Micro- and Nanoforce Metrology at PTB

Uwe Brand, Lutz Doering, Vladimir Nesterov
and Febo Menelao

PTB (Germany)

1. **Mass balance based devices**

   a) 400 mN Microforce Measuring Device

   - Calibration of microforce transfer standards

   b) 20 mN Nanoforce Measuring Device

   - Stiffness calibration of AFM cantilevers

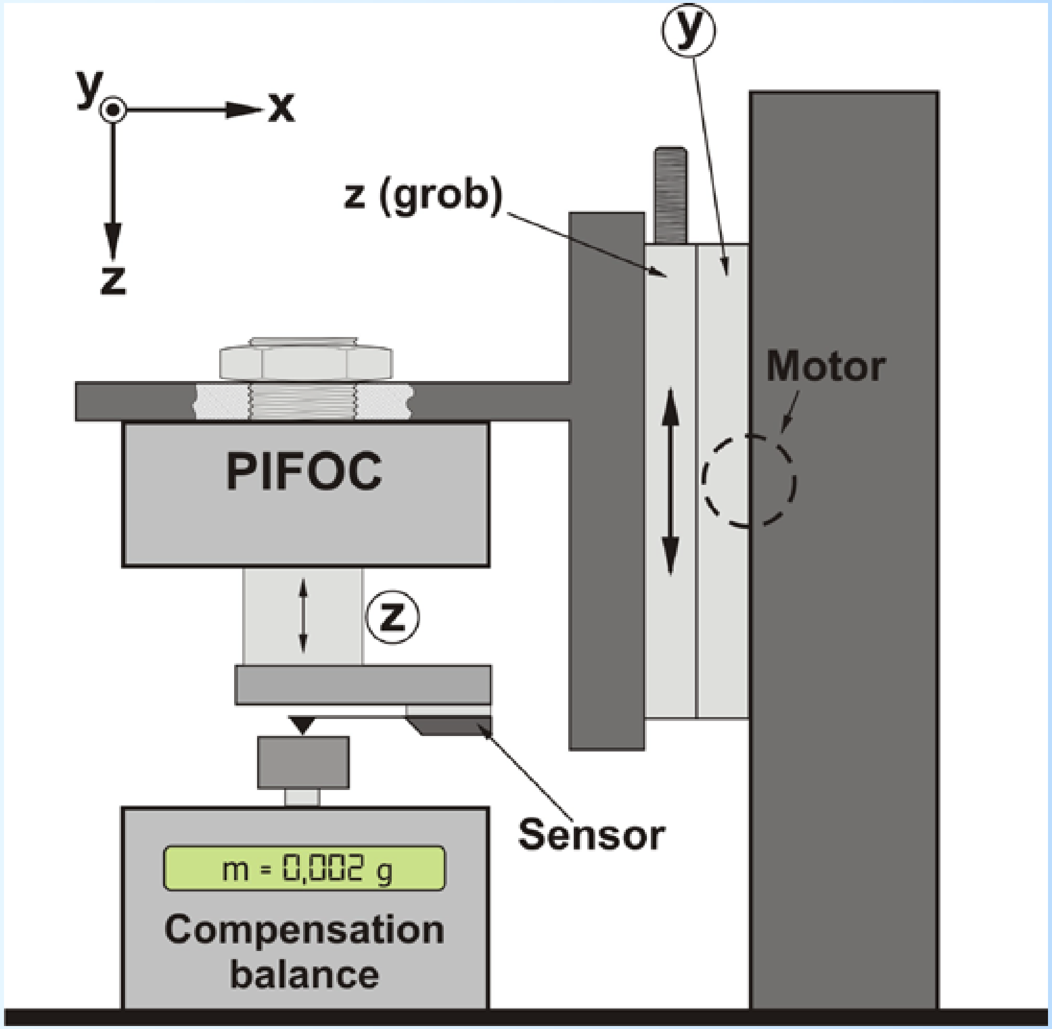
2. **Electrostatic Nanoforce Prototype**

   - Calibration by tilting

3. **Proposal of international stiffness comparison**

1.a) 400 mN Microforce Measuring Device (U. Brand)

Objectives: stiffness calibration in the µN-range (simultaneous measurement of force and displacement)



Properties of balance:

resolution: 0.1 µN

repeatability: 0.2 µN

non-linearity: 0.3 µN

Expected uncertainty of stiffness reachable:

U(k) = 2 %

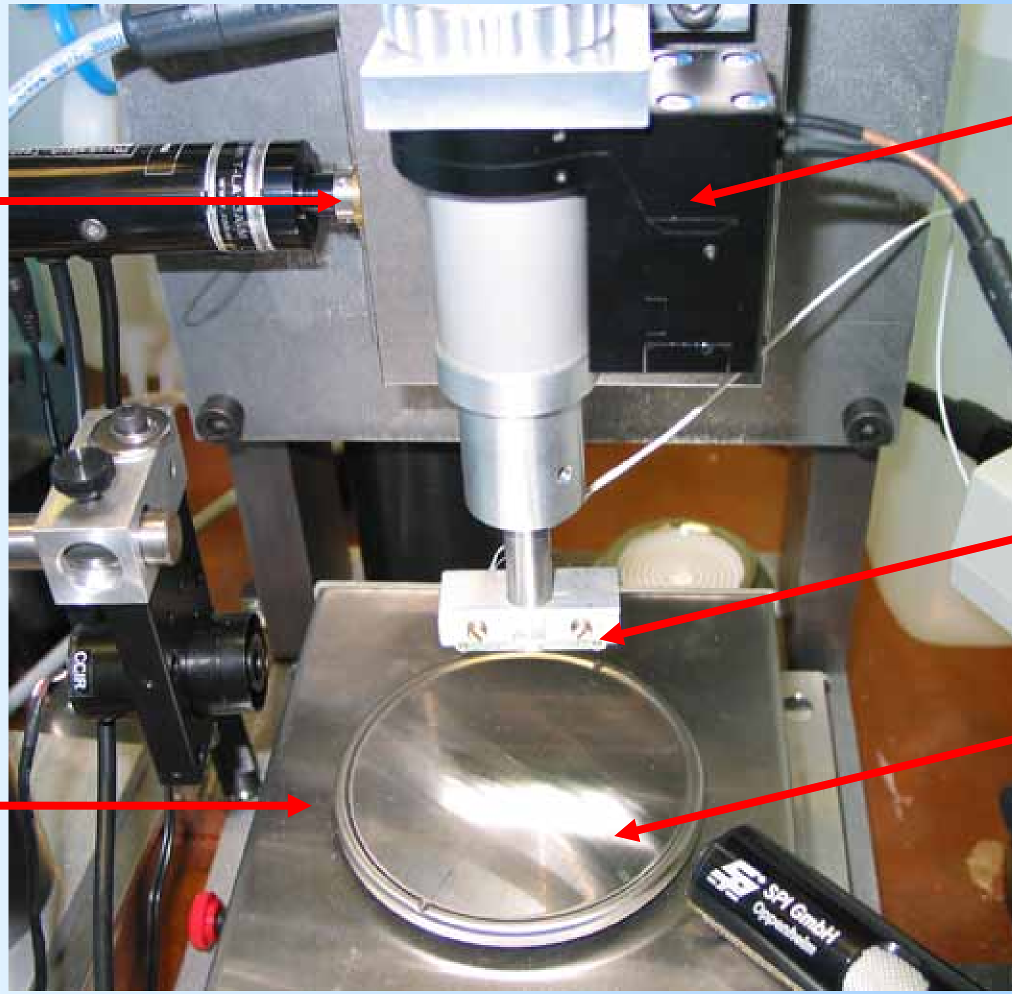
Temperature drift:
<< 6 mK/h

Photo of 400 mN Microforce Measuring Device

PTB

Coarse table

z-Pifoc®, 100 µm capacitive controlled



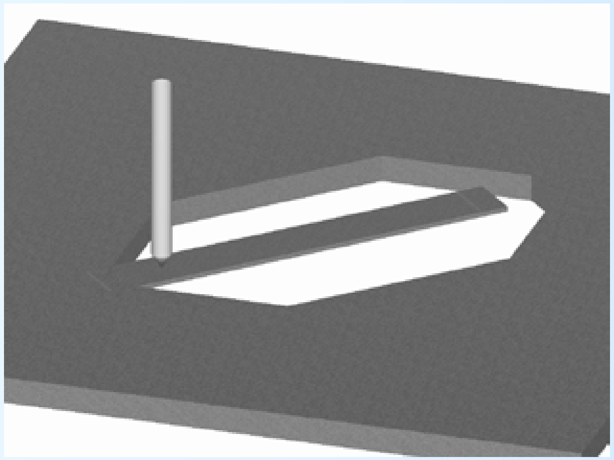
Mount with artifact

Balance load button

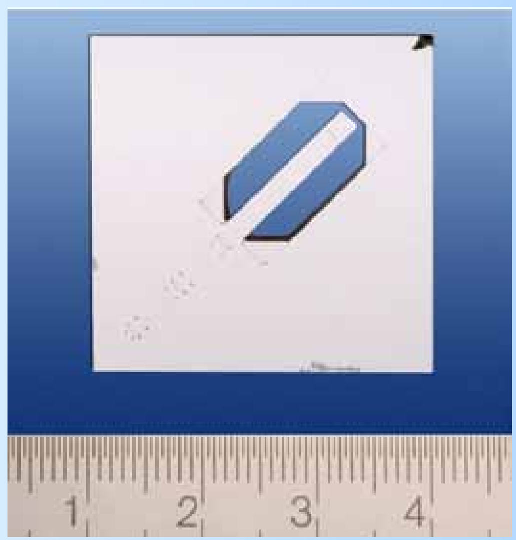
Balance:
Mettler SAG 245

Calibration of probing force setting standards for stylus instruments

Stiffness values: 15, 50, 130 und 1000 N/m
Probing force range: 1 µN - 100 mN



Technical University Chemnitz (Prof. J. Frühauf) in cooperation with SiMetrics GmbH (see www.simetrics.de) and the PTB (calibration)



Physikalisch-Technische Bundesanstalt

Braunschweig und Berlin

Kalibrierschein

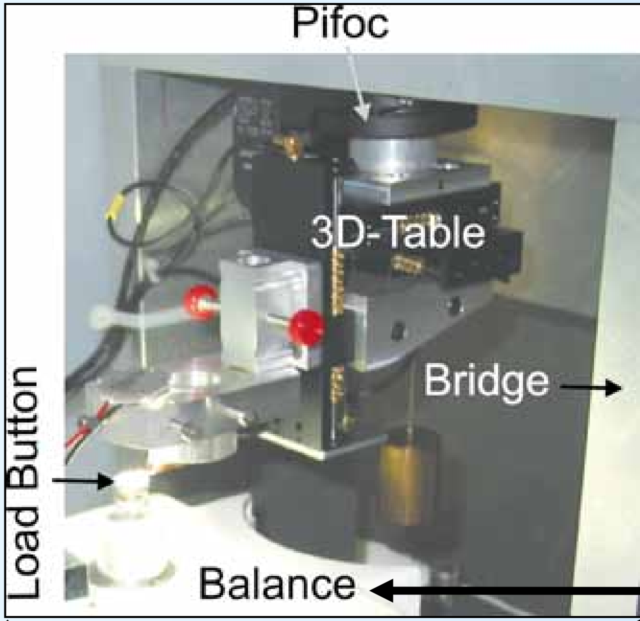
Calibration certificate

Gegenstand	Kraft-Einstellnormal	
Hersteller	SIMETRICS GmbH Am Südhang 5 09212 Limbach-Oberfrohna	
Typ	FS-C 15 Silizium Kraftnormal	
Kennnummer	0242	
Auftraggeber	SIMETRICS GmbH Am Südhang 5 09212 Limbach-Oberfrohna	
Anzahl der Seiten	6	
Geschäftszeichen	5.11-4040 1-003595	
Kalibrierzeichen	50597 PTB 10	
Datum der Kalibrierung	29. September 2010	
Im Auftrag	Braunschweig, 2010-10-13 Siegel	Bearbeiter
Dr. Uwe Brand		Harald Schwädelbach

1.b) 20 mN Nanoforce Measuring Device (L. Doering)

Objectives: stiffness (k) calibration in the nN-range (AFM cantilevers)

Uncertainty: U(k) > 3.3 %



Sartorius SC2

<u>Properties of z-stage (Pifoc):</u>
- **resolution: 1 nm**
- **uncertainty: 5 nm per step**

<u>Properties of balance SC 2:</u>
- **resolution: 1 nN**
- **repeatability: 2.5 nN**
- **non-linearity: 9 nN**

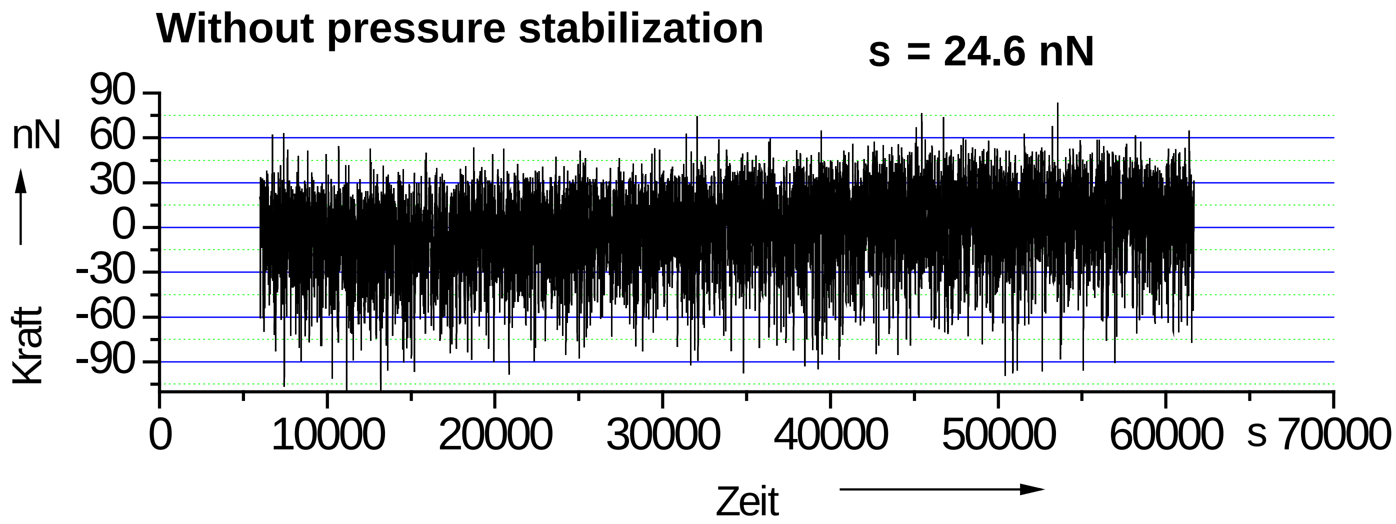
<u>Properties of chamber:</u>

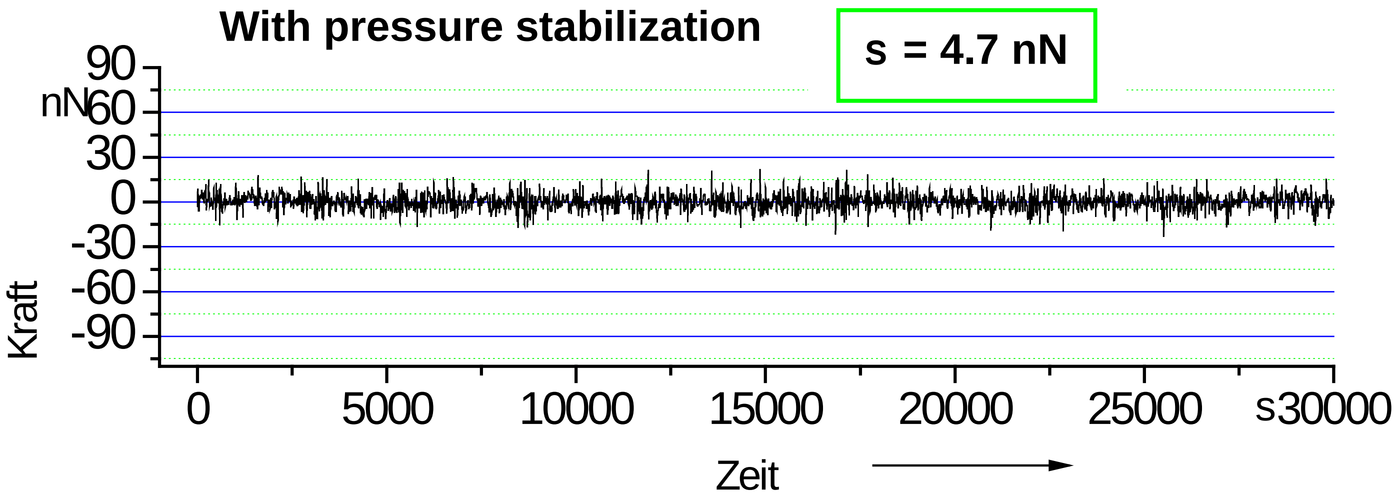
- **Pressure: 900..1100 hPa ± 0.7 Pa (0.1 nN)**

and

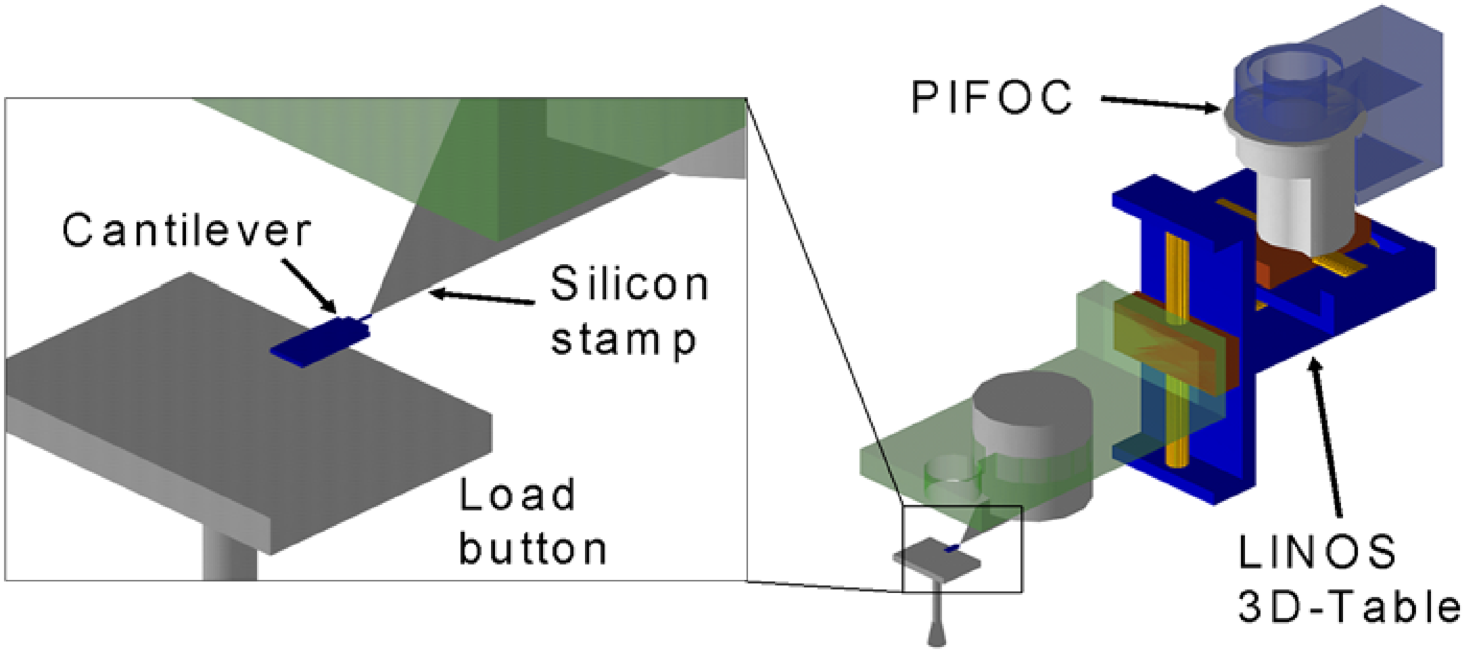
- **Rel. Humidity: 10…80 % ± 0.013 % (0.4 nN)**
- **Temperatur drift: < 6 mK/h**

Noise of 20 mN Nanoforce Measuring Device

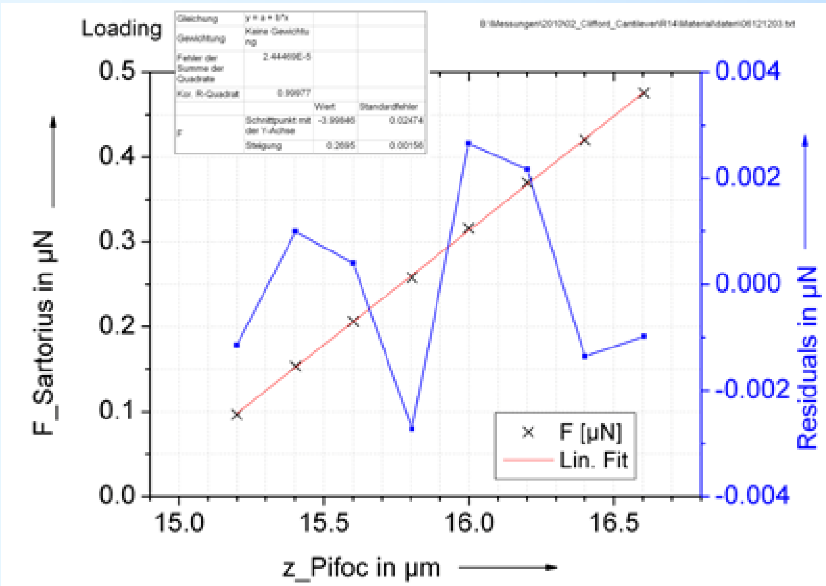


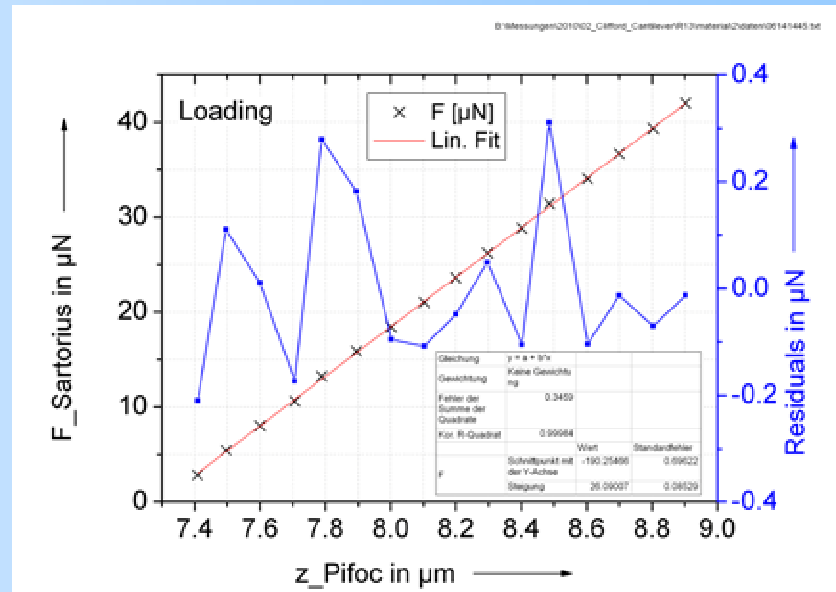


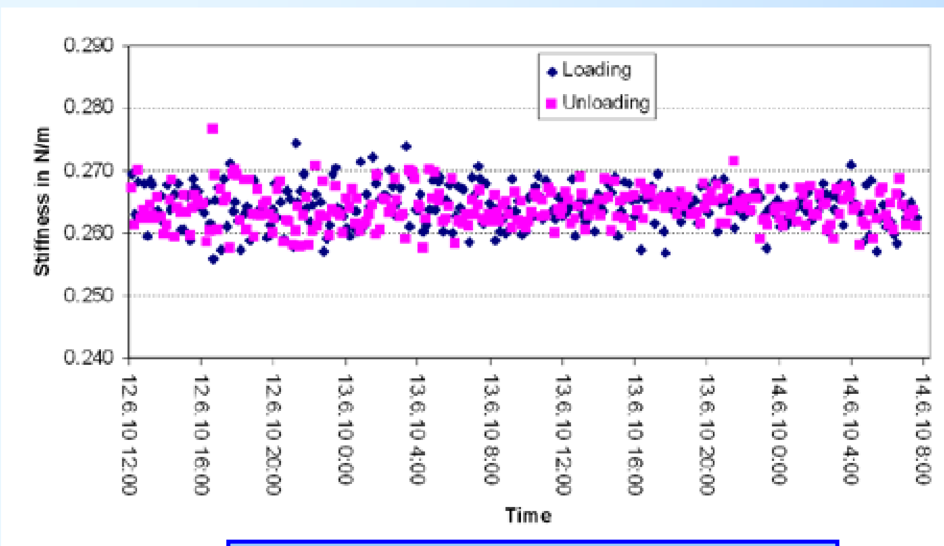
Calibration of AFM cantilevers with the Nanoforce measuring device

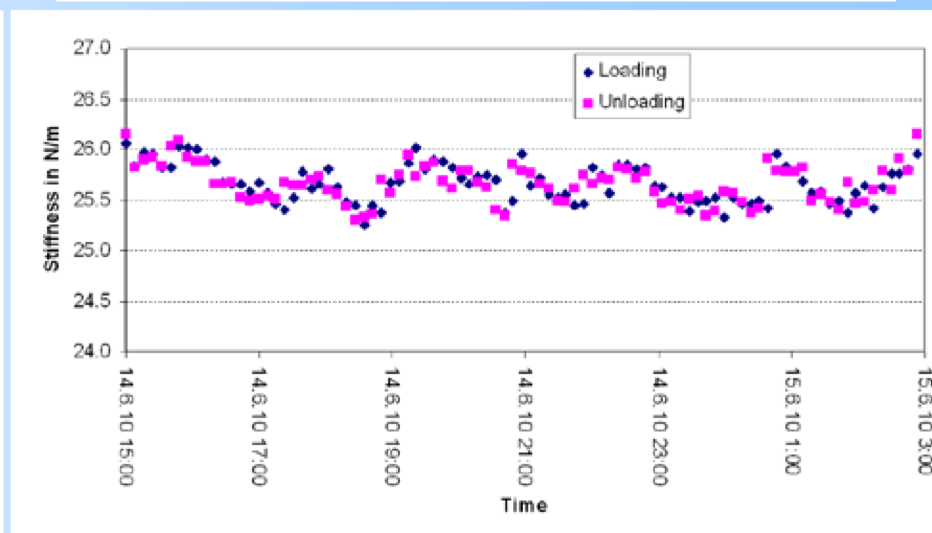


Experimental Results: Force-Deflection and Stiffness









k_C = (0.263 ± 0.009) N/m

3.3 %

k_S = (25.65 ± 1.3) N/m

5.4 %

2 Electrostatic Nanoforce Prototype (V. Nesterov)

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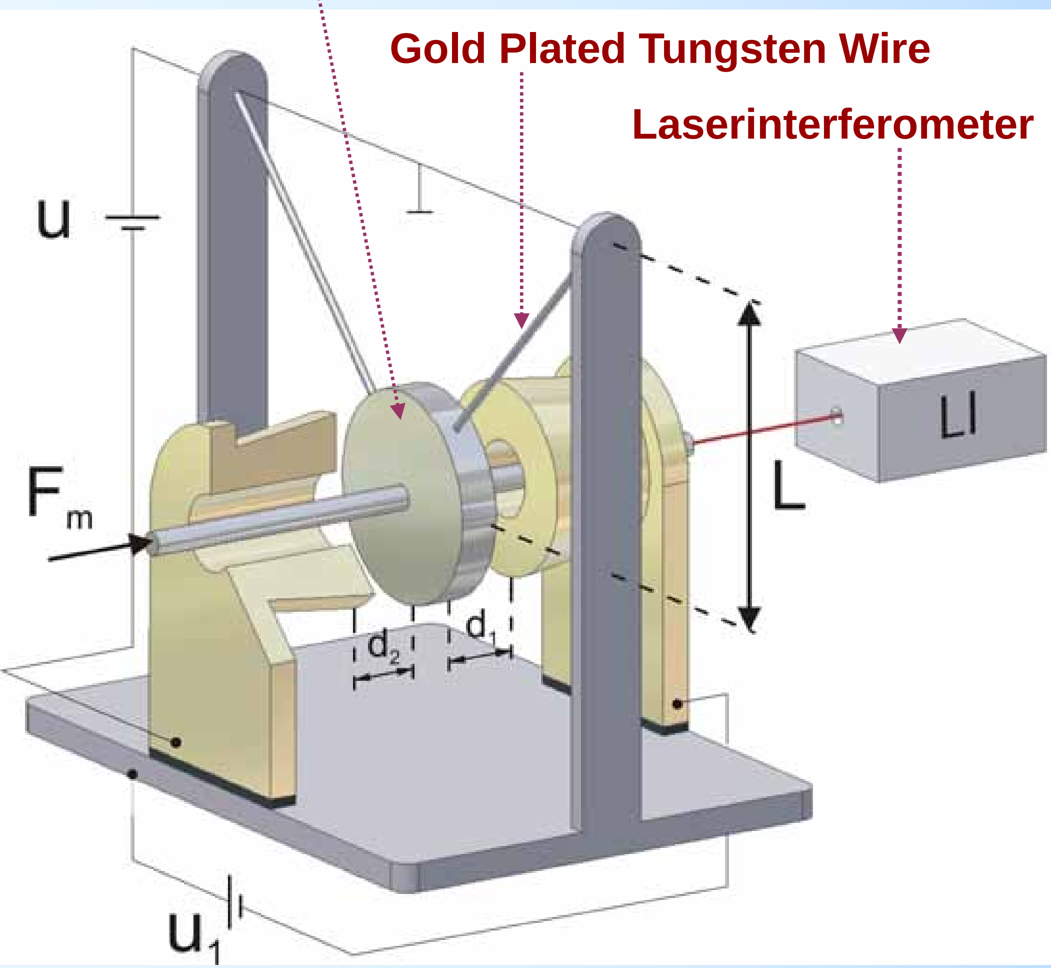
Disc Pendulum

Electrostatic Stiffness Reduction and Force Compensation



Stiffness K = Force F/Deflection x:

$$K_u \approx \frac{m \cdot g}{L} - \frac{2 \cdot \varepsilon_r \cdot \varepsilon_0 \cdot S \cdot u^2}{d^3},$$

$0.13\ \text{N/m} < K_u < 7.4 \cdot 10^{-3}\ \text{N/m}$

Force to be measured:

$$F_m = F_K \pm K_u \cdot \Delta x$$

Electrostatic Compensation Force:

$$F_K(x=0) \approx \frac{\varepsilon_0 \cdot S \cdot u \cdot \Delta u}{d^2}$$

Δx : Resolution Laserinterferometer

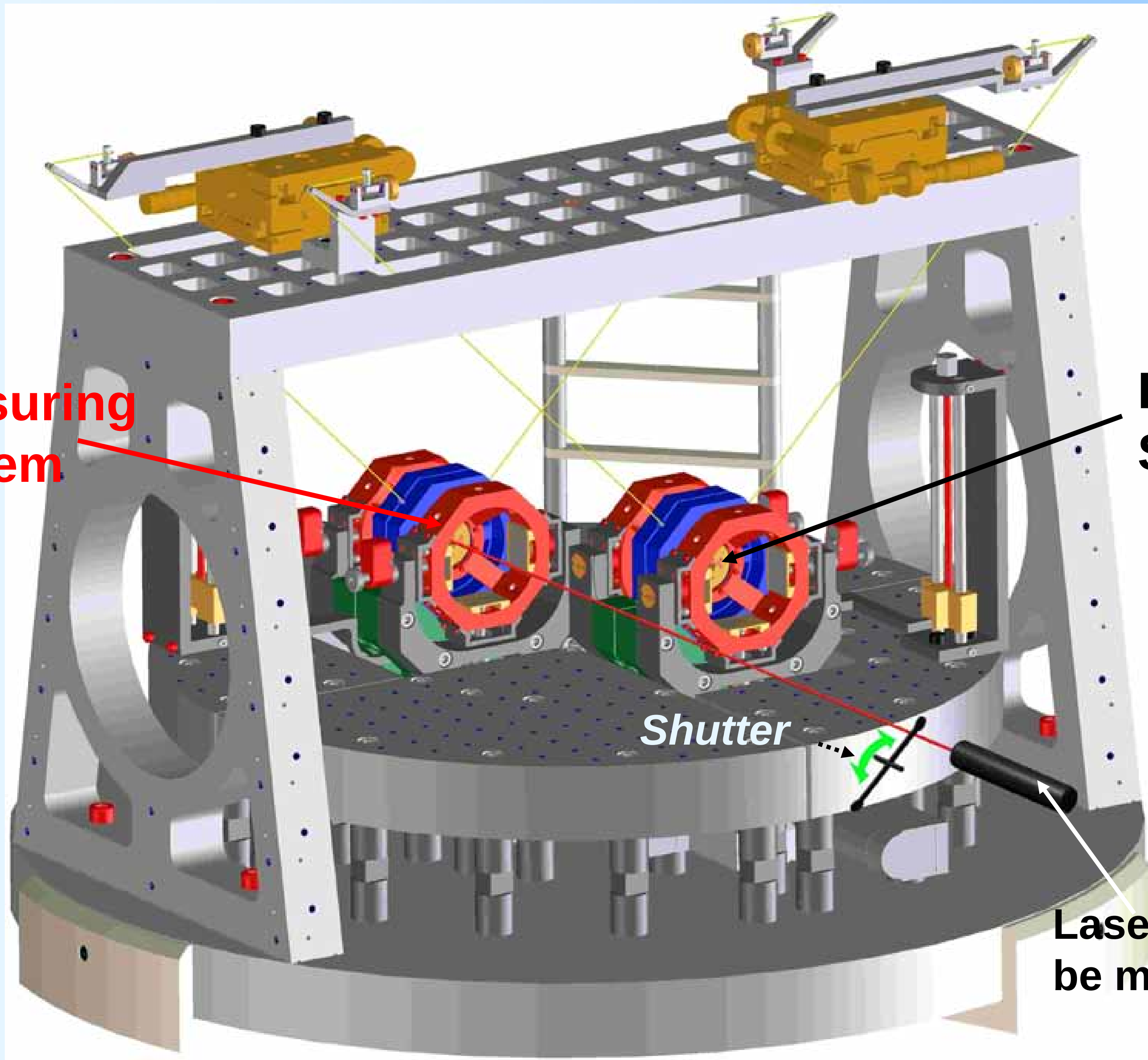
u : Voltage for Stiffness Reduction

$\Delta u = u_1 - u$: Compensation Voltage

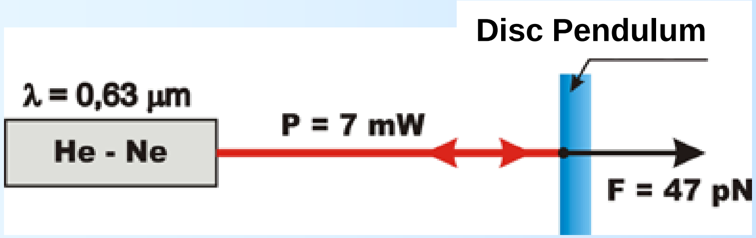
$$(S = 4 \cdot 10^{-4}\ m^2; m = 4 \cdot 10^{-3}\ kg; d = 10^{-4}\ m; L = 0{,}3\, m)$$

Nesterov, V.: Facility and methods for the measurement of micro and nano forces in the range below 10^{-5} N with a resolution of 10^{-12} N (development concept). *Measurement Science and Technology* Vol. 18 (2007) S. 360-366

Reference pendulum for subtraction of seismic noise

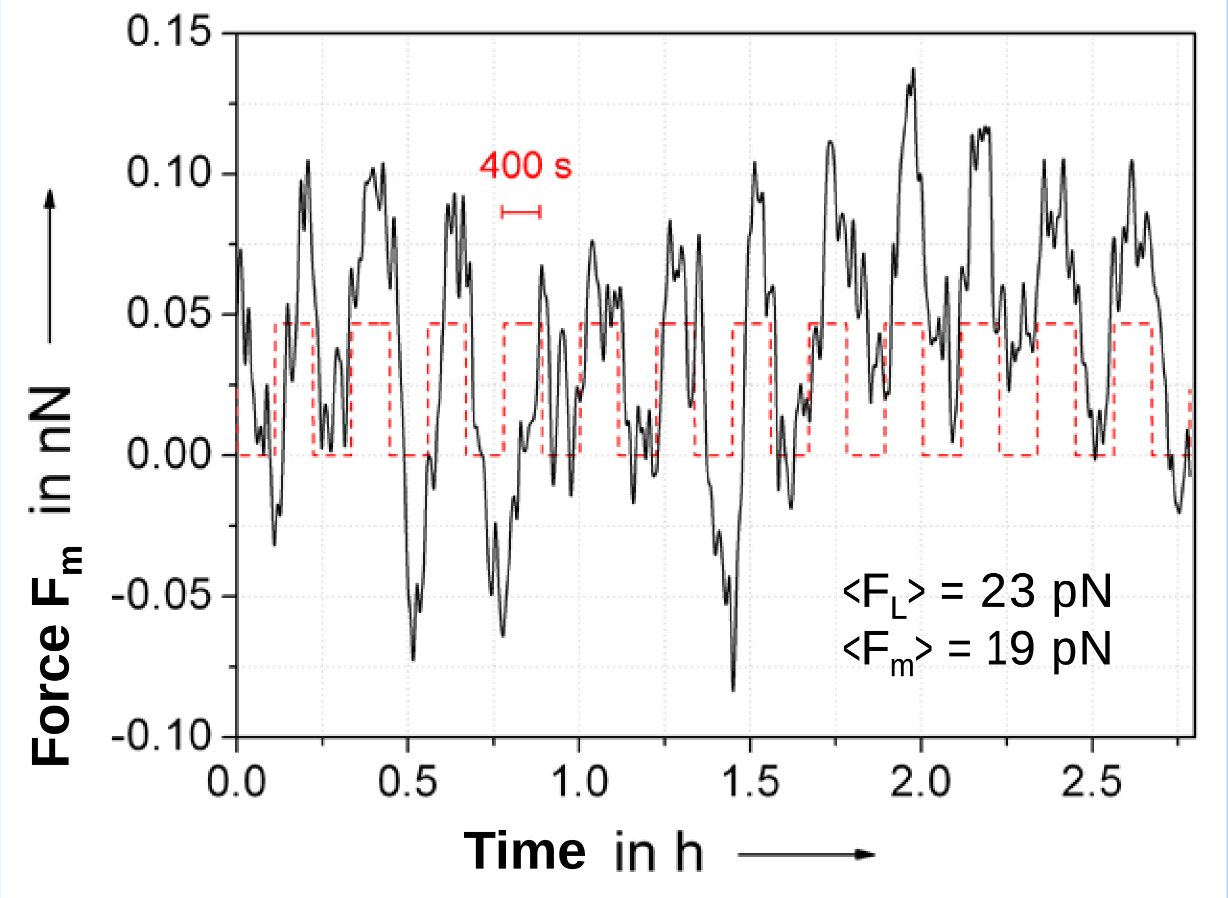


Measuring the Force of Laser Radiation (in air)

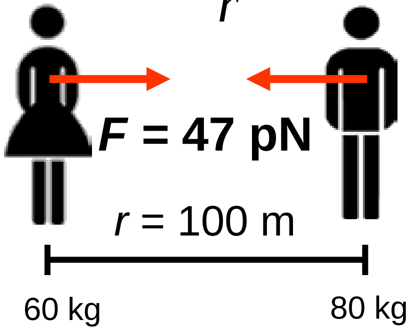


$$F_L = \frac{P}{c} \times (1 + R)$$

P: Laser Power
c: Velocity of Light
R: Reflection Coeff.



$$F = \frac{G \times M \times m}{r^2}$$



Mass attraction of two persons

Nesterov V, Mueller M, Frumin L L and Brand U 2009 A new facility to realize a nanonewton force standard based on electrostatic methods *Metrologia* **46** 277-82

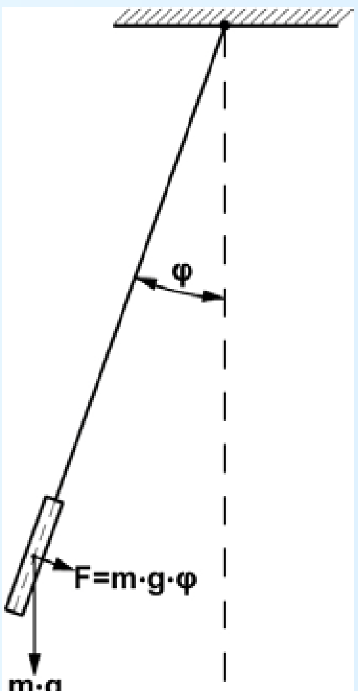
Calibration by periodically tilting the table

Small tilt φ of the measuring device à deflection of the disc pendulum à electrostatic compensation force *F*

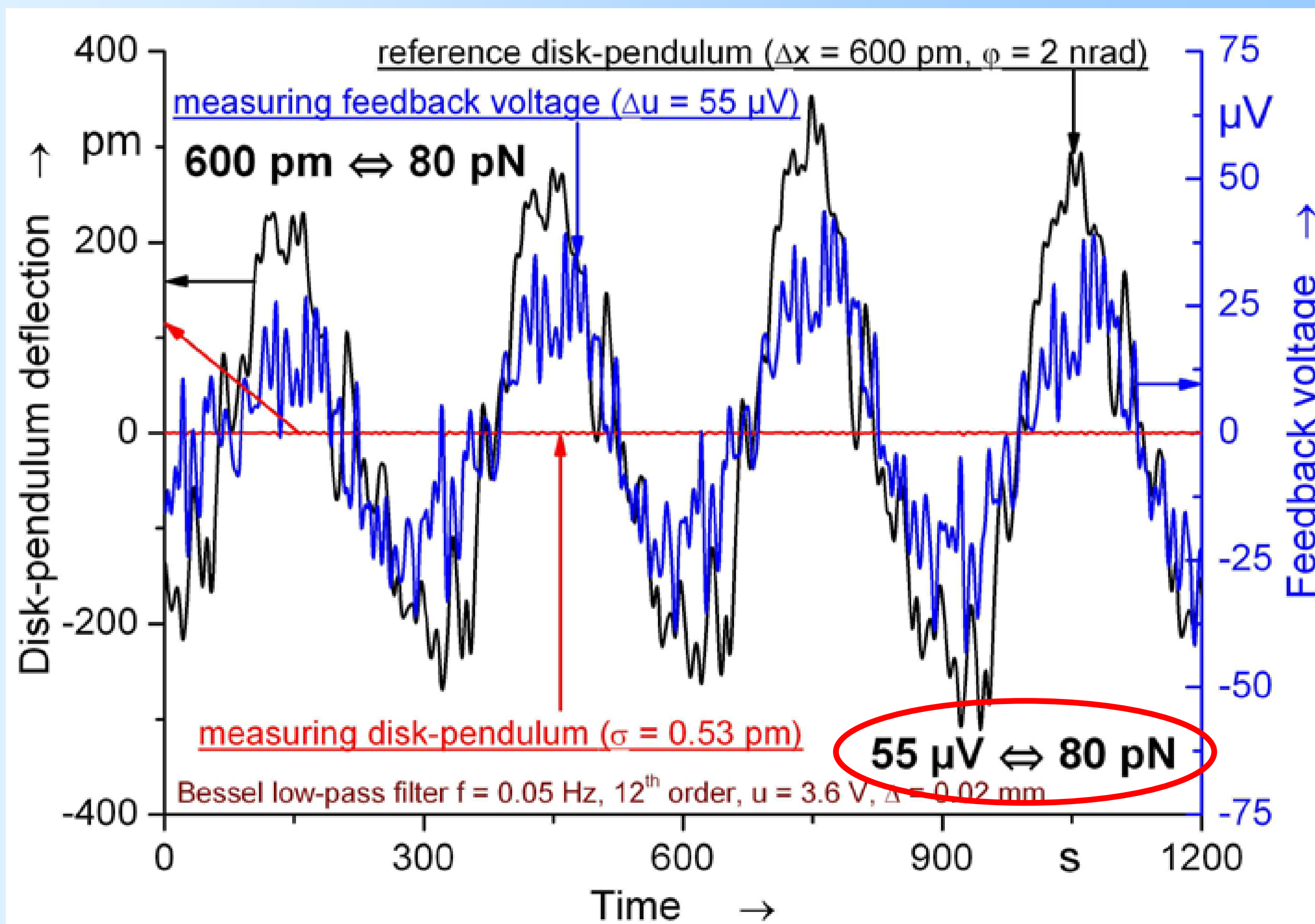
***j* = *Dx*/*l* = 2 nrad, *F* = *m*·*g*·*j* = 80 pN, 80 pN ó 55 µV**

(with: Dx = 600 pm deflection of the reference disc pendulum, Du = 55 µV compensation voltage of the measuring pendulum, m = 3,97 g mass of the disc pendulum, g = 9.81 m/s^2 , l = 0,3 m pendulum length).

Periodically tilting the table

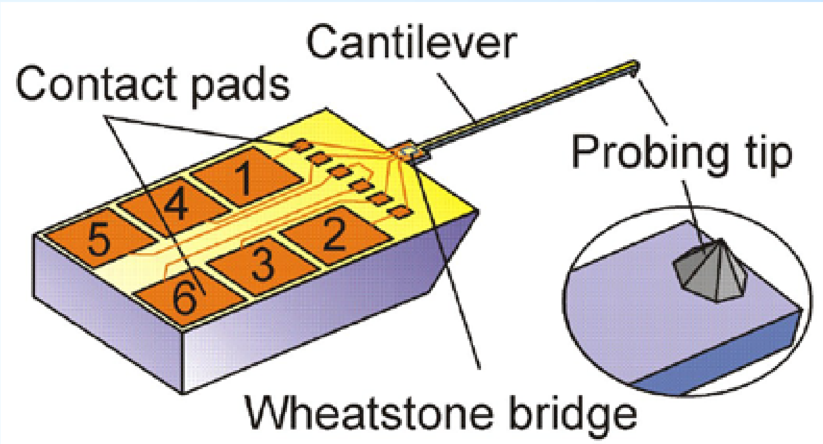


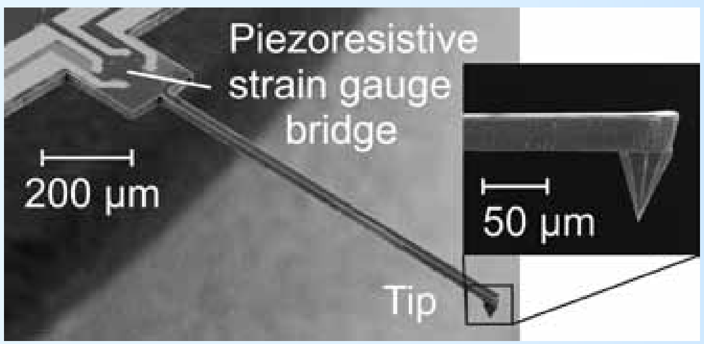
Periodical deflection



3 Proposal of 2nd international stiffness comparison

2009: 1st international comparison (M. S. Kim)

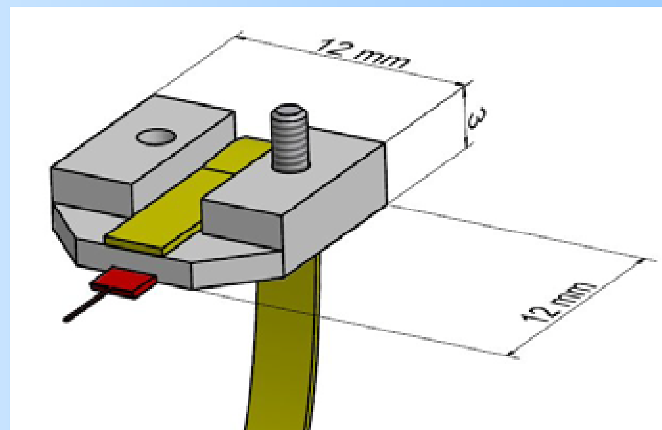


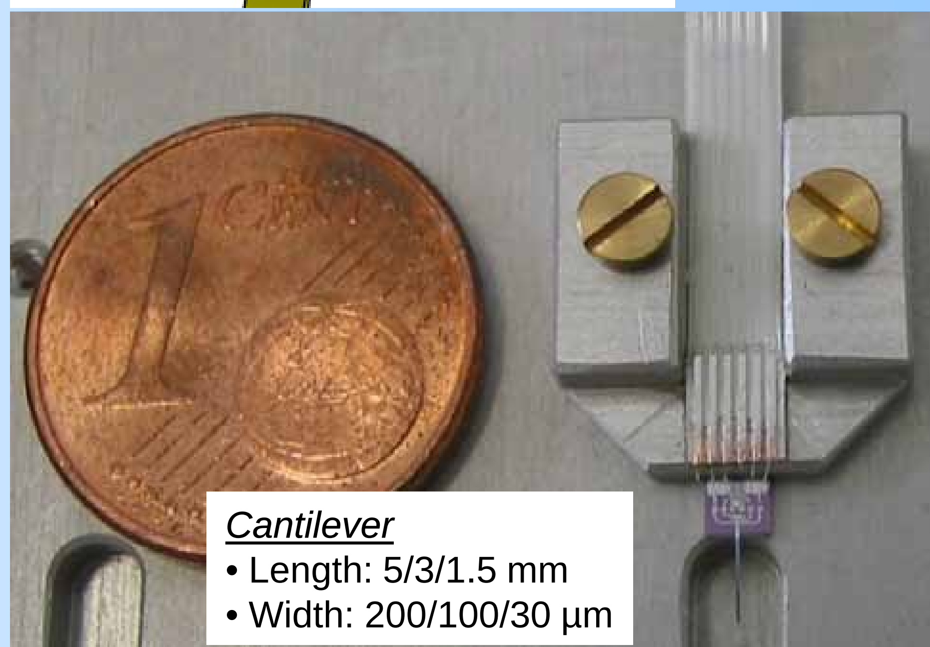


Fabrication of piezoresistive sensors:
- Institute for Semiconductor Physics (IHT), Braunschweig Technical University (PD Dr. Peiner)
- CIS, Erfurt (Dr. Voellmecke)

Industrial partner:
- Mahr GmbH, Goettingen

Measures
Stiffness k: 2…10 N/m
Output signal: 1 V





Cantilever
- Length: 5/3/1.5 mm
- Width: 200/100/30 µm

Visit also in this conference:

Christian Schlegel, Oliver Slanina, Günther Haucke, Rolf Kumme:
Construction of a standard force machine for the range of 100 µN – 200 mN. 23. Nov. 2010 10:00