vertical scanner
- Surface topography measurement
- System requirements

Range	> 10 µm	human cell
1σ uncertainty	< 10 nm	haemoglobin molecule
Resolution	< 0.1 nm	atom diameter
Bandwidth	> 2 kHz	80 g
Volume	10 cm cube	

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Scanner assembly

piezoelectric actuator

structural frame

sensor mount bracket

flexure

flexural stage

capacitive sensor target

AFM probe

capacitive sensor probe

Working principle

stage actuation

amplifier

Abbé

feedback (PI control)

topography measurement

topography input

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Probe mount

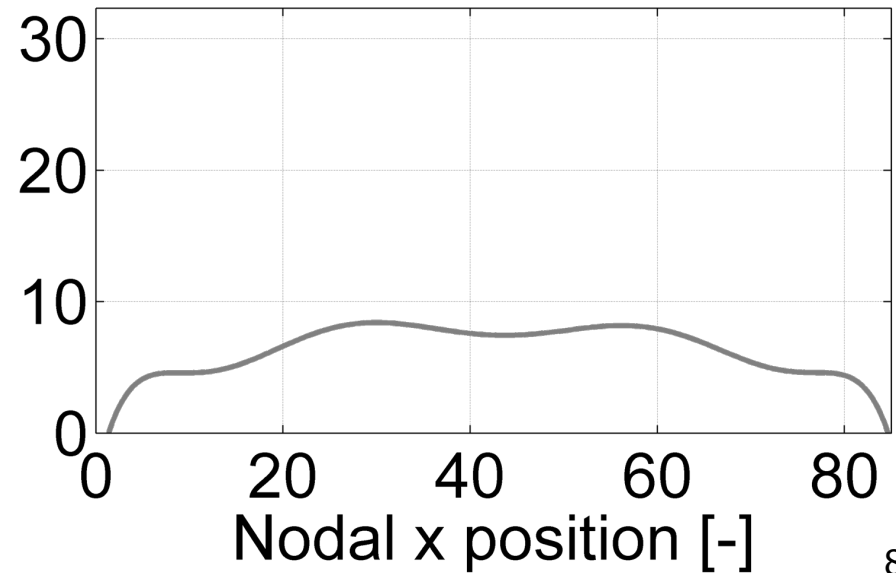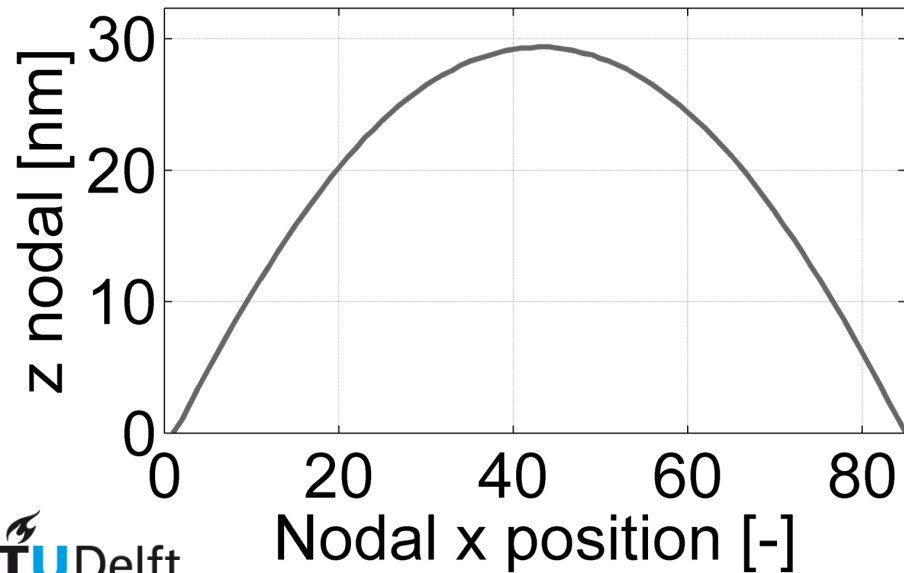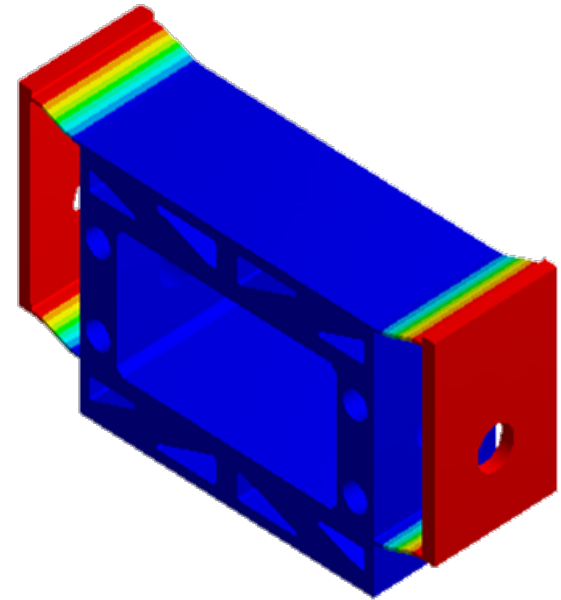silver line

soldering pad
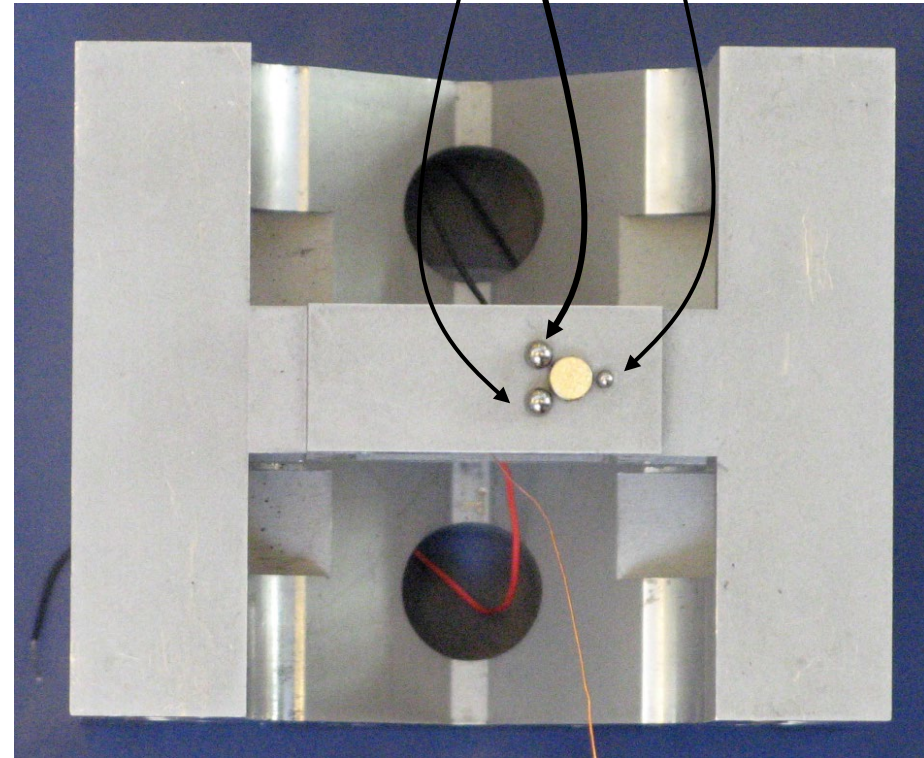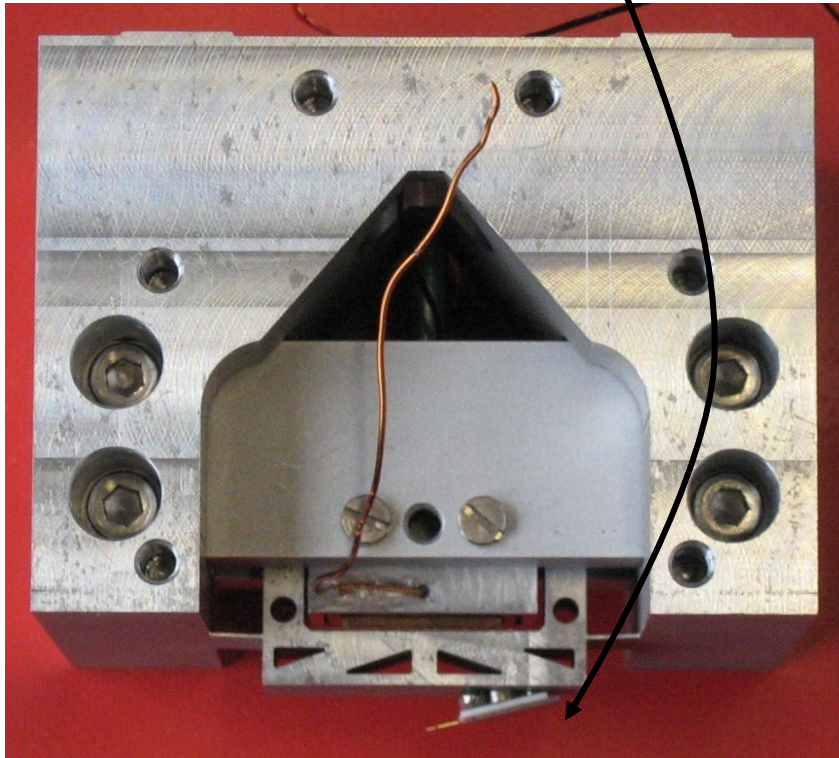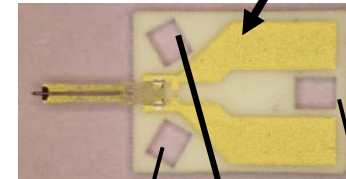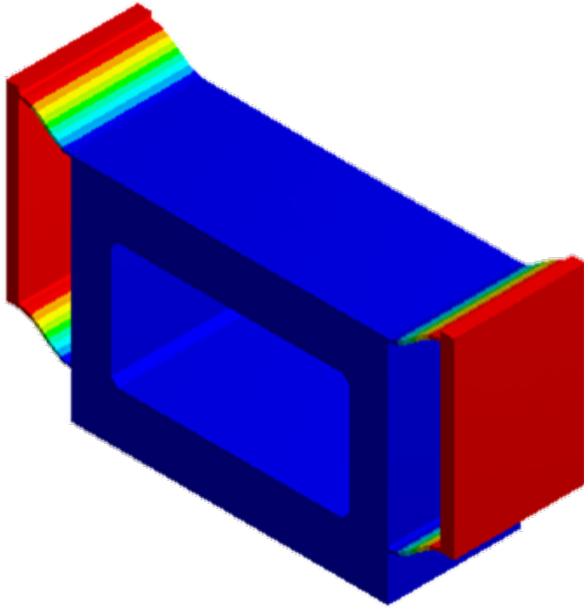
gold pad

steel plate

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Flexure stage

- Monolithic design
- Al 7075 - T6
- Elastic guidance
- Overconstrained
- PZT preload
- High f_0 > 6 kHz
- Low mass (6.6 g)
- High PZT stiffness
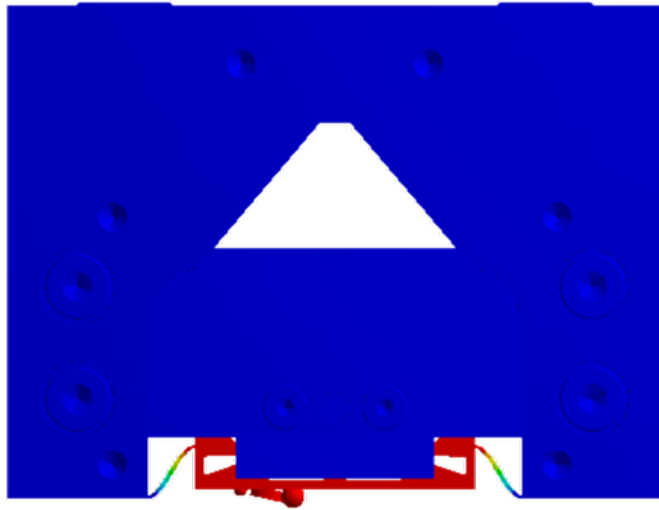- Low deformation
- Low actuation forces (5 N)
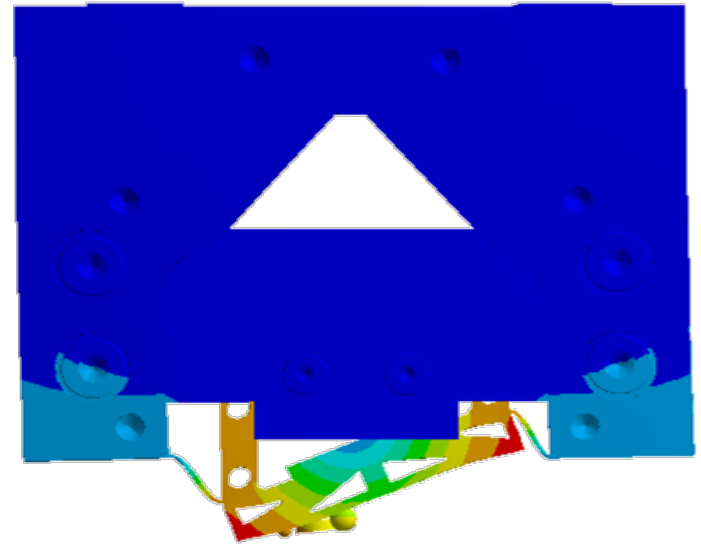
F$_{pzt}$
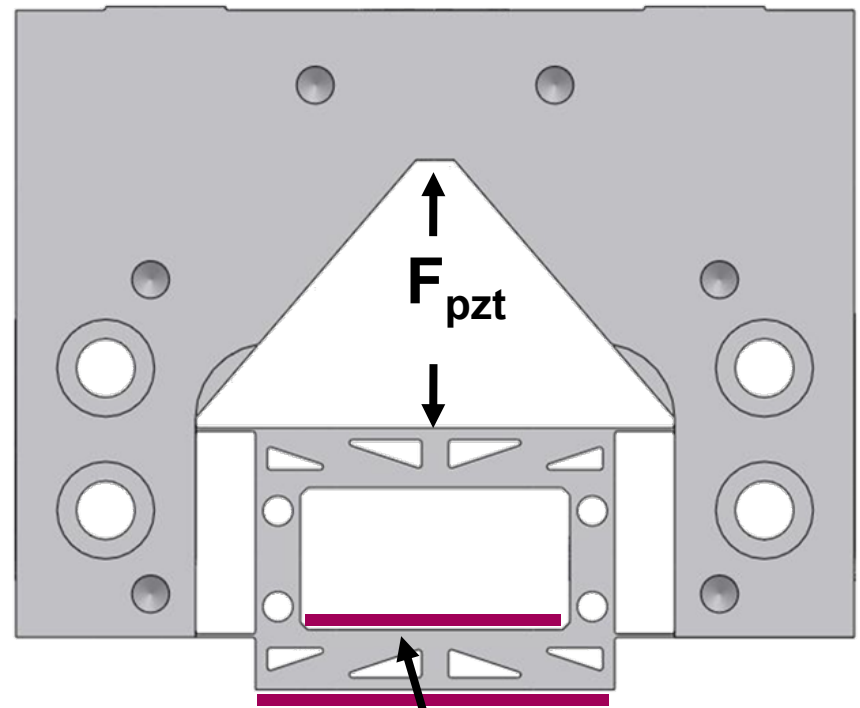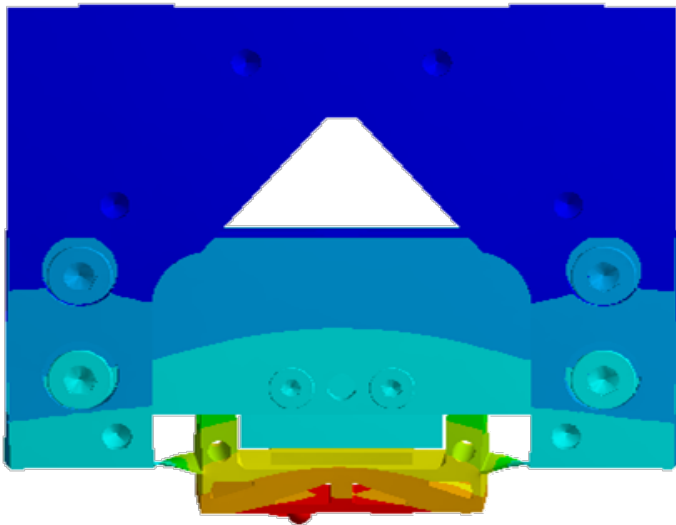
Metrology sensitive
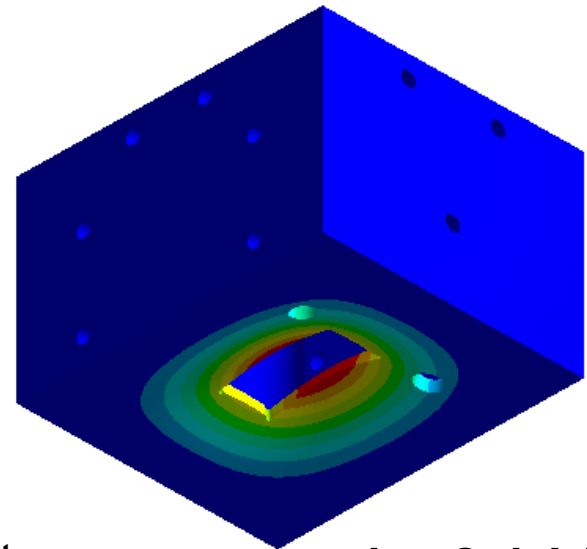
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Deflection shaping

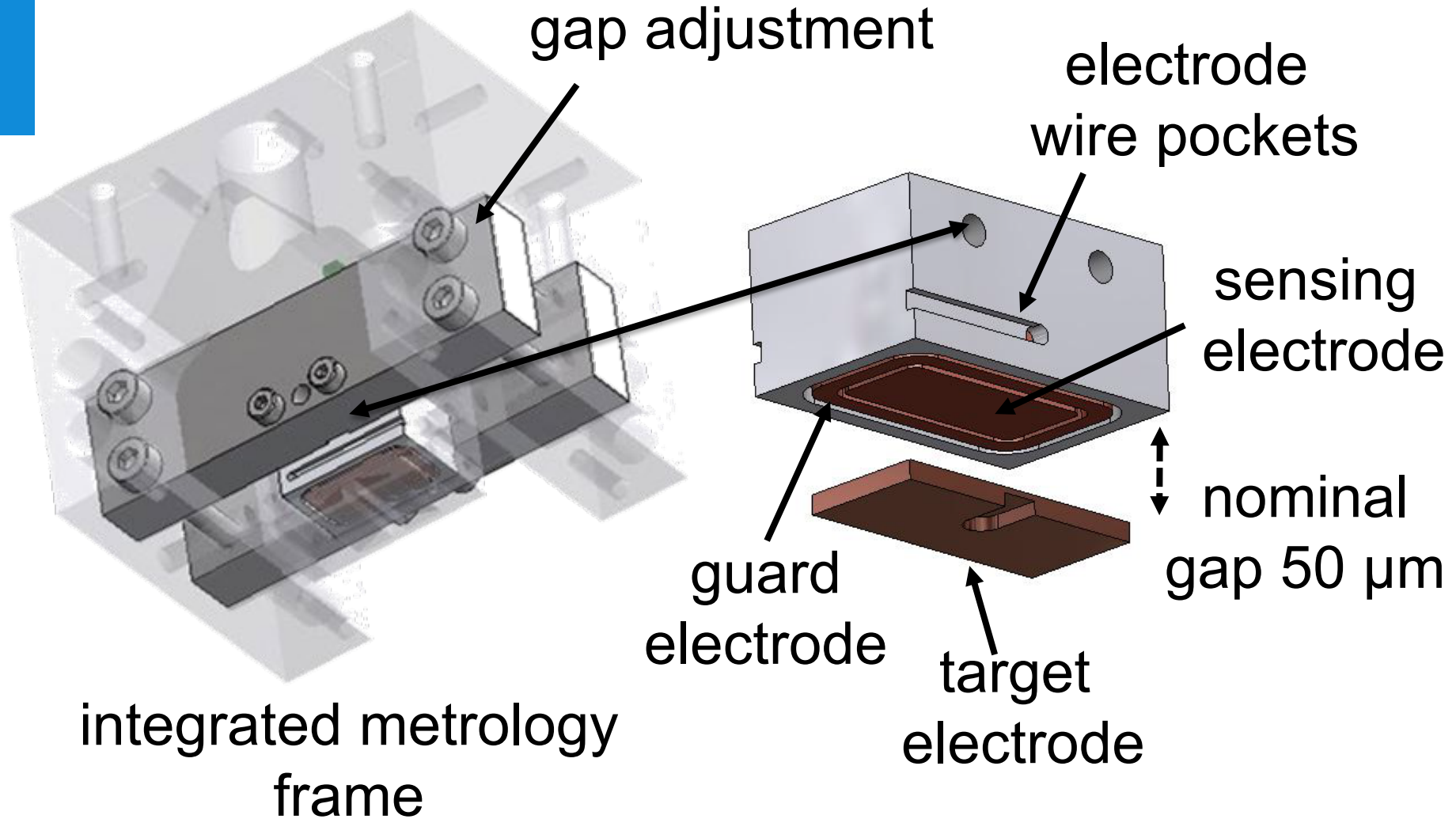# ANSYS modal analysis

1st mode 5.2 - 6.8 kHz

2nd mode 7.85 kHz

3rd mode 7.9 kHz

1st cover mode 9 kHz

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9

Capacitive sensor

gap adjustment

electrode wire pockets

sensing electrode

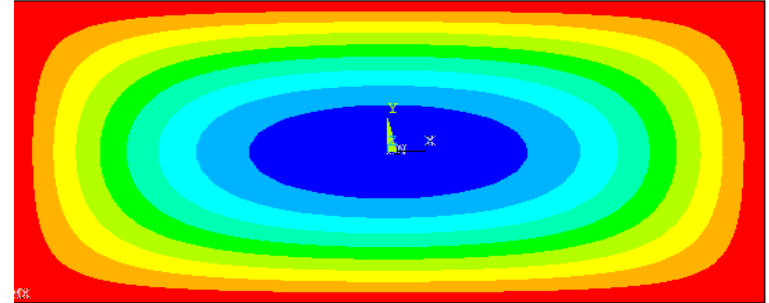nominal gap 50 μm

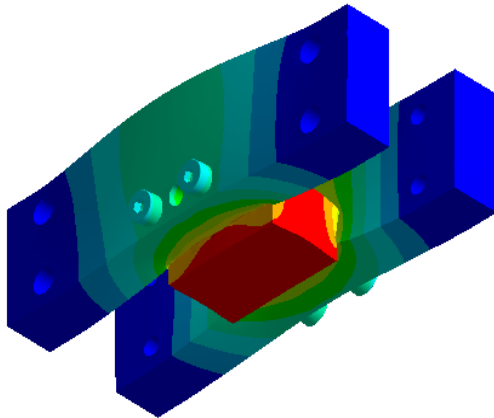guard electrode

target electrode

integrated metrology frame

Squeeze film damping ANSYS, Green's function
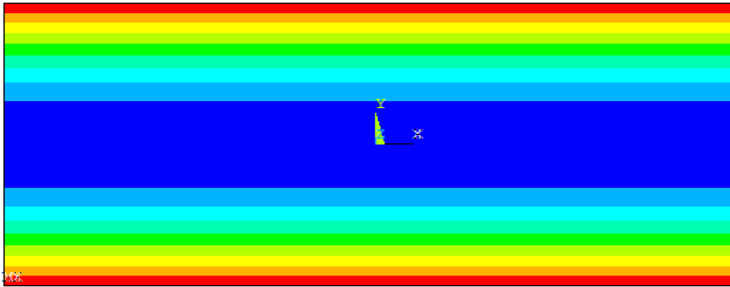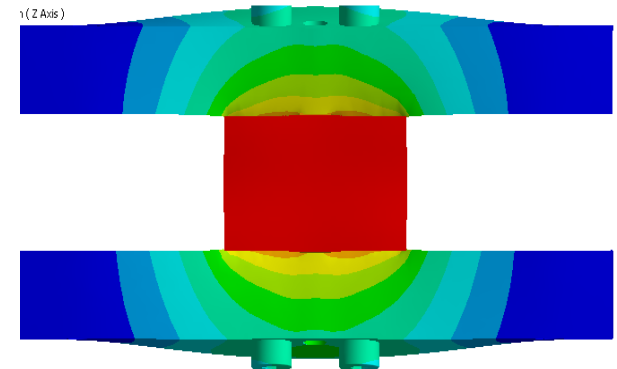
Pressure distribution
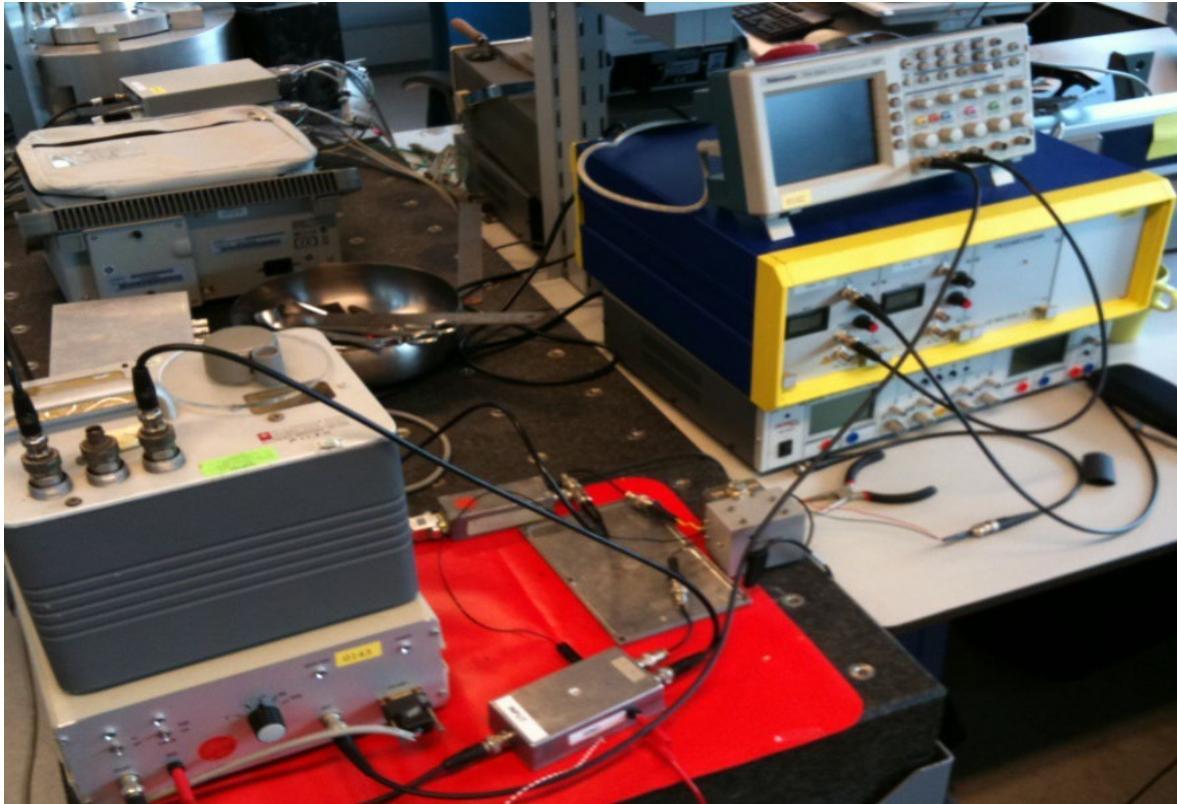2 vented edges

Pressure distribution
4 vented edges

Elastic deformation

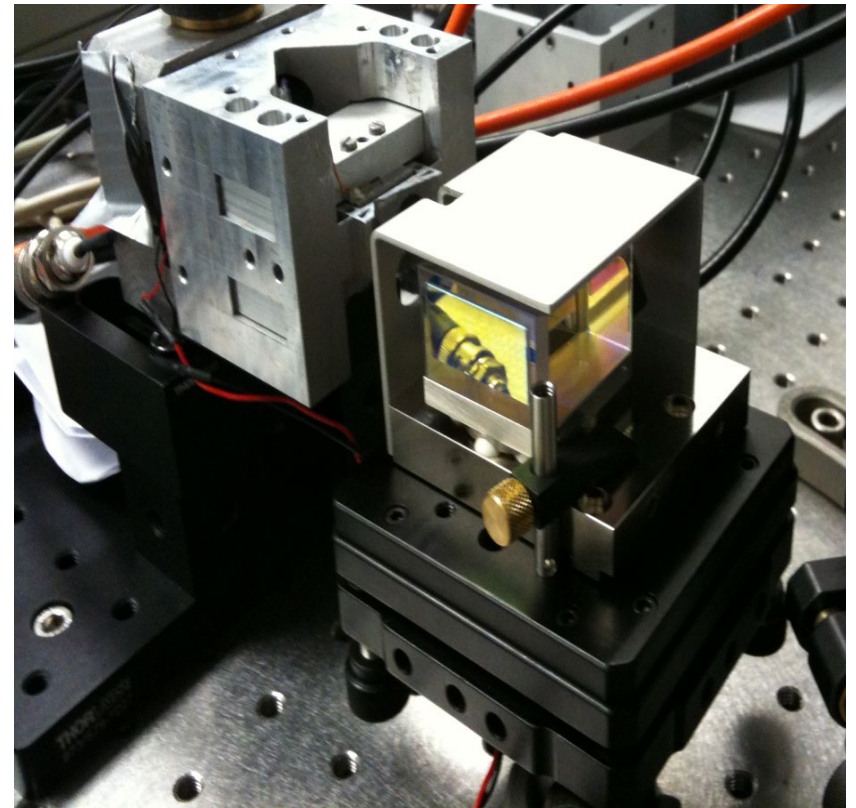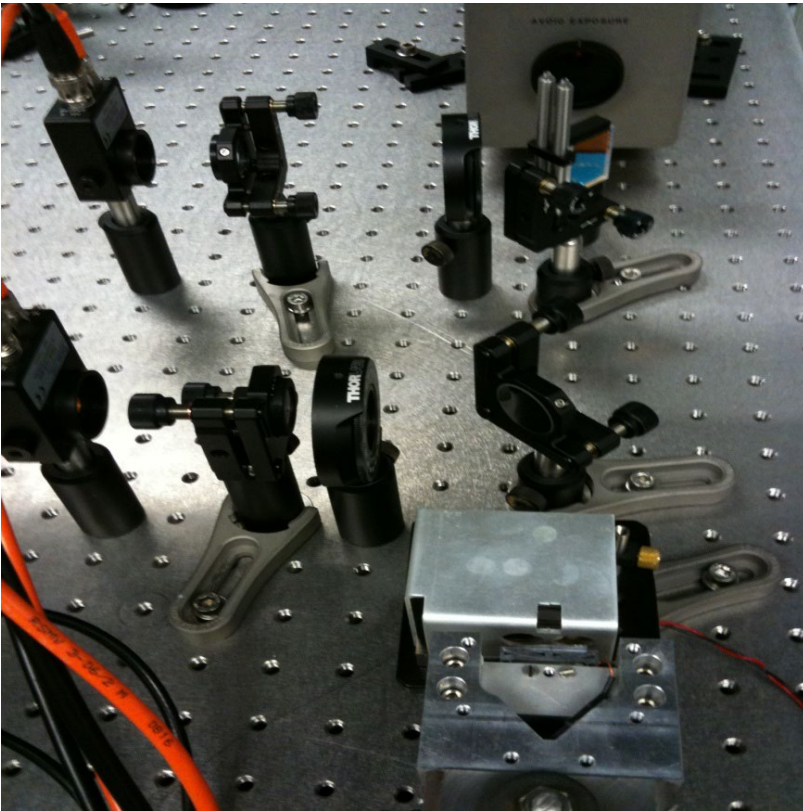F = 0.1 N, b = 0, r = 0.4 nm

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Capacitive sensor electronics

- AC transformer bridge
- Implementation issues
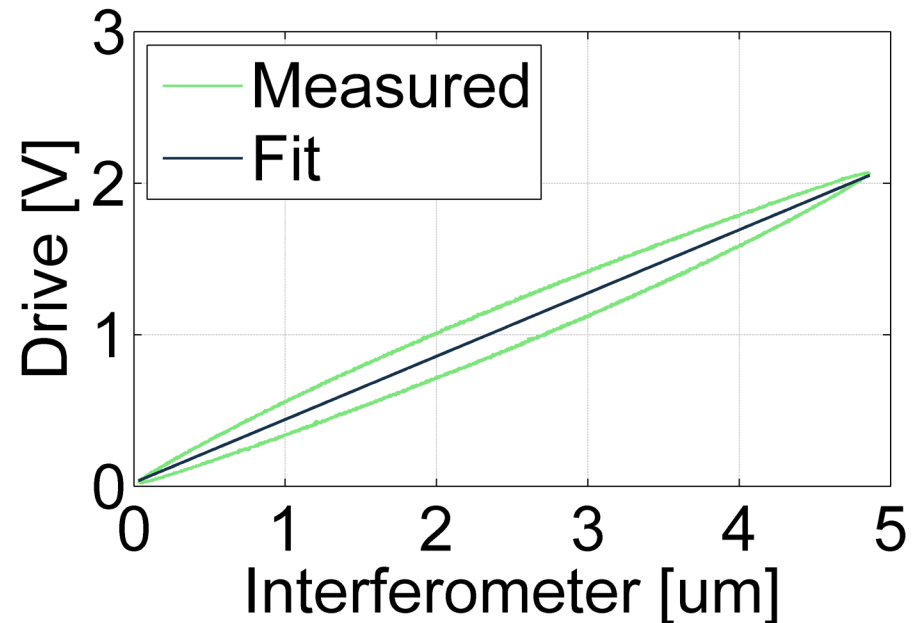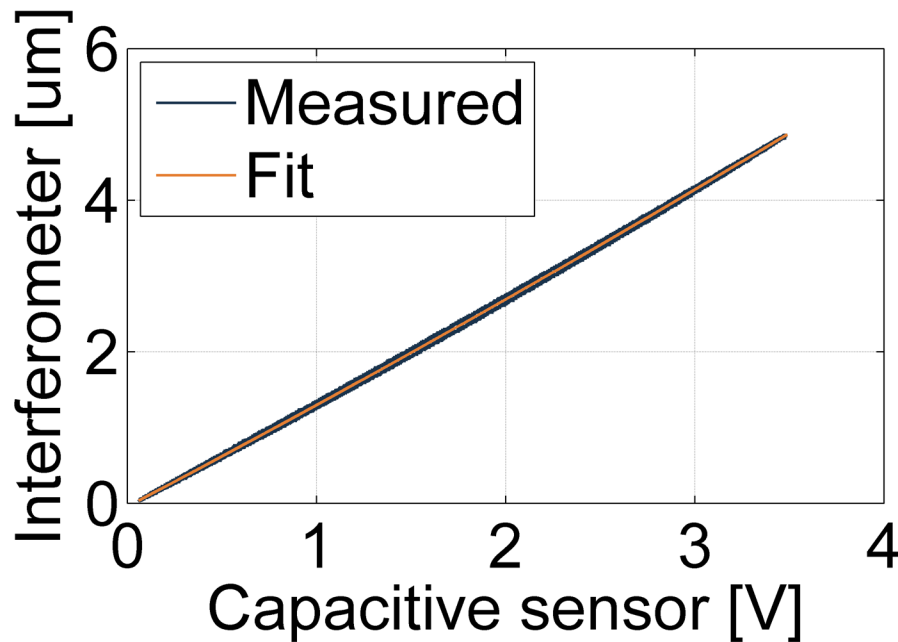 - Grounding loops elimination
  - Shielding

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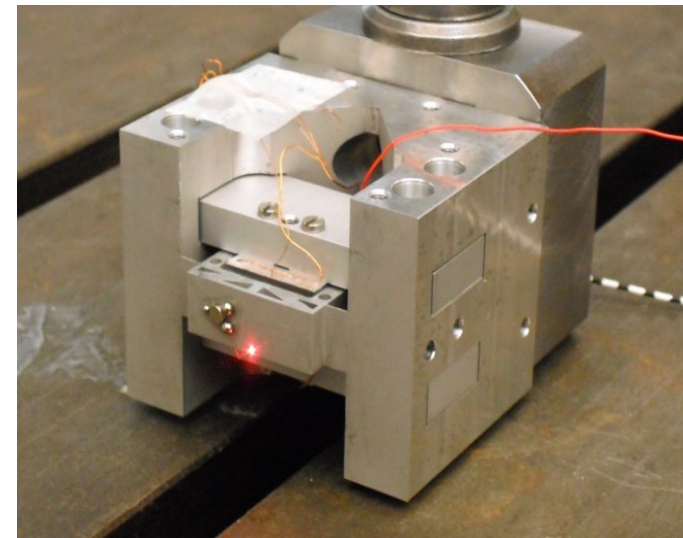# Capacitive sensor calibration by laser interferometer

Calibration results

- 1 nm traceable uncertainty calibration
- Capacitive sensor : 2nd order fit
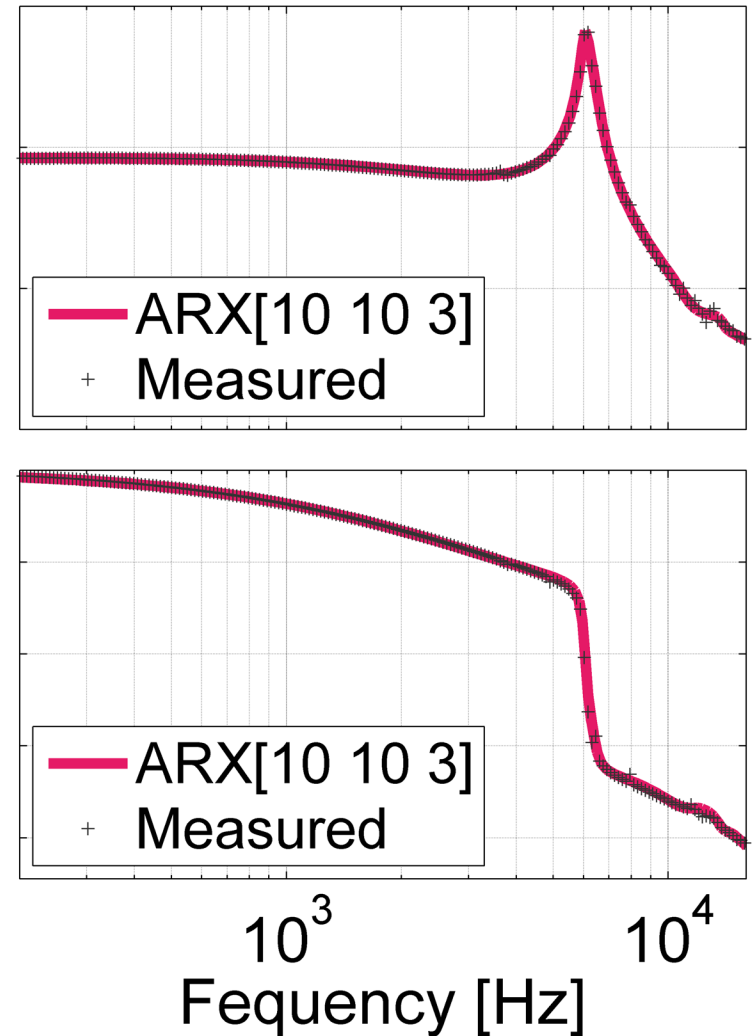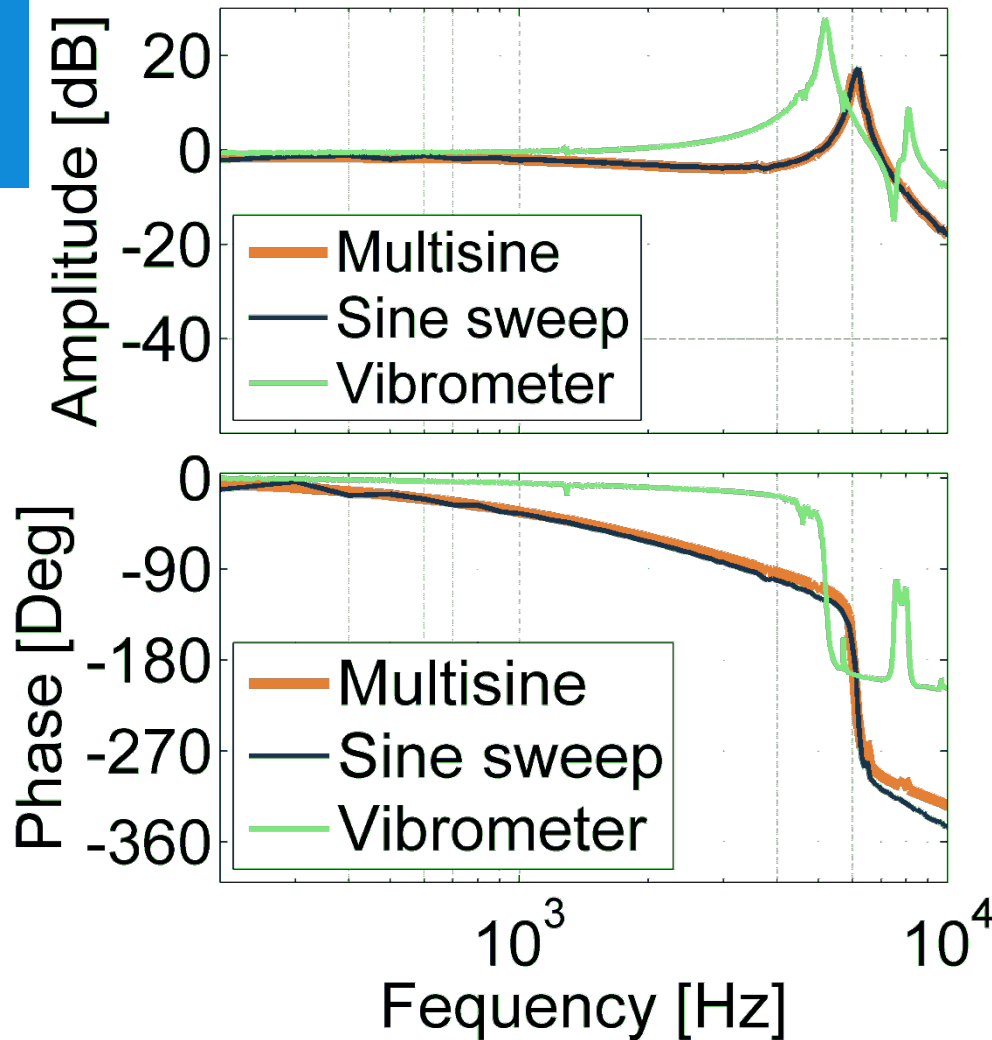- Actuator open loop hysteresis

Frequency response analysis

- Three methods used
  - Laser vibrometer
  - Multisine feed
  - Sine sweep

- Capacitance sensing
- PZT stiffness variation
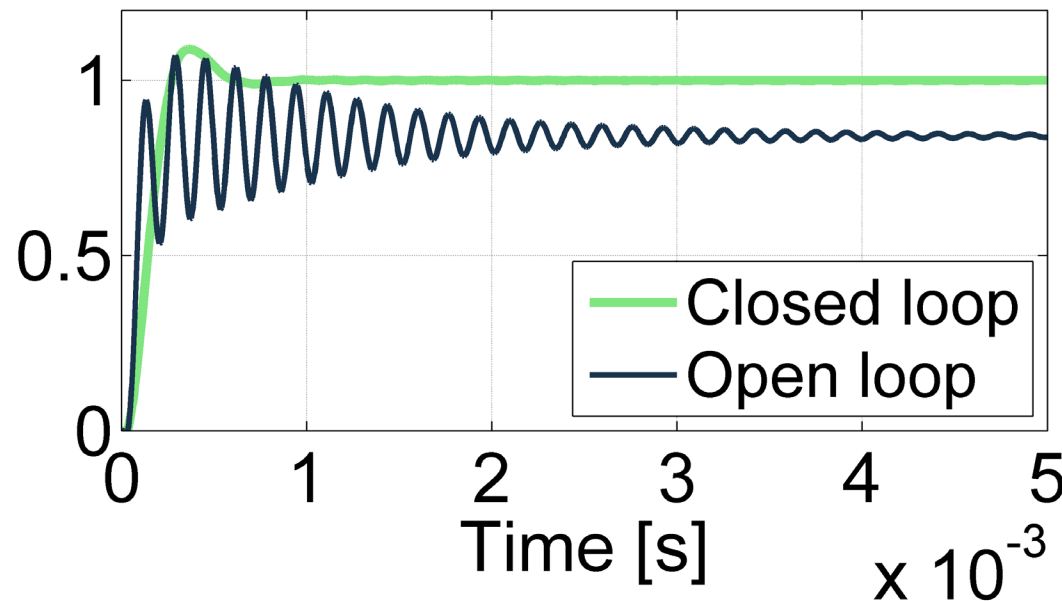- Stiffening cover effect
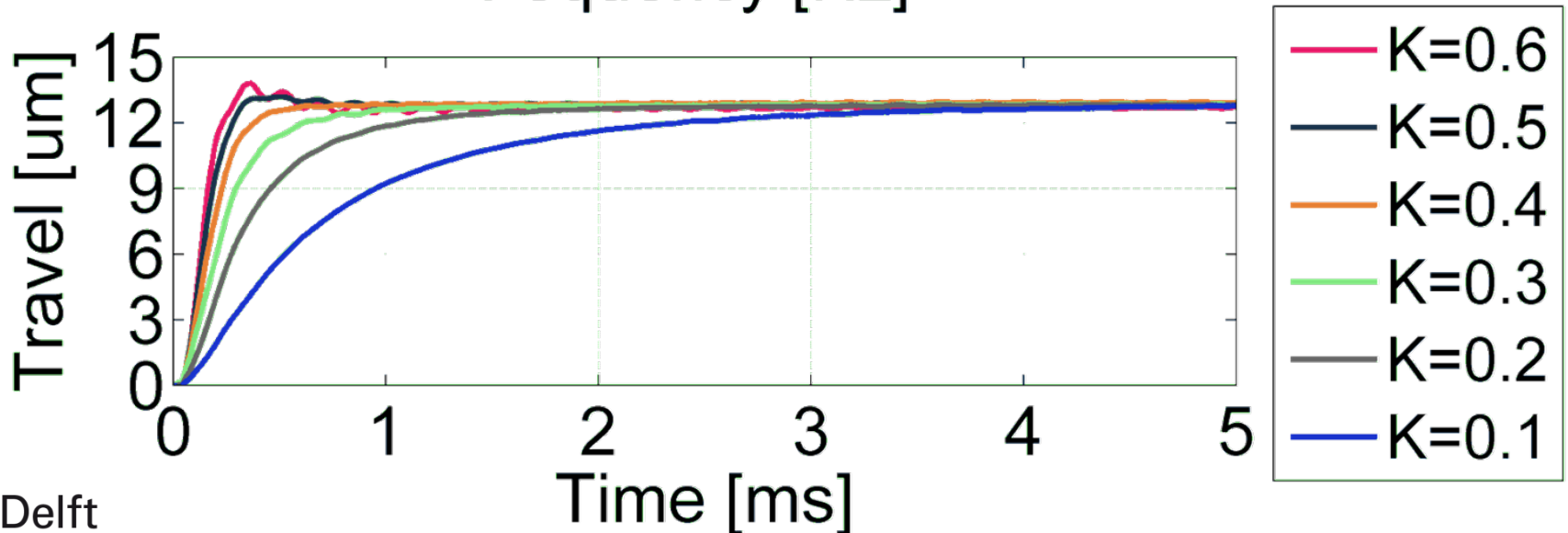

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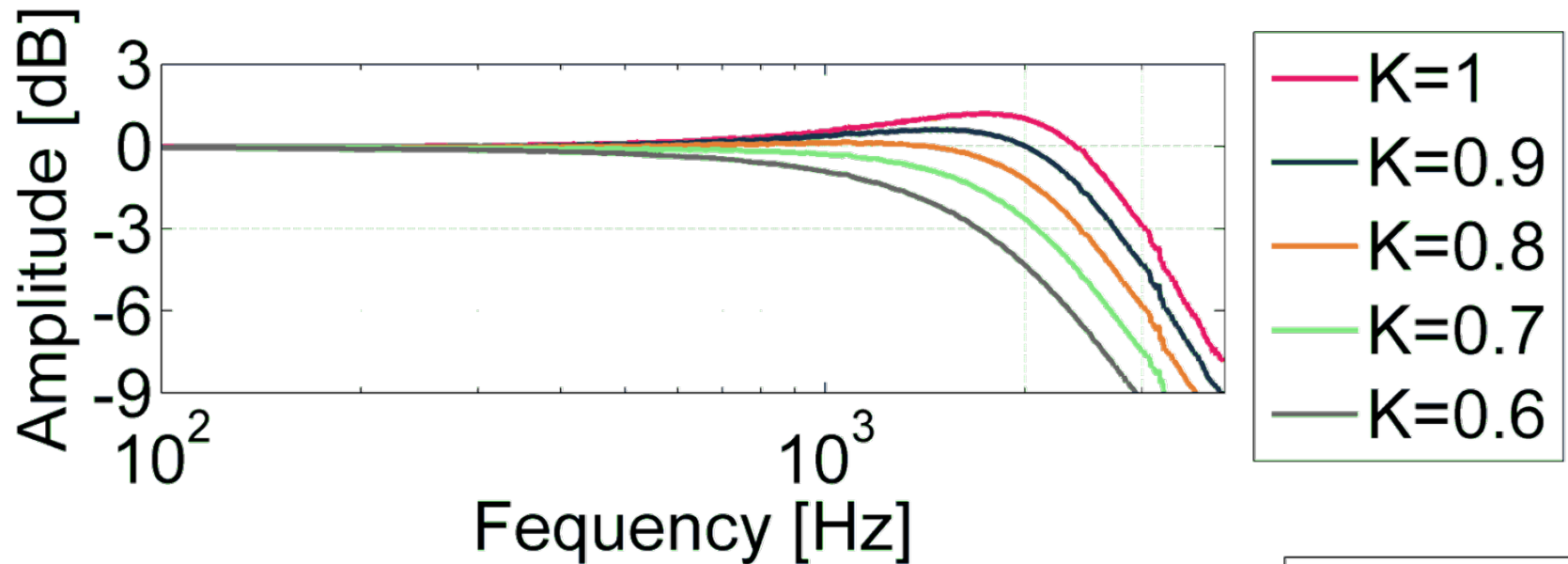
System identification
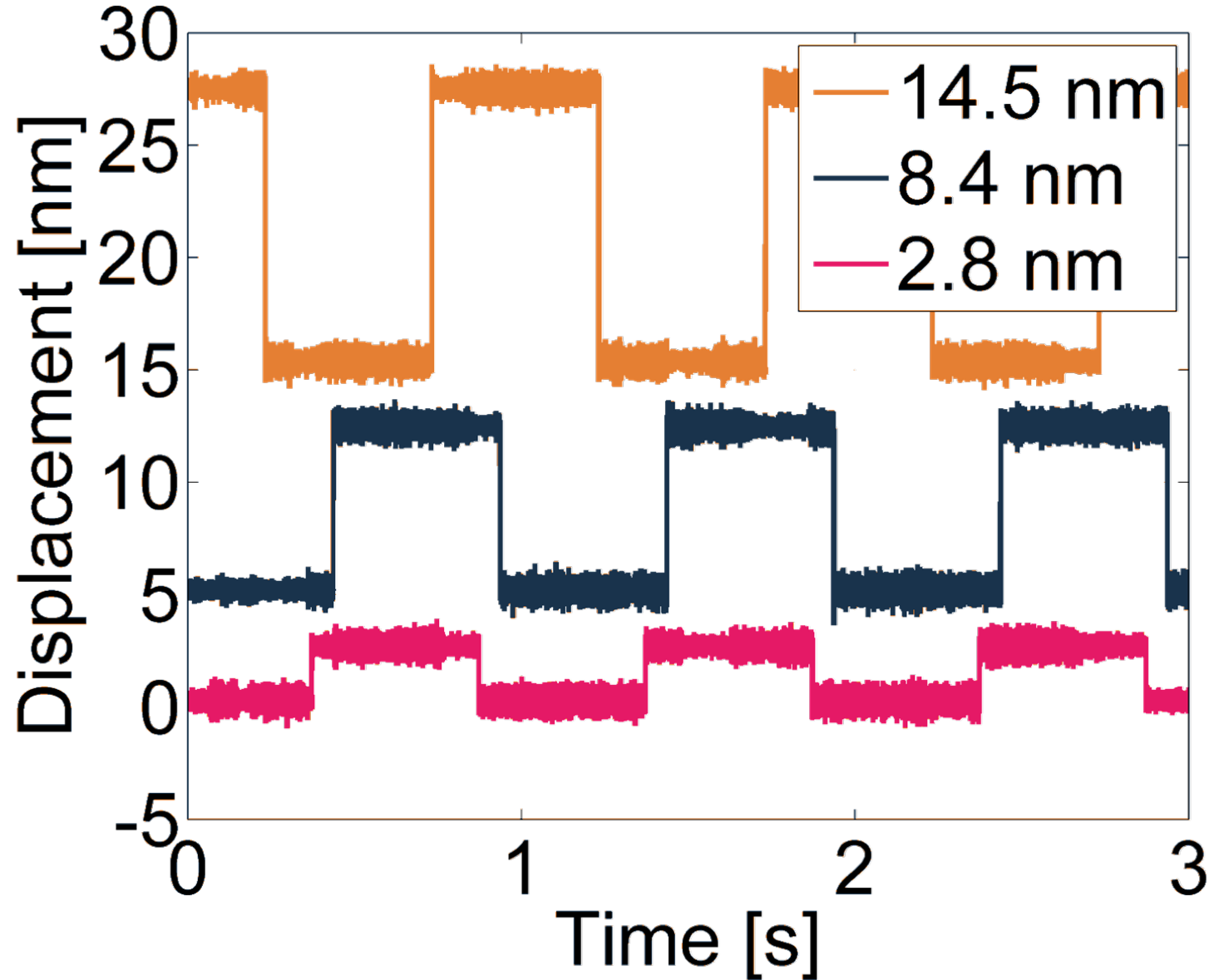
Feedback controller

- Based on ARX [10, 10, 3] system model
- Digital Proportional Integral (PI) and notch filter, 100 kHz sampling
- Robust design for loop gain variation
- Piezoelectric hysteresis elimination (I)

# Closed loop performance

Stage resolution

Uncertainty sources

|	
Structural frame deformation	1.2 nm
Thermal expansion	0.8 nm
Abbé and cosine error	0.71 nm
Static stage calibration	1 nm
Sensor elastic deformation	0.4 nm
Capacitive sensor noise	0.7 nm
Overall uncertainty (1σ)	2 nm

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Conclusions (1)

- START: specifications
- Concept, modelling, design
- Stage, sensor, AFM probe, probe mount
- Actuator, driving amplifier
- PCB design
- Manufacturing
- Assembly
- Integration

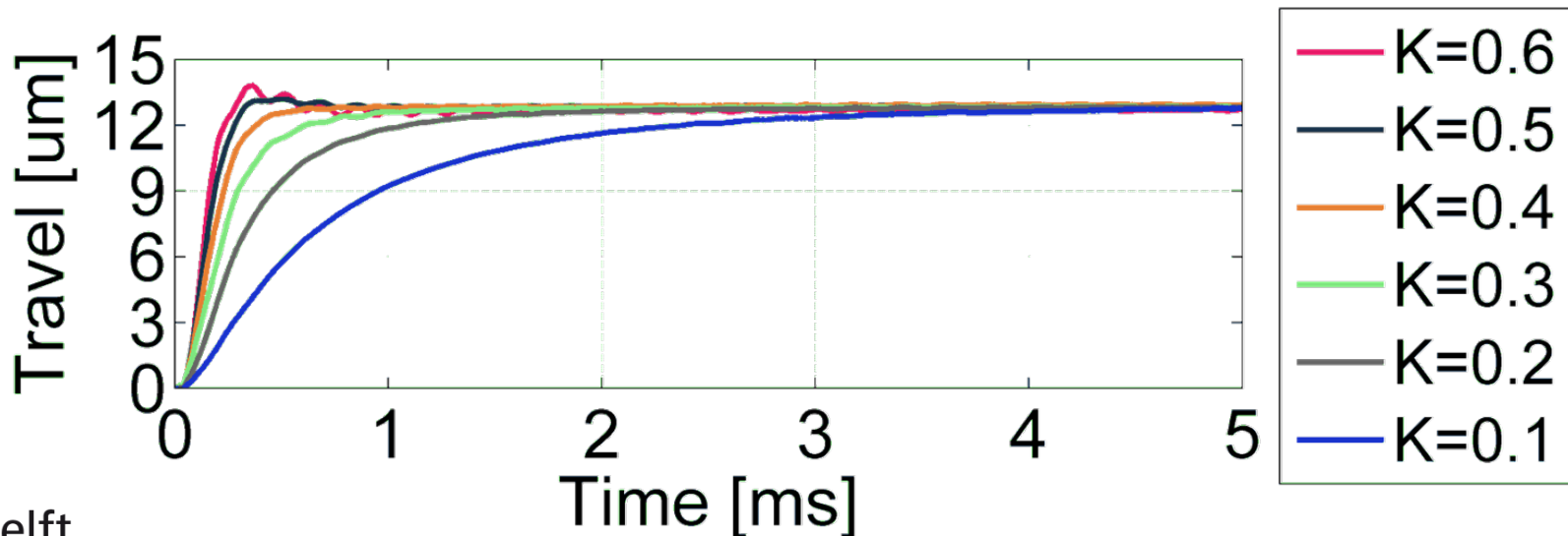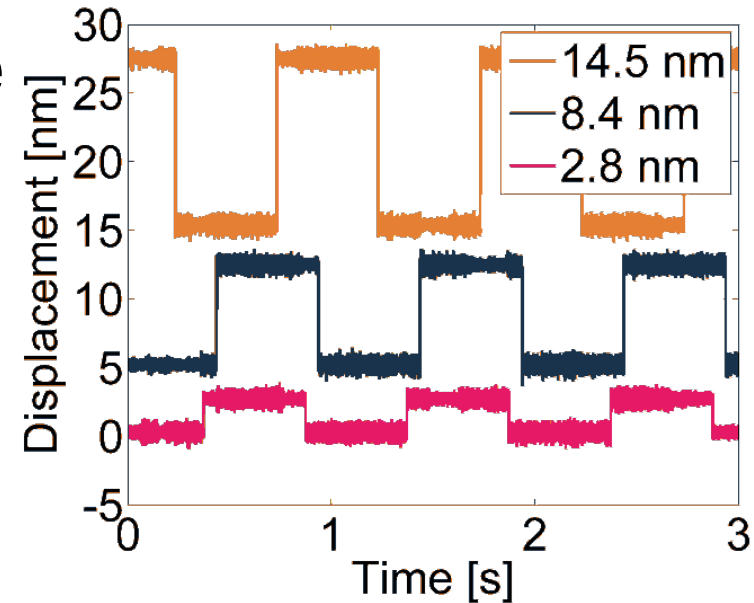**T U** Delft
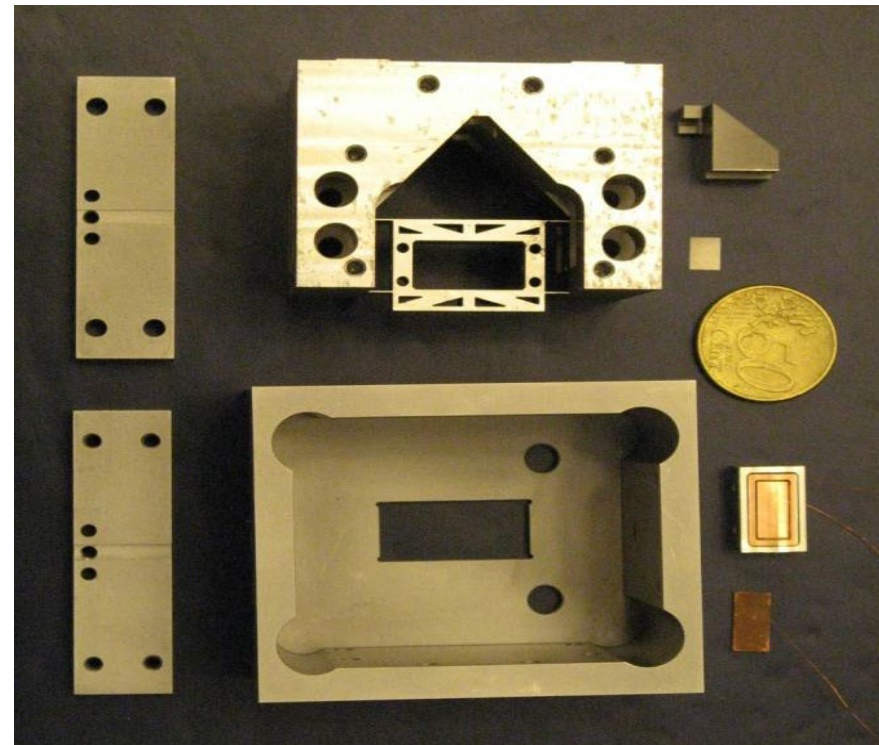
Conclusions (2)

- Electronics implementation
- Calibration
- Frequency response
- System identification
- Feedback control
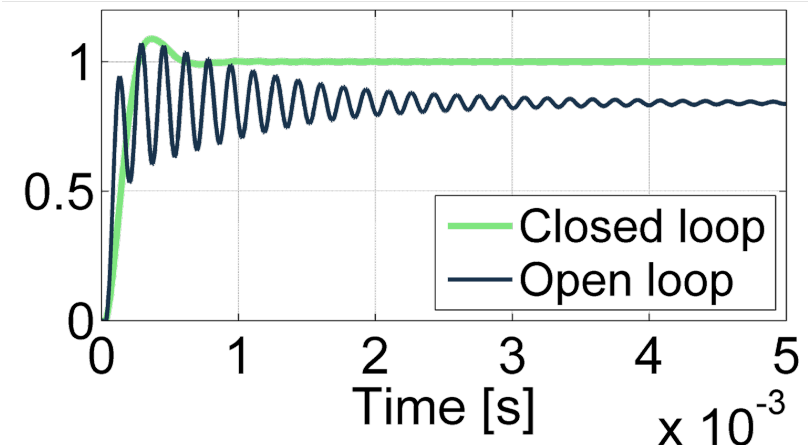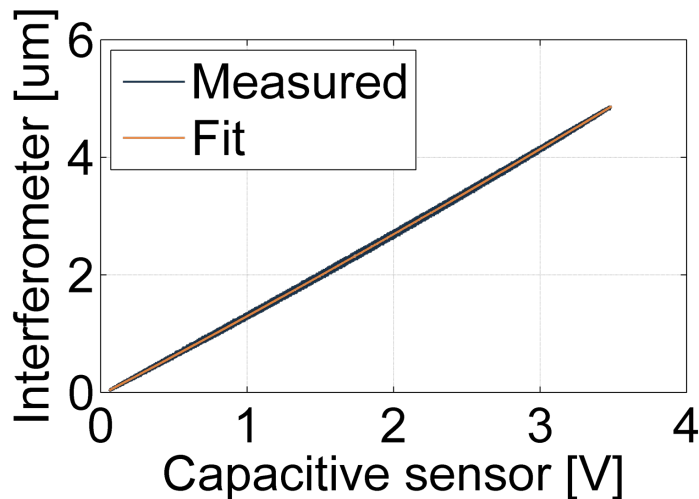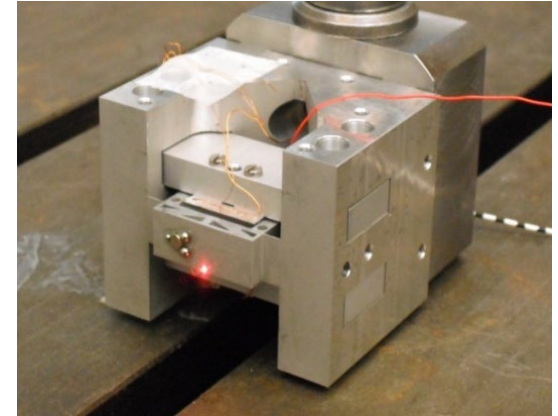
Conclusions (3)

- END: working hardware
- 2.5 kHz bandwidth
- 2 nm uncertainty (1σ)
- 13 µm steps
- 2.8 nm resolution

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THANK YOU FOR YOUR ATTENTION!

DISCUSSION

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